# ICES Framework for Ecosystem-Informed Science and Advice (FEISA)

Volume 359 I March 2024

ICES COOPERATIVE RESEARCH REPORT

RAPPORT DES RECHERCHES COLLECTIVES

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
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Prepared under the auspices of ICES Science Committee (SCICOM) and ICES Advisory Committee (ACOM).
Peer-reviewed by Robert Stephenson (Fisheries and Oceans Canada) and an anonymous reviewer.

ISBN number: 978-87-7482-987-4
ISSN number: 2707-7144

ICES Cooperative Research Report

Volume 359 I March 2024

# ICES Framework for Ecosystem-Informed Science and Advice (FEISA)

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Recommended format for purpose of citation:

Roux, M. J., Pedreschi, D. (eds.). 2024. ICES Framework for Ecosystem-Informed Science and Advice (FEISA). ICES Cooperative Research Reports Vol. 359. 39 pp. https://doi.org/10.17895/ices.pub.25266790

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# Contents

# I Summary

Ecosystem-based management (EBM) of human activities is key to achieving long-term sustainable use of marine resources and ecosystems. ICES is committed to developing the evidence base in support of EBM and providing scientific advice that can inform EBM decision-making. To this end, a framework has been developed which aims to create an avenue of inclusion for the full variety of data, knowledge, methods, and syntheses that are required to deliver practical and operational EBM. Informed by existing and emerging science and advice needs, the framework combines a system of indicators with a risk-based approach to advance and coordinate knowledge and data developments and to translate these into the evidence base for ecosystem-informed ICES advice. The framework is designed to integrate and operationalize qualitative, semi-quantitative, and quantitative indicators in context-based and objective-based risk assessments that form the foundation of ecosystem-informed advisory products. Context-based risk assessments are used to situate and prioritize human activities and ecosystem components for science and management within the broader socio-ecological context. Objective-based risk assessments are used to evaluate the performance of alternative management options in meeting operational biological, ecological, and/or social, economic, and cultural objectives; this is given both the inherent complexity and the quantifiable and as yet unquantifiable uncertainties intrinsic to EBM. The risk-based approach requires the routine formulation, communication, and exploration of alternative hypotheses and management options for achieving competing socio-ecological objectives in advice, such as those relevant to identifying safe operating spaces and to identifying and understanding where trade-offs exist. Scientists already assess the risk to various ecosystem components, and managers make decisions to manage that risk. Risk evaluation and management practice is already enshrined in the widely adopted precautionary principle. As such, risk provides a common currency for merging different types of indicators at various levels of experiential, empirical, and/or analytical understanding. The proposed Framework for Ecosystem-Informed Science and Advice (FEISA) provides the architecture, flexible approach, and common ground required for iterative and incremental adaptation of ICES science and advisory practice to better inform EBM.

# II Foreword

The joint ACOM/SCICOM Group on Ecosystem-Based Management (hereafter referred to as the EBM group) was initiated in October 2020 by ICES Advisory Committee (ACOM) and Science Committee (SCICOM) recognizing the need for a coordinated way forward following parallel discussions on EBM in both committees. The EBM group was tasked with producing a strategy for EBM that would serve to:

- progress the implementation of EBM evidence into ICES advice;
- prioritize the development of the evidence basis for EBM within ICES; and
- facilitate and improve the integration of EBM evidence across ICES.

Through iterative tasks and discussions, the group identified (i) clear operational definitions, (ii) a common direction, and (iii) a flexible approach as key building blocks for incremental improvements and adaptation of ICES science and advisory practice to better inform EBM. The group proposed a general framework for explicit framing of all advice in an ecosystem context that can be used to address operational priorities, steer direction, facilitate and evaluate ongoing progress in EBM implementation, and ensure continuous and varied methods development, testing, and optimization moving forward. This report details this general framework and its context and demonstrates how it can be applied to existing examples from the literature. It is intended to serve as a reference document that can help progress the framework from concept to operationality.

# 1 Introduction

## 1.1 The need for ecosystem approaches and systems thinking

The ongoing biodiversity crisis and climate emergency bring renewed urgency to the need to improve how human societies collectively share and manage natural resources and the ecosystem services they provide. The continued increase in human population under a changing climate, coupled with pervasive inequities in the distribution of benefits from uses of nature (Rice, 2021), are putting increasing pressure on Earth's ecosystems and endangering opportunities for a sustainable future. To meet these challenges requires a transformative approach to both management practice and the scientific process that underpins management decisions. A more inclusive, integrative, and holistic approach is needed, such as through the practical implementation of ecosystem approaches, systems thinking, and EBM.

The ecosystem approach began to feature in international instruments in the 1980s. However, the first internationally recognized framework can be traced back to the 1992 Convention on Biological Diversity (Enright and Boteler, 2020). In the marine realm, the concept was primarily developed as the ecosystem approach to fisheries (EAF) or ecosystem-based fisheries management (EBFM; FAO, 2003; Pikitch *et al*., 2014). Ecosystem-based management of marine resources now features in many key policies and legislation, including *inter alia*; the Marine Strategy Framework Directive (MSFD; European Union, 2008), Common Fisheries Policy (CFP; European Union, 2013), Maritime Spatial Planning Directive (MSPD; European Union, 2014), Sustainable Fisheries Act, (SFA: US Congress, 1996), Norwegian Cross Sector Management Plans [Meld. St. 20 (2019–2020)], Australia's Oceans Policy (Environment Australia, 1999), Canadian Oceans Act (Department of Fisheries and Oceans, 1996); Oceans Act of 2000 (US Congress, 2000), and South African National Water Act (Government of the Republic of South Africa, 1998).

Ecosystem approaches recognize that ecosystems and ecosystem components interact, just as human societies and activities interact, with impacts proliferating throughout the various systems, often with unexpected and unintended consequences. For human activities and uses of natural resources to be sustainable and equitable, they must minimize, eliminate, or mitigate negative ecosystem impacts and maximize benefits and well-being to all components of societies for current and future generations. The simplifying assumptions and siloed approaches (i.e. single-sector and single-species) commonly used to inform management decisions have proven to be ineffective and incompatible with long-term sustainability goals in a changing world (Curtin and Prellezo, 2010; Long *et al*., 2015; Enright and Boteler, 2020; Fulton, 2021). Systems thinking must be applied when evaluating and managing how human activity sectors characterized by various self-organizing interrelationships benefit from and affect natural systems similarly characterized by self-organizing interrelationships (Stephenson *et al*., 2021; McAlister *et al*., 2022). Hence, nature, societies, and their interdependencies must be viewed and studied together as socio-ecological systems (Collins *et al*., 2011; Bodin and Tengö, 2012).

As a broadly recognized concept and approach, EBM tackles the complexity and interdependencies of biological, ecological, social, cultural, economic, and governance aspects of decision-making (O'Higgins *et al*., 2020). ICES has long recognized the need for EBM and systems thinking (e.g. ICES, 2004). However, as a process, EBM remains highly aspirational, with yet few examples of successful practical implementation (Patrick and Link, 2015). For example, in the Baltic Sea region, despite adoption of EBM (*sensu* "the ecosystem approach"; HELCOM, 2003) as a guiding principle over the past 20 years in policy and the recognition of eutrophication and climate as major drivers of change of the ecosystem (ICES, 2022a), progress to integrate such drivers in advice on fishing opportunities has been slow, and not all available knowledge is being incorporated into decision-making processes (Ojaveer *et al.*, 2018).

## 1.2 Challenges to operationalizing EBM

There are several guidelines outlining the core aspirations for EBM (Long *et al.*, 2015; Delacámara *et al.*, 2020; Enright and Boteler, 2020). Adoption in practice has been slow and limited, given the complexity and inherent difficulties of transdisciplinarity, data and knowledge gaps, and various institutional constraints including a lack of specificity of mandates and dedicated resource and capacity investments (Ruckelshaus *et al.*, 2008; Nalau *et al.*, 2018; Link *et al.*, 2020). Hence, taking into account all components of socio-ecological systems and their interactions is no simple task. The time, personnel, and financial resources required to assemble and monitor a solid evidence base for ecosystem-based decision-making are enormous and, as a general rule, not yet prioritized. Biological, ecological and socio-economic data are rarely available at the temporal and spatial scales relevant to inform EBM. The available biological and ecological data and knowledge are usually biased towards areas and/or species with high commercial value. Social data relating to marine systems are not routinely collected, are extremely temporally and spatially limited, and are rarely comparable between jurisdictions. The socio-economic dimensions of EBM in natural science and resource management practice still receive limited or no dedicated support in most research and governance institutions. Until recently, common practice has been for social and economic aspects of EBM decisions to remain implicit as opposed to explicit and transparent, leading to poorly specified objectives, unfocused research efforts, and limited uptake of assessment results and research findings at the science–policy interface (Stephenson *et al.*, 2017).

Implementation can be slow even when knowledge about systems structure and dynamics is readily available. Factors such as collective learning patterns, cognitive bias, path dependencies, and the role of dominant paradigms in scientific and decision-making processes are now being recognized as fundamental limitations to transdisciplinary learning and integration, change in general, and practical EBM implementation (Fulton, 2021; McAlister *et al.*, 2022). This underlines the need for research and governance institutions involved in delivering EBM to make space and time for systems thinkers to challenge and reframe existing paradigms in order to facilitate change and the integration of diverse perspectives (McAlister *et al.*, 2022). Engagement is a key challenge and opportunity for EBM requiring novel participatory process and approaches aimed at welcoming and integrating knowledge from multiple perspectives, and collaborative working models that can improve communication, knowledge exchange, and incorporation of feedback loops between science and policy (Ballesteros *et al.*, 2018; Goethel *et al.*, 2022; Hinrichs-Krapels *et al.*, 2020; Karcher *et al.*, 2022; Mikkelsen *et al.*, 2023). This engagement at multiple levels will help to facilitate the identification of explicit objectives and the examination and communication of trade-offs. Challenges to practical EBM implementation can be viewed as opportunities for horizontal (cross-sectoral) and vertical (across management levels) integrated dialogues to develop adaptive solutions. Within ICES, unlocking the vast potential of qualitative data (Alexander *et al.*, 2020) and encouraging systems thinking as well as epistemic fluency (Markauskaite and Goodyear, 2017; Kamarainen and Grotzer, 2019) throughout the network are pivotal challenges and opportunities to meeting EBM commitments.

## 1.3 ICES strategic role and commitment with regards to EBM

ICES sees EBM as the primary way of adaptively managing human activities affecting marine ecosystems (ICES, 2017) and is responsible for providing scientific evidence to guide EBM decision-making in ICES areas (ICES, 2020a). In doing so, ICES is committed to facilitating the incorporation of wide-ranging scientific information in the assessment and evaluation of how human activities affect and are being affected by the state of our seas and ocean and by climate change (ICES, 2019a, 2020a).

ICES is committed to further developing capacity to provide ecosystem-based advice by developing and undertaking analyses for an increasingly wider range of activities, pressures, and impacts and by including social, cultural, and economic information in fisheries, ecosystem, and aquaculture overviews (ICES, 2019b, 2020b). The overviews (ecosystem, fisheries, and aquaculture overviews) are currently the main advisory instrument for informing EBM. These are produced by ICES ecoregion and are intermittently updated with new information and approaches through a ”pipeline process” (ICES, 2023a). ICES commits to further improving mechanisms for incorporating experiential knowledge and diverse ecosystem-informed narratives into its overviews, to further developing viewpoints to showcase bottom-up ideas and scientific knowledge into advice, and to further developing benchmarking methods for ecosystem services and effects advice in support of EBM (ICES, 2022b). ICESworks iteratively with recipients of its advice (Annual Meeting between ICES and Requesters of ICES Advice [MIRIA]) to improve its science and advisory processes and outputs for use in management and decision-making. Examples include the ”key signals” found in the ecosystem overviews (EOs), the benchmark for recurrent advice on vulnerable marine ecosystems (VMEs; ICES, 2022c), the roadmap for bycatch advice on protected, endangered, and threatened species (PETS; ICES, 2022d), and recent special request advice (e.g. ICES, 2023b, 2022e). Information on ecosystem trends and variability is generally incorporated into the advice on fishing opportunities (ICES, 2022f). Moreover, the inclusion of conservation aspects in advice on fishing opportunities (ICES, 2022g) is used to highlight human pressures other than fisheries that are affecting fish stocks (and the probability of achieving fisheries objectives), with relevant management recommendations. The main route for including ecosystem information in single-species advice remains through the benchmarking process (ICES, 2023c).

