WORKSHOP ON ECOSYSTEM BASED FISHERIES ADVICE FOR THE BALTIC (WKEBFAB; OUTPUTS FROM 2021 MEETING)

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Contents

i Executive summary

The main aim of the meeting was to organise a meeting with members of the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) and the ICES Baltic Fisheries Assessment working group (WGBFAS), as well as invited experts on ecosystem-based fisheries management from other sea regions, to propose a roadmap towards providing ecosystem based fisheries advice (EBFAdvice) for the Baltic Sea. The specific objective was to conclude on ecosystem aspects that could be added to the fisheries advice provided by ICES. In order to achieve this, the WK reviewed working international EBF approaches, reviewed ecosystem indicators relevant for EBFAdvice in the Baltic and evaluated how existing ecosystem models can be used for giving advice on ecosystem-based catch options. The lack of management strategy evaluations implemented for the Baltic Sea became apparent and the WK stresses their development and application as a key step for implementation of EBFAdvice. Several ecosystem indicators are currently operational for the Baltic Sea region, mainly via developments in HELCOM and in relation to the Marine Strategy Framework Directive. These indicators could potentially support an EBFAdvice by providing an integrated ecosystem assessment framing, but further work is needed to assess how selected existing indicators could be analytically linked to the developing EBFAdvice.

The WK proposed a roadmap on utilising ecosystem information in stock assessment and advice for the Baltic Sea over 2022-2023. As a central aim for the work, the WK agreed to test the use of Scaling factors for the species-specific long term Ftarget derived catch options (hence, applying an approach similar to the Feco approach developed by WKDICE and WKIRISH). The WK also proposed to produce Ecological and socio-economic profiles (ESP) of the specific stocks, which would identify quantitative indicators/factors for ecological processes that can be used to scale the species-specific Ftarget. Additionally, the WK proposed to amend the regular fisheries advice with information on Ecosystem consequences / Ecosystem risks as a result of the stock specific advice in question. The WK agreed that at its first stage of implementation, the EBFAdvice would focus on developing the F scaling factor, ESP and risks, as described above, in relation to the already existing single species assessment and stock-prediction models (while in the long term, multi-species or specific food web models would preferentially be used). It was identified that the implementations should be part of the ICES Benchmark process, where the approach would be tested and accepted. The proposed next benchmark of the small pelagic stocks in the Baltic 2022-2023, creates the first window of opportunity to test scaling factors.

The WK recommends that the F scaling factor, ESP and risks be formulated in such a way that they can be integrated into existing ICES advice products, namely the advice on fishing opportunities, the Baltic Sea Ecosystem Overview and the Baltic Sea Fisheries Overview. The WK, further, proposed a number of changes to the ICES advisory process, in order to facilitate the operationalization of the roadmap and EBFAdvice.

The work required to eventualize the proposed roadmap is dependent on further funding, and is foreseen to be facilitated by two more workshops (WKEBFAB 2 and 3). It should be noted that the working group for integrated assessment (WGIAB) has already suggested in their meeting ToRs for 2022-2024 to assist in the work of WKEBFAB and this collaboration is expressed as an item in the TORs.

ii Expert group information

Expert group name	Workshop on Ecosystem Based Fisheries Advice for the Baltic (WKEBFAB)
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chairs	Mikaela Bergenius Nord, Sweden
	Stefan Neuenfeldt, Denmark
	Maciej Tomczak, Sweden
Meeting venue(s) and dates	10-12 November 2021, Stockholm, Sweden (44 participants)

Acknowledgement

The Workshop on Ecosystem Based Fisheries Advice for the Baltic (WKEBFAB) was funded by the Swedish Agency for Marine and Water Management.

1 Introduction

The advice delivered by ICES annually consists of catch options, fisheries overviews and ecosystem overviews. Generally, the catch options gain most attention, as they comprise the expert groups' advice on stock-wise total allowable catches for the subsequent year. For the European fisheries, the outcomes form the basis for the forthcoming decision-making process. ICES advice is tightly linked to fisheries biomass reference points, which are revisited approximately tri-annually and updated by expert groups.

Ecosystem and fisheries overviews are also regularly updated, albeit on a lower frequency. Yet, there are no analytical links between the Ecosystem overviews and the work of the reference points or assessment working groups, although ecosystem processes affect, among others, natural mortality, somatic growth, and productivity of fish stocks. This decoupling is based on historical reasons, as fisheries assessment and management was developed largely assuming that environmental and ecological trends could be dealt with statistically as random noise. Furthermore, there is a lack of compatible ecological indicators that can readily be used for stock assessments.

More recently management attention towards reaching and maintaining good environmental status of marine waters has increased, enabled by the European Marine Strategic Framework Directive. Additionally, productivity changes have been observed in the Baltic Sea, which are sometimes clearly directional and sometimes have a higher frequency of change than covered by the reference expert group meetings. Last, the notion is growing that species interactions need to be included in fisheries assessment and management to enable a stepwise change from single-species management to an ecologically based fisheries management and ultimately ecosystem-based management.

The terms EAFM (ecosystem approach to fisheries management), EBFM (ecosystem-based fisheries management), and EBM (ecosystem-based management) have been widely used in the context of incrementally including ecosystem and environmental information in fisheries assessment and management process (Table 1.1). For this workshop, we use the definitions given by Patrick & Link (2015, Figure 1.1). However, the developments suggested by the WK depart from the current *ICES advice* on fishing opportunities, which form the basis of the current assessment, advice and management chain for Baltic fish stocks, identifying Ecosystem-Based fisheries Advice (EBFAdvice) as one crucial first step for implementing the Ecosystem Approaches to Fisheries Management (EAFM).

Operationally, ICES already implements some ecosystem aspects in advice for the Baltic Sea. One example is extended single species/stock assessments, where biological reference points incorporate ecosystem considerations, such as predation mortality or indirectly growth and fish condition. In order to further steps towards EBFAdvice for the Baltic Sea, WKEBFAB worked towards achieving 4 ToRs (outlined above). The tasks of the WK included to review international EBF approaches that have been successfully implemented (section 2 below), to review ecosystem indicators relevant for EBFAdvice in the Baltic (section 3) and to evaluate how existing ecosystem models can be used for giving advice on ecosystem-based catch options (section 4). The WK used the information from ToR i-iii to propose a roadmap on steps to utilise ecosystem information in fish stock assessment and advice in the Baltic Sea (section 5) and conclude on ecosystem aspects that could be added to the fisheries advice provided by ICES.

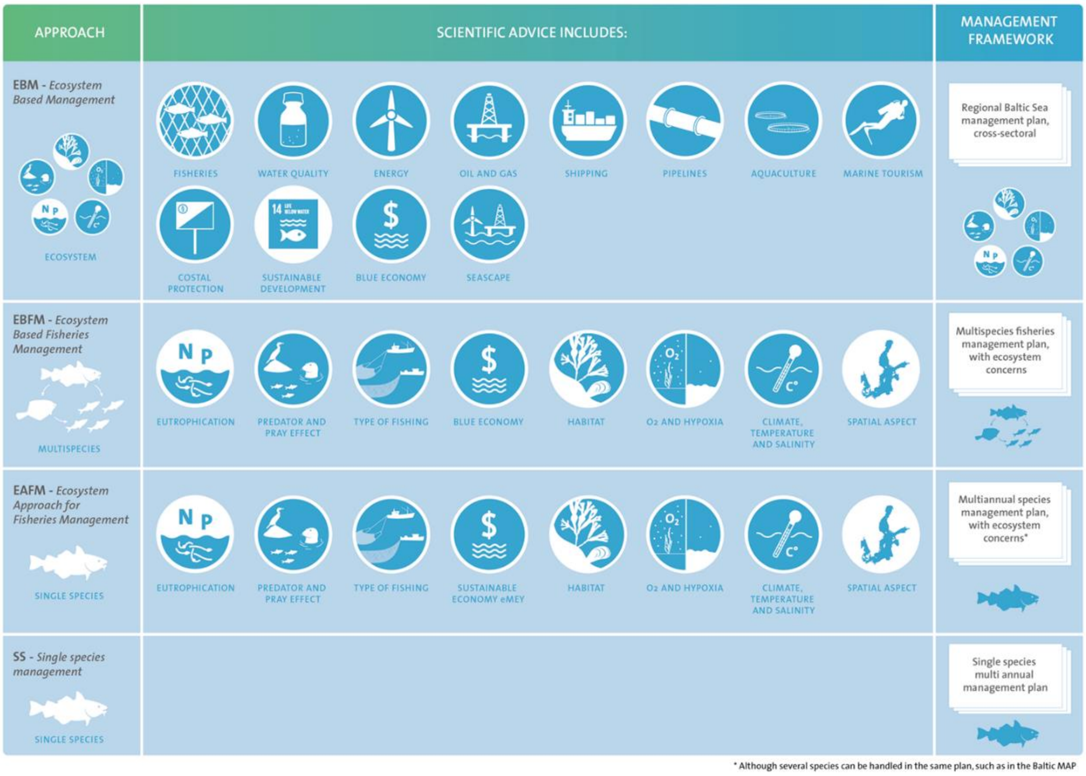

Figure 1.1. Levels of ecosystem management (EM) as applied in a fisheries context for the Baltic Sea: EAFM (ecosystem approaches to fisheries management), EBFM (ecosystem-based fisheries management), and EBM (ecosystem-based management). (Based on Patrick & Link 2015, modification and design by MT Tomczak and G Almqvist)

Table 1.1. Definitions of levels of ecosystem management (EM) as applied in a fisheries context: EAFM (ecosystem approaches to fisheries management), EBFM (ecosystem-based fisheries management), and EBM (ecosystem-based management; Patrick & Link 2015).

