VeriFish

The sustainability indicator framework to communicate responsible aquafood production and consumption patterns

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D2.5 VeriFish Knowledge Base

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Task	T2.3 Integrate fishery and aquaculture indicators into the GRSF model and database
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Glossary of Terms

Term	Description
AI	Adequate Intake
AMR	Antimicrobial Resistance
API	Application Programming Interface
ASC	Aquaculture Stewardship Council
BAP	Best Aquaculture Practices
CAPA	Argentine Chamber of Jigger Fishing Vessels Shipowners
CFP	Common Fisheries Policy
CMO	Common Market Organisation
CO_2	Carbon dioxide
DRV	Dietary Reference Value
EEZ	Exclusive Economic Zone
EFSA	European Food Safety Authority
ETP	Endangered, Threatened, and Protected
FAD	Fish Aggregating Device
FAO	Food and Agriculture Organization
FIP	Fishery Improvement Project
GFCM	General Fisheries Commission for the Mediterranean
GGGI	Global Ghost Gear Initiative
GHG	Greenhouse Gas
GRSF	Global Record of Stocks and Fisheries
GSSI	Global Sustainable Seafood Initiative
ICES	International Council for the Exploration of the Sea
ILO	International Labour Organization
ISSCFG	International Standard Statistical Classification of Fishing Gear
IUCN	International Union for Conservation of Nature
IUU	Illegal, Unreported, and Unregulated
KB	Knowledge Base
LCA	Life Cycle Assessment
LFA	Life Cycle Analysis
MSC	Marine Stewardship Council
MSFD	Marine Strategy Framework Directive
MSY	Maximum Sustainable Yield
MT	Metric Ton

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NRV	Nutrient Reference Value
OWI	Operational Welfare Indicator
PEFCR	Product Environmental Footprint Category Rules
PRI	Population Reference Intake
PSA	Productivity Susceptibility Analysis
PSMA	FAO-UN Port State Measures Agreement
RAS	Recirculating Aquaculture Systems
RFMO	Regional Fisheries Management Organisation
SCET	Seafood Carbon Emissions Tool
SFP	Sustainable Fisheries Partnership
SSB	Spawning Stock Biomass
STECF	Scientific, Technical and Economic Committee for Fisheries
TCMF	Technical Conservation Measures Framework
WG	Working Group
WOAH	World Organisation for Animal Health

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Executive Summary

This deliverable presents the final version of the VeriFish Knowledge Base (KB), developed under Task T2.3, as well as its associated API and access services, which constitute the final demonstrator supporting the VeriFish Indicator Framework. The KB enables unified, verifiable access to environmental, socio-economic, and nutrition and health data, allowing users to explore, query, and retrieve indicator-related information through the VeriFish web application. Building upon the initial KB version, which was based on the Global Record of Stocks and Fisheries (GRSF), the final version is significantly extended both in terms of its scope and coverage. The VeriFish KB integrates an expanded set of 22 distinct authoritative data sources both at European and global levels, strengthening the representation of all sustainability dimensions addressed by the VeriFish framework. VeriFish KB integrates these datasets and assumes their reliability based on the credibility and established practices of the source organizations curating them. In parallel, the services for discovering and accessing KB resources have been further developed, offering enhanced querying capabilities and improved usability.

Given the complexity of the demonstrator and its underlying data integration and semantic modeling processes, this deliverable is accompanied by the current report that documents the structure, functionality, and usage of the KB and its API. This documentation is necessary to support transparency, reproducibility, and effective use by stakeholders. In addition, updates to the VeriFish Indicator Framework are reported, including refinements to existing indicators and their explicit alignment with the underlying data sources. These updates are directly operationalised within the KB and are therefore essential for understanding how indicator values are derived and accessed through the demonstrator. The KB enables the integration and combined analysis of heterogeneous datasets within a single system, supporting the computation and comparison of sustainability indicators in a way that is not possible when using these sources in isolation.

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1. Indicator Framework Updates

The updates to the VeriFish Indicator Framework are included in this deliverable as an essential component for interpreting and validating the VeriFish Knowledge Base (KB). Although the formal scope of the current deliverable focuses on the KB, the updates indicator definitions, refinements and their alignment with data sources are intrinsically embedded in the KB structure and services. In particular, the KB operationalises the indicator framework by linking each indicator to specific datasets, semantic representation and querying mechanisms. Without documenting these updates, it would not be possible to fully understand how indicator values are derived, how data sources are integrated, or how the KB supports verifiability and traceability. Furthermore, no subsequent deliverable is foreseen to report these refinements following D2.1 [1] and D2.2 [2]. Their inclusion here therefore ensures completeness, transparency, and consistency across the VeriFish indicator framework and technical implementation of the VeriFish web application.

1.1. Environmental Pillar – Capture Fisheries

1.1.1. Attributes

Capture fisheries in the VeriFish framework are characterised through three core attributes: species, capture method, and fishing area. These attributes are required to identify the fishery unit, connect it to the relevant data sources, and determine which environmental indicators can be assessed. Beyond uniquely identifying a fishery unit, these attributes are fundamental for determining which sustainability indicators can be assessed and how they are computed. Each attribute provides essential contextual information that directly influences the interpretation of environmental, governance, and biological indicators within the VeriFish Indicator Framework.

Table 1. Attributes used for capture fisheries

Attribute	Commentary
Species	Accurate species identification is vital for reliable sustainability assessment. Scientific names (*Genus & specific epithet)* should be used to avoid ambiguity caused by regional or commercial common names. For certain aquafood products, Regulation No. 1379/2013[1] mandates the use of scientific names. In addition, species identification underpins biological assessments such as stock status, resilience, and vulnerability to fishing pressure, and is therefore essential for several environmental indicators.
Capture method	The gear used to capture the aquatic animal. Gears expressed as provided by the FAO International Standard Statistical Classification of Fishing Gear (ISSCFG) which categorises fishing equipment into 10 broad groups and 47 gear types (classification and illustrated definition of fishing gears[2]). This is more detailed than legally required under Regulation No. 1379/2013[3]. The capture method is a key determinant for multiple environmental indicators, including climate impact (e.g., through fuel consumption), habitat impact,

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32013R1379
[2] https://openknowledge.fao.org/server/api/core/bitstreams/d194ba36-af7a-48ed-9e58-563143b96863/content
[3] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32013R1379

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	bycatch risk, and gear loss, as different gears interact with ecosystems in fundamentally different ways.
Area	The location where fish are caught (be that an ocean, lake, or river) is crucial for a sustainability assessment. Oceanic catch areas are categorised into FAO regions worldwide (e.g., NE Atlantic as FAO 27, Mediterranean as FAO 37) and further divided into smaller GFCM regions (General Fisheries Commission for the Mediterranean), some designated by ICES (International Council for the Exploration of the Sea), which are mandatory for products caught in European Union waters under Regulation (EU) No 1308/2013[4]. The fishing area is essential for assessing stock status, as well as for understanding applicable management and governance frameworks. It also enables linkage to region-specific datasets, which are required for the computation and validation of several indicators.

1.1.2. Case Studies

To demonstrate how environmental indicators can be applied through the VeriFish web application, four capture fisheries case studies were selected. These case studies are illustrative and they cover a range of species, fishing methods, spatial contexts, and data availability conditions.

- **Case Study 1: Plaice, North Sea**.
  - Fishery details: Plaice caught by large mesh twin rig in the North Sea. The fishery is represented by a vessel operated by fisherman Hendrik Kramer, part of the Joint Demersal Fisheries MSC-certified fishery.
  - Reason for inclusion: This case represents a data-rich fisher with detailed vessel-level information, including practices that exceed standard certification requirements.
  - Sustainability relevance: The case is relevant for indicators related to climate impact (e.g., due to high fuel efficiency achieved because of the innovative vessel design), habitat impact (e.g., demersal gear interaction), and animal welfare (e.g., ongoing trials with stunning techniques). It also highlights how individual vessels can achieve performance beyond certification benchmarks and seek market recognition for these improvements.
- **Case Study 2: Iberian sardine, Iberian waters**
  - Fishery details: Iberian sardine caught by Spanish and Portuguese small-scale purse seine vessels.
  - Reason for inclusion: This case illustrates a fishery that has undergone significant management challenges and subsequent improvements, particularly following the suspension of MSC certification in 2014 and the adoption of a new multi-annual management plan in 2021; 132 Portuguese vessels and 185 Spanish ones are included in the certificate.
  - Sustainability relevance: This case is relevant for stock status and governance indicators, demonstrating how coordinated management measures between countries can support stock recovery. It also reflects the role of certification schemes and management plans in improving sustainability performance. The Portuguese vessels target around 34,000 metric

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013R1308

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ton (MT) quota of Iberian sardine in 2025, while Spain targets around 17,000 MT

- **Case Study 3: Skipjack tuna, Indian Ocean**
  - Fishery details: Skipjack tuna caught by large-scale Spanish purse seine vessels using Fish Aggregating Devices (FADs), in the Indian Ocean, while also targeting yellowfin and bigeye tuna.
  - Reason for inclusion: This case represents a large-scale, industrial, and globally significant fishery, with substantial contribution to both regional and global tuna catches and strong involvement in international management and certification schemes. Just indicatively, the Spanish fleet is among the most important distant-water tuna fleets operating in the region, accounting for roughly 26% of the skipjack and yellowfin tuna caught in the Indian Ocean, which corresponds to about 3% of global catches of these species.
  - Sustainability relevance: This case is relevant for indicators related to ecological impact (notably bycatch and the use of FADs), climate impact (fuel-intensive operations), and governance (regional fisheries management and certification). It also highlights the role of industry groups such as OPAGAC, which represents 15 purse-seine vessels and contributes around 14% of the region's total tropical tuna catch, and the achievement of MSC certification in 2021.
- **Case Study 4: Argentinian shortfin squid, Argentine EEZ**
  - Fishery details: Argentinian shortfin squid caught by jigging in the Argentine Exclusive Economic Zone (EEZ) and adjacent high seas.
  - Reason for inclusion: This case represents a challenging fishery, characterized by high variability in stock abundance, limited stock assessments, and significant unregulated fishing activity.
  - Sustainability relevance: This case is relevant for governance and stock status indicators, highlighting challenges related to the absence of coordinated international management, lack of catch limits, and the presence of Illegal, Unreported, and Unregulated (IUU) fishing. At the same time, it demonstrates low environmental impact in terms of habitat and bycatch due to the selective nature of jigging. The ongoing Fishery Improvement Project (FIP), led by the Argentine Chamber of Jigger Fishing Vessels Shipowners (CAPA) and Sustainable Fisheries Partnership (SFP), illustrates efforts to improve sustainability and move towards MSC standards.

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1.1.3. Indicators overview

The current, finalised list of environmental indicators for capture fisheries is shown in

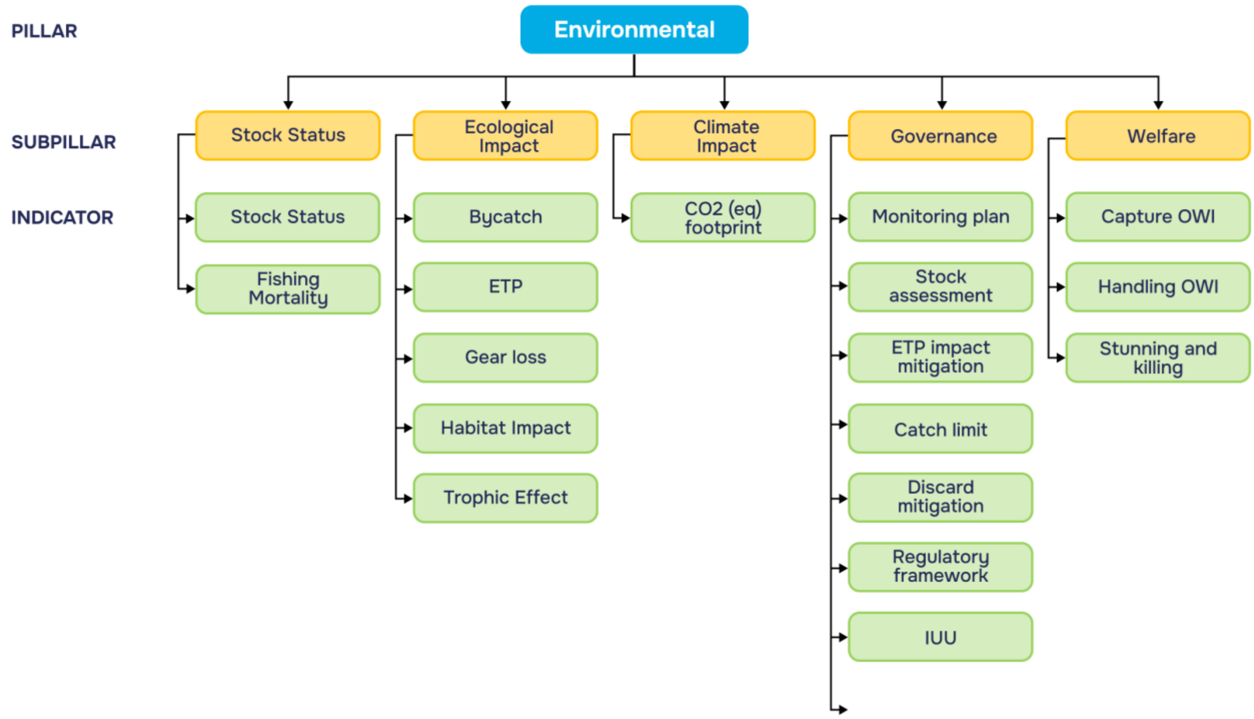

Figure 1. They have been organised in five sub pillars related to: stock status, ecological impact, climate impact, governance and animal welfare.

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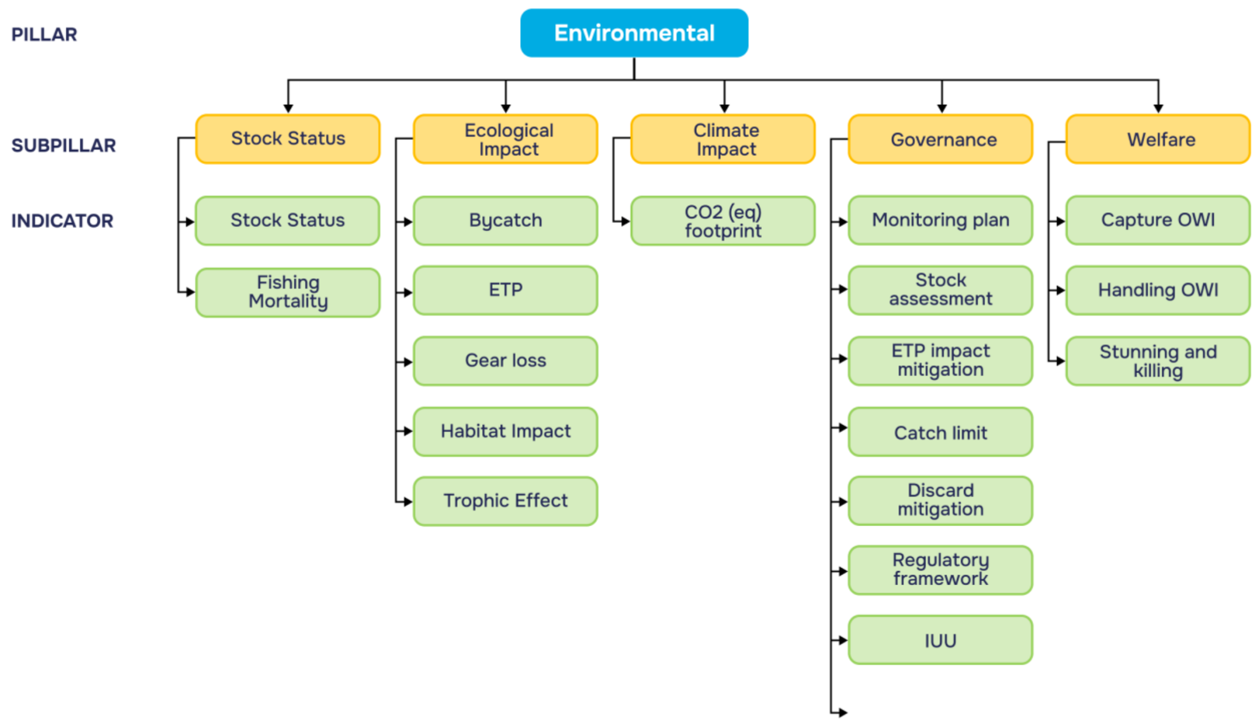

Figure 1. The updated list of environmental indicators (for capture fisheries)

Table 2 summarizes the updated capture fisheries indicators, with the key relevant attributes (i.e. species, capture method, area) and the data sources that are required for T1 and T2. Subsequently, more details are provided for each indicator. It should be noted that, within the current scope of the demonstrator and its use cases, not all indicators are fully implemented. In particular, animal welfare indicators (10-12) are not currently operational due to limited data availability and methodological constraints. Governance indicators (14-18) are partially integrated through related sub-pillars, rather than being addressed as standalone indicators. Furthermore, Indicator 19 (IUU) is incorporated within the socio-economic pillar of the framework. These choices reflect the current availability of data and the implementation priorities, while allowing for future extension of the Knowledge Base.

As described in D2.1 [1] and D2.2 [2], the framework is built on a tiered data system; Tier 1 (T1) comprises publicly available data from global or regional or even country-level repositories. These datasets are highly accessible, free, and scientifically validated. These offer broad, high level and less detailed insights disparately but are more comprehensive when consolidated. Tier 2 (T2) differs because these sources can be attributed to specific value chains, detailing production methods, practices, and proprietary information.

Table 2. Capture fisheries indicators with key relevant attributes and data sources for Tier 1 and Tier 2 levels

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	Indicator	Sub-pillar	Key attributes to be assigned			T1 data needs / sources	T2 data needs / sources
			1	2	3		
01	Stock status	Stock status	x		x	GRSF	Not applicable at vessel level
02	Fishing mortality	Stock status	x		x	GRSF	Not applicable at vessel level
03	Resilience	Stock status	x			Resilience score from Fishbase	Not applicable at vessel level
04	CO2eq/kg landed catch	Climate impact		x		Typical fuel consumption data per catch method and species	Greenhouse gas emissions of vessel as CO2eq/kg landed product
05	Habitat impact	Ecological impact		x	x	Gear x seabed type proxy. Scoring through association of species with certain habitat	Specific information on fishing location. Related to EUNIS https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification.
1	Trophic effects	Ecological impact		x	x	Biomass data from GRSF	Not applicable at vessel level
07	Bycatch	Ecological impact		x	x	Amount of discard typical for gear type and landed catch	Amount of discard typical for vessel and landed catch
08	Potential bycatch risk of sensitive Species	Ecological impact		x	x	STECF-EWG 23-18 risk assessment methodology, CITES convention, CMS convention, IUCN red list of threatened species.	(Digital) registration of catch of ETP species at vessel level
09	Gear loss	Ecological impact		x	x	Gear based risk	Vessel based mitigation measures or plan
10	Capture OWI	Animal welfare	x	x		Generic OWI score for gear operation	OWI Score at vessel level. Or applied extra mitigation measures.
11	Handling OWI	Animal welfare	x	x		Generic OWI score for gear operation	OWI Score at vessel level. Or applied extra mitigation measures.
12	Stunning and Killing	Animal welfare	x	x		Unlikely at generic level. Maybe in future when legally required, then RFMO or region determines	Effective stunner implemented on board yes/no

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	Indicator	Sub-pillar	Key attributes to be assigned			T1 data needs / sources	T2 data needs / sources
			1	2	3		
13	Monitoring plan	Governance	x		x	Level of monitoring. Present, intensity and quality	Not applicable at vessel level
14	Stock assessment	Governance	x		x	Information on HCR, TAC sharing agreement and enforcement	Not applicable at vessel level
15	ETP impact mitigation	Governance		x	x	Mandatory measures by regulation	Use of escape panels, pingers. No or adapted FAD's, active avoidance of aggregations
16	Discards mitigation	Governance		x	x	Mandatory measures by regulation	Use of measures on board
17	Catch limit	Governance	x		x		
18	Regulatory framework	Governance	x		x	On government level	Not applicable at vessel level
19	IUU	Governance			x	The Global Record of Fishing Vessels, Refrigerated Transport Vessels and Supply Vessels	Future: digitalised proof of uninterrupted AIS
20	Certification	Governance	x	x	x	Fleet level certification (GSSI/ISEAL benchmarked) or Fishery Improvement Program (FisheryProgress)	Vessel-level certification

The indicators presented in Table 2 can be grouped according to their current level of implementation within the VeriFish KB and the web application. A first group includes indicators that are operational and can be accessed through the KB and its services. A second group comprises indicators that are partially supported through available proxy data or aggregated information, allowing for indicative assessment but not full quantification at all levels. A third group includes indicators that are currently under development, where further data integration or methodological refinement is required before full implementation.

1.1.4. Indicator: Stock status (01-02-03)

Purpose and scope

Stock status refers to the current condition of a stock relative to established sustainability goals. Assessing stock status is essential for effective fisheries management, as it indicates whether fish populations in particular areas remain within biologically sustainable limits or are at risk of overfishing and depletion, due to

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factors such as fishing pressure and biological reference points. It is crucial to distinguish between stock biomass **B** (total weight of all the fish in a population), fishing yield **Y** (the catch, or number of fish harvested by a fishery over a specified period), and fishing mortality rate **F** (proportion of fish caught and removed by fishing). Understanding these distinctions is vital for maintaining sustainable fisheries and preventing over-exploitation.

In fisheries biology and economics, maximum sustainable yield (MSY) represents the largest average catch that can theoretically be sustained indefinitely under stable environmental conditions. To ensure a viable and thriving fishing industry, stock status must remain consistently above those required to produce MSY over the long term.

It is increasingly debated whether MSY is appropriate for sustainable fisheries management as it is based on single species assessments [49][50]. Considering the general lack of information for better reference levels, MSY-based reference points may best be considered as limits.

Decision Points

For the major commercial fisheries stocks, biomass B and fishing mortality F information is available. However, for many more commercial stocks, particularly those of many imported species, this information is not available, and proxies will have to be used to assess stock status. These proxies consider the International Union for Conservation of Nature (IUCN) status of a fish stock, and the vulnerability to fishing pressure. One may characterise a stock's vulnerability to fishing pressure through a Productivity–Susceptibility Analysis (PSA). A PSA It works with data-poor species where full stock assessments are not feasible. It provides a transparent, semi-quantitative means of comparing multiple species within multispecies or ecosystem-based fisheries. A PSA is assessed by two principal dimensions:

1. Productivity: this dimension represents the biological capacity of a species to withstand and recover from fishing mortality. Species with high productivity (fast growth, early maturity, high fecundity) receive lower risk scores, because they are more resilient to fishing impacts. Species with low productivity (slow-growing, late-maturing) receive higher risk scores, indicating greater vulnerability.
2. Subsceptibility: this dimension describes the likelihood that a species will be captured or otherwise negatively affected by the fishery. A species with high overlap, high catchability, and low discard survival will score as highly susceptible.

Each attribute is assigned a score (commonly on a 1–3 scale: low, medium, high risk). The overall vulnerability score is then calculated—most commonly using the geometric mean:

$$\textbf{Vulnerability} = \sqrt{(\textbf{Productivity Score})^2 + (\textbf{Susceptibility Score})^2}$$

The final output places each species or stock in one of three broad categories:

- Low vulnerability: high productivity and/or low susceptibility
- Medium vulnerability: mixed attributes
- High vulnerability: low productivity and high susceptibility

The decision points are described in the scoring decision tree below, adapted from the Scientific, Technical and Economic support to the Common Fisheries Policy (STECF) [51]. The decision points apply both to Tier 1 and Tier 2.

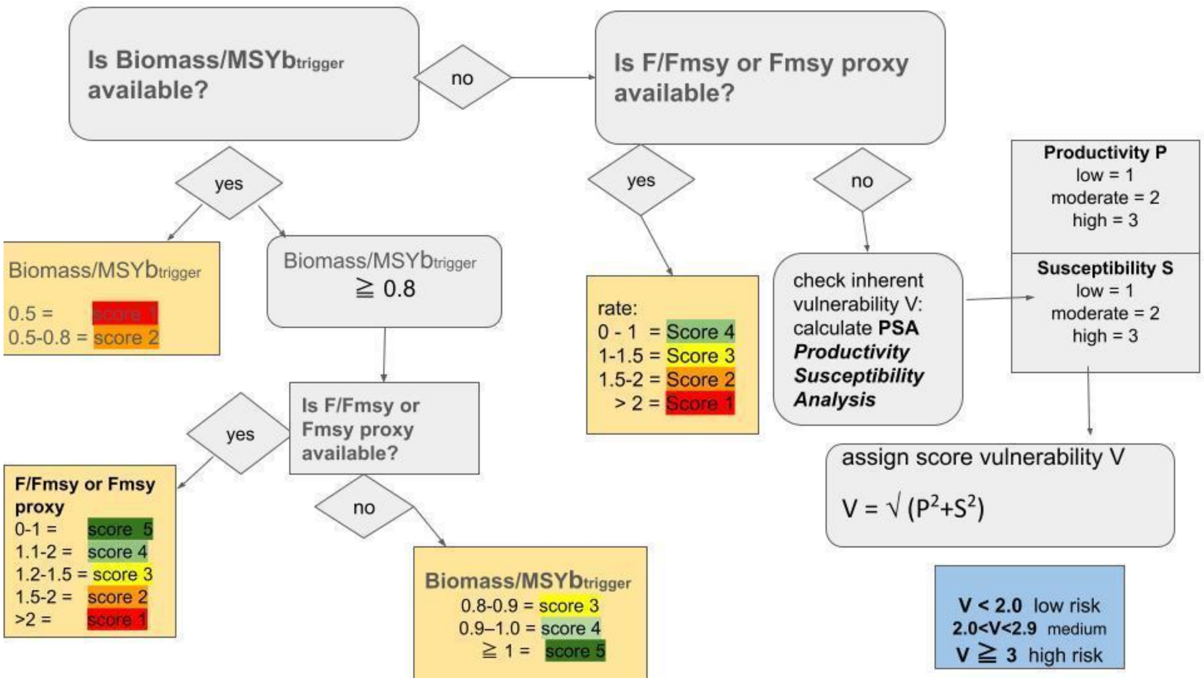

Figure 2. Decision tree relating to stock status

Data Sources

For the indicators relating to stock status (biomass, fishing mortality, resilience), a lot of the information is available through databases. The GRSF has detailed information, both on biomass levels and fishing mortality. Where information on stock status is and fishing pressure is limited, data on productivity and susceptibility can be retrieved from the corresponding STECF report [51].

Alternatively, stock status scores can be directly derived from FishSource, which assigns scores across various indicators, each focusing on a different aspect of fisheries management. These indicators are scored on a 0–10 scale. For example, the score for stock health measures the SSB as a percentage of the $MSY_{Btrigger}$. Where no information on either stock or fishing mortality is available, resilience information can be derived from FishBase. In a situation with data deficiency, combined with a low resilience, a species should receive the high-risk score 1.

For a subset of the species from the GRSF database, calculations on stock status following the method described above have been carried out by STECF. These results are available in the knowledge base and used in the web-app.

Case Studies

Table 3. Case studies for 'stock status'

Species	Plaice *Pleuronectes platessa*	Sardine *Sardina pilchardus*	Skipjack tuna *Katsuwonus pelamis. Spanish fleet.*	Argentinian short-finned squid *Illex argentinus*
Gear type	Twin rig large mesh	Purse seine	Purse seine	Jigging
Catch area	North Sea ICES 4b-c	ICES 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	Indian Ocean (FAO 51/57)	Southwestern Atlantic (FAO 41), Falklands (Argentina & UK)
Stock status score	5	4	5	2
rationale	Is biomass (SSB) and $BMSY_{trigger}$ available? > Yes: SSB (1) / BMSY trigger (0,5) = 2 which is bigger than 0,8 > Is F/FMSY available? > Yes > F (0,8) / FMSY (1,6) = 0,5 results in Score 5.	Is Biomass (SSB) and $Bmsy_{trigger}$ available? > Yes: SSB (0.5) / Mmsytrigger (0.25) = 2 Is F/F_{msy} available? > Yes > F $(0.12)/F_{msy}$ (0.10) = 1.2	$SSB_{current}/SSB_{MSY}$ = 2.30 $F_{current}/F_{MSY}$ is estimated to be 0.49	Biomass and Fishing Mortality is not available. With cephalopod fisheries, reference points are difficult to estimate. IUU fishing takes place. Stock size is unknown. The analysis of catch and/or effort data has been used in place of formal assessments to get information on abundance trends.
References	Plaice ICES 4c[5]	Sardine ICES 8c[6] & 9a	ISSF 2026-01: Status of the World Fisheries for Tuna. January 2026[7]	Argentina Shortfin Squid Fishery Progress report[8]

[5] https://ices-library.figshare.com/articles/report/Plaice_i_Pleuronectes_platessa_i_in_Subarea_4_North_Sea_and_Subdivision_20_Skagerrak_/25019441?file=47281186

[6] https://ices-library.figshare.com/articles/report/Sardine_i_Sardina_pilchardus_i_in_divisions_8_c_and_9_a_Cantabrian_Sea_and_Atlantic_Iberian_waters_/27692337?backTo=%2Fcollections%2FICES_Advice_2025%2F7488219&file=60316211

[7] https://www.iss-foundation.org/about-issf/what-we-publish/issf-documents/issf-2026-01-status-of-the-world-fisheries-for-tuna-january-2026/

[8] https://fisheryprogress.org/fip-profile/19585/overview

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1.1.5. Indicator: Climate impact (04)

Purpose and Scope

To address the environmental footprint of products, the European Commission is developing product environmental footprint category rules (PEFCR) to standardise calculation and comparisons of environmental impacts across products and services. These rules are comprehensive and consider multiple factors, but they require extensive data, posing challenges for widespread implementation. Also, they only consider marine fish. Crustaceans, molluscs, freshwater fish, and prepared and preserved products are not included. Moreover, these PEFCR do not include biodiversity aspects. For capture fisheries, climate impact is the most relevant parameter in the Product Environmental Footprint. We therefore suggest limiting this indicator and not use PEFCR. The most suitable metric for assessing climate impact of seafood is CO_2-equivalents (CO_2-eq) per Kg of unprocessed fish or shellfish.

Decision Points

- 0-5kg CO_2-equivalents (CO_2-eq) per Kg of unprocessed fish or shellfish = 5
- 5-10 kg CO_2-equivalents (CO_2-eq) per Kg = 4
- 10-15 kg CO_2-equivalents (CO_2-eq) per Kg = 3
- 15-20 kg CO_2-equivalents (CO_2-eq) per Kg = 2
- >20 kg CO_2-equivalents (CO_2-eq) per Kg = 1

Data Sources

For Tier 1, the scores are based on fuel use per gear type and fishery. Several databases have data on fuel use in fisheries, for example the Seafood Carbon Emissions Tool[9].

For Tier 2, more detailed information can be calculated through the Climate Impact Tool that is currently being developed by the Marine Stewardship Council (MSC) and this will be publicly available. A similar tool is also being developed on aquaculture by the ASC.

Case Studies

Table 4. Case studies for 'climate impact'

Species	**Plaice** ***Pleuronectes platessa***	**Sardine** ***Sardina pilchardus***	**Skipjack tuna** ***Katsuwonus pelamis. Spanish fleet.***	**Argentinian short-finned squid** ***Illex argentinus***
Gear type	Twin rig large mesh	purse seine	Purse seine	jigging
Catch area	North Sea ICES 4b-c	ICES 8.c and 9.a (Cantabrian Sea	Indian Ocean (FAO 51/57)	Southwestern Atlantic (FAO 41), Falklands (Argentina & UK)

[9] http://seafoodco2.dal.ca/

		and Atlantic Iberian waters)		
Climate impact score	3	5	5	5
Rationale	CO_2- eq/kg of fish 12.2-14.6 = 10 - 15 = score 3	0.4-0.5 CO_2 eq/kg of fish	1.6-3.1 CO_2 eq/kg of fish	1.1-5.3 CO_2 eq/kg fish
Reference	Seafood Carbon Emissions Tool Profile European plaice - Bottom trawl	Seafood Carbon Emissions Tool purse seine European pilchards	Seafood Carbon Emissions Tool purse seine skipjack	Seafood carbon emissions tool - Argentine shortfin squid

1.1.6. Indicator: Habitat impact (05)

Purpose and Scope

It is well known that some fishing gears have impacts on marine habitats, and these impacts can be more severe in habitats that are structurally complex or particularly sensitive. The extent to which these habitats can recover from disturbance varies, as recovery rates depend on factors such as biological productivity and ecosystem dynamics. Highly productive habitats may recover relatively quickly, whereas fragile or low-productivity habitats may require much longer recovery periods. The overall impact therefore depends on multiple factors, including habitat type, spatial scale, the fishing method used, and the interaction between fishing activities and ecosystem components. This concept usually is typically applied to benthic habitats.