## 1.4 Purpose and objective

Given the ecological urgency and the prevalence of EBM in existing legislation and associated policy expectations, yet the lack of widespread implementation to date, both ICES science and advisory committees identified the need for a strategic subgroup to work on ”*defining and demonstrating a framework for scientific development, integration, and implementation of the evidence base for EBM into scientific advice*”. The goal was to build on ICES Guidance on the Application of the Ecosystem Approach to Management of Human Activities in the European Marine Environment (Rice *et al.*, 2005), on the importance and rationale of EBM to ICES (ICES, 2020a), and on lessons learned and international guidance in order to progress the implementation of EBM through operational, ecosystem-informed science and advice. ICES has unparalleled knowledge and innovation within its network, where an exceptionally high standard of science and peer review has become the norm. This initiative seeks to tap into the potential of ICES network by devising a framework that adheres to and promotes generally accepted EBM principles (Long *et al.*, 2015), builds on established practices, illustrates both mechanisms and pathways for working groups to engage in, and proposes novel ways of working, assessing, advising, and managing diverse human activities in marine ecosystems.

# 2 Foundations for ecosystem-informed science and advice

The term "ecosystem-informed science and advice" is introduced and adopted through the document to distinguish the role and responsibilities of ICES as a knowledge and science provider to relevant EBM decision-making authorities. The term "ecosystem-informed" is also intended to fit within existing practice while providing the basis for incremental improvement and recognizing the already strong basis of science and advice provision in ICES.

## 2.1 Building blocks: clear operational definitions; common direction; flexible approach

Traditionally, the assessment and management of human activities affecting ecosystem components has been done separately for each human activity. This approach assumes a **single-loop process** between the nature and extent of the activity, the intrinsic structure and dynamics of a single resource or ecosystem component, and component-specific management objectives associated with measurable indicator(s) and reference levels against which status can be evaluated (Figure 2.1a). The reality of interacting or conflicting human activities and social/cultural/economic development objectives is generally not considered. The socio-economic objectives specific to the human activity and ecosystem component under evaluation (e.g. fishery and targeted fish stock) are usually present, but rarely explicitly stated or explicitly considered in the assessment process (e.g. Stephenson *et al.*, 2017). Due to these assumptions, the **achievability of management objectives** is evaluated as being only influenced by the intrinsic dynamics of the ecosystem component under consideration and by management decisions affecting the nature and extent of the human activity in focus. All other pressures, components, and processes interacting with and/or directly or indirectly affecting the objective are ignored, leading to reduced realism, reliability, and relevance of the assessment. Failure to account for interlinkages among elements of socio-ecological systems can result in assessments that are biased or too "optimistic" as the effects of combined, interactive, or cumulative pressures over time and/or space are ignored, hindering the ability to identify the most effective or sustainable management option and unwittingly causing negative impacts in other parts of the system.

Ecosystem-informed assessments aim to consider all human activities, pressures, ecosystem components, and ecosystem services relevant to the management question, and the interactions between them, as an improved representation of reality (Figure 2.1b). Such assessments consist of multiple indicators and **multiple feedback loops** consistent with systems thinking and multiloop learning (Medema *et al.*, 2014; McAlister *et al.*, 2022). In this context, management objectives for a specific ecosystem component need to be defined considering interdependencies and compatibilities with overarching ecosystem-scale objectives and social, cultural, and economic development objectives reflecting stakeholder priorities at relevant temporal and spatial scales (Stephenson *et al.*, 2017). Evaluations of a given human activity–ecosystem component pair are performed considering the broader socio-ecological context within which each pair occurs. Evaluation of the **achievability of management objectives** is influenced by component-specific and whole-systems dynamics and by management decisions affecting the nature and extent of all relevant human activities. This approach is better suited to encompass variation and trends in relevant and monitored ecosystem components and socio-economic factors (individual or aggregated), as well as dependencies between human well-being and environmental status. However, it requires a transparent and explicit treatment of risk and uncertainty, which can be perceived as high when multiple stressors occur and are considered simultaneously (Rullens *et al.*, 2022).

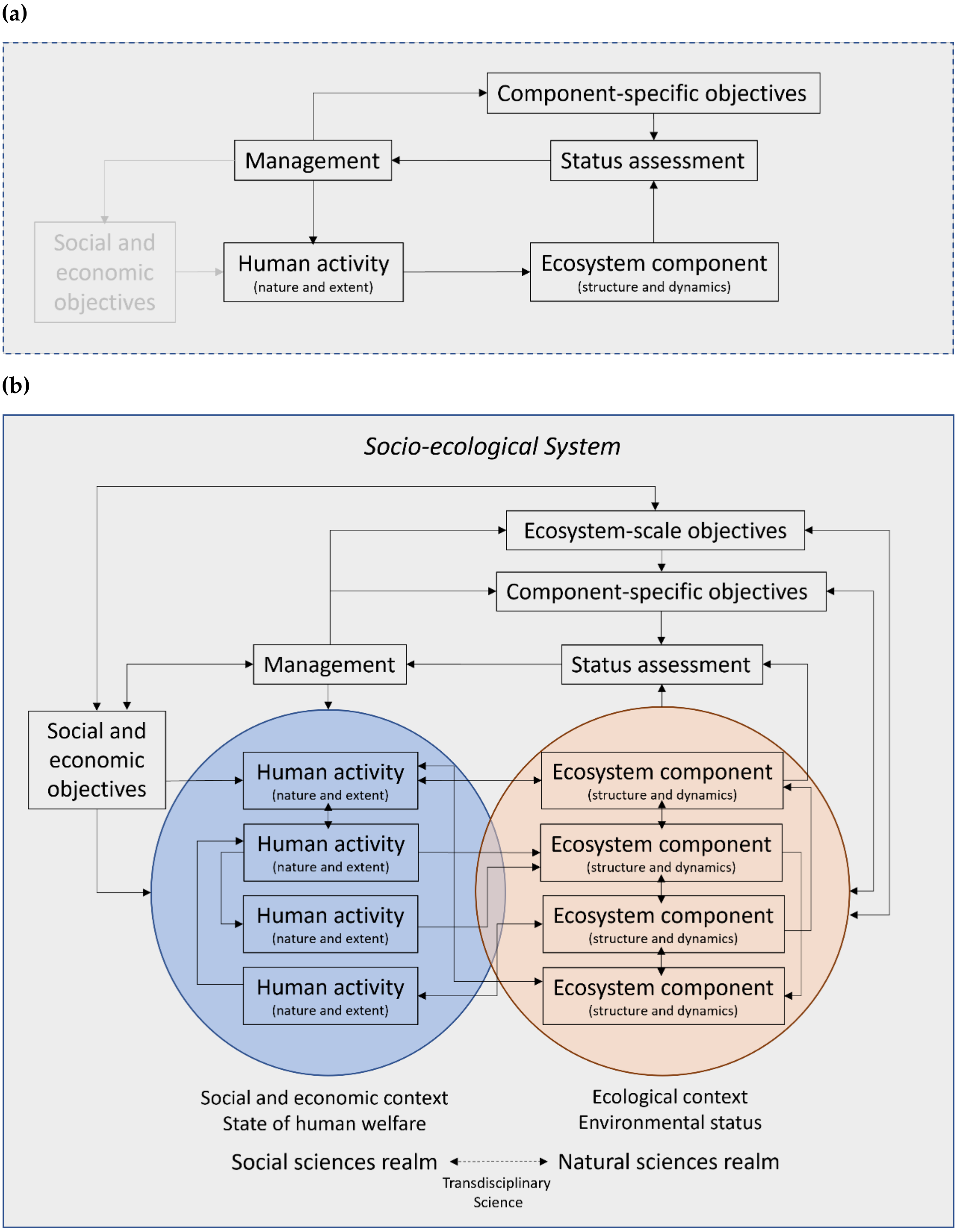


**Figure 2.1. Conventional (panel a) and ecosystem-informed (panel b) process for science and advice within ICES. Conventional process (a) considers single loops between a human activity, a specific resource or ecosystem component, and component-specific operational and management objectives. Social and economic objectives are present but rarely explicitly stated and considered. An ecosystem informed process (b) considers multiple feedback loops between all relevant human activities and ecosystem components (and interactions among them), component-specific, socio-economic, and overarching ecosystem-scale operational and management objectives, and a changing climate affecting individual components and the entire socio-ecological system.**

There is no universally agreed definition of EBM in science or law (Long *et al*., 2015; Delacámara *et al*., 2020; Enright and Boteler, 2020). The core of EBM is thought to be best described by a set of principles of which practitioners and advisors should be cognizant. The EBM group considered the six ICES Ecosystem Approach Common Principles (Rice *et al.*, 2005) and the 26 principles reviewed by Long *et al*. (2015) when developing the proposed framework. A conceptual representation of EBM (Figure 2.1) and clear operational definition (Box 2.1) were nonetheless necessary to unite the diversity of backgrounds, expertise, perspectives, and experiences with regard to EBM within the group and provide a coherent way forward. Without the conceptual model and operational definition, group discussions tended to fall back and focus on "What is EBM?" instead of on "How can we progress the evidence base for EBM and its practical implementation into advice?".

**Box 2.1. Operational EBM definition.**

EBM is a process for managing how human activities, shaped by socio-economic objectives, affect the ecosystem, its components, functions, and the services it provides, while considering how human well-being, activities, ensuing pressures, ecosystem components and functions, and their interactions are affected by environmental conditions.

The operational definition presented in Box 2.1 was developed to be specific enough to provide direction yet broad enough to provide space for growth and adaptation as our understanding, objectives, societies, and management frameworks continue to evolve. Both the operational definition and conceptual model emphasize EBM as a process involving multiple feedback loops among interconnected components. The emphasis on EBM as a process recognizes its iterative nature and the need for adaptive, incremental implementation under continued innovation and development. Different elements and aspects may be prioritized in turn, ideally based on overarching (context-based) risk assessment and evaluation and incrementally combined to augment the scientific basis and deepen societal understanding in support of ecosystem-based decision-making. The EBM process should be continual, iterative, reflective, and adaptable.

# 3 ICES Framework for Ecosystem-Informed Science and Advice (FEISA)

## 3.1 Basic architecture: combination of a system of indicators and risk-based approach

Explicit framing of all advice in an ecosystem context requires a general structure for developing, synthesizing, and standardizing knowledge and information across various disciplines and a general approach for conveying that information into advice in a manner that is clear, consistent, and credible. The proposed ICES Framework for Ecosystem-Informed Science and Advice (FEISA) combines a **system of indicators** for knowledge development and integration as relevant to stated management objectives (i.e. consolidation of the evidence base in support of EBM) and a **risk-based approach** for operationalizing indicators into advice (implementation of the evidence-base for EBM into advice products; Figure 3.1). Such structure emphasizes the development of biological, ecological, and socio-economic indicators, and their practical application in context-based and objective-based risk assessments:

- **Context-based risk assessments** are used to prioritize human activity sectors and/or components of socio-ecological systems for monitoring and management actions. They are generally performed on the basis of experiential knowledge and/or empirical information and are often used for the purpose of risk identification.
- **Objective-based risk assessments** are probabilistic and used to evaluate the potential consequences of alternative management strategies and options, as well as trade-offs. They require operational objectives to be specified and can be performed empirically or analytically, depending on the availability of mechanistic/process knowledge. Objective-based risk assessments are usually implicitly or explicitly informed by experiential knowledge, although rarely recognized as such.