Level of EM	Definition	Focus of Management	Management framework	References
EAFM	Inclusion of ecosystem factors into a (typically single species) stock focus to enhance our understanding of fishery dynamics and to better inform stock-focused management decisions	Fisheries stocks	Fishery Management Plan	Pitcher *et al.*, 2009; Link and Browman, 2014
EBFM	Recognizes the combined physical, biological, economic, and social trade-offs for managing the fisheries sector as an integrated system, specifically addresses competing objectives and cumulative impacts to optimize the yields of all fisheries in an ecosystem	Fisheries systems	Fishery Ecosystem Plan	Link, 2010; Link and Browman, 2014
EBM	A multi-sectored approach to management that accounts for the interdependent components of ecosystems, and the fundamental importance of ecosystem structure and functioning in providing humans with a broad range of ecosystem services	All sectors, including fisheries	Regional Ocean Plan	MacLeod and Leslie, 2009; Curtin and Prellezo, 2010; Link and Browman, 2014

2 ToR i) A review of international ecosystem-based fishery management approaches (by ICES, NOAA etc.), including MSEs, relevant to the Baltic Sea.

2.1 Scope

For ToR i) WKEBFAB reviewed in plenary several international ecosystem-based fishery management (EBFM) approaches and its components, that is, assessment methods, biological reference points settings (BRP), advisory process and management plans. For this ToR, the participants also reviewed the management strategy evaluations that have been conducted (MSEs) for the Baltic, with a focus on the Eastern Baltic Cod stock and discussed gaps in the MSE applications (see below).

For the review of EBFM approaches, the group focussed on the United States, where ecosystem processes and ecosystem assessment have been taken into account and incorporated into the fishery management process, and which could be applicable for the Baltic Sea fish stocks. Invited speakers from the US shared with the WK their own experiences and work within this area. Participants also reviewed the efforts already conducted within ICES to make steps towards an ecosystem-based fishery management and discussed why some of these efforts stalled.

ICES is moving from fisheries oriented to an ecosystem-based advice framework and has, since 2017, three categories of advice products: fisheries opportunities, Ecosystem and Fisheries Overviews. The role of the Overviews is to give the ecosystem background for fisheries management decisions. A number of initiatives have been performed by ICES to operationalize ecosystem aspects into ecosystem-based advice, such as ICES Workshop(s) on DEveloping Integrated AdviCE for Baltic Sea ecosystem-based fisheries management (ICES 2016, 2017, WKDEICE) and ICES Workshop on an Ecosystem Based Approach to Fishery Management for the Irish Sea (ICES 2020a, WKRISH) or ICES Workshop on the Ecosystem-Based Management of the Baltic Sea (ICES 2020b, WKBALTIC).

Based on presented examples (section 2.2) and revised knowledge, WKEBFAB learned about different approaches, tools, knowledge gaps, EBFAdvice needs and how to possibly operationalize it for Baltic fish stocks. From experiences shared by NOAA and WKIRISH, the WK concluded on suitable elements to bring the EBFAdvice forward: i.e. the Feco concept (see below), Ecosystem and Socioeconomic Profiles and ecosystem Management Strategy Evaluation (section 2.3) which can all be adjusted and adopted at ICES advisory process for Baltic fish stocks.

Summaries of the presentations held at the WK relevant to ToR i are presented below.

2.2 Summaries of WK presentations

ICES Workshop on Ecosystem-Based Fisheries Advice for the Baltic (WKEBFAB) – historical background

Maciej T. Tomczak, Baltic Sea Centre, SU

The ecosystem aspects of the ICES advice on fisheries opportunities on the Baltic Sea stocks were discussed broadly since 2000 by The Study Group On The Scientific Basis For Ecosystem Advice In The Baltic [SGBEAB] (ICES 2000). Despite well-known characteristics of the Baltic Sea ecosystem and stocks as environmentally driven with strong intra- and inter-species connection, ICES advice on fishing opportunities is still, in a large extent, single species. However, stock assessment incorporates some aspects of fish biology and indirectly chosen ecosystem processes. Möllman *et al.* (2014) provide a conceptual framework of ecosystem-based advice (Figure 2.1).

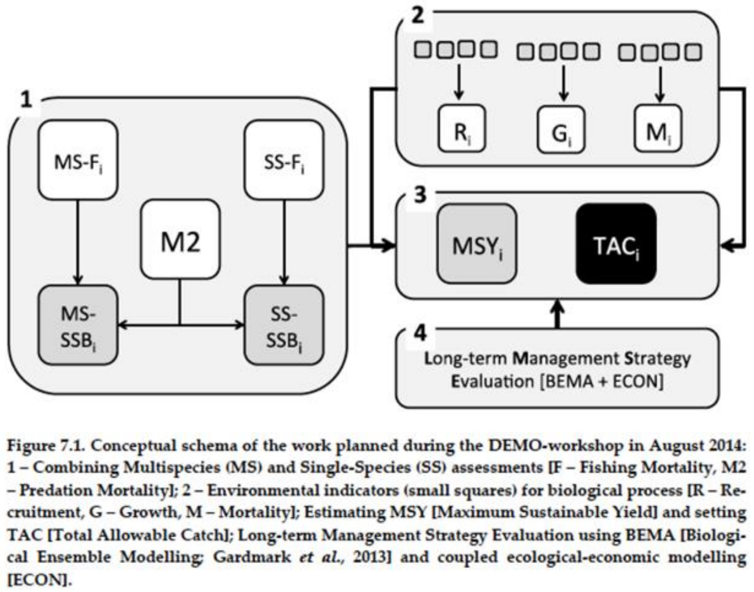

Figure 2.1. Conceptual schema of introduction of ecosystem process into fisheries opportunities advice (Möllmann *et al.*, 2014)

At the DEMO projects (DEMOnstration Exercise of Integrated Ecosystem Assessment and Advice for Baltic Sea fish stocks) and ICES Workshop(s) on DEveloping Integrated AdviCE for Baltic Sea ecosystem-based fisheries management (WKDEICE, ICES 2016), the ways of implementing EB advice were discussed. Discussions covered EB advice in relation to relevant indicators, stock assessment and scenarios (see Figure 2.2 left panel) ICES advisory process (Figure 2.2 right panel).

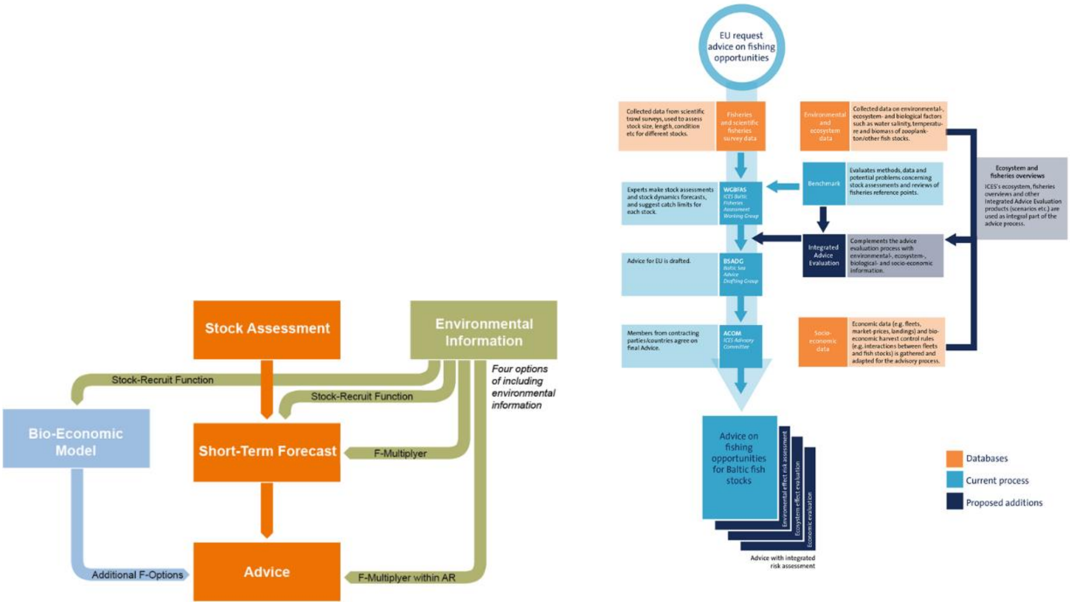

Figure 2.2. ICES WKDEICE (ICES 2016) and WKDEICE2 (ICES 2017) concepts of EB advice application and ICES advice process modification