Decision Points

Based on what is currently available we can at least score for gear related impact as scored by Morgan and Chuenpagdee (2003) [52] in Figure 3. The physical and biological scores were averaged and inverted to match the low-high ranking of other indicator scores, meaning that high habitat impact (5) scores as low performing (1), resulting in the matrix shown in Table 5. The original matrix in [52] did not include demersal seines, therefore scores were added by the authors based on expert judgement.

	Habitat		Bycatch				
Gear class	Physical	Biological	Shellfish & crabs	Finfish	Sharks	Marine mammals	Sea birds & turtles
Dredges	5	5	4	2	1	1	1
Gillnet - bottom	3	2	1	4	3	4	3
Gillnet - midwater	1	1	1	4	4	5	5
Hook and line	1	1	1	2	3	1	2
Longline - bottom	2	2	1	4	3	1	2
Longline - pelagic	1	1	1	3	4	3	5
Pots & traps	3	2	4	2	1	3	1
Purse seine	1	1	1	2	2	3	2
Trawl - bottom	5	5	3	5	2	2	2
Trawl - midwater	1	1	1	3	2	2	2

1 Very low 2 Low 3 Medium 4 High 5 Very high

Figure 3. Ratings of habitat and bycatch impacts for each gear class, as determined by participants of workshop held in March 2022, in Seattle, WA [52]

*Table 5. Gear related habitat impact scores derived from Morgan and Chuenpagdee (2003) [52],*complemented with expert judgement, where higher scores indicate lower habitat impact (5=low impact, 1=high impact)*

Gear	Habitat impact score
Dredges	1
Gillnets - bottom	3
Gillnets midwater	5
Hook and line	5
Longlines - bottom	4
Longlines - pelagic	5
Pots and traps	3
Purse seine	5
Trawl - bottom	1
Trawl - midwater	5
Demersal seine*	2

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Scoring Decision Tree

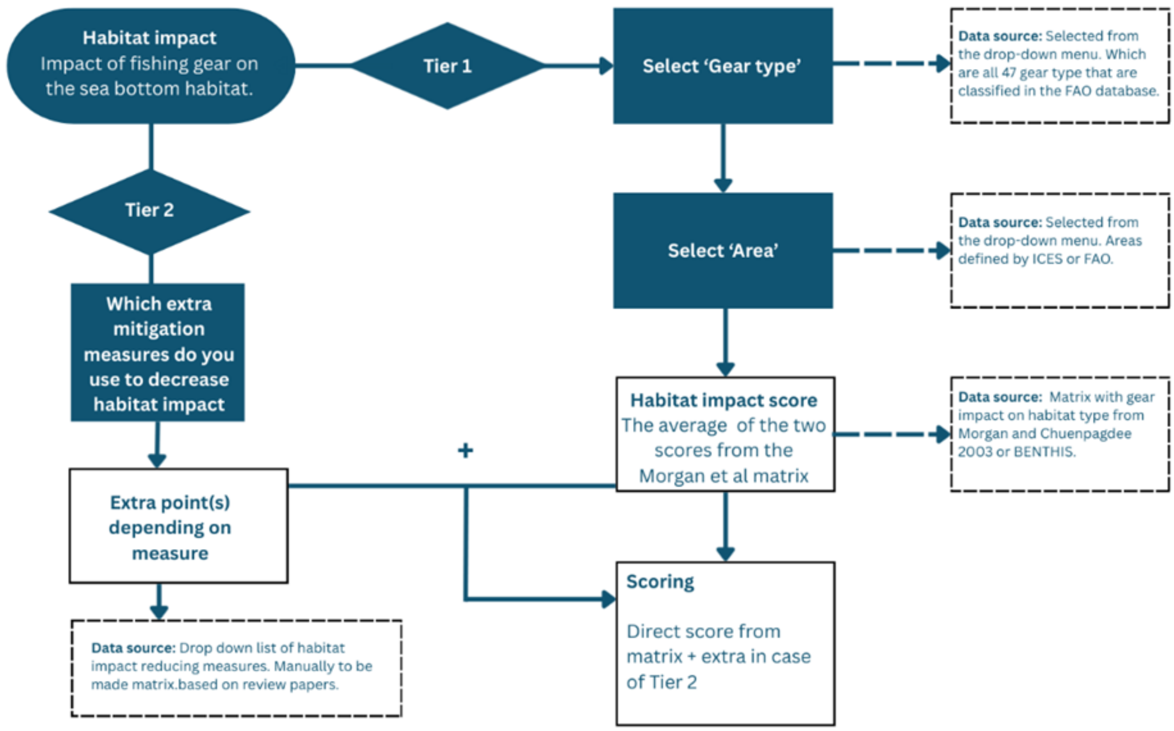

Figure 4. Scoring decision tree for 'habitat impact'

Case Studies

Table 6. Case studies for 'habitat impact'

Species	Plaice *Pleuronectes platessa*	Sardine *Sardina pilchardus*	Skipjack tuna *Katsuwonus pelamis. Spanish fleet.*	Argentinian short-finned squid *Illex argentinus*
Gear type	Twin rig large mesh	Purse seine	Purse seine	Jigging
Catch area	North Sea ICES 4b-c	ICES 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	Indian Ocean (FAO 51/57)	Southwestern Atlantic (FAO 41), Falklands (Argentina & UK)
Habitat impact score	1	5	5	5

Rationale	According to gear specific matrix from Table 5	According to gear specific matrix from Table 5	According to gear specific matrix from Table 5	According to gear specific matrix from Table 5

Scoring approach from STECF

Building on work by the STECF, Grati et al [51] proposed a scoring approach based on associating the gear type to a given impact on benthic marine habitats. The impact of fishing gears on the physical structure of habitats of the seafloor was first categorised using a simple method based on levels (high, medium, low) following a simplified version of the procedure reported in Morgan and Chuenpagdee (2003) [52].

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 Common Market Organisation (CMO) data and spatial habitat information cannot thus be used directly. To achieve this, [51] 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 habitat data were issued from various sources such as fishbase.org, sealifebase.org, scientific literature, and technical reports (details in [53]). 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 (low, medium, high). In addition, water depth-related terms were assigned to each habitat.

The score of the seabed impact indicator for the fishery product (ranging from 1 to 6) was 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 Figure 5.

The system as suggested by Grati *et al* has been put in a provisional app by DG MARE. The first test version of this app (Feb 2025) appeared to have various limitations. Nevertheless, the methodology is a first step. By using the GRSF as a data source for the framework, detailed information on habitats, species and gears is available, potentially allowing for a more refined and truthful outcome of habitat score.

The data from the STECF methodology have also been added to the VeriFish Knowledge base. In the Web-app, the results from both the VeriFish and STECF method can be found.

In a tier 2 system, fisheries could have the option to specify, in a reliable and verifiable manner, where exactly the fish species was caught. This information could be overlaid with EMODnet maps using the EUNIS habitat classification system[10].

Such an expert system could be developed by a specialized team, guided by the principles outlined in Morgan and Chuenpagdee (2003) [52]. The impact scores—by gear, habitat, and potentially by target species—would

[10] https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification

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be reviewed and validated by a network of scientists selected for their expertise in fishing gear technologies and their knowledge of gear-related habitat impacts

		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

Figure 5. Calculation of the resulting score for the impact on the seabed indicator (sum of the scores from the fishing gears impact and habitat sensitivity)

1.1.7. Indicator: Ecological impact- bycatch (07)

Purpose and Scope

Total catch in a fishery generally includes both targeted catch and non-target catch. Non-target catch, commonly referred to as bycatch, includes organisms that are caught unintentionally, or that are not the primary target of the fishing operation. Bycatch can be further divided into retained (wanted) and discarded (unwanted) species. Retained bycatch typically refers to species that are not the primary target but that can still be legally landed and sold/used. Discarded bycatch, on the other hand, includes undersized individuals of commercial species, low value species which are often discarded, or non-commercial species with no market value. Bycatch can also include endangered, threatened, or protected (ETP) species. The impact on these ETP species is scored in a separate bycatch indicator (see section 1.1.8).

For the bycatch indicator, the most robust information comes from dedicated bycatch monitoring systems, particularly independent observer programmes and Remote Electronic Monitoring (REM), where coverage is sufficient to reflect the fleet across relevant areas and seasons. These sources can provide information on the volume, composition, and fate of bycatch, including retained and discarded components. Landing data may complement these sources by documenting retained bycatch, but they do not adequately capture discarded catch on their own.

In some fisheries, technical measures such as selective gears or escape panels are used to reduce unwanted catch. Where such measures are in place, evidence on their implementation, compliance, and effectiveness can improve interpretation of bycatch performance. This type of fishery-specific information is particularly relevant in Tier 2 assessments.

When no reliable data on bycatch and/or discards are available, a risk-based assessment can be completed based on the gear type and the species.

Scoring Decision Tree

For this indicator, scoring is based on the discard ratio, which is the proportion of total catch that is discarded. It is difficult to obtain this data in an automated way. The discard ratio for a given gear type in a particular region must be obtained from reports. If there is no discard data available for a given region, a general discard ratio for a given gear type is used instead. The discard ratio determines the score, as shown in the decision tree below.

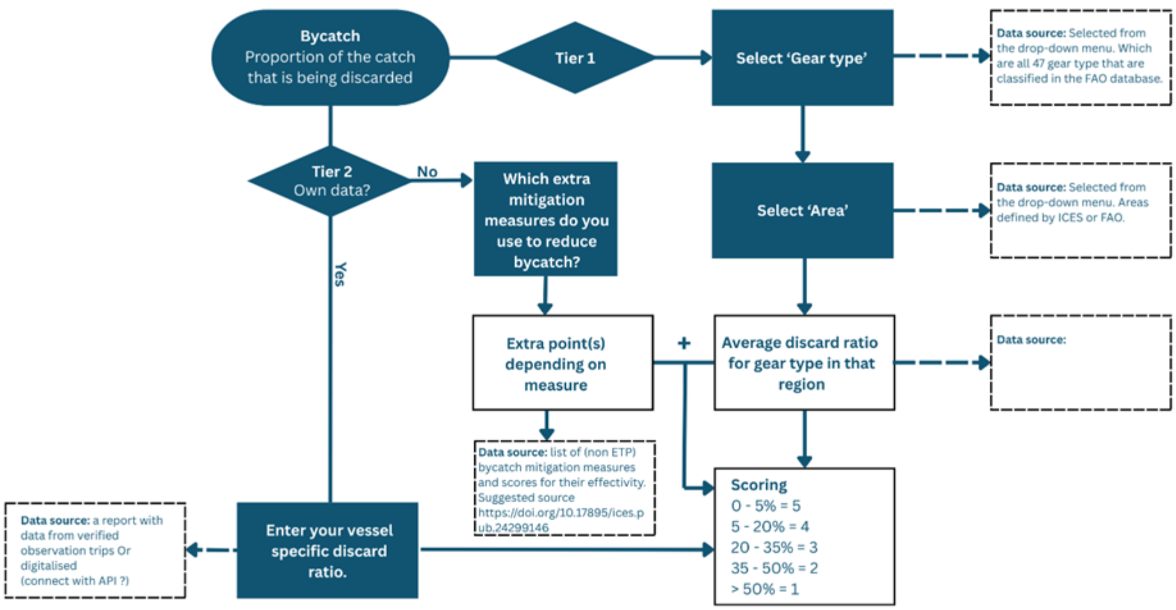

Figure 6. Decision tree for 'ecological impact- bycatch'

Case Studies

Table 7. Case studies for 'ecological impact- bycatch'

Species	**Plaice *Pleuronectes platessa***	**Sardine *Sardina pilchardus***	**Skipjack Tuna *Katsuwonus pelamis.* *Spanish fleet.***	**Argentinian short-finned squid *Illex argentinus***
Gear type	Twin rig large mesh	Purse seine	Purse seine	Jigging
Catch area	North Sea ICES 4b-c	ICES 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	Indian Ocean (FAO 51/57)	Southwestern Atlantic (FAO 41), Falklands (Argentina & UK)

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Bycatch impact score	1	5	5	5
Rationale	Discard rate: 71%	Discards are negligible	The level of non-target species reported as bycatch (retained and discarded) during 2016-2020 is considered relatively low, approximately 4.06% of total catches.	Jigging is a highly selective catching method
Reference	Good Fish vessel specific assessment for MDV-2: based on data from validated observer trips by Wageningen Marine Research (not public)	ICES Iberian Sardine[11]	MSC assessment report ANABAC Indian Ocean tropical tuna purse seine fishery (2024)[12]	How squid jigging works (AFMA)[13]

Scoring approach from STECF

To allow for a more meaningful classification of fishing gear types, the STECF (STECF 20) identified 12 categories, going beyond the 7 which are mandatory in the EU CMO regulation. The STECF categories include: seines, bottom trawls, pelagic trawls, set nets, driftnets, purse seines, hooks and lines, set longlines, drifting longlines, dredges, pots and traps, and hand implements. The CMO 7 gear categories are considered too broad to differentiate between risks such as bycatch rates or habitat impacts. For example, pelagic trawling poses different risks compared to demersal (bottom) trawling; demersal trawling typically involves mixed-species fisheries, while pelagic trawling usually targets single species schools, leading to different ecological and bycatch profiles.

Yet, also the 12 categories were considered insufficiently detailed by the STECF EWG 23-18 to properly represent the bycatch risk diversity for the full set of species marketed in the EU. Therefore, the STECF suggested using more detailed information on corresponding gears and codes (28 gears, plus 4 gears added

11 https://ices-library.figshare.com/articles/report/Sardine_i_Sardina_pilchardus_i_in_divisions_8_c_and_9_a_Cantabrian_Sea_and_Atlantic_Iberian_waters_/27692337?backTo=%2Fcollections%2FICES_Advice_2025%2F7488219&file=60316211
12 https://fisheries.msc.org/en/fisheries/anabac-indian-ocean-tropical-tuna-purse-seine-fishery/
13 https://www.afma.gov.au/methods-and-gear/squid-jig

by the EWG 23-18 for a total of 32 gear categories). Including these gears would however require a revision of the CMO regulation by increasing the mandatory level of details on gear categories.

The Global Record of Stocks and Fisheries (GRSF) utilises standardised fishing gear classifications to ensure consistency and interoperability across diverse data sources. Specifically, GRSF adopts the FAO's International Standard Statistical Classification of Fishing Gear (ISSCFG) as its primary framework. Additionally, it incorporates the Sustainable Fisheries Partnership (SFP) fishing gear classification, which is mapped to the ISSCFG within the GRSF knowledge base.

The ISSCFG system categorises fishing gear based on operational characteristics, such as how the gear is deployed and retrieved, and the nature of its interaction with target species. This classification encompasses various gear types, including; trawls (e.g., bottom trawls, pelagic trawls), seines (e.g., purse seines, beach seines), gillnets and entangling nets, hooks and lines (e.g. longlines, handlines), lift nets, falling gear (e.g. cast nets), stow nets, traps and pots, dredges, and harpoons and spear guns, and miscellaneous gear (e.g. pumps, explosives). By employing the ISSCFG, the GRSF ensures that gear types are consistently classified, facilitating accurate assessments of fishing practices, their environmental impacts, and aiding in the development of sustainable fisheries management strategies.

In case no information can be derived from the various data sources, The FAO report by Kelleher [54] provides an overview of discard estimates on a fishery-by-fishery approach.

1.1.8. Indicator: Ecological impact- potential bycatch risk of sensitive species (08)

Purpose and Scope

Over the past decades, growing public awareness around environmental health has led to a sharp decline in societal tolerance for unsustainable practices, especially when emblematic species are affected. As a result, the incidental catch of Endangered, Threatened, and Protected (ETP) and sensitive species is not only an ecological concern but also a matter of strong public expectation. Addressing this issue is essential in defining a sustainable fishery.

ETP species are defined as *Endangered*, *Threatened*, and *Protected* species in accordance with IUCN criteria:

- **Endangered**: Species or taxa whose populations have been drastically reduced to critical levels, or whose habitats have been so severely degraded that they are considered at risk of extinction in the short or medium term. This category also includes species that are, in all likelihood, already extinct—those that have not been observed in the wild for the past 50 years.
- **Threatened**: Species facing a significant risk of extinction, based on factors such as population dynamics, biological characteristics (e.g., body size, trophic level, life cycle, breeding behavior, or social structure), and vulnerability related to their tendency to aggregate or to natural fluctuations in population size over time and magnitude, as defined by the IUCN.
- **Protected**: Refers broadly to any species that has been granted legal protection by a *national government*. Most protected species fall into either the threatened or endangered categories. This definition also includes species listed under regional or international agreements, which recognize

their declining populations in the wild due to human or other impacts. One of the most stringent international protections is provided by **CITES**, an agreement ratified by nearly all countries, giving listed species a unique and legally binding status. Other international conventions, whether binding or not, ratified by EU Member States or the countries of origin of a product, should also be taken into consideration. The listing of any species at the national or regional level is a clear indication of the need for heightened attention and protection.

- **Sensitive species** are defined as those whose conservation status -including habitat, distribution, population size, or condition - is negatively impacted by pressures resulting from human activities, including fishing. In European waters, this category includes species listed in Annexes II and IV of Directive 92/43/EEC, those covered by Directive 2009/147/EC, and species requiring protection to achieve good environmental status under Directive 2008/56/EC.

The incidental capture of ETP and other sensitive species is considered to pose a major conservation concern because even limited additional mortality may be significant for populations that are protected, depleted, or slow to recover. This issue primarily affects marine mammals, seabirds, sea turtles, many sharks and rays, and certain finfish species.

Protecting ETP and sensitive species is a fundamental requirement under the European Union´s Common Fisheries Policy (CFP), which aligns closely with European environmental legislation. This includes the Birds and Habitats Directives, as well as the Marine Strategy Framework Directive (MSFD), all of which are implemented through the Technical Conservation Measures Framework (TCMF). Beyond the TCMF, additional technical measures are enacted through Commission acts and stand-alone regulations. These include rules targeting specific issues such as cetacean bycatch and shark finning onboard vessels. Outside the EU, protection of ETP species is dependent on local legislation. In many regions, the level of protection is not as well-regulated as in the EU.

Scoring Decision Tree

Based on what is currently available we can at least score for the general gear related impact as given in Figure 3. The different species scores were averaged and inverted to match the low-high ranking of other indicator scores, meaning that high impact on ETP species (5) scores as low performing (1), resulting in the matrix shown in Table 5. The original matrix in Morgan and Chuenpagdee (2003) [52] did not include demersal seines, therefore scores were added by the authors based on expert judgement.

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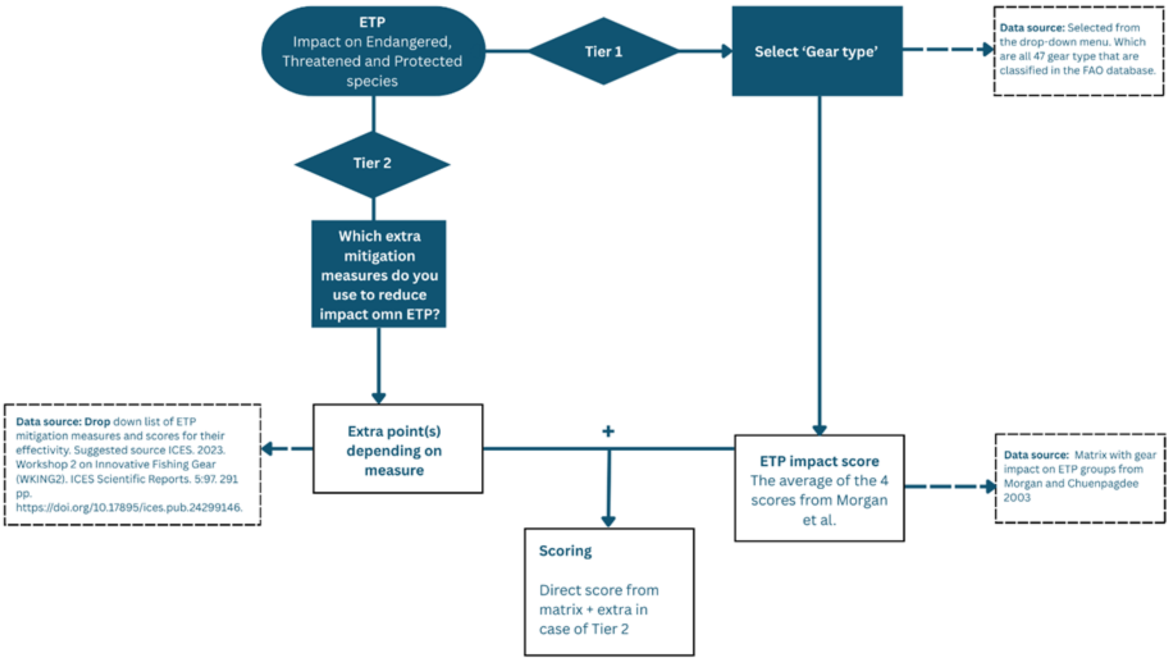

Figure 7. Decision tree for 'ecological impact- potential bycatch risk of sensitive species'

*Table 8. Gear related ETP and sensitive species impact scores derived from Morgan and Chuenpagdee (2003) [52], *complemented with expert judgement (5=low impact, 1=high impact)*

Gear	ETP Impact
Dredges	5
Gillnets - bottom	3
Gillnets midwater	2
Hook and line	4
Longlines - bottom	4
Longlines - pelagic	2
Pots and traps	4
Purse seine	4
Trawl - bottom	4
Trawl - midwater	4
Demersal seine*	4

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Case Studies

Table 9. Case studies for 'ecological impact- potential bycatch risk of sensitive species'

Species	**Plaice** ***Pleuronectes platessa***	**Sardine** ***Sardina pilchardus***	**Skipjack tuna** ***Katsuwonus pelamis. Spanish fleet.***	**Argentinian short-finned squid** ***Illex argentinus***
Gear type	Twin rig large mesh	purse seine	purse seine with FAD	jigging
Catch area	North Sea ICES 4b-c	ICES 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	Indian Ocean (FAO 51/57)	Southwestern Atlantic (FAO 41), Falklands (Argentina & UK)
ETP and Sensitive Species impact score	4	3	2	5
rationale	According to gear specific matrix above	The frequency of interactions with turtles, birds and cetaceans is kept at low levels, with the only exception of the common dolphin and Balearic shearwater	The impact on some ETP species is low, but the impact on one of the major bycatch species is large: Primary species such as yellowfin tuna and bigeye tuna are considered subject to overfishing by the RFMO.	Jigging is a highly selective catching method

Scoring approach from STECF

Theoretically, when the occurrence of ETP species in an area is known, the combination of information on gear type used, and fishing area, should enable it to generate a risk score on interactions with ETP species for a fishery. Data can be derived from risk-based approaches such as vulnerability of cetaceans to impacts from fisheries bycatch [55].

However, deriving a meaningful and scientifically robust indicator from the mandatory information currently available under the CMO regulation is not feasible. The gear categories can be considered to be too broad (for example, there is no distinction in the category trawl: pelagic or demersal), and the FAO fishing area is also broad. This aggregation lacks the required resolution to provide a valid or informative scoring for the intended purpose of the indicator.

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The STECF faced this problem as well and has tried to develop a consistent scoring system for both EU and imported fishery products. This assessment is derived from the potential overlap between these species and fishing activities in various areas, using available literature on bycatch rates, existing risk assessments, and general knowledge about gear selectivity and post-capture mortality.

The STECF decided to base the assessment on information derived from national databases or reports, scientific publications, and various forms of grey literature. By the number of scientific records (qualitative, semi-quantitative and quantitative, mainly scientific papers) identified at FAO area level, the WG could establish a risk score of sensitive species bycatch per FAO fishing area and species group.

The STECF EWG 23-18 recommended an implementation in 6 steps, the last step being an operational update:

- Step 1: (pre-)database prepared by the EWG 23-18 (12/2023),
- Step 2: Pre-database filling by further ad hoc (dedicated scientific group of experts in bycatch assessments) and/or STECF EWG,
- Step 3: A beta-version of the database is proposed to the stakeholders on a permanent platform (to be decided),
- Step 4: the database is filled by the dedicated scientific group after analysing the existing peer reviewed scientific bycatch information received from the stakeholders in step 3 - the analysis of new scientific bycatch information by the scientific group can take place in parallel,
- Step 5: first operational and publicly available database used to score the products for the bycatch risk of sensitive species (with merging with the other indicators) - kept separate to prepare the next update of the scoring system,
- Step 6: after a fixed period (e.g., 5 years) or substantial changes in the database or continuously depending on practical feasibility, the operational database will be updated, keeping in mind that a too low frequency of update may represent an obstacle to rapid implementation of the best practices of bycatch reduction.

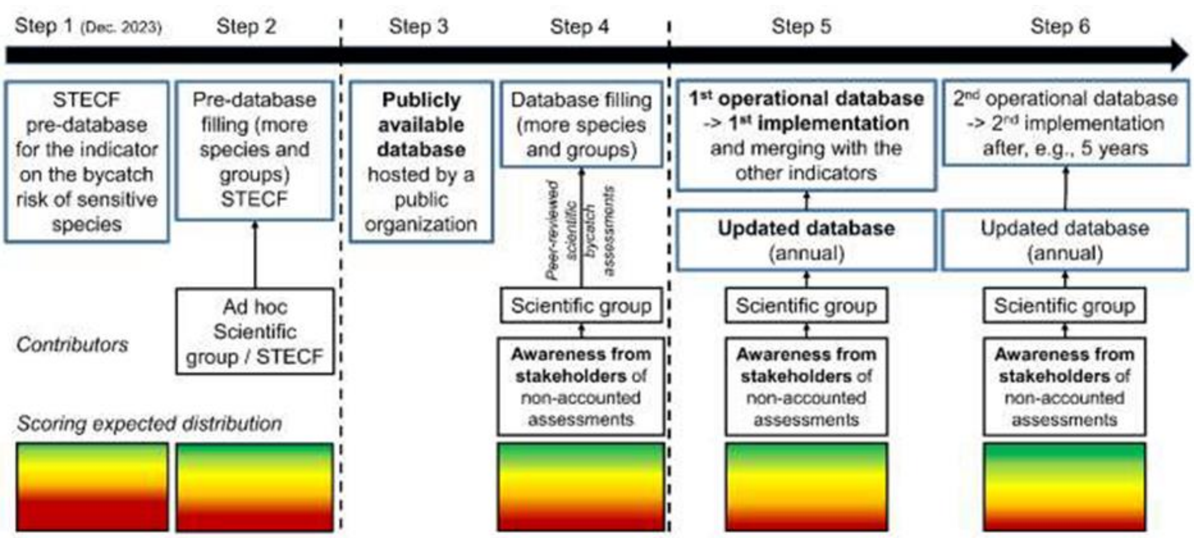

Figure 8. Workflow for implementing a sensitive species indicator (STECF EWG 23-18)

The STECF has drafted a first database, which has been included in the VeriFish Knowledge base. The steps that were followed in the overall scoring process are described in [51].

1.1.9. Ecological Impact- gear loss (09)

Purpose and Scope

In line with STECF definitions, this indicator includes information on plastic waste and pollution. In practice, the main data information sources will be on gear loss. Also, the risk of losing Fish Aggregating Devices (FADs) is included in this indicator. STECF suggests for Tier 1 a Risk Based Approach by pseudo-meter. For Tier 2, measures taken by a vessel such as the use of biodegradable escape panels, having a waste mitigation plan in place, or having lost gear retrieval devices installed can be used. Taking part in the Global Ghost Gear Initiative[14] could also be scored. Measures that are taken to reduce the impact of Fish Aggregating Devices can also be included, such as the use of biodegradable materials, or non-entangling FAD design, equipping FADs with GPS and ID codes to monitor and retrieve lost devices.

Scoring Decision Tree

GEAR CLASS	LIKELIHOOD	IMPACT	TOTAL RISK
Gillnets	5	5	25
Fish aggregating devices	5	4	20
Traps and pots	4	4	16
Longlines	3	3	9
Bottom trawls	2	3	6
Hooks and lines	3	2	6
Mid-water trawls	1	2	2
Seine nets	1	2	2

Figure 9. Gear impact scores (from Global Ghost Gear Initiative)

Based on what is currently available we can at least score for the general gear related impact as given by the Global Ghost Gear Initiative (shown in Figure 9). The likelihood and impact scores were averaged and inverted to match the low-high ranking of other indicator scores, meaning that high gear loss risk (5) scores as low performing (1), resulting in the matrix shown in

Table 10. The original GGGI matrix did not include demersal seines and dredges, therefore scores were added by the authors based on expert judgement.

[14] https://www.ghostgear.org/

*Table 10. Gear related gear loss risk scores derived from GGGI, *complemented with expert judgement, (5=low risk, 1=high risk)*

Gear	Gear loss impact
Dredges*	4
Gillnets - bottom	1
Gillnets midwater	1
Hook and line	3
Longlines - bottom	3
Longlines - pelagic	3
Pots and traps	2
Purse seine	4
Trawl - bottom	3
Trawl - midwater	4
Demersal seine*	3

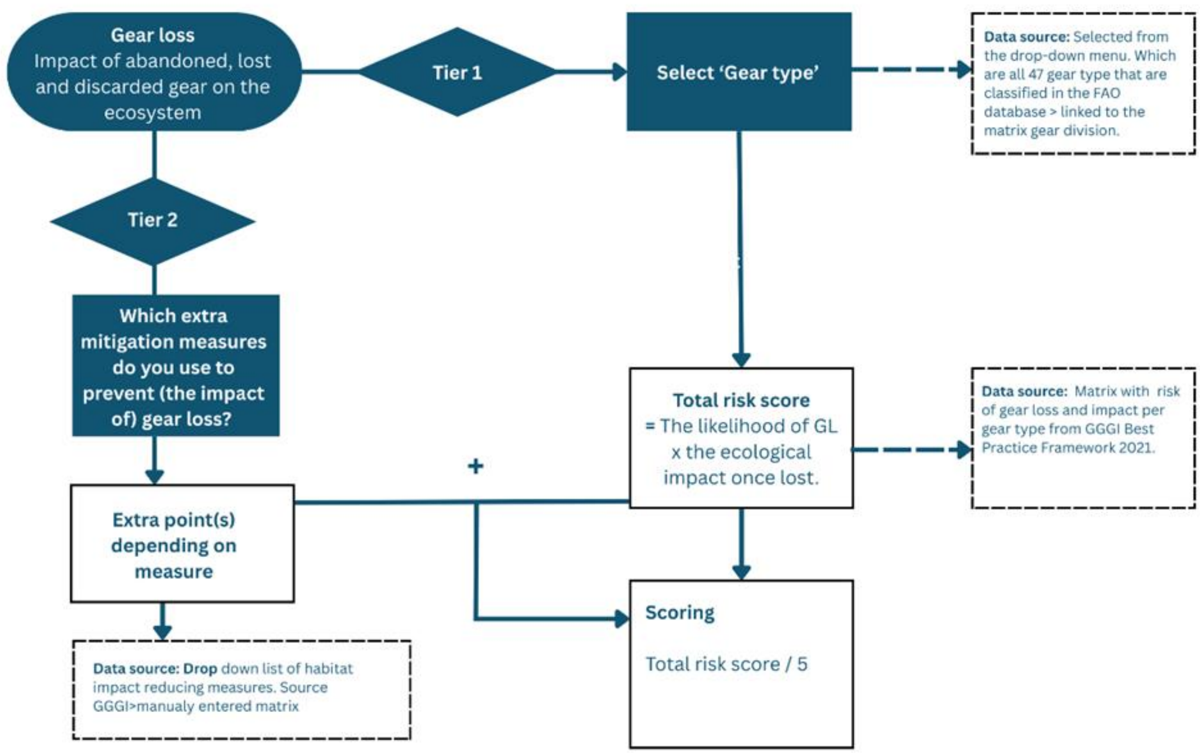

Figure 10. Decision tree for 'ecological impact- gear loss'

1.1.10. Indicator: Catch welfare (10-11-12)

Purpose and Scope

Animal welfare is a topic in capture fisheries that is always under some scrutiny and that is of consideration for the sector. Although a growing body of scientific work and industry-led initiatives is addressing welfare during capture, handling, and slaughter, there are currently no established and widely operational welfare indicators for capture fisheries. Relevant indicators are still under development and may become available for selected species in the coming years.