The framework builds on well-established approaches and is intended to facilitate the integration, utilization, and translation into advice of the wide range of knowledge/data/information types available in ICES community and beyond. It is designed to be applicable to all ICES advice products, i.e. advice on fishing opportunities (ICES, 2022f), advice on ecosystem services and effects and viewpoints (ICES, 2022b), and overviews (ICES, 2022h, 2023a), and to support the development of new advice as established in ICES Advisory Plan and ICES Strategic Plan. The framework provides the architecture needed to optimize, expand, and transform existing practice in order to advance ecosystem-informed science and advice. The expectation is for the framework to be adopted in an iterative and adaptive manner in all ICES advisory processes; this can be done, for example, by incrementally expanding the scope of the data and knowledge considered and utilized by expert groups, by developing measurable indicators for experiential knowledge that can progressively translate different perceptions into advice, and by pairing risk assessment methodologies to situate research or management questions within their broader socio-ecological contexts and explore the potential consequences of management actions (or lack thereof) along the data and knowledge continuum, incrementally from qualitative to fully quantitative assessments. The framework architecture is designed to support and inform objective-based and/or outcomes-based management decision-making systems.

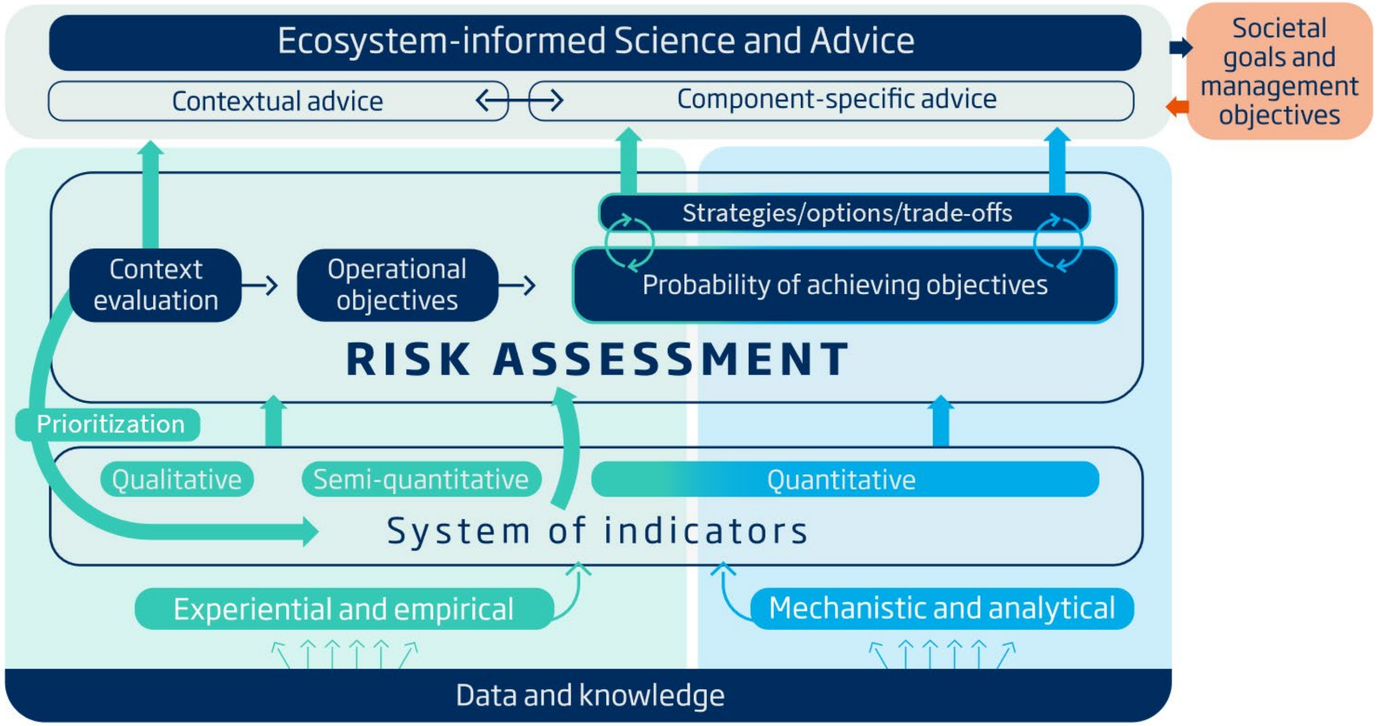


**Figure 3.1. ICES Framework for Ecosystem-Informed Science and Advice (FEISA). Different types of data and knowledge are mobilized to define measurable qualitative, semi-quantitative, and/or quantitative indicators. Indicators are integrated into advice via risk assessments, which can be context-based or objective-based. Contextual risk assessments are used to inform generic advice, such as overviews and viewpoints, and to prioritize human activities and associated pressures for data and knowledge development and management actions. Objective-based risk assessments are used in advice on specific management strategies, options, or trade-offs such as advice on fishing opportunities, vulnerable marine ecosystems, and bycatch of protected species. Objective-based risk assessments are probabilistic and require operational objectives to be specified, either as a separate process (e.g. with advice requesters) or as informed through context-based risk assessments. Objective-based risk assessments are performed using empirical data and tools (green labels) or analytical tools where mechanistic understanding is available (blue labels). Context-based risk assessments have an experiential and empirical foundation (green). The distinction between experiential and empirical evidence and risk assessment pathways/methodologies (green space) and mechanistic and analytical evidence and risk assessment pathways/methodologies (blue space) is key to operationalizing different indicators and handling different sources and types of uncertainties in advice.**

## 3.2 System of indicators

Scientific evidence in support of EBM covers a wide range of disciplines and includes various types of data, knowledge, and information that may differ greatly in format, precision, availability, spatial and temporal scale, quality, and confidence. Indicator systems provide a flexible platform for knowledge development, monitoring, trend identification, and synthesis in all aspects likely to affect the performance of management strategies, plans, and operational objectives. Indicators have multifaceted uses and can take a variety of forms. For the purpose of developing ecosystem-informed advice in support of EBM, a broad-ranging operational definition for indicators is provided in Box 3.1.

**Box 3.1. Indicator definition.**

Indicators are measurable information on the properties of human and ecological systems relevant to:

1. the assessment of the state and functions of socio-ecological systems and system components in response to human and environmental pressures;
2. the evaluation of how (and to what extent) human activities affect and are being affected by environmental and social/cultural/economic drivers;
3. the assessment of progress towards management objectives; and
4. different stakeholder perspectives.

The development of a system of indicators consists of identifying, defining, monitoring, and iteratively updating and reviewing a set of measurable variables relevant to the full spectrum of international and regional EBM objectives, including:

- entire marine ecosystems and habitats, their structure and functions;
- individual biological, chemical, and physical ecosystem components;
- social, cultural, and economic aspects of human and societal well-being;
- human activities and associated pressures including a changing climate;
- ecosystem services and interactions among socio-ecological system components; and
- governance and management performance.

Guidance on the development and selection of indicators to inform EBM is plentiful (Rice and Rochet, 2005; Niemeijer and de Groot, 2008; Shin *et al*., 2010; Kershner *et al*., 2011; Bundy *et al*., 2019). Within FEISA, the key properties of indicators are measurability, relevance to different stakeholder and rightsholder perspectives, and a clear association with societal goals and EBM objectives. Relevant indicators will generally be place-based or context-specific and have clear temporal and spatial dimensions. Indicators can be parameters, metrics, ratios, proportions, or indices that can be measured or scored and ranked (e.g. into high, moderate, and low categories). Indicator values and trends may be defined and monitored in qualitative and semi-quantitative space using expert, stakeholder, traditional, indigenous, and local (ILK) knowledge (experiential evidence) or in quantitative space through empirical data acquisition (e.g. laboratory studies), time-series development (empirical evidence; e.g. trawl surveys), or using outputs from analytical models and simulated forecasts (mechanistic evidence; e.g. climate projections). Multimetric indicators can be obtained by aggregating information from various aspects or components within a natural hierarchy (e.g. community indices derived from species-specific functional traits) or by combining model outputs.

The selection of indicators for use in ecosystem-informed advice may involve (i) qualitative and expert-based syntheses of the available knowledge and information, (ii) an empirical data-mining approach, and/or (iii) the development of full ecosystem models. Each of these steps and approaches will have advantages and limitations considering the time frame and lifespan of the advice.

To operationalize EBM, discrete indicator values or ranges of values need to be specified. Such (reference, target, threshold) indicator values are referred to as **operational objectives** (Box 3.2). Operational objectives provide the measurable context for monitoring changes over time and/or space and for measuring progress towards sector or component-specific management objectives for socio-ecological systems. The distinction between operational objectives and management objectives is important to operationalize EBM:

- **Operational objectives** are rooted in natural, social, and economic sciences. They are used to evaluate statuses and trends and assess relative or absolute risks and opportunities associated with changing environmental conditions, social/cultural/economic landscapes, and/or management actions.
- **Management objectives** are framed in governance and policy and implemented in regulatory frameworks by legitimate governing bodies. They represent long-term aspirational goals for the state and function of socio-ecological systems and their components. Progress towards management objectives in science advice is frequently measured through operational objectives.

**Box 3.2. Operational objectives.**

Operational objectives are indicator values (or ranges of values) associated with particular biological, ecological, social, cultural, or economic conditions and/or consequences. They can be defined as an upper or lower level of the range of an indicator or discrete values which are tracked over space and/or time. Operational objectives need to be relevant to tracking progress towards management objectives that represent long-term aspirational goals for the state of marine socio-ecological systems and their components. Operational objectives are used to monitor status and trends, detect changes, and evaluate the risks and opportunities associated with changing conditions and/or management actions.

Baselines, reference levels, reference points, standards, limits, benchmarks, and thresholds are all examples of operational objectives. Operational objectives are purpose-specific and context-dependent and will typically differ between ecosystem types, regions, habitats, communities, species, socio-economic and governance systems, etc. They may be defined by making an explicit or implicit assumption about the biological, ecological, and/or socio-economic context within which they are applied (e.g. fisheries reference points assume a stationary or randomly varying environment about some long-term historical mean), in which case, regular evaluation is needed to confirm the underlying assumptions, and operational objectives remain valid.

The rationale and importance for the distinction between operational and management objectives relates to the diversity of advice needs and the incremental nature of practical EBM implementation. Operational objectives need to be cognisant of and compatible with the hierarchy of management objectives that characterize EBM (i.e. component or sector-specific, socio-economic, and ecosystem-scale management objectives) and are relevant to evaluating incremental progress towards management objectives. As such, operational objectives and management objectives need to be fully aligned and complementary. The specification of operational objectives must have a clear purpose, such as detection of a change in risk or opportunity or the evaluation of the probability of an undesirable vs. desirable consequences occurring (i.e. objective-based risk assessment). Examples of paired operational and management objectives include:

- Good Environmental Status (GES) for benthic habitats (management objective) and benthic community biomass level corresponding to a healthy or functioning state (operational objective);
- Long-term sustainable fisheries and short-term maximum yield (management objectives) and fish stock biomass levels corresponding to reduced ($B_{trigger}$) or impaired ($B_{lim}$) recruitment (operational objectives);
- Protection of VMEs (management objective) and swept-area ratio corresponding to significant adverse impacts on VMEs from bottom-contacting trawl fishing gear (operational objective).

Through its science and advice, ICES can guide the identification of operational objectives in support of EBM in accordance with e.g. the Malawi principles, Food and Agriculture Organization of the United Nations (FAO) guidance, and the European Union (EU) Marine Strategy Framework Directive (MSFD). Recognizing the role of ICES community in exploring and guiding the identification of measurable biological, ecological, social, cultural, and economic indicators and operational objectives is key to the successful practical implementation of EBM.

Adopting a system of indicators is compatible and complementary with approaches taken by other organizations operating within policy landscapes where ICES provides advice, including organizations such as OSPAR and HELCOM (ICES, 2017), the Northeast Atlantic Fisheries Commission (NEAFC), the Arctic Council working groups, the European Environment Agency (EEA), national agencies, and the European Commission (ICES, 2019b, 2019c, 2020b). A system of indicators builds on existing knowledge and practice to provide an efficient way forward to integrate knowledge, identify information gaps, facilitate capacity-building, set priorities for further developing integrated monitoring, identify and track reference conditions, and evaluate progress towards EBM objectives.

