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Advancing an Ecosystem Approach to Fisheries Management in the Northeast Atlantic: ICES's Scientific Framework, Advice Products, and Implementation Pathways

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Abstract

Achieving marine management objectives and long-term sustainability requires moving beyond conventional, single-species management, towards an Ecosystem Approach to Fisheries Management (EAFM), that accounts for complex ecological interactions, cumulative human pressures, and environmental variability. The International Council for the Exploration of the Sea (ICES) advances EAFM in the Northeast Atlantic by providing scientific frameworks and advice products that address fundamental aspects of EAFM: understanding the ecosystem's influence on fisheries, quantifying fisheries' impact on the wider ecosystem, contextualizing fisheries among other pressures, and analyzing trade-offs between competing management objectives. Examples are provided for ICES integration of ecosystem information into advice, including the ecosystem-based fishing mortality reference point (F_{ECO}), the regional benthic impact assessments and trade-off analysis and the ICES Framework for Ecosystem-Informed Science and Advice (FEISA). These examples illustrate how ICES is moving from the single species model and contextual ecosystem assessment towards more operational ecosystem-informed advice. Despite progress, key challenges remain, including a fragmented governance structure and a lack of clear, formalized process translating ecosystem advice into management actions. Furthermore, there are significant data gaps concerning social and economic dimensions that need to be addressed to truly achieve a comprehensive EAFM.

Keywords: Ecosystem Approach to Fisheries Management (EAFM); Ecosystem-Based Management (EBM); Ecosystem-Informed Advice; Fisheries Management; Northeast Atlantic.

Introduction

Achieving long-term sustainability goals for marine fisheries requires management approaches that account for ecological interactions, cumulative human pressures, environmental variability, and social and economic dimensions. This has driven a shift from traditional single-stock and sector-based fisheries management towards the Ecosystem Approach to Fisheries Management (EAFM), which applies ecosystem-based management principles specifically to fisheries. In the Northeast Atlantic, ICES has played a central role in advancing this transition by developing scientific frameworks and advice products that incorporate ecosystem information into fisheries advice and support more integrated decision-making.

EAFM requires a systems-thinking approach to fisheries as interconnected socio-ecological systems. Its overarching goal is to use fisheries resources sustainably, conserve biodiversity, and support robust decision-making in a changing climate, while ensuring public participation and adhering to global governance principles. The implementation of EAFM can be separated into three main components representing the key dimensions of a fishery system: ability to achieve, ecological well-being, and human well-being (FAO, 2021). Ability to achieve includes elements such as governance and policy frameworks, environmental and external drivers, and stakeholder engagement. Ecological well-being includes target species management, protection of vulnerable species, and bycatch monitoring, while human well-being covers economic performance, social and cultural benefits, and equity.

Globally, the Northeast Atlantic is considered a leading region in the implementation of Ecosystem Based Management (EBM). The International Council for the Exploration of the Sea (ICES) contributes to this progress by providing a robust scientific framework and a suite of products targeting four fundamental aspects: understanding the influence of the marine ecosystem on fisheries; quantifying the impact of fisheries on the wider ecosystem; placing fisheries within the context of other marine activities and pressures; and analyzing the trade-offs between competing management objectives. ICES provides advisory services to regional and international fisheries management organizations, Regional Seas Conventions, and governments. It is a recognized and trusted independent scientific advisor, with advice grounded in best available peer-reviewed science, developed through transparent and participatory processes, and agreed by consensus (ICES, 2023b).

This paper synthesizes how ICES operationalizes EAFM in the Northeast Atlantic through complementary science and advice products. We examine the Ecosystem Overviews, advice on ecosystem effects on fisheries, assessments of fisheries impacts on ecosystems, guidance on EAFM implementation pathways, and the ICES Framework for Ecosystem-Informed Science and Advice (FEISA; Roux and Pedreschi, 2024). We then discuss how these products collectively support ecosystem-informed advice, where limitations remain, and what is needed to strengthen their operational use in fisheries management.

ICES implements EAFM across multiple levels of its advisory system, from data collection and stock assessment methods to integrated ecosystem analysis and advice. This includes expanding monitoring programmes to incorporate ecosystem information, environmental drivers, and multispecies interactions alongside traditional fisheries data, reflecting the broader data requirements of an ecosystem approach (FAO, 2003; FAO, 2021; ICES, 2024a).

Within ICES stock assessments and advisory framework, ecosystem information is incorporated through ecosystem-informed assessment methods where available, mixed-fisheries analyses, consideration of environmental variability, and evaluation of trade-offs among species, fisheries, and ecosystem components. In this way, ICES complements its established fisheries advice with ecosystem information that supports decision-making consistent with EAFM objectives.

To make EAFM applicable across the diversity of commercial fisheries managed in the Northeast Atlantic, the ICES advisory framework applies the Maximum Sustainable Yield (MSY) or a Precautionary Approach (PA) to all 260 ICES stocks, spanning data-rich stocks with analytical assessments and more data-limited stocks (ICES, 2023c). While MSY and PA reference points are primarily derived from single-species population dynamics, ecosystem considerations are incorporated through adjustments to reference points, the use of ecosystem-informed assessment methods where available, and through the broader advisory process, including mixed-fisheries analysis, consideration of environmental variability, and the evaluation of trade-offs between species and ecosystem components. As a result, MSY- and PA-based advice is complemented by ecosystem information to better support decision-making that is consistent with the objectives of EAFM (ICES, 2023b; ICES, 2023c; ICES, 2025a).

Results

ICES supports EAFM through a set of complementary science and advice products that operate at different levels of the advisory system. Ecosystem Overviews provide regional ecological and governance context; ecosystem-informed fisheries advice incorporates environmental variability and multispecies interactions into stock advice; spatial assessments quantify fisheries impacts on habitats, vulnerable ecosystems, and non-target species; implementation guidance supports uptake by management organizations; and FEISA provides an integrating framework for linking indicators, risk assessment, and advice. The following sections describe these products and illustrate how, collectively, they contribute to more operational ecosystem-informed advice.

Ecosystem overviews: regional context for EAFM

The ICES Ecosystem Overviews (EOs) are a key scientific product developed to support an Ecosystem-Based Management (EBM) of marine environments. The EOs illustrate how ICES has expanded its scope beyond fisheries to consider a broader range of human activities and the pressures they exert on marine ecosystems (ICES, 2023a). They also highlight the complexity of governance in these regions, where multiple competent authorities, including national governments, the European Union, Regional Fisheries Management Organizations (RFMOs), and Regional Seas Conventions, implement policies and legislation across sectors that may not always be fully aligned.