Presentation on ICES approach to EMB and EMFB

Sarah Millar, Professional Officer, ICES

The presentation provided a background and summary of the ICES network, advice requesters, and current use of Ecosystem Based Management. ICES has ten principles that influence its advice, intended to facilitate a move from a fisheries focused framework to ecosystem-based management. The current published guidelines ICES on EBM include: *ICES advice on ecosystem services and effects* and the *guide to ICES framework and principles*. There are three main categories of ICES advice: the single stock advice, and the ecosystem and fisheries overviews. The overviews implicitly consider the ecosystem based management approach, are more flexible in structure than the single-stock advice, and provide the most possibility of inclusion of new types of information.

Recent workshops such as WKIRISH and WKDICE have given possible windows into incorporating more EBM into current ICES advice and there is active development to bring in the ecosystem approach to stock assessment methods, reference points, and advice. WKIRISH provided the possibility of including an ecosystem based reference point. However, there have been no examples as of yet where this has actually been implemented. WKBALTIC attempted to build on the work of WKIRISH in the Baltic context. There have been numerous attempts to incorporate EBM/EBFM into the ICES advice but for various reasons there has been a stall in this process progressing fully.

Overview of WKIrish process and outcomes

Jacob Bentley, UK

Irish Sea fisheries have undergone considerable change in recent years following the decline of commercially important finfish stocks and their slow response to management measures following recovery plans. Addressing the challenges facing Irish Sea fisheries required a holistic approach, with modelling to improve ecosystem understanding alongside the refinement of single-species assessment methods, in order to improve ecosystem understanding. This process took the form of the first ICES Integrated Benchmark Assessment in 2015 (WKIrish), which established the WKIrish Framework, bringing management, stakeholder groups, fishermen, scientists, regulators and other interested parties together to develop an operational, transdisciplinary route for EAFM and enhanced fisheries advice

The work plan for WKIrish was a multi-year process focussed on improving the single-species stock assessments for cod, haddock, herring, plaice, and whiting in ICES division 7.a, incorporating a mixed fisheries model, and developing an approach for the integration of ecosystem aspects in order to work towards an integrated assessment.

The first WKIrish workshop (WKIrish1) centred around the co-design and co-production of knowledge with an information exchange between scientists and stakeholder groups concerning ecosystem processes, fisheries issues, and management and policy issues, leading to the identification of data and tools that could assist with the integration of this information into tactical advice. Workshops were held to evaluate the scientific (fisheries) data available for the region (WKIrish2), update Irish Sea single-stock assessments (WKIrish3), integrate stakeholder knowledge into ecosystem models (WKIrish4), and identify ways to operationalise EAFM (WKIrish5 and 6).

An approach was developed between WKIrish 5 and 6 that uses stock-specific ecosystem indicators to advise where we might set an ecosystem-based fishing mortality reference point (FECO) within the "Pretty Good Yield" ranges advised by ICES. FECO allows the F_{target} to be adjusted to take account of medium-term changes in productivity which are not directly included in the assessment model, while remaining within pre-calculated precautionary limits. In order to operationalize this, it is necessary to first identify that such medium-term productivity changes are having significant impacts on stock development, and then identify stock-specific ecosystem factors or indicators which track these changes and be used as the basis for such adjustment.

On the scientific side, a key requirement to implement FECO is to identify indicators which can be used as indicators of clear productivity changes and hence be used as a basis for adjusting F_{target}. This should be kept as simple as possible, identifying the least number of key factors or indicator(s) to be used for each stock. For the Irish Sea, ecosystem indicators were identified for cod (temperature), whiting (temperature), herring (zooplankton abundance), and Nephrops (trophic level 4+ biomass).

Indicators were identified for Irish Sea stocks using the following steps:

- An integrated trend analysis was developed to identify plausible drivers of stock production;
- Ecosystem/multi species models were developed. Models were designed from the outset to focus on commercial stocks and tease apart key drivers of stock production. Results from the integrated trend analysis were used to inform the addition of environmental drivers to the models;
- Multiple simulations were generated with and without key ecosystem and fishing drivers to identify their impacts on stock production;
- Key environmental indicators were identified and used to calculate FECO. The placement of FECO within the pretty good yield ranges is based on the current condition of the indicator relative to its long-term trend.

There is also a need for stakeholder interaction, explaining the approach as a way of accounting for the changing environment to fine tune the long term F_{MSY} to produce the most appropriate fishing level for current conditions. There may also be a need for stakeholder input into the modelling process, filling in gaps in the knowledge requirement. Such engagement was vital to gather support and momentum for the FECO approach.

Ecosystem Modelling for Fisheries Management: examples from the U.S. Atlantic Coast and Gulf of Mexico

David Chagaris, University of Florida, dchagaris@ufl.edu

Two case studies from the U.S. Atlantic Coast and Gulf of Mexico were presented that incorporated ecosystem modeling output into management advice, the first was applied to forage fish and the second to episodic mortality caused by harmful algae blooms. Atlantic menhaden (*Brevoortia tyrannus*) are an important forage fish for a suite of predators that support valuable recreational fisheries, and they are also harvested commercially at an average of 180 000 mt/yr, making it the largest fishery by tonnage on the U.S. east coast. For over ten years, the ASMFC has pursued ecosystem approaches to managing this fishery. An existing Ecopath with Ecosim model of the Northwest Atlantic Continental Shelf (NWACS) was reduced in complexity from 80 to 15 species/functional groups (NWACS-MICE). Ecological Reference Point (ERP) target and threshold values were based on the trade-off relationship between equilibrium biomass of striped bass (a key predator) and Atlantic menhaden fishing mortality (F) using NWACS-MICE. They correspond to an ERP F_{TARGET} and $F_{THRESHOLD}$ for menhaden that are lower than the single species F reference points by about 30-40%, but higher than current F. These ERPs were fed back into the stock assessment to generate the TAC. The approach described here represents a first step towards actual ecosystem based fishery management in the U.S and could be applied for managing other forage fisheries. In the Gulf of Mexico, episodic red tide blooms caused by the dinoflagellate *Karenia brevis* negatively impact fish populations. For over a decade, stock assessments have attempted to incorporate red tide into the models, and on several occasions, managers have made uninformed decisions about next years' catch while a red tide was ongoing. To address this challenge, we updated a WFS Ecospace model to estimate past red tide mortality rates and provide near-real time estimates of ongoing blooms. The model accounts for spatial overlap of red tide with species, bloom duration and severity, lethal and sublethal effects, avoidance, and food web effects. We focused on Gag Grouper (*Mycteroperca microlepis*), because empirical data suggests the species is severely impacted by red tides and management decisions have been linked to assumed red tide impacts. Our results show high red tide mortality rates for Gag Grouper, especially for younger stanzas that are distributed closer to shore and for the year 2005, which was the most severe year in our analysis. Further, our estimates of red tide mortality improved fits to the index data when included in the stock assessment model. This suggests that out from WFS Ecospace is consistent with other data streams used for stock assessment and also that future stock assessments could be improved by including red tide effects in this manner. Near-real time estimates of the 2021 red tide event were used in stock projections to set future years' catch limits, marking the first time an ecosystem model has been used in actual fisheries management advice in the Gulf of Mexico. Both of these case studies demonstrate practical ways for ecosystem models to inform and improve fisheries management, working within the existing single species assessment and management framework to advance EBFM.