### 3.2.1 Operational readiness level within ICES

Quantitative indicators are an area of active research and interest within ICES community. ICES is already working to progress and operationalize integrated ecosystem assessments (IEAs) through the ecoregional IEA groups[1]. These groups (despite facing resourcing challenges) are progressing key aspects of IEAs.

Some ICES groups and workshops (e.g. *inter alia* WGECO[2], WGECON[3], WKFooWI[4], WGCERP[5],

[1] ICES Integrated Ecosystem Assessments Steering Group (IEASG). 2024. ICES. https://www.ices.dk/community/groups/Pages/IEASG.aspx

[2] ICES Working Group on Ecosystem Effects of Fishing Activities (WGECO). 2024. ICES>

[3] ICES Working Group on Economics (WGECON). 2024. ICES. https://www.ices.dk/community/groups/Pages/WGECON.aspx

[4] ICES Workshop to develop recommendations for potentially useful Food Web Indicators (WKFooWI). 2024. ICES. https://www.ices.dk/community/groups/Archive%20for%20Community%20pages/WKFooWI.aspx

[5] ICES Working Group on Common Ecosystem Reference Points (WGCERP). 2024. ICES. https://www.ices.dk/community/groups/Pages/WGCERP.aspx

WGSOCIAL[6], WGBIODIV[7], and WKINTRA[8]) are specifically looking at advancing and/or producing indicators, reference points, and/or trend analyses for use in IEAs, the EOs, and/or ecosystem services and effects advice in general. Progress has already been made, meaning momentum is there to progress further in the near future.

Qualitative indicators are an area of great potential yet remain under-researched within ICES. Qualitative indicator frameworks do exist, however, and could be used for providing information where quantitative data are lacking and/or immature, hard to quantify, and/or more appropriate in qualitative forms (Pitcher and Preikshot, 2001; Fletcher, 2005, 2015; Smith *et al.*, 2019; Conservation International, 2021). Qualitative data are most often used to inform (semi-) quantitative analyses (e.g. Dambacher *et al.*, 2009; Pascoe *et al.*, 2009; Knights *et al.*, 2015; Pedreschi *et al.*, 2019, 2023) and may be most useful for synthesizing knowledge and for progressing understanding and uptake of socio-economic concerns, and socio-ecological thinking in ICES advice in line with the Strategic Initiative on the Human Dimension (SIHD).

### 3.2.2 Established indicator frameworks

A range of agreed and candidate ecological indicators exist and have been used by a number of institutions, including ICES. These indicators have most often been used for performing status assessments; e.g. OSPAR Common Indicators[9] used in its Quality Status Report[10] (QSR), MSFD[11] indicators, and the NOAA Ecosystem Status Reports[12]. ICES has already used indicators to provide advice (e.g. that on protected, endangered, and threatened species [PETS] bycatch [ICES, 2020c] and VMEs [ICES, 2020d]). These reports are relevant to ICES ecoregions, particularly for the "state" section of the EOs[13].

A number of ICES working groups (e.g. WGBIODIV and WGECO) and workshops (e.g. WKFooWI) have developed, reviewed, and proposed indicators that could be included in ICES EOs. Other groups such as those under the Integrated Ecosystem Assessments Steering Group (IEASG) have terms of reference (ToRs) directly related to developing indicators. An internal review mechanism has already been informally established for ecological indicators where WGECO acts as a review group for indicator quality and applicability. To date, there has not been active uptake of these indicators into ICES advice products. This framework can help to address this issue.

## 3.3 Risk-based approach

The concept of **risk** provides a common currency for the inclusion and communication of ecosystem considerations into scientific advice (Roux *et al.*, 2022). There are two interconnected

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[6] ICES Working Group on Social Indicators (WGSOCIAL). 2024. ICES. https://www.ices.dk/community/groups/Pages/WGSOCIAL.aspx

[7] ICES Working Group on Biodiversity Science (WGBIODIV). 2024. ICES. https://www.ices.dk/community/groups/Pages/WGBIODIV.aspx

[8] ICES Working Group on Ecosystem Effects of Fishing Activities (WGECO). 2024. ICES. https://www.ices.dk/community/groups/Pages/WGECO.aspx

[9] OSPAR Common Indicators. 2024. OSPAR. https://www.ospar.org/work-areas/cross-cutting-issues/ospar-common-indicators

[10] OSPAR Quality Status Report 2023. 2024. OSPAR. https://www.ospar.org/work-areas/cross-cutting-issues/qsr2023

[11] EU marine and coastal environment. 2024. European Commission. https://environment.ec.europa.eu/topics/marine-environment_en

[12] IEA Ecosystem Status Reports. 2024. National Oceanic and Atmospheric Administration (NOAA). https://www.integratedecosystemassessment.noaa.gov/ecosystem-status-reports

[13] Ecosystem Overviews. 2024. ICES. https://www.ices.dk/advice/ESD/Pages/Ecosystem-overviews.aspx

and fundamental components of risk: "consequences" and "uncertainties" (Andersen *et al*., 2022). A risk-based approach enables a formal and transparent treatment of "uncertainties" in the evaluation of the possible "consequences" from human activities and management

decisions. Outcomes from risk assessment processes conducted in the natural and social sciences realms are used to inform decision-making under uncertainty i.e., risk management. Thus, risk can be used to effectively handle complexity, facilitate the translation of scientific results and conclusions into advice, and streamline the uptake of scientific advice at the science–policy interface (Cormier *et al*., 2013; Stelzenmüller *et al*., 2018; Roux *et al*., 2022;).

International standards such as those available under the International Organization for Standardization (ISO) provide definitions, performance criteria, and a baseline process for identifying, analysing, evaluating, and managing risks (ISO, 2018). Within FEISA, this foundation is further extended to support the practical implementation of various knowledge and information sources/types into ICES science and advice in a process that is adaptive and aligned with systems thinking. In this context, **risk assessments** can be broadly described as a process for identifying natural and man-made pressures, ranking or estimating the consequences of such pressures on specific components or entire socio-ecological systems, and evaluating outcomes from alterative management options in a way that conveys demonstrated, anticipated, or projected effects of uncertainties. Multiple risk assessment methods exist; their relevance, use, and definitions vary depending on the needs and purposes of the assessment and the information available to conduct the assessment. All risk assessments involve a risk identification, risk analysis, and risk evaluation step. **Risk identification** is about documenting pressures, their drivers, potential consequences, and the sensitivity of ecosystem components under investigation to such pressures. **Risk analysis** consists of ranking or estimating the level of risk associated with different pressure–component interactions and management options, considering sensitivity (and dynamics), pressure loading (or exposure), and uncertainties. **Risk evaluation** is used to compare outcomes from risk analysis against operational objectives and/or risk criteria. **Risk equivalence**, which seeks to identify management options permitting to maintain a comparable or equivalent level of risk, is also increasingly recognized as a key component of risk evaluation, with relevance to EBM (Duplisea *et al*., 2021; Fulton *et al*., 2016; Roux *et al*., 2022; Fisher *et al*., 2023).

Risk assessment methods have been developed and applied across numerous disciplines, which can broadly be categorized as meeting two different main purposes:

1. context evaluation and prioritization (contextual or context-based risk assessments), and
2. potential consequences and trade-off evaluation in relation to objectives (objective-based risk assessments).

The distinction and complementarity between context-based and objective-based risk assessments are key to operationalizing the evidence base for EBM into science advice and are at the core of FEISA.

### 3.3.1 Context-based risk assessments

Context-based risk assessments are used to prioritize human activities, pressures, ecosystem components, and indicators for monitoring and data acquisition (e.g. Gaichas *et al*., 2018; Stelzenmüller *et al*., 2018; Hodgson *et al*., 2019). They are usually performed using qualitative or semi-quantitative methods and often without explicit consideration of uncertainty or management outcomes. They can also be used as a first "scoping" step of an IEA, where high data availability exists (Holsman *et al*., 2017; Pedreschi *et al*., 2023), and to identify ecosystem components most at risk from human activities and/or distinguish such activities contributing greater risks (via pressures) in lower data availability contexts (e.g. Pedreschi *et al.*, 2019). When used as part of an IEA cycle, the assessments prioritize elements for inclusion in more quantitative analyses which account for uncertainty and assess management scenarios (Levin *et al.*, 2009, 2014; Holsman *et al.*, 2017).

In ICES, context-based risk assessments are generally implemented first and iteratively in the (ecosystem, fisheries, and aquaculture) overviews. In the ecosystem overviews, a standardized assessment protocol has been developed (Pedreschi *et al.*, 2023) that is being applied by all of the IEA groups for each ecoregion, improving comparability and transparency. This risk assessment enables identification of the top (max five) pressures affecting an ecoregion. These top pressures are then detailed throughout the overview, along with contextual information and reporting on indicators where available. All three overview types provide important contextual EBM information, including economic, social, and governance aspects and external "shocks" that may impact the system (e.g. Brexit, COVID-19, and fuel shortages).

The contextual information provided in the overviews can be used to inform the definition of operational objectives (e.g. thresholds) capturing the potential biological, ecological, and socio-economic effects of human activity. Stakeholder engagement in scoping and carrying out context-based risk assessments can greatly facilitate this process and/or highlight where data or knowledge is lacking to enable objective-based risk assessments. The identification of a "safe operating space" (Cormier *et al.*, 2017; Roux *et al.*, 2022) or "viability kernel" (Cury *et al.*, 2005) bounded by operational objectives is key to formulating and providing ecosystem-informed advice for the management of human activities.

### 3.3.2 Objective-based risk assessments

Objective-based risk assessments are used to quantify and explore the effects of uncertainty on the evaluation of impacts and consequences from human activities, trade-offs, and potential outcomes from management actions (or lack of management actions). In such assessments, risk is evaluated as the probability of breaching "consequence-embedding reference levels that reflect policy objectives" (ICES, 2020a). Within FEISA, such reference levels are referred to as operational objectives. The specification of operational objectives is key to linking context-based and objective-based risk assessments across the data and information/process knowledge continuum and operationalizing the evidence base for EBM across ICES overviews, viewpoints, and component-specific advice (Figure 3.1).

Objective-based risk assessments are well established in fisheries. ICES advice on fishing opportunities identifies operational objectives that represent limits for biological consequences that should be avoided with a high probability (e.g. productivity impairment below $B_{lim}$ and a 95% probability rule to maintain stock status above $B_{lim}$) and targets for biological and socio-economic consequences (e.g. healthy stock, fishery sustainability, and maximum yield if stock is maintained above $B_{MSY}$ with a 50% probability). For any given stock, ecosystem considerations such as environmental and climate change, biomass fluctuations in other stocks, and/or human activities other than fisheries will affect the probability of achieving consequence-embedding operational objectives (e.g. maintaining stock status above a level that can ensure socio-economic and/or biological sustainability). In other words, **ecosystem considerations will affect the level of risk associated with the advice**. If a mechanistic understanding of ecosystem effects on the target stock is available and included, this change in risk will be estimated within the assessment and considered in the advice. In cases when a mechanistic understanding is still lacking, unquantified uncertainty arising from ecosystem considerations can still be approximated externally (based on experiential and/or empirical evidence) and used to adjust the advice to ensure it remains consistent with acceptable risk levels and expected management outcomes. This approach is consistent with the application of risk equivalence in risk evaluation, and several methods and approaches are emerging that are proposing to head in this direction (e.g. Plagányi *et al*., 2013; ICES, 2019d; Dorn and Zador, 2020; Duplisea *et al*., 2021; Howell *et al*., 2021). All such methods/approaches are currently applied/demonstrated in the context of fisheries advice; however, the underpinning concept of risk equivalence is applicable to all ICES advice products. Risk equivalence requires (i) considering and distinguishing all relevant sources of uncertainty in the assessment (quantifiable or not), (ii) comparing outcomes from management options with/without considerations of relevant ecosystem factors in scenario evaluation, and (iii) formulating advice that clearly communicates the change in risk associated with not considering ecosystem information and uncertainties, including options for maintaining a comparable risk when such information is considered and included using best available evidence.

