WORKSHOP ON THE OPERATIONAL USE OF FOOD WEB INDICATORS AND INFORMATION (WKFOODWEB; OUTPUTS FROM 2024 MEETING)

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i Executive summary

The Workshop on the operational use of Food Web indicators and information (WKFoodWeb), held in Copenhagen from February 19–21, 2024, focused on the future integration of food web information into ICES advice and progress towards Ecosystem-Based Management and Ecosystem-Based Fisheries Management (EBFM). Key discussions focused on how food web and ecosystem information could compliment the existing ICES advisory framework, including catch advice and Ecosystem Overviews. Invited presentations addressed ecosystem-informed scientific advice, the use of food web indicators, and the development and availability of food web models. Examples from academics, NGOs, and government advisors showcased how ICES might use food web indicators (such as feeding guild indicators and Ecological Network Analysis indicators) to deliver food web information to requesters which is consistent with their objectives under various policy commitments (e.g., Good Environmental Status; GES). Participants emphasised the need for standardised and accessible methods across ecoregions and ICES expert groups with improved data integration, stakeholder engagement, and transparent and robust communication of uncertainties. Breakout groups discussed options for the integration of food web information in advice, where and when needed, by means of pragmatic mechanisms for EBFM and the inclusion of more informative food web products in Ecosystem Overviews. The workshop concluded with actions and priorities focused on 1) synthesizing information and efforts regarding the development food web indicators across ICES expert groups, 2) developing and communicating options for ecosystem-informed fisheries advice, and 3) creating a roadmap for the systematic and transparent use of food web models within ICES.

ii Expert group information

Expert group name	Workshop on the operational use of Food Web indicators and information (WKFoodWeb)
Expert group cycle	Annual
Year cycle started	2024
Reporting year in cycle	1/1
Chairs	Jacob Bentley, UK
	Eider Andonegi, Spain
	Maciej Tomczak, Sweden
	Marian Torres, Spain
Meeting venue and dates	ICES HQ, Copenhagen, Denmark, 19–23 February 2024 (66 participants)

1 Introduction

The integration of food web information into marine management and advisory frameworks is crucial for advancing towards Ecosystem-Based Management (EBM), Ecosystem-Based Fisheries Management (EBFM), and Ecosystem Approach to Fisheries Management (EAFM). These approaches require a holistic understanding of marine ecosystems, recognising in-part the complex interactions between species, their environments, pressures, and ecosystem services. Decision-makers are increasingly committed to ecosystem approaches and objectives within national and international policy and are facing mounting pressures on marine ecosystems from diverse and competing uses. There is therefore a growing need to incorporate food web and wider ecosystem information into advisory products and processes. The pace of change, however, has been slow, necessitating concerted efforts to find pragmatic solutions for the integration of food web information into practical management advice.

The International Council for the Exploration of the Sea (ICES) holds the principles of EBM at its core and hosts an international community of world leading marine ecosystem experts. Ecosystem and food web research and dissemination is prominent within the outputs of the ICES Scientific Committee (SCICOM) and is increasingly being incorporated into the advice delivered to requesters via the ICES Advisory Committee (ACOM). Dedicated efforts are being made to support the delivery of ICES ecosystem-informed advice through, for example, the Framework for Ecosystem-Informed Science and Advice (FEISA; Roux and Pedreschi, 2024), the development of Ecological Reference Points (ERPs), the delivery of conservation advice, the establishment of the ICES Stakeholder Engagement Strategy, and the publication of Ecosystem, Fishery, and Aquaculture Overviews.

However, progress towards EBM and EBFM is often singular and sporadic in its achievement. Advice and capacity pipelines, such as those that exist to update stock-assessment data and models to deliver single species advice, infrequently exist for food web data and models. The lack of a systematic pipeline to update the tools and information needed to deliver ecosystem-informed advice may impact the feasibility of using such approaches to generate outputs such as ERPs at the scale and frequency which might be requested. Therefore, guidelines, support networks, dedicated positions, and political impetus as exist for the development of stock-assessment models, will be needed to streamline and maintain the integration of ecosystem information into the existing advice delivered to requesters.

ICES has a role to play in supporting the community and providing a framework through which experts can deliver ecosystem-informed advice. Through the ICES Workshop on the operational use of Food Web indicators and information (WKFoodWeb), experts explored the capacity, barriers, and opportunities for the delivery of ecosystem-informed advice. The group reviewed and discussed 1) the use of food web indicators and their relevance to decision maker’s needs, 2) opportunities for integrating food web information into ICES advice products, 3) how we might best support and develop food web modelling approaches used by the ICES community, and 4) the development of food web products for the Ecosystem Overviews.

1.1 Food web indicators

There are suites of indicators which have been developed to quantify the structure and function of marine food webs and ecosystems (e.g., Rombouts *et al.*, 2013; Tam *et al.*, 2017; Thompson *et al.*, 2020). Most ecosystem indicators focus on describing the ecological system, however, there is a growing number of indicators which focus on human dimensions, albeit most frequently focused on economic aspects (Hornborg *et al.*, 2019). Ecological ecosystem indicators that can describe the whole ecosystem, such as Ecological Network Analysis (ENA) indicators, can be difficult to interpret across the science-policy interface. This is likely one of the reasons they are not currently widely adopted by decision makers as metrics to assess the condition of marine ecosystems and performance of management interventions. Instead, species specific indicators (e.g., indicators species, hub species, or sentinel species) and indicators related to biomass, catch, and community composition (species assemblage, size, and age) are more commonly adopted as targets and thresholds (e.g., GES and OSPAR). Nevertheless, network indicators are becoming more accessible to decision makers as metrics to quantify ecosystem functioning and ecosystem services. The following Qualities (ROAR) and Characteristics (SMART) have been suggested to evaluate the appropriateness of network indicators for decision makers (Fath *et al.*, 2019; Table 1.1).

Table 1.1 Qualities and characteristics which can be used to evaluate the appropriateness of network indicators for decision makers (from Fath *et al.*, 2019).

Qualities of Good Indicators (ROARS)	
Relevant	Relates to an important part of an objective or output
Objective	Based on facts, rather than feelings or impressions and thus measurable
Available	Data should be readily available or reasonably measurable
Realistic	It should not be too difficult or too expensive to collect the information
Specific	The measured changes should be expressed in precise terms
Characteristics of Good Indicators (SMART)	
Specific	Measured changes should be expressed in precise terms and suggest the direction of actions
Measurable	Indicators should be related to things that can be measured in an unambiguous way
Achievable	Indicators should be reasonable and possible to reach, and therefore sensitive to changes
Replicable	Measurements should be the same when made by different people using the same method
Time-bound	There should be a time limit within which changes are expected and measured

1.2 Food web information in ICES advice

ICES provide support systems and frameworks which can be used to deliver ecosystem-informed advice. These include the advice framework and principles, data policy and quality assurance, Transparent Assessment Framework (TAF), Stakeholder engagement strategy, and the Framework for Ecosystem-Informed Science and Advice (FEISA). These systems and frameworks are currently used to deliver multiple ecosystem-informed services, including Maximum Sustainable Yield (MSY) via mixed fisheries, conservation advice, escapement rules, ICES overviews (Ecosystem, Fishery, Aquaculture), and ecological reference points (e.g., Feco).

Requests for ecosystem-informed advice are increasing, many of which may require the evolution of existing advice services or the development of new advice services.

1.3 Food web modelling

Food web models (e.g. Ecopath with Ecosim (EwE) and Atlantis) are being increasingly used both within and outside of ICES to deliver evidence and advice for EBM, EBFM, and EAFM. To achieve the necessary confidence in model simulations and assessments of uncertainty, it is important that models are developed transparently with thorough records and review of model parameters. ICES provide pipelines through which information can be shared (e.g., TAF) as well as forums for the critical review of models (Working Group for Multispecies Assessment Methods; WGSAM). Often food web models (even those built using the same simulator, e.g. EwE) operate under different assumptions, at different resolutions, and with different policy origins. Their development and use can also be compromised by a lack of consistent maintenance when experts move on, as these more complex models tend to be difficult to rehome and/or find experts with time to commit to their development.

1.4 Food web products for ICES Ecosystem Overviews

ICES Ecosystem Overviews (EOs) use risk-based methods to identify the main human pressures and explain how these affect key ecosystem components in each ICES ecoregion. EOs include food web sections but they tend to be primarily qualitative and are relatively inconsistent in their presentation for different ecoregions. During the ICES Workshop on the Design and Scope of the 3rd Generation of ICES Ecosystem Overviews (WKEO3; ICES 2019), experts recommended further development of food web products for the EOs. There was a consensus that a diagram of the food web structure with its key components should be included in the EOs, with some level of complexity being desirable to illustrate the strength of trophic interactions and present advice relevant information. Prior to WKEO3, DG-ENV provided some thoughts on how the EOs may become more useful to them, suggesting links to Good Environmental Status (GES) and indicators for the state of the whole ecosystem.

1.5 WKFoodWeb

1.5.1 Objectives

ICES WKFoodWeb was established to review the latest advances in food web research, explore needs and pragmatic solutions for integration into ICES advice, and consider how complex food web models can be more systematically applied across ICES ecoregions.

Term of Reference (ToR)	
ToR a	Streamline existing examples, knowledge, experience, and recommendations on food web, trophic level and other ecological indicators from across the ICES network (e.g., from IEA groups, WGECO, WKFOOWI, WKASCAPES) and beyond (e.g. MSFD, OSPAR, HELCOM, UKMS, etc.)
ToR b	Identify priority areas where food web information/indicators could enhance existing advice and align with the ICES EBM framework (including advancing the Feco approach).
ToR c	Prepare a roadmap, including risks and opportunities, for the systematic and transparent use of food web models to support ICES advice with information on trade-offs.
ToR d	Develop a pipeline proposal to strengthen the 'food web' component of ICES ecosystem advice (ICES Ecosystem Overviews) that can be applied in a consistent way across ICES ecoregions and preferentially on the short-term timescale

1.5.2 Overview

Making food web information operational requires a trans-disciplinary approach. WKFoodWeb therefore sought experts with a range of skills and knowledge, including food web ecologists and specialists, multi-species and single species modellers, fisheries scientists, and social scientists working in the social-ecological systems and ecosystem services arena. The hybrid workshop was attended by a total of 66 participants, with the most prevalent skillsets including ecosystem modelling, food web ecology, and fisheries research, and with string links to multiple ICES expert groups, particularly the Integrated Ecosystem Assessment (IEA) groups (Figure 1.1).

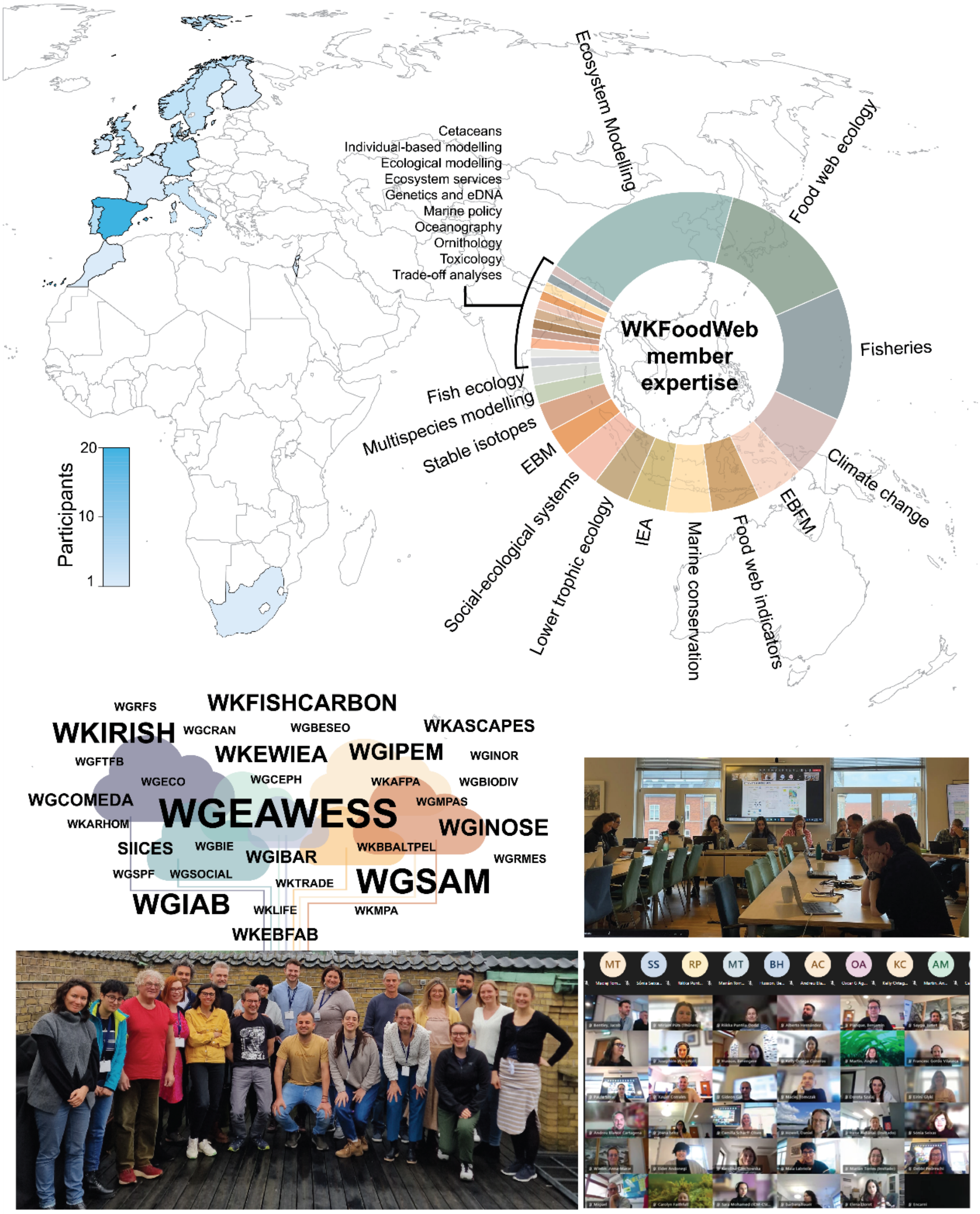


Figure 1.1 Summary of those who attended the ICES Workshop on the operational use of Food Web indicators and information (WKFoodWeb) in Copenhagen, Denmark, February 2024. The summary includes information on expert host institutes (top-left), experts' knowledge (top-right), and links to other ICES expert groups (bottom-left).

2 ToRa: Food web indicators

Tor a) Streamline existing examples, knowledge, experience, and recommendations on food web, trophic level and other ecological indicators from across the ICES network (e.g., from IEA groups, WGECO, WKFOOWI, WKASCAPES) and beyond (e.g. MSFD, OSPAR, HELCOM, UKMS, etc.)