Case studies of EBFM advice and support from the U.S. Integrated Ecosystem Assessment program

Chris Harvey – NOAA National Marine Fisheries Service

To help develop science products in support of EBFM in the U.S., the National Marine Fisheries Service (NMFS) formed Integrated Ecosystem Assessment (IEA) projects in five regions of U.S. coastal waters, beginning in 2010. The projects follow the flexible IEA framework outlined by Levin *et al.* (2009). The first step of the framework is to define EBM goals and targets. IEA teams have pursued this step through ongoing engagement in settings like fishery management council meetings and stakeholder workshops. IEA teams have worked with stakeholders and partners to build conceptual models of ecosystem structure. These models have been used to co-develop goals and knowledge (Rosellon-Druker *et al.*, 2019, 2021) and to prioritise risks (Gaichas *et al.*, 2016; DePiper *et al.*, 2021; Muffley *et al.*, 2021). The next steps in the IEA framework involve developing indicators and using them to assess ecosystem state. IEA teams have compiled ecosystem status reports that describe climate, ocean physics, ecology, fisheries, and social and economic dimensions in marine ecosystems around the U.S. (e.g. Harvey *et al.*, 2021). Some managers are requesting indicator reports that focus on high-priority target stocks. The most advanced examples are the Ecosystem and Socio-Economic Profiles (ESPs) for crab and groundfish stocks managed by the North Pacific Fishery Management Council[1]. The IEA framework's next step is to assess risk factors that threaten or constrain ecosystem goals and objectives. Risk assessment is an area where IEA teams have made notable progress. One example is an analysis of how different management strategies relate to risks of whale entanglement and revenue loss in crab fisheries on the West Coast (Samhouri *et al.*, in press). In Alaska, researchers and managers are using "risk tables" to set quotas for many stocks (Dorn and Zador, 2020). The tables describe levels of risk, uncertainty, and agreement across four sources of information (assessment models, population dynamics models, ecosystem information [including the ESPs mentioned above], and fishery performance). High levels of perceived risk or disagreement across information sources can lead to precautionary quota recommendations. The final step in the IEA framework is evaluating management strategy alternatives. The IEA program has made fewer direct contributions to management in this area. Much of the focus in the IEA program has been on using end-to-end ecosystem models to examine the effectiveness of management practices under long-term climate and ocean change scenarios (e.g. Marshall *et al.*, 2017; Hodgson *et al.*, 2018). Another effort is EcoCast, a near-real time data assimilation tool designed to identify areas with high risk of protected species bycatch (Hazen *et al.*, 2018). NMFS and partners are pursuing formal management strategy evaluations (MSEs) for many individual stocks; some MSEs consider environmental factors, while others are beginning to incorporate multiple species (Kaplan *et al.*, 2021).

Many challenges remain in the IEA program's work to provide products and advice for EAFM and EBFM. These include building research capacity to understand dynamics within human dimensions to the same degree as in the biophysical dimensions. We also are lacking in integrative ecosystem-level reference points, and we face crises of extreme events and climate change while also anticipating increases in non-fisheries ocean uses such as offshore renewable energy development and offshore aquaculture. Meeting these challenges will require, among other things: continued engagement with management partners and stakeholders; research innovation; open sharing of knowledge among IEA regions and with like-minded researchers and managers in other parts of the world, including the Baltic Sea; and balancing our short-term goals and tactical objectives with our long-term needs and strategic objectives.

Implementing Ecosystem Based Management Across Different Scales: Whole systems, EBFM and single species approaches

Elliot Brown, DTU Aqua, Denmark

The incorporation of ecosystem information into fisheries advice and management has long been sought. These activities can be thought of as existing on a scale from strategic advice that addresses all components across whole marine systems (namely, an Ecosystem Approach to Management), through to targeted tactical advice that applies directly and immediately to the

[1] For example, see S.K. Shotwell (2020) report to the North Pacific Fishery Management Council, https://meetings.npfmc.org/CommentReview/DownloadFile?p=8f5233fb-3b62-4571-9b49-8bb7ce675916.pdf&fileName=ESP_Shotwell.pdf

Samhouri, J.F., B. E. Feist, M. C. Fisher, O. Liu, S. Woodman, B. Abrahms, K. A. Forney, E. L. Hazen, D. Lawson, J. Redfern, L. E. Saez. In press. Marine heatwave challenges solutions to human-wildlife conflict. Proceedings of the Royal Society B.

regulation of a specific fishery (namely, Ecosystem Based Fisheries Management). At the broad end of this spectrum exists Integrated Ecosystem Assessments, which identify and quantify the relationships between human activities, pressures, ecosystem components and the services they provide in a given system. There are different frameworks for undertaking IEAs, of which the ODEMM approach is one that is being applied across seven Large Marine Ecosystems of the Atlantic Ocean in the Horizon 2020 project Mission Atlantic. In the middle of this continuum are a range of tools used to incorporate ecosystem interactions, and ecosystem model output into medium term fisheries plans, and directly into annual fisheries advice, such as being investigated in the Horizon 2020 project SEAwise. Finally, at the very tactical end of the spectrum, are efforts to account for environmental factors with strong local and stock specific influence directly within existing assessment models and frameworks, such as the approach of the European Maritime Fisheries Fund funded HypCatch project. While the analyses required to provide tactical advice are much more focussed and specific, they often rely upon information from, or miss interactions identified in broader ecosystem analyses. The primary challenge for incorporating ecosystem level processes into scientific advice is knowledge synthesis. With more publicly available data, an ever-growing corpus of ecological and fisheries literature and the expanding scope of subjects involved in full system assessments, there is an abundance of data and an abundance of knowledge available to inform management and policy. However, these data and knowledge are highly disparate in the forms of collection, the formats, the scales and resolutions, and contexts. There are different tools available for synthesising these data and knowledge, and while they are often supported by best-practice guidance, there remain trade-offs between the feasibility of incorporating all knowledge (extensibility), the ability to integrate across disparate disciplines (integration), avoiding biases in collection and processing (objectivity), and the production of meaningful, intuitively understandable results for decision makers and non-scientific audiences (accessibility). The selection of the overall approach and the tools used within it are dependent on the scale of the advice (strategic to tactical), the need for system specificity or replicability across multiple systems and the abundance of literature and data available for any given sub-component of the system.

Feco

Daniel Howell

F_{eco} is an approach to allow ecosystem information or outputs of ecosystem models to be used to tune the long term F_{target} to account for medium term ecosystem driven variability in productivity. Assessment models are tuned to as long a time-series of data as possible, and there is good evidence that curtailing these time-series imposes errors in the assessment. Obviously, the ecosystem rarely remains unchanged over time periods measured in multiple decades. In some cases, the variability can be accounted for in the assessment model and potentially used directly in the calculation of the fishing target reference point. However, in many cases this medium-term variability is not accounted for in the fisheries target reference point, meaning that the fishing pressure is out of step with the current state of the ecosystem.

Ecosystem models are generally not suitable for setting annual quota advice, but they do provide the best ecosystem overview available. F_{eco} entails identifying indicators (either physical or synthetic model outputs) which track stock productivity, and then using these to scale up or down the predefined F_{target}, while not exceeding the pre-defined limit reference points (F_{lim}, B_{lim}). This approach allows for some influence of the ecosystem information, while retaining the advantages of the current single species workflow. This approach is being adopted in management in several regions, and gives a large degree of flexibility in accounting for ecosystem variability. Examples presented at this meeting which fall under this framework cover reducing catch to account for predator needs, variable stock productivity, and the use of risk assessment to potentially reduce catch if required to remain precautionary.

Integrating diverse model results into decision support for good environmental status and blue growth

Heikki Peltonen, Finnish Environment Institute (SYKE), Helsinki Finland

Ecosystem-based management of renewable marine resources may need integration of modelling results and other information from multiple models and other sources of information. Bayesian networks (BN) provide a shortcut to work with complex models in a probabilistic context. A decision support system was built by combining several Bayesian subnetworks to integrate a large body of diverse research and model projections about potential management alternatives and climate scenarios for the Central Baltic Sea ranging to the end of the 21st century. The integrated BN model is an emulator and ensemble of models, integrating information from disciplines such as climatology, biogeochemistry, marine and fisheries ecology, as well as fisheries economics. The learning data for the Bayesian emulators were generated with dynamic simulations by a food-web model, and two alternative biogeochemical marine ecosystem models. The predictions with the food-web model included MC simulations with alternative parameter sets.

The developed model (Figure 2.3) can be applied to explore characteristics and sustainability indicators of the ecosystem, the fish stocks and economics of fisheries considering different scenarios on climatic change, anthropogenic nutrient loads to the sea and exploitation of fish stocks. The Baltic Sea example shows that the two biogeochemical models frequently used in future projections give considerably different predictions. Further, inclusion of parameter uncertainty of the food web model clearly increased uncertainty in the outcomes and reduced the predicted manageability of the system. As the model allows simultaneous evaluation of environmental and economic goals, while illustrating the uncertainty of predictions, it provides an approach towards a more holistic view on the challenges and potential utilities of ecosystem-based management.