The Ecosystem Overviews apply a risk-based assessment approach, to identify and prioritize the top pressures and associated activities on which management actions should focus on these complex governance seascapes. ICES has published EOs for eleven ecoregions in the Northeast Atlantic, from the Gulf of Cadiz to the Central Arctic Ocean, including the Baltic Sea, and these are updated in cycles of approximately five years.

The EOs identify the main pressures affecting ecosystem components through the main human activities in each ecoregion (Fig. 1). This identification is done by the specialized regional Ecosystem Approach methods groups which include expertise across the different ecosystem components (see Fig. 1, right column) and is complemented by other expert groups where a knowledge gap is identified. The risk-based assessment uses a driver–pressure–state linkage framework which scores all direct pressures and human activities in an ecoregion by examining the temporal and spatial scale and degree of impact of each activity-pressure pair on the ecosystem components. The assessment is semi-quantitative,

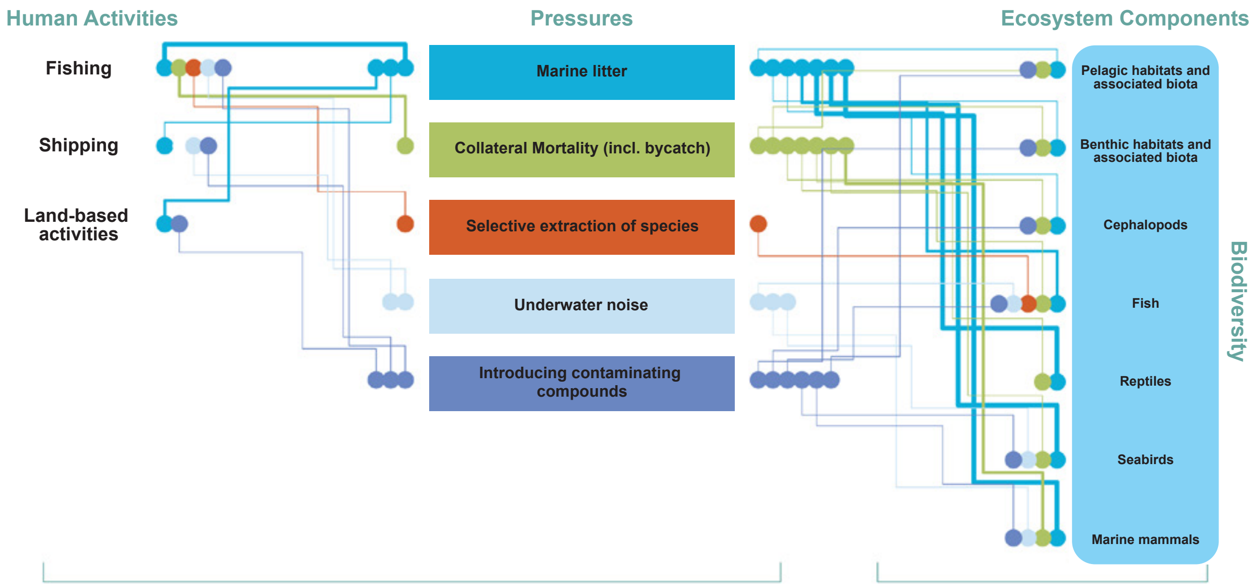

Fig 1. Example of an assessment summary from the Oceanic Northeast ecoregion (ICES, 2025b) including most relevant regional pressures, human activities, and state of ecosystem components (representing biodiversity). The width of the lines indicates the relative importance of the main individual links. Human activities and pressures are listed in decreasing order of relative contribution to the total risk score. The absence of a line does not necessarily imply a total absence of any link; only the main contributors are shown in the figure.

informed by both quantitative information where available and qualitative information (*e.g.* expert judgement) where little or no quantitative information is available. The risk assessment is produced following the guidelines developed in the ICES Workshop on methods and guidelines to link human activities, pressures and state of the ecosystem in Ecosystem Overviews (WKTRANSPARENT; ICES, 2021) and detailed in the ICES Ecosystem Overviews Technical Guidelines (ICES, 2023a).

The Ecosystem Overviews highlight the most important pressures, in order of importance, with the main links to the sectors and to the state of the ecosystem components (see Fig. 1). These should be pressures that can be managed at the regional level. The assessments also produce outcomes at a finer resolution, with the complete list of activities and pressures available in the working groups' scientific reports and/or published in the literature (Pedreschi *et al.* 2023). These main outcomes are represented in a wire diagram, an example of which is shown in Fig. 1.

The EOs provide contextual regional advice and support cross-sector integration, helping to situate otherwise isolated sectorial advice (*i.e.* advice on offshore renewables, VMEs, bycatch, etc.) within a broader ecosystem context. They also identify the most pressing ecosystem risks, which can be used by the scientific community to develop more holistic ecosystem models and environmental indicators, and by decision-makers to concentrate policy efforts on the most pressing regional issues. They further identify knowledge gaps and uncertainties where more science and data are needed to support operational decisions. While the overviews provide regional advice, they also relate to specific states of ecosystem components and to specific pressures linked to wider regional drivers such as climate change, global pollution and biodiversity loss, highlighting where these processes have a higher impact.

As part of its communication and dissemination efforts, ICES also develops ecosystem overviews (EOs) infographics. Fig. 2 shows the infographic of the Central Arctic ecosystem highlighting the key signals: human activities and their pressures, the state of the ecosystem, and climate change.

EBM is an iterative process, and hence the ecosystem overviews are in continuous evolution. Since their earliest conception in 2016, this advice has adapted and incorporated new sections following evaluation and feedback from stakeholders and policymakers, and in response to new scientific evidence and methods. A Climate Change section was thus incorporated in 2019 recognizing climate change as a main global driver with effects at a regional scale on ecosystem components (ICES, 2019). This section is in continuous evolution, in collaboration with ICES-PICES Strategic Initiative for Climate Change (SICCME), to account for past and projected climatic changes in the ecoregions, including key variables and the ecosystem components affected.