2.1 Background to ToRa

Advances in food web indicator creation and assessment are ongoing within ICES, across research programs, and within governing bodies to measure progress against national and international biodiversity commitments. ToR a aims to provide a review of the current state of play to help identify opportunities and avoid duplicating efforts.

2.2 Report from break out groups focussing on food web indicators

2.2.1 What makes a good and useful food web indicator?

Incorporating food web knowledge into marine management and policy advice, particularly for fisheries in the Northeast Atlantic, requires robust and reliable indicators. A good food web indicator must meet several criteria to be effective for management purposes. Here, we summarize the key points discussed in a workshop focused on defining and evaluating such indicators.

Table 2.1 Criteria for good and useful food web indicators.

Criteria	Description
Robustness and consistency	Indicators need to be robust to underlying assumptions, models, and data quality. They should be supported by robust observations and tools, such as food-web models evaluated through benchmarks. The ability to reconstruct past dynamics and update indicators regularly is also important. Adhering to the FAIR principles (Findable, Accessible, Interoperable, Reusable) ensures that indicators are well-documented and usable by the scientific and management community.
Management relevance	Indicators should address key management questions or be relevant to policy instruments. Questions include assessing the ecosystem's status, understanding the impacts of fishing and other pressures on the ecosystem, and determining the effects of environmental changes on fishing potential. For collapsed stocks, it's essential to identify the conditions necessary for species recovery and to understand how to reverse once a threshold or tipping point has been crossed.
Measurable and applicable	Indicators should be measurable and applicable across different ecoregions. They should be easily understood by stakeholders, offering clear trends or thresholds with a good signal-to-noise ratio for accurate change detection. Reproducibility, sensitivity to various stressors and drivers, and unbiased representation of food web dynamics are crucial. Indicators should be straightforward to explain relative to operational objectives.
Replicable	Indicators should be robust and consistent across different models. Evaluating this involves assessing the indicator's performance under various model topologies and assumptions through uncertainty

Criteria	Description
	analyses. Consistent indicators provide similar results regardless of the model used, enhancing their reliability and comparability.
Driver-response relationships	A thorough understanding of the driver-response relationship is essential for interpreting changes in the indicator concerning drivers. Good indicators can act as early warning signals and have established reference points. Crossing these reference points should trigger a management response, making the indicator not only a monitoring tool but also an actionable metric for policy and management decisions.
Thresholds	Identifying indicator thresholds is useful as thresholds (or tipping points) have implications for risk assessment, trade-off analyses, and management decisions. Indicators may have linear or non-linear responses to stressors, in which thresholds may exist, beyond which large changes in ecosystem state or properties may occur abruptly and irreversibly.

In summary, a good food web indicator for marine management must be robust, consistent, and address relevant management questions. It should be measurable, understandable, reproducible, and applicable across regions. Indicators need to be supported by robust tools and data, reflect food web dynamics accurately, and provide clear guidance for management actions. By meeting these criteria, food web indicators can effectively inform and guide sustainable marine management and policy decisions.

2.2.2 What are the issues with the operational use of food web indicators?

Operational use of food web indicators in marine management presents several challenges, many of which are comparable to those faced in ecological, social, and economic systems.

Table 2.2 Issues with the operational use of food web indicators

Issue	Description
Reference points and scales	One major challenge is identifying appropriate reference points for indicators. These benchmarks are crucial for assessing ecosystem health but can be difficult to determine due to variability in spatial, temporal, and ecological scales. Defining baselines is particularly challenging due to the dynamic nature of food webs and the ongoing exploitation of ecosystems by humans. Inconsistencies in scale can complicate the interpretation of indicators and their applicability across different regions and timeframes.
Data limitations and model dependency	Food web indicators are often limited by data availability and can be dependent or biased by underlying assumptions of models. A preferable method would be to use multiple approaches to estimate related indicators to mitigate the risk of bias from any single model.
Indicator complexity and communication	Indicators of whole ecosystem structure and function can be complex which might present a challenge for communicability. This complexity can hinder the practical application of these indicators in decision-making processes. Simplifying and effectively conveying the significance of food web indicators is essential for their operational use.
Tool and model complexity	When discussing the use of food web models to generate food web indicators, it is important to recognise limitations which may hinder the systematic development of complex models, such as associated costs, capacity issues, and data limitations. These barriers may impact the renewal of indicators for subsequent advice products.
Trade-offs and uncertainty	Ideally ecosystem or food web indicators would help decision makers to navigate trade-offs between ecological, social, and economic considerations. Ensuring certainty in the indicators is challenging, particularly when balancing these different aspects. An ensemble or portfolio approach, using

Issue	Description
	multiple indicators and models, can help address these trade-offs by providing a more comprehensive view of the ecosystem.

In summary, while food web indicators hold significant potential for informing marine management, addressing these operational challenges is crucial for their effective implementation. Ensuring that indicators are understandable, comparable, and robust across different models and scales will enhance their utility in ecological, social, and economic contexts.

2.2.3 ToR a priorities

Priority 1

Synthesise information of the food web indicators explored across ICES expert groups:

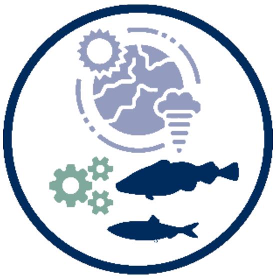
- Evaluate indicators against a common criterion to measure their operational potential (e.g., ROARS qualities and SMART characteristics).

Priority 2

Demonstrate options for developing operational indicators which may inform decision makers and pre-empt future requests.

- Explore opportunities to deliver indicators for Good Environmental Status (GES), feeding guilds, ecosystem effects of fishing (plus additional pressures as capabilities increase), and the effects of the environment on fishing opportunities.

3 ToRb: Food web information into advice



Tor b) Identify priority areas where food web information/indicators could enhance existing advice and align with the ICES EBM framework (including advancing the Feco approach).

3.1 Background to ToRb

Marine ecosystem services are impacted by environmental and ecosystem variation. It is likely that there are opportunities where accounting for these impacts in our advice could enhance existing management. However, making ecosystem information operational often requires a developed understanding of the existing regulatory and advice frameworks to deliver pragmatic solutions. ToR b will identify priority areas where food web information could enhance advice and explore/advance routes for its integration.

3.2 Report from break out groups focussing on the integration of food web information in ICES advice

3.2.1 Where do we need to prioritise the integration of ecosystem information into ICES advice?

Integrating ecosystem and food web knowledge into the advice provided by the International Council for the Exploration of the Sea (ICES) is crucial for the sustainable management of marine resources. This integration should prioritize several areas, including catch advice, trade-offs, ecosystem overviews, and spatial management, to meet policy objectives and address regional management questions effectively.

Table 3.1 Opportunities for the development of ecosystem-informed advice

Advice category	Description
Fishing opportunities	There is a policy requirement for Ecosystem-Based Fisheries Management (EBFM) in catch advice under the Common Fisheries Policy (CFP). However, integrating indicators of ecosystem health into catch advice is challenging. Food web models are not specifically designed to give catch advice but can provide long-term predictions that inform policy-making. While catch advice typically focuses on the short-term, ecosystem models can forecast the potential impacts on the ecosystem, offering a range of uncertainties driven by the given advice. Currently, catch advice primarily links ecosystem health to the biomass of specific commercial stocks. This could be extended to include other regulatory measures such as seasonal, spatial, and gear restrictions. Exploring the use of food web-based Functional Ecosystem Components (Feco), which consider resilience, trophic levels, and predator interactions, can enhance the depth of ecosystem considerations in catch advice. Conservation advice

Advice category	Description
	Temporally, fisheries advice should prioritize stocks of great commercial importance and key species with well-known biology, testing first if these stocks need ecosystem considerations.
Trade-off advice and marine planning	Food web model indicators are particularly useful for assessing trade-offs between potential management objectives, tools, and policies. These trade-offs are often easier to communicate to policymakers and managers compared to the complexity of food web indicators themselves. For instance, the concept of Acceptable Biological Catch (ABC) used in Alaska considers the total catch of multiple species, facilitating the understanding of trade-offs among species. Although integrating trade-off information is critical, defining these options and incorporating them into management advice will require a longer timeline. Initially focusing on ecological trade-offs, this approach could eventually expand to include economic considerations. Incorporating spatiotemporal considerations involves adding sections on the state of the ecosystem, including current and past states, climate change impacts, and spatial effects such as physical loss and seabed disturbance. Spatial management working groups, especially those focused on Marine Protected Areas (MPAs) and Offshore Wind Farms, should discuss model specifications and focus areas. In the long term, spatial considerations should be integrated into fisheries advice and aquaculture overviews.
Ecosystem Overviews	Ecosystem Overviews currently include a literature review of the present and past ecosystem states. However, they often lack specific sections on climate change and future predictions of food web responses to current pressures. Including this information would enhance communication and understanding of ecosystem dynamics. Prioritising the integration of ecosystem information depends on regional management questions and relevant topics. This regional specificity can be informed by groups such as the Integrated Ecosystem Assessment (IEA) groups, regional projects, researchers, and stakeholder groups. Ecosystem Overviews should include information on food web structures, status, and predator needs

Prioritising the integration of ecosystem information into ICES advice requires a multi-faceted approach. Catch advice should incorporate EBFM principles and explore broader regulatory measures. Trade-offs between management objectives need clear communication and long-term integration. Ecosystem Overviews should expand to include future predictions and region-specific priorities. Finally, spatial and temporal management should be incorporated into ICES advice, addressing the dynamic and complex nature of marine ecosystems for sustainable resource management.

3.2.2 What are the barriers to integrating food web information in ICES advice and how can they be overcome?

Integrating ecosystem information into ICES advice is essential for effective and sustainable marine management. However, several barriers hinder this integration, including capacity constraints, model uncertainties, communication challenges, and data limitations. Identifying these barriers and proposing solutions is crucial for overcoming these challenges and enhancing the use of ecosystem information in advisory processes.

Barriers

Table 3.2 Barriers for integrating food web information into advice

Barrier	Description
Capacity constraints	One of the primary barriers is the limited capacity, especially in terms of providing recurrent advice. The workload and resource demands for integrating ecosystem information into ICES advice are significant, requiring sustained effort and expertise.
Uncertainty and trust	Model uncertainties and external trust issues present substantial barriers. The complexity of ecosystem models can lead to uncertainty, and the lack of trust between scientific communities and society can impede the acceptance and use of these models. Cognitive biases also affect the perceived reliability of ecosystem-based advice.
Systemic inertia	Inertia within management bodies and subsequent advice requests impede the operational use of ecosystem information in ICES advice. Despite recent progress, the slow pace of change remains a challenge.
Model complexity	The complexity of ecosystem models makes them difficult to communicate and understand. Simplified versions or emulators might help bridge this gap, but the inherent complexity remains a significant hurdle.
Scale mismatch	There is often a mismatch between the scales of fish stocks, models, and ecoregions. This discrepancy complicates the application of ecosystem models and derived ecosystem information to specific management needs and areas.
Effective communication	The perception of the importance and utility of ecosystem models is not always positive. Effective communication is needed to convey the benefits of considering ecosystem information and the risks of neglecting it.
Data limitations	Data limitations are a major barrier, as valid and comprehensive data are necessary inputs for ecosystem models. Additionally, having relevant and objective-specific food web models and the expertise to run them is essential.

Overcoming Barriers

Table 3.3 Overcoming barriers for ecosystem-informed advice

Barrier	Description
Enhanced communication	Improving communication between stakeholders and scientists is critical. This includes simplifying complex models through emulators, using tables, scorecards, graphics, and illustrations to convey trends and metrics.
Long-term data monitoring and security	Establishing long-term security for data collection through consistent monitoring and securing funding at international and national levels will ensure the availability of high-quality data. Open-source data repositories should be promoted, potentially supported by EU requirements.
Peer-reviewed model validation	Regular peer-reviewed meetings for model validation, such as those conducted by ICES WGSAM, is important for the credibility and acceptance of ecosystem models as tools to support ICES advice.
Highlighting EBM importance	Emphasising and effectively communicating the importance of Ecosystem-Based Management (EBM) with ICES requesters and observers, relative to their management and policy needs, is vital to enable the use of ecosystem-informed advice. Routine funding for EBM work is a necessary precursor to its successful operationalisation.

Barrier	Description
Standardization and harmonisation	Harmonising approaches and outputs across different groups within ICES, using standard procedures where possible, will make the integration process smoother and more consistent.
Collaboration and avoiding duplication	Encouraging collaboration between steering groups and expert groups can help to avoid duplication where detrimental, support group capacities, and maximise the reach and impact of outputs. Established groups and processes should be supported to their full potential.
Ensemble modelling	Using ensemble modelling approaches can help address uncertainties and improve the robustness of ecosystem-based advice.
Training and capacity building	Providing training for stakeholders and non-ecosystem experts can improve understanding and recognition of opportunities for ecosystem-informed advice. Building capacity within ICES and among its stakeholders is essential for sustained progress.

Integrating ecosystem information into ICES advice faces several barriers, including capacity constraints, model uncertainties, systemic inertia, model complexity, scale mismatches, perception issues, and data limitations. To overcome these challenges, enhancing communication, securing long-term data monitoring, promoting open data repositories, conducting peer-reviewed model validations, highlighting the importance of EBM, standardizing approaches, fostering collaboration, using ensemble modelling, and providing training are crucial steps. Addressing these barriers will facilitate the effective use of ecosystem information in ICES advice, promoting sustainable marine management practices.

3.2.3 ToR b priorities

Priority 1

Establish an ICES Working Group to act as a bridge between steering groups for the delivery of ecosystem-informed advice: hub for the development of ecosystem informed advice (WGECOHUB).

- WGECOHUB would be a primarily action orientated and methods-based group, identifying options for the operational use of food web information in ICES advice.
- The groups responsibilities could include 1) EBFM opportunity identification and development, 2) food web model development, documentation, and assessment, 3) food web and ecosystem indicator development and application, 4) support and guidance for EBM orientated Workshops (e.g., those akin to WKIRISH and WKEBFAB).

Priority 2

Develop an Ecosystem-Based Fisheries Management (EBFM) showcase and implementation plan.

- Showcase and communicate existing and new approaches to integrate food web and ecosystem information into advice. These include: Feco, conservation advice, ecological reference points, multi-species reference points, Management Strategy Evaluation (performance statistics, risk assessment, and food web informed operating models), trade-off analyses, medium to long-term simulations, and prey availability index.

- The showcase should be tailored to communicate internally with the ICES community but also with stakeholders and requesters (visualisations, infographics, summary cards).
- Provide an overview of the potential risks of not accounting for food web info while also recognising that EBFM exploration may lead to no change if current management is optimal.
- Provide example EBFM questions and case-studies.
- Discuss the Research development/implementation needs: capacity, routine funding, model development, quantified uncertainty, communication approaches or tools, standardised reporting and methods [TAF], methods/action orientated WG (WGECOHUB).