More detailed information:

Uusitalo, L., Blenckner, T., Puntila-Dodd, R., Skyttä, A., Jernberg, S., Voss, R., Müller-Karulis, B., Tomczak, M.T., Möllmann, C., Peltonen, H. 2022: Integrating diverse model results into decision support for good environmental status and blue growth. Science of The Total Environment, Volume 806, Part 2, 150450, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2021.150450

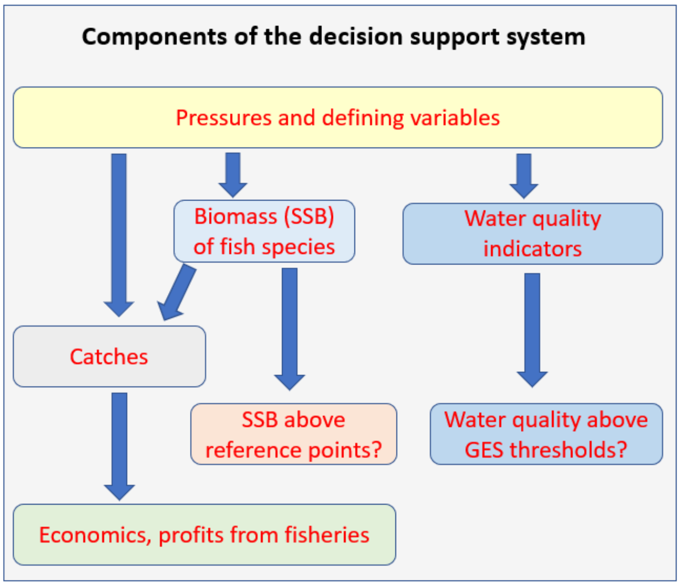

Figure 2.3. A simplified diagram of the developed decision system model.

Robust, ecological–economic multispecies management of Central Baltic fishery resources

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The Baltic fisheries are in distress. In the Central Baltic, fisheries management is challenged by reduced cod stock productivity, and altered species interactions. Here, we use an age-structured, ecological–economic multispecies model, which includes the latest biological and economic knowledge, to advance our understanding of optimal fisheries management and related trade-offs between user groups under such altered conditions. We contribute to the scientific discussion (i) by showing that the economic importance and optimal stock size of cod largely decreased under prevailing conditions, while clupeids increased in importance. (ii) We challenge the current MSY management objective in a multispecies setting (MMSY) and suggest that an economic multispecies management objective (MMEY) might be more useful for setting future management targets. (iii) We identify new trade-offs and synergies by including a consumer perspective: There is a win–win situation for ecological conservation, and profits in the fishery, while fishery management faces trade-offs between these two on the one hand, and consumer surplus on the other hand. (iv) Finally, we suggest an easy to implement new management approach, called robust management, which is capable of better dealing with variability and time-trends in recruitment, as observed for cod, in order to safeguard the Central Baltic fishery resources.

2.3 Management strategy evaluation on Baltic stocks with a focus on the Eastern Baltic Cod stock – literature review (based on ICES WKDEICE 2016)

Management strategy evaluation (MSE) is the state-of-the-art approach for testing and comparing management strategies in a way that accounts for multiple sources of uncertainty (e.g. monitoring, estimation, and implementation). Management strategy evaluation can help identify management strategies that are robust to uncertainty about the life history of the target species and its relationship to other species in the food web (Siple *et al.*, 2021).

One area where EBFM has gained traction is in the management of commercial fisheries for lower-trophic-level prey species, which can reduce food availability for predators. For this reason, management advice about major prey species is starting to include EBFM considerations, such as predation, climate drivers and habitat needs (Anstead *et al.*, 2021; Marshall *et al.*, 2019).

A literature review on Eastern Baltic Cod stock MSE and management related simulations efforts was done by WKDICE (ICES 2016) to identify the type of simulations, scenarios and management evaluations performed. In general, three different types of analysis were recognized:

i. with Harvest Control Rules (HCR) and full iterative Management Strategy Evaluations (MSE), with focus on fleets (fleet base, Table 2.1) and métiers driven by fisheries economy, and fish stock dynamic reflected by relatively simple biological stock models (Bastardie *et al.*, 2010, 2010a; Kraus *et al.*, 2009; Röckmann *et al.*, 2007, 2007a, 2009);
ii. with focus on stock (stock based) and food web development under certain assumed scenarios, reflecting environmental conditions and exploitation levels (Radtke, 2003; Gårdmark *et al.*, 2013; Hansson *et al.*, 2007; Österblom *et al.*, 2007; Niiranen *et al.*, 2012; Niiranen *et al.*, 2013; Lindegren *et al.*, 2010)
iii. with objective optimization as a goal, mainly focusing on economic aspects (Lassen *et al.*, 2012; Döring and Egelkraut, 2007; Froese and Quaas, 2011; Voss *et al.*, 2014; Thøgersea *et al.*, 2015).

Few models address the spatial aspects of stock dynamics (Bastardie *et al.*, 2010, 2010a; Kraus *et al.*, 2009; Köster *et al.*, 2009) or fishing activity (Bastardie *et al.*, 2010, 2010a; Kraus *et al.*, 2009;

Röckmann *et al.*, 2007). In most of the age-structure models the ecosystem impacts on fish stocks are mainly reflected as an environmentally driven stock–recruitment relationship (Kraus *et al.*, 2009; Röckmann *et al.*, 2007, 2007a, 2009; Gårdmark *et al.*, 2013, Köster *et al.*, 2009; Döring and Egelkraut, 2007; Heikinheimo, 2011), while the food web approach stresses either the changes in productivity (Hansson *et al.*, 2007; Österblom *et al.*, 2007; Niiranen *et al.*, 2012; Niiranen *et al.*, 2013) or the statistical relationship (Lindegren *et al.*, 2010; Lade *et al.*, 2015). Approaches presented by Röckmann *et al.* (2007, 2007a, 2009), Kraus *et al*. (2009) and Bastardie *et al*. (2010, 2010a) incorporate most of these aspects (environment, stock dynamic, multispecies interactions, fleets desegregation, full MSE, spatial component, and economy). However, environmental changes are not the main focus and driver in these approaches.

Furthermore, in models addressing stock development and interactions within food webs, fisheries is treated as one of the drivers, similar to i.e. eutrophication or temperature (Hansson *et al.*, 2007; Österblom *et al.*, 2007; Niiranen *et al.*, 2012; Niiranen *et al.*, 2013).

Models address questions on different time-scale – tactical (short- and midterm) and strategic (long term). Most of the models based on age structure, including HCR and economy, operate in a tactical time-scale of 10–30 (max 50) years of forward simulations, i.e. Bastardie *et al.*(2010, 2010a) or Kraus *et al.* (2009), which is reasonable from a management point of view. Models based on scenario simulations, with focus on ecosystem effects, operate in a tactical time-scale of 100 years, and are therefore better equipped to reflect long-term changes in the whole ecosystem. The 100-year time-scale also allows a possibility to highlight long-term effect of multiple pressures i.e. Gårdmark *et al.* (2013) or Niiranen *et al.* (2013). A number of studies has used the multi-model approach, Gårdmark *et al.* (2013), Niiranen *et al.* (2013), Lassen *et al.* (2012) or Uusitalo *et al.* (2015) to link the model and to use ensemble results.

A modelling framework that focuses on Eastern Baltic Cod stock, can cover most questions regarding management and different MSE-types of analysis, as well as issues regarding effects resulting from changes in the environment. But gaps of knowledge still remain, such as: analysis (MSE type) that include extrinsic drivers on stock and fishery as short-term predictions, using environmentally driven SR and/or type where HCR include environmental information at tactical time-scale as e.g. ICES advice framework.

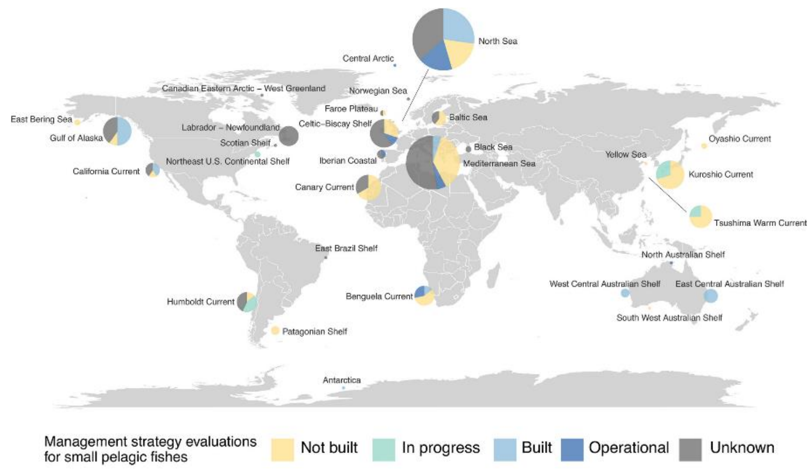


Figure 2.4. The locations of commercial fisheries for small pelagic fishes worldwide. Pie chart size indicates the number of stocks in each ecosystem; colours indicate whether a management strategy evaluation has been developed for a given stock, and if so, whether it is operational in management (Siple *et al.*, 2021).