1.1.11. Indicator: Governance- management indicators (13-14-15-16-17-18)

Purpose and Scope

The indicators monitoring plan, stock management plan, measures on mitigating impact on ETP species, measures to minimize discards and measures to reduce impact on the environment can be captured into one meta-indicator 'management effectiveness'. Management effectiveness is difficult to score as it is very much dependent on the origin of the product, and the level of detail that is known. Consequently, quantitative data are not yet available on management effectiveness. Therefore, the VeriFish App has not yet specified these indicators.

The STECF suggests for System 1 Risk Based Assessments using a scoring of the Regional Fisheries Management Organisation performances. In the VeriFish Tier 1 level, this can be applied as well. Possibly, through the GRSF, more advanced management information is available. In case the FishSource management scores can be used, this might be a useful data platform.

FishSource is a platform developed by Sustainable Fisheries Partnership (SFP) that provides information on the sustainability of fisheries around the world. One of the key components of FishSource profiles is the Management Score Indicators.

FishSource assigns management scores across five key indicators, each focusing on a different aspect of fisheries management. These indicators are scored on a 0–10 scale. Management Score Indicators 1 and 2 are in the VeriFish framework under sub-pillar Stock Status. In future versions of the VeriFish Knowledge base and app, possibly the FishSource Management Score Indicators 3-4-5 could be used for the sub-pillar Governance.

The five FishSource Management Score indicators are:

- Status of the Target Stock: measures whether the stock is overfished or subject to overfishing. Considers scientific assessments and biomass levels.
- Fishing Mortality: evaluates whether fishing pressure is in line with sustainable levels. Looks at catch limits, effort controls, and enforcement effectiveness.
- Quality of Management: assesses the robustness of the management system. Considers the presence of harvest control rules, compliance, monitoring, and scientific advice use.
- Compliance and Enforcement: reflects the degree to which regulations are enforced and followed. It includes monitoring, reporting, and enforcement mechanisms.

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- Management of Other Impacts (Ecosystem Effects): how well does the fishery manage impacts on non-target species and habitats. It evaluates bycatch management, habitat protection, and ecosystem-based approaches.

1.1.12. Indicator: Risk of Illegal, or unreported (IUU) fish (19)

Purpose and Scope

Depending on the data source that is being used in the management effectiveness indicators, a separate indicator to assess the risk level of IUU fish can be used. In a situation of a very data deficient fishery, this indicator might provide information that is otherwise not available. This indicator has been integrated with the social and economic pillar, since the risk of forced labour is considered to be higher in an illegal fishing operation. Data sources such as the IUU vessel list or the Flags-Of-Convenience list relevant for the social and economic indicators are also relevant for the indicator on IUU fisheries.

1.1.13. Indicator: Certification and fishery improvement programmes (20)

Purpose and Scope

If a fishery undergoes the process of becoming certified by a recognised independent certification scheme that has environmental criteria it can use this certificate as a way to demonstrate that the fishery is environmentally sustainable. Moreover, certification schemes typically also provide Chain of Custody control, by way of an additional assessment process, allowing catch that has been certified to be identifiable throughout the entire supply chain.

To assess the quality of certification schemes, it is relevant that a scheme adheres to a set of internationally recognized best practices for sustainability standards. Two major relevant benchmarks are the ISEAL Alliance[15] and the Global Sustainable Seafood Initiative (GSSI)[16].

The ISEAL Alliance is the global membership association for sustainability standards, and its Codes of Good Practice are a set of guidelines that ensure certification schemes are robust, transparent, and credible. Being ISEAL Code compliant helps demonstrate that a certification scheme is legitimate, transparent, and committed to achieving meaningful sustainability outcomes. It is an assurance to both producers and consumers that the certified product or service has been evaluated according to rigorous, fair, and credible standards. ISEAL provides a framework of best practices through its Codes of Good Practice[17], which guide certification schemes to be credible, transparent, and effective.

[15] https://isealalliance.org/

[16] https://ourgssi.org/benchmarking/

[17] https://isealalliance.org/what-we-do/credible-practice/iseal-code-good-practice-sustainability-systems?gad_source=1&gbraid=0AAAAApIOm1ofGEVTWnh4JvJyWkcjF0XjS&gclid=Cj0KCQjw2ZfABhDBARIsAHFTxGwwic1EsNXG3gY-2YlFoyq_xCxdyE07Y89Mw3yWSdDZTROqBV0ANkIaAkNHEALw_wcB

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The Global Sustainable Seafood Initiative (GSSI) benchmark[18] is specifically focused on sustainable seafood certification. GSSI's role is to benchmark and recognize credible, existing seafood certification schemes, ensuring they meet a set of globally accepted sustainability criteria.

ISEAL helps ensure the quality and integrity of certification systems globally across multiple industries, while GSSI works to streamline and harmonize the certification process within the seafood industry specifically. Both organizations play complementary roles in ensuring sustainability certifications are credible and effective, but they focus on different aspects of the certification landscape.

The Marine Stewardship Council (MSC)[19] is both ISEAL compliant and GSSI recognised. It is widely considered the leading fisheries certification scheme. Main reasons are the credibility and robustness of its science-based approach. It is the most widely used ecolabel for wild capture fisheries and covers hundreds of certified fisheries across all continents and oceans. The MSC has major market influence and buyer trust. Retailers and food service companies use MSC to source responsibly. Many public and private seafood procurement policies require MSC certification or equivalent.

Fisheries that are not certified may voluntarily choose to work towards certification [or equivalent standards] through a fisheries improvement programme (FIP). FIPs may be initiated by various organisations or initiatives. The SFP pioneered the use of FIPs to address environmental challenges in marine fisheries. SFP evaluates [FIPs] through the FIP Evaluation Program. The FIP Evaluation Tool[20] defines and assesses FIPs against six stages of achievement, including development of the FIP structure (Stages 1 and 2), implementation (Stage 3), improvements (Stages 4 and 5), and MSC certification (Stage 6). Each FIP receives a rating, ranging from an "A" grade of Exceptional Progress to an "E" grade of Negligible Progress.

SFP's progress ratings is the lead metric on FisheryProgress.org[21], the 'one-stop shop' for information on the progress of global FIPs. It makes tracking progress more efficient, consistent, and reliable for businesses that support fishery improvement projects. Ratings for all public FIPs that SFP is aware of are maintained and displayed in the FIPs section for all FishSource profiles that are linked to fishery improvement projects. The Fishery Progress database does not yet have the possibility to be included in the VeriFish Knowledge Base.

Case Studies

Table 11. Case studies for 'certification and fishery improvement programmes'

Species	**Plaice** ***Pleuronectes platessa***	**Sardine** ***Sardina pilchardus***	**Skipjack tuna** ***Katsuwonus pelamis.* *Spanish fleet.***	**Argentinian short-finned squid** ***Illex argentinus***
Gear type	Twin rig large mesh	purse seine	Purse seine with FAD	jigging

[18] https://ourgssi.org/benchmarking/
[19] https://www.msc.org/
[20] https://drive.google.com/file/d/1-uDxBtDRNAcl_ELuPpW-EBjY3M8YB4Dm/view?usp=sharing
[21] https://fisheryprogress.org/

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Catch area	North Sea ICES 4b-c	ICES 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters)	Indian Ocean (FAO 51/57)	Southwestern Atlantic (FAO 41), Falklands (Argentina & UK)
Governance indicator 19: MSC certified?	yes Joint Demersal Fisheries North Sea[22] & JDF Vessel list[23]	yes Iberian Sardine purse seine fishery[24]	yes ANABAC Indian Ocean tropical tuna purse seine fishery (2024)[25]	no
Governance Indicator 20: Fisheries Improvement Programme?	no	no	no	yes[26]

1.2. Environmental Pillar – Aquaculture

D2.1 [1] and D2.2 [2] provided an initial assessment of both attributes and provisional indicators of the assessed environmental level of sustainability of products coming from aquaculture. Both these aspects have been reviewed and refined and the results presented below. Below we describe the main attributes (i.e., the specific characteristics of the indicators), and indicators (i.e., the measurable variables or parameters of a particular aspect) of aquaculture, followed by case studies.

1.2.1. Global and EU Aquaculture production

World aquaculture production in 2022 achieved an all-time record of 130.9 million tonnes, up by 8.1 million tonnes from 122.8 million tonnes in 2020. According to FAO (2024), its estimated farm-gate value was USD 312.8 billion in 2022, an increase of USD 34.2 billion from USD 278.5 billion in 2020. It comprised 94.4 million tonnes (live weight equivalent; worth USD 295.7 billion) of aquatic animals and 36.5 million tonnes (wet weight; worth USD 17 billion) of algae (seaweed and micro-algae), plus a further 2,700 tonnes (worth USD 138.5 million) of shells and pearls (see production by species in Table 12).

With an annual production of almost 1.05 million tonnes (t) in 2023 (Eurostat), the European Union (EU) is ranked the tenth biggest aquaculture producer in the world, with a value of EUR 4.8 billion. This is a decrease of -1.7% per annum from 2014 to 2023 in volume and an increase of 3.4% per annum in value, although much of this growth occurred in the 2015 – 2017 period (Eurostat, 2025). There is insufficient information to estimate the growth over the 2021 – 2024 period, with production and employment data only available up to 2022 [43].

[22] https://fisheries.msc.org/en/fisheries/joint-demersal-fisheries-in-the-north-sea-and-adjacent-waters/@@view
[23] https://cvo-visserij.nl/gecertificeerde-vis/
[24] https://fisheries.msc.org/en/fisheries/iberian-sardine-purse-seine-fishery/@@view?about=
[25] https://fisheries.msc.org/en/fisheries/anabac-indian-ocean-tropical-tuna-purse-seine-fishery/
[26] https://fisheryprogress.org/fip-profile/19585/overview

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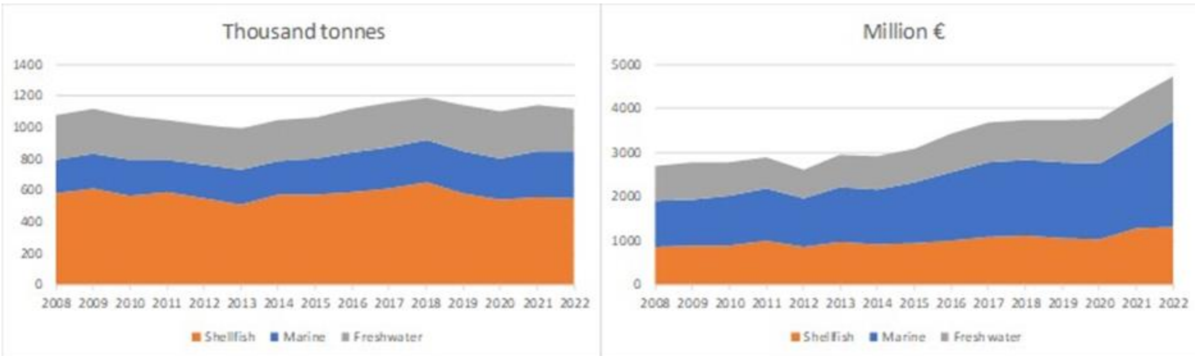

Figure 11. Aquaculture production in the EU (2008-2022). Source FAO data [28], elaborated in [43]

EU aquaculture is based on relatively few species and is dominated by mussels (37% by volume) and trout (15%), see figure below. However, the production of bivalves has declined by 2% per annum over the past ten years (see Figure 12). The recent increase in value is mainly due to the increased production in high value products such as trout, salmon, seabass and the ranching of blue fin tuna, combined with strengthening prices for key species such as seabream, oysters, clams and seaweed (EUMOFA, 2023).

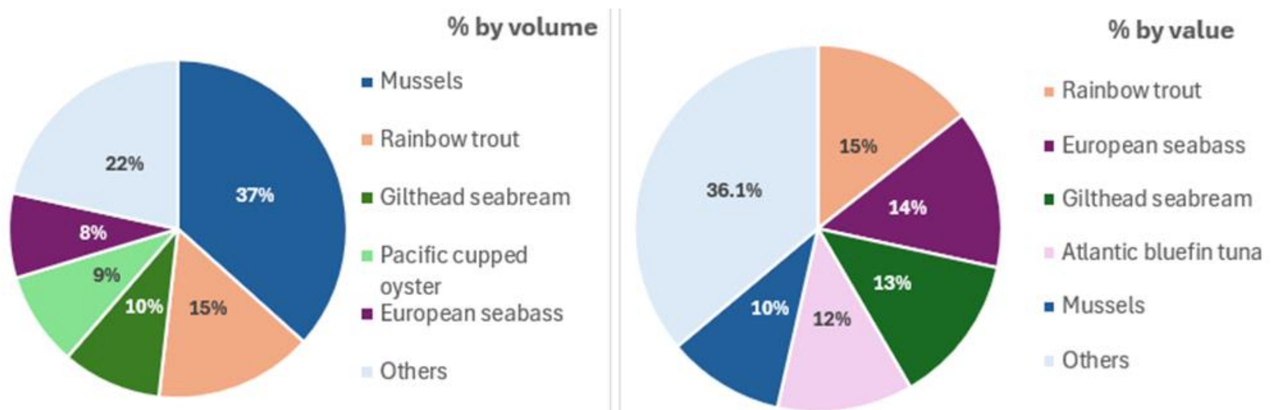

Figure 12. Main species produced in the EU (2022). Source FAO FishStatJ database [29]

Table 12. Top 10 species in terms of production (2023). Source FAO FishStatJ database [29]

Global			EU		
Species	**Production (t)**	**%**	**Species**	**Production (t)**	**%**
Japanese Kelp	13,253,569	11%	Mussels	360,504	34%
Eucheuma seaweeds (NEI)	8,254,317	7%	Rainbow trout	170,246	16%
Gracilaria seaweeds	7,021,566	6%	Gilthead seabream	105,924	10%
Cupped oysters (NEI)	6,705,610	5%	European flat oyster	90,346	9%
Grass carp (= White amur)	6,218,513	5%	European seabass	86,547	8%

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Nile tilapia	5,195,916	4%	Common carp	63,430	6%
Silver carp	5,147,718	4%	Atlantic bluefin tuna	32,638	3%
Catla	4,478,973	4%	Japanese carpet shell	22,904	2%
Constricted tagelus (bivalve)	4,449,106	4%	Pacific cupped oyster	15,630	1%
Common carp	4,091,350	3%	Turbot	12,683	1%
Others	57,661,100	47%	Others	97,206	9%
Total	**122,477,738**	**100%**	**Total**		**100%**

The VeriFish system is global in scope and will therefore eventually cover all farmed species and production systems. However, for this development phase we will focus on the following four key species produced in both inside and outside the EU for human consumption.

- Mussels (*Mytilus spp.*)
- Atlantic salmon (*Salmo salar*)
- Common carp (*Cyprinus carpio*)
- White-legged shrimp (*Litopenaeus vannamei*)

Please note that the main scope of the indicators is up to **farm gate only**, thus covering the primary production phase, but not the ongoing post-harvest processing, product development and distribution elements.

1.2.2. Attributes

Table 13. Attributes used for the VeriFish aquaculture indicators

Attribute	Commentary
Species	The species of the cultivated plant or animal, at least to genus level. The species will dictate a number of other attributes e.g., feeding level. Accurate species identification is vital, with Latin (scientific) names preferred to avoid confusion caused by regional variations in common names. For fresh aquafood products, Regulation No. 1379/2013[27] mandates the use of scientific names.
Country	The country of production is important because it dictates many of the governance elements of aquaculture production, such as laws and regulations governing aquaculture production, welfare and environmental protection. This will be based on the 'undata' database[28] that provides a recognised list of countries and their statistical tables. It is noted that in some cases information may be relevant at regional level. For instance, the EU has a number of regulations and directives that are applicable to all EU-27 Member States, although these are transcribed into national legislation.

[27] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32013R1379
[28] https://data.un.org/?utm

Attribute	Commentary
Feeding level	This is based on the approach used by Ziegler *et al* in [41]. In this we have categorised feeding levels as follows: ● **Non-fed & extractive**: no feed inputs during the main grow-out phase. This includes low trophic species that are considered as extractive, as they remove nutrients and particulate matter from the environment and metabolise it into biomass. This includes macroalgae and filter-feeding invertebrates. ● **Non-fed - not extractive**: also no feed inputs during the main grow-out phase. These species are not extractive, in that they rely on primary production e.g. phytoplankton and zooplankton, as well as other naturally occurring food matter for their growth. An example might be extensive carp farming in ponds, often in polyculture, where no supplementary feed is provided. ● **Fed – herbivorous**: the stock is provided additional feed inputs during the main grow-out phase. However, this does not include any animal protein (marine or terrestrial). An example might be semi-intensive carp farming in ponds, often in monoculture, where supplementary feed is essential for growth. ● **Fed - inc. animal protein**: the stock is provided additional feed inputs during the main grow-out phase. Usually associated with higher trophic, carnivorous species where some inclusion of animal protein (marine or terrestrial) is key for good growth. Examples include intensive salmonid, sea bass, sea bream, catfish and shrimp farming. Extractive species have a strong environmental performance as not only do they have low nutrient emissions or energy costs associated with their cultivation, they can also provide ecosystem services in terms of removing excessive nutrients and/or capturing and sequestering carbon. As one increases feeding levels there is usually an increase in the trophic level, the scale and nature nutrient emissions and the carbon footprint of production. For example, carnivorous species require marine protein that is usually obtained from geographically distant fisheries and that requires energy-intensive reduction to fishmeal, with aquafeed production contributing to the majority of the carbon footprint of carnivorous fish aquaculture. This is well recognised and for this and economic reasons there have been successful attempts to partially substitute marine proteins with novel alternatives. However, these often have their own environmental concerns and 100% substitution is rarely acceptable.
Production system type	The production system used, especially for the longer grow-out period. The key environmental consequence is the 'openness' of the system, which affects issues such as the ability to escape and its consequences, as well as the potential impact of nutrient emissions. The following types are proposed:

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Attribute	Commentary
	● Off-bottom Rafts — Open ● Off-bottom Longlines — Open ● On-bottom — Open ● Barrages and irrigation systems — Open ● Lakes, coastal lagoons and other natural water — Open ● Integrated culture: Rice-Fish culture — Open ● Off-bottom Baskets, Net bags, Net trays, Poles — Open ● Extensive ponds — Semi-open ● Enclosures and pens — Semi-open ● Cages / pens — Semi-open ● Integrated culture: IMTA — Semi-open ● Integrated culture: Other polyculture — Semi-open ● Intensive ponds — Semi-closed ● Tanks and raceways — Semi-closed ● Integrated culture: Aquaponics — Semi-closed ● Recirculating systems — Closed ● Plastic bags, photobioreactor tubes or panels — Closed
Production cycle status	Includes (i) *full cycle* (i.e., has been hatchery-bred and grown to final harvest), (ii) *restocking* (i.e., hatchery-bred and grown for release into the wild as a stock enhancement exercise - also called ranching); or (iii) *grow-out only* (i.e., juveniles are caught in the wild and then grown out to final harvest in captivity).
Environment	Divided into (i) *marine water* (e.g., full seawater above 30 parts per thousand (‰)), (ii) *brackish water* (e.g., 0.5 – 30 ‰) or (iii) *fresh water* (e.g., less than 0.5 ‰).
Alien status	Whether the whether the species being reared is (i) *endemic* (e.g., the species is naturally distributed in the location of the aquaculture operation) or (ii) *introduced* (e.g., the species has been anthropogenically introduced to the location of the aquaculture operation).
Sentience	Sentience, in terms of animal welfare at slaughter, is the scientifically recognized ability of animals to feel pain and distress, requiring that slaughter practices prevent unnecessary suffering and ensure humane treatment throughout the process.

1.2.3. Scoring Approach

Indicator scoring at the Tier 1 level is informed by two main sources:

- **Publicly-available data**: comprises publicly available data from global or regional or even country-level repositories. These datasets are highly accessible, free (in general), and scientifically validated. Like capture fisheries, Tier 1 data, which can be sourced from public repositories including those of

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the FAO's GRSF[29], the Aquaculture Stewardship Council (ASC)[30], GLOBALG.A.P. [31], Best Aquaculture Practices (BAP)[32], other third-party certification organisations, and other open-source data. Other sources of Tier 1 data include regional and national legislation (e.g. restrictions on the use of GMO raw materials in feeds, adherence to extended producer responsibility legislation), published LCA studies, protected area databases (e.g., European Environment Agency EU database on Natura 2000[33]) and national statistics (e.g., FAO FishStat [29]). Whilst all the above are public information, it might not be possible to automate data access and re-use, which suggests some level of additional processing for prospective Tier 1 entries for VeriFish (see next).

- **Datasets generated by VeriFish and others**: given the lack of publicly available data on aquaculture, the majority of Tier 1 scoring will need to be based upon pre-agreed scoring guidance based on established facts and conditions such as the species and its innate characteristics. These are explored further in the indicators below, but includes the following elements:

Species: the species dictates both attributes and characteristics such as the feeding level, sentience levels and to some extent, carbon footprint.

Production system: has an important role in defining the GHG potential, ability for animals to escape, the use of fresh water and effluent production.

In contrast, Tier 2 data are provided by value chains, specifically relating to production methods, products and processes. The advantage of these data is relatively high degrees of granularity can across the different indicators, which can be used to assess performance. The disadvantages, however, are that this information is not readily findable or accessible, subject to bias or error, less interoperable, and potentially not re-useable.

Please note that the scoring proposed in this document is science-based where possible and generally precautionary in nature, especially for Tier 1. This provides the opportunity for producers to submit Tier 2 data and information to improve scores from their Tier 1 levels.

1.2.4. Indicators

Nine indicators have been chosen from an original short-list of 21. These are listed below and are each described in the following sections.

1. Human & ethical slaughter
2. Stocking density during grow-out
3. Site habitat alteration
4. Stock escape potential & impact
5. Greenhouse gas potential
6. Freshwater consumption potential
7. Antimicrobial therapeutic treatments used

[29] https://www.fao.org/fishery/en/knowledgebase/175
[30] https://asc-aqua.org/
[31] https://www.globalgap.org/
[32] https://www.bapcertification.org/
[33] https://www.eea.europa.eu/en/datahub/datahubitem-view/6fc8ad2d-195d-40f4-bdec-576e7d1268e4

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8. Effluents released to the external environment
9. Circularity: proportion plastics reused / recycled

It might be noted that while indicators on feed consumption per kilogram of fish are included (in #5), the assessment as to whether the fish used in feed is sourced sustainably is not included as an indicator. This is because the source of feeds will vary, both within and between farms, and therefore cannot be measured at Tier 1 level. It is also noted that it is possible to assess this factor through the capture fisheries indicators described in Section 1.1 which allows access to the GRSF database.

1.2.5. Indicator: Humane and ethical slaughter

Purpose and Scope

Animal welfare is a fast-moving ESG issue in seafood production, and especially in aquaculture where humans control the full life cycle of the animal. Scientific understanding of sentience, pain perception, and stress response in aquatic species has advanced significantly in recent years — and keeps advancing — and the seafood sector is increasingly being held to the same scrutiny as terrestrial livestock industries. Key welfare concerns include the slaughter method (this indicator) during what is referred to as the 'harvest' process in aquaculture and stocking density (Indicator #02. This specific indicator covers the issue of humane and ethical slaughter. Welfare at the time of killing has long centred on finfish but now clearly includes invertebrates such as decapod crustaceans (prawns/shrimps, crabs, etc.). There is also active EU work on humane slaughter approaches for cephalopods as interest in farming them expands.

This indicator rates slaughter practices by species sentience, legal context and verifiable on-farm evidence. The **purpose** is to provide as objective and verifiable indicator of humane and ethical welfare at slaughter, with particular attention to pain, fear and stress before the animal enters the food chain.

The **scope** covers all aquaculture species globally, including seaweeds and seagrasses, invertebrates and vertebrates, with emphasis on the latter two groups. The indicator is designed for comparability across systems and for incremental improvement tracking.

Tier 1 decision points

A scoring decision tree for this indicator is presented in the sequel of this section. The main steps to Tier 1 scoring are as follows:

Step 1: Select species to allocate corresponding sentience level.

Indicator scoring at the Tier 1 level needs to be made through publicly-available data or through pre-agreed scoring guidance based on established facts and conditions such as the species' innate characteristics. This will be based on the following:

Table 14. Default scores for species sentience

Sentience level (default scoring)	Description	Species allocation
Inanimate (5)	Macroalgae and seagrasses have no nervous system or nociceptors and cannot experience pain or distress. Their physiology is plant-like and they lack any structures associated with sensory perception. They are treated as non-sentient for the purpose of this indicator. Default score of 5	Macroalgae, seagrasses
Low sentience (4)	These animals show basic taxic or withdrawal responses to negative stimuli and may display simple stress physiology. There is no evidence that they experience conscious pain or have the neural machinery needed for complex affective states. They are therefore placed in a low-sentience category that reflects limited behavioural and neurological complexity. Evidence supports withdrawal and physiological stress, not conscious suffering comparable to vertebrates (Crook, 2020; Smith and Lewin, 2023). Default 4 unless national rules or Tier 2 evidence justify adjustment.	Bivalves, most gastropods and simple filter feeders.
Medium sentience (2)	These groups have simple but integrated nervous systems and can show coordinated responses to noxious stimuli that go beyond basic reflex withdrawal. Some work suggests limited forms of learning and stress responses, although there is no convincing evidence of conscious pain. They are more behaviourally complex than bivalves but fall well short of the cognitive and sensory capacities seen in cephalopods or decapod crustaceans. Advanced nociception, learning and motivational trade-offs consistent with pain experience. The precautionary principle applies. Methods should achieve rapid insensibility. Default 2 may increase where robust legislation and compliance are demonstrated. See Birch *et al*. 2021 for the evidential basis.	Holothurians and polychaetes.
High sentience (1)	These animals have well developed nervous systems and show behavioural, physiological and cognitive features that are consistent with pain experience and affective processing. Cephalopods[34] and decapods meet the formal evidential criteria for sentience and are recognised as such in recent reviews. Welfare at slaughter for these species requires effective stunning that ensures rapid and sustained loss of consciousness. Default 1 unless strong legal and compliance signals are met.	Finfish, cephalopods, decapods, amphibians & reptiles

[34] : cephalopods have a large, centralised brain and a distributed nervous system that supports complex learning, problem solving and flexible behaviour. They show nociception and prolonged protective responses after injury which is consistent with pain experience rather than simple reflexes. The UK Government's independent review concluded that cephalopods meet the evidential criteria for sentience and should receive full welfare protection (Birch et al. 2021).

Drop-down menus linking species to the four broad levels of sentience needs to be developed, a fairly simple exercise. This will provide both the sentience level as well as the default preliminary scoring of between 1 and 5.

Step 2: Is there legislation that requires humane slaughter?

This second step allows the default sentience-based scoring to be adjusted based on whether there is national legislation in place that requires producers to ensure the farmed animals' welfare at the point of slaughter of this species in a particular manner and how this is enforced.

This will be based around a country-level database that will provide the following information:

1. **Pre-slaughter stunning mechanisms** permitted and their effectiveness, based on best available scientific evidence. These could include:
    a) Percussive blow for stunning (followed by gill cut for slaughter)
    b) Electrical current for stunning (followed by gill cut for slaughter)
    c) Shooting for instant slaughter
    d) Mechanical spiking, coring, for instant slaughter
    e) Ikejime[35] & others

    Essentially, we need to consider whether national rules require methods that reliably produce rapid unconsciousness based on current evidence. Effective examples include percussive or electrical stunning for finfish and mechanical spiking for larger species. Electrical parameters for decapods may be used where validated. Methods known to cause poor welfare, such as CO_2 hypoxia for finfish, should not be permitted. Scores can increase where prescribed methods align with best evidence and exclude ineffective ones.
2. **Scales of application.** Is there credible evidence that the permitted method is applied correctly at scale?
3. **Levels of derogation**: Derogation is a legal term which allows for part or all of a provision in a legal measure to be applied differently, or not at all. In certain cases, levels of derogation are provided to different sector participants and the likely impact on the effectiveness of the legislation in terms of enforcement. Reduce the score where regulations exclude common production systems or species, or where exemptions allow slaughter without equivalent welfare outcomes. Broad derogations weaken the likelihood of consistent practice and should limit any uplift.
4. **Compliance and enforcement**: Use available inspection reports, audits or national reviews to assess whether requirements are followed. Increase the score where there is documented evidence that animals remain unconscious from stunning to killing. Decrease it where authorities report equipment failures, missing records or weak enforcement. For example, a country may mandate stunning yet still warrant a cautious uplift if documentation is incomplete (*e.g.*, Norway).

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[35] *Ikejime (活け締め) or ikijime (活き締め) is a method of killing fish that maintains the quality of its meat. The technique originated in Japan but is now in widespread use.*

Based on the above, the default scoring can be adjusted. For instance, in the example of salmon being raised in open pens in country x, if there is legislation that requires all farmers to ensure the good welfare of finfish at slaughter then the default score of 1 could be raised to 2. If the legislation goes further and required certain practices that have a scientifically-proved effect on welfare at slaughter, this could be raised further e.g., to 3 or even 4. However, if there are wide-scale derogations that exclude parts of the sector, or compliance levels are low, then the score could be reduced. This will require development of a comprehensive 'welfare database for the main aquaculture producing countries. In time this could be replaced by AI models that can determine these scores based on publicly available data. Further hypothetical examples are given in the case studies at the end of this section.

Scoring guidance

- Strong legislation with effective methods, limited derogations and clear evidence of compliance: +2 to +3.
- Moderate legislation or uncertain compliance: +1.
- No relevant legislation or broad derogations: 0.
- Tier 1 scores should not exceed 4. Any further uplift depends on Tier 2 evidence.

Tier 2 decision points

Accept auditable evidence only: written policy covering species-specific stunning, SOPs, calibrated equipment logs, staff training records, and batch-level stun-to-kill verification. Require objective indicators of unconsciousness where applicable. Time-bound plans with committed capital expenditure (CAPEX) can raise scores provisionally for one cycle. Missing logs or non-functional stunners trigger down-weighting.

Data sources

Primary sources include national legislation and competent authority guidance that set out permitted slaughter methods and welfare requirements. Additional sources include third-party standards, audit reports and scientific reviews on humane slaughter for the relevant taxa. Secondary sources such as NGO assessments or sectoral scorecards may be used where methods and evidence are transparent. We can use the project's welfare law database as the canonical source once available. Another for cephalopods and decapods is described in [21]. The EU's EURCAW Aqua info hub acts as a reference centre and contains information such as approved methods of slaughter based on scientific evidence.

Methodological caveats

Tier 1 relies on species traits and legal signals because public data on aquaculture slaughter practices are limited. Legislation does not always reflect practice and documentation quality varies. Some taxa lack validated stunning parameters which limits comparability across systems. Apply conservative uplifts where compliance evidence is weak and keep Tier 1 scores within the range of one to four. Reserve 5 for inanimate taxa only.