In addition, two other sections have been introduced in recent years: a Social and Economics section, led by WGSOCIAL and WGECON, linked mostly to fisheries;

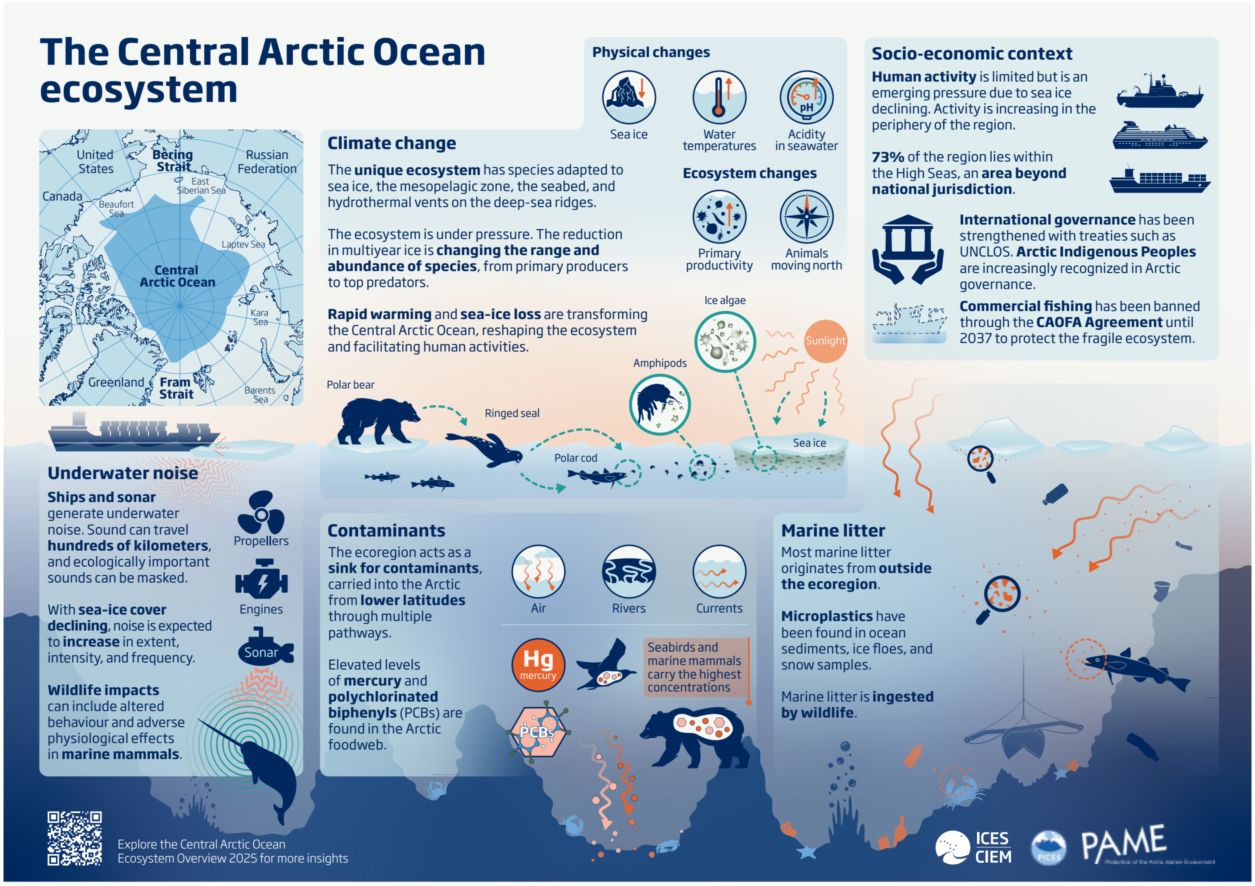

Fig. 2. Infographic of the Central Arctic Ocean ecosystem (ICES, PICES, PAME). (https://www.ices.dk/SiteCollectionImages/ecosystem%20overviews/Central%20Arctic%20Ocean/Ecosystem_Overview_CAO_Infographic_2025.png

and a benthic assessment section (based on the work of WGFBIT (ICES, 2025b), in which specific trade-offs are considered (*i.e.* sea bed impacts from the use of mobile bottom-contacting gear (MBCG) on different seabed habitats and communities (see section 2.3)). In the future, the social and economic section will need to incorporate management objectives and social indicators for other human activities, specifically shipping, as this is one of the other main activities highlighted by several EOs as an important pressure.

The EOs help identify key drivers and risks, and could be used to explore trade-offs between competing fisheries, ecosystem protection, and other human activity management objectives. They are consequently a platform through which different human activities are contextualized in an advice format. The Ecosystem Overviews therefore have a great opportunity ahead as a vector to advance EBM within the ICES community. Their adaptive nature will allow them to have more explicit links with global challenges (*i.e.* climate change, pollution and biodiversity loss) and to strengthen the pillars of sustainability by incorporating quantitative indicators and thresholds linked to operational management objectives. In this way, the overviews will better fulfil their role, moving from a contextual form of advice providing actionable advice linked to decision-makers needs to promote systemic changes in how society interacts with the marine environment.

ICES advice on the impact of ecosystems on fisheries

One of the key fisheries management objectives in the Northeast Atlantic is the Maximum Sustainable Yield (MSY) concept, which aims to maximize long-term exploitation of stocks while remaining precautionary. The ICES MSY approach is based primarily on single-stock assessments, although ecosystem considerations may be incorporated where relevant and supported by available information. For example, ICES advice for North Sea sandeel under the MSY approach explicitly adjusts catch advice based on recent recruitment variability, with reduced catches following consecutive years of low recruitment, thereby implicitly reflecting environmental influences on stock productivity (ICES, 2025d). However, increasing environmental variability and long-term changes driven by climate change are not systematically accounted for within the MSY framework, highlighting the need to better integrate these factors into fisheries management.

Historically, incorporating complex ecosystem information into short-term single-stock fisheries management advice has proven challenging. Multi-species models are complex and often uncertain, and finding environmental drivers with sufficient explanatory power to warrant incorporation into single stock assessment has also proven largely elusive (Trenkel *et al.*, 2023).