Although some substantial modelling efforts have been made to evaluate management strategies also for cod in the Baltic, the MSE process has had limited implementation in Europe and North America, including in the Baltic Sea (See Figure 2.4. Punt *et al.*, 2016, Siple *et al.*, 2021). The MSE process is important as it allows managers to focus on long-term trade-offs instead of just short-term outcomes (Butterworth, 2007, Lucey *et al.*, 2021).

Taking into account that: i) The ecology of Baltic sea fish stocks is relatively well recognised, ii) ecosystem and stocks dynamic are environmentally driven, iii) most of the main Baltic stock are ICES assessment category 1 or 2, and iv) a number of stock dynamic processes are included indirectly in the assessment MSE should be a tool for testing management strategies (Baltic Multiannual Plan for Baltic fish Stocks), testing biological reference points and quantifying the risks associated with assessment errors, management applications and environmental/ecosystem changes. As concluded by Lucey *et al.* (2021), "using ecosystem models as Operational Model (OM) for MSE fisheries management can benefit greatly by using integrated ecosystem or multi-species strategies rather than single species procedures (Fulton *et al.*, 2019). It is also theorized that EBFM can provide both ecological and economic benefits by explicitly addressing trade-offs within a system (Link, 2018; Link, 2010). A good way to explore trade-offs within the system and the impact of both ecosystem and single species strategies is with an MSE utilising a full ecosystem model. A good compromise between complexity and system components is a mass balance food web model.

Applying MSE for Baltic fish stocks may support the implantation of EBFAdvice and reduce uncertainty, inform about risk or fisheries management actions and provide credibility of EBFAdvice in a changing ecosystem.

Table 2.1. list of the MSE and management scenarios for Eastern Baltic Cod stock published and presented (ICES WKDEICE 2016). At the columns Reference: model publication; Model: Model name; Type: model focus and simulation type; Simulation time: time of model application; Elements of the model applied: Fleets, Spatial, HCR, Economy; Environment: Environmental factors applied and how; Other: a short description of model aim and application.

Reference	Model	Type	Simulation time	Fleets	Spatial	HCR	Economy	Environment	Other
Bastardie *et al.*, 2010	FLR	Fleet based	2008−2015	Yes	Yes	Yes	Yes	No (hockey stick based SR)	Evaluate the performance and robustness of the 2008 multiannual management plan for the eastern stock. total allowable catch control, direct effort control, and closed areas and seasons.
Bastardie *et al.*, 2010a	FLR	Stock base	2008−2015	No	Yes	Yes	Yes	No (hockey stick based SR)	Evaluate the performance and robustness of the 2008 multiannual management plan for the eastern stock. total allowable catch control, direct effort control.
Kuikka *et al.*, 1999	MCMC/ Bayesian	Simulations						Yes	Exploitation level and mesh size used by a trawl fishery on some variables of management interest under different environmental conditions
Kell *et al.*, 2006	Structural model Age structure	Short−, medium−, and long−term simulations	30 years	No	No	Yes	No	No (different option of Ricker SR)	Study evaluated management strategies that stabilised catches by setting bounds on the interannual variability of TACs.
Radtke, 2003	Cohort analysis	Alternative strategy; hind−cast	1976−1997	No	No	TAC based; F constant BRP	Yes	No	Age reading error evaluated And investigate the number of “what would be if” scenarios
Kraus *et al.*, 2009	ISIS−Fish, age structure	Scenario testing, short− mid term projections	2004−2025	Yes	Yes	Yes	No	Yes (good and bad) oxygen related SR; larval settlement according to	Evaluate proposed and implemented fishery closures, combining an age−structured population module with a multifleet exploitation module and a

Reference	Model	Type	Simulation time	Fleets	Spatial	HCR	Economy	Environment	Other
								Hinrichsen at al 2009	management module in a single model environment.
Gårdmark *et al.*, 2013	Multimodel “Biological ensemble modelling approach	Long-term scenarios		No	No	No	No	Yes, assumptions dependent on model with in “biological ensemble modelling approach	Investigate different ecological assumptions to climate forcing, using multiple realisations of each climate scenario. We simulated the long−term response of cod to future fishing and climate change in seven ecological models
Köster *et al.*, 2009	MSVPA	Long-term simulations; hindcast	1987–2005	No	Yes (subdivision disaggregated)	No	No	Yes	Environmental conditions affecting recruitment matter not only for the determination of limit reference points, but according to long−term simulations also for target fishing mortalities, being central parts of harvest control rules in several management plans.
Döring and Egelkraut, 2007	Ernst *et al.* (2000); Bethke (2006)	Stock base and fleets base	1981−2004 hind−cast+ 50 years scenarios	yes	No	No, explicitly but switch possible between gears	Yes	Yes − SR and M	Studies show that a recovery program is economically and ecologically viable and reduces negative externalities. While policy-makers must assist fishers during the early years of the program, fishers will experience greater landings and profits in subsequent years.
Froese and Quaas, 2011	Age−structured model with 8 age groups as in the respective standard assessment conducted by the Baltic Fisheries Assessment Working	Stock base	2010−2030	No	No	Yes– generic MSY rule, and scenarios F	Yes	SR – hockey stick	Using these numbers as a start, we simulated the development of SSB, catches, and profits under 4 different management options.

Reference	Model	Type	Simulation time	Fleets	Spatial	HCR	Economy	Environment	Other
	Group of ICES (ICES, 2010)								
Voss *et al*., 2014	the single−species age-structured fishery model of Tahvonen (2009) and Tahvonen *et al.* (2013), similar in scope to that of Nieminen *et al.* (2012)	Stock base	2006−2012	No	Per country	No – optimization	Yes	No, species interactions	Investigate a set of different strategic management options single species MSY and M_{MSY}
Lindegren *et al.*, 2010	Stochastic food-web−model driven by regional climate scenarios BALMAR	Stock base	1974−2004 hindcast + scenarios; multiple simulations for each combination of salinity and fishing 1977−2150	No	No	No – scenario based	No	Yes	Assesses the combined impacts of climate and fishing on marine food web dynamics and provides estimates of the confidence envelope of the forecasts.
Rõckmann *et al.*, 2007	Baltic cod population dynamics is age structured and calculates stock size on a time-step of three months explicitly for three SD in the Eastern Baltic Sea. The model includes the migration of mature cod between subareas based on	Stock based	1975−2005 hindcast; simulations 2006−2055	No	Yes	Yes	Yes	Yes; SR driven by RV	The simulation provides an analysis of stock, yield, and revenue development under various management policies and environmental scenarios. The policy analysis, focusing on different regulations of fishing mortality, is embedded into three environmental scenarios, assuming low, medium, or high climate and environmental change.

Reference	Model	Type	Simulation time	Fleets	Spatial	HCR	Economy	Environment	Other
	theoretical,process-oriented assumptions.								
Rõckmann *et al.*, 2009	Same as above Rõckmann *et al.*, 2007	Stock based	1975−2005 hindcast; simulations 2006−2055	No	Yes	Yes	Yes	Yes; SR driven by RV	This study adds a cost analysis of the Eastern Baltic cod fishery to the existing model presented in Rockmann *et al.* (2007)
Rõckmann *et al.*, 2007	Single species, but is fed with output from an area disaggregated MSVPA.	Stock based	1975−2005 hindcast; simulations 2006−2055	No	Yes	Yes – spatial management	No	Yes; SR driven by RV	Investigate management policies reduce fishing mortality and range from a moratorium on the Eastern Baltic cod fishery via the establishment of a permanent or a seasonal marine reserve in ICES Subdivision 25 to a fishing as usual scenario
Heikinheimo, 2011	Develop a 'minimum−realistic' model that could reproduce the development of the fish stocks of the Baltic Sea in 1974–2004	Stock based	1974−2004 hindacast + 200 time-steps (years) scenarios with different F	No	No	No	No	Yes − salinity index in SR	The goal of this study was to explore the dynamics resulting from interactions within the fish (*i*) examine the effect of different types of functional responses, (*ii*) simulation the plausibility of the stock−recruitment relationship incorporating an environmental index for cod, and (*iii*) compare the dynamics of the cod stock under different fishing scenarios.
Hjerne and Hansson, 2001	The model is a single species model based on the (MSVPA) developed within ICES (Sparre, 1991; Magnusso, 1995).	Stock based	50 years	No but cpue involved	No	Harvest option testing	No	No	Explored the potential of a management strategy based on constant catches, by modelling the fishery on the eastern Baltic Sea cod (*Gadus morhua* L.)