Scoring decision tree

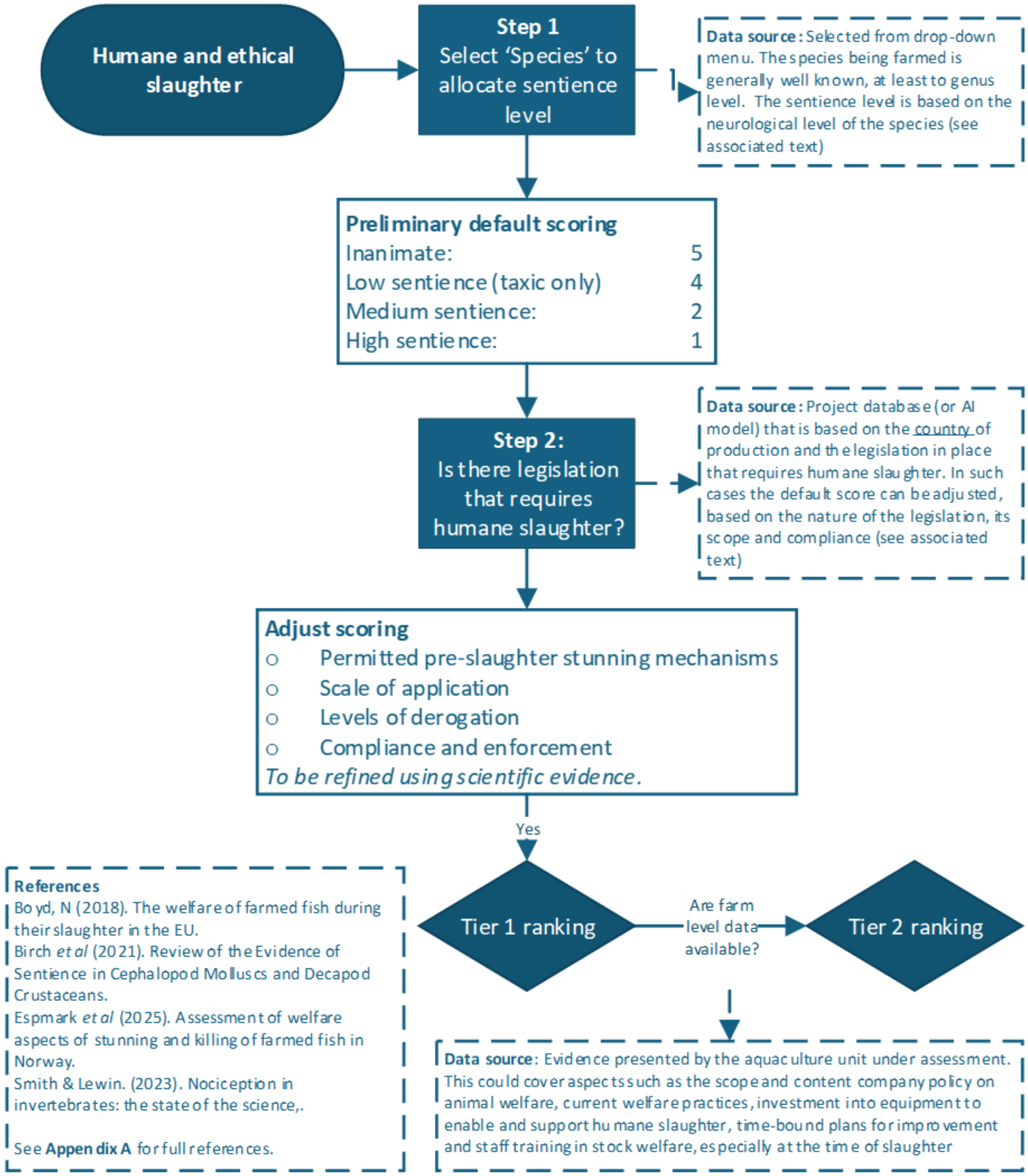

Figure 13. Scoring decision tree for 'Human and ethical slaughter'

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Case studies

Table 15. Case studies for 'humane and ethical slaughter'

Scoring decision-making step	Case studies			
	Longline Mediterranean mussel in Atlantic Spain	**Open pen Atlantic salmon in Norway**	**Extensive pond-raised common carp in Hungary**	**Intensive pond-raised white-legged shrimp in Vietnam**
Step 1: Select 'Species' to allocate sentience level	Mediterranean mussel (*Mytilus galloprovincialis*), a bivalve mollusc, so **has low sentience, with a default score of 4**.	Atlantic salmon (*Salmo salar*), a finfish, so has **high sentience, with a default score of 1**.	European carp (*Cyprinus carpio)*, a finfish, so has **high sentience, with a default score of 1**.	White legged shrimp (*L. vannamei*). A decapod crustacean, so has **high sentience, with a default score of 1.**
Step 2: Is there legislation that requires humane slaughter?	At EU level, there is Council Regulation (EC) No 1099/2009 on the protection of animals at the time of killing. While this is EU-law, Spain as a Member State must apply it, this regulation "does not detail specific methods for fish slaughter" (AWEC, 2024) but the principle applies that animals must not suffer avoidable pain, distress or suffering. Although it does not detail specific methods for fish slaughter, it is clear that any method used must not cause suffering to them, **so default score could be raised to 5**. However, it may not necessarily be applied to the bivalve sector, so **it is recommended the score remain at 4.**	Norwegian Regulation No. 1250 of 30 October 2006 titled 'Regulations concerning slaughterhouses and processing plants for aquaculture animals (in Norwegian: *Forskrift om slakterier og tilvirkingsanlegg for akvakulturdyr*) is a legal basis requiring that fish used in aquaculture (farmed fish) must be stunned before or simultaneous with killing, must remain unconscious until death, and methods that cause unnecessary suffering (e.g., using CO_2 to kill by hypoxia) are prohibited. **This suggests that the score could be raised to 3.** However a recent report suggests there is a lack of documentation ensuring that farmed fish remain unconscious from stunning to killing as required by laws and regulations and there is also a lack of documentation that the methods and equipment used for slaughtering various fish species ensure animal welfare [25]. This **suggests that a score of 3 is recommended.**	At EU level, there is Council Regulation (EC) No 1099/2009 on the protection of animals at the time of killing. While this is EU law and that Hungary as a Member State must apply it, this regulation does not detail specific methods for fish slaughter. Furthermore, there is no legislation In Hungary that clearly and explicitly governs the welfare of farmed carp specifically at slaughter in a manner that sets out species-specific humane slaughter requirements. Given the extensive nature of production, the number of animals slaughtered at one time is low, so due care and attention to their welfare can be provided. Although it does not detail specific methods for fish slaughter, it is clear that any method used must not cause suffering to them, **so default score should be raised to 2**.	The Animal Health 2015, Animal Husbandry 2018) laws focus largely on terrestrial livestock (cattle, pigs, poultry) rather than aquaculture/farmed crustaceans. At present, it is thought that there are no specific local standards and guidelines for shrimp welfare. However, there are general local laws which a) mentions the need to provide better animal welfare and b) regulate humane treatment of animals which is only applicable to terrestrial animals [47]. Overall, **we recommend that that the score remains at a default 1**.
Tier 2 potential	Evidence that the welfare of mussels is considered at slaughter. However most mussels are sold live and killed at the point of consumption, so the potential for Tier 2 evidence to change the score is limited.	Producer specific evidence of company policy on animal welfare, current welfare practices, investment into equipment to enable and support humane slaughter, time-bound plans for improvement and staff training in stock welfare.	Producer specific evidence of company policy on animal welfare, current welfare practices, investment into equipment to enable and support humane slaughter, time-bound plans for improvement and staff training in stock welfare.	Producer specific evidence of company policy on animal welfare, current welfare practices, investment into equipment to enable and support humane slaughter, time-bound plans for improvement and staff training in stock welfare.

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1.2.6. Indicator: Stocking density during grow-out

Purpose and Scope

Stocking density is a critical welfare parameter in aquaculture systems. Overstocking can increase stress, aggression, fin damage, disease susceptibility, and mortality, while understocking may lead to inefficient resource use. Species-appropriate density thresholds must reflect the biological and behavioural needs of the farmed species. The implementation of well-defined limits indicates a proactive approach to managing animal welfare.

The purpose of this indicator is to provide an objective verifiable assessment as to whether stocking densities are limited to improve welfare, either through general guidance (at Tier 1 level) or operator or from specific limits (at Tier 2).

The scope of this indicator is all species produced through aquaculture on a global level, including seaweeds, invertebrates and vertebrates, although will focus on the latter two groups. It does not include the broodstock, hatchery or nursery stages and only covers the stocking density over grow-out e.g., after the juveniles are stocked into the final growing facility.

Tier 1 decision points

A scoring decision tree for this indicator is presented in later in this section. The main steps to Tier 1 scoring are as follows:

Step 1: Select 'Production cycle type'.

If the farming system is either (i) full cycle (i.e., has been hatchery-bred and grown to final harvest) or (ii) grow-out only (i.e. juveniles are caught in the wild and then grown out to final harvest in captivity), then progress to Step 2. This is the default response.

If the stock is released into open water e.g., a 'hatch to catch' system, then this indicator is not applicable.

Step 2: Are acceptable stocking density norms know for 'Production system type' and / or 'Species' combination?

This is composed of the following sub-steps:

- **Step 2a: Select the 'production system' type**. This could be made available from a drop-down menu using the proposed attributes.
- **Step 2b: Select 'Species' from the VeriFish species database**.
- Step **2c: Are acceptable norms know for 'Production system type' and / or 'Species'?** This is the key decision point. We propose the following scoring guidelines:
    - If no such norms or guidance exist, the indicator should not be scored at Tier 1.
    - If generic norms do exist for the farming unit e.g., at national or sector level[36] that specifically require producers to limit stocking densities to improve stock welfare, **then a**

[36] e.g., from producer associations.

score of 3 should be considered** (see comment below).

- If these norms of guidance provided specific guidance on limiting stocking densities for the species and production system involved, **then a score of 4 should be considered** (see comment below).
- If these norms show a strong degree of precautionality, then **a score of 5 should be considered.** It would need to demonstrate that under this system, there is a high degree of welfare being considered for the species / system under assessment.

This will require development of a comprehensive 'welfare database for the main aquaculture producing countries. In time this could be replaced by AI models that can determine these scores based on publicly available data. Further hypothetical examples are given in the case studies at the end of this section.

Tier 2 decision points

Tier 2 decision points would be based on evidence presented by the aquaculture unit under assessment. This could cover aspects such as the scope and content of company policy on stocking densities, current stocking practices and records.

Note that for **salmonids** (salmon, trout):

- In open pen farming in sea water leading practice is a maximum stocking density of 10 kg/m^3. Acceptable practice is averaging <10 kg/m^3 over grow out but not exceeding 25 kg/m^3 at any stage.
- In open pen farming in fresh water leading practice is a maximum stocking density of 8 kg/m^3. Acceptable practice is averaging <8 kg/m^3 over grow out but not exceeding 20 kg/m^3 at any stage.
- In flow-through systems (the flow rate must ensure a minimum of 60% oxygen saturation for stock and must ensure their comfort and the elimination of farming effluent) the leading practice is a maximum stocking density of 20 kg/m^3.

For **shrimp**: The average stocking density on-farm should be 5-15 shrimp per m2 is leading practice. Higher stocking densities e.g., up to 500 shrimp/m^3 are possible for good welfare, depending upon flow /aeration / water quality / pond condition factors.

Data sources

The main data sources for understanding guidance on stocking densities include the EU good husbandry practice publications ([15][16]). Other sources include:

- Commission Implementing Regulation (EU) 2020/46465
- ASC Salmon Standard Version 1.4.1 , 2 May 2024. https://asc-aqua.org/wp-content/uploads/2024/05/ASC-STD-010-Salmon-Standard-V-1.4.1-May-2024.pdf
- Salmon Welfare Scorecard. Compassion in World Farming (CIWF). https://www.ciwf.org.uk/media/7455986/sws23-methodology.pdf
- The Farmed Salmonid Handbook, Marine Institute, 2011. https://www.fishhealth.ie/fhu/health-surveillance/aquaplan-fish-health-management-ireland/farmed-salmonid-handbook
- Shrimp Welfare Index v1-0

Scoring decision tree

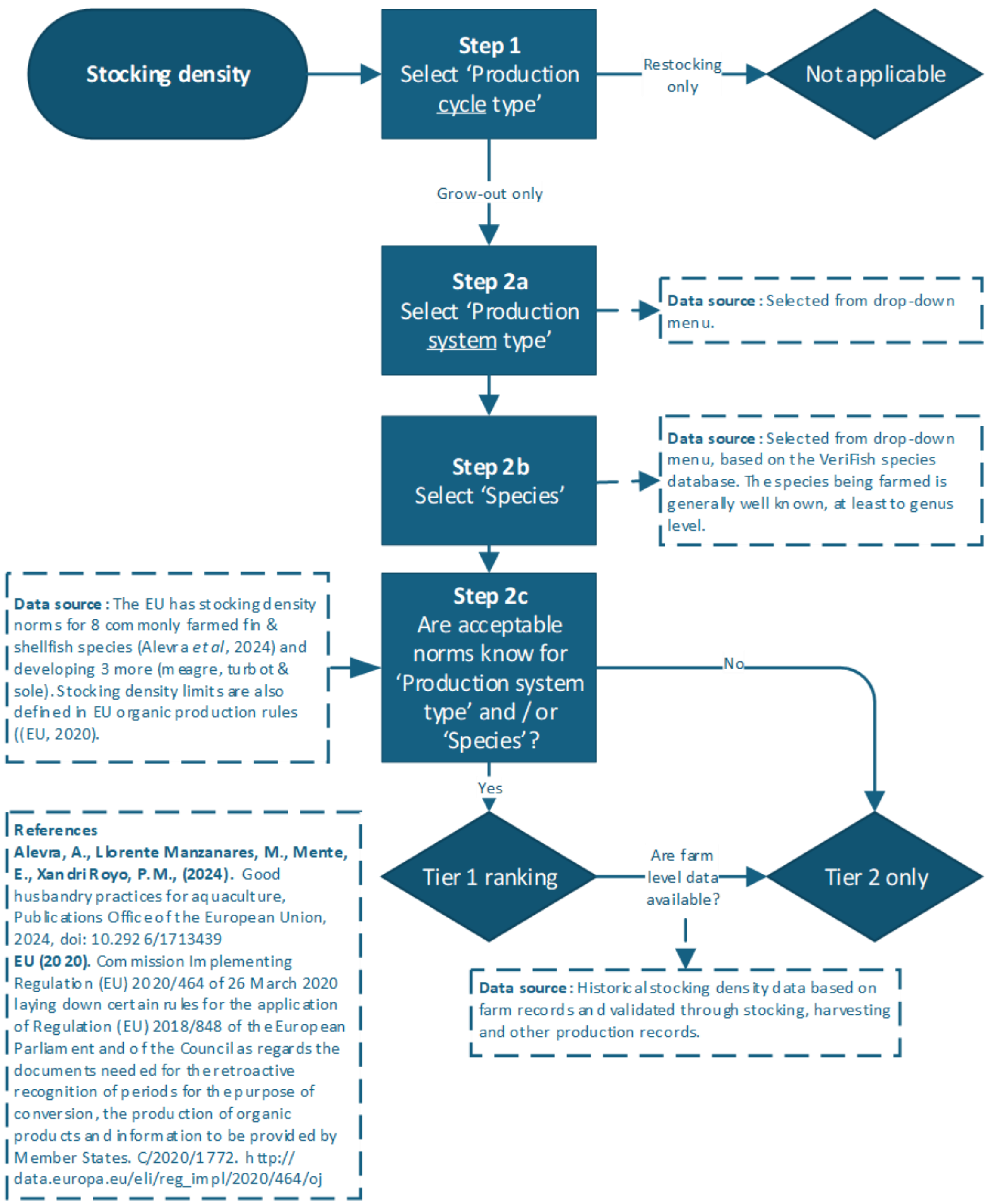

Figure 14. Scoring decision tree for ' Stocking density during grow-out'

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Case studies

Table 16. Case studies for 'stocking density during grow-out'

Scoring decision-making step	Case studies			
	Longline Mediterranean mussel in Atlantic Spain	**Open pen Atlantic salmon in Norway**	**Extensive pond-raised common carp in Hungary**	**Intensive pond raised shrimp (*L. vannamei*) in Vietnam**
Step 1: Select 'Production cycle type'.	Is grown out from natural seed (spat), so is in scope.	Is full cycle e.g. from hatchery-bred juveniles and raised in captivity, so is in scope.	Is full cycle e.g. from hatchery-bred juveniles and raised in captivity, so is in scope.	Is full cycle e.g. from hatchery-bred juveniles and raised in captivity, so is in scope.
Step 2: Are acceptable stocking density norms know for 'Production system type' and / or 'Species' combination?	Is 'Off-bottom longlines, inc. suspended from rafts' farming the Mediterranean mussel *M. galloprovincialis*. This system / species combination is specifically covered in [16], which also notes that Spanish producers control both raft areas, as well as mussel size grading requirements during farming. **It is recommended this scores 4** as these norms of guidance provided specific guidance on limiting stocking densities for the species and production system involved, specifically referencing raft farming of mussels in Galicia. However there is no strong degree of precautionality, so a score of 5 cannot be warranted.	Is in 'Cages / Pens' farming Atlantic salmon (Salmo salar) in open seawater conditions. There is no single Norwegian law that sets a fixed kg/m³ mandatory stocking-density number for Atlantic salmon in open-water sea cages. Instead Norway regulates total biomass per licence (Maximum Allowable Biomass, MAB) and requires that fish density be kept "forsvarlig" (appropriate/defensible) given water quality, health and welfare. The 2008 'Aquaculture Operations Regulations' (Art. 25) states that the fish density per production unit with broodstock and edible fish of salmon and rainbow trout, except in slaughter cages and closed production units, shall in any case not exceed 25 kg/m³ . **It is recommended this scores 4** as these norms of guidance provided specific guidance on limiting stocking densities for the species and production system involved. However there is no strong degree of precautionality, so a score of 5 cannot be warranted.	Is in 'Ponds (land-based)' farming common carp *C. carpio*. This system / species combination is specifically covered in [16], **It is recommended this scores 4** as these norms of guidance provided specific guidance on limiting stocking densities for the species and production system involved, specifically mentions that carp farmed in Central and Eastern Europe on earthen ponds must not exceed 1,500kg of fish growth per hectare [34]. However there is no strong degree of precautionality, so a score of 5 cannot be warranted.	Is in 'Ponds (land-based)' farming white-leg shrimp (*Litopenaeus vannamei*). The legal instrument Circular No. 45/2010/TT-BNNPTNT of the Ministry of Agriculture and Rural Development [36] sets conditions for intensive farming of, among other species, white-leg shrimp (*L. vannamei*). It states for stocking density in the "technological process" section: For intensive white-leg shrimp farming: > 60 shrimps/m². **It is recommended this scores 4.** The regulatory text is a minimum threshold rather than a strict maximum. That suggests the regulation is more about defining "intensive" category and conditions than imposing a definitive cap.
Tier 2 potential	Additional details on raft / longline density, longline stocking densities and grading practices could increase the score to a maximum score of 5	For organic certified products under Commission Implementing Regulation (EU) 2020/46454 the following detailed production rules apply: Part VI of Annex II. The latter includes a maximum stocking density 10 kg/m³ for salmonids in net pens in marine waters.	For organic certified products under Commission Implementing Regulation (EU) 2020/46454 the following detailed production rules apply: Part VI of Annex II. The latter includes a maximum stocking density for organic carps, notably: the total production of species is limited to 1,500 kg of fish per hectare per year.	

1.2.7. Indicator: Site habitat alteration

Purpose and Scope

Aquaculture takes pace in a wide variety of different habitats and utilises a number of different production methods, that in turn necessitate different degrees of habitat alteration during construction. For instance pond farms require considerable earth removal and pod wall construction. In some cases the farm's operation will have an effect on the local habitat, such as sediment deposition adjacent to fish pens or downstream from flow-through farms. Likewise, there are defences in the effort needed to reinstate decommissioned aquaculture farms back to their previous condition. Again, pond farms will require a considerable movement of earth. For offshore anchored systems, the pens / longlines are easily removed, but anchoring systems maybe more problematic to decommission.

The purpose of this indicator is to provide an objective verifiable indicator of the degree to which the habitat might need to be altered on construction, the degree of habitat change over operation, and the ease in which habitats can be restored on decommission.

The scope of this indicator is all species produced through aquaculture on a global level, including seaweeds, invertebrates and vertebrates.

Tier 1 decision points

A scoring decision tree for this indicator is shown later in this section. The main steps to Tier 1 scoring are as follows:

Step 1: Preliminary scoring based on production system type

As discussed above, the habitat alteration risk (e.g., likelihood and impact) is closely relate to the production system. This has been used to generate default scores for different aquaculture production systems (see table below). This is based on a risk analysis in Appendix A.

Table 17. Preliminary habitat attribution score attribution, (5=low impact, 1=high impact)

System	Score	Comment
Ponds (land-based)	1	Major habitat disturbance & expensive to reinstate.
Tanks and raceways (land-based)	1	Requires engineered foundations and buildings.
Recirculating systems (land-based)	1	Requires engineered foundations and buildings.
Plastic bags, photobioreactor tubes or panels	1	Requires engineered foundations and buildings.
Integrated culture: Aquaponics	2	Requires substantial habitat disturbance and engineering.
Integrated culture: Other polyculture	2	Requires substantial habitat disturbance and engineering.
Barrages and irrigation systems	2	Water control can impact wetland system function.

Integrated culture: IMTA (open)	3	May require multiple containment systems & anchors.
Lakes, coastal lagoons and other natural water	3	Water control can impact wetland system function.
Integrated culture: Rice-Fish culture	3	Requires some engineering (dykes, channels)
Cages / pens	3	Easily removable, except for anchor blocks.
Enclosures and pens	4	Easily removable.
On-bottom	4	Easily removable, mostly inter-tidal.
Off-bottom Baskets, Net bags, Net trays, Poles	4	Easily removable, except for anchor blocks.
Off-bottom Rafts	4	Easily removable, except for anchor blocks.
Off-bottom Longlines	5	Easily removable, except for anchor blocks.

Step 2: Adjust scoring on other public data evidence.

The second step allows the score to be adjusted through the use of other public data available for Tier 1 indicators. These might include regional or national legislation regarding:

- Environmental management of aquaculture site, especially in sensitive areas
- Requirements for robust Environmental Impact assessments (EIAs)
- Requirements for decommissioning sites following closure, including habitat restoration and the need for financial bonds.

Other aspects might also be considered. For instance, if there is public data available on the sensitivity of the majority of habitats occupied by the production system type, then a reduction in score might be considered.

Tier 2 decision points

Tier 2 decision points would be based on evidence presented by the aquaculture unit under assessment. This could cover aspects such:

- Third-party certification including habitat impacts and mitigation.
- Habitat management & mitigation plans
- Post-decommissioning reinstatement plans and funding

Data sources

The main data sources for Table 17 were Huntington et al, 2006 [33].

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Scoring decision tree

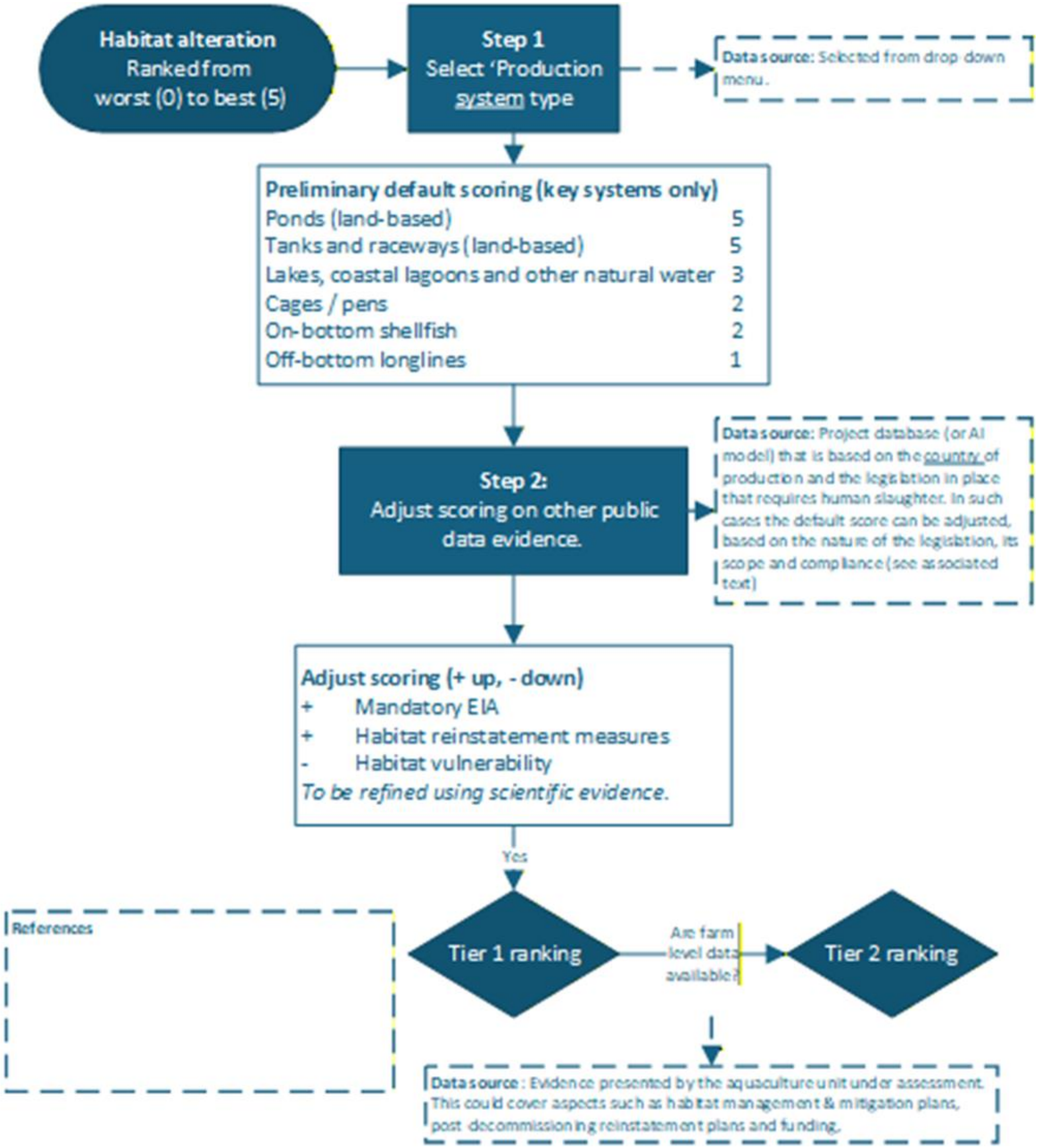

Figure 15. Scoring decision tree for 'site habitat alteration'

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Case studies

Table 18. Case studies for 'site habitat alteration'

<table>
<tr><th rowspan="2">Scoring decision-making step</th><th colspan="4">Case studies</th></tr>
<tr><th>Longline Mediterranean mussel in Atlantic Spain</th><th>Open pen Atlantic salmon in Norway</th><th>Extensive pond-raised common carp in Hungary</th><th>Intensive pond raised shrimp (L. vannamei) in Vietnam</th></tr>
<tr><td>Step 1: preliminary scoring based on production system type.</td><td>Longline mussels are mainly farmed of batea rafts in the Galicia region of NW Spain, with some moving to the New Zealand continuous longline method. On this basis this is allocated a preliminary score of 4.</td><td>Atlantic salmon are raised in open water pens off the coast of Norway. On this basis this is allocated a preliminary score of 3.</td><td>Extensive pond-raised common carp are raised in natural water-bodies that might have some degree of management e.g., dams and other water control mechanisms. On this basis this is allocated a preliminary score of 3.</td><td>Intensive shrimp can be farmed in lined ponds with associated water supply and drainage systems. On this basis this is allocated a preliminary score of 1.</td></tr>
<tr><td>Step 2: Adjust scoring on other public data evidence.</td><td>Spain, as an EU Member State, needs to abide by the following regulations and national counterparts:
Water Framework Directive (2000/60/EC) – ensures good ecological status of water bodies.
Marine Strategy Framework Directive (2008/56/EC) – aims to achieve Good Environmental Status (GES) of marine waters.
Habitats Directive (92/43/EEC) – protects marine biodiversity, including habitats potentially affected by aquaculture.
Spain's Law on Environmental Protection mandates Environmental Impact Assessments (EIAs) for aquaculture projects, especially in sensitive coastal or marine area. However batea rafts may be exempt from full EIAs as they are in pre-zoned aquaculture areas (polígonos de bateas).
Overall the score remains at 4.</td><td>In Norway, the Aquaculture Act (Act No. 79 of 2005) is the primary law regulating aquaculture in Norway[37] . It:
Requires licensing for all aquaculture operations & mandates environmental sustainability as a condition for licensing.
Allows the government to shut down or fine facilities that cause environmental harm.
Prohibits aquaculture in protected areas.
Requires site restoration if operations cease.
EIAs are also required under the Aquaculture Act, as well as the Regulations on Environmental Impact Assessments (EIA Regulations).
Given the above measures, the score is increased to 4.</td><td>Hungary, as an EU Member State, needs to abide by the following regulations and national counterparts:
Water Framework Directive (2000/60/EC) – ensures good ecological status of water bodies.
Habitats Directive (92/43/EEC) – protects marine biodiversity, including habitats potentially affected by aquaculture.
These directives require appropriate assessments to ensure no adverse effects on protected habitats or species.
Government Decree No. 314/2005 (XII.25.) implements the EU EIA Directive (2011/92/EU) in Hungary. It defines thresholds and criteria for when an EIA is mandatory or subject to screening. However open water lakes are unlikely to fall into this category.
Given the protection afforded by the Habitats Directive in particular, the score is increased to 4.</td><td>Law on Environmental Protection (LEP) – 2020 (Law No. 72/2020/QH14) is the primary environmental law in Vietnam.
Requires Environmental Impact Assessments (EIAs) for aquaculture projects that may significantly affect the environment.
EIAs are mandatory for large-scale or intensive aquaculture farms, especially those near sensitive ecosystems (e.g., mangroves, wetlands).
Decree No. 08/2022/ND-CP implements the LEP and provides detailed criteria for EIA thresholds.
Shrimp farms exceeding 10 hectares or located in ecologically sensitive areas must undergo an EIA.
Requires environmental permits and wastewater treatment plans for aquaculture operations.
Given the protection afforded by the LEP, the score is increased to 2.</td></tr>
<tr><td>Tier 2 potential</td><td colspan="4">Certification reports, habitat management plans, decommissioning plans & records</td></tr>
</table>

[37] https://leap.unep.org/en/countries/no/national-legislation/act-no-79-2005-relating-aquaculture-aquaculture-act

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1.2.8. Indicator: Stock escape potential impact

Purpose and Scope

Aquaculture systems contain a variety of different species, from the sessile mussel (e.g. *Mytilus spp*.) to highly mobile finfish such as the migratory Atlantic salmon (*S. salar*). Their containment systems are liked to this relative mobility, but different systems have different risks in terms of escape potential, either through containment failure or human error. This risk and the resultant impact is based on two factors:

1. **The openness of the system**. If a system is open to the receiving environment, there is a higher likelihood that stock might escape into the wild. For instance, salmon net pens are usually in open water and therefore have a higher likelihood of escaping e.g. via n accidental or deliberate net tear than say a land-based tank system where there are barriers in the form of screens, pipes, filters and settlement areas.
2. **The risk of the farmed plant or animal impacting the external environment**. There are a wide range of factors why a lost plant / escaped animal might impact the eternal environment. Some of the key factors include:
    - Genetic impacts on wild population. Escaped farmed fish (e.g., Atlantic salmon or common carp) may breed with wild counterparts, leading to: (i) genetic introgression, which can reduce the fitness of wild populations, and (ii) the loss of local adaptations that are crucial for survival in natural environments. Farmed strains are often selected for traits like fast growth, which may not be advantageous in the wild.
    - Ecological disruption. Includes (i) competition for resources e.g. escaped fish may outcompete native species for food, habitat, or spawning grounds and (ii) predation e.g. some escapees may prey on native species, including juveniles or eggs.
    - Habitat alteration: For example, escaped carp can stir up sediments while foraging, increasing turbidity and reducing water quality.
    - Disease and parasite transmission. Escaped aquaculture species can carry pathogens or parasites (e.g., sea lice, viruses) that spread to wild populations. This is especially concerning in areas with endangered or vulnerable native species.
    - Invasive species risks. Non-native species can become invasive if they escape and establish breeding populations. This can lead to biodiversity loss, altered food webs, and economic damage to local fisheries.