In some cases, ICES implicitly integrates these complex environmental drivers into short-term tactical management advice by using recent biological parameters or recruitment assumptions. The ICES Working Group on Multispecies Assessment Methods (WGSAM) develops multispecies models that consider species, food-web and fishery interactions, and multiple sources of uncertainty, including climate change (ICES, 2024g). Multi-species model "key runs" are used to provide dynamic natural mortality-at-age estimates for stocks in the Baltic and North Sea. Outputs from these models are used to provide dynamic natural mortality-at-age estimates for several Baltic and North Sea stocks (Trenkel *et al.*, 2023).

To allow flexibility in TAC setting, ICES introduced the "Pretty Good Yield" (PGY) approach in 2015, using fishing mortality ranges around F_{MSY} (the fishing mortality rate expected to achieve MSY in the longer term), from $F_{MSYlower}$ to $F_{MSYupper}$ (Hilborn, 2010). This approach reflects that yields near MSY can be achieved across a range of fishing pressures, with only minor losses in long-term catch. Fishing within these ranges is considered precautionary and allows managers to balance trade-offs, including mixed-fisheries constraints and ecosystem considerations. However, clear and consistent guidance on how to select values within the range in practice has remained limited, leaving operational decisions largely case-specific.

A more recent tool for directly integrating quantitative environmental drivers is the ecosystem-informed F (F_{ECO}) approach, which uses indicators derived from ecosystem models to adjust the advised target fishing mortality within the predefined F_{MSY} ranges depending on ecosystem condition (Bentley *et al.*, 2021). The ecosystem-based fishing mortality reference point ($F_{ECO)}$ approach) was co-developed during a series of ICES workshops known as WKIrish, focused on the Irish Sea (ICES division VIIa). WKIrish brought together scientists, stakeholders, policy advisors, and environmental non-governmental organizations (eNGOs) to align research objectives with policy needs, engage early and often with stakeholders, apply best practice in model development and ultimately co-design and operationalize EAFM. F_{ECO} utilizes ecosystem indicators to select a target fishing mortality within these established ranges (Bentley *et al.*, 2021). F_{ECO} is defined as a precautionary reference point that varies dynamically based on the strategic understanding derived from ecosystem models, scaling fishing mortality down when ecosystem conditions are poor for a specific stock, and up when conditions are favorable, while maintaining the integrity of ICES precautionary rules. The F_{ECO} concept allows for the integration of multiple indicators by using weighting factors to estimate an overall indicator status for a stock.

The concept does not require replacing standard assessment methodologies, thus maintaining the robustness of existing models for short-term forecasting. While currently limited in application to data-rich stocks with existing F_{MSY} advice, F_{ECO} offers a pragmatic and transparent stepping-stone for incorporating ecosystem information into tactical fisheries advice, accelerating progress towards Ecosystem-Based Fisheries Management (EBFM).

In a recent paper, Trenkel *et al.* (2023) presented a comprehensive audit of how ecosystem trends and variability (ETV) are currently incorporated into ICES fishing opportunities advice in the Northeast Atlantic . This analysis covered 87% of stocks, representing 99% of total landings, and showed that ETV was incorporated in at least one way (tactical or strategic advice) for nearly three-quarters (73%) of the stocks that responded to the audit. The inclusion of ETV is often implicit, driven by a general commitment to use the "best available science" rather than explicit, systematic instruction. For example, environmental drivers such as sea surface temperature influencing recruitment are commonly accounted for through recruitment estimates and short-term forecasts, while trophic processes are reflected through the incorporation of time-varying natural mortality driven by predation in multispecies assessments. While ETV is widely considered, only 46% of the stock assessments included it quantitatively. The authors conclude that while the commitment to use "best available science" has led to significant implicit inclusion of ETV in ICES advice, accelerating progress toward EBFM requires a shift from implicit to explicit instructions, with routine documentation of ecosystem information throughout the advice cycle.

Fisheries impacts on ecosystems: spatial advice and trade-offs

The recognition that fishing activities create complex spatial impacts across marine ecosystems has driven ICES to develop approaches for understanding and quantifying these effects, with particular emphasis on trade-off analyses between the extent of disturbance to seabed habitats from mobile bottom-contacting gear (MBCG) and potential costs to fisheries. ICES's approach to assessing fisheries impacts on ecosystems encompasses both the immediate physical disturbance to seabed habitats and the broader ecological consequences, including bycatch of protected species, impacts on vulnerable marine ecosystems (VMEs), and alterations to marine food webs.

Underpinning ICES spatial assessments is the work of its Working Group on Spatial Fisheries Data (WGSFD), which serves as the primary conduit for ingesting highly resolved fisheries effort data. Through its annual "VMS (Vessel Monitoring System) and Logbooks Data Call", WGSFD compiles spatially explicit fishing activity data from ICES Member Countries, providing the empirical foundation for assessing fishing pressure at fine spatial scales. The data call requests anonymized and gridded VMS data, linked to logbook records of gear codes and vessel parameters (length and power), enabling calculation of swept area and swept-area ratio (SAR) at fine scales for MBCGs, as well as associated catch weights and values. This standardized approach to spatial data collection and quality control ensures that fishing intensity estimates are comparable across regions and consistent over time. WGSFD's ongoing methodological development addresses challenges such as differentiating fishing from non-fishing activity based on vessel speed, allocating landings weight and value to spatial locations, and estimating gear dimensions for swept area calculations.

The Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT) is ICES's primary forum for developing methods and assessments to evaluate the benthic impact of fisheries at regional scales while considering trade-offs between fisheries and seabed health. The group has developed a quantitative Europe-wide assessment of bottom-trawl impacts across the Baltic, Atlantic, Mediterranean, and Black Seas. This approach utilises two key indicators of seabed status: RBS_{tot} (biomass relative to fauna carrying capacity) and RBS_{sen} (biomass of the 10% most sensitive fauna relative to carrying capacity), enabling scientists to identify significant regional and habitat differences in bottom-trawling impacts (ICES, 2025a).

ICES's approach incorporates methodological frameworks for assessing significant adverse effects on seabed habitats and has developed evaluation criteria for both state-based and pressure-based indicators. It applies systematic approaches to threshold setting, distinguishing between qualitative risk assessments suitable for data-limited circumstances and quantitative assessments requiring extensive monitoring data. This framework enables ICES to provide regionally appropriate advice while maintaining scientific rigour across different data-availability scenarios (ICES, 2022a).