Of note, the **precautionary principle** and precautionary approach (FAO, 2003) is a form of risk equivalence. While fundamentally relevant to risk-based management and decision-making, the precautionary approach is applied in the formulation of scientific advice to deliver options that maintain a consistently low risk of negative consequences from human activities, notwithstanding the evidence base available and used to assess the risk (Roux *et al*., 2022; Fischer *et al*., 2023). As such, the precautionary approach remains a critical element of EBM (HELCOM, 2003), enshrined legally in the European Union (European Commission, 2000) and elsewhere, which needs to be considered in routine formulation and exploration of alternative hypotheses, scenarios, and pathways for ecosystem effects in ecosystem-informed advice (see FEISA principles below).

### 3.3.3 Risk assessments within FEISA

Explicit consideration of all sources/types of uncertainty, whether internal or external to the assessment, offers a common way forward for formulating ecosystem-informed advice. Risk assessments provide a single currency (risk) for merging different types of information (i.e. different indicators) at multiple levels of understanding (i.e. qualitative, semi-quantitative, and quantitative), enabling the inclusion of ecosystem considerations into advice as factors influencing the risk of biological, ecological, or socio-economic consequences associated with management decisions. This approach can be implemented across the data and process–knowledge continuum and incrementally into advice, initially including both *status quo* assumptions/scenarios of no ecosystem effects along with alternative scenarios for plausible, demonstrated, or estimated ecosystem effects (e.g. through foresighting/futures visioning).

Both context-based and objective-based risk assessments are relevant to the development of ecosystem-informed ICES advice. Contextual risk assessments give an umbrella perspective and identify the key links and components to prioritize in different management settings. They also facilitate ongoing efforts to synthesize, standardize, and prioritize information (indicators) at the scale of ecoregions (i.e. ecosystems, fisheries, and aquaculture overviews and viewpoints). Objective-based risk assessments concern the evaluation of the performance of alternative management options in meeting management objectives, given quantifiable and yet unquantifiable uncertainty. The latter is applicable to all types of advice from fishing opportunities to benthic impacts, bycatch, and cumulative effects assessments (including climate change) and may be undertaken using tools such as management strategy evaluation (MSE) and IEAs.

# 4 FEISA implementation

The relevance, broad applicability, and utility of FEISA are illustrated in Annex 3 using examples from the literature and the existing ICES advisory process. Situating examples within the FEISA architecture serves to demonstrate how the framework can handle different types of data, knowledge, and advice needs and facilitate incremental and iterative developments of ecosystem-informed advice in a variety of contexts. The use of a common framework allows for consistency, transparency, and can facilitate communication. However, practical FEISA implementation throughout the network still implies a shift from aspirational goals to changes in practice. **Five operational or actionable FEISA implementation principles** consistent with ICES commitment and aspirations as stated in ICES (2019a, 2020a) are proposed in Box 4.1. The five principles are not presented by order of importance or relevance. A focus on these principles will assist with identifying priorities and pathways as we move forward with implementation and guide the development of ecosystem-informed ICES science and advice.

**Box 4.1. FEISA actionable principles.**

- **Knowledge plurality** as a basis for ecosystem-informed science and advice.
- Ecosystem-informed science has a role in guiding the identification of **operational objectives.**
- Ecosystem-informed advice involves routine formulation and exploration of alternative hypotheses, scenarios, and pathways for ecosystem effects (**scenario-based approach**).
- Ecosystem considerations will affect the level of risk associated with the advice (**risk assessment**).
- Risk is the currency for effectively and consistently communicating potential, demonstrated of projected consequences of alternative management options and ecosystem effects in advice (**risk communication**).

Examples of current practice and priorities for adapting practice moving forward are provided below.

## 4.1 Current practice

- Indicator development has long been a focus and strength of ICES science; the emphasis has largely been on biological and ecosystem-component-specific indicators with primarily empirical and/or analytical indicator developments.
- There is a realistic expectation from science that management objectives will be defined, clarified, and prioritized by management. However, this is not always the case. There is a similar expectation from managers for science to guide the identification of operational objectives in support of EBM. While objectives are often implied, they are becoming increasingly explicit in national legislations and international agreements (Stephenson *et al.*, 2021).
- Scenario-based approaches are currently ubiquitous in ICES advice but are rarely used to investigate ecosystem (or climate change) effects on the advice or consequences in

relation to ecological, economic, social/cultural, or governance objectives. Scenario assumptions and outcomes are also not consistently nor systematically communicated.

- Despite risk and risk assessment being used in a range of contexts, there remain very different understandings of risk in the ICES community (e.g. risk as a prioritization tool in qualitative space vs. risk as a probability of achieving objectives in MSE). This is sometimes seen as an obstacle when in reality these approaches can be used to harmonize progress (e.g. via a common currency such as risk).

## 4.2 Priorities moving forward

- Strengthen and broaden the scientific (including experiential and qualitative) basis for indicator development as related to existing or candidate EBM objectives.
- Broaden the scope of stakeholder engagement in ICES science and advisory process and reappraise how ICES engages with the scientific community, managers, and society.
- Enhance efforts to develop measurable social, cultural, economics, human wellbeing, and climate-change indicators as related to existing or candidate EBM objectives.
- Develop tools and/or methodologies for translating perceptions of resource users and communities into measurable indicators (e.g. social acceptability).
- Strengthen dialogue and collaborations with partners/advice requesters and the social science community to inform the development of clear and meaningful operational objectives aligned with management objectives and societal goals.
- Map interim, incrementally achievable operational objectives in line with both management expectations and the available evidence (e.g. roadmap for PETS bycatch advice (ICES, 2022d).
- Identify, propose, and implement in advice meaningful and ecosystem-informed operational objectives for well-developed indicators (e.g. $F_{eco}$; Bentley *et al*., 2021, Howell *et al*., 2021).
- Advance socio-ecological science to underpin the distinction between good vs. degraded, good vs. resilient, and degraded vs. compromised, etc.
- Continue developing risk assessment methodologies for full-spectrum scenario comparisons and integrating complementary contextual (prioritization) and objective-based (probability estimation) risk assessments for operationalizing different data and knowledge types in recurring and developing advice.
- Advance socio-ecological science to investigate interactions between socio-economics and bioecological objectives and explore "viable pathways" and trade-offs.
- Develop guidelines for the evaluation and effective communication of the consequences and benefits of alterative management options, trade-offs, and ecosystem effects in advice (ΔRisk).
- Promote the proposal of new ideas across the community (e.g. via "pipeline" processes) to strengthen ecosystem-informed advice.

# 5 Conclusion and next steps

The combined indicator/risk framework for ecosystem-informed science and advice has the advantage of building on existing practice and being readily compatible with current and ongoing developments, e.g. cumulative effects assessments, ensemble approaches, existing EBFM and IEA methodologies, and ICES benchmarking process. The framework uses risk as the currency for handling and communicating ecosystem considerations into advice as sources of quantifiable or yet unquantifiable uncertainty. The selection of relevant indicators (using context-based risk assessments, ecosystem models, integrated ecosystem assessments, etc.) and the routine formulation, communication, and exploration of alternative hypotheses for ecosystem effects in advice will facilitate the evaluation of the performance of alternative management options in meeting objectives under *status quo* assumptions (no ecosystem effects) vs. plausible, alternative hypotheses for ecosystem effects. The framework will improve communication of ecosystem considerations into advice as factors altering the level of risk associated with the advice and provide a pathway for addressing (and possibly reconciling) multiple competing objectives. The framework is broad and intended to be non-limiting, thus allowing the development of future science and advice products to be better aligned with societal drivers, management objectives, and needs. The intention is not to be prescriptive, but instead to provide a space in which science can become advice and progress EBM by illustrating the wide range of avenues and methods that can fall under the FEISA umbrella. As such, the limitations are not so much in the approach, but in the resources and capacity to drive change in the way ICES operates and engages with the scientific community, managers, and society. This framework provides the first step towards implementing this change.

# 6 Acknowledgments

The authors wish to acknowledge and thank all ICES Secretariat staff who directly or indirectly provided support for this work and all participants of the ACOM/SCICOM EBM *ad hoc* group listed in Annex 2 for their respective contributions. Mark Dickey-Collas was involved in creating and promoting the work of a joint ACOM/SCICOM group on EBM and provided guidance to the chairs throughout the process. Members of ICES Science Committee (SCICOM) and Advisory Committee (ACOM) provided valuable comments at different steps of the process. Special thanks to two reviewers for constructive insights and suggestions that contributed to both improve and enhance the content of this report.

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# Annex 2: List of participants to the joint ACOM/SCICOM EBM Group in 2020/2021

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# Annex 3: Situating FEISA within existing practice

The original framework design proposed by the ACOM/SCICOM EBM *ad hoc* group is presented in Figure A3.1. This version includes the ToRs for the group (grey arrow on the right) and distinguishes between qualitative, semi-quantitative, and a quantitative basis for indicators development. This version is used to demonstrate framework applicability to various examples from the literature or the ongoing ICES advisory process.

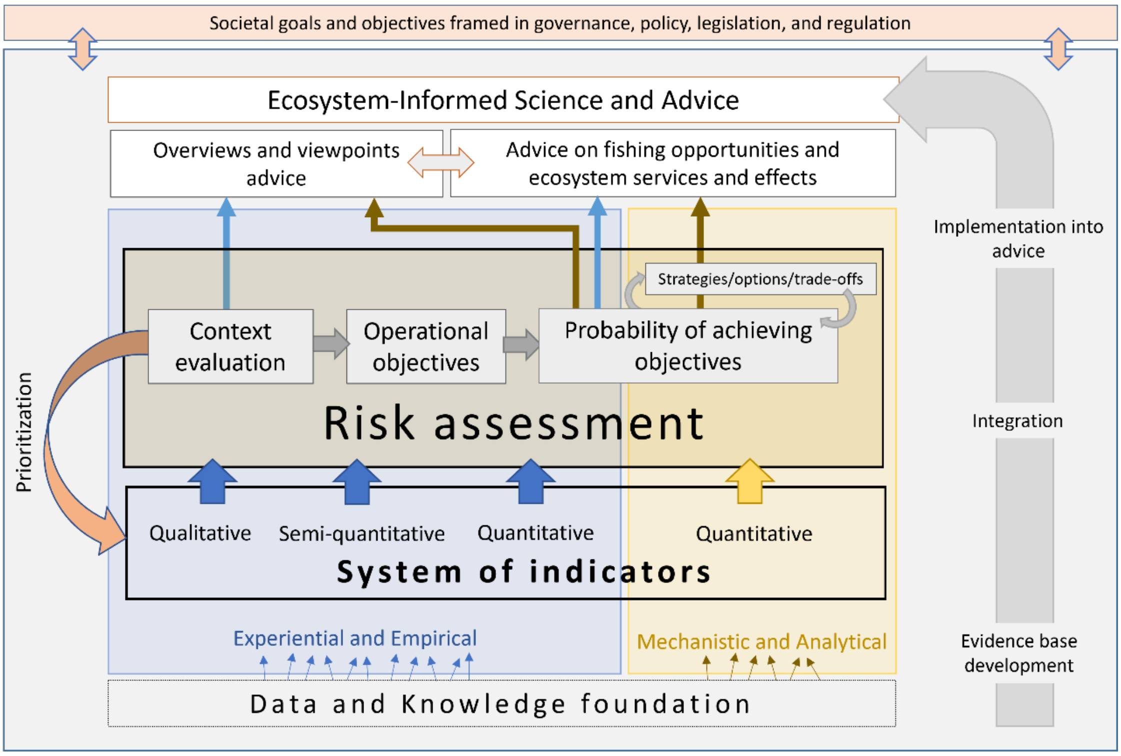


**Figure A3.1. Original Framework for Ecosystem-Informed Science and Advice (FEISA) proposed by the ACOM/SCICOM EBM *ad hoc* group.**

## A3.4 Operationalizing ecosystem-informed context evaluation and advice

The EBM framework provides an avenue for operationalizing contextual advice, such as the EOs. A key example for this work is through IEA.