The **purpose** of this indicator is to provide an objective verifiable indicator of both the likelihood escapes might happen and the consequential impacts.

The **scope** of this indicator is all species produced through aquaculture on a global level, including seaweeds, invertebrates and vertebrates, although will focus on the latter two groups.

Tier 1 decision points

A scoring decision tree for this indicator is presented later in this section. The main steps to Tier 1 scoring are as follows:

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Step 1: Preliminary scoring based on production system type.

As discussed above, the habitat alteration risk (e.g., likelihood only – the risk is more associated with species type and is considered in Step 2 below) is closely related to the production system. This has been used to generate default scores for different aquaculture production systems (see Table 19).

Table 19. Preliminary escape likelihood score attribution, (5=low likelihood, 1=high likelihood)

System	Score	Comment
Barrages and irrigation systems	1	Open system with unscreened inlets / outlets.
Integrated culture: IMTA	1	Open system, likely with unscreened inlets / outlets.
Lakes, coastal lagoons and other natural water	1	Open system, likely with unscreened inlets / outlets.
Integrated culture: Rice-Fish culture	1	Open system, likely with unscreened inlets / outlets.
Off-bottom Rafts	1	Open water system, no containment
Off-bottom Longlines	1	Open water system, no containment
On-bottom	2	Some containment e.g. mesh bags
Off-bottom Baskets, Net bags, Net trays, Poles	2	Some containment e.g. baskets, mesh, trays, etc.
Ponds (land-based)	2	Open flow-through, but with screened inlets / outlets
Cages / pens	2	Open water systems, with net containment.
Enclosures	2	Open water systems, with net containment.
Tanks and raceways (land-based)	3	Full/partial flow-through with screened pipes.
Integrated culture: Other polyculture	3	Open system with variable connectivity
Integrated culture: Aquaponics	4	Open system with variable connectivity
Recirculating systems (land-based)	5	Closed system.
Plastic bags, photobioreactor tubes or panels	5	Closed system.

Step 2: Adjust score based on species-related impact.

Whilst Step 1 deals with the likelihood an escape will happen, this Step 2 looks at the potential impact of these escapes. This will be based on the nature of the species involved e.g., its level of genetic domestication, trophic level, tendency to modify habitats, ability to transit diseases and parasites and whether or not it is a native species. A simple risk analysis has been taken along these lines with the four case study species (see Appendix A) and the results summarised below.

Table 20. Escape impact assessment for the four case study species, (5=low impact, 1=high impact)

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Species (location)	Score (1 worst, 5 best)					
	Genetic impacts	Ecological disruption	Habitat alteration	Disease	Invasive spp. risk	Overall score
Mediterranean mussel (Spain)	5	5	4	5	5	5
Atlantic salmon (Norway)	1	3	5	3	5	3
Common carp (Hungary)	3	4	3	4	5	4
White-legged shrimp (Vietnam)	4	4	4	3	1	3

This assessment would be used to adjust the production system-based scope in Step 1 to account for the possible impact on the receiving environment to give a final Tier 1 score. It will be necessary to develop a small database and escape impact assessment matrix for all farmed species over time. However, a more focused table based on the top 10 farmed species would be a relatively easy task.

Tier 2 decision points

Tier 2 decision points would be based on evidence presented by the aquaculture unit under assessment. This could cover aspects such as the robustness and design of primary and secondary containment systems, escape risk assessment and mitigation / contingency plans, track record of escapes, and species-specific measures taken e.g. use of triploids to reduce the chance of genetic impacts on wild populations.

Data sources

The main data sources for examining risks in aquaculture include Arthur *et al* (2009) [18] and more specifically for escapes Atalah and Sanchez-Jerze (2020). For India and eastern African countries, see Harikrishnan *et al*, 2024 [31].

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Scoring decision tree

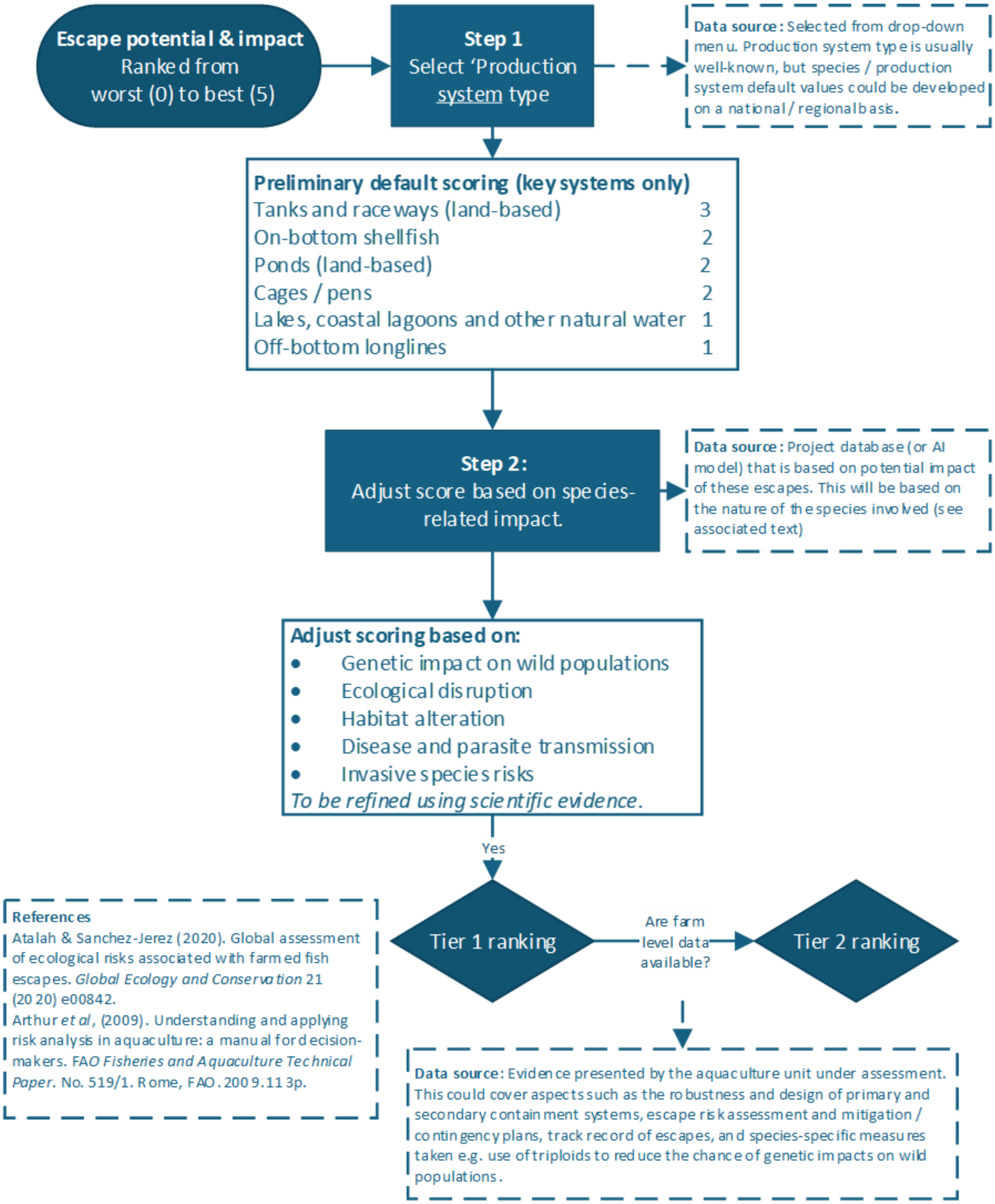

Figure 16. Scoring decision tree for 'stock escape potential impact'

Case studies

Table 21. Case studies for 'stock escape potential impact'

Scoring decision-making step	Case studies			
	Longline Mediterranean mussel in Atlantic Spain	**Open pen Atlantic salmon in Norway**	**Extensive pond-raised common carp in Hungary**	**Intensive pond raised shrimp (*L. vannamei*) in Vietnam**
Step 1: Preliminary scoring based on production system type.	Longline mussels are mainly farmed of *batea* rafts in the Galicia region of NW Spain, with some moving to the New Zealand continuous longline method. This open-water system has no containment. **On this basis this is allocated a preliminary score of 1**.	Atlantic salmon are raised in open water pens off the coast of Norway. This open-water system is contained through a net. However, this is vulnerable to storm damage, vessel collisions as well as human error allowing stock to escape **On this basis this is allocated a preliminary score of 2**.	Extensive pond-raised common carp are raised in natural water-bodies that might have some degree of management e.g. dams and other water control mechanisms. However they are usually fully connected with adjoining rivers and water courses, allowing stock movement. **On this basis this is allocated a preliminary score of 1**.	Intensive shrimp can be farmed in lined ponds with associated water supply and drainage systems. These ponds are open flow-through systems, but with screened inlets / outlets **On this basis this is allocated a preliminary score of 3**.
Step 2: Adjust score based on species-related impact.	Mussels are sessile animals with no drive to move. They are also based on natural seed, so pose no genetical threat. Mussels may form a reef if sufficient animals leave the ropes, but this is not necessarily ecologically damaging. Overall the impact of 'escaped' mussels is very low. **The score is therefore revised up to 4.**	Norwegian farmed salmon are highly migratory. They are also selected for fast growth and low grilsing rates, which are different traits to their wild counterparts, so inter-breeding can potentially be highly damaging. They also can carry sea lice, another threat to wild populations. Overall there is a medium risk of impact, and **the score is reduced to 1.**	Common carp may be selected for their traits that are not beneficial in the wild and this could impact wild populations. They can also cause some habitat impacts, stirring up mud and destroying submerged aquatic vegetation whilst foraging. They can also compete with native fish for space and resources. Overall there is a low to medium impact, and **the score is revised up slightly to 2.**	The white legged shrimp is not native to Vietnam and there poses a number of potential ecological risks to local habitats and associated communities. They also can carry diseases such as White Spot Syndrome Virus (WSSV), Taura Syndrome Virus (TSV) and Infectious Myonecrosis Virus (IMNV). While L. vannamei has been found in wild catches in Southeast Asia (e.g., Thailand[38]), there is limited evidence of self-sustaining populations in Vietnam. Overall there is a medium risk of impact, and **the score is reduced to 2.**
Tier 2 potential	Track record of losses, and species-specific measures taken e.g. use of triploids to reduce the chance of genetic impacts on wild populations.	The robustness and design of primary and secondary containment systems, escape risk assessment and mitigation / contingency plans, track record of escapes, and species-specific measures taken e.g. use of triploids to reduce the chance of genetic impacts on wild populations.	The robustness and design of primary and secondary containment systems, escape risk assessment and mitigation / contingency plans, track record of escapes, and species-specific measures.	The robustness and design of primary and secondary containment systems, escape risk assessment and mitigation / contingency plans, track record of escapes, and species-specific measures.

[38] *See Panulrakul & Senanan (2021) [38]*

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1.2.9. Indicator: Greenhouse gas (GHG) potential

Purpose and Scope

The greenhouse gas (GHG) potential – usually expressed in terms of kilograms of CO2-equivilent / tonne of live weight production – of aquaculture is an important indicator of its potential contribution to climate change. Normally measured up to farm gate, this includes the GHG potential of raw materials (e.g. aquafeeds), production processes and any processing and transport required to produce one tonne of aquaculture production.

The **purpose** of this indicator is to provide an objective verifiable indicator of the climate change potential of a specific aquaculture production system.

The **scope** of this indicator is all species produced through aquaculture on a global level, including seaweeds, invertebrates and vertebrates. As mentioned above, the functional unit is only up to the farm gate. However, it does include the GHG potential of all inputs (e.g., feed, juvenile production, containment facility construction), processes and waste outputs, including mortalities.

Tier 1 decision points

There are two possible approaches to this indicator.

Approach 1: Use data from the Seafood Carbon Emissions Tool developed by the Monterey Bay Aquarium Seafood Watch and Dalhousie University.

This online tool uses multiple sources of data, including life cycle assessments (LCAs), fuel use datasets, industry and government reports, and direct communication with experts which were used to calculate the carbon footprints presented in the Seafood Carbon Emissions Tool. The tool includes carbon footprint estimates for 154 seafood products, of which 53 are for aquaculture (and 101 for fisheries).

For aquaculture this tool constructed carbon footprint estimates for aquaculture production systems using Monte Carlo simulations (repeated sampling of datasets with estimated distributions) with five input parameters. These parameters were:

- the economic feed conversion ratios (eFCR) of the species (kg of feed required to produce 1 kg of fish)
- the relative amount of feed coming from fishery, crop, and poultry by-product sources (mammal by-products were not considered here as their use in aquafeeds is uncommon)
- the reported GHG emissions associated with the different feed inputs used in aquaculture operations
- the rates of total on-farm energy use, including both hatchery/juvenile production and grow-out
- the amount of on-farm energy derived from diesel, petrol/gasoline, and electricity

As with the capture fisheries indicators, the GHG (kg CO2-e / tonne of live weight production) has been scored as follows:

Table 22. GHG potential scoring table (5=low emissions, 1=high emissions)

GHG (kg CO_2-e / t	Score
>20	1
15 – 19.9	2
10-14.9	3
5 – 9.9	4
0 – 4.9	5

Table 23. GHG for 53 species in different aquaculture production systems, expressed in terms of GHG (kg CO2-e / tonne of live weight production)

Species	Production system (mapped to VeriFish production system types)								
	On-bottom	Cages / pens	Off-bottom longlines	Off-bottom rafts	Integrated culture: Rice-Fish culture	Extensive ponds	Intensive ponds	Tanks and raceways	Recirculating systems
Mediterranean mussel			0.12	**0.06**					
Atlantic salmon		**2.25**						5.3	3.55
Common carp		2.25			1.5	**8.1**			
Whiteleg shrimp							**4.35**		
American cupped oyster	0.65								
Arctic char									3.05
Atlantic bluefin tuna		5.7							
Barramundi		3.5				14.2			17.35
Blue mussel			0.12	0.06					
Channel catfish						13.1			
Cobia		5							
European bass		3.5						34.85	
Giant river prawn							4.93		
Gilt-head seabream		3							13.9
Grass carp		2.2			1.5	8.15			
Japanese amberjack		3							
Nile tilapia							7.45		
Pacific cupped oyster	0.6								
Pangasius/Basa		2.4				13.75			
Rainbow trout								5	6.95
Sea trout		1.9							5.8
Silver carp		2.25			1.5	8.05			
Turbot									20.4

Table 24. GHG for 53 species in different aquaculture production systems, expressed as Tier-1 scores (source: Seafood Carbon Emissions Tool (http://seafoodco2.dal.ca/). Note case studies are with red boundaries), (5=low emissions, 1=high emissions)

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Species	Production system (mapped to VeriFish production system types)								
	On-bottom	Cages / pens	Off-bottom longlines	Off-bottom rafts	Integrated culture: Rice-Fish culture	Extensive ponds	Intensive ponds	Tanks and raceways	Recirculating systems
Mediterranean mussel			5	5					
Atlantic salmon		5						4	5
Common carp		5			5	4			
Whiteleg shrimp							5		
American cupped oyster	5								
Arctic char									5
Atlantic bluefin tuna		4							
Barramundi		5				3			2
Blue mussel			5	5					
Channel catfish						3			
Cobia		4							
European bass		5						1	
Giant river prawn							5		
Gilt-head seabream		5							3
Grass carp		5			5	4			
Japanese amberjack		5							
Nile tilapia							4		
Pacific cupped oyster	5								
Pangasius/Basa		5				3			
Rainbow trout								4	4
Sea trout		5							4
Silver carp		5			5	4			
Turbot									1

This is a simple system e.g., basing the scoring on GHG potential bands from the Seafood Carbon Emissions Tool (SCET). However, we do question some of the results, which are at odds with both our Option 2 approach (see below) as well as the STECF scoring [41]. In particular, the SCET scores both open pen farming of salmon and the farming of white legged shrimp in intensive ponds to have very low GHG potential (<5 kg CO2-e / tonne) and thus scoring a maximum of 5, whilst Option 2 score these both a minimum score of 1. It maybe that this reflects the generally low GHG potential of most farmed seafood against terrestrial livestock, rather than being a relative measure of GHG potential within the single pool of aquaculture species and systems.

Approach 2: Calculate scores based on the species and feed level and adjust by production system type

A scoring decision tree for this indicator is presented in later in this section.

The main steps to Tier 1 scoring are as follows:

Step 1: Select 'Species' and 'Feed level'.

This is composed of the following sub-steps:

- step 1a: Select 'Species' from the VeriFish species database.
- Step 1b: Select 'feed level' from the following four options and allocate preliminary scores as follows:
  - Non-fed & extractive Scores 5
  - Non-fed - not extractive Scores 4
  - Fed – herbivorous Scores 3
  - Fed - inc. animal protein Scores 2

Step 2: Select 'Production system type' and adjust scoring accordingly.

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This is composed of the following sub-steps:

- Step 2a: Select 'Production system type'. This could be made available from a drop-down menu using the proposed attributes.
- Step 2b: Adjust scoring on the following basis:
  - Extensive open systems e.g. lakes, large natural ponds, lagoons: increase by 1 as low inputs (e.g. supplementary feeding, often low protein diets).
  - Open-water pen system: reduce by 1. Will require servicing via boat e.g. feed, husbandry & harvesting, so can be fuel-demanding.
  - Land-based flow-through: increase by 1. No pumping costs and easy access.
  - Land-based pumped: no change. Easy access, but some pumping cost.
  - RAS closed system: reduce by 1. Pump, filtration and other machinery costs.

Tier 2 decision points

Tier 2 decision points would be based on evidence presented by the aquaculture unit under assessment. This could cover aspects such (i) the company ambitions and commitments for reaching net zero, (ii) energy auditing e.g., via PEFR, (iii) use of low-carbon and / or renewable energy in the farm's supply chain, and (iv) does the company engage in projects to reduce or mitigate emissions from its suppliers?

Data sources

For Option 1 the 'Seafood Carbon Emissions Tool' developed by the Monterey Bay Aquarium Seafood Watch and Dalhousie University.

For Option 2, the main data sources for establishing the levels of sentience includes scientific research e.g. Birch et al, 2021 [21], sectoral, regional and other collective bodies e.g. and NGOs e.g. Boyd, 2018 [22].

Methodological caveats

As noted above we do question some of the results of the Seafood Carbon Emissions tool, which are at odds with both our Option 2 approach as well as the STECF scoring [41]. In particular, the SCET scores both open pen farming of salmon and the farming of white legged shrimp in intensive ponds to have very low GHG potential (<5 kg CO_2-e / tonne) and thus scoring a maximum of 5, whilst Option 2 score these both a minimum score of 1.

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Scoring decision tree

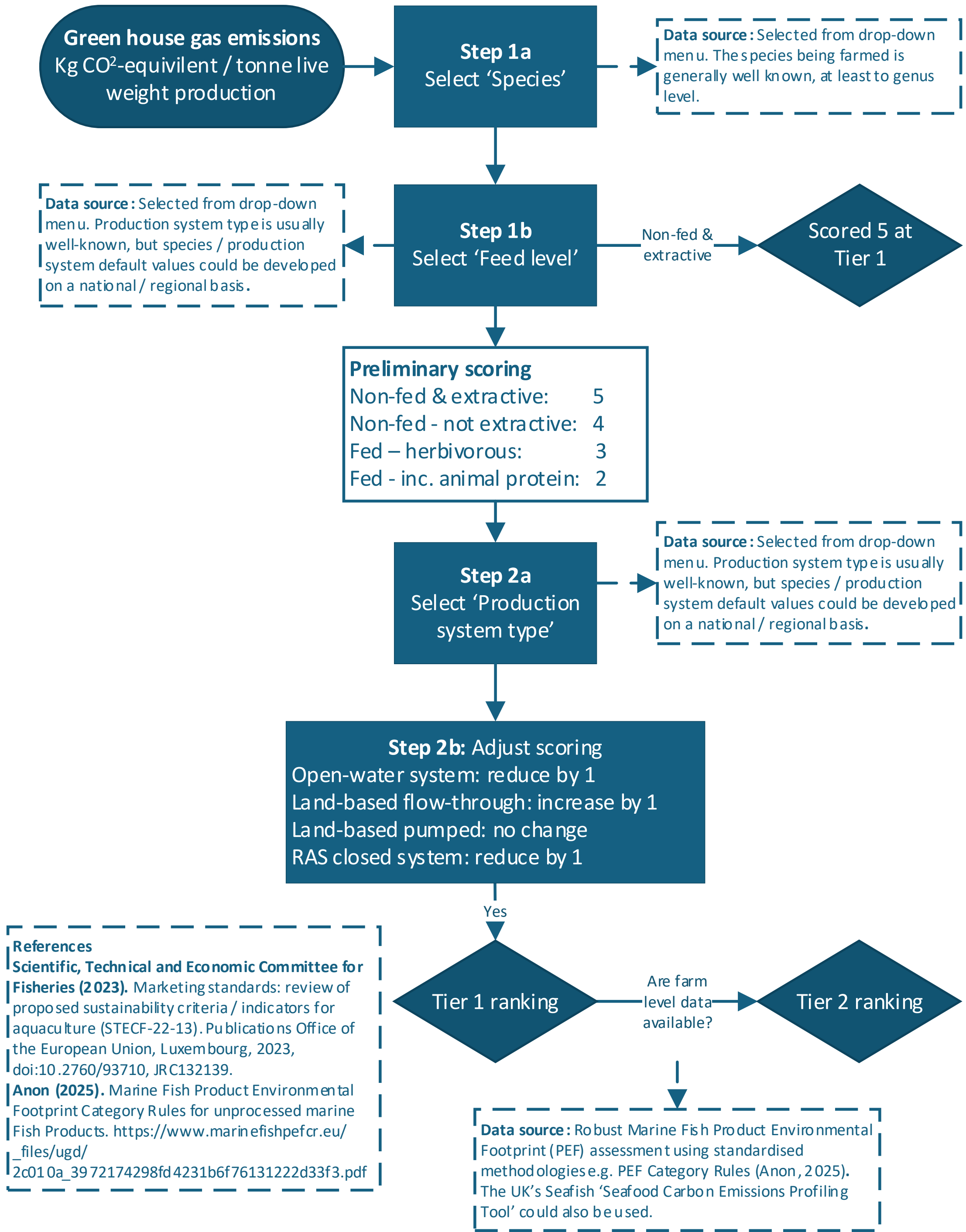

Figure 17. Scoring decision tree for 'greenhouse gas emissions'

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Case studies

Table 25. Case studies for 'greenhouse gas emissions'

Scoring decision-making step	Case studies			
	Longline Mediterranean mussel in Atlantic Spain	**Open pen Atlantic salmon in Norway**	**Extensive pond-raised common carp in Hungary**	**Intensive pond raised shrimp in Vietnam**
Option 1	**Scores 5**	**Scores 5**	**Scores 4**	**Scores 5**
Option 2 **Step 1: Select 'Species' and 'Feed level'.**	Mediterranean mussel (*Mytilus galloprovincialis*), a bivalve mollusc, so **is non-fed and extractive, with a default score of 5**.	Atlantic salmon (*Salmo salar*), a carnivorous finfish, so is **fed with animal protein (>5%), with a default score of 2**.	European carp (*Cyprinus carpio)*, a omnivorous finfish, may be **fed with animal protein (>15%), with a default score of 2**.	White legged shrimp (*L. vannamei*). A carnivorous decapod crustacean, so is **fed with animal protein (>15%), with a default score of 2**.
Option 2 **Step 2: Select 'Production system type' and adjust scoring accordingly.**	Is 'Off-bottom longlines, inc. suspended from rafts' farming the Mediterranean mussel *M. galloprovincialis*. Is an open-water system that needs servicing via boat e.g. husbandry & harvesting, so can be fuel-demanding, so **recommended to reduce score to 4**.	Is in 'Cages / Pens' farming Atlantic salmon (*Salmo salar*) in open seawater conditions. Is an open-water system that needs servicing via boat e.g. feeding, husbandry & harvesting, so can be fuel-demanding, so **recommended to reduce score to 1**.	Is in farmed extensively in freshwater ponds. Extensive pond-reared carp are fed on a supplementary diet (e.g. they also derive nutrition from natural production in the lake). The feed is a low-protein formulation so **recommended to increase score to 3**.	Is in 'Ponds (land-based)' farming white-leg shrimp (*Litopenaeus vannamei*). Intensively farmed in lined ponds with pumped sea water and constant aeration, so can be fuel-demanding, so **recommended to reduce score to 1**.
Tier 2 potential	Life cycle analysis (LFA) or other evidence that demonstrates energy saving approaches, inc. renewable energy generation and use and other effective means to reduce fossil fuel and electricity use.	Life cycle analysis (LFA) or other evidence that demonstrates energy saving approaches, inc. renewable energy generation and use and other effective means to reduce fossil fuel and electricity use.	Life cycle analysis (LFA) or other evidence that demonstrates energy saving approaches, inc. renewable energy generation and use and other effective means to reduce fossil fuel and electricity use.	Life cycle analysis (LFA) or other evidence that demonstrates energy saving approaches, inc. renewable energy generation and use and other effective means to reduce fossil fuel and electricity use.

1.2.10. Indicator: Freshwater consumption potential

Purpose and Scope

Like most primary productive industries, aquaculture has the potential to consume finite resources such as freshwater. For this it will compete with other users, including agriculture, many industries, households and of course, the natural environment. As a result of industrialisation, mechanisation and population growth this demand is growing, yet climate change, pollution are also threatening the quantity and quality of supply.

Water use in aquaculture has direct impacts on the availability of water for other users and biological processes, making it important that aquaculture operations in sensitive regions are aware of their water use and act to improve the water efficiency of their farming processes. It is therefore important that aquaculture minimises water use and where consumption is required, ensures that effluent water is returned in the same, if not better quality.

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Aquaculture is unusually as a primary industry in that, as it depends on good quality water as the main medium for holding stock and in most cases the water is passed through the system with minimum loss through incorporation into the stock (like in horticulture), seepage or evaporation.

The rate of consumption is mainly dictated by the production system type. Some systems – such as pens or enclosures – do not 'use' water, whilst flow-through systems such as ponds or raceways abstract and retain the water for a short time before returning it back to source.

The species is a secondary consideration. Some are only reared in full seawater and therefore freshwater consumption is minimal. Others – such as the anadromous Atlantic salmon – only utilise freshwater during an early phase in their life before being reared to adulthood in sea water. Others, such as rainbow trout are usually raised exclusively in freshwater (although they can be raised in seawater, where they are known as steelhead trout) and as active carnivorous fish need high levels of water exchange.

The **purpose** of this indicator is to provide an objective verifiable indicator of the potential use of freshwater and its net consumption.

The **scope** of this indicator is all species produced through aquaculture on a global level, including seaweeds, invertebrates and vertebrates. As mentioned above, the functional unit is only up to the farm gate. However, it does include the GHG potential of all inputs (e.g., feed, juvenile production, containment facility construction), processes and waste outputs, including mortalities.

Tier 1 decision points

A scoring decision tree for this indicator is presented later in this section. The main steps to Tier 1 scoring are as follows:

Step 1: Preliminary scoring based on production system type

As discussed above, the level of freshwater consumption is closely related to the production system. This has been used to generate default scores for different aquaculture production systems (see Table 26)

Table 26. Preliminary freshwater consumption score attribution (5=low consumption, 1=high consumption)

System	Score	Comment
Tanks and raceways (land-based)	1	Abstractive, intensive systems.
Ponds (land-based)	2	Abstractive, extensive to semi-intensive systems.
Barrages and irrigation systems	3	Are flow-through, but aquaculture is usually a secondary user.
Integrated culture: Rice-Fish culture	3	Uses freshwater for both crops. Not flowthrough, but replacement for evaporation & seepage.
Integrated culture: IMTA	4	Non-abstractive. Requires low current through system.
Off-bottom rafts	4	Non-abstractive. Requires low current through longlines.
Cages / pens	4	Non-abstractive. Requires low current through pens.
Off-bottom Longlines	4	Rarely used in freshwater environments.

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Lakes, coastal lagoons and other natural water	4	Non-abstractive, based on natural water flows.
Enclosures	4	Non-abstractive. Requires low current through enclosures.
Integrated culture: Other polyculture	4	Non-abstractive. Requires low current through system.
Integrated culture: Aquaponics	4	Uses freshwater for all crops. But is highly efficient with low replacement levels.
Recirculating systems (land-based)	4	May utilise freshwater but minimised by recirculation.
On-bottom	5	Rarely used in freshwater environments.
Off-bottom baskets, net bags, net trays, poles	5	Rarely used in freshwater environments.
Plastic bags, photobioreactor tubes or panels	5	Low levels of freshwater replacement.

Step 2: Adjust score based on species-related impact

This second step allows the refinement of the preliminary production system-based scores from Step 1 by considering any species-related characteristics that might influence freshwater consumption potential above that of the genetic production system types. These include:

1. Is the species adapted to marine, freshwater or both during its life stages? For instance, if the species being farmed is exclusively marine, then the score should be increased to 5. However, some species, such as the anadromous Atlantic salmon, has a freshwater stage up to smoltification, after which the fish is transferred to full sea water.
2. The oxygen demand from the farmed plant or animal. As a general rule, the oxygen demand of the species being farmed dictates freshwater flow rates and therefore usage. This of course demands upon the production system being used, but this is accounted for in Step 1. Based on the metabolic rates and oxygen demand of different categories of species, we suggest the following approach to adjusting the scoring:
    - Low oxygen demand e.g. macroalgae and sedentary molluscs. Score increased by 1 or more.
    - Low to medium oxygen demand e.g. decapod crustaceans. Score increased by 1.
    - Moderate oxygen demand e.g. cyprinids. Score possibly reduced by 1.
    - High oxygen demand e.g. salmonids. Score reduced by 1 or more.

Tier 2 decision points

Tier 2 decision points would be based on evidence presented by the aquaculture unit under assessment. This could cover aspects such system design characteristics and modifications to reduce freshwater use, effluent water salinity and quality, use of recirculation systems to reduce freshwater use and other fresh water conservation systems used on farm.