Reference	Model	Type	Simulation time	Fleets	Spatial	HCR	Economy	Environment	Other
Hansson *et al.*, 2007	Ecopath with Ecosim	Stock based	Hindcast 1974−2000 + 2001−2100	No	No	Management and environmental scenarios testing	No	Yes	Paper explored possible effects of different management scenarios for the Baltic Sea. The scenarios include an oligotrophication of the system, a drastic increase in the number of seals, and changes in the fishery management.
Österblom *et al.*, 2007	Ecopath with Ecosim	Stock based	Hindcast 1974−2000 Simulations 1900−2000	No	No	No	No	Yes	Authors investigate likely regime shifts in the Baltic Sea throughout the 20th century and address the underlying mechanisms that could help stabilise ecosystem states
Niiranen *et al.*, 2012; Niiranen *et al.*, 2013	Ecopath with Ecosim	Stock based	Hindcast 1974−2005 Simulations 2005−2100	No	No	No	No	Yes	Simulate for the first time how the combined changes in future climate, fishery, and nutrient loads may affect the Baltic Sea food web dynamics, using the open Baltic Sea Ecopath with Ecosim food web model BaltProWeb (Tomczak *et al.*, 2012)
Lassen *et al.*, 2012	Fishrent model (Salz *et al.*, 2011) EwE Baltic foodweb (Tomczak, 2012)	Fishrent – fleet based EwE Stock based	Fishrent 2004−2006 EwE Hindcast 1974−2005 26 years simulations	Fishrent – yes EwE –No	No	No	Fishrent – yes EwE – No	Fishrent – No EwE – Yes	Study presents an approach for analysing/integrating both the economics of the fisheries and the impact from fisheries on ecosystem components other than the target species, e.g. biodiversity and abundance of non−target species.
Uusitalo *et al.*, 2015	Multi approach − spatial visualization of cumulative pressures (Korpinen *et al.*, 2012), (2) Baltic Sea foodweb model (Tomczak *et al.*,	Stock based focus on GES	2007−2014 for EwE 2007−2100	No	Yes	No fix options	No	Yes	Present cumulative effects of the management of nutrient inputs and fishing mortality are likely to exist.

Reference	Model	Type	Simulation time	Fleets	Spatial	HCR	Economy	Environment	Other
	2012 (3) a Bayesian network model (Uusitalo, 2007).								
Lade *et al.*, 2015	Generalised modelling	Socio–ecological system		yes	no	no	yes	yes	Review generalised modelling and use a recent study on the Baltic cod fishery's boom and collapse to demonstrate its application to modelling the dynamics of empirical social–ecological systems.
Thøgersea *et al.*, 2015	age–structured FishrentAge model, which is an extension of the Fishrent model (Salz *et al.*, 2011)	Multi species Stock based and fleet based	2012–2036	Yes	No	Optimization of harvest strategy	Yes	Yes	This paper investigates the economic impacts of managing the cod, sprat, and herring stocks in the eastern Baltic Sea, given ongoing climate change, which is known to affect cod recruitment negatively.
Isomaa *et al.*, 2013	Age–structured	Stock based	2001–2012	No	No	Simplified Proportional harvest and threshold harvest,	No	Yes	Analysed the recovery potential of the Eastern Baltic cod (*Gadus morhua callarias*) under different fishery and environmental scenarios.

3 ToR ii) A review and gap analysis of ecosystem-indicators for the Baltic Sea, relevant for advice on future fishing opportunities;

3.1 Scope

The indicator-system is widely applied in marine management as a way to convey knowledge on the state of the environment and to synthesise ecosystem information in support of tactical and strategic management decisions. Key requirements for indicators to serve this purpose include that they are measurable and take account of trends in space and time. They should also reflect properties of relevance for management, such as being responsive to, or related to, a process of interest for the analysis. In practice, qualitative, semi-quantitative as well as fully quantitative indicators can meet these needs. In relation to assessments supporting ecosystem-based management, risk assessments and ecosystem overviews can potentially encompass a wide range of indicator types under the same framework, while quantitative indicators are usually a prerequisite for supporting environmental status assessments or stock advice.

The indicators can serve several purposes in the management framework: to quantify management goals (such as indicators reflecting management objectives, indicators of environmental status), to support the design of measures for reaching these goals (surveillance indicators, pressure indicators, driver indicators), or to survey steps reached in the implementation of measures (indicators of management progress).

In the ecosystem-based management context, indicators should provide information on ecological as well as societal aspects. However, societal indicators are still not developed on the regional scale in the Baltic Sea. As a result of this, and following the aim of WKEBFAB to support Ecosystem-Based Fisheries Advice (EBFAdvice; see Introduction section), the focus of ToR ii under this first workshop was to screen existing operational ecosystem indicators in the Baltic Sea for potential links to processes affecting fish stocks, such as affecting recruitment, growth or mortality.

3.2 Currently used ecosystem indicators in the Baltic Sea

HELCOM core indicators

Outside of ICES, the main development of regional ecosystem indicators in the Baltic Sea is carried out within HELCOM. This work was initiated with the CORESET[2] project (2010-2013) and has since then continued through various projects and initiatives to develop indicators for evaluating progress in relation to the objectives of the Baltic Sea Action Plan (HELCOM 2021). In doing so, HELCOM also acts as a coordination platform for regional implementation of the EU Marine Strategy Framework Directive (MSFD; EC 2017a,b).

The HELCOM indicators presented in Table 3.1 were used in the Second HELCOM holistic assessment of ecosystem health of the Baltic Sea (HOLAS II; HELCOM 2018) to assess the status of selected elements of biodiversity and human-induced pressures on the Baltic Sea. The indicators were assessed in relation to regionally agreed threshold values (referred to as "Core indicators"). The HOLAS II assessment also included some indicators without (yet) regionally agreed

[2] https://helcom.fi/helcom-at-work/projects/coreset-i/

threshold values, assessed as "Test indicators" (also included in Table 3.1). The potential connection of each indicator to fish stocks is loosely indicated in the Table, but should be considered in more detail in relation to specific fish stocks and advice products.

In the future, additional links between HELCOM indicators and the development of ICES EBFAdvice might be identified, as the indicator development work continues. In addition to refining and widening the scope for indicators of status and pressures, which are currently in focus, an update of climate-related variables is also expected with the next holistic assessment, HOLAS3[3]. Current hydrographical variables used in HELCOM include hydrography and oxygen in the deep basins, development of sea surface temperature, ice season, total and regional runoff, water exchange between the Baltic Sea and North Sea, as well as Wave climate[4]. Qualitative, review-based, assessments of future climate change effects on Baltic Sea ecosystems were recently presented by the HELCOM EN-CLIME network (HELCOM/Baltic Earth 2021).

Table 3.1. Indicators used in HOLAS II, which was presented in 2018. Indicators with a potential close link to either fish productivity, growth or mortality are marked*. The second column provides information on the development state of the indicator. If nothing is stated, the indicator is a core indicator with regionally agreed threshold values for good environmental status. Currently, the third HELCOM holistic assessment is being prepared (to be published in 2023) and additional indicators could be included to the list.