The spatial dimension of ICES's benthic impact assessments has evolved considerably, moving from simple pressure mapping to sophisticated models that account for habitat sensitivity, recovery rates, and cumulative effects. The methodology developed by WGFBIT estimates the relative decline in biomass of the most vulnerable community components, with indicators designed to be responsive to gradients of trawling pressure while maintaining comparability across different regions and assessment methods. This approach has enabled ICES to provide spatially explicit advice on where fishing activities are likely to cause the greatest ecosystem impacts and where protective measures might be most effectively implemented. This advice examined mobile bottom-contacting gear (MBCG) fisheries and revealed that fishing activities are spatially aggregated into core areas accounting for most of the landings value, and peripheral areas of relatively low economic importance. On average, 90% of MBCG landings value originates from less than 50% of the fished area when evaluated at 0.05° grid cells (ICES, 2024a).

The analysis demonstrated that maintaining a persistently unfished state in 50% of all Marine Strategy Framework Directive Broad Habitat Types within the Greater North Sea and Celtic Seas would reduce annual mean MBCG landings value by approximately 20%. More stringent protection levels showed steeper trade-offs, with 70% habitat protection associated with landings value reductions of 31.6% and 36.7% per year in these two regions, respectively. The Baltic Sea, however, demonstrated a different set of trade-off relationships, with maintaining 70% of habitats in an unfished state resulting in a reduction of less than 7% of annual mean MBCG landings value, reflecting the existing limited distribution of bottom-contacting fishing activities there (ICES, 2024a).

These analyses reveal the spatial heterogeneity of fishing pressure and economic dependency. Core fishing grounds (defined as the smallest area yielding 90% of landings value) exhibit temporal variability, with fewer than 50% of c-squares[1] fished by individual métiers being classified as core fishing grounds in every year during 2017–2022, in the EU waters of the Greater North Sea and Celtic Seas areas. This temporal instability has important implications for spatial management measures, suggesting that fixed area closures may not consistently protect the most economically valuable fishing grounds.

The theoretical foundations underpinning ICES's trade-off approaches draw on optimisation models demonstrating that biodiversity protection and sustainable harvest can often be achieved simultaneously when important biodiversity components are spatially isolated or differentially affected by various fishing gears. Research suggests that roughly 80% of potential harvestable yield can be maintained while protecting 70% of biodiversity when spatial and gear-based management strategies are effectively implemented (Hilborn *et al.*, 2020).

ICES's work on vulnerable marine ecosystems (VMEs) exemplifies the organisation's evolving spatial approach to protecting ecosystem components that are particularly vulnerable to fishing impacts. The advice on areas

1 a c-square (concise spatial query and representation system) is a standardized geographical grid system used to divide the ocean into equal-sized spatial units for mapping and data analysis. https://doi.org/10.5670/oceanog.2003.52

where VMEs are known or likely to occur in EU waters (ICES, 2024b) demonstrates the evolution of spatial management from simple area closures to sophisticated risk-based approaches. ICES presented five spatial management scenarios based on updated information on VME occurrence and the distribution of MBCG fishing activity, providing advice requesters with options covering a range of risk tolerances, and resulting in VME protection polygons ranging from 102–115 in number and covering 9,752–14,885 km² in total area. This evidence-based procedure for producing recurrent ICES advice on VME was benchmarked in 2022 (ICES, 2022b).

The organisation's approach to providing advice on VME protection extends beyond EU waters to the North-East Atlantic Fisheries Commission (NEAFC) regulatory areas, where ICES has evaluated the biodiversity attributes of restricted bottom fishing areas. Each of the 14 polygons identified in NEAFC Regulatory Areas 1 and 2 contains multiple biodiversity attributes as articulated in Convention on Biological Diversity guidance, including communities of rare, threatened or endangered species, representative natural ecosystems, and areas providing critical ecosystem functions. This work demonstrates how ICES translates international biodiversity criteria into operational spatial management advice (ICES, 2024c).

The spatial dimension of bycatch impacts (ICES, 2024d) represents another critical area where ICES provides ecosystem-focused advice. Recent analysis of static net fisheries revealed complex spatial patterns in marine mammal bycatch, with acoustic deterrent devices (ADDs) showing effectiveness in reducing harbour porpoise bycatch to 0.23 of background rates, while simultaneously increasing seal bycatch rates by a factor of 2.43 (ICES, 2024e). These findings highlight the spatial heterogeneity in the effectiveness of mitigation measures, the need for location-specific management approaches, and the recognition that such measures may relocate problems spatially or temporally rather than solving them.

Contemporary ICES work increasingly focuses on fishing displacement effects caused by emerging human activities, such as offshore renewable energy developments and marine protected areas, using spatial effort and catch data to identify critical fishing areas and analyse catch rates of key commercial species. This research provides essential information for understanding how spatial restrictions in one area may intensify impacts in others, supporting marine spatial planning (MSP) and more holistic ecosystem-based management approaches.

Implementation pathways for EAFM

ICES plays a central role as an advice provider for fisheries management organizations adopting an EAFM. A recent example is ICES advice to NEAFC outlining ecosystem-based approaches to fisheries management (ICES, 2024a). In this advice, ICES detailed five distinct methods ranging from low to high complexity and data needs (ICES, 2024f). ICES advised that operational ecological objectives for EAFM should span six core ecological issues: target species; bycatch species or groups; discards; Endangered, Threatened, and Protected (ETP) species; benthic habitat impacts; and ecosystem structure and function impacts. The process for setting these operational objectives should be inclusive, consultative, and evidence-informed, based on a shared understanding between managers, scientists, and stakeholders. These objectives must be clearly linked to existing or potential management actions within the managing authority's competence.

The five approaches to EAFM implementation

The five approaches described—Qualitative Risk Assessment (RA), Semi-quantitative RA, Ecosystem Status Indicators Framing Fisheries Decision-Making (ESI), Northwest Atlantic Fisheries Organization (NAFO) EAF Roadmap, and the Marine Strategy Framework Directive (MSFD)—were compared based on their requirements, maturity, and contribution to EAFM (ICES, 2024e).

1. Qualitative Risk Assessment (Qualitative RA): This approach is used when the evidence base is sparse or highly uncertain. It is a quick assessment method, often applied as an initial screen, that can address almost all EAFM issues. It uses expert opinion to provide general guidance on management actions. Monitoring requirements are low to medium, and it can be applied even when data are very limited. However, adequate precautions must be applied to offset significant assumptions, which may cause concern among stakeholders and regulators.