Priority 3

Develop a case study to demonstrate ICES capacity to deliver ecosystem-informed advice using forage fish as an example.

4 ToRc: Food web models

Tor c) Prepare a roadmap, including risks and opportunities, for the systematic and transparent use of food web models to support ICES advice with information on trade-offs.

4.1 Background to ToRc

Food web models (e.g. Ecopath with Ecosim (EwE) and Atlantis) are being increasingly used across ICES and by decision makers to guide the delivery of EBM, EBFM, and EAFM. Often models (even those built using the same simulator, e.g. EwE) operate under different assumptions, at different resolutions, and with different policy origins. Their utility to provide food web information is clear and progress should be made to use them in an operational management context (see recent paper by Craig and Link (2023) in Fish and Fisheries). Their current application within ICES is unsystematic relative to the use of less complex models. ToR C will explore options to enhance how food web models are used across ICES to support the delivery of ecosystem-based advice.

4.2 Report from break out groups focussing on the systematic and transparent use of food web models

4.2.1 What steps are needed for the more transparent and systematic use of food web models?

To enhance the transparency and systematic use of food web models, such as Ecopath with Ecosim (EwE), a structured framework and standardized practices are necessary. This involves building trust, improving accessibility, ensuring replicability, and maintaining rigorous documentation and review processes. Below are the steps needed to achieve these goals and how they can feed into a framework for model review.

Table 4.1 Opportunities for the transparent and systematic use of food web models

Category	Description
Participatory modelling	Involving stakeholders in the modelling process through participatory modelling can build trust. This approach ensures that stakeholders understand the model's purpose, inputs, and limitations, fostering a collaborative environment.
Peer review and evaluation	Regular peer review, benchmarking, and evaluation of models by the scientific community can enhance credibility. Engaging a global network of ecosystem modellers for reviews ensures diverse perspectives and rigorous scrutiny.
Transparency in objectives and capabilities	Clearly communicating the strengths, weaknesses, and specific questions that a model can address is crucial. Highlighting what a model can and cannot do helps manage expectations and ensures appropriate application.

Category	Description
FAIR principles	Model outputs should adhere to FAIR (Findable, Accessible, Interoperable, and Re-usable) principles. This includes making data and model outputs easily accessible in open-source repositories and ensuring standardization across the modelling community.
Standardisation and community tools	Developing community tools and standardising model assumptions and documentation (where sensible) enables more effective sharing and interpretation of models and modelling resources. Sharing code and integrating code into pipelines that maintain functionality over time, despite updates in programming languages and libraries, is essential.
Version control and documentation	Implementing version control and comprehensive documentation, such as the TRACE framework (TRAnsparent and Comprehensive model Evaluation; Grimm *et al*., 2014), ensures that models are transparent and replicable. Documentation should include objectives, data sources, calibration and validation processes, and uncertainty analyses.
Best practice	Establishing best practice approaches for each type of food web model and software module is necessary. Clear guidelines on formulating questions, selecting appropriate software, and orienting models according to specific objectives will streamline the modelling process.
ICES templates	Creating a standardised template for model reporting and key run development could encourage reporting and ensure consistency and transparency.
Effective communication	Using simple communication methods, such as tables of trends, scorecards, graphics, and illustrations, can make complex models more understandable. Emphasising the importance of ecosystem-based management (EBM) to national authorities and securing routine funding for EBM work are also crucial.

Achieving a more transparent and systematic use of food web models requires building trust, enhancing communication, standardizing practices, and ensuring robust documentation and review processes. By following these steps, the modelling community can create a framework that supports the reliable integration of ecosystem information into marine management and policy advice. This approach will not only improve the credibility and usability of models but also facilitate their adoption and application in diverse ecological contexts.

4.2.2 What are the existing or foreseeable issues with the use of food web models for ICES advice and what actions could enhance systematic use?

The incorporation of food web models into ICES advice presents both opportunities and challenges. While these models offer valuable insights into ecosystem dynamics and potential management outcomes, several barriers hinder their systematic use. Addressing these barriers requires concerted efforts across multiple dimensions, from improving communication to enhancing data availability and fostering interdisciplinary collaboration.

Barriers to the Use of Food Web Models

Table 4.2 Barriers to the use of food web models to deliver ICES advice.

Barrier	Description
Rigid management structures	Management structures are often inflexible, making it challenging to introduce new methods and gain acceptance into existing frameworks. Bridging the communication gap between managers, stakeholders, policymakers, and scientists is essential to overcome this inertia.

Barrier	Description
Capacity and resource constraints	Maintaining multiple models is costly, and the limited capacity in terms of funding, time, and expertise poses a significant barrier.
Data limitations	Data sharing and availability remain significant challenges in many regions. Poorly informed models due to data limitations reduce the reliability of food web models and their outputs.
Communication between disciplines	There is often a disconnect between stock assessment modellers and ecosystem modellers, leading to misaligned advisory questions and model capabilities. Effective interdisciplinary communication is crucial to ensure cohesive and relevant model applications.
Dealing with uncertainties	Handling and communicating uncertainties inherent in food web models can be complex. Developing standardised ways of presenting and visualising outputs, such as using tools like the advice explorer, can aid in this process.
Institutional support	Modellers often lack recognition and credit for their work, with many running out of contracts and struggling for time to publish papers. An official mandate and external recognition could enhance the motivation and output quality.

Actions to Enhance the Systematic Use of Food web Models

Table 4.3 Actions to enhance the systematic use of food web models to deliver ICES advice.

Action	Description
Inventory and roadmap development	Creating an inventory of models, their objectives, and regional questions is a foundational step. Developing a roadmap from the initial idea to model publishing can streamline the process and ensure systematic progress.
Outward communication	Promoting the work of ICES expert groups using food web models, demonstrating their capabilities, may attract increased support or interest from ICES requesters.
Standardisation of indicators	Establishing a list of standard indicators and linking them to advice ensures consistency, relevance, and a targeted purpose for the development of food web models.
Joining benchmarks	Increased collaboration between single species and ecosystem research silos may be encouraged by engagement during benchmark workshops, where ecosystem experts or food web modellers are encouraged to attend.
Evaluation pipelines	Developing a pipeline, inspired by the key run recommendations of WGSAM, could help to standardise model evaluation and reporting and increase transparency and comparability.
Stakeholder engagement	Involving stakeholders in model development builds trust and ensures models are fit for purpose. Engagement with MIRIA and MIACO could also increase understanding of ecosystem approaches and methods.
Funding and data improvements	Securing funding to improve data availability and quality is critical. Research groups need support to maintain and enhance ecosystem models, develop more ensemble models, and continue or establish new time series.
Open data sources	Promoting open data sources and ensuring data accessibility will support broader model development and application.
Interdisciplinary collaboration	Ensuring that stock assessors, ecosystem modellers, and other relevant disciplines are involved in working groups fosters a holistic approach to ecosystem management.

Incorporating food web models into ICES advice requires overcoming several barriers, including rigid management systems, capacity constraints, data limitations, and communication gaps between disciplines. By developing standardized practices, enhancing interdisciplinary collaboration, and securing funding, the systematic use of these models can be significantly improved. Establishing clear guidelines, promoting open data sources, and ensuring robust training and stakeholder involvement are critical steps toward making food web models a reliable tool for ecosystem-based management.

4.2.3 ToR c priorities

Priority 1

Develop a library of the food web models (approach and area) used across ICES expert groups.

Priority 2

Develop systematic and transparent food web model documentation and assessment pipelines.

- Improve links with the modelling community and the Transparent Assessment Framework (TAF).
- Develop and share scripts for the generation of model documentation and assessment reports which link to the skill assessment criteria established by WGSAM.

5 ToRd: Food webs and Ecosystem Overviews

Tor d) Develop a pipeline proposal to strengthen the 'food web' component of ICES ecosystem advice (ICES Ecosystem Overviews) that can be applied in a consistent way across ICES ecoregions and preferentially on the short-term timescale

5.1 Background to ToRd

The ICES EOs include food web sections but they remain largely disparate between EOs and often lack information or indicators of status. Food web indicators were identified as a priority for EOs by WKEO3. ToR d will explore options and development needs (building on ToRs a-c) for the development of an evidence pipeline to systematically improve the food web information included in EOs.

5.2 Report from break out groups focussing on the development of food web products for Ecosystem Overviews

5.2.1 Food web indicators

Table 5.1 Short-, medium-, and long-term objectives for the incorporation of food web indicators in ICES Ecosystem Overviews.

Short-term
Recommend exploring the use of the network indicator developed by the EwE4GES working group
Recommend exploring the use of the network indicators developed by Lenfest working group on 'Benchmarks for Ecosystem Assessment'
Establish the criteria for indicators: ○ Integrated food web indicators covering several trophic levels ○ Easy to explain and easy for non-experts to understand ○ Clear response to an identifiable driver/pressure ○ The change in the indicator should be proportional to the response of the food web. ○ Where indicators are taken from models, models should be sufficiently peer reviewed (i.e., ICES key run) ○ Indicators should be comparable and applicable across ecoregions ○ Indicators should be linked explored relative to thresholds/tipping points ○ Indicators should be relevant to management needs and policy objectives
Medium-term
Systematic review of the capacity to produce food web indicators within ICES, with a focus on those derived from EwE models: which indicators are most influenced by model topology. Peer-reviewed publication from WKFoodWeb.

Investigate area specific thresholds or tipping points for indicators. Develop additional key run models to support the development of food web indicators for ICES advice products.
Long-term
Investigate and communicate trends and changes in the food web indicators included in ICES advice.

5.2.2 Food web visualisation

Table 5.2 Short-, medium-, and long-term objectives for the development of a food web visualisation tool for Ecosystem Overviews.

Short-term
Represent key trophic groups in ICES ecoregions and enable edits based on key species within ecoregions: ○ Information already exists in the EOs to specify the groups/species which are key ○ Suggest 8 core components: primary producers, zooplankton, pelagic fish, demersal fish, seabirds, mammals, benthos, and cephalopods. ○ Illustrate biomass of each group Visualise trophic links between groups: ○ Incorporate a simplified and relative visualisation on the infographic to enable comprehension and comparison between ecoregions. ○ Link strength should be quantified by best available information (ecosystem models, Linear Inverse Modelling, qualitative information, conceptual models) ○ Include flows to fisheries Add advice relevant information to encourage ecosystem-informed requests: ○ Highlight key species and predator/prey dependencies ○ Identify the most important drivers of change or ecosystem/environmental signals impacting ecosystem structure and function.
Medium-term
Interactive version that enables users to click on food web components to access additional information. Links from species/groups to ecosystem services Trade-off information
Long-term
Incorporate information on carbon and the biological carbon cycle (WKFISHCARBON) Visualise how pressures propagate across ecosystem services via direct and indirect mechanisms.

5.2.3 ToR d priorities

Priority 1

Ecosystem Overview product 1: Food web visualisation

- Purpose: visualise key food web interactions, food web structure, and highlight considerations for EBM/EBFM (e.g., priority links between production and environment).

Priority 2

Ecosystem Overview product 2: Food web indicators

- Purpose: describe the state of the food web using indicators which are useful in the context of policy and management needs

6 Ecosystem-based fisheries management showcase

ICES sees Ecosystem-Based Management (EBM) as the primary approach for the management of human activities affecting the ecosystems and Ecosystem-Based Fisheries Management (EBFM) as the constituent part of the management addressing the fishing sector. The ICES community possess the necessary tools and expertise to develop ecosystem informed fisheries advice, when requested and/or needed, which recognises the impacts of environmental variation on stock production and/or assesses trade-offs, for example between prey harvest and predator carrying capacities. Tools such as Management Strategy Evaluation (MSE) and Ecological Reference Points (ERPs), informed by ecosystem information, offer robust frameworks for assessing the potential impacts of alternative management strategies on commercially targeted populations, their predators, and the wider ecosystem, facilitating integrated decision-making, and promoting ecosystem resilience. These tools can be used to stress test the existing advice system and evaluate whether current advice can meet broader ecosystem goals (e.g., Good Environmental Status).

ICES science and advice on fishing and fishing opportunities includes ecosystem information both implicitly (e.g., as variability in single-species stock assessments; Trenkel *et al.*, 2023) and explicitly (e.g., as ecological reference points [Feco] and within ICES Ecosystem, Fishing, and Aquaculture Overviews) (Figure 6.1).

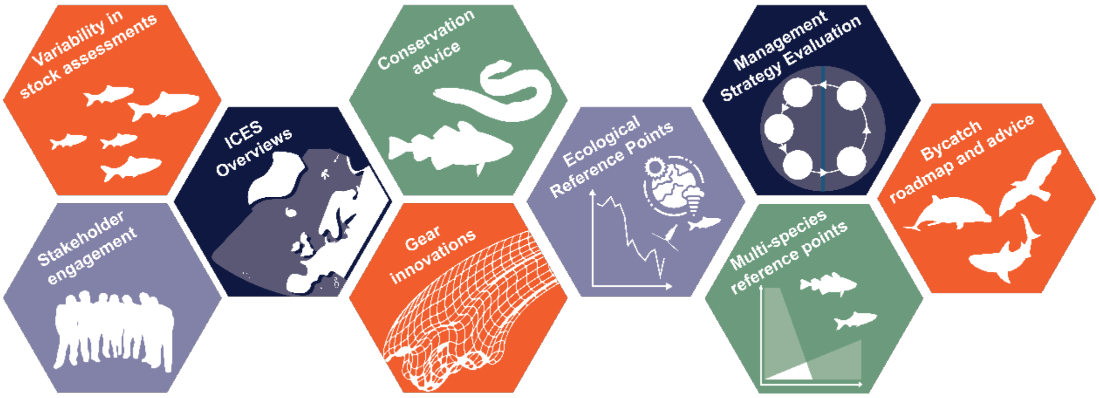


Figure 6.1 Ecosystem informed ICES science and advice.

We have provided an overview below of five pragmatic EBFM approaches which could be further explored, refined, and requested for ecosystem-informed advice. These include:

1. ICES ecosystem-based fishing reference point (Feco)
2. Ecological Reference Points (ERPs) for predator-prey trade-offs
3. Management Strategy Evaluation (MSE)
4. Multispecies reference points
5. Prey availability index

6.1 ICES ecosystem-based fishing reference point (F_{eco})

In 2019, an ecosystem-based fishing reference point (F_{eco}) was proposed by the ICES benchmark workshop for the Irish Sea (WKIrish; ICES, 2020; Howell *et al.*, 2020; Bentley *et al.*, 2021). F_{eco} is an approach to allow ecosystem information or outputs of ecosystem models to be used to tune target species catch advice to account for medium term ecosystem driven variability in productivity. In many cases, this medium-term variability is not accounted for in assessment models and subsequent catch advice, meaning that there is a risk that the advised fishing pressure is out of step with the current state of the ecosystem. ICES WKREF2 (Workshop on ICES reference points; ICES, 2022b) recommended that ICES guidelines include the possibility to use an F_{eco} approach to adjust the catch advise based on ecosystem model information, given that 1) advise does not violate the precautionary principle, 2) the model used is reviewed by ICES WGSAM, and 3) the implementation is evaluated and reviewed via ICES benchmark processes.