IEA is a key tool in progressing EBM (Levin *et al.*, 2009, 2014; Walther and Möllmann, 2014; DePiper *et al.*, 2017). They work to integrate relevant information from all aspects of the socio-ecological system, considering human activities and anthropogenic pressures, ecosystem changes, and social and ecological impacts. An IEA consists of five stages: scoping, indicator development, risk analysis, management strategy evaluation, and ecosystem assessment (Levin *et al.*, 2009, 2014; Samhouri *et al.*, 2014). Working through an IEA loop can parallel working through the FEISA, moving from qualitative to quantitative assessments as data, knowledge, and methodologies allow (Holsman *et al.* 2017). FEISA additionally provides the critical next step: clear operational pathways for implementation into ICES advice at all stages of data and knowledge development.

Two key steps in IEAs are risk assessment and the use of indicators. The identification and selection of appropriate indicators enable an assessment of risk in relation to management objectives, with the aim to highlight areas of greatest concern and those in need of management action. As IEAs are carried out with specific operational objectives in mind (specified by stakeholders and/or clients), the selection of indicators should identify those relevant for addressing progress towards these objectives under different ecological and management conditions.

### A3.4.1 Inclusion of quantitative indicators in contextual advice

Suites of indicators identified in IEA processes could be used to provide critical contextual information of relevance to EBM. These IEA methods make use not only of status-based indicators and operational objectives reflecting specific conditions (see WGCERP) but trend indicators, building on initiatives such as the WKINTRA workshops [WKINTRA (ICES, 2018) and WKINTRA2 (ICES, 2019e)] on developing common/best practice integrated trend analyses methodologies. Reporting on these indicators in the EOs not only provides a crucial outlet for this knowledge held by the community but helps to provide avenues to improve the "operationality" or usefulness of the EOs.

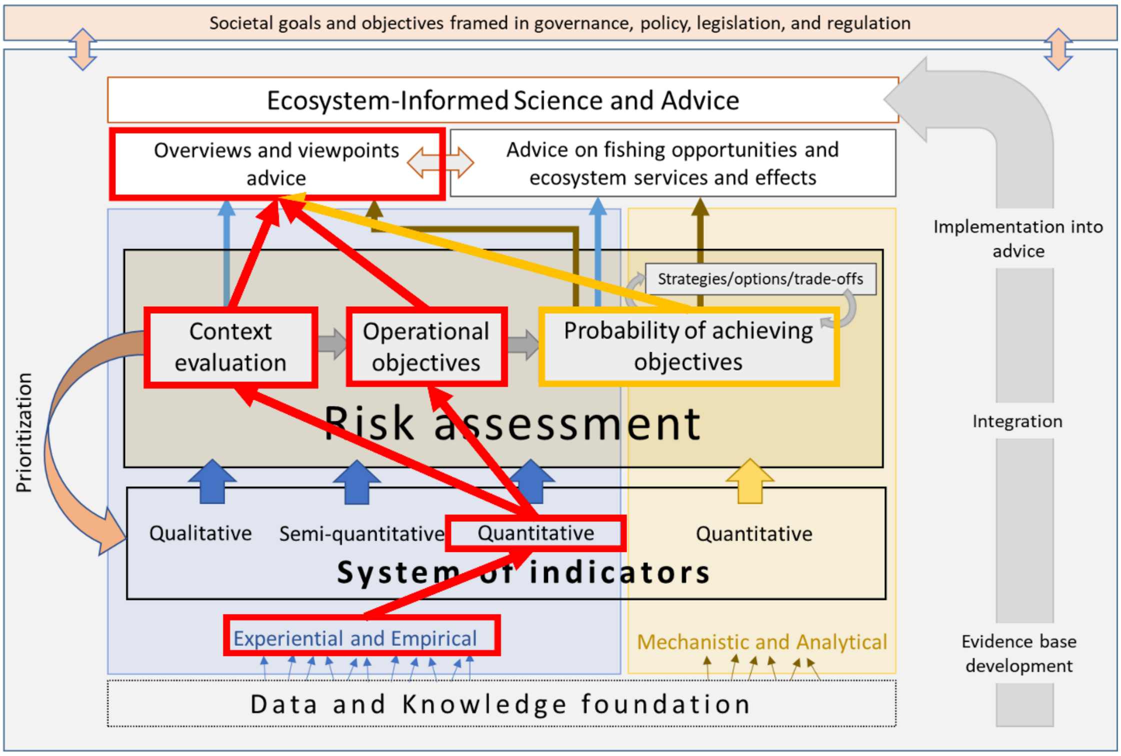


**Figure A3.2. Illustration of how quantitative indicators for context-specific advice can fit within FEISA architecture (red pathway). Quantitative indicators can be used directly in contextual advice, such as the overviews, or to report on status against existing operational objectives, such as in relation to MSFD descriptors and criteria. Quantitative risk assessment is also performed through modelling and scenario testing in IEAs (yellow arrows), and this can also contribute to contextual advice (for component-specific advice see 'Operationalizing ecosystem-informed single-sector/component-specific evidence and advice' section below).**

Figure A3.2 indicates how this example could migrate through the proposed framework. Quantitative analyses can feed into context evaluation through providing information on state (state assessment, risk to ecosystem components) but also potentially into operational objectives (e.g. risk to GES for the MSFD) and providing early warning signals of concern/relevance to managers (e.g. trend analyses) via the EOs. In latter stages of the IEA cycle[14], the indicators/trends can be simulated using ecosystem models (e.g. via MSE) to assess the probability of achieving operational objectives linked to policy and/or management goals, providing information on trade-off options. This approach would help to build on established IEA initiatives within ICES and progresses the development and application of IEAs while providing useful outputs from the ongoing work as IEA capacity is building.

An extra benefit/consideration is that key signals from trend analyses, red flags from existing status assessments, and/or risk to EBM management/policy objectives will also be relevant for other types of ICES advice (e.g. identification of parameters of potential concern/relevance to individual fish stocks, see single-sector/component-specific examples below). This may help to better integrate EBM considerations across the strands of ICES advice.

### A3.4.2 Inclusion of semi-quantitative indicators in contextual advice

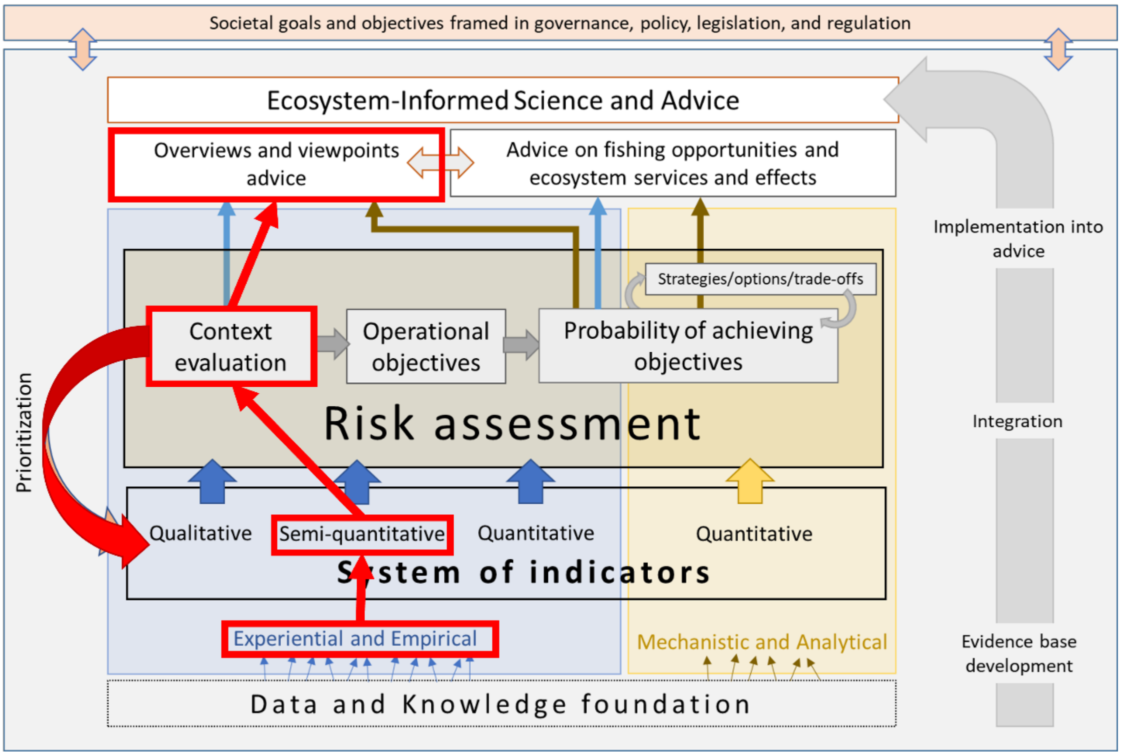


**Figure A3.3. Illustration of how the semi-quantitative risk assessment methodology used to inform ICES ecosystem overviews (EO; contextual advice) fits within FEISA (red pathway). Outcomes from the context evaluation are then used to inform priorities for the next steps in the IEA (i.e. scoping).**

Semi-quantitative risk assessment has recently been adopted by ICES as the scoping tool used in IEA groups and to provide the "wire diagrams" included in each of the EOs (ICES, 2021). The assessment consists of a driver–pressure–state type of assessment adapted from the ODEMM[15] project (EEA, 1999; Knights *et al.*, 2013; Pedreschi *et al.*, 2023). In this process, all sectors, pressures, and ecosystem components relevant to the region are identified, their relationships (linkage chains) established, and assessed (for spatial and temporal overlap and degree of

[14] National Oceanic and Atmospheric Administration (NOAA) Integrated Ecosystem Assessments (IEA). 2024. NOAA. https://www.integratedecosystemassessment.noaa.gov/

[15] Options for Delivering Ecosystem-Based Marine Management (ODEMM). 2023. University of Liverpool, UK. https://www.liverpool.ac.uk/odemm/

impact). The assessment is carried out through panel assessments, informed with data (e.g. maps) where they are available. The assignation of scores for each linkage chain allows ranking and a pressure or risk assessment to be carried out. The assessment does not consider uncertainty beyond evidence and/or confidence scores supporting the identified linkages. It identifies priority risks and pressures for the region, focusing the next steps of an IEA (i.e. scoping) and helping to direct where to focus future research efforts, including those of high risk and low knowledge. Such an assessment helps to inform discussions of management priorities and narrow the scope for the identification of operational objectives.

In the case of ICES EOs, a semi-quantitative risk assessment serves to identify the top pressures and sectors acting in each ecoregion. The section on pressures then focuses on these top pressures, providing a more detailed description of each issue and its current status within the ecoregion. These types of assessments can be expanded further to include elements such as ecosystem services and objectives in the form of MSFD criteria and descriptors.

### A3.4.3 Inclusion of qualitative indicators in contextual advice

Examples of qualitative assessments that may be of use include the well-established Rapid Appraisal for Fisheries (RAPFISH; Pitcher and Preikshot, 2001) and the more recent Fishery Socioeconomic Outcomes Tool (FSOT; Smith *et al.*, 2019). Both approaches enable the evaluation and tracking of fishery management through the use of qualitative indicators scored by key informants. RAPFISH provides attributes across social, economic, ecological, technological, institutional, and ethical aspects. FSOT focuses on socio-economic outcomes by linking them directly to fishery management objectives and weighting responses according to the importance of particular objectives. Both methods result in standardized scores of fishery management outcomes that can then be compared across fisheries and tracked over time. The tools are free and relatively quick to use and thus cost-effective to implement. As such, they present viable options for developing ecosystem-informed science and advice for the management of human activities at the scale of ICES ecoregions, particularly to fill gaps in available knowledge and as a mechanism to include experience, perceptions, and/or behaviour in the evidence base for advice.