2. Semi-quantitative Risk Assessment (Semi-quantitative RA): This requires some quantitative data and provides risk estimates with greater formality than Qualitative RA. Its outputs can lead to precise advice on management actions and may estimate absolute risk and attribution between fleets, strengthening the link to decision-making. It has medium, variable data needs, and monitoring requirements are often met by existing data.

3. Ecosystem Status Indicators Framing Fisheries Decision-Making (ESI): This approach supplements existing decision processes by using a broad range of data types to provide ecosystem context. Information is often delivered via risk tables to improve consistency in decision-making. While the approach provides a system-scale view and is easily integrated with existing processes, its link to management is informal and dependent on the willingness of decision-makers to use the information, as there is no formal quantitative link to decision rules.

4. NAFO Ecosystem Approach to Fisheries (NAFO EAF) Roadmap: This approach is relatively resource-intensive and addresses a subset of EAFM issues, including targets for Vulnerable Marine Ecosystems (VMEs), biodiversity, and ecosystem overfishing. It explicitly links objectives to indicators and targets. Its monitoring needs are medium-high, relying on extensive annual scientific trawl surveys.

5. Marine Strategy Framework Directive (MSFD): This is the most data- and resource-intensive approach, applied in EU marine waters, involving detailed monitoring and assessment across eleven descriptors. It informs decision-making by tracking trends in ecosystem components and pressures (EU, 2008). However, the set of targets remains incomplete, and its efficacy is challenged by the lack of a clear, direct link between its requirements and the management actions taken through the Common Fisheries Policy (EU, 2002).

Implementation and Challenges

All five approaches inform management and, in most cases, lead to management actions related to ecological well-being. Importantly, the implementation of EAFM can be incremental, often using risk assessments to screen issues and define priorities for more resource-demanding methods. However, methods to assess ecosystem structure and function impacts are still in the early stages of development across jurisdictions. Furthermore, while most approaches can address ecological aspects, non-ecological requirements like social and economic performance are generally not thoroughly considered or directly addressed.

FEISA as an integrating framework

The ICES Framework for Ecosystem-Informed Science and Advice (FEISA; Roux and Pedreschi, 2024) provides the framework needed to support Ecosystem-Based Management (EBM).

The rationale for EBM and FEISA

Conventional siloed approaches to resource management (single-sector/single-species) have proven ineffective for achieving long-term sustainability goals, and there is a need to apply a systems-thinking approach to understand and manage interconnected socio-ecological systems. However, operationalizing EBM is challenging due to inherent complexity, resource and capacity limitations, and significant data and knowledge gaps, especially concerning social and economic data.

FEISA's architecture: indicators and risk

FEISA addresses these challenges by combining two core building blocks to translate knowledge into evidence for advice, namely a system of indicators and a risk-based approach (Fig 3):

1. A System of Indicators: Indicators are measurable information on the socio-ecological systems. They must be relevant to the full spectrum of EBM objectives, including marine ecosystems, individual components, human activities/pressures (including climate change),

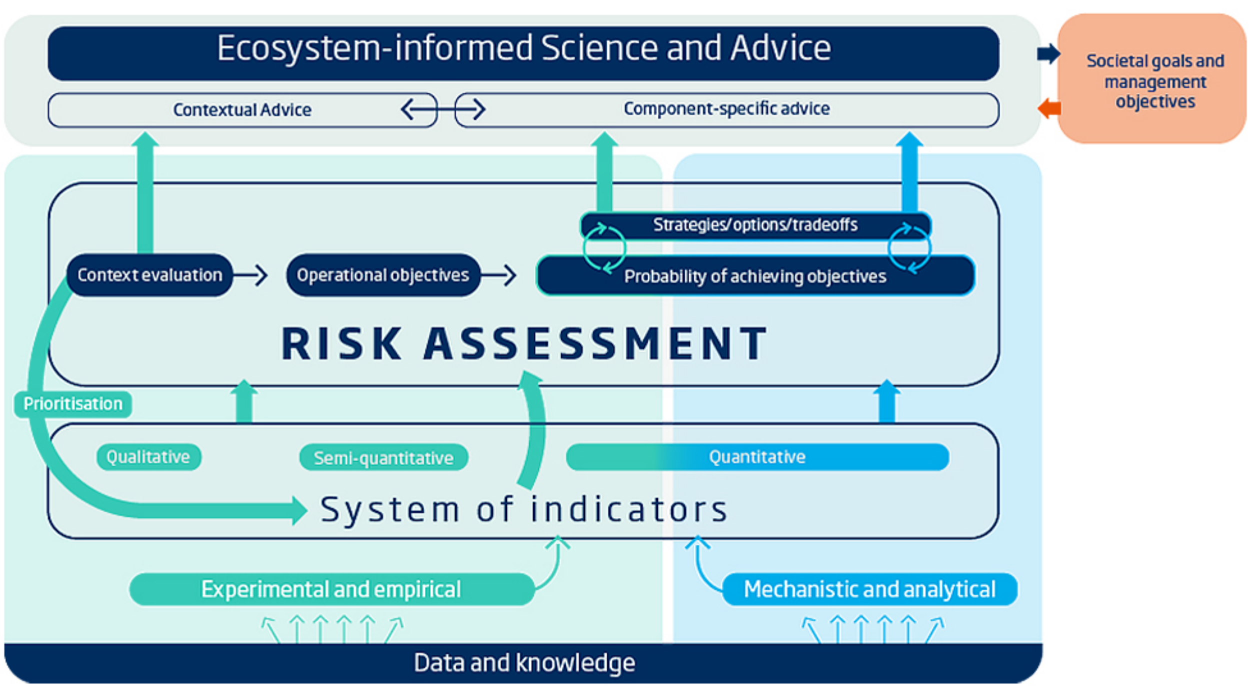

Fig. 3. ICES Framework for Ecosystem-Informed Science and Advice (FEISA). See description in text.

and social, cultural, and economic well-being. Indicators can be qualitative, semi-quantitative, or quantitative. To be operational, indicators must be linked to operational objectives—specific values or ranges (*e.g.*, baselines, limits) used to track status, trends, and risk. These differ from management objectives, which are long-term aspirational goals set by governing bodies.

2. A Risk-Based Approach: Risk provides a common currency for merging different types of indicators and formally treating consequences and uncertainties. This approach aligns with the widely adopted precautionary principle. FEISA uses two types of risk assessment:

- **Context-based risk assessments:** Used primarily for risk identification and prioritization of human activities, pressures, and components within the broader socio-ecological context (e.g., in ICES Ecosystem Overviews (EOs)). These often rely on experiential and empirical evidence.