F_{eco} entails identifying indicators (either physical or synthetic model outputs) which track stock productivity, and then using these indicators to scale up or down the predefined single species fishing mortality targets (Figure 6.2), while not exceeding the predefined limit reference points (i.e., ICES Flim and Blim). The F_{eco} approach is currently operational for Irish Sea cod (ICES, 2023c), which has an F_{eco} reference point responsive to changes in temperature: fishing mortality is reduced towards the lower end of the 'pretty-good yield' range when temperatures are above the long-term average, and vice versa. It is important to note that only Category 1 stocks currently support 'pretty-good yield' ranges.

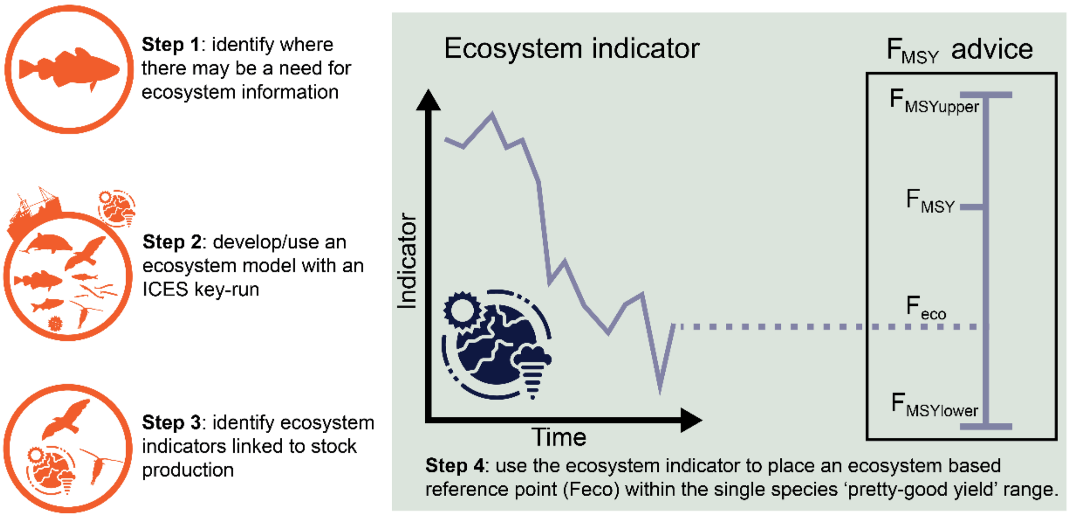


Figure 6.2 ICES ecosystem-based fishing reference point (Feco). Feco provides an option to adjust Total Allowable Catch advice, within the existing 'pretty good yield' range, in recognition of links between environmental/ecosystem variation and stock production.

6.2 Ecological Reference Points (ERPs) for predator-prey trade-offs

Ecological Reference Points (ERPs) can be developed to account for the dietary needs of forage fish predators. While quantitatively based predation mortality is often included in forage species assessments (Trenkel *et al.*, 2023), specific analysis of whether forage fish biomass meets predator requirements is not systematically conducted (ICES, 2023a). ERPs provide a mechanism to enhance catch advice in recognition of the trade-offs between forage fish yield and predator carrying capacity.

As an example, the Atlantic States Marine Fisheries Commission (ASMFC) determined that ERPs were needed that accounted for the dietary needs of predators which were dependent on an important forage fish found along the U.S. Atlantic coast: menhaden (*Brevoortia tyrannus*) (Chagaris *et al.*, 2020; Anstead *et al.*, 2021). Managers and stakeholders were concerned that recent declines in several predator stocks, also managed by the ASMFC, were linked to insufficient prey, and wanted quantitative reference points that accounted for menhaden's role as a forage fish to use for determining stock status and setting quotas. ERPs were established based on the trade-off between menhaden fishing mortality and the biomass of the most sensitive predator: striped bass (*Morone saxatilis*). ERPs were designed using ecosystem models to strategically inform assessment models, where, based on ecosystem information, the target fishing mortality could be scaled down to ensure enough prey remained for striped bass to reach their biomass target (Figure 6.3).

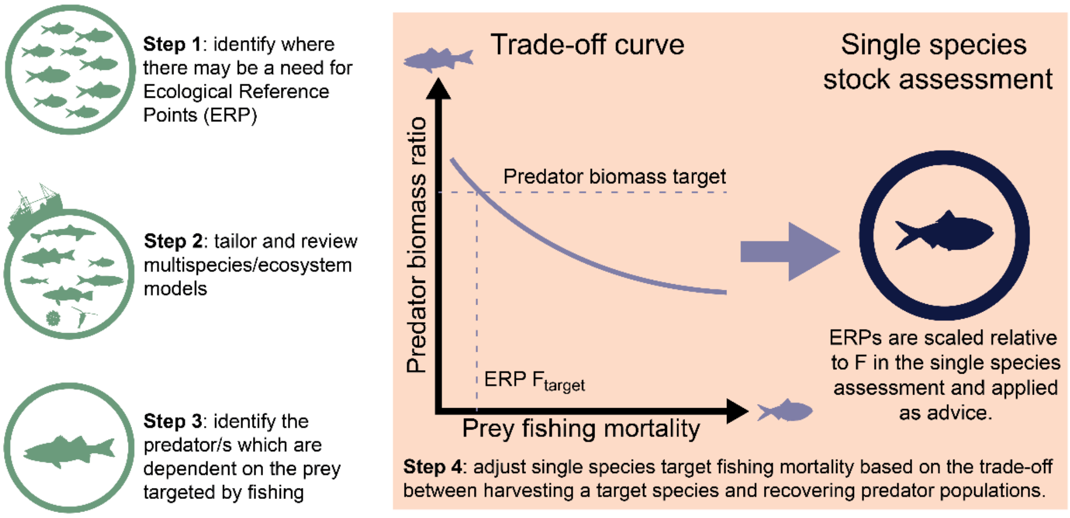


Figure 6.3 Ecological Reference Point (ERP) to adjust single species advice based on the trade-off between harvesting a target species and reaching predator biomass targets.

6.3 Management Strategy Evaluation (MSE)

Management Strategy Evaluation (MSE) has been used to develop management plans that are robust to uncertainty for a variety of data-rich stocks but also data-limited stocks such as English Channel sprat (Siple *et al.*, 2021; Walker *et al.*, 2023). MSE is a simulation approach that tests alternative options for management, monitoring, and assessment given the uncertainty in ecological, fishery, and survey observational processes. It has become a key method for evaluating trade-offs between management objectives, communicating with decision-makers, and has grown from a single-species approach to one relevant to multispecies and ecosystem-based management (Kaplan *et al.*, 2021).

There are several ways in which ecosystem objectives and reference points for target species could be evaluated and Operating Models (OM) conditioned when conducting MSE (Figure 6.4). The choice depends on the level of knowledge, data, and models available, summarised by de Moor (2023) and include:

1. Using an ecosystem model as an OM.
2. One-way coupling of a single-species OM with a Predator Model.
3. Splitting natural mortality into the background mortality and predation mortality.
4. Using performance statistics based on ecosystem thresholds.
5. Informing control parameters of the Harvest Control Rule.
6. Adjusting performance statistics related to the ecosystem.

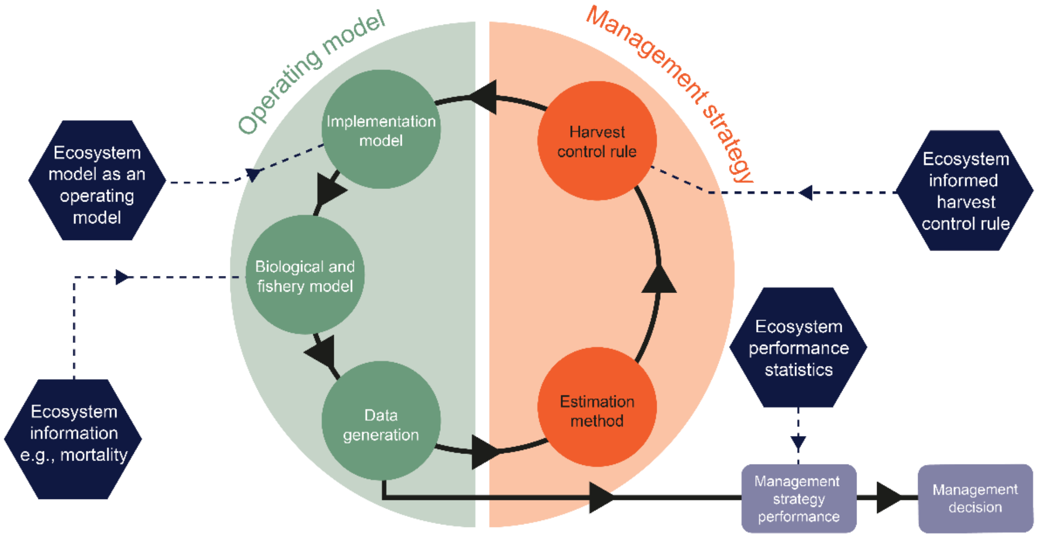


Figure 6.4 Routes for the integration of ecosystem information (hexagons) into Management Strategy Evaluation (MSE) to assess Ecosystem-Based Fisheries Management strategies.

6.4 Multispecies reference points

Following the precautionary approach, fishing mortality is considered precautionary if there is a less than 5% probability that Spawning Stock Biomass (SSB) will fall below B_{lim} in the long-term. However, as recognised for the development of ERPs, fishing on one species affects the biomass of other species. Single-species models largely disregard interspecific interactions when delivering estimates for MSY. This is problematic in a multispecies context (Fulton *et al.*, 2021), as it is impossible for single species MSY to be simultaneously attained for different species whose maximum yields correspond to different ecosystem states (Walters *et al.*, 2005; Link *et al.*, 2018).

Alternative multispecies translations of single-species MSY have demonstrated how multi-species/ecosystem models can be used to account for species interactions to simultaneously maximise the yields of multiple species (e.g., Thorpe *et al.*,2019; Del Santo O'Neill *et al.*, 2024). In the context of the ICES precautionary approach, it is possible to search for fishing mortality scenarios where multiple species are simultaneously precautionary (Figure 6.5). Doing so requires a rigorous quantification of uncertainty, which requires the use of an ensemble of ecosystem models to predict long-term spawning stock biomasses under alternate fishing mortalities (Spence *et al.*, 2018; Spence *et al.*, 2022).

The use of multispecies models to simultaneously maximise yields, and ensemble models to quantify uncertainty, provides a path to overcome the current limitations of single-species MSY and deliver more holistic and rigorous approaches for EBFM.

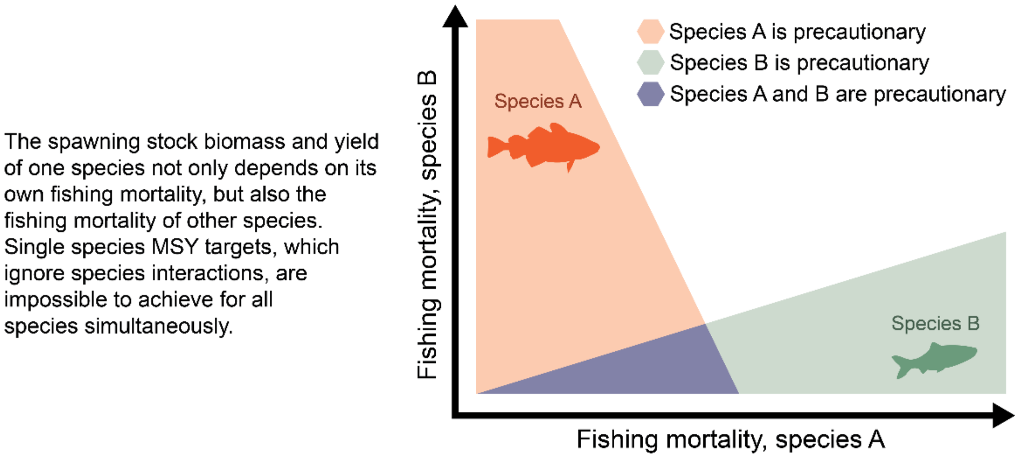


Figure 6.5 Precautionary multispecies harvest. The image demonstrates a two-dimensional precautionary harvest, showing regions where species A is precautionary and species B is precautionary, with the intersecting region being the space where both species are simultaneously precautionary.

6.5 Prey availability index

Cafferty (2024) proposed a simplified "Available Food Index (AFI)" to measure variable food availability: fish populations respond to food availability, yet evaluating available food for a species without detailed ecosystem modelling can be challenging (Figure 6.6). Food limitation is often modelled using density dependence, which oversimplifies the reality by assuming constant food availability. AFI uses stomach data and prey abundance indices: stomach data is limited for most stocks, but when combined with the often-better prey abundance data, it can create a useful AFI. AFI can be integrated into stock assessment models as a covariate on productivity parameters or as a tuning index for ecosystem models. The AFI challenges the simplistic focus on a single prey species by offering a comprehensive view of multiple prey species' effects on predator condition over time. In such cases, the AFI provides a more complete picture of food availability and predator-prey dynamics, informing more accurate assessment models and improving fisheries management.

The AFI has been demonstrated for Northeast Arctic (NEA) cod in the Barents Sea using prey biomass time series from stock assessments and 40 years of cod stomach data. Capelin biomass alone was a reasonable approximation for NEA cod food availability during peak periods as it accounted for most of the variability in the diet. While focusing on capelin alone suffices for NEA cod, this may not be valid for predators without a dominant single species prey. AFI can be used as a metric for the growth and development of predator fish, providing useful additional information to enhance existing single-species assessments.