Figure A3.4 indicates how this example could migrate through FEISA to inform ICES contextual advice products. Analyses can remain qualitative or feed semi-quantitative analyses (e.g. via scoring of responses). These analyses can support both context evaluation through providing information on state (status assessment, risk to ecosystem, and/or socio-economic components), but also potentially to operational objectives (e.g. risk to GES for the MSFD for low-data components, risk to achieving ”thriving coastal communities” [CFP; European Union, 2013 ]).
In the case of repeated assessments, indicators could provide trend information of concern/relevance to managers via the EOs. The tools can be used to identify and prioritize relevant questions/issues for IEAs, areas of potential conflict between socio-economic and ecological objectives (i.e. trade-offs), and/or conflicts among objectives set by different management bodies or jurisdictions (e.g. different priorities at national rather than regional level). Critically, they have potential to provide a way to identify and monitor socio-economic risks essential for trade-off analyses and informing quantitative MSE exercises that would otherwise be omitted/missed due to a lack of quantitative data. Furthermore, these types of analyses may be able to capture perception and behavioural issues which are of particular relevance when considering ”wicked problems” such as in sustainable management (Jentoft and Chuenpagdee, 2009; DeFries and Nagendra, 2017; de Salas *et al.*, 2022). This approach

would help to maximize ongoing initiatives within ICES (e.g. the work of WGSOCIAL[16], WGECON[17], WGBESEO[18], SIHD[19]), crucially advancing towards integrated socio-ecological assessment and understanding.

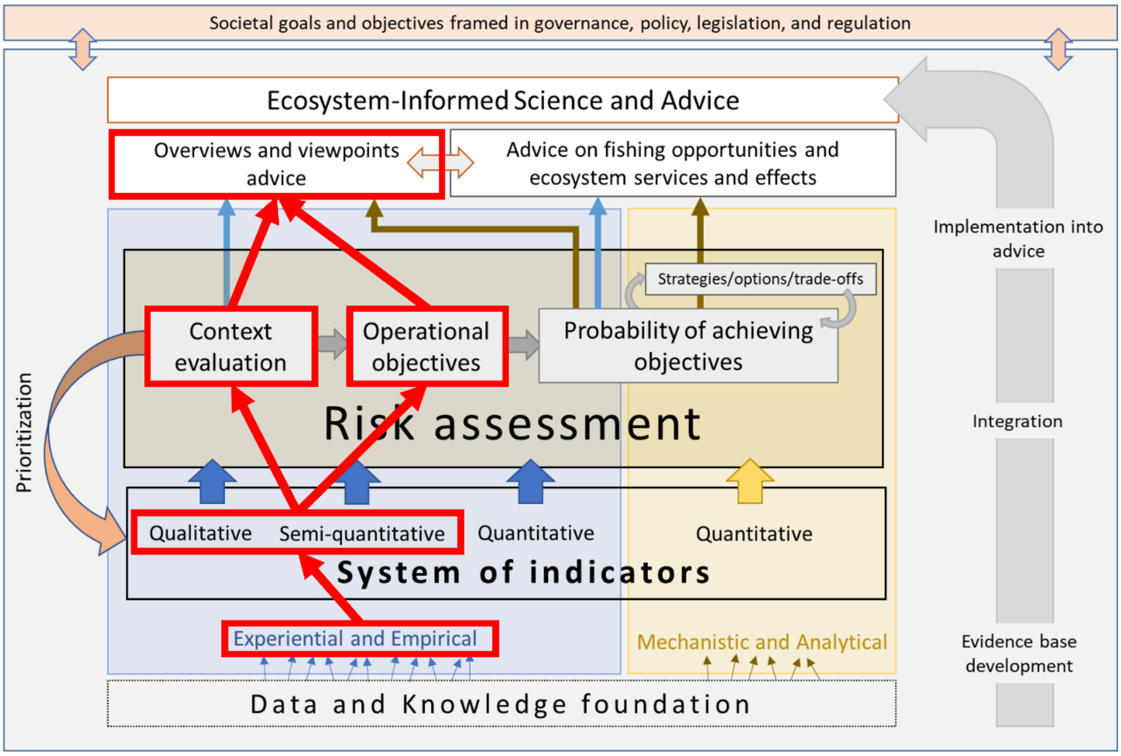


**Figure A3.4. Illustration of how qualitative indicators can be utilized within FEISA architecture to inform context-specific advice. Qualitative indicators could be used directly in context advice such as the overviews or to report on the status of often overlooked objectives such as "thriving coastal communities" (CFP; European Union, 2013).**

The examples above can be considered as tools and approaches for progressing towards full implementation of ecosystem-informed contextual advice that takes account of ecosystem, social, economic, and resource-specific evidence and objectives, multiple human activities/uses of natural systems, and interdependencies between the state of ecosystems and ecosystem components, and human and societal welfare (see Figure 2.1). The ICES "pipeline process" provides an avenue through which new information and approaches, such as those highlighted above, could be included in contextual advice products (ICES, 2023a).

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[16] ICES Working Group on Social Indicators (WGSOCIAL). 2024. ICES. https://www.ices.dk/community/groups/Pages/WGsocial.aspx

[17] ICES Working Group on Economics (WGECON). 2024. ICES. https://www.ices.dk/community/groups/Pages/WGECON.aspx

[18] ICES Working Group on Balancing Economic, Social and Ecological Objectives (WGBESEO). 2024. ICES. https://www.ices.dk/community/groups/Pages/WGBESEO.aspx

[19] ICES Strategic Initiative on the Human Dimension (SIHD). 2024. ICES. https://www.ices.dk/community/groups/Pages/SIHD.aspx

# A3.5 Operationalizing ecosystem-informed single-sector/component-specific evidence and advice

Component-specific advice is provided to inform the management of human pressure effects on individual species or ecosystem components. This type of advice is commonly provided to address a specific management question regarding a specific human activity sector. It includes advice on fishing opportunities (single-stock and mixed fisheries) and advice on "ecosystem services and effects", including advice on bycatch of protected, endangered, or threatened species (PETS) and VMEs. Nearly all are currently provided in relation to the fishery sector. This emphasis on fisheries is bound to change rapidly over the coming years with fast-growing science and advice needs for offshore renewables.

The development of ecosystem-informed component-specific advice relies on the implementation of objective-based risk assessments, which are used to formulate management options within a "safe operational space" (Cormier *et al.*, 2017; Roux *et al.*, 2022) or "viability kernel" (Cury *et al*., 2005) bounded by objectives, with explicit consideration and handling of uncertainty arising from ecosystem, socio-economics, and other considerations. Risk outcomes are implemented into advice as the probability of breaching operational objectives associated with clear biological, ecological, social, and/or economic consequences.

Objective-based risk assessments are standard practice in fisheries and can be used to compare management options among scenarios including and propagating ecosystem effects and uncertainties, where a mechanistic understanding of such effects is available. However, this is seldom the case, and mechanistic relationships for ecosystem effects are rarely robust in time. Alternatively, examples are emerging of objective-based risk approaches for operationalizing indicators into single-stock advice, even in the absence of mechanistic knowledge (Dorn and Zador, 2020; Bentley *et al*., 2021; Duplisea *et al*., 2021; Howell *et al*., 2021). These include approaches using qualitative indicators and expert judgement information (Dorn and Zador, 2020), measurable empirical indicators derived from ecosystem models or available time-series of oceanographic variables (Bentley *et al*., 2021; Duplisea *et al*., 2021) or both (Plagányi *et al*., 2013). In all such cases, indicator selection, evaluation, and the exploration of plausible relationship(s) between indicators and stock status/trajectory, productivity, or individual life history parameters is performed externally in parallel to the stock assessment. Selected candidate indicator(s) are then used to "adjust" fishing pressure levels in order to formulate fisheries management options that are consistent with acceptable risk levels, considering additional uncertainty contributed from ecosystem drivers.

These approaches can be generalized as performing an "adjustment" or "conditioning" of advice for ecosystem considerations through the application of risk equivalence. They focus on approximating/estimating, propagating, and explicitly communicating different sources and types of uncertainty, as opposed to achieving mechanistic understanding (which is desirable, but rarely achievable within the time-frames available for delivering ecosystem-informed advice). It is immediately applicable and can be incrementally extended to all component-specific ICES advice.

## A3.5.1 The $F_{eco}$ example: Using an ecosystem model and stock assessment model outputs to define an ecosystem-informed catch option

The $F_{eco}$ proposal (Bentley *et al*., 2021; Howell *et al*., 2021) developed during WKIRISH (ICES, 2020e) involves using ecosystem modelling results external to the stock assessment to refine the F target and advice on fishing opportunity within the precautionary $F_{MSY}$ range ($F_{MSY\ lower}$ – $F_{MSY\ upper}$) estimated by the single-species stock assessment. The ecosystem model is used to synthesize knowledge and perspectives among stakeholders, i.e. across the data and process knowledge continuum. Relevant ecosystem indicators are empirically determined/identified using stock trajectories from the full ecosystem models and considering plausible biological/ecological relationships. Indicator status is evaluated relative to the ecosystem model tuning period. Values above/below the long-term average are taken to indicate favourable/unfavourable ecosystem conditions for the stock, in which case the refined F target ($F_{eco}$) will be in the upper/lower $F_{MSY}$ range, respectively. This information is used to provide an ecosystem-informed, single-species catch option consistent with ICES precautionary approach for providing fisheries advice (Figure A3.5). The ecosystem-informed catch option provides a presumptively risk-equivalent option that takes into account a plausible ecosystem effect on management outcomes and associated uncertainty. This approach requires the pairing of ecosystem models and single-stock assessment models at the benchmark process. It relies on the assumptions that indicator values will remain within the range of the available observations and that linear relationships between indicators and stock trajectories will remain relevant (i.e. will not break) in between benchmarks. It may be applicable to and facilitate indicator selection for other marine ecosystem components for which advice is formulated (e.g. marine mammals). The approach also has potential applicability for developing ecosystem-informed mixed fisheries advice (Bentley *et al.*, 2021).

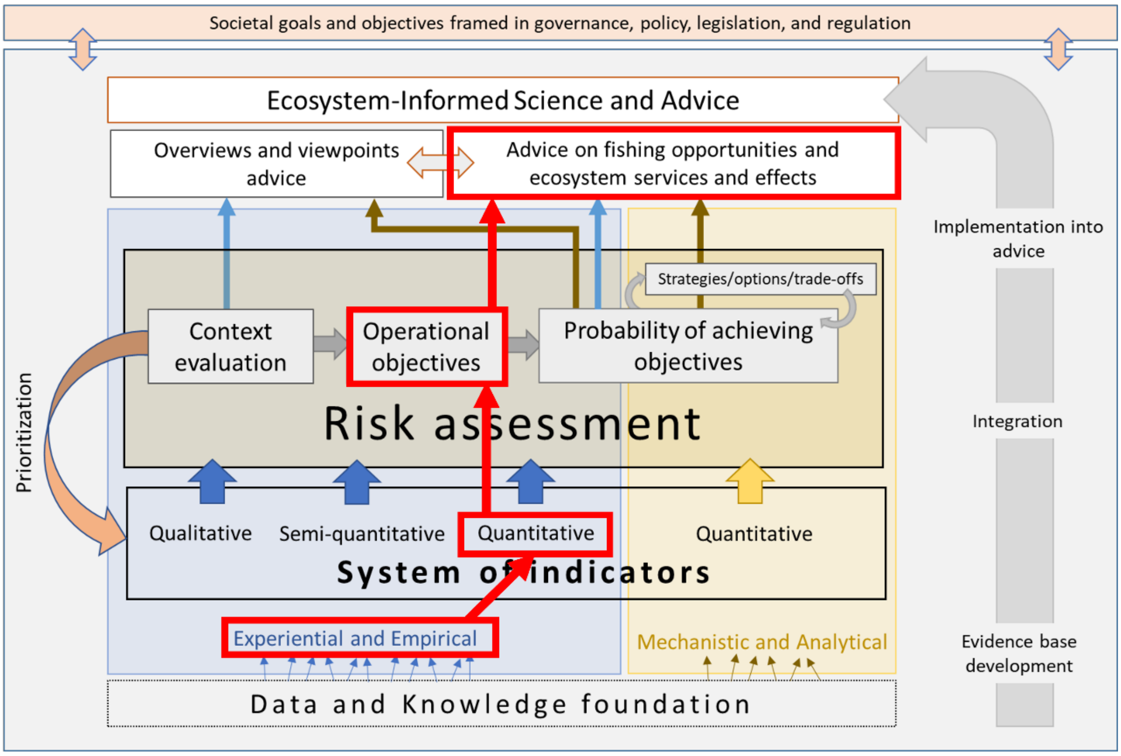


**Figure A3.5. Illustration of how the $F_{eco}$ proposal (Bentley *et al.*, 2021) fits within FEISA. An empirical relationship between an ecosystem indicator and stock-status indicator is developed using an ecosystem model and used to set an operational objective within the $F_{MSY}$ range and provide an ecosystem-informed catch option for use in single-stock advice. The ecosystem-informed catch option provides a presumptively risk-equivalent option that takes into account a plausible ecosystem effect on management outcomes and associated uncertainty.**

### A3.5.2 The risk table example: using qualitative risk evaluation to provide an ecosystem-informed catch option

The North Pacific Fishery Management Council (NPFMC) risk tables (Dorn and Zador, 2020) operate in qualitative/semi-quantitative space (Figure A3.6). The construction of risk tables require assessment authors and ecosystem scientists to perform a qualitative evaluation of the risks arising from assessment, population dynamics, and environmental/ecosystem considerations not modelled analytically within the stock assessment. The risk evaluation is based on available indicators and known information derived from ecosystem status report and species-specific ecosystem and socioeconomic profiles[20]. The resulting risk tables are used as information support for recommending a reduction in the maximum acceptable biological catch (ABC), thus allowing to "adjust" single-stock advice for anticipated negative ecosystem/environmental impacts on marine resources that may require a rapid management response. In this case, the adjusted ABC option is the risk-equivalent option accounting for anticipated or projected ecosystem effects and associated uncertainty.