- **Objective-based risk assessments:** Used to probabilistically evaluate the potential outcomes, consequences, and trade-offs of alternative management options against operational objectives. These require explicit specification of objectives and are standard practice in fisheries advice (*e.g.*, evaluating the probability of breaching biological limits).

Discussion

The examples reviewed in this paper show that ICES is moving from largely single-stock and sector-specific advice towards a more integrated, ecosystem-informed advisory system. Ecosystem Overviews provide regional context and identify priority pressures (ICES, 2023a; ICES, 2025c); ecosystem-informed stock advice incorporates environmental variability and multispecies interactions into fisheries advice (Trenkel *et al.*, 2023; Bentley *et al.*, 2021); spatial assessments quantify fisheries impacts and trade-offs (ICES, 2024a; ICES, 2024b; ICES, 2024c; ICES, 2024d; ICES, 2024e); and implementation guidance supports managers in selecting approaches suited to available data, resources, and objectives (ICES, 2024f). Taken together, these products form a layered advisory pathway for operationalizing EAFM in the Northeast Atlantic.

FEISA provides the conceptual and operational architecture for connecting these products. Its emphasis on indicators, risk assessment, uncertainty, and incremental implementation allows ecosystem information to be incorporated across a wide range of advice contexts, from data-limited qualitative assessments to quantitative evaluations of management options (Roux and Pedreschi, 2024). This is important because EAFM does not require perfect information before action can be taken; rather, it requires transparent use of available knowledge, explicit treatment of uncertainty, and clear links between scientific advice and management objectives.

Nevertheless, the transition from ecosystem-informed science to operational management remains incomplete. Many ecosystem considerations are already included in ICES advice, but often implicitly or case by case rather than through systematic instructions and routine documentation. In addition, ICES advice can identify risks, trade-offs, and management options, but implementation depends on whether management authorities define operational objectives, clarify acceptable levels of risk, and establish processes for translating advice into action (ICES, 2024e; Garcia *et al.*, 2014).

Transitioning to ecosystem-based fisheries management (EAFM) requires balancing biological, ecological, economic, and social objectives, supported by effective dialogue among policymakers, managers, scientists, and stakeholders. Progress remains constrained by institutional readiness, capacity limitations, and gaps in socio-economic data, alongside differing expectations on the role of ICES advice in integrating human dimensions.

Achieving ecosystem objectives is further challenged by fragmented governance and limited formal processes for integrating ecosystem considerations into fisheries management, as well as by misalignments between key policy frameworks such as the Common Fisheries Policy (EU, 2013), the Marine Strategy Framework Directive (EU, 2008), the Maritime Spatial Planning Directive (EU, 2014), and the Nature Restoration Regulation (EU, 2024).

Governance systems and management instruments (*e.g.* TACs, technical measures, and effort controls) shape not only ecological outcomes but also the social and economic sustainability of fisheries and dependent communities (Garcia *et al.*, 2014).

In this context, ICES has developed integrative approaches to support the transition towards EAFM, notably through the Framework for Ecosystem-Informed Science and Advice (FEISA), which provides a structured and iterative way to incorporate diverse knowledge types into ecosystem-based advice (Roux and Pedreschi, 2024; ICES, 2024).

Integration and synthesis of ICES's EAFM framework

The Framework for Ecosystem Informed Science and Advice (FEISA) represents an operational basis through which ICES can translate complex ecosystem science into actionable management advice.

The common theme unifying the examples given above is FEISA's capacity to incorporate diverse forms of knowledge and multiple levels of data availability. The Ecosystem Overviews, for example, highlight

FEISA's context-based risk management approach, using both quantitative data and expert judgement to identify and prioritize regional pressures. This mixed methodology has proven particularly valuable in data-limited scenarios, allowing ICES to provide meaningful advice whilst explicitly acknowledging uncertainties. Similarly, the F_{ECO} approach demonstrates how FEISA's indicator-based system can operationalize ecosystem information within existing single-species frameworks, maintaining precautionary management while enhancing responsiveness to ecosystem conditions.

What distinguishes FEISA from previous frameworks is its pragmatic acceptance that perfect information is neither achievable nor necessary for effective management. By establishing a common approach to risk, FEISA enables the integration of different information sources – from VMS positional data to stakeholder sentiment – into coherent advice products. This flexibility is important as ICES moves to address increasingly complex questions involving multiple objectives, sectors, and scales.

FEISA supports incremental implementation, allowing progression from qualitative risk assessments in data-limited situations to more quantitative analyses as information availability improves. This graduated approach removes the artificial barrier between 'data-poor' and 'data-rich' contexts, enabling all regions and stocks to benefit from ecosystem considerations regardless of their current monitoring capacity. Ultimately, FEISA provides the structure needed to promote knowledge plurality and the routine exploration of alternative hypotheses and scenarios, ensuring advice is better aligned with societal drivers and ecosystem-based management goals.

The trade-off analyses developed by WGFBIT exemplify FEISA's objective-based risk assessment in practice, evaluating the consequences of management scenarios against explicit operational objectives. These analyses move beyond simple impact assessments to quantify the relationships between different activities and ecosystem protection, providing decision-makers with the evidence base needed to navigate the political choices around resource allocation and conservation priorities.

Implementation

While ICES has demonstrated several operational assessments and examples that provide advice according to EBFM principles, these assessments are often project-based and frequently constrained by time, budget, or data availability. ICES's Framework for Ecosystem-Informed Science and Advice (FEISA) provides the overarching structure within which spatial fisheries impact assessments are integrated with broader ecosystem considerations. The framework mobilizes different types of data and knowledge to define measurable indicators, which are then integrated into advice via both context-based and objective-based risk assessments. This ensures that spatial analysis of fisheries impacts contributes to comprehensive ecosystem assessments rather than remaining isolated technical exercises.

The evolution of ICES's spatial approach to fisheries ecosystem impacts reflects both advancing scientific understanding and growing policy demands for quantitative trade-off analyses. By combining sophisticated modelling approaches with pragmatic consideration of implementation challenges, ICES continues to refine its capacity to provide actionable advice on balancing fishing activities with ecosystem protection across the complex spatial mosaic of Northeast Atlantic marine systems.