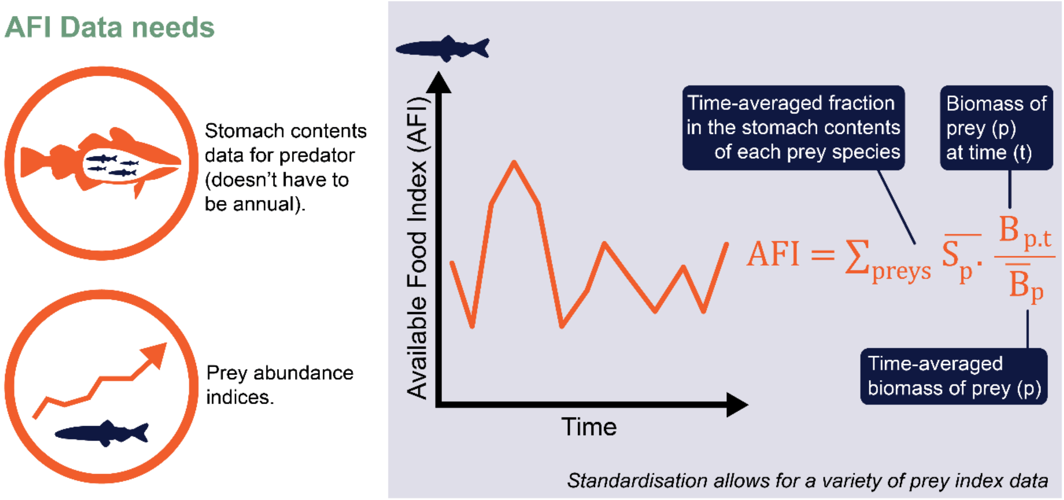


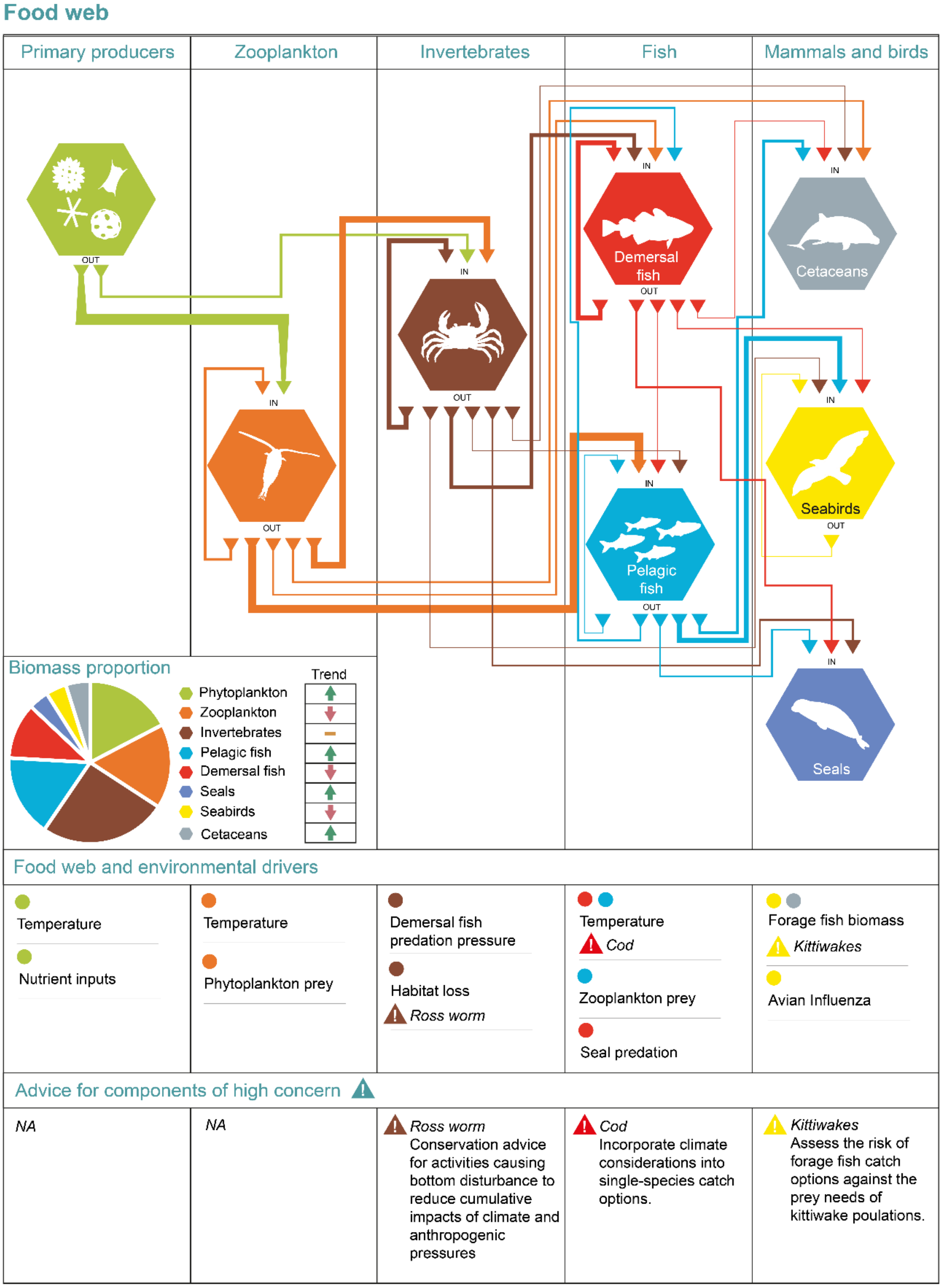
Figure 6.6 The Available Food Index (AFI; Cafferty, 2024) is created by multiplying the time averaged fractions of prey in the stomach by the standardize index through time. The fraction is averaged as a simple mean across years for each age. This process creates individual prey abundance indices which can be compared with the individual prey diet fraction and overall diet composition.

7 Ecosystem Overview food web visualisation concept

WKFoodWeb were asked to develop concepts for food web products to be included in the ICES Ecosystem Overviews. The group identified that it would be important to visualise marine food webs in a way that 1) can be applied across ICES ecoregions, irrespective of the preferred or available tools within ecoregions, and 2) can convey not just information (a common critique of EOs) but also tangible ecosystem-informed advice for decision makers.

Building on this, WKFoodWeb proposed that the product should be structured into four complementary components to effectively communicate food web information in a way that is actionable and consistent across ecoregions. These components are: (1) a flow network diagram that illustrates the main food web components and their interactions, offering a clear visualisation of key trophic relationships and energy flows; (2) an overview of general trends in key food web components, summarising whether they are increasing, decreasing, or stable, to highlight temporal changes and potential areas of concern; (3) a way to highlight the key environmental drivers influencing the productivity of food web components; and (4) a component linking observed trends and established relationships to management actions, such as ecosystem-informed catch advice or habitat protection measures, ensuring that the product not only informs but also actively supports decision-making and the implementation of ecosystem-informed science and advice.

A concept for the food web product is provided (Figure 7.1), along with a breakdown of the purpose of its individual components.



Biomass proportion	Trend
Phytoplankton	↑
Zooplankton	↓
Invertebrates	–
Pelagic fish	↑
Demersal fish	↓
Seals	↑
Seabirds	↓
Cetaceans	↑

Primary producers	Zooplankton	Invertebrates	Fish	Mammals and birds
● Temperature ● Nutrient inputs	● Temperature ● Phytoplankton prey	● Demersal fish predation pressure ● Habitat loss ⚠ *Ross worm*	●● Temperature ⚠ *Cod* ● Zooplankton prey ● Seal predation	●● Forage fish biomass ⚠ *Kittiwakes* ● Avian Influenza

Advice for components of high concern ⚠

Primary producers	Zooplankton	Invertebrates	Fish	Mammals and birds
NA	*NA*	⚠ *Ross worm* Conservation advice for activities causing bottom disturbance to reduce cumulative impacts of climate and anthropogenic pressures	⚠ *Cod* Incorporate climate considerations into single-species catch options.	⚠ *Kittiwakes* Assess the risk of forage fish catch options against the prey needs of kittiwake poulations.

Figure 7.1 Concept for the visualisation of marine food webs for the ICES Ecosystem Overviews. The concept includes four components: 1) an illustration of the structure and flow of energy within the food web, 2) an overview of the current trends in ecological components, 3) identified environmental drivers of ecological components, and 4) specific recommendations for ecosystem-informed advice and management.

7.1 Component 1: Ecosystem structure and flows

The first component of the food web product focuses on visualising how energy flows between key food web components, emphasising the interconnectedness and relative dependencies within ecoregions.

At a minimum, we suggest that the flow network should include primary producers, zooplankton, invertebrates, demersal fish, pelagic fish, cetaceans, seabirds, and seals. These categories provide a baseline structure applicable across ICES ecoregions. However, ecoregions might be encouraged to disaggregate these components when specific species or groups are of particular importance. For example, the Baltic Sea might choose to display fish as sprat, herring, cod, and other species, ensuring that the visualisation reflects regional ecological nuances while maintaining consistency with the broader framework.

The connections between nodes, representing energy transfer (e.g., consumption), should display the relative dependence of each component. These flows can be quantified using the best available knowledge, whether derived from empirical data, analytical approaches, expert knowledge, or modelling. This flexibility ensures that the product can be applied consistently across regions, regardless of data availability or methodological preferences.

7.2 Component 2: Food web biomass proportions and trends

The second component of the product focuses on quantifying and presenting the relative contribution of each food web node (specified in component 1) to the total biomass of the ecosystem, along with recent trends in biomasses. This component provides context for understanding the balance and dynamics of the food web, offering a snapshot of the ecosystem's state and its trajectory over time.

The biomass proportion aspect serves to describe the relative contribution of each food web component to the total biomass of the system. Visualising these proportions highlights the dominant groups within the ecosystem. Recent trends in the biomass of each component are equally important to provide insights into how the ecosystem is changing over time. These trends can reveal shifts in the balance of the food web, such as declines in top predators or increases in lower trophic levels, which may signal ecological changes or pressures. Many ICES ecoregions can use this as an opportunity to implement the extensive Integrated Trend Analyses (ITA) conducted in recent years to inform this aspect. However, as with component 1, ecoregions might also rely on other best available information, including empirical data, expert assessments, or modelling outputs.

By coupling this component with the links to environmental drivers in component 3 (key environmental drivers), it becomes possible to identify potential causes behind observed trends, such as climate change, habitat loss, etc. This integration can help to inform prioritisation processes, allowing decision-makers to focus efforts on the most critical components of the food web or the pressures driving significant changes.

7.3 Component 3: Links to environmental drivers

The third component aims to identify and describe the environmental drivers influencing the productivity and mortality of described food web components. Drivers might include physical indicators (e.g., temperature), predation, pollution, disease, prey availability, and indirect effects of human activities such as habitat loss.

Environmental drivers can be linked to specific nodes in the food web (e.g., temperature influencing demersal fish productivity), offering a broad overview of pressures on ecosystem components. Additionally, this section should provide an opportunity to highlight species or populations of particular concern. For example, a specific cod stock experiencing changes due to warming waters or increased predation pressure can be explicitly addressed. This dual-level approach—linking to general nodes and specific cases—enhances the utility and specificity of the product for cross ecoregion comparison.

Links to drivers can be informed by the retrospective analyses conducted by IEA and other groups, which have explored the environmental and anthropogenic factors shaping food web dynamics. As with the other components, the data and insights for this section should draw on the best available science, whether quantitative (e.g., statistical analyses, models) or qualitative (e.g., expert judgment, observational studies). The methods and data underpinning these links should be transparently documented, allowing for traceability and reproducibility. Where appropriate, detailed descriptions of the connections can be included in Ecosystem Overview workshop reports.

This component is critical for bridging the gap between food web structure and trends (components 1 and 2) and the actionable advice outlined in component 4 (Ecosystem-informed advice). By establishing clear links between drivers and food web components, this section provides the contextual understanding necessary for translating ecosystem science into ecosystem advice.

7.4 Ecosystem-informed advice

The fourth component seeks to address a common critique of ICES Ecosystem Overviews—that they are primarily informational and not directly used or useful for decision-making. The objective of this component is to seek the maturation of Ecosystem Overviews by explicitly linking ecosystem information to actionable advice, providing pathways for the integration of ecosystem considerations into management decisions. By doing so, it progresses Ecosystem Overviews from a descriptive product towards a proactive product for decision-making.

The goal is to bridge the gap between ecological knowledge and actionable advice by connecting the insights provided in Components 1–3 (ecosystem flows, biomass proportions and trends, and links to drivers) with specific management recommendations. The outputs could be directly linked to advice (e.g., ecosystem reference points or conservation considerations in catch advice) or could be used to signpost opportunities for requesters to seek additional or enhanced advice products, depending on the maturity of the underpinning science and the specific needs of stakeholders.

The advice provided in this section can vary depending on the level of understanding and data availability for a given ecoregion. In cases where the science is well-developed, detailed and specific advice may be offered. In other cases, where science is still evolving, the advice may focus on identifying gaps or proposing exploratory approaches for integrating ecosystem information into management. This approach is in line with the iterative development of science and advice as described in the ICES Framework for Ecosystem-Informed Science and Advice (FEISA).

Investment in the development of component 4 (and similar initiatives) is essential for ensuring that the Ecosystem Overview have tangible impacts and that ICES are active in progressing advice for Ecosystem-based Management and Ecosystem-Based Fisheries Management.

8 Ecosystem Overview food web indicator concept

WKFoodWeb were asked to develop concepts for food web products to be included in the ICES Ecosystem Overviews. Workshop participants recommended that the group explore and identify candidate indicators which can be used to deliver comprehensive ecosystem information and advice that encourages the implementation of Ecosystem-Based Management (EBM). During a breakout workshop, participants discussed important criteria for indicators (in addition to those in Table 1.1) which might be of value to Ecosystem Overviews relative to the needs of requesters of ICES advice. Key characteristics discussed included:

- ***Ability to holistically describe marine ecosystems***:

Indicators which capture the overall condition of marine ecosystems were discussed as a high priority given their relative absence in existing advisory products and management considerations in the Northeast Atlantic. For example, indicators commonly used, such as those for Good Environmental Status (GES), tend to focus ecosystem components which may be reflective of wider ecosystem condition (e.g., seabirds and plankton). These indicators may be favourable in frameworks which require regular monitoring to meet statutory obligations, however WKFoodWeb discussed whether such restrictions would apply to the indicators produced by ICES, which might have greater freedom to incrementally develop more holistic ecosystem indicators for strategic guidance. Such indicators could summarise the condition, trends, or thresholds in biodiversity, productivity, and ecological interactions (network analyses).

- ***Indicators should be linked to advice for management***:

A preference should be given to indicators which can be linked to recommendations for management actions based on indicator status. For example, indicators linked to exploitation, pressures, or hub species may be useful in the context of fisheries, aquaculture, and conservation advice, among other opportunities.

- ***Indicator estimation should be possible across ecoregions***

For comparison between ecoregions, it would be preferable for indicators to follow a common method for estimation, whether using data or models. However, given the breadth of ecoregions and disparity in available data, models, and capacity between them, it would be sensible to not be too restrictive and encourage the incremental development of indicators using the best available science for each ecoregion (following the FEISA framework). This may lead to the use of alternative methods for estimation of indicators which we would argue has positive repercussions, such as widening our capacity to understand structural uncertainty in estimation methods and scope possibilities for the development of ensemble approaches.