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Scoring decision tree

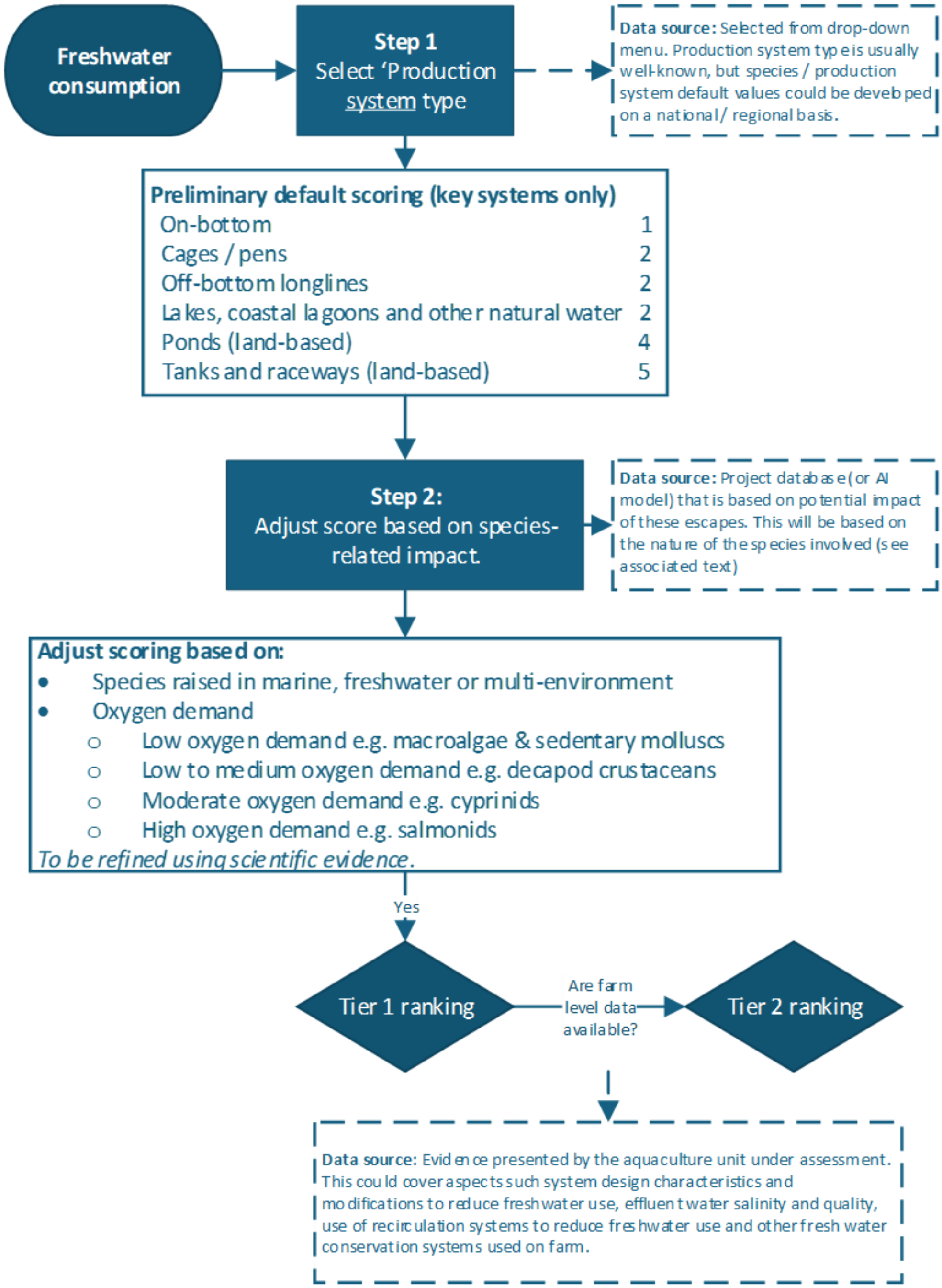

Figure 18. Scoring decision tree for 'freshwater consumption potential'

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Case studies

Table 27. Case studies for 'freshwater consumption potential'

Scoring decision-making step	Case studies			
	Longline Mediterranean mussel in Atlantic Spain	**Open pen Atlantic salmon in Norway**	**Extensive pond-raised common carp in Hungary**	**Intensive pond raised white-legged shrimp in Vietnam**
Step 1: Preliminary scoring based on production system type.	Longline mussels are mainly farmed on *batea* rafts in the Galicia region of NW Spain, with some moving to the New Zealand continuous longline method. This open-water system is non-abstractive, using natural currents. **On this basis this is allocated a preliminary score of 4**.	Atlantic salmon are raised in open water pens off the coast of Norway. This open-water system is non-abstractive, using natural currents. **On this basis this is allocated a preliminary score of 4**.	Extensive pond-raised common carp are raised in natural water-bodies that might have some degree of management e.g. dams and other water control mechanisms. This open-water system is non-abstractive, with natural water flows. **On this basis this is allocated a preliminary score of 4**.	Intensive shrimp can be farmed in lined ponds with associated water supply and drainage systems. These ponds abstractive, highly intensive systems but are not fully flow-through . **On this basis this is allocated a preliminary score of 2**.
Step 1: Adjust score based on species-related impact	Mussels are raised only at sea. Juveniles are obtained from wild spat. Therefore, no significant amounts of freshwater is used in their culture and **the score is adjusted to maximum score of 5.**	Atlantic salmon are raised to between 100 – 300 g in freshwater at the early stages from eggs to fingerlings before they smolt. After smoltification they are transferred to sea water tanks (sometimes up to 500g) before stocking into sea pens in full seawater for growth to harvest at 4 – 6 kg. Salmon fingerlings are active swimmers with a high oxygen demand. Given this freshwater stage and their high oxygen demand, **the score is reduced to 3.**	Carp are only raised in freshwater. Carp have a moderate oxygen demand of around 36.7 ml $O_2 \cdot kg^{-1} \cdot h^{-1}$. However their extensive culture in freshwater ponds suggests that no additional abstraction or use of freshwater is required beyond natural levels. As a result **the score remains at 4.**	White-legged shrimp (*L. vannamei*) in Vietnam are mainly raised in waters with a salinity of 15 – 25 parts per thousand (ppt). With seawater at around 28 – 35 ppt, shrimp dilute the main pumped seawater with freshwater, usually groundwater. Given that shrimp are predominantly raised in saline water the score can be raised substantially. However freshwater is required to maintain pond salinity at around 15-25 ppt. **The score is therefore raised to 3.**
Tier 2 potential	None	Consider aspects such smolt production system design characteristics and modifications to reduce freshwater use, effluent water salinity and quality, use of recirculation systems to reduce freshwater use and other fresh water conservation systems used on smolt production unit.	None	Consider aspects such freshwater supply system design characteristics and modifications to reduce freshwater use, effluent water salinity and quality, use of recirculation systems to reduce freshwater use and other fresh water conservation systems used on farm.

1.2.11. Indicator: Use of antimicrobial therapeutic treatments

Purpose and Scope

An antimicrobial is an antibiotic, antiviral, or antifungal drug used to treat disease or infection. The overuse and misuse of antibiotics in animal production is a well-established public health concern due to its contribution to antimicrobial resistance (AMR), a growing global health threat. In aquaculture, antimicrobials are used both therapeutically and, in some contexts, prophylactically to treat or prevent bacterial infections. Poor management can lead to antibiotic residues in products, resistance development in bacterial strains, and impacts on surrounding ecosystems. Seafood, particularly shrimp and freshwater aquaculture in high-intensity systems, has been flagged as a sector where antibiotic stewardship varies widely, depending on regional regulations, company practices, and market requirements. Certain importing markets (e.g. EU, US, Japan) enforce strict residue limits, while other markets have fewer controls. Investors are increasingly focused on AMR risk management, both from a human health and a regulatory liability perspective. Transparent disclosure of antibiotic policies, usage levels, and risk mitigation is now a basic expectation in ESG performance assessments across protein sectors.

The **purpose** of this indicator is to provide an objective verifiable indicator of the potential for a farming system to utilise antimicrobial therapeutant treatments in their farming systems. At Tier 1 this will firstly be based upon the regulatory structures in place at country level and secondly amended based on the species and production system used. At Tier 2 this can be refined to include measures to improve effluent quality and reduce the overall impact on the external environment.

The **scope** of this indicator is all species produced through aquaculture on a global level, including seaweeds, invertebrates and vertebrates, although will focus on the latter two groups.

Tier 1 decision points

A scoring decision tree for this indicator is presented in later in this section. The main steps to Tier 1 scoring are as follows:

Step 1: Determine national antimicrobial regulation levels

Given the concern over the impact of poorly regulated antimicrobial use, they are usually subject to government control at various levels. This includes aspects such specifying which antimicrobials are allowed in aquaculture and which are banned, defining conditions of use, such as veterinary oversight, dosage rules, or treatment duration; requiring withdrawal periods to ensure food is free of unsafe residues; and limiting or prohibiting prophylactic (preventive) or growth-promotion uses.

We have proposed a preliminary scoring system based on the strength of legislation at country level. These levels are defined in the table overleaf. This information is publicly available but has not been compiled in any database as yet. The case studies in Table 30 demonstrates their use in Spain, Norway, Hungary and Vietnam.

For countries that are undescribed, lack public data or have not imposed any regulation a second step examines the risk of antimicrobial use based on the attributes of the plant / animal farmed and the production system type.

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Table 28. National antimicrobial regulation levels scoring table (5=strong regulation, 1=weak or absent regulation)

Level of regulation	Description	Score
Level 1: No regulation / free use	Antimicrobials can be used freely, without oversight. ● No residue enforcement ● No banned list ● Minimal export controls	**1**
Level 2: Light Regulation	Basic rules exist but enforcement is limited. ● Some banned substances ● Weak monitoring ● Prescription not strictly required ● Limited surveillance	**2**
Level 3: Moderate Regulation	Functional system, but controls vary by region or species. ● Prescription usually required ● Residue monitoring in place ● Approved drug list exists ● Enforcement inconsistent	**3**
Level 4: Strong Regulation	Well-developed regulatory framework with good enforcement. ● Mandatory veterinary prescription ● Regular residue testing ● AMR surveillance ● Strict controls on medicated feed ● Banned critically important antimicrobials	**4**
Level 5: Very Strong / Highly Restricted Regulation	Antimicrobials are allowed only under strict conditions & used rarely. ● Very limited approved antibiotics ● Mandatory reporting of all antimicrobial use ● Vaccination used to replace antibiotics ● Intensive AMR monitoring ● Extremely low actual usage	**5**

Step 2: For countries where Tier 1 data is missing or no regulation of antimicrobial use has been imposed, a risk-based system based on the likelihood of an animal / production system combination requiring antimicrobial use.

This second step allows a risk-based scoring for countries lacking the Tier 1 data or has not enacted any regulation of antimicrobial use. In such cases the Step 1 results should be replaced with the results from the species / production system matrix provided in Table 28.

Table 29. Risk assessment matrix of antimicrobial use by species and production system (5=low risk, 1=high risk)

Production system / Species type	Seaweeds / seagrass	Bivalves / gastropods / other invertebrates	Crustacea	Finfish
On-bottom systems	5	5		
Off-bottom systems	5	5		
Lakes & coastal lagoons	5	5	4	4
Enclosures and pens		5	2	2
Integrated culture	5	5	2	2
Barrages and irrigation systems		5	3	3
Extensive ponds	5	5	2	2
Cages / pens			1	1
Intensive ponds	5	5	1	1
Tanks and raceways	5	5	1	1
Recirculating systems	5	5	1	1

Tier 2 decision points

Tier 2 decision points would be based on evidence presented by the aquaculture unit under assessment. This could include the following:

Data subset	Possible Assessment Areas
Commitments & Ambition	Public commitments to reduce antimicrobial use; timebound targets for phasing out prophylactic and critically important antimicrobials; alignment with WHO guidelines and national action plans on AMR.
Coverage & Implementation	Supplier requirements for responsible antimicrobial use; integration of AMR risk into procurement and production policies; support for farmers to adopt alternatives (e.g. vaccines, probiotics); investment in biosecurity and disease prevention infrastructure.
Production Practices	Elimination of routine prophylactic use; restriction of critically important antimicrobials; implementation of veterinary oversight and prescription-only use; adoption of good husbandry and health management practices.
Monitoring & Verification	Surveillance of antimicrobial use at farm level; monitoring of resistance patterns and AMR risks; third-party audits or certification schemes (e.g. OIE, GlobalG.A.P.); traceability systems for antimicrobial inputs.
Transparency & Disclosure	Public reporting of antimicrobial use volumes and types; disclosure of progress against reduction targets; reporting on AMR surveillance outcomes; publication of supplier compliance rates and certification status.

Data sources

The main data sources on the regulation of antimicrobials includes papers such as Luthman *et al* (2024) [35] as well as World Organisation for Animal Health (WOAH) Aquatic Animal Health Code and the WOAH List of Antimicrobial Agents of Veterinary Importance.

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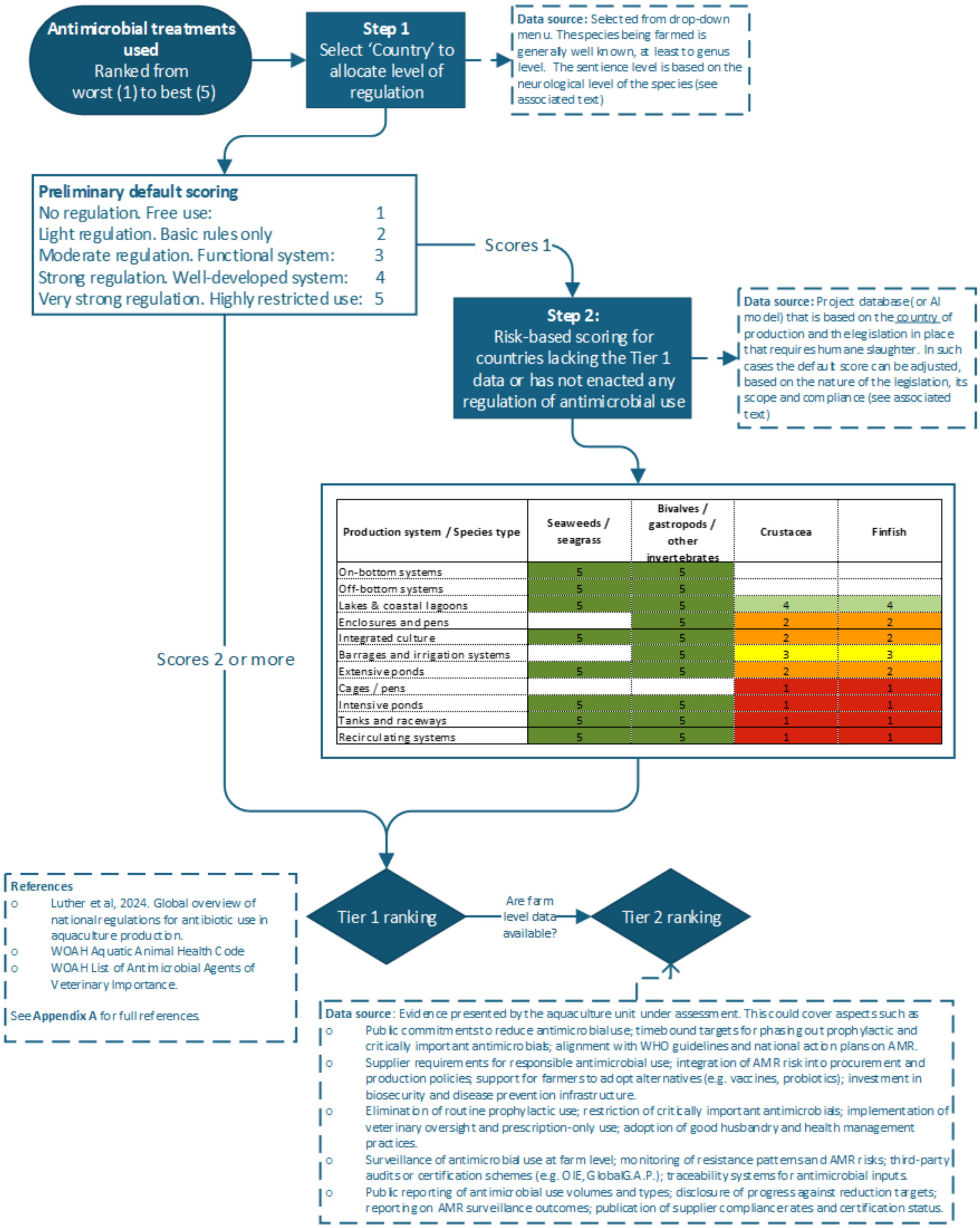
Scoring decision tree



Production system / Species type	Seaweeds / seagrass	Bivalves / gastropods / other invertebrates	Crustacea	Finfish
On-bottom systems	5	5		
Off-bottom systems	5	5		
Lakes & coastal lagoons	5	5	4	4
Enclosures and pens		5	2	2
Integrated culture	5	5	2	2
Barrages and irrigation systems		5	3	3
Extensive ponds	5	5	2	2
Cages / pens			1	1
Intensive ponds	5	5	1	1
Tanks and raceways	5	5	1	1
Recirculating systems	5	5	1	1

Figure 19. Scoring decision tree for ' use of antimicrobial therapeutic treatments'

Case studies

Table 30. Case studies for 'use of antimicrobial therapeutic treatments'

<table>
<tr><th rowspan="2">Scoring decision-making step</th><th colspan="4">Case studies</th></tr>
<tr><th>Longline Mediterranean mussel in Atlantic Spain</th><th>Open pen Atlantic salmon in Norway</th><th>Extensive pond-raised common carp in Hungary</th><th>Intensive pond raised shrimp (L. vannamei) in Vietnam</th></tr>
<tr><td>Step 1: Determine national antimicrobial regulation levels</td>
<td>Spain is a MS of the EU. Aquaculture antimicrobial use is regulated under:
● Regulation (EU) 2019/6 (veterinary medicinal products)
● Regulation (EC) No 470/2009 & MRL database
● EU residue monitoring programs
Key features:
● No antibiotic growth promoters
● Prescription-only use
● Only approved veterinary medicinal products allowed
● Mandatory residue testing, especially for export species
● AMR monitoring required under EU One Health strategies.
Scores 4.</td>
<td>A non-EU country but aligned with EU food-safety rules for trade.
Regulated by:
● Norwegian Food Safety Authority (Mattilsynet)
● Veterinary Medicines Act and Aquaculture Food Safety Regulations
Key strengths:
● Extensive vaccination programs (salmon) → 95–99% reduction in antibiotic use
● Prescription-only antimicrobial access
● Mandatory reporting of all antimicrobial use
● Strict AMR surveillance of fish pathogens.
Scores 5.</td>
<td>Hungary is a MS of the EU. Aquaculture antimicrobial use is regulated under:
● Regulation (EU) 2019/6 (veterinary medicinal products)
● Regulation (EC) No 470/2009 & MRL database
● Directive on medicated feed
● EU residue monitoring programs
Key features:
● No antibiotic growth promoters
● Prescription-only use
● Only approved veterinary medicinal products allowed
● Mandatory residue testing, especially for export species
AMR monitoring required under EU One Health strategies.
Scores 4.</td>
<td>Vietnam's system is evolving due to export requirements (EU, US):
Regulated by:
● MARD (Ministry of Agriculture & Rural Development)
● National Decrees and Circulars on veterinary drugs
Key elements:
● List of banned antimicrobials, including many WHO critical antibiotics
● Allowed drug list for aquaculture with specific withdrawal times
● Residue monitoring for export species (shrimp, pangasius)
● Programs promoting good aquaculture practices (VietGAP)
● Still higher usage than EU/Norway, but trending downward
Vietnam is heavily strengthening AMR controls to meet international market standards.
Scores 3.</td></tr>
<tr><td>Step 2: For countries where Tier 1 data is missing or no regulation of antimicrobial use has been imposed.</td>
<td>Not scored under Step 2 as scores 2 or more at Step 1.
Could be increased to 5</td>
<td>Not scored under Step 2 as scores 2 or more at Step 1.</td>
<td>Not scored under Step 2 as scores 2 or more at Step 1.</td>
<td>Not scored under Step 2 as scores 2 or more at Step 1.</td></tr>
<tr><td>Tier 2 potential</td>
<td>Could be increased to 5 as mussels rarely if ever us antimicrobial treatments.</td>
<td></td>
<td>Producer antimicrobial policies, usage records and independent veterinary records.</td>
<td>Producer antimicrobial policies, usage records and independent veterinary records.</td></tr>
</table>

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1.2.12. Indicator: Effluents released to the external environment

Purpose and Scope

Like any form of biological production system, the plants or animals under aquaculture will produce metabolic byproducts. For macroalgae this is mainly the balance of oxygen produced during photosynthesis and carbon dioxide when respiring. Bivalves produce low levels of carbon dioxide and can also excrete pseudofaeces (excess or unsuitable food particles bound in mucus) whilst crustaceans and finfish produce variable amounts of carbon dioxide depending upon their activity, as well as faeces that reflects their diet and consumption levels. These can all contribute to the quality of the effluent water produced by the farming unit and how this might be released into the external environment. Aquaculture effluent can contain elevated levels of nutrients such as nitrogen and phosphorus, as well as increasing the organic and suspended solid loads.

The production system type can also have an influence on the final effluent released into the naturel environment. Open water systems – such as pens and cages – allow a waste stream directly to the external environment. Flow through systems such as ponds or tanks are also open, but they have the potential for modification e.g. the use of filters, water treatment and settlement facilities. Closed systems such as RAS can fully control the effluent stream and its disposal.

The **purpose** of this indicator is to provide an objective verifiable indicator of the potential for a farming system to release farm effluent into the external environment. At Tier 1 is will be a broad indication of potential and does not take into account the sensitivity or otherwise of the receiving environment. At Tier 2 this can be refined to include measures to improve effluent quality and reduce the overall impact on the external environment.

The **scope** of this indicator is all species produced through aquaculture on a global level, including seaweeds, invertebrates and vertebrates, although will focus on the latter two groups.

Tier 1 decision points

A scoring decision tree for this indicator is presented later in this section. The main steps to Tier 1 scoring are as follows:

Step 1: Determine feeding level based on the species.

As discussed above, a primary factor determining the potential effluent level is the types of species being farmed and its feeding level. As discussed in the attributes table in Section 1.2.2, this is based on the approach used by Ziegler et al in STECF (2023) [41]. In this we have categorised feeding levels and the resultant effluent quality scoring levels in the table overleaf.

This classification and scoring system has been developed solely for VeriFish and is not contained in any current public database. However, there is sufficient publicly available data to both refine the categorisation and build a species database around this, using a combination of feeding level and trophic level data available through sources such as FishBase.

Table 31. Preliminary effluent quality score attribution (5=low impact, 1=high impact)

Feeding level	Description and species	Preliminary scoring
Non-fed & extractive: no feed inputs during the main grow-out phase.	This includes low trophic species that are considered as extractive, as they remove nutrients and particulate matter from the environment and metabolise it into biomass. This includes macroalgae e.g. seaweeds and filter-feeding invertebrates e.g. bivalve molluscs. These are both Primary producers, at trophic levels 1 (seaweeds) and Primary consumers at trophic level 2 (bivalve molluscs).	**5**
Non-fed - not extractive: also no feed inputs during the main grow-out phase.	These species are not extractive, in that they rely on primary production e.g. phytoplankton and zooplankton, as well as other naturally occurring food matter for their growth., with no supplementary foods or nutrient sources added. Would include the traditional farming of carps and tilapias, usually at subsistence level. These are Primary consumers, at trophic level 2.	**4**
Fed – herbivorous: the stock is provided additional feed inputs during the main grow-out phase. However this does not include any animal protein (marine or terrestrial).	An example might be extensive, usually herbivorous fish farming in ponds (e.g. grass carp, silver carp & bighead carp), often in polyculture, and where supplementary feed is essential for growth. These are Primary consumers, at trophic level 2.	**3**
Fed - inc. low levels (<15%) animal protein: the stock is provided additional feed inputs during the main grow-out phase.	Usually associated with species where some inclusion ((<15%) of animal protein (marine or terrestrial[39]) is key for good growth. This could include common carp and some tilapias. These are Secondary consumers with a trophic level of 2-3.	**2**
Fed - inc. high levels (>15%) animal protein: the stock is provided additional feed inputs during the main grow-out phase.	Usually associated with higher trophic, carnivorous species where the inclusion of high levels of animal protein (marine or terrestrial) is key for good growth. Examples include intensive salmonid, sea bass, sea bream, catfish and shrimp farming. It should be noted that animal protein levels in many finfish feeds have	**1**

[39] Mainly fishmeal, blood meal, poultry by-products, etc.)

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	dropped from the 25-30% levels in the 2000s to 10 – 20% through substitution with plant protein alternatives. These are Tertiary consumers with a trophic level of 4.	

Step 2: Adjust score based on the connectedness of the production system with the external environment.

This second step allows the refinement of the preliminary species-specific scores on the potential for generating waste in effluent streams from Step 1, by considering any production system characteristics that will influence how these can be controlled before their release into the external environment. This is based on the ecological classification of aquaculture proposed in [33]) that classification is based on the openness of the system to the external environment and therefore indicates its ability to impact sensitive areas outside of the immediate system. These include:

Table 32. Production system 'openness' (adapted from [33])

Classification	Description	Relevant production systems
Open aquaculture systems	Open aquaculture systems are those without any form of physical containment and therefore have direct connectivity with the external environment.	Barrages and irrigation systems Integrated culture: Rice-Fish culture Integrated culture: IMTA Off-bottom raft Off-bottom longlines Lakes, coastal lagoons and other natural water bodies On-bottom
Semi-open aquaculture systems	Semi-open systems are usually located in the open sea, existing waterbodies or in low-lying areas. They are closely linked to, and dependent upon, the surrounding environment but are usually decoupled through a physical barrier such as a cage or pen net. This barrier is intended to prevent the interchange of stock yet allows the exchange of water and the discharge of effluents into the external environment. There are little control of water inflow and outflow from the farming system.	Cages / pens Extensive ponds Enclosures Off-bottom baskets, net bags, net trays, poles
Semi-closed aquaculture systems	Semi-enclosed systems have a substantial physical barrier in the form of sluice gates, pipework and mesh screens to prevent stock escape. They also have much better inflow control mechanisms (e.g. pumping systems,	Intensive ponds Tanks and raceways (land-based) Integrated culture: Aquaponics

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Classification	Description	Relevant production systems
	water control valves, sluices) and outflow controls e.g. inline filtration and settlement.	
Closed aquaculture systems	Closed systems are usually intensive aquaculture units that recirculate the bulk of its water supply, thus allowing a high degree of isolation from the external environment. These systems are extremely productive (>100 kg/m^3), usually land-based with a minimal footprint and relying entirely on external resources. Site selection therefore reflects location of these external resources rather than in situ land characteristics	Plastic bags, photobioreactor tubes or panels Recirculating systems (land-based)

It is proposed that the preliminary scoring in Step 1 is adjusted as follows:

- Open systems: Reduce by 2
- Semi-open systems: Reduce by 1
- Semi-closed systems: Increase by 1
- Closed systems: Increase by 2

Tier 2 decision points

Tier 2 decision points would be based on evidence presented by the aquaculture unit under assessment. This could cover aspects such as additional mechanisms to control effluent volumes e.g. through recirculation as well as mechanisms to reduce waste levels within the effluent e.g. filtration, settlement, bio-remediation (inc. IMTA) and other nutrient stripping approaches.

Scoring decision tree

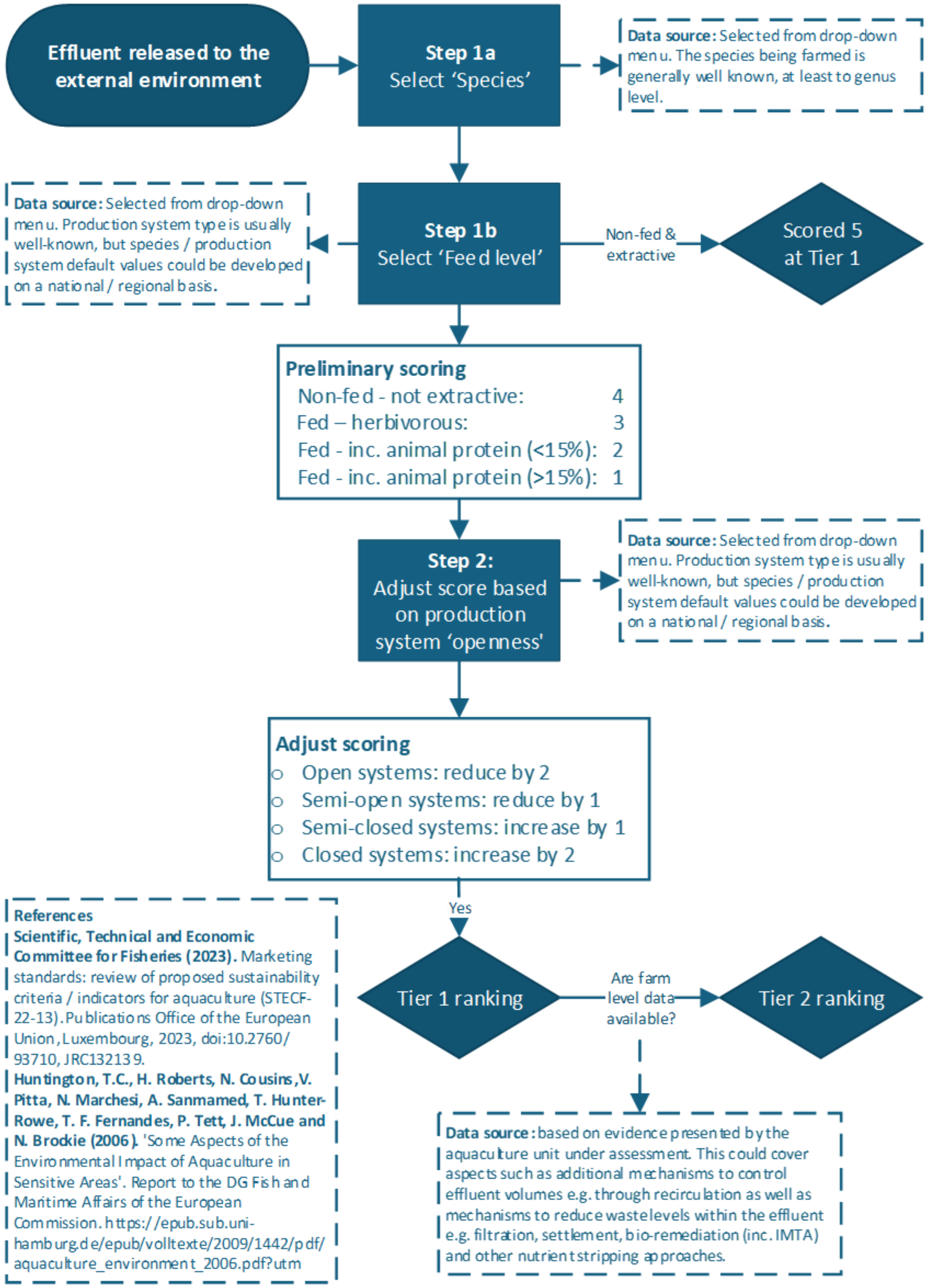

Figure 20. Scoring decision tree for 'effluents released to the external environment'

Case studies

Table 33. Case studies for 'effluents released to the external environment'

Scoring decision-making step	Case studies			
	Longline Mediterranean mussel in Atlantic Spain	**Open pen Atlantic salmon in Norway**	**Extensive pond-raised common carp in Hungary**	**Intensive pond-raised white-legged shrimp in Vietnam**
Step 1: Select 'Species' and 'Feed level'.	Mediterranean mussel (*Mytilus galloprovincialis*), a bivalve mollusc, so is **non-fed and extractive, with a default score of 5**.	Atlantic salmon (*Salmo salar*), a carnivorous finfish, so is **fed with animal protein (>15%), with a default score of 1**.	European carp (*Cyprinus carpio)*, a omnivorous finfish, may be **fed with a supplementary feed, with a default score of 3**.	White legged shrimp (*L. vannamei*). A carnivorous decapod crustacean, so is **fed with animal protein (>15%), with a default score of 1**.
Step 2: Adjust score based on production system 'openness'	Is 'Off-bottom longlines, inc. suspended from rafts' farming the Mediterranean mussel *M. galloprovincialis*. Is an open-water system with a high degree of openness. Although mussels are not fed, they do produce a pseudofaeces, so it is **recommended to reduce score to 4**.	Is in 'Cages / Pens' farming Atlantic salmon (*Salmo salar*) in open seawater conditions. Is an open-water system that has no control over inflows and outflows from within the pen. Apart from careful feeding strategies, it is difficult to control nutrient production and suspended solid production, so **recommended to maintain score at 1**.	Is in farmed extensively in freshwater 'Lakes, coastal lagoons and other natural water'. Pond-reared carp are fed on a low-protein supplementary diet (e.g. they also derive nutrition from natural production in the lake). Whilst the system is open, stocking densities are low so there is little additional waste produced by the farmed stock. Therefore it is **recommended to increase score to 4**.	Is in 'Ponds (land-based)' farming white-leg shrimp (*Litopenaeus vannamei*). Shrimp are intensively farmed in lined ponds with pumped sea water and constant aeration. The system is semi-closed and therefore it is possible to control water inflows and outflows. It is also possible to control effluent quality through filtration and settlement, with outflow environmental monitoring mandatory in Vietnam. On this basis it is **recommended to increase score to 2**.
Tier 2 potential	This could cover aspects such as additional mechanisms to control effluent volumes e.g. bio-remediation (inc. IMTA) and other nutrient stripping approaches.	This could cover aspects such as additional mechanisms to control effluent volumes e.g. through the use of semi-enclosed systems as well as mechanisms to reduce waste levels within the effluent e.g. filtration, settlement, bio-remediation (inc. IMTA) and other nutrient stripping approaches.	This could cover aspects such as additional mechanisms to control effluent volumes e.g. through mechanisms to reduce waste levels within the effluent e.g. filtration, settlement, bio-remediation (inc. IMTA) and other nutrient stripping approaches.	This could cover aspects such as additional mechanisms to control effluent volumes e.g. through partial recirculation as well as mechanisms to reduce waste levels within the effluent e.g. filtration, settlement, bio-remediation (inc. IMTA) and other nutrient stripping approaches.