Remaining challenges and limitations

ICES has made significant progress in obtaining and analyzing VMS and logbook data, which now underpin much of its spatial analysis. These data have inherent limitations linked to the scale at which impacts can be interpreted, challenges in inferring fishing activity and legal hurdles in sharing and presenting outputs. Spatial data on other human activities at sea remain limited and restricted, hampering comprehensive assessment of cumulative impacts and interactions between sectors. Social and economic data lag even further behind, creating imbalanced assessments that may inadequately capture the bigger picture. Climate and environmental modelling, while improving, still show temporal and spatial gaps that limit the precision at which ecosystem change can be monitored and interpreted.

EAFM assumes coordinated management actions across sectors and jurisdictions, yet governance structures remain predominantly sectoral and national. ICES can provide integrated scientific advice but translating that advice into coherent management actions requires institutional arrangements that may not exist. The divide between the spatial scales at which ecosystems function and the administrative boundaries through which they are governed creates persistent challenges for implementing ecosystem-based management.

Resource limitations constrain what is possible. Comprehensive assessment of ecosystems is resource-intensive and costly, requiring specialist expertise, extensive data collection, sophisticated analytical capabilities, and sustained political commitment. As advice demands grow to cover more ecosystem components, human activities, and management questions, there is a risk of overextending available resources, compromising the quality of advice, or limiting ICES's capacity to respond to other priorities.

Future directions and priorities

While Trenkel *et al.* (2023) demonstrated that ecosystem trends and variability are already widely incorporated into ICES advice, their analysis revealed that much of this integration remains implicit rather than systematic. The transition to a systematic integration represents the next critical step in ecosystem-based advice, requiring both methodological changes and institutional commitment to standardized approaches for incorporating ecosystem information explicitly across advice products. The FECO concept provides a template for this transition, showing how ecosystem indicators can be integrated into advice, while maintaining existing advisory frameworks (Bentley *et al.*, 2021). Extending such approaches beyond data-rich stocks presents both technical and resourcing challenges.

Current EAFM implementation has made substantial progress on ecological dimensions but remains comparatively underdeveloped in systematically addressing social and economic considerations beyond fisheries. The recent incorporation of social and economic sections into the ICES Ecosystem Overviews represents a first step, but comprehensive operationalization requires expanding this work to other marine sectors.

Future development requires advice requesters and managers to establish operational social and economic objectives, with associated indicators and thresholds, comparable to those now routine for ecological components. ICES can provide the scientific framework and methodological guidance to support such objectives, but their definition and prioritization must be co-developed with management bodies. This is particularly pressing for sectors like shipping, which the Ecosystem Overviews identify as a major regional activity, yet for which management objectives and social indicators remain largely undefined. Collaborative dialogue between ICES and its advisory requesters will be essential to clarify what questions need answering and what operational objectives are required to support cross-sectoral management decisions.

Broader policy context and implications

ICES's EAFM development has not occurred in isolation, but in response to the evolving policy landscape at both global and regional scales. The UN Decade of Ocean Science for Sustainable Development (2021-2030) and the post-2020 Global Biodiversity Framework, with its target of effectively conserving 30% of marine areas by 2030, create a context in which ecosystem-based approaches shift from aspirational to essential.

At the regional level, the European Union's interlinked policy frameworks- the Common Fisheries Policy, Marine Strategy Framework Directive, Maritime Spatial Planning Directive, and emerging initiatives on offshore renewable energy - demand integrated scientific advice that can address interactions among objectives and sectors. ICES's development of tools such as the Ecosystem Overviews and trade-off analyses directly responds to these policy drivers, providing the evidence base needed for decisions that must simultaneously address biodiversity conservation, food security, climate mitigation, and economic development.

The NEAFC advice on EAFM implementation approaches illustrates how ICES translates these broad policy commitments into operational guidance suited to different institutional contexts and resource availabilities. By describing a continuum of approaches from qualitative risk assessment to comprehensive frameworks like the MSFD, ICES acknowledges that EAFM implementation must be pragmatic and incremental, adapted to the specific circumstances and capacities of different management jurisdictions.

However, this policy landscape also creates tensions. The proliferation of sectoral and environmental legislation fragments governance, creating situations where policies pull in different directions or where cumulative requirements exceed available monitoring and assessment resources. ICES's integrative approach, embodied in FEISA and the Ecosystem Overviews, offers a potential antidote to such fragmentation. Realizing this potential requires policy-makers to actively use integrated advice products in decision-making and that governance structures to evolve in support of cross-sectoral coordination.

Conclusions and Key Messages

The Northeast Atlantic provides an important example of how ecosystem-informed fisheries advice can be developed within a complex ecological, environmental, and governance landscape. The ICES products reviewed in this paper show that EAFM is being operationalized through a layered advisory pathway: Ecosystem Overviews provide regional context and identify priority pressures; ecosystem-informed fisheries advice incorporates environmental variability and multispecies interactions into stock advice; spatial assessments quantify fisheries impacts and trade-offs; and implementation guidance supports management organizations in selecting approaches suited to their objectives, data availability, and capacity.

FEISA provides a unifying framework for this work by connecting these products across different levels of data, information, analytical complexity, and risk. FEISA's value lies not in requiring a single comprehensive model of the ecosystem, but in linking indicators, risk assessment, and uncertainty to the transparent and incremental use of available knowledge, from qualitative expert judgement to quantitative evaluation of management options. This makes it particularly useful for moving ecosystem information from contextual assessment towards more operational advice.

Important challenges remain. Many ecosystem considerations are still incorporated implicitly or case by case rather than through systematic procedures, and implementation depends on management authorities defining operational objectives, acceptable levels of risk, and mechanisms for translating advice into action. Social and economic dimensions also remain less developed than ecological components, particularly beyond fisheries. Strengthening EAFM will therefore require clearer links between science and management objectives, sustained investment in data and capacity, improved treatment of human dimensions, and continued development of advice products that are transparent, risk-based, and actionable.

Overall, the ICES experience demonstrates that operationalizing EAFM is not a single methodological shift, but a gradual reconfiguration of the advisory system. For regional fisheries management organizations and other management bodies, the key lesson is that ecosystem-informed advice can be developed incrementally, provided that scientific products are linked to explicit objectives, uncertainty is communicated transparently, and governance systems are able to act on integrated advice.

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