8.1 Selected indicators

Table 8.1 provides an overview of indicators identified by WKFoodWeb as potential products for ICES ecosystem overviews.

Indicator	Information	Reference
Ryther index	Ecosystem overfishing indicator. The Ryther Index is defined by Link and Watson (2019) as total catch per unit area in the ecosystem and represents an advanced way to detect the total removal of fish biomass by area in a Large Marine Ecosystem relative to how much that entire ecosystem can produce. In	Link and Watson, 2019; Link 2021

Indicator	Information	Reference
	general terms, the lower the Ryther index, the less likely an ecosystem will be experiencing ecosystem overfishing. (Data based)	
Topology/ hub-index	Topology indicates how the ecosystem is structured and which species are most integral to this structure (hub-index). Calculating the hub-index involves calculating standard network metrics for each species in the ecosystem.	Fulton and Sainsbury, 2024a; Fulton and Sainsbury, 2024b
Resiliency	Network resiliency provides a deeper understanding of network structure and strength by estimating the effective state of the system in the space of all possible conditions.	Gao *et al*., 2016; Fulton and Sainsbury, 2024b
Distortive pressure	Identifies which stocks are receiving the greatest distortive pressure in the system, thereby informing when and where management actions should take place. A "Green Band" method is used to identify which stocks are receiving the greatest distortive pressure in the system. The Green Band Index is calculated by plotting the fishing pressure on an ecosystem against its unfished profile.	Fulton and Sainsbury, 2024b
Ecosystem Traits Index	Topology, resiliency, and distortive pressure can be calculated on their own, but when combined, they produce a qualitative score of ecosystem traits and health. An ecosystem's ETI score signals its spectrum of health, from pristine to when it is at risk for collapse.	Fulton and Sainsbury, 2024b
Biomass to fisheries catch ratio (B/C)	Model or empirical data based, sensitive to fishing impact. Also responds to changes in primary productivity. Tested in Fu *et al*. (2019). The consistent threshold response in the indicator B/C at low levels of fishing pressure (around 0.4*FMSY) suggested that this indicator would be a good candidate for assisting in ecosystem-level decision making for fisheries management across the globe, although B/C is unlikely to be responsive at higher levels of fishing pressure.	Fu *et al*., 2019
Integrated trophic indicators	Data or model based. Mean trophic level of the catch, the mean trophic index of the fish community and mean trophic links per species. Tam *et al*., 2017	Fu *et al*., 2019; Tam *et al*., 2017
Guild level biomass (and production)	The guilds should be determined as appropriate for the taxa in a given regional sea, i.e. primary and secondary producers, benthos, planktivores etc.	Tam *et al*., 2017; Thompson *et al*., 2020; Faithfull & Bergström, in press
PPR to sustain a fishery	Primary production required to sustain a fishery	Tam *et al*., 2017 Pauly and Christensen, 1995
Seabird (charismatic megafauna) productivity	The breeding success of seabirds or mammals addresses the structural and functional attribute of a food web and can also serve as a proxy for resilience. (sandeels)	Tam *et al*. 2017 OSPAR, HELCOM, MSFD, UK MS
Zooplankton size biomass index	This Zooplankton Mean Size and Total Stock HELCOM core indicator evaluates the zooplankton community structure to determine whether it reflects good environmental status (GES).	Tam *et al*., 2017 OSPAR, HELCOM, MSFD, UK MS

8.2 Case study: the Baltic Sea Ecoregion

Lead authors: Riikka Puntila and Carolyn Faithful

The data/model availability for the Baltic Sea ecoregion was evaluated as the first step to address the applicability of the indicators. Many of the indicators from Fulton and Sainsbury (2024b) rely on network models, although the metrics can also be calculated from data.

8.2.1 Ryther index

- ***Introduction:***

The proposed thresholds are based on carrying capacity limits of the production of communities of fish populations, which are limited by trophic transfer efficiencies (TTEs). The index reflects the basic tenet of renewable natural resource management, such that any harvest meets the condition of Rremoval ≤ Rrenewal for each rate (R).

- ***Data/model needed:***

The Ryther index is composed of total catch presented on a unit area basis for an ecosystem. A general threshold of 1 t/km/y is proposed by Link & Watson (2019), with the recommendation that the Ryther index should probably be 0.3–1.1 t/km/y. Tipping points for overfished ecosystems occur at 3–5 t/km/year (Bundy *et al.*, 2012; Tam *et al.*, 2017) at expected system-wide MSYs of 1–3 t/km/year.

- ***Data/model available for the case study area:***

Total catches of individual species for each ICES sub-division are reported to ICES on a yearly basis. This data can be summed to encompass the whole Baltic Sea or a specific area or basin of interest.

- ***Gaps identified:***

The Ryther index is solely based on total catch per unit area and does not consider the productivity of the system. Other similar indices incorporate the productivity of the ecosystem, i.e. the Fogarty index is the ratio of total catches to total primary productivity in an ecosystem and the Friedland index is the ratio of total catches to chlorophyll in an ecosystem. However, some studies have found that PP or chlorophyll does not correlate well with MSY (Bundy *et al.*, 2012). Water temperature has a major influence on productivity, although different measures of temperature were important in different sea areas. Thus, basins with different average surface water temperatures may need to have different thresholds for the Ryther index (Bundy *et al.*, 2012). MSYs ranges of 0.1–0.4 /y were the optimal exploitation rate (Bundy *et al.*, 2012).

- ***Evaluation of operationality:***

Can be easily calculated with current available data and can be back calculated to estimate historical levels of overfishing. However, this is not a comprehensive ecosystem indicator, but can be used to estimate ecosystem overfishing. In common with all metrics based on catches, the accuracy of this index is subject to errors in catch reporting. Can be operational directly.

8.2.2 Topology/hub-index

- ***Introduction***

Topology is estimated by conducting a criticality analysis to define "Hub Species". These are defined via two parameters 1) Degree score and 2) Page Rank Index. The first, degree score, highlights species with high connectivity—those that have many “local” connections (high local centrality) and the Page Rank Index often highlights forage species such as large zooplankton, forage fish, and invertebrates as important prey species that support the foodweb.

- ***Data/model needed:***

The index involves calculating standard network metrics for each species/functional group in the ecosystem. The index can be calculated for each species, but in essence a highly resolved network model would readily provide the information.

The Hub Index is calculated as:

Hub(index) = min (Rdegree, Rdegree_out, Rpagerank)

where Rdegree is the rank for that species or group based on its degree (sum of connections in and out of the group, for example, the number of its predators and prey), Rdegree out is the rank for that species or group based on its degree out (the number of predators the group has) and Rpagerank is the rank for that species based on the number and quality (weight) of links to that species (species that are cross linked, supporting many other species achieve a higher page rank).

A Hub index score of 1 indicates the highest score for that measure in the network. The species ranked in the top 5% for the network based on this score are considered hub species.

- ***Data/model available for the case study area:***

Data available, network models are available for the Baltic Sea (Bauer *et al.*, 2018; Kortch *et al.*, 2021; Korpinen *et al.*, 2022).

- ***Gaps identified:***

Models require review by WGSAM for key run and use in ICES advice.

- ***Evaluation of operationality:***

Can be operational within 5 years.

8.2.3 Resiliency

- ***Introduction***

This index builds on work by Gao *et al.* (2016). The index relies on two metrics of the network: 1) network heterogeneity of flow (aka degree heterogeneity) and 2) density of network connections. Furthermore, the parameter βeff (which is the effective state of the system in the space of all possible conditions β) is needed to define the potential states available for the network. The final resilience score (R)—is based on where the network sits in (H, <s>) space versus the βeff surface.

- ***Data/model needed:***

The index is calculated for the entire network (aka ecosystem). The parameters can perhaps be calculated from data but would be easily extracted from a network model. Models available for the Baltic Sea (Bauer *et al.*, 2018; Kortch *et al.*, 2021; Korpinen *et al.*, 2022).

- ***Data/model available for the case study area:***

Data available, network models available (Bauer *et al.*, 2018; Kortch *et al.*, 2021; Korpinen *et al.*, 2022).

- ***Gaps identified:***

Models require review by WGSAM for key run and use in ICES advice.

- ***Evaluation of operationality:***

Can be operational within 5 years.

8.2.4 Distortive pressure

- *Introduction:*

Ecosystems have evolved to withstand pressures that are placed on them from natural processes such as predator-prey dynamics, weather patterns, and species interactions. Pressure applied to the system outside of these dynamics, i.e. fishing will create a pattern differential that potentially distorts the system structure.

- *Data/model needed:*

The unfished profile of the system needs to be calculated, which is the relationship between fish biomass and production. To calculate the unfished profile, data on the biomass of the species (t/km/y) and the production of the species (t/km/y) are needed. Using the regression line from the unfished biomass the "acceptable" pressure levels in the fished system (also called the "Green band") are defined as 1+ a where a is the slope of the regression line and the upper bounds of the acceptable pressure levels are given by: Ybound = min (0.5P, P^1+a). The range of the acceptable fishing levels is typically set based on the degree of variance (spread of points either side) of the unfished profile regression line (with values for the lower bound typically within two orders of magnitude of the upper bound). Current data for yield versus production is then plotted and compared to the range of acceptable fishing levels ("green band"). This can be calculated as a snapshot or moving through time to see if management is moving stocks toward to away from the optimal fished biomass.

- *Data/model available for the case study area:*

To calculate unfished biomass, time series data is available from ICES for spawning stock biomass (biomass of the species) and fish production can be estimated using stock assessment models.

- *Gaps identified:*

There is currently no published research (except for the lenfest report) using this method to estimate "distortive pressure" or acceptable fishing levels, which means there are no results to compare with or further background information to critique or verify this method.

- *Evaluation of operationality:*

Can be easily calculated with current available data and can be back calculated to estimate historical levels of overfishing. Can be operational directly, but should be used in combination with the ecosystem traits index, topology and resilience indicators.

8.2.5 Ecosystem Traits Index (ETI)

- *Introduction:*

ETI score describes the state of an ecosystem in terms of its spectrum of health. Each species or taxonomic group is classified into a category, and for each category there is a target relative biomass depletion and a statistical weight of importance. The target depletion and statistical weights may be altered in different situations (e.g. for specific management related questions). Groups are Vulnerable, Habitat, Target, Byproduct, Bycatch, Robust and Hub (as Hub species, defined earlier). These groups are rated based on its position relative to the Green Band (see Distortive pressure) and current relative biomass. The values are then combined into a matrix that is used to calculate a combination score ($\mathcal{K}$). The values of the combination scores and the Gao's resilience score (see above) are used to produce the final ETI score (Fulton *et al.*, 2024).

- ***Data/model needed:***

Most of the values used in the ETI are data based. However, the final product, the ETI score, also combines values from Resilience and Hub species indices that rely on network models.

- ***Data/model available for the case study area:***

Data available, network models are available for the Baltic Sea (Bauer *et al.*, 2018; Kortch *et al.*, 2021; Korpinen *et al.*, 2022).

- ***Gaps identified:***

Depend of the models require review or update by WGSAM for key run and use in ICES advice. The dependency of network model derived parameters requires some modelling effort. However, the biomass-based components could be useful.

- ***Evaluation of operationality:***

Can be operational within 5 years.

8.2.6 Biomass/Catch ratio

- ***Data/model needed:***

Ecosystem simulation model for the whole Baltic Sea, i.e. Ecopath with Ecosim (EwE), OSMOSE, Atlantis.

- ***Data/model available for the case study area:***

Central Baltic EwE model (Bauer *et al.*, 2018), others are being developed.

- ***Gaps identified:***

Might be difficult with current methods of estimating biomass for some groups that are not in models.

- ***Evaluation of operationality:***

Full operationality requires ecosystem models for the whole Baltic Sea or each basin. Baltic Sea model at regional sea scale are under development (Kulatska and Tomczak, in prep).

8.2.7 Integrated trophic indicators

- ***Data/model needed:***

Data or model based. Can encompass one or several of the following metrics: Mean trophic level of the catch, the mean trophic index of the fish community and mean trophic links per species.

- ***Data/model available for the case study area:***

Central Baltic EwE model, others are being developed. All metrics require good quality and regularly updated data on dietary relationships, time series of survey catch, or landings from broad regional seas and accurate, agreed upon and regularly updated assessments of the trophic levels of the ingested food. Data on dietary relationships should be available for the Baltic Sea as there are many published studies on food web linkages but would need to be collated to calculate indices. Catch data is available through ICES.

- ***Gaps identified:***

There are no agreed or general threshold values established to trigger management actions so these would need to be investigated by determining how different levels of pressures influence these indices.

- ***Evaluation of operationality:***

If using empirical data this would be operational after collation and calculation of data. If using models a full scale Baltic Sea model is needed. Baltic Sea model at regional sea scale are under development (Kulatska and Tomczak, in prep).

8.2.8 Guild level biomass and production

- ***Introduction:***

This method is similar to the MSFD and UK MS requirements for food web status and so potentially results could be linked, although we would advise against replicating existing indicators, rather developing complementary indicators (e.g., feeding guild biomass).

- ***Data/model needed:***

Data or model based. For some regional seas data may be lacking for some trophic guilds. Long time-series are useful to see how the system has changed over time.

- ***Data/model available for the case study area:***

Central Baltic EwE model, others are being developed (Bauer *et al.*, 2018). Biomass of trophic guilds for the Baltic Sea is available for primary and secondary producers, benthic deposit, filterer and predator guilds, fish planktivores, demersal fish, fish predators, apex predators (seals). This gives quite a good coverage of the trophic structure. Water bird indices (not biomass) are also available. Time series for production of trophic guilds is much more limited and these would need to be modeled.

- ***Gaps identified:***

There are no agreed or general threshold values established to trigger management actions so these would need to be investigated by determining how different levels of pressures influence these indices. There is no single metric obtained from this analysis - although this could be developed using evenness or diversity metrics or ratios between higher and lower trophic levels.

- ***Evaluation of operationality:***

If using empirical data this would be operational (for biomass) after collation and calculation of data. Development of thresholds and potentially a single metric would be required. If using models a full-scale Baltic Sea model is needed (which has been developed).

8.2.9 Primary Production Required (PPR) to sustain a fishery

- ***Data/model needed:***

Primary production estimates - which can be made from satellite data. Trophic transfer efficiencies, which can be estimated as 10–15% between trophic levels.

- ***Data/model available for the case study area:***

Data available from Copernicus.

- ***Gaps identified:***

This metric is similar to the Friedland and Fogarty indices (discussed under Ryther index). Can be problematic as there is some evidence that fisheries yields are more dependent on temperature than primary productivity.