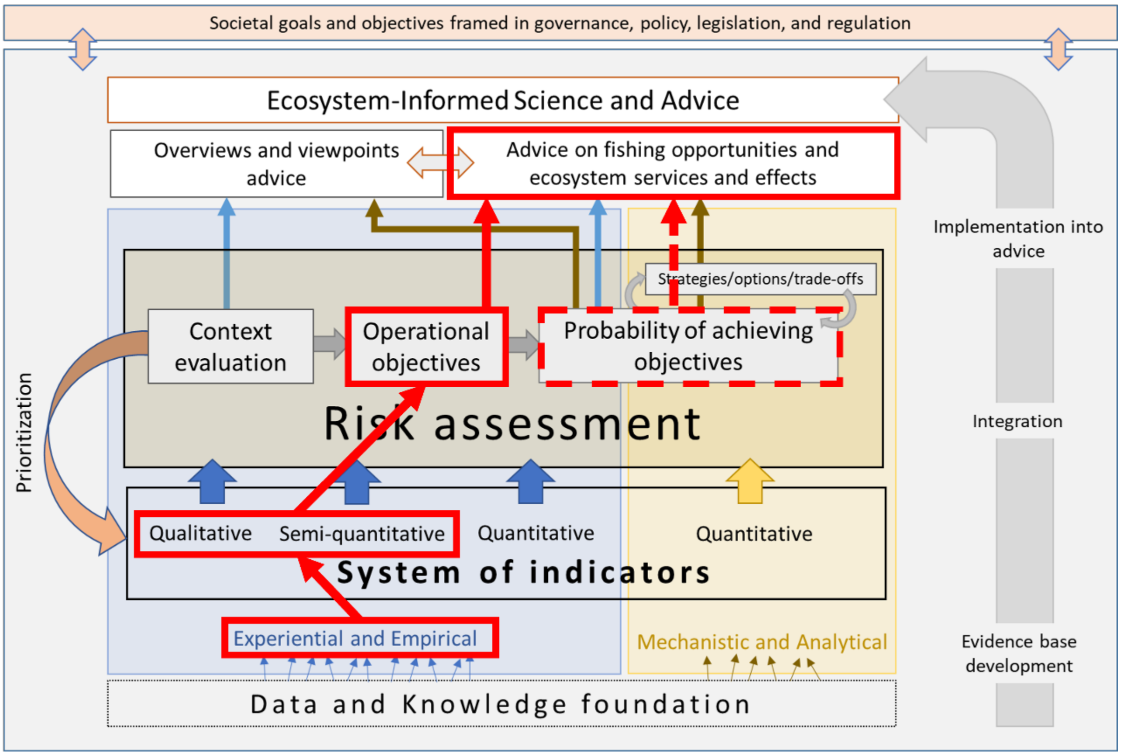


**Figure A3.6. Illustration of how the North Pacific Fishery Management Council (NPFMC) risk table example (Dorn and Zador, 2020) fits within FEISA. Qualitative and semi-quantitative indicators are used to evaluate whether a change in risk arising from ecosystem factors not explicitly considered in the stock assessment would justify a further reduction in the maximum acceptable biological catch (ABC; operational objective). A further reduction would account for additional uncertainty and serve to maintain a level of risk consistent with the level considered acceptable by the management system.**

## A3.5.3 A sea cucumber mixed fishery example: Combining different knowledge types in spatial MSE to assess the performance of harvest strategies under climate change

Plagányi *et al*. (2013) use qualitative expert knowledge and empirical evidence in analytical objective-based risk assessment (spatial MSE) to evaluate climate change impacts on fisheries production in a data-poor and mixed-species sea cucumber fishery. Climate risks are evaluated based on projected changes in climate change indicators including physical variables (sea surface temperature, sea level rise, changes to current systems, storms and cyclones, rainfall,

[20] Ecosystem Socioeconomic Profile Update 2020 (npfmc.org)

and ocean acidification), critical habitat availability (seagrass and coral reefs), and phytoplankton productivity. Qualitative likelihood and "severity of impact" evaluation is based on expert opinion and subjective ratings criteria that could be updated as more information becomes available. MSE simulations are used to assess the performance of alternative harvest strategies in meeting operational objectives under posited climate-change impacts on life history parameters (growth, mortality, movement, distribution, and reproduction), relative to equivalent no-fishing, no-climate-change scenarios. Projected climate change impacts on fisheries production are thus measured and quantified as a change in risk (application of risk equivalence). This approach provides a first step for linking a range of possible climate effects over a range of life history components and critical habitats for fisheries and could be used to formulate ecosystem-informed and climate-aware advice (Figure A3.7).

The above examples illustrate that different methods can be implemented in parallel or jointly and incrementally to deliver ecosystem-informed options for the management of human activities that take into account demonstrated, anticipated, or projected ecosystem effects on management outcomes and associated uncertainty.

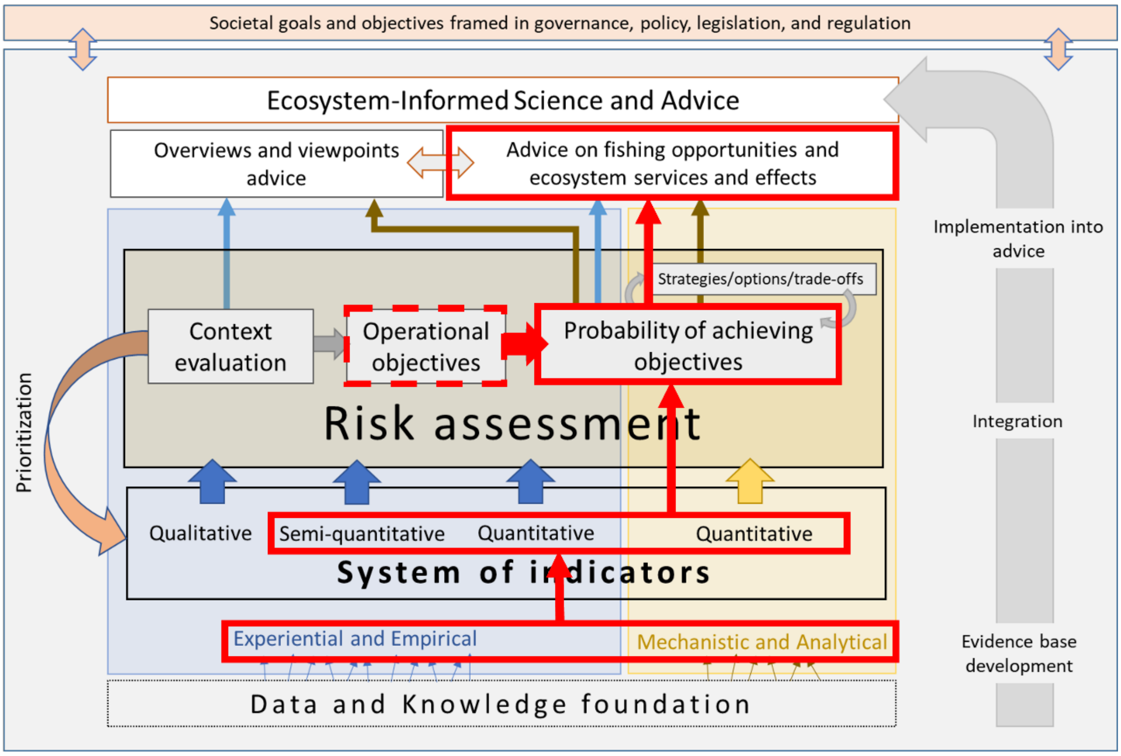


**Figure A3.7. Illustration of how the Australian sea cucumber study (Plagányi *et al.*, 2013) fits within FEISA. Several knowledge and information types are used in management strategy evaluation (MSE) to identify harvest strategies permitting to achieve objectives for data-poor, mixed-species fisheries under climate change scenarios.**

# Annex 4: List of abbreviations and acronyms

| | |
|---|---|
| ABC | Acceptable biological catch |
| ACOM | ICES Advisory Committee |
| Brexit | The withdrawal of the United Kingdom from the European Union |
| CFP | Common Fisheries Policy |
| COVID-19 | Coronavirus disease caused by the SARS-CoV-2 virus |
| EAF | Ecosystem approach to fisheries |
| EBFM | Ecosystem-based fisheries management |
| EBM | Ecosystem-based management |
| EEA | European Environment Agency |
| EO | Ecosystem overview |
| EU | European Union |
| FAO | Food and Agriculture Organization of the United Nations |
| $F_{eco}$ | An ecosystem-based fishing mortality reference point |
| FEISA | Framework for ecosystem-informed science and advice |
| $F_{MSY}$ | Fishing mortality consistent with achieving maximum sustainable yield |
| FSOT | Fishery socioeconomic outcomes tool |
| GES | Good environmental status |
| HELCOM | The Baltic Marine Environment Protection Commission – also known as the Helsinki Commission |
| ICES | International Council for the Exploration of the Sea |
| IEA | Integrated ecosystem assessment |
| IEASG | ICES Integrated Ecosystem Assessments Steering Group |
| ILK | Indigenous and local knowledge |
| ISO | International Organization for Standardization |
| MIRIA | Meeting between ICES and Requesters of ICES Advice |
| MSE | Management strategy evaluation |
| MSFD | Marine Strategy Framework Directive |
| MSPD | Maritime Spatial Planning Directive |
| NEAFC | Northeast Atlantic Fisheries Commission |
| NPFMC | North Pacific Fishery Management Council |
| OSPAR | The body overseeing the implementation of the Convention for the Protection of the Marine Environment of the North-East Atlantic (the Oslo-Paris Convention) |

| | |
|---|---|
| PETS | Protected, endangered, and threatened species |
| QSR | OSPAR Quality Status Report |
| RAPFISH | Rapid appraisal for fisheries |
| SCICOM | ICES Science Committee |
| SIHD | ICES Strategic Initiative on the Human Dimension |
| ToR | Terms of Reference |
| VME | Vulnerable marine ecosystem |
| WGBESEO | ICES Working Group on Balancing Economic, Social and Ecological Objectives |
| WGBIODIV | ICES Working Group on Biodiversity Science |
| WGCERP | ICES Working Group on Common Ecosystem Reference Points |
| WGECO | ICES Working Group on Ecosystem Effects of Fishing Activities |
| WGECON | ICES Working Group on Economics |
| WGSOCIAL | ICES Working Group on Social Indicators |
| WKFooWI | ICES Workshop to develop recommendations for potentially useful Food Web Indicators |