1.2.13. Indicator: Circularity- proportion of plastics reused/recycled

Purpose and Scope

With the increasing awareness of the impact of plastics on aquatic environments, attention is also being focused on aquaculture. Plastics are used extensively in marine fish farming; for example, in cages (e.g., in the collars and nets themselves, as well as in feeding systems), in coastal fishponds (e.g., in pond liners), and in shellfish farming (e.g., in mussel socks, oyster spat collectors and mussel pegs). These plastics are susceptible to loss through extreme weather events, mismanagement of waste or deliberate discharge. Although global losses of plastics from aquaculture to the aquatic environment are probably lower in volume than from fishing [32], aquaculture continues to grow worldwide, being the fastest growing food producing sector with an expected growth of 37% by 2030 over 2016 rates [28].

As with fisheries, there is increasing regulation of aquaculture and the circularity of plastic in its use. Within the European Economic Area (EEA), the 2019 Single Use Plastic (SUP) Directive requires the producers of aquaculture gear to cover the costs of collecting end-of-life gear and its subsequent transport and treatment. There is also a plethora of national legislation covering the operation and decommissioning of equipment on aquaculture farms, but this is not uniform across the North East Atlantic Maritime Area. In addition to mandatory legislation, a recent European Committee for Standardisation (CEN) standard on the circularity and recyclability of aquaculture gear was also introduced in 2024, adding to national standards in Norway and the UK. Areas of good practice in minimising marine litter from aquaculture include improved maritime spatial planning, the inclusion of plastic waste management and decommissioning requirements in seabed leasing agreements, company and producer organisation waste management policies as well as strengthened third-party certification standards for responsible aquaculture.

The **purpose** of this indicator is to provide an objective verifiable indicator of the likelihood that plastics used in aquaculture will be either responsibly reused or recycled.

The **scope** of this indicator is all species produced through aquaculture on a global level, including seaweeds, invertebrates and vertebrates.

Tier 1 decision points

The single step to Tier 1 scoring is as follows:

Step 1: Establish the level of regulation to enforce the responsible reuse or recycling of plastic from aquaculture

Although there are regulatory mechanisms emerging to encourage the monitoring and quantification of aquaculture gear purchased and its end-of-life fate and disposal rates, there is no systematic quantification of plastic reuse or recycling from aquaculture. Our indicator is therefore based upon the scope and robustness of legislation at country level to encourage and enforce this. We have identified ten 'regulatory levers' that countries can use to enforce this. These are described in Table 34.

In order to score this, each of the ten levers are scored in terms of 1 (worst) to 5 (best) in line with the VeriFish scoring system. The average score across the 10 levers can then be averaged for the net country score. We have assembled scores for the four case study countries, and these are presented in Table 42 and summarised in the case studies themselves (Table 35) This dataset could be expanded to more countries and scored through an evaluation of national regulation against the then regulatory levers. Both the initial preparation and updates could be supported through targeted searches using AI assistance.

Table 34. Regulatory levers available to encourage the responsible reuse and recycling of plastics in aquaculture

1. Establish Extended Producer Responsibility (EPR) Schemes Require manufacturers and importers of aquaculture gear (e.g., nets, ropes, buoys, cages, feed bags) to take financial or operational responsibility for their products at end-of-life. **How it helps** ● Makes recycled or reusable materials cheaper than virgin plastics. ● Encourages design for durability and recyclability. ● Funds collection points, recycling plants, and take-back systems. **Regulatory tools** ● Mandatory producer take-back programs. ● Fees based on recyclability (higher fee for non-recyclable gear). ● Targets for percentage of recycled content in new gear.
2. Mandate Gear Identification and Traceability Require plastic aquaculture gear to carry unique IDs or QR codes linking it to the operator. **How it helps** ● Prevents “ghost gear” by improving recovery after storms or operational loss. ● Makes producers and farmers accountable for lost or abandoned items. ● Supports data systems for plastic flows. **Regulatory tools** ● Gear marking requirements. ● Digital asset registers for aquaculture equipment. ● Penalties for unregistered or unmarked gear.
3. Ban or Phase Out High-Risk, Non-Recyclable Plastics Certain plastics used in aquaculture (e.g., expanded polystyrene floats) fragment easily and are hard to recycle. **How it helps** ● Reduces waste at the source. ● Forces a transition to more durable, recyclable materials. **Regulatory tools** ● Legal prohibition on polystyrene buoys. ● Mandatory use of high-density polyethylene (HDPE) or recyclable alternatives. ● Standards for gear durability and weather resistance.
4. **Create Mandatory Collection and Recycling Systems for End-of-Life Gear**

Set up national frameworks requiring farmers to return old gear and ensuring it is processed responsibly. **How it helps** ● Ensures predictable supplies of plastic feedstock for recycling. ● Reduces stockpiling, land burning, or illegal dumping. **Regulatory tools** ● Licensed collection centres in each major aquaculture region. ● Required proof of proper disposal as part of farm license renewals. ● Subsidies for innovative recycling businesses (e.g., rope-to-pellet systems).
5. Use Economic Instruments Governments can shift incentives using taxes, fees, or rebates. **Options** ● Deposit–refund schemes for nets, ropes, cages, or feed bags. ● Landfill or incineration taxes to discourage improper disposal. ● Recycling credits or tax reductions for operators using verified recycled plastic gear. ● Differential import duties favouring recyclable equipment.
6. Integrate Plastic Management Into Aquaculture Licensing Tie farm licensing to good plastic stewardship. **How it helps** ● Makes responsible gear handling a condition for operating. ● Improves compliance through routine inspections. **Possible requirements** ● Annual inventory of plastic gear. ● Storm-preparedness plans for minimizing gear loss. ● Mandatory participation in certified recycling or take-back programs. ● Reporting of lost gear within 24–48 hours.
7. Set National Standards for Recyclability, Reuse, and Design Governments can define the technical criteria equipment must meet before entering the market. **Examples** ● Standardizing plastic types (e.g., requiring mono-material HDPE ropes). ● Minimum recycled content in new aquaculture materials. ● Certifying products as “reusable for X cycles.”
8. Strengthen Monitoring, Enforcement, and Data Transparency Regulation only works if compliance is measurable.

Tools ● National registry of aquaculture plastics. ● Remote sensing or inspections for abandoned or unauthorized gear. ● Required annual reporting of waste generation and recycling performance.
9. Support Research, Innovation, and Public–Private Partnerships Governments can fund the transition toward circular systems. **Support options** ● Grants for R&D on biodegradable or recyclable materials. ● Pilot programs for plastic-to-plastic recycling technologies. ● Local cooperative recycling facilities shared between small farms.
10. Align with International Frameworks Regulation becomes more effective when harmonized with broader agreements. **Relevant frameworks** ● FAO Voluntary Guidelines for the Marking of Fishing Gear ● EU Single-Use Plastics Directive (for regions influenced by EU standards) ● MARPOL Annex V (prohibits disposal of plastics at sea) ● Aligning with these helps standardize gear design, traceability, and recycling approaches.

Tier 2 decision points

Tier 2 decision points would be based on evidence presented by the aquaculture unit under assessment. This could cover aspects such as:

- Evidence of formal risk assessments to ensure that potential vulnerabilities that might result in infrastructure failure or loss are identified, the likelihood and potential impacts estimated, and appropriate contingency plans developed.
- Evidence that management and staff are provided adequate training to (i) ensure they are aware of the potential and impact of plastic loss into the aquatic environment and (ii) they are able to undertake the necessary protocols (e.g. SOPs) to prevent equipment failure or aquatic debris and litter loss.
- Copies of corporate policies for (i) the management of solid, non-biological waste, with a particular focus on plastics and other persistent materials; (ii) the minimization of the use of single use plastics (SUPs) in farming operations; and (iii) the monitoring of waste management effectiveness at farm / organizational levels.
- Evidence of the use biodegradable materials where possible. Whilst biodegradable materials are not typically suitable for long-term applications, they may be useful for short-term fixes.
- Evidence of an appropriate in / out inventory system for all key plastic components, with evidence that end of life equipment is responsibly recused or recycled.

Data sources

For a detailed review of the use of plastics in aquaculture and their management see the following:

- GGGI, 2020. The Global Ghost Gear Initiative (GGGI) 'Best practice framework for Aquaculture Gear.
- Sandra M., et al, (2020) [40]. Knowledge wave on marine litter from aquaculture sources. D2.2 Aqua-Lit project.
- Skirtun et al, (2022) [45]. Plastic pollution pathways from marine aquaculture practices and potential solutions for the North-East Atlantic region.
- Systemiq, Handelens Miljøfond & Mepex (2023) [48]. Achieving Circularity for Durable Plastics. A low emissions circular plastic economy in Norway.

Scoring decision tree

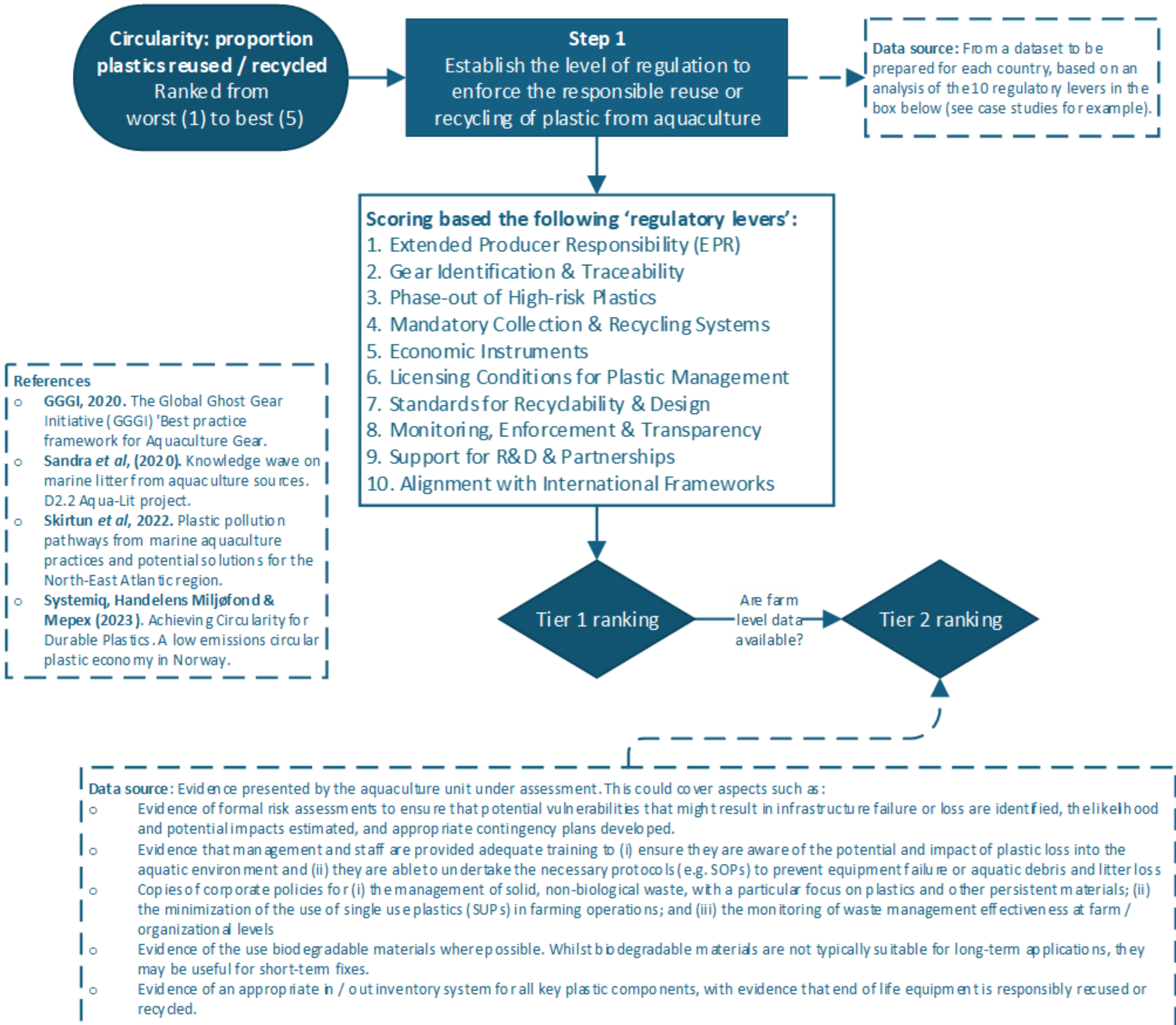

Figure 21. Scoring decision tree for 'circularity- proportion of plastics reused/recycled'

Case studies

Table 35. Case studies for 'circularity- proportion of plastics reused/recycled'

Scoring decision-making step	Case studies			
	Longline Mediterranean mussel in Atlantic Spain	**Open pen Atlantic salmon in Norway**	**Extensive pond-raised common carp in Hungary**	**Intensive pond raised shrimp (*L. vannamei*) in Vietnam**
Step 1: Establish the level of	Spain benefits from strong alignment with EU waste and circular-economy directives,	Norway is the global benchmark for responsible aquaculture plastic	Hungary's framework is shaped largely by EU directives, providing	Vietnam has developed ambitious national action plans on marine plastic

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regulation to enforce the responsoble reuse or recycling of plastic from aquaculture	giving it a solid regulatory foundation for managing aquaculture plastics. Regional initiatives—especially in Galicia and the Basque Country—demonstrate effective pilots for port-based collection, recycling trials, and awareness programmes. However, national consistency is uneven, with significant variation in enforcement and infrastructure between autonomous regions. While Spain has moderate EPR development and growing research capacity, it lacks a fully integrated national system for gear traceability, mandatory take-back, and sector-wide recycling, limiting its overall effectiveness. **Spain therefore scores 3 across the ten regulatory levers**.	management. It combines stringent regulatory oversight with strong industry participation, supported by mature systems for gear reporting, loss notification, retrieval programmes, and recycling infrastructure. Producer-responsibility principles are increasingly embedded in practice, and extensive R&D efforts focus on biodegradable gear, improved recyclability, and reduced plastic leakage. Licensing conditions, monitoring, and enforcement are consistently applied nationwide. Weaknesses are relatively minor but include ongoing challenges in reducing gear loss during extreme weather and scaling innovations to all producers. Nevertheless, Norway remains the best-performing country across nearly all regulatory levers. **Norway therefore scores 5 across the ten regulatory levers**.	robust general EPR rules and modernised waste legislation. However, because Hungary's aquaculture sector is small, inland, and dominated by pond-based systems, plastics regulation specific to aquaculture is minimal. Gear traceability, collection systems, and standards for recyclable design are underdeveloped. While administrative structures exist to incorporate plastic stewardship into licensing and farm modernisation, this has not yet occurred in practice. Strengths include strong national compliance mechanisms, but weaknesses lie in the absence of targeted measures for aquaculture gear. **Hungary therefore scores 3 across the ten regulatory levers**.	pollution and shows strong alignment with international efforts. However, implementation capacity is uneven, and enforcement of waste-management rules in aquaculture is limited. Collection infrastructure, port waste systems, and gear traceability remain underdeveloped, especially in small-scale coastal and delta communities. Economic instruments and EPR are still emerging, and many improvements depend on donor-funded pilots. Vietnam's main strengths are political commitment, increasing awareness, and growing participation in international partnerships; its weaknesses are insufficient infrastructure, limited monitoring, and low compliance incentives for farmers and fishers. **Vietnam therefore scores 2 across the ten regulatory levers**.
Tier 2 potential	• Evidence of formal risk assessments to ensure that potential vulnerabilities that might result in infrastructure failure or loss are identified, the likelihood and potential impacts estimated, and appropriate contingency plans developed. • Evidence that management and staff are provided adequate training to (i) ensure they are aware of the potential and impact of plastic loss into the aquatic environment and (ii) they are able to undertake the necessary protocols (e.g. SOPs) to prevent equipment failure or aquatic debris and litter loss • Copies of corporate policies for (i) the management of solid, non-biological waste, with a particular focus on plastics and other persistent materials; (ii) the minimization of the use of single use plastics (SUPs) in farming operations; and (iii) the monitoring of waste management effectiveness at farm / organizational levels • Evidence of the use biodegradable materials where possible. Whilst biodegradable materials are not typically suitable for long-term applications, they may be useful for short-term fixes. • Evidence of an appropriate in / out inventory system for all key plastic components, with evidence that end of life equipment is responsibly recused or recycled.			

1.3. Nutrition & Health Pillar

This section provides the details regarding the methodology and advances regarding the indicators under the nutrition and health pillar of the framework. More specifically, we adopted a multi-phase approach, that transitioned from the identification of the fundamental nutrient attributes to their implementation for supporting the scoring system[40]. This process was essential to maintain a clear line of traceability between the

[40] *Discussed in deliverable D2.3. Guideline for the use of seafood verifiable indicators*

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developed indicators and the authoritative data sources that were used, ensuring that the scientific background of the indicators remains solid.

D2.1 [1] defined the conceptual foundations of the VeriFish framework by identifying nutrition and health indicators for aquafoods and specifying underlying attributes, such as species, edible portion, and nutrient composition. The emphasis was on indicator relevance and scientific validity. At this stage, indicators were expressed as measurable variables (e.g. nutrient content per 100 g edible portion). This reflected the aim ensure transparency, traceability, and scientific validity.

In contrast, D2.2 [2] extended the framework by documenting how indicators might be operationalised, focusing on data availability, access mechanisms, and alignment with existing repositories. For nutrition and health indicators, this included systematic mapping to established food composition resources, such as FAO/INFOODS[41] and EuroFIR FoodEXplorer[42], as well as ensuring consistency across species. Crucially, D2.2 still did not define a nutrient scoring model. Instead, it provided technical preconditions such as harmonised nutrient definitions, comparable units, documented data provenance, and clarity on data gaps. This distinction ensured that any subsequent scoring approach would be grounded in robust, well-characterised data rather than in ad hoc assumptions.

The interim version of the VeriFish Knowledge Base deliverable (D2.4) provided the infrastructure layer to connect seafood nutrient datasets with species, fisheries, and aquaculture contexts. Through the knowledge base the linkage between species records and food composition data was made possible, while preserving source attribution and update pathways. For nutrients, this meant compositional data that can be consistently associated with species-level entities, allowing downstream analytical steps including scoring to be reproducible. Importantly, the Knowledgebase supports data integration but does not impose interpretative logic or weighting across indicators.

The nutrient scoring methodology represents an analytical step that builds upon the foundations of the framework and the infrastructure of the knowledge base. Responsibility for developing nutrient scoring lies within the nutrition and health pillar and does not extend to scoring of aquaculture practices or fisheries management performance, which are addressed separately within environmental and governance pillars. The approach applies a transparent, rule-based method to translate nutrient composition data into comparative scores by normalising nutrient values using consistent reference units, aligning for public health relevance, and maintaining data traceability. By separating indicator definition, data integration, and scoring, VeriFish has ensured that nutrient scores are defensible, reproducible, and adaptable as new data become available. This staged development also allows the nutrition scoring system to evolve independently of fisheries and aquaculture scoring methodologies, whilst remaining fully interoperable within the overall VeriFish framework.

The scoring is based on quantitative seafood composition data from EuroFIR's FoodEXplorer. Data were mapped to harmonized food descriptors (species, part, processing state), checked for unit consistency and alignment with INFOODs and EuroFIR standards, and filtered to retain nutrients with sufficient data coverage

[41] https://www.fao.org/infoods/infoods/en/
[42] https://www.eurofir.org/foodexplorer/

for relevance (e.g. fibre was not included because there is insufficient in all seafood species to have public health relevance). This step ensures that differences in scores reflect genuine nutritional variation rather than artifacts of data structure or formatting.

While the framework is broad, the scoring model focuses on a subset of 25 positive health benefits and two negative health impacts that met the following criteria:

1. **Public health relevance**: nutrients of concern in a European context;
2. **Reliable reference values**: aligned with EFSA's dietary reference values (DRVs), including population reference intakes (PRIs), adequate intakes (AIs), or nutrient reference values (NRV) used in food labelling in the case where EFSA did not define any DRV;
3. **Sufficient data availability** across seafood species

Accordingly, the scoring model prioritises nutrients such as protein, omega-3 fatty acids (EPA+DHA), vitamin D, iodine, selenium, and vitamin B12 as well as sodium and saturated fat. For each nutrient, food composition values were normalised against corresponding EFSA reference values. This facilitated expression of nutrient contribution as a percentage of the DRV, allowing nutrients with different units and magnitudes to be compared on a common scale. EFSA DRVs were taken from the most recent EFSA opinions, taking the average between male and female. These steps convert absolute nutrient quantities into cumulative relative nutritional significance rather than weighting nutrients according to production, environmental, or economic criteria, reflecting nutrition-specific logic and the complementary role of nutrients in health, and ensuring transparency and interpretability for communication purposes. The scores mirror nutrient provision per portion.

The final cumulative score is presented without upper thresholds or capping rules. This illustrates the full extent of a product's nutrient contribution, which is particularly informative for populations with specific needs where intakes above reference values are beneficial. Applying a cap would reduce the distinction between foods providing moderate versus high contributions (e.g., 80% vs 300% of the DRV). The resulting nutrient scores represent relative nutrient density, not health claims, dietary advice, or risk assessments. They are intended to support comparison across seafood species and other protein sources in typical European diets (i.e., pork chicken and beef) under consistent assumptions, whilst remaining traceable to original food composition data, documented EFSA reference values, and explicit calculation rules.

To support consumer-facing communication, products were grouped into four nutrient density categories based on their relative position within the theoretical range:

- **Lower density**: < 4 (less than 1/6 of the theoretical maximum score)
- **Moderate**: 4 – 8 (> 1/6 and < 1/3 of the theoretical maximum score)
- **High**: 8 – 13 (> 1/3 and < 1/2 of the theoretical maximum score)
- **Very high**: >13 (> 1/2 of the theoretical maximum score)

These thresholds are proportional, avoiding terminologies such as "good", "acceptable", or "recommended", as such value-laden descriptors are poorly suited to comparative sustainability communication and might be misinterpreted as nutritional advice. Subsequently, the contribution of individual nutrients to daily requirements was categorised based on relative contribution to dietary reference values (DRVs) per 100 g of raw or uncooked product. Thresholds were defined using established regulatory reference points to ensure consistency and regulatory neutrality.

Finally, a product was classified as a source (✓) of a given nutrient when a portion provided ≥15% of the corresponding DRV per 100 g and as high in (✓✓) when it provided ≥30% of the DRV per 100 g. These thresholds reflect Codex Alimentarius and EU food information as well as nutrition claims frameworks, which define a significant amount of a vitamin or mineral as 15% of the nutrient reference value per 100 g, and a "high" level as at least twice this amount. Within the application, composite nutrient density scores and nutrient-specific "source of" and "high in" classifications are combined and visualised using a colour-coded heat map (macronutrients = yellow, vitamins = blue, and minerals = green) with nutrient-specific contributions further supplemented by the corresponding percentage of the dietary reference value per standard portion to support transparent, intuitive interpretation.

1.4. Socio-Economic Pillar

This section presents the updates in socio-economic indicators, the authoritative data sources that were used as well as the rule-based scoring approaches.

1.4.1. Indicator: Vessel engaged in IUU fishing

Compared to the other indicators in this pillar, this indicator specifically looks at the vessel entity. To collect the data for this indicator, we used information published by TMT, a non-profit organization that provides services to target the reduction of illegal fishing. TMT collects and publishes [3] up-to-date information on all fishing and related vessels that appear on the illegal, unregulated, and unreported (IUU) fishing vessel lists published by Regional Fisheries Management Organisations (RFMOs) and related organisations.

Approach to scoring

We used binary scoring, with a value of 1 if a vessel is included on an IUU list, otherwise 5.

1.4.2. Indicator: Vessel flagged to a country with high-levels of foreign ownership

For this indicator, we relied on the IUU Fishing Risk Index [4], which provides a measure of the likelihood that states are exposed to and effectively combat IUU fishing. The index provides an IUU fishing risk score for all coastal states of between 1 and 5 (1 being the best, and 5 the worst). The index includes scores with respect to different attributes; for supporting our indicator, we relied on scores for "Registered vessels with foreign or unknown ownership" from IUU Fishing Risk Index.

Approach to scoring

We used the inverted scores as derived from the IUU Fishing Risk Index, so that 1 is the worst and 5 the best.

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1.4.3. Indicator: Perception of levels of corruption

Aquafood should be considered at higher risk if it is produced in or landed into a country with high levels of perceived corruption, as identified in the Transparency International Corruption Perceptions Index (CPI) [5]. High corruption levels can undermine enforcement of fisheries regulations, labour rights, and environmental protections.

Approach to scoring

Derived scores based on bands of CPI indicator scores. More specifically we score based on:

- CPI=[0, 19] → score=1
- CPI=[20, 39] → score=2
- CPI=[40, 59] → score=3
- CPI=[60, 79] → score=4
- CPI=[80, 100] → score=5

1.4.4. Indicator: Vessel from a country that is a party to FAO-UN PSMA

Aquafood can be considered higher risk if it is landed into a country that has not ratified the PSMA. It measures whether a country is a party to the FAO-UN Port State Measures Agreement [6] and actively implements inspections of foreign fishing vessels in its ports. Ratification is used as a minimum indicator of a country's commitment to preventing IUU fishing through effective port controls, acknowledging that implementation effectiveness may vary and is not consistently documented.

Approach to scoring

We used a binary scoring approach, with value 1 if a country has not ratified, otherwise 5.

1.4.5. Indicator: Decent wages and working conditions

Aquafood can be considered higher risk if it is produced in a country assessed as having widespread violations of workers' rights, including inadequate protection for fair wages and decent working conditions. It assesses whether minimum wages, decent working conditions, and legal protections are upheld in the workplace. Assessments will draw on the ITUC Global Rights Index [7] and national labour law frameworks, recognising that country-level conditions are used as a proxy for workplace standards in the absence of vessel- or farm-specific data.

Approach to scoring

We used the inverted scores as derived from ITUC Global Rights Index, so that 1 is the worst and 5 the best.

1.4.6. Indicator: Freedom of association and collective bargaining

Aquafood can be considered at higher risk if it is produced in a country that has not ratified key ILO conventions [8] on freedom of association and collective bargaining. It evaluates the extent to which workers

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are able to organise, bargain collectively and join trade unions freely. For these reasons we relied on whether countries has ratified certain conventions. More specifically, we relied on the following conventions:

- C087 - Freedom of Association and Protection of the Right to Organise Convention, 1948
- C098 - Right to Organise and Collective Bargaining Convention, 1949
- C188 - Work in Fishing Convention, 2007

Approach to scoring

For capture fisheries, we relied on C087, C098, and C188:

- Country has not ratified any convention → score=1
- Country has ratified either C087 or C098, but not C188 → score=2
- Country has ratified C087 and C098, but not C188 → score=3
- Country has ratified one of C087 and C098, as well as C188 → score=4
- Country has ratified all conventions → score=5

For aquaculture, we relied on C087 and C098 because C188 is only relevant to fishing, and distributed the scoring accordingly across two conventions rather than three:

- Country has not ratified any convention → score=1
- Country has ratified one of C087 or C098 → score=3
- Country has ratified all conventions → score=5

1.4.7. Indicator: Prevention of child labour

Aquafood can be considered at higher risk if it is produced in a country where child labour is known or suspected to occur in the fishing or aquaculture sectors, or where the country has not ratified key international conventions aimed at preventing child labour. It indicates whether countries prohibit and take active steps to prevent child labour in fisheries and aquaculture. Assessments will use the U.S. Department of Labor's Child Labor Reports [9], ILO ratification records [8], and enforcement data as references [10], recognising that country-level conditions are used as a proxy where direct supply chain evidence is unavailable. From ILO conventions, we relied on the following:

- C138 - Minimum Age Convention, 1973
- C182 - Worst Forms of Child Labour Convention, 1999

Approach to scoring

Regarding ILO conventions ratifications:

- Country has not ratified any convention → score=1

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- Country has ratified one of C138 or C182 → score=3
- Country has ratified all conventions → score=5

Regarding data from the U.S. Department of Labor's Child Labor Reports:

- Country is not listed in fish-related list of goods → score=1
- Country is listed in fish-related list of goods → score=5

Regarding ILOSTAT data about SDG indicator 8.7.1 – Proportion of children engaged in economic activity:

- Percentage= [0, 1) → score=5
- Percentage= [1, 3) → score=4
- Percentage= [3, 5) → score=3
- Percentage= [5, 8) → score=2
- Percentage= [8, 100) → score=1

1.4.8. Indicator: Prevention of forced slavery & human trafficking

Aquafood can be considered at higher risk if it is produced in a country identified as having significant risks of forced labour, modern slavery, or human trafficking in the fishing or aquaculture sectors, or where national protections are weak. It measures efforts to combat forced labour and trafficking, including ratified conventions and implementation. We relied on data from the Walk Free- Global Slavery Index [11], as well as from certain ILO conventions [8]. Regarding the latter we relied on:

- C029 - Forced Labour Convention, 1930
- C105 - Abolition of Forced Labour Convention, 1957
- C188 - Work in Fishing Convention, 2007

Approach to scoring

Regarding ILO conventions for capture fisheries, we relied on C029, C105, and C188:

- Country has not ratified any convention → score=1
- Country has ratified either C029 or C105, but not C188 → score=2
- Country has ratified both C029 and C105, but not C188 → score=3
- Country has ratified one of C029 or C105, but not C188 → score=4
- Country has ratified all conventions → score=5

Regarding ILO conventions for aquaculture we relied on C029 and C105:

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- Country has not ratified any convention → score=1
- Country has ratified one of C029 or C105 → score=3
- Country has ratified all conventions → score=5

Regarding data from Global Slavery Index, we used the following scoring approach:

- GSI value=[0, 2) → score=5
- GSI value=[2, 4) → score=4
- GSI value=[4, 10) → score=3
- GSI value=[10, 50) → score=2
- GSI value=[50, 100] → score=1

1.4.9. Indicator: Access to healthcare and medical facilities

Aquafood can be considered at higher risk if it is produced in a country where there is limited legal protection or enforcement to ensure fishers and aquaculture workers have access to healthcare services, both at sea and on land. It indicates the availability of health services and medical care for fishers at sea and on shore. Assessments will rely on the following ILO conventions [8]:

- C130 - Medical Care and Sickness Benefits Convention, 1969
- MLC, 2006 - Maritime Labour Convention, 2006

Approach to scoring

- Country has not ratified any convention → score=1
- Country has ratified either C130 or MLC → score=3
- Country has ratified all conventions → score=5

1.4.10. Indicator: Occupational health & safety at work

Aquafood can be considered at higher risk if it is produced in a country where occupational health and safety (OHS) standards are weak, poorly enforced, or not aligned with international norms. It assesses legal and institutional protections for occupational safety and accident prevention. Assessments will draw on ratification of key ILO conventions [8], the list of countries that ratified STCW-F 1995 [12], and list of countries that ratified the 2012 Cape Town Agreement (CPA) [13]. From ILO conventions we relied on:

- C155 - Occupational Safety and Health Convention, 1981
- C162 - Asbestos Convention, 1986
- C187 - Promotional Framework for Occupational Safety and Health Convention, 2006

Approach to scoring

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For capture fisheries we relied on C155 (from ILO), STCW-F and CPA ratifications:

- Country has not ratified any convention → score=1
- Country has ratified one of the applicable conventions → score=2
- Country has ratified two of the applicable conventions → score=3
- Country has ratified all the conventions → score=5

For aquaculture we relied on C155, C161, and C187:

- Country has not ratified any convention → score=1
- Country has ratified either C155 or C187, but not C161 → score=2
- Country has ratified one of C155 or C187 and C161 → score=3
- Country has ratified both C155 and C187, but not C161 → score=4
- Country has ratified all the conventions → score=5

1.4.11. Indicator: Equality & prevention of discrimination

Aquafood can be considered at higher risk if it is produced in a country where legal protections against discrimination based on gender, ethnicity, or other social factors are weak or poorly enforced. It assesses laws and enforcement mechanisms against discrimination based on gender, ethnicity, etc. Assessments will draw on ratification of key ILO conventions [8] and international indicators such as the OECD Social Institutions and Gender Index (SIGI) [14], recognizing that country-level conditions are used as a proxy for workplace equality in the absence of direct supply chain data. From ILO conventions we used:

- C100 - Equal Remuneration Convention, 1951
- C111 - Discrimination (Employment and Occupation) Convention, 1958
- C188 - Work in Fishing Convention, 2007

Approach to scoring

Regarding capture fisheries we used C100, C111, and C188:

- Country has not ratified any convention → score=1
- Country has ratified either C100 or C111, but not C188 → score=2
- Country has ratified both C100 and C111, but not C188 → score=3
- Country has ratified either C100 or C111, and C188 → score=4
- Country has ratified all conventions → score=5

Regarding aquaculture we used C100 andC111:

- Country has not ratified any convention → score=1
- Country has ratified either C100 or C111 → score=3
- Country has ratified all conventions → score=5

Regarding indicators from OECG SIGI:

- Discrimination index score=[0, 15) → score=5
- Discrimination index score=[15, 25) → score=4
- Discrimination index score=[25, 35) → score=3
- Discrimination index score=[35, 40) → score=2
- Discrimination index score=[40, 100) → score=1

1.4.12. Indicator: Respect for indigenous peoples

Aquafood can be considered at higher risk if it is produced in a country where the rights of indigenous peoples are not adequately recognised or protected, particularly regarding traditional fishing rights, participation in decision-making, and protection of cultural heritage. It evaluates national frameworks that recognize and protect the rights of indigenous communities. Assessments will be based on ratification of the ILO Convention C169 - Indigenous and Tribal Peoples Convention, 1989.