- ***Evaluation of operationality:***

Can be calculated with existing data and EwE model (i.e Bauer *et al.*, 2018). The length of the time series depends on copernicus data availability. Recommend this is combined with the Friedland index.

8.2.10 Zooplankton mean size

- ***Introduction***

This Zooplankton Mean Size and Total Stock HELCOM core indicator evaluates the zooplankton community structure to determine whether it reflects good environmental status (GES). As a rule, good status is achieved when large-bodied zooplankters (older stages of calanoid copepods and adult cladocerans) are abundant in the plankton community. This indicator reflects both pressures (eutrophication) and food web interactions (abundance of planktivores). Increased abundance of small zooplankton (rotifers and cladocerans) is a probable consequence of eutrophication, and a decreased share of copepods, especially the older stages, is a probable consequence of size-selective predation by zooplanktivorous fish.

- ***Data/model needed:***

Zooplankton mean size and total biomass preferably long time-series.

- ***Data/model available for the case study area:***

Time series are available from HELCOM. Baltic Sea basins are assessed separately.

- ***Gaps identified:***

NA

- ***Evaluation of operationality:***

Already operational within HELCOM. Threshold values are available to indicate good environmental status. [may therefore not be needed within ICES advice if risk of replication exists]

8.2.11 Seabirds/Waterbirds or Charismatic megafauna breeding success

- ***Data/model needed:***

Water bird breeding success for a range of species. Marine mammal breeding success metrics.

- ***Data/model available for the case study area:***

HELCOM indicators for waterbird breeding success and marine mammal reproduction. Patchy time-series data are available are available for marine mammal reproduction and no recent data for harbour seals is available. For waterbird breeding success data is patchy, but available for Guillemot in the central Baltic Sea region.

- ***Gaps identified:***

HELCOM threshold status for aggregated pregnancy ratio is 90% for seals. This is currently debated as none of the seal populations meet this threshold although abundance of grey and harbour seals has reached high numbers and appears to be levelling off, indicating the seal populations may be reaching carrying capacity. It would be recommended that ICES establish its own threshold value for seal reproduction that reflects the current carrying capacity of the region.

- ***Evaluation of operationality:***

Marine mammal breeding success is operational within HELCOM. Waterbird breeding success is still under development by HELCOM (pre-core indicator). Thresholds are available for waterbird breeding success; however marine mammal breeding success thresholds may need to be revised. [may therefore not be needed within ICES advice if risk of replication exists].

8.2.12 Conclusions

Many of the indicators reviewed for the Baltic Sea ecoregion depend on availability of network models. In theory the indices can be calculated from data but in essence that would lead to a network model. There are available ecosystem models as EwE (for Central Baltic Sea i.e Bauer *et al*., 2018, and R packages that can be used to calculate the metrics (e.g. NetIndices, or once used in Kortch *et al*., 2021 (https://rfrelat.github.io/BalticFoodWeb.html)).

There is a network model available for the Gulf of Riga ecosystem, and it was used to illustrate calculations for topology and resiliency. Multiple EwE models are available for the region, although would require review by WGSAM key-run for operational use. The Ryther index or the similar Fogarty and Friedland indices (which include ecosystem production) are ecosystem overfishing indices and thus have a specific focus and relevance for fisheries. Therefore, it is recommended that these indices are used in combination with more general ecosystem indicators.

Fu *et al*. (2019) emphasised that a multi-model and multi-indicator approach will be needed to identify ecosystem changes at different levels of environmental pressure in different types of ecosystems. This is partly due to different responses and sensitivities of indicators to fishing and changes in primary productivity were more likely to be influenced by ecosystem structure (e.g. the species/taxa composition of a given ecosystem) and, to a larger extent, by fishery exploitation history. Thus, there is currently no “one indicator” that is sufficient to identify thresholds under the range of conditions found in ICES sea areas today.

Additionally, we also need to determine if we want to primarily focus on indicators that respond to fishing pressure (i.e. Ryther index) or include a wider range of indicators that respond to other types of pressures (i.e. Charismatic megafauna breeding success).

9 Proposal for the Creation of an ICES ECOHUB: Enhancing Ecosystem-Informed Science and Advice through Cross-Steering Group Collaboration

ICES expert groups work together to advance scientific understanding to inform the management of marine systems. Expert groups belong to one of eight ICES steering groups, which manage portfolios of expert groups and workshops. While ICES has long encouraged interdisciplinary and transdisciplinary research, the current structure sometimes limits the potential for sustained, systematic collaboration and the integration of information across steering groups.

Workshops which have specifically embraced cross-steering group engagement and the co-production of knowledge (e.g., WKIRISH, WKEBFAB, WKFISHCARBON, WKWIND), have often led to novel and pragmatic outcomes which have progressed ICES capabilities to provide ecosystem-informed advice. However, members of WKFoodWeb voiced that those opportunities for cross-steering group engagement felt fleeting: members were keen to see greater collaboration between the Fisheries Resource Steering Group (FRSG) and Integrated Ecosystem Assessment Steering Group (IEASG), among others.

WKFoodWeb suggests that there is a need for the development of a new type of expert group which may act as a bridge between multiple steering groups and ACOM. We propose that these groups, or ‘hubs’, would improve collaboration and focus primarily on the development of indicators, risk-based methods, and pipelines which can better align and channel the science of ICES to produce enhanced interdisciplinary advice. This would also contribute to improve communication with ACOM leadership and advice requesters and observers of ICES science and advisory processes, to ensure that the advice produced is not only scientifically robust but also directly responsive to societal and policy needs. Collaboration between ICES and stakeholders will become increasingly important as decision makers pursue their commitments to Ecosystem-Based Management (EBM), Successful implementation of EBM can be facilitated by actionable advice which reconciles decision makers needs for simple answers to complex questions in the face of complexity and increasing uncertainty.

To illustrate the utility of such groups, we recommend the creation of ICES ECOHUB (Figure 9.1). ECOHUBs purpose is to identify pathways for the development of ecosystem informed science and advice, primarily focusing on the appropriate development and use of food web indicators, information, and models that can be operationalised to provide ecosystem-informed ICES advice. Following ICES Framework for Ecosystem-informed Science and Advice (FEISA), ECOHUB would deliver the following functions:

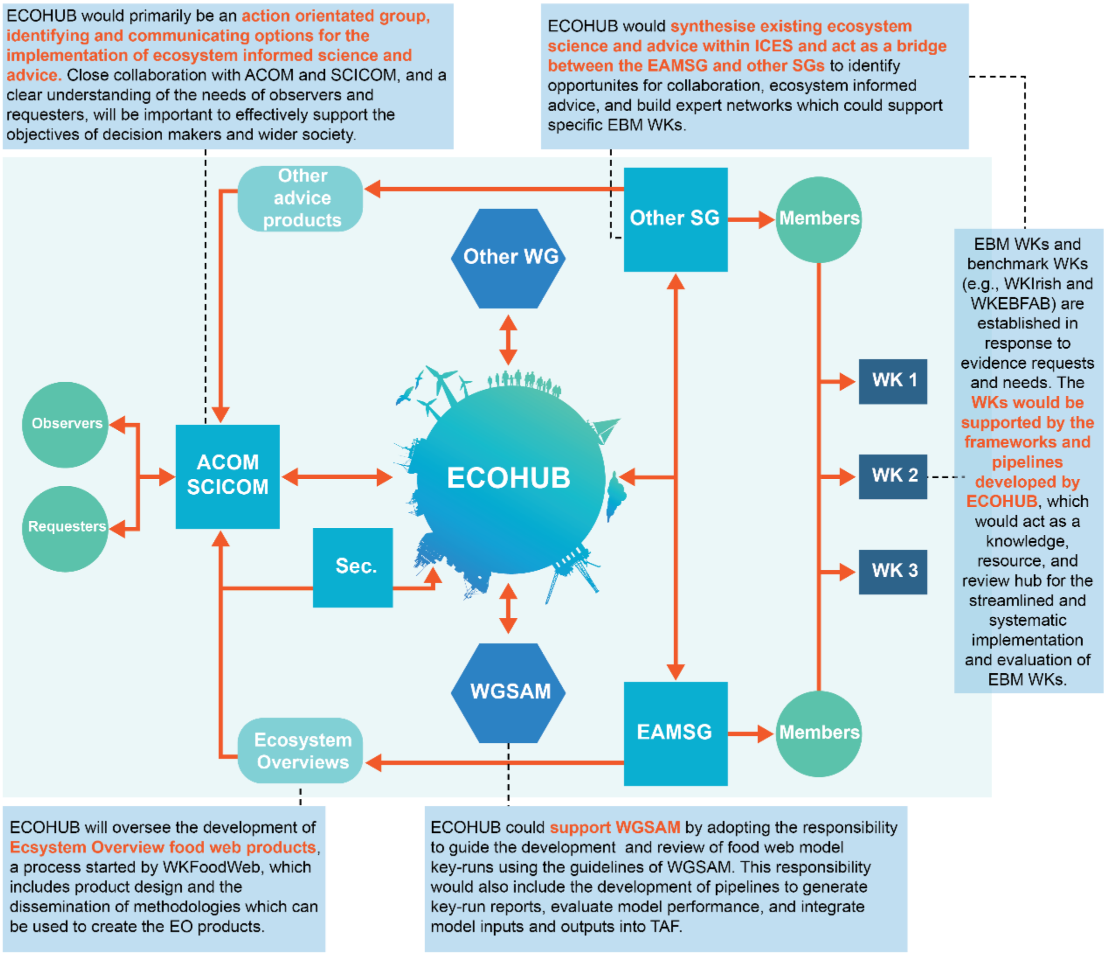
Overarching functions (FEISA implementation)

1. Develop, use, and disseminate iterative, measurable indicators and risk-based approaches in support of ecosystem-informed advice where knowledge and data gaps are explicitly handled or considered.
2. Identify incremental steps for science and advice development that are consistent with the available evidence and policy frameworks and can be achieved based on existing capacity.
3. Develop appropriate techniques, methods, and tools to convey different types of knowledge into best available science and advice, iteratively moving along the

knowledge and data continuum from qualitative and experiential to quantitative and analytical to inform decision makers.

Specific functions (potential Terms of Reference)

1. Support the systematic development of food web products and pipeline proposals across ICES ecoregions as appropriate to ICES Overviews (Ecosystem, Fisheries, and Aquaculture).
2. Synthesise existing food web relevant ecosystem science from across ICES and identify new and existing opportunities for implementation into advice through collaboration with multiple working groups, across steering groups.
3. Support the systematic development of food web models across the ICES network by developing and sharing common methodologies for model parameterisation, documentation, use, review (close collaboration with WGSAM), and application.
4. Building on the previous ToRs, identify opportunities for the development of ecosystem-informed fisheries advice and provide the support needed to streamline the implementation and evaluation of such opportunities (e.g., through Workshops or Benchmark Workshops).



ECOHUB would primarily be an **action orientated group, identifying and communicating options for the implementation of ecosystem informed science and advice.** Close collaboration with ACOM and SCICOM, and a clear understanding of the needs of observers and requesters, will be important to effectively support the objectives of decision makers and wider society.

ECOHUB would **synthesise existing ecosystem science and advice within ICES and act as a bridge between the EAMSG and other SGs** to identify opportunites for collaboration, ecosystem informed advice, and build expert networks which could support specific EBM WKs.

EBM WKs and benchmark WKs (e.g., WKIrish and WKEBFAB) are established in response to evidence requests and needs. The **WKs would be supported by the frameworks and pipelines developed by ECOHUB**, which would act as a knowledge, resource, and review hub for the streamlined and systematic implementation and evaluation of EBM WKs.

ECOHUB will oversee the development of **Ecsystem Overview food web products**, a process started by WKFoodWeb, which includes product design and the dissemination of methodologies which can be used to create the EO products.

ECOHUB could **support WGSAM** by adopting the responsibility to guide the development and review of food web model key-runs using the guidelines of WGSAM. This responsibility would also include the development of pipelines to generate key-run reports, evaluate model performance, and integrate model inputs and outputs into TAF.

Figure 9.1 Proposed structure and roles for ICES ECOHUB, a group which prioritises cross-steering group collaboration and the development of ecosystem informed advice.

10 Summary of presentations

10.1 ToR a

Eirini Glyki gave an introductory presentation on the ICES advice structure, including the 'Pipeline Process' for proposing new topics for inclusion in ICES advice. Debbi Pedreschi (IEASG Chair) followed up with an overview of the Ecosystem Overviews (EOs) and introduced the ICES Framework for Ecosystem-Informed Science and Advice (FEISA). Together these presentations aimed to provide context for the WKFOODWEB discussions, highlighting the existing avenues and mechanisms for contributing to ICES advice. Information on the content and structure of the EOs, who contributes to them, the review process, etc. were all detailed. An overview of topics highlighted as relevant to WKFOODWEB was provided based on the WKEO3 priority list (ICES 2019).

ICES Framework for Ecosystem Informed Science and Advice.

Debbi Pedreschi & Marie-Julie Roux.

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. 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.

The framework was presented, along with some worked examples relevant to WKFOODWEB to contextualise and illustrate its application.

For more information see: 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

Are Marine Food Webs Real?

Andrea Belgrano

SLU

A perspective on food webs reviewing some of the milestones in ecological research shows that our understanding of structure and functioning of marine food webs is robust and plays a key role in our current understanding of marine ecosystem dynamics and fisheries. The work that has been developed within the ICES network and beyond, based on the best-available science, provides relevant and timing information on marine food webs structure and functioning for each of the ICES ecoregions, and a portfolio of marine food webs indicators. The information that marine food webs provide on the structure and functioning of marine ecosystems and fisheries, highlights key messages that will provide a valuable and timing contribution towards EBFM/EBM, and to the ICES advice on Ecosystem Overviews (EOs).

Regulatory needs for food-web knowledge from the perspective of marine management authorities in Germany

Barbara Bauer

Umweltbundesamt (UBA), Germany

There are various types of food web models (interaction networks, energy flow networks, spatially explicit models), which differ in the types of indicators that can be derived from them. A few examples of management-relevant food web indicators are discussed for each food web type. Some objections to using such indicators for management are the time-consuming nature of modelling, and that general indicators are sometimes misleading for specific systems. The way forward to address such concerns are thoughtful baseline and target values established based on ecological principles, historical reconstructions or scenario modelling. In addition, the applicability range of indicators and their complementarities to other indicators (e.g. eutrophication, pelagic habitats) should be considered.

Topological structure of marine communities: potential *vs.* realised networks

Lucía López-López

Oceanographic Centre of Santander, Spanish Institute of Oceanography (COST-IEO, CSIC)

Binary networks based on feeding interactions are considered the most straightforward method to characterise the structure of complex ecological communities. Despite their simplicity, these basic structural models can provide essential information on the topological characteristics of ecosystems and their resilience to change. In this talk, we provide guidelines to construct topological networks from bibliographic information, to ensure their comparability. To this aim, we exemplify the construction and interpretation of binary food-web networks in the pelagic and bento-demersal environment. Finally, we compare the potential interactions, as estimated from these binary networks at the local level, with the interactions recorded in the field based on stomach content analysis (realised interactions). Our results demonstrate that only 20% of the potential interactions became realised, and that the probability of the interaction to be realised strongly depended from the abundance of predator and prey, the size of predator and prey, and the abundance and diversity of alternative prey in the community. We hypothesise that this difference between potential and realised interactions could be related with food web resilience.

10.2 ToR b

Overview of Ecopath with Ecosim

Jacob Bentley

Natural England

Ecopath with Ecosim (EwE) is one of the most widely used food web modelling approaches across the ICES ecosystem modelling community. An overview of the software was provided given the context of WKFoodWeb and the multiple following presentations which use EwE. EwE has three core components which are used to generate mass-balanced snapshots of an ecosystem (Ecoapth), temporal simulations of ecosystem dynamics (Ecosim), and spatial-temporal simulations of ecosystem dynamics (Ecospace). Plugins have also been developed to, for example, simulate ecological indicators (EcoInd), simulate contaminants through food webs (Ecotracer), and assess the impacts of parameter uncertainty (EcoSampler). EwE has been predominantly used to increase our understanding of ecosystem structure and function as well as the impact of fisheries in the context of marine food webs. The modelling approach has also been used to simulate the impacts of climate change, infrastructure development (e.g., OWF), invasive species, marine pollution, and spatial management measures such as protected areas. Of relevance to WKFoodWeb and ICES science and advice, EwE is being increasingly used to enhance single-species stock assessments and advice using derived strategic ecosystem information (e.g., natural mortality, predator needs, and impacts of environmental variability on production).

Ecosystem-Based Fisheries Management

Jacob Bentley

Natural England

The practical application of pragmatic mechanisms for Ecosystem-Based Fisheries Management (EBFM) within single species advice is increasing. This presentation provided an overview of multiple examples where ecosystem information has been used to inform catch opportunity advice. These examples have been summarised in section 6. The presentation also stressed the importance of effective communication and engagement across disciplines and with stakeholders to enable the implementation of EBFM mechanisms.

Pew Ecosystem-Based Fisheries Management campaign

Josephine Woronoff

Pew

The presentation, delivered at the ICES WKFoodWeb workshop on February 20, 2024, focused on the implementation of Ecosystem-Based Fisheries Management (EBFM) in the Northeast Atlantic. The Pew Charitable Trusts, through its International Fisheries work, is leading an EBFM campaign to enhance the governance of shared fisheries by incorporating ecosystem considerations into fisheries management. This campaign promotes a management approach that moves beyond single-species management to safeguard ecosystem functioning and biodiversity and that addresses trade-offs and benefits, while being adaptive to tackle risks such as climate change.

Opportunities for Implementation: The Northeast Atlantic has existing political commitments, well-established scientific institutions, and advisory bodies that provide a strong foundation for implementing EBFM. Recent requests to ICES for ecosystem-level advice demonstrate momentum towards this approach. The political mandates of the Region’s countries, and the scientific advancements create a conducive environment for EBFM implementation.

Actions towards EBFM: The presentation outlined specific actions that could be taken to implement EBFM, including commissioning and applying ecosystem-level scientific advice, setting fishing limits within ecosystem constraints, enhancing cooperation between fisheries and biodiversity bodies, developing long-term management strategies, and protecting areas of key fishery and ecosystem importance. The use of Harvest Strategies (HS) or Long-Term Management Strategies (LTMS) is crucial in this context. It allows the establishment of a pre-agreed, formulaic approach to setting fishing opportunities based on population status. LTMS in the Northeast

Atlantic, particularly for small pelagic and forage fish, can be used as vehicles to incorporate ecosystem considerations and climate adaptability in the management. Management Strategy Evaluation (MSE) is a critical tool for advancing EBFM. MSE evaluates the performance of candidate harvest strategies under a range of potential future scenarios, accounting for inherent uncertainties in the system. This approach allows for the selection of a harvest strategy that meets management objectives taking into account various plausible future outcomes, making it an effective tool for implementing EBFM. There certainly are challenges in transitioning from policy to practice but there is a need for political intent and stakeholder engagement to develop operational objectives and implement EBFM.

In conclusion, the Pew EBFM campaign calls for more cooperation between parties, de-siloing biodiversity conservation and fisheries management, and proactively deploying existing EBFM tools and science. It stresses the importance of adapting single-species tools to function at the ecosystem level and of embedding environmental considerations into the foundation of fisheries management.

Spatial impact on ecological indicators – and potential use in ICES advice

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The Ecospace model for the southern part of the North Sea (Püts *et al.*, 2020) has been utilised to assess the effects of fishing redistribution resulting from spatial closures induced by marine protected areas and offshore wind farms on both the ecosystem and related fisheries. The impacts of these closures were evaluated using the plug-in ECOIND that can be applied to derive standardised ecological indicators (Coll & Steenbeek, 2017). These indicators were used in various steps of the study. Next to providing an understanding of the system in Ecopath and changes over time in Ecosim, indicator maps created with Ecospace were used to inform about the spatial structure of ecosystem components. Two indicators, Kempton's Q as a measure of biodiversity and biomass of IUCN red listed species, were used to test the impact of hypothetical closures on the ecosystem. Finally, ecological indicators were used to assess the impact of the spatial closures on the system and the fisheries. These revealed trade-offs within the food web but also between fishing, conservation and offshore wind farms. However, there are a few things to keep in mind when working with these indicators. They have proven to be very effective when analysing the spatial impact of management measures and communicating such impacts. However, the difference in impact strength, which can vary based on the amount of species/functional groups included, needs to be considered. Furthermore, some indicators may include trade-offs between species or functional groups included that need to be evaluated. In terms of applicability within ICES these indicators on a spatial scale could be used within ecosystem overviews and potentially fisheries overviews, but also in the various expert groups targeting spatial impact analysis or spatial management.

10.3 ToR c

StrathE2E - a strategic modelling tool for ecosystem-based fisheries management

Jack H. Laverick, Douglas C. Speirs, Michael R. Heath
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StrathE2E is a light-weight end-to-end ecosystem model designed to provide strategic insight for the management of shelf ecosystems. This talk covered the simplifying assumptions in terms of spatial and taxonomic complexity, and how the resulting speed can be used for experimentation, model fitting, and optimisation. The capabilities of the model were demonstrated by generating yield curves that showed the trade-offs between pelagic and demersal harvesting, and the impacts on top predator biomass. We finished by pointing out we need a way of evaluating the outcomes of these simulations to choose the best management strategy; are we maximising tonnes of fish landed, landed value, predator biomass, or a scaling of different metrics?

Assessing climate change impacts in the Southern Benguela using a model ensemble

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The southern Benguela upwelling system supports a productive fisheries sector that provides jobs and livelihoods for thousands of people living along the southern African coastline. This system has experienced considerable environmental variability and change in recent decades, and climate projections indicate that this is likely to continue into the future. A number of ecosystem models are available for the southern Benguela and these have captured many aspects of the observed variability and dynamics of this ecosystem. This study aims to evaluate the possible impacts of climate change in the southern Benguela ecosystem using Atlantis and Ecopath with Ecosim. These ecosystem models are forced with climate projections from the Geophysical Fluid Dynamic Laboratory ESM2M model and the Institut Pierre Simon Laplace Earth system models to evaluate the effects of warming and primary productivity changes on the southern Benguela ecosystem under Shared Socioeconomic Pathways 2.6 and 8.5. Results from the ecosystem models are compared to determine agreement and differences in biomass-based indicators for this system under two climate change scenarios. The results of this study have the potential to inform future ecosystem-based management decisions and increase understanding of climate change impacts at the system level but also to increase adaptive capacity at the local scale.

10.4 ToR d

Multi-basin ITA of the Baltic Sea, Preliminary results

Carolyn Faithfull
SLU

Assessing the status of marine food webs is difficult due to their complexity. There is currently no standard method employed by ICES or the EU for determining food web status, and reporting of food web status for the MSFD has been inconsistent across countries (Boschetti *et al.*, 2021). However, integrated trend analysis can be useful to help determine if food web status has changed according to Marine Strategy Framework guidelines, i.e. if the diversity within trophic guilds and the balance between trophic guilds is being negatively affected by anthropogenic pressures. The joint ICES/HELCOM working group for integrated analysis of the Baltic Sea (WGIAB) is currently working on a multi-basin integrated trend analysis (ITA) of the Baltic Sea to determine how the food web has changed over time (1977–2021), what is driving this change and how the changes may differ between the Baltic basins. Principal components analysis using chord distances were calculated for a response dataset of phytoplankton, zooplankton, benthos, fish spawning stock biomass and seal counts. Pressures considered were nutrients, temperature, ice coverage, winter Baltic Sea Index, salinity, oxygen concentrations and fishing mortality. The Central Baltic and Bothnian sea food webs have changed over time, with the central Baltic shifting from a period with high cod and herring biomass to a state with more flounder, sprat and seals and very low biomasses of cod and herring. These changes may be explained by an expanding hypoxic area, climate change and fishing mortality. The Bothnian Sea has also undergone changes, with herring and amphipod biomasses declining and cyanobacterial biomasses increasing. Changes in the Bothnian Sea food web were coupled with changes in salinity and fishing mortality. Different results were obtained when only trophic guilds were considered versus dividing species into key trophic groups. Although the food web has changed over time in response to both human and environmental pressures, the analysis does not determine if these changes are positive or negative, i.e. if the food web is in poor or good environmental status (GES). Determining what constitutes GES needs to be a human directive.

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Annex 2: Resolution

2022/WK/IEASG09 The **Workshop on the operational use of Food Web indicators and information (WKFoodWeb)**, chaired by Maciej T. Tomczak (Sweden), Eider Andonegi (Spain), Marian Torres (Spain), and Jacob Bentley (UK) will be established and will meet in Copenhagen, Denmark, 19–23 February 2024 to work on the following Terms of Reference (ToRs):

a) Streamline existing examples, knowledge, experience, and recommendations on food web, trophic level and other ecological indicators from across the ICES network (e.g., from IEA groups, WGECO, WKFOOWI, WKASCAPES) and beyond (e.g. MSFD, OSPAR, HELCOM, UKMS, etc.).; (Science Plan codes: 1.3, 1.4, 1.7, 6.3);

b) Identify priority areas where food web information/indicators could enhance existing advice and align with the ICES EBM framework (including advancing the Feco approach).; (Science Plan codes: 2.2, 5.1, 5.2, 5.3, 6.1, 6.2, 6.3, 6.4);

c) Prepare a roadmap, including risks and opportunities, for the systematic and transparent use of food web models to support ICES advice with information on trade-offs.; (Science Plan codes: 2.5, 4.3, 6.6);

d) Develop a pipeline proposal to strengthen the ‘food web’ component of ICES ecosystem advice (ICES Ecosystem Overviews) that can be applied in a consistent way across ICES ecoregions and preferentially on the short-term timescale.; (Science Plan codes: 1.3, 1.4, 1.7, 1.9, 6.5).

WKFoodWeb will report by June 2024 for the attention of the SCICOM.

Supporting information

Priority	WKFoodWeb will address the growing requests from previous workshops (WKEO3, WKCONSERVE, WKFOOWI, WKEWIEA, WKASCAPES, WKIRISH, WKEBFAB) and working groups (WGECO, WGIAB, WGEAWESS) for the operational use of food web indicators and information in ICES advice. It will be the priority of this workshop to (i) review existing and developing evidence products, (ii) identify methods for evidence production that can be systematically applied across ICES ecoregions, and (iii) develop and demonstrate the use of a pipeline to operationalise food web products within ICES advice.

Scientific justification	Term of Reference a) Advances in food web indicator creation and assessment are ongoing within ICES, across research programs, and within governing bodies to measure progress against national and international biodiversity commitments. ToR a aims to provide a review of the current state of play to help identify opportunities and avoid duplicating efforts. Term of Reference b) Marine ecosystem services are impacted by environmental and ecosystem variation. It is = likely that there are opportunities where accounting for these impacts in our advice could enhance existing management. However, making ecosystem information operational often requires a developed understanding of the existing regulatory and advice frameworks to deliver pragmatic solutions. ToR b will identify priority areas where food web information could enhance advice and explore/advance routes for its integration. Term of Reference c) Food web models (e.g. Ecopath with Ecosim (EwE) and Atlantis) are being increasingly used across ICES and by decision makers to guide the delivery of EBM, EBFM, and EAFM. Often models (even those built using the same simulator, e.g. EwE) operate under different assumptions, at different resolutions, and with different policy origins. Their utility to provide food web information is clear and progress should be made to use them in an operational management context (see recent paper by Craig and Link (2023) in Fish and Fisheries). Their current application within ICES is unsystematic relative to the use of less complex models. ToR C will explore options to enhance how food web models are used across ICES to support the delivery of ecosystem-based advice. Term of Reference d) The ICES EOs include food web sections but they remain largely disparate between EOs and often lack information or indicators of status. Food web indicators were identified as a priority for EOs by WKEO3. ToR d will explore options and development needs (building on ToRs a-c) for the development of an evidence pipeline to systematically improve the food web information included in EOs.
Resource requirements	Hybrid meeting (online component only mornings or afternoons: TBD)

Participants	This will be of interest to participants who are involved in food web and ecosystem research and the integration of ecosystem information into ICES advice. Members from the following groups may be particularly interested: WKFOOWI, WKEWIEA, WGECO, WGIAB, WGEAWESS, WGINOSE, WKASCAPES, WKIRISH, WKEBFAB, WKEO3, WKCONSERVE, WGIPEM, WGSAM. Chairs intend to reach out to a list of participants who are heavily involved in this work area (also open to nominations from SCICOM), with wider attendance being driven by advertising of the WK on the ICES website and social media. If the workshop is oversubscribed, ICES reserves the right, in consultation with the workshop Chairs, to select the final workshop participants based on their expertise and geographical distribution.
Secretariat facilities	Meeting facilities (in person and online), registration support.
Financial	No financial implications.
Linkages to advisory committees	ACOM, SCICOM
Linkages to other committees or groups	EAMSG and IEA working groups. Builds on work and requests of WKFOOWI, WKEWIEA, WGECO, WGIAB, WGEAWESS, WGINOSE, WKASCAPES, WKIRISH, WKEBFAB, WKEO3, WKCONSERVE, WGIPEM, WGSAM
Linkages to other organizations	OSPAR, HELCOM, JRC, Ecopath International Initiative (EII)