Approach to scoring

We used a binary scoring approach, with value 1 if a country has not ratified, otherwise 5.

2. VeriFish Knowledge Base

The VeriFish Knowledge Base has been constructed through the semantic integration of heterogenous and thematically diverse data sources, addressing the fragmentation and the multidimensional nature of domain data. The integrated sources vary not only in structure, format, terminology, and access mechanisms, but also in thematic focus, encompassing environmental, socio-economic, nutrition and health-related data. These differences reflect the complex sustainability challenges addressed by the VeriFish Indicator Framework and require an integration approach capable of linking information across domains.

To this end, the KB has been constructed through a semantic approach that aligns concepts, entities, and identifiers across datasets with distinct thematic scopes and levels of granularity. This shared semantic layer enables the coherent combination of environmental data, socio-economic information and nutrition and health data. As a result, the KB provides a unified and interoperable view over otherwise disconnected resources, enables deeper research and complex query answering, while preserving the provenance and specificity of each source.

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Figure 22, illustrates the workflow used for integrating heterogeneous data sources into the VeriFish KB [56]. Data are collected from their original sources and, after being normalized into a structured format, are transformed into a shared semantic representation based on the MarineTLO[43] ontology and its required extensions. To support this transformation, the X3ML Framework [57] is used to define schema mappings that describe how resources will be converted into MarineTLO-compliant instances. Eventually, the transformed data are ingested into the VeriFish KB.

Beyond this construction workflow, the KB can be understood as a functional system comprising an integrated semantic data layer, where harmonized data from multiple sources are stored, and an access layer that supports querying and data retrieval. These components are further utilized by the VeriFish API that provides programmatic access, enabling users to access and combine information across datasets through a unified interface.

Interoperability in the VeriFish KB is achieved through the integration of heterogeneous data sources into a common semantic model, based on the GRSF and extended with additional domain concepts. This enables the harmonization of data originating from different providers, formats, and levels of granularity into a unified representation. As a result, users can query and combine information across datasets through a single access point, without needing to interact with the original data sources individually. For example, the KB enables queries that combine data from multiple sources, such as retrieving the stock status of a species (from GRSF), its resilience (from FishBase), and combine it with nutritional information (from FoodExplorer) and other information, within a single query. Thai demonstrates how heterogeneous datasets are interoperable within the KB.

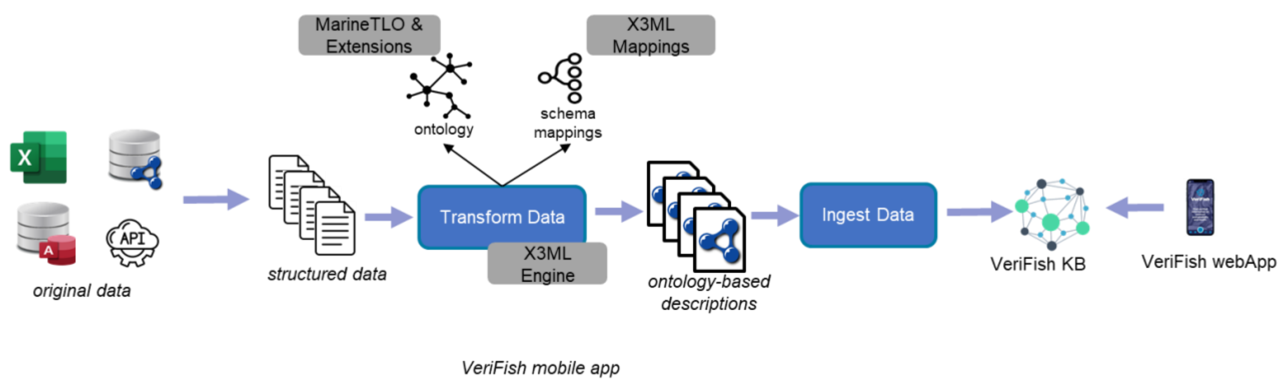

Figure 22. Workflow for constructing the VeriFish KB

Table 36, enumerate the different data-sources that were used for integrating their data into the VeriFish KB, while Figure 23 shows an indicative depiction of some of those sources, illustrating their thematic diversity as well.

Table 36. Data Sources integrated into the VeriFish KB

[43] https://projects.ics.forth.gr/isl/MarineTLO/

Data Source	Pillar	Contents	Format / Structure
Global Record of Stocks and Fisheries (GRSF) consisting of: • FAO FIRMS • RAM Legacy Stock Assessment DB • SFP FishSource • FAO SDG 14.4.1 Questionnaire data	Environmental	Stocks, fisheries, species, fishing areas, fishing gears, timeseries	RDF Graph
FishBase	Environmental	Species information	MS Access
Global Biodiversity Facility (GBIF)	Environmental	Species common names	API
IUCN Red List of Threatened Species	Environmental	Species information	API
STECF Reports	Environmental	Fisheries indicator data (stock status, seabed impact, bycatch risk on sensitive species)	CSV
FoodExplorer	Nutrition & Health	Nutrition information and attributes	API
Nutrition datasets from FishEUTrust & SEAFOOD TOMORROW	Nutrition & Health	Nutrition infromation	CSV
Seafood recipes	Nutrition & Health	Seafood recipes	CSV
IUU Vessels	Socio-Economic	List of vessels on IUU lists from all regional fisheries organisations	CSV
IUU Fishing Index	Socio-Economic	Indicator scores	CSV
Transparency International	Socio-Economic	CPI index scores	CSV
UN FAO Port State Measures Agreement	Socio-Economic	Information on whether flag state is a party to PSMA	CSV
ITUC Global Index Rights	Socio-Economic	Information from ITUC Global Index Rights index	CSV
ILO Conventions Ratifications	Socio-Economic	Information from ILO on ratifications by countries	CSV
US Department of Labour	Socio-Economic	Data from US Department of Labour	CSV

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Global Slavery Index	Socio-Economic	Information from the Walk Free Global Slavery Index	CSV
OECD Social Institutions & Gender Index	Socio-Economic	OECD SIGI dahsboard data	CSV

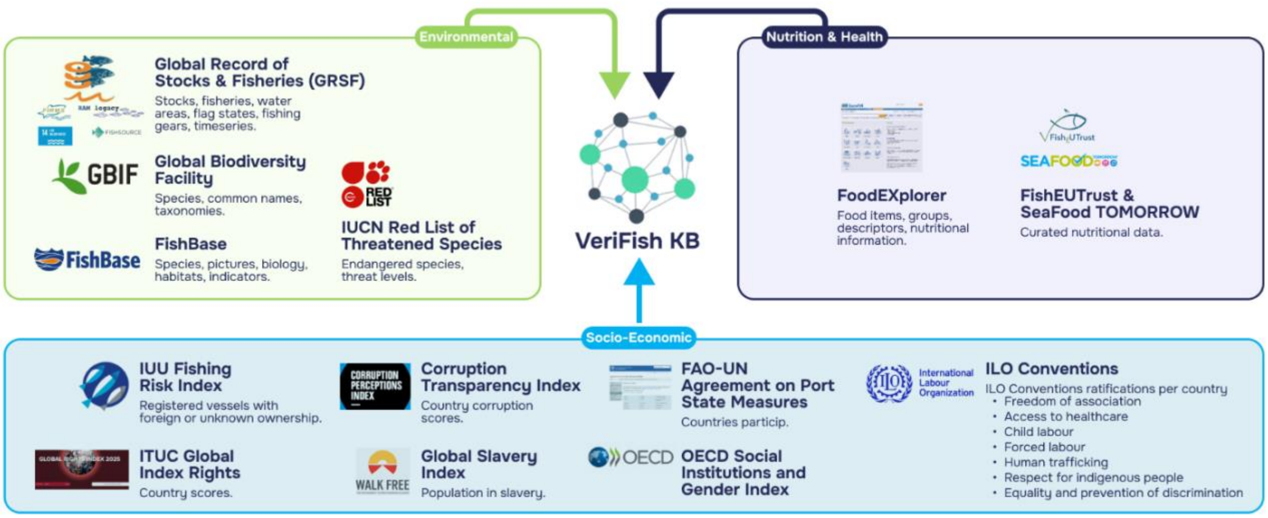

Figure 23. Indicative data sources integrated into the VeriFish KB, covering: (a) environmental, (b) nutrition and health dimensions, and (c) socio-economic

The following table provides statistics about the actual contents of the VeriFish KB so far.

Table 37. Statistics for the key entities of the VeriFish KB

Entity in the KB	Total	Entity in the KB	Total
Stocks	3,745	Fisheries	17,173
Species	13,602	Water Areas	1,680
Fishing Gears	82	Flag States	169
Fisheries indicator data	54,385	Time series	573,733
Species Scient. Names	13,602	Species Common names	16,157
Species Identifiers	71,568	Species IUCN data	5,282
Food Items	141	Nutritional Attributes	77
Socio-Economic values	8,553	Nutrient values	5,663

Figure 24 illustrates how semantic data integration in the VeriFish KB, interconnects resources originating from multiple heterogeneous data sources around a common entity, in this case a fish species. Starting from the species "*Mullus barbatus*" the KB, links biological characteristics and habitat information, taxonomic classification, conservation and stock status, and nutritional attributes of food products derived from the species. In addition, the species is connected to socio-economic information related to countries operating fisheries that harvest it, including indicators on labour rights, discrimination, and others. Through these interconnected resources, the KB enables the combination of diverse types of information to answer complex cross-domain questions and the deduce new insights that would not be possible when accessing the original data sources in isolation.

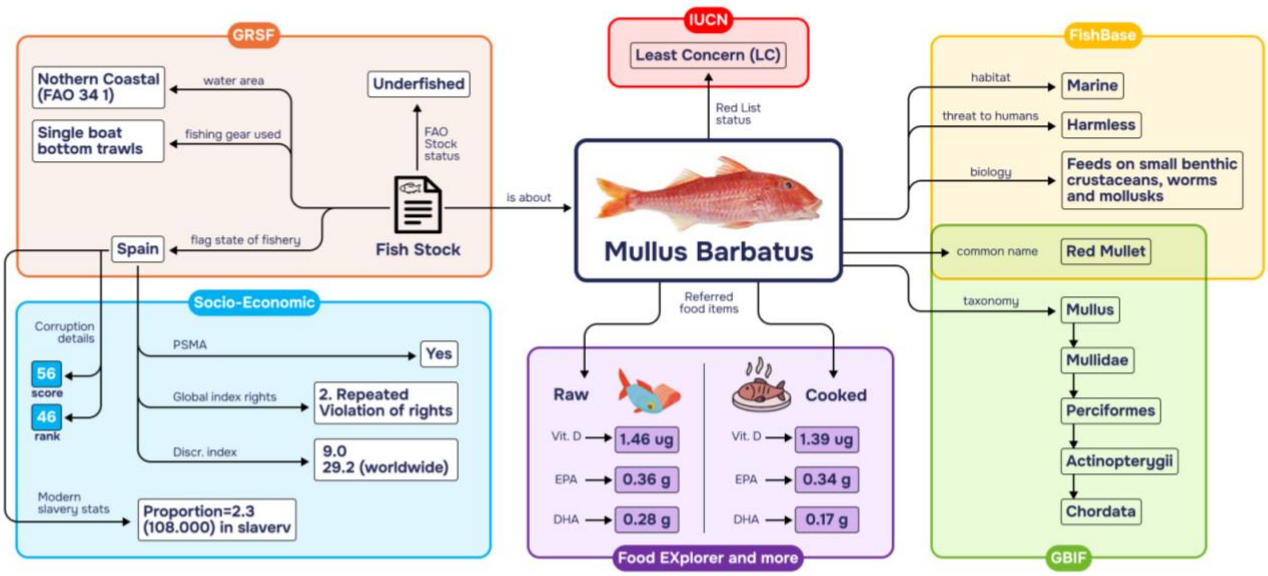

Figure 24. Example of semantically interconnected resources in the VeriFish KB

The VeriFish KB is designed to support a range of end-users, including policymakers, industry stakeholders, researchers, and certification bodies. Through the VeriFish API (described later) and the web application, users can explore sustainability indicators, compare information and details about fisheries or aquaculture systems, and retrieve data from multiple integrated sources. The KB enables users to access harmonized and comparable information across environmental, socio-economic, nutrition and health dimensions, supporting evidence-based decision-making. For example, policymakers can use it to assess the sustainability performance of fisheries across regions, while industry stakeholders can benchmark practices and identify areas for improvement.

The novelty of the VeriFish KB lies in the integration and operationalization of heterogeneous data sources into a unified, semantically structured framework that directly supports sustainability indicator computation. While existing resources such FishBase, and STECF provide valuable datasets individually, they are not designed to be used together in an interoperable manner. The KB enables the combination of thematically diverse data across multiple sources, allowing users to derive and compare sustainability indicators, within a single system. This integration supports cross-domain analysis, which would otherwise require significant manual effort and expertise to achieve. Furthermore, it provides programmatic access and other access features (described later), enabling consistent, transparent, and reproducible sustainability assessments.

2.1. Means of Access

VeriFish KB has been implemented as a semantic web triplestore. Its data are stored as triples on the graph in the form *<subject, predicate, object>*. Technically, access to the triplestore is provided through a dedicated SPARQL endpoint[44]. To facilitate discovery and access to the KB, we have implemented two distinct facilities: (a) a SPARQL-2-CSV feature and (b) the VeriFish API.

SPARQL-2-CSV is a feature that supports the submission of precompiled SPARQL expressions to the KB and the generation of results in an intuitive manner. It supports the construction of complex query paths that collect particular information from the KB and deliver them in a more flattened manner. A list of indicative SPARQL-2-CSV calls is shown below.

VeriFish API[45] (also depicted in Figure 25) is the official access method for VeriFish KB. It has been implemented as a RESTful API offering methods for accessing particular resources (i.e. fisheries, stocks, species, etc.) by specifying the corresponding parameters. The implementation of the API was carried out by adopting the existing GRSF API and extending it accordingly. More specifically, the following API methods have been implemented to cover VeriFish requirements

- **Environmental (Stocks and Fisheries)**
  - getFishingGearsAndSpecies: retrieves information about fishing gears and the fish species associated with them through fisheries
  - getFlagStatesAndSpecies: retrieves information about flag states and the fish species associated with them through fisheries
  - getWaterAreasAndSpecies: retrieves information about water areas and the fish species associated with them through fisheries
  - searchStocksWithFaoStatus: retrieves fish stock records together with their FAO stock status category (e.g. fully exploited, overexploited, underexploited, overfished, etc.)
- **Environmental (Stocks and Fisheries)**
  - searchSustainableFisheriesIndicatorScores: retrieves indicator scores about fishing practices on seabed habitats, fish stock status, and bycatch risk of sensitive species
- **Environmental (Aquaculture)**
  - searchAquacultureScore: retrieves all available aquaculture-related resources indicator data for a given species, country, and production system including VeriFish scores
- **Nutrition and Health**
  - searchNutrientsUsingSpecies: retrieves nutrient information for food products that use specific fish species as source ingredients
- **Socio-Economic Indicators**
  - searchSocioEcoCorruptionLevels: retrieves Corruption Perceptions Index (CPI) scores and rankings for a country across different reference years
  - searchSocioEcoIUUFishingRiskIndex: retrieves IUU fishing risk across different reference years

[44] https://www.w3.org/TR/sparql11-query/
[45] https://demos.isl.ics.forth.gr/verifish/verifish-api/

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- searchSocioEcoPSMA: retrieves information on whether a country participates in the FAO-UN Agreement on Port State Measures (PSMA)
- searchSocioEcoITUCGlobalRightsIndex: retrieves rankings and summary information for countries based on the ITUC Global Index Rights Index
- searchSocioEcoIloRatifications: retrieves the International Labour Organization (ILO) conventions ratified by a country
- searchSocioEcoModernSlavery: retrieves modern slavery statistics for a country from the Walk Free - Global Slavery Index
- searchSocioEcoChildLabour: retrieves child labour statistics from the US Department of Labour and lists of goods produced using child labour from ILOSTAT
- searchSocioEcoDiscriminationIndex: retrieves OECD discrimination index values for a country from OECD, ranging from 0 (no discrimination) until 100 (absolute discrimination)
- searchSocioEcoAll: retrieves all available socio-economic data resources for a country, including VeriFish indicator scores

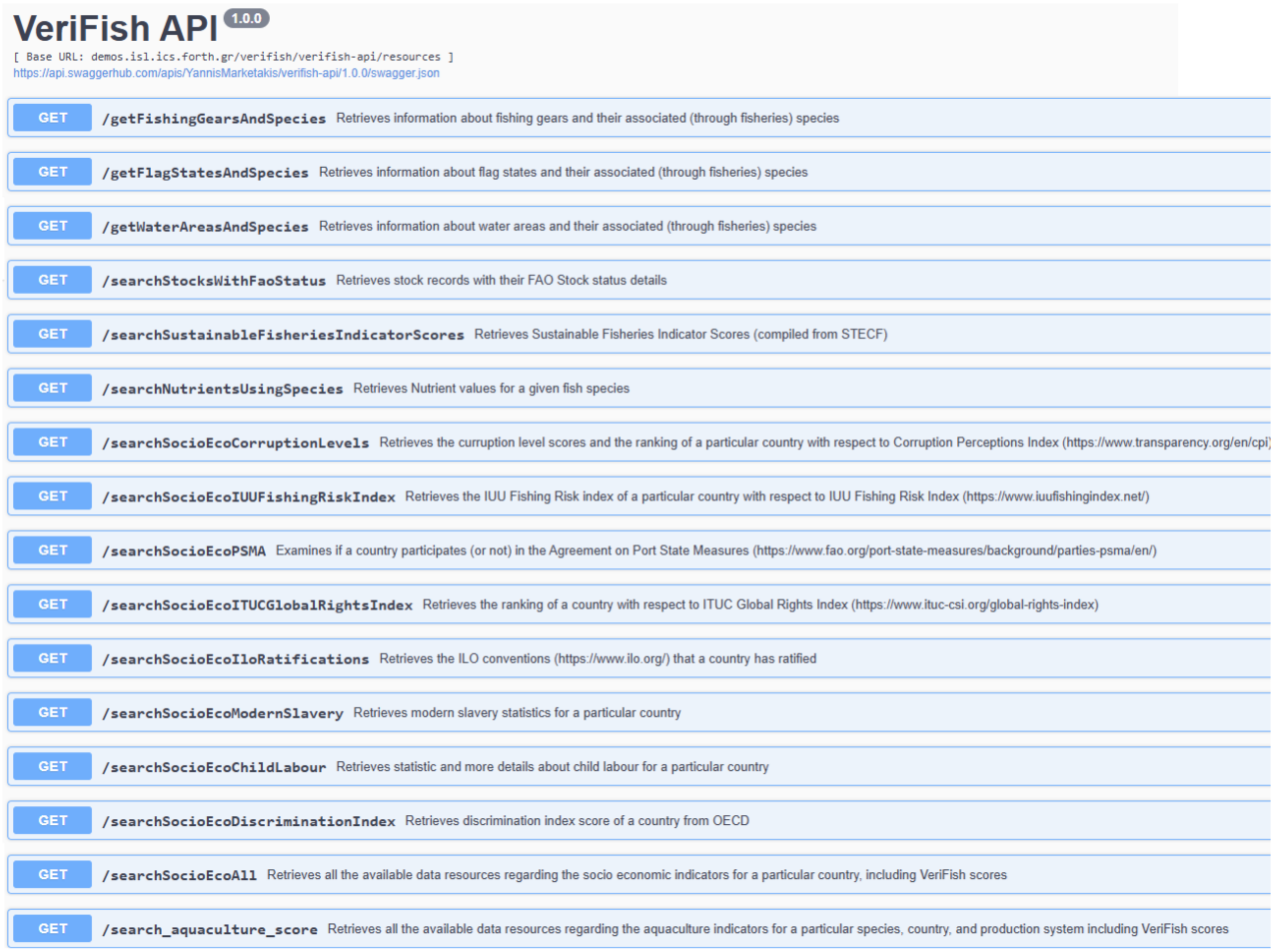

Figure 25. Screenshot of the latest version of the VeriFish API, providing access to the VeriFish KB

2.2. Indicative queries/lists

Below we provide indicative examples (either using the SPARQL-2-CSV feature or the VeriFish API). In both cases, the results can be previewed from a web browser (among others).

- Retrieve all fishing gears with their abbreviation and ISSCFG codes
- Retrieve all water areas with their codes and corresponding water area system
- Retrieve all fisheries with their related information (species, water areas, fishing gear types, etc.)
- Retrieve the fishing gears that can be used for harvesting yellowfin tuna
- Retrieve the fish species harvested using Gear nei (ISSCFG 10.9)
- Retrieve flag states where fisheries harvesting yellowfin tuna operate
- Retrieve stocks that are fully-exploited (FAO Stock status categories = fully exploited)
- Retrieve recipes with the related fish species that can be used as ingredients

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4. Appendix A

Supporting tables for Aquaculture indicators

Table 38. Habitat impact scoring

System	Likelihood	Impact	Risk	Score	VF score
Ponds (land-based, open)	5	5	5	5	1
Tanks and raceways (land-based, closed)	4	5	4.5	5	1
Recirculating systems (land-based, closed)	4	5	4.5	5	1
Plastic bags, photobioreactor tubes or panels (closed)	4	5	4.5	5	1
Integrated culture: Aquaponics (closed)	4	4	4	4	2
Integrated culture: Other polyculture (open)	4	4	4	4	2
Barrages and irrigation systems (open)	3	4	3.5	4	2
Integrated culture: IMTA (open)	3	3	3	3	3
Lakes, coastal lagoons and other natural water (open)	2	3	2.5	3	3
Integrated culture: Rice-Fish culture (open)	3	2	2.5	3	3
Cages / pens (open)	2	3	2.5	3	3
Enclosures and pens (open)	2	2	2	2	4
On-bottom (open)	2	2	2	2	4
Off-bottom Baskets, Net bags, Net trays, Poles (open)	2	2	2	2	4
Off-bottom Rafts (open)	2	1	1.5	2	4
Off-bottom Longlines (open)	1	1	1	1	5

Table 39. Escape likelihood assessment

System	Likelihood	VF score
Tanks and raceways	Medium	3
Rice-Fish culture	Very high	1
Off-bottom rafts	Very high	1
On-bottom	High	2
Ponds	High	2
Off-bottom baskets, bags, trays, poles	High	2
Cages / pens	High	2
Lakes, coastal lagoons, etc.	Very high	1
Enclosures	High	2
Off-bottom Longlines	Very high	1
Other polyculture (open)	Medium	3
Aquaponics (closed)	Low	4
Recirculating systems	Negligable	5
Plastic bags, photobioreactor tubes, etc	Negligable	5

Table 40. Escape Impact assessment

Species (location)	Impact (1 Low, 5 high)					
	Genetic impacts	Ecological disruption	Habitat alteration	Disease	Invasive spp. risk	Overall score
Mediterranean mussel (Spain)	1	1	2	1	1	1
Atlantic salmon (Norway)	5	3	1	3	1	3
Common carp (Hungary)	3	2	3	2	1	2
White-legged shrimp (Vietnam)	2	2	2	3	5	3

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Table 41. Impact assessment of the four key species / country locations on ecosystem elements

Species (location)	Impact (1 Low, 5 high)					
	Genetic impacts	Ecological disruption	Habitat alteration	Disease	Invasive spp. risk	Overall score
Mediterranean mussel (Spain)	1	1	2	1	1	1
Atlantic salmon (Norway)	5	3	1	3	1	3
Common carp (Hungary)	3	2	3	2	1	2
White-legged shrimp (Vietnam)	2	2	2	3	5	3

Table 42. Case study country scoring matrix across ten regulatory levers for the re-use and recycling of plastics in aquaculture (source: AI-based assessment of regulation in the four countries across the ten regulatory levers)

Regulatory Lever	Spain	Hungary	Norway	Vietnam
1. Extended Producer Responsibility (EPR)	3	3	5	2
2. Gear Identification & Traceability	3	2	5	2
3. Phase-out of High-risk Plastics	3	2	4	2
4. Mandatory Collection & Recycling Systems	3	2	5	2
5. Economic Instruments	3	3	5	2
6. Licensing Conditions for Plastic Management	3	2	5	2
7. Standards for Recyclability & Design	3	2	5	2
8. Monitoring, Enforcement & Transparency	3	2	5	2
9. Support for R&D & Partnerships	4	3	5	3
10. Alignment with International Frameworks	5	5	5	4
Average	**3**	**3**	**5**	**2**

Based on the following analysis

1. Extended Producer Responsibility (EPR) & producer take-back

- Spain: Spain implements EU-level measures (Single-Use Plastics / EPR obligations for fishing gear are in scope of recent EU work) and regional projects target circular fishing gear, but national EPR for aquaculture gear is still being operationalised via EU frameworks and projects.
- Hungary: Hungary has introduced strengthened EPR obligations for packaging and other categories and is updating sanctions and operational rules — but evidence of aquaculture-gear-specific EPR implementation is limited (Hungary is more focused on packaging EPR).
- Norway: Norway is actively implementing producer-responsibility approaches for fishing and aquaculture gear, with national organisations and regulations supporting take-back, reporting and cost internalisation. Reporting and recovery systems for lost gear are already practiced.
- Vietnam: Vietnam has national plans and action plans targeting reduction of marine plastic waste and fisheries sector measures, but comprehensive EPR schemes for aquaculture gear are not yet well established. Implementation remains a challenge.

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2) Gear identification & traceability

- Spain: Spain's authorities and regional projects promote marking and retrieval of lost gear; national guidance documents address lost fishing gear. Full-scale mandatory national traceability for aquaculture gear not yet universal.
- Hungary: Hungary's aquaculture sector is mostly freshwater/pond-based; there's little evidence of a national mandatory gear-ID scheme for plastics in aquaculture. Traceability is more advanced in EU maritime states.
- Norway: Norway requires reporting of lost gear and has strong tracking and retrieval culture; national registries and industry programs support traceability.
- Vietnam: Action plans call for better management and source controls, but mandatory gear marking/traceability systems are not widely implemented. Field reports show limited uptake of waste collection equipment on boats.

3) Ban / phase-out of high-risk non-recyclables

- Spain: As an EU member, Spain follows EU measures limiting single-use plastics; stricter bans on some problematic materials exist EU-wide, but targeted bans (e.g., polystyrene buoys) depend on national/regional choices and market availability of alternatives.
- Hungary: No evidence of aquaculture-specific bans — sector is small and inland; plastics policies focus on packaging/consumer SUPs.
- Norway: Norwegian industry and research are actively seeking alternatives (including trials of biodegradable materials) and regulators encourage substitution of high-loss or non-recyclable gear.
- Vietnam: Vietnam's national policy contains ambitions to reduce problematic plastics, but switching gear at scale is constrained by cost, availability and enforcement.

4) Mandatory collection & recycling systems

- Spain: There are port-based and regional projects for circular fishing gear and collection points; full national systems for aquaculture gear vary by region.
- Hungary: Little evidence of dedicated aquaculture gear collection infrastructure; freshwater farms may reuse nets, but there's no national infrastructure focused on fish-farm plastics.
- Norway: Norway runs established collection, retrieval and recycling initiatives for fishing/aquaculture gear; licensed recyclers and recovery programs exist and government supports retrieval efforts.
- Vietnam: Vietnam has national action plans and pilot initiatives to improve collection in fisheries, but on-the-ground port collection and recycling infrastructure remain patchy. Reports note limited waste collection equipment on vessels and ports.

5) Economic instruments (deposits, landfill taxes, incentives)

- Spain: Spain follows EU instruments (landfill/incentive rules vary by region). Some pilots use incentives for circular gear.
- Hungary: Hungary's EPR and eco-contributions cover multiple categories; direct aquaculture incentives are limited.
- Norway: Norway uses funding and incentives for recovery, R&D on recycling and biodegradable gear;

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economic levers to encourage returns and recycling are in practice.

- Vietnam: Vietnam's national plans outline economic measures and incentives but practical deployment—especially at small-scale fisher/farmer level—lags.

6) Integrate plastic management into aquaculture licensing

- Spain: Some regions include environmental conditions in licences; national enforcement and explicit plastic-management conditions vary.
- Hungary: Hungarian licensing for inland aquaculture focuses on water use and biosecurity; explicit plastic-management license conditions are not prominent.
- Norway: Norwegian Directorate of Fisheries ties environmental stewardship (including marine litter reporting and retrieval) into fisheries/aquaculture oversight and expectations.
- Vietnam: Fisheries/aquaculture regulations exist, and action plans call for better source controls; however explicit licence-linked plastic stewardship is not yet consistently enforced.

7) National standards for recyclability, reuse and design

- Spain: Several research groups and projects (AZTI, universities) are developing best-practice guides and circular-design pilots; national standards are mainly driven by EU norms.
- Hungary: No sector-specific standards for aquaculture plastics evident; standards more focused on packaging/product requirements.
- Norway: Research institutions (SINTEF), industry and government collaborate on technical standards for net maintenance, recyclability and material choice; guidebooks exist.
- Vietnam: Standards and technical guidance exist in broader waste management plans, but detailed recyclability/design standards for aquaculture gear are still emerging.

8) Monitoring, enforcement & data transparency

- Spain: Spain publishes guidance on lost gear and marine litter; monitoring efforts exist but national consolidated datasets for aquaculture plastics are incomplete.
- Hungary: Hungary has monitoring programmes for aquaculture sustainability but dedicated data on plastics in aquaculture is limited.
- Norway: Norway collects data on lost gear, runs retrieval surveys and government agencies actively monitor and report on marine litter related to fisheries/aquaculture.
- Vietnam has national targets and action plans for marine plastics, but data collection and enforcement capacity vary regionally and are weaker than in developed-country examples.

9) Support for R&D, pilots & public-private partnerships

- Spain: Several EU-funded projects and national research groups (e.g., AZTI) are piloting circular gear solutions and port-based collection.
- Hungary: Hungary runs national aquaculture programmes to modernise farms and sustainability pilots, but fewer plastics-specific R&D initiatives are evident.
- Norway: Strong R&D presence (universities, SINTEF), industry partnerships and government support for biodegradable gear trials and recycling tech.
- Vietnam: International donors (IUCN, FAO) and NGOs support pilots; Vietnam is increasingly active in

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pilot projects but domestic R&D capacity and funding are still developing.

10) Alignment with international frameworks

- Spain: As EU member Spain follows EU directives (SUP, waste/litter policies) and international guidance on gear marking.
- Hungary: Hungary implements EU waste directives and EPR frameworks; specific aquaculture gear alignment is less visible because of sector scale.
- Norway: Norway aligns national action with international guidance and OECD/FAO recommendations and has national strategies tackling ghost gear.
- Vietnam: Vietnam has national action plans reflecting international commitments (FAO, IUCN support) and aims to meet ambitious reduction targets, but implementation needs strengthening.

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