Indicator	Comment
Eutrophication indicator	
Dissolved inorganic nitrogen	
Dissolved inorganic phosphorus	
Total nitrogen	
Total phosphorus	
Chlorophyll-a*	Potential link to growth and productivity (food availability)
Cyanobacterial bloom index	Test indicator, no threshold value
Secchi depth during summer*	Potential link to growth and productivity (feeding rates and food availability)
Oxygen debt*	Potential link to growth and productivity (food availability)
State of the soft-bottom macrofauna community*	Potential link to growth and productivity (food availability)
Hazardous substances indicators	
Hexabromocyclododecane (HBCDD)	
Metals (Cadmium, Lead, Mercury)	
Polybrominated biphenyl ethers (PBDEs)	

[3] https://portal.helcom.fi/meetings/HOD%2061-2021-896/MeetingDocuments/5-5-Rev.1%20Updated%20assessment%20workplan%20and%20timeline%20for%20HOLAS%203.pdf

[4] https://helcom.fi/baltic-sea-trends/environment-fact-sheets/hydrography/

Indicator	Comment
Perfluorooctane sulphonate (PFOS)	
Polyaromatic hydrocarbons (PAHs) and their metabolites	
Polychlorinated biphenyls (PCBs), dioxins and furans	
TBT and imposex	Test indicator, no threshold value
Diclofenac	Descriptive assessment only
Radioactive substances	
White-tailed sea eagle productivity (coastal waters only)	
Operational oil spills from ships	
Indicators related to maritime activities	
Beach litter	Descriptive assessment only
Litter on the seafloor	Descriptive assessment only
Microlitter	Descriptive assessment only
Continuous low frequency anthropogenic sound	Descriptive assessment only
Distribution in time and space of loud low- and mid-frequency impulsive sound	Descriptive assessment only
Seabed loss and disturbance*	Descriptive assessment only Potential link to quality of fish recruitment areas
Trends in arrival of new non-indigenous species	
Fishing mortality and Spawning stock biomass	(Obtained from ICES)
Biodiversity indicators	
State of the soft-bottom macrofauna community*	Implemented only in some sub-basins. This is the same one as assessed above under eutrophication
Oxygen debt*	This is the same one as assessed above under eutrophication
Zooplankton mean size and total stock*	Implemented only in some sub-basins Potential link to growth and productivity (food availability but also food quality)
Chlorophyll-a*	(same as mentioned above)
Cyanobacterial bloom index*	Test indicator, no threshold value; same indicator as mentioned above Potential link to growth and productivity (food availability)
Diatom/Dinoflagellate index*	Test indicator, no threshold value

Indicator	Comment
	Potential link to growth and productivity (food availability)
Seasonal succession of dominating phytoplankton groups*	Test indicator, no threshold value Potential link to growth and productivity (food availability)
Abundance of key coastal fish species*	
Abundance of coastal fish key functional groups*	
Abundance of seatrout spawners and parr*	
Abundance of salmon spawners and smolt*	
Fishing mortality and Spawning stock biomass	(Obtained from ICES) same as above
Population trends and abundance of seals*	Potential link to natural mortality
Nutritional status of seals*	
Reproductive status of seals*	
Distribution of Baltic seals*	Potential link to natural mortality
Number of drowned mammals and waterbirds in fishing gear*	Descriptive assessment only (Potential link to effect of fisheries)
Abundance of waterbirds in the breeding season*	
Abundance of waterbirds in the wintering season	
Number of drowned mammals and waterbirds in fishing gear*	Descriptive assessment only (Potential link to effect of fisheries)

Indicators in the Baltic Sea Ecosystem overview

The Baltic Sea Ecosystem overview (ICES 2019) contains an ecoregion description and a summary of key signals within the environment and ecosystem. The summary reflects results from short evaluations of changes over time in pressures and climate change impacts, and of the state of the ecosystem. The indicators included are from the Baltic Sea regional assessment as presented in HOLAS II (Table 3.1), and from the Baltic Sea Fisheries overview (see below), but also some other data are included. This additional data could potentially support the further development of EBFM indicators or the refinement of existing indicators, including time-series and spatial data.

Indicators in the Baltic Sea Fisheries overview

The Baltic Sea Fisheries Overview (ICES 2020) contains information on who is fishing in the Baltic Sea, with country-wise descriptions of the fisheries, including time-series data on total landings by country and selected data on fishing effort.

Further, catches over time at the Baltic regional level are shown as landings by species groups (pelagic, demersal, benthic and other), by the dominating species, and by gear types. It also includes a brief assessment of discards. More detailed data show fishing effort by gear type for EU vessels over time, and the spatial distribution of average fishing effort for Bottom otter trawls, bottom seines, pelagic trawls and seines and static gears. The overview also includes a brief summary of the current fisheries management.

The status of the fishery resources is reported as a status summary of the number of stocks in good, not good and not assessed status, separately for benthic, demersal and pelagic species, and in total. Status is assessed in relation to the ICES maximum sustainable yield (MSY) approach or precautionary approach (PA), while stocks with unknown reference points are noted as not assessed. The status assessment is in alignment with the MSFD, focusing on the descriptors D3C1 (Fishing pressure) and D3C2 (reproductive capacity of the stock). Data for D3C3 (size and age structure) are missing.

More detailed data show the temporal development over time for selected stocks with respect to D3C1 and D3C2, and gives an overview of status for different species groups with respect to these. The Fisheries overview does not reflect mixed fisheries advice as this has not yet been developed for the Baltic Sea, but contains a text on this. It also included a text on species interactions based on a simplified Baltic food web.

Effects of fisheries on the ecosystem are shown by spatial data on surface and subsurface abrasion by mobile bottom-contacting fishing gear (otter trawls, dredges, and demersal seines), and by a descriptive text on other aspects.

Indicator work in WGBFAS

Some ecosystem indicators are already included in the work of WGBFAS, as described below. Initial screening also suggests some additional indicators that may be relevant. The evaluation is focused on Baltic sprat (*Sprattus sprattus*) as well as Central Baltic and Gulf of Riga herring (*Clupea harengus*) in the Baltic Sea, as these stocks are most likely to be piloted since they are benchmarked in 2022-2023 and the use of additional indicators may be relevant.

Herring

Natural mortality

The populations of cod and sprat affect the CBH recruitment and spawning stock dynamics through predation and competition, respectively. The predation mortality of CBH stock is estimated from the multi-species assessment model SMS (Stochastic Multi Species; Lewy and Vinther, 2004) every 3-4 years (ICES, 2021). The estimate of the cod stock biomass is used as an external variable to estimate the predation mortality.

For Gulf of Riga herring fixed natural mortality of 0.2 is used in the assessment, except for the period of 1979-1983 when due to cod invasion into the gulf, M was assumed equal to 0.25 in all age groups (ICES, 2021).

Recruitment

Beverton-Holt and Ricker stock-recruitment models have often only explained a small fraction of the interannual recruitment variation in herring. It has been assumed that considerable extent of the variation is caused by the influence of different environmental factors. Cardinale *et al.* (2009) showed that for CBH, food supply, August SST (sea surface temperature) and spawner's condition (individual weights at age 3+) are the best predictors for recruitment. For GoR herring, the additive model with SSB and May SST was found to be the best model to describe recruitment variation. Margonski *et al.* (2010) found similar results, showing that SSB, Baltic Sea Index (BSI) in December-February prior to spawning and potentially November-December SST (winter following spawning) helps to explain the variability in recruitment. For CBH, SSB and August SST were the most important environmental variables for explaining the variability in recruitment.

For GoR herring, variables identified as significant predictors of R include the Fulton condition factor of age groups 2-5 (Putnis *et al.*, 2011), Baltic Sea Index (BSI) in winter, SST and SSB (Cardinale *et al.*, 2009; Margonski *et al.*, 2010), larval abundance in coastal areas, winter air temperature, and SSB during the mild winters (Ojaveer *et al.*, 2011), and prey density in the open GoR and the severity of the first winter the individuals survived (Ojaveer *et al.*, 2021).

There have been attempts to include environmental variables for predictions of R for GoR herring short-term projections. The recruitment-at-age 1 in the intermediate year until 2011 was estimated using RCT3 where the values of mean water temperature in April and abundance of zooplankton in May were regressed against the 1-group from the XSA. However, it was found that RCT3 poorly predicts strong year classes and since 2012 the intermediate year R is predicted as the geometric mean. Poor prediction of strong year classes is a shortcoming that is present also in other models (Ojaveer *et al.*; 2021, Margonski *et al.*, 2010).

Stock-recruitment relationships fail to capture the whole variation in R, due to multiple drivers of R dynamics. Work of Zimmermann *et al.* (2021) suggests predation on early life stages could be the main cause of weak empirical evidence of clear S-R relationship. Kornilovs (1995) concluded that the appearance of poor year-classes in the beginning of 80's was defined by the abundance of cod in GoR, however, since the 1990s cod has been practically absent in the gulf and not considered to affect herring in there (this is taken into account as fixed M for GoR herring stock assessment; ICES, 2021). Furthermore, large scale habitat loss for life-history stages that mediate population size (e.g. egg survival and early life-history stages) have been documented for herring across the Baltic (Kanstinger *et al.*, 2018; Illing *et al.*, 2016) but the seasonal availability of habitat has not been linked to recruitment.

Sprat

The biomass of sprat in the Baltic is strongly influenced by recruitment, natural mortality and fishing pressure. Sprat in the Baltic inhabit the northern boundaries of the species distribution (Muus *et al.*, 1999). Low temperature can thus have a negative impact on productivity and survival:

Natural mortality

The predation mortality of sprat is estimated from the multi-species assessment model SMS (Stochastic Multi Species; Lewy and Vinther, 2004) every 3-4 years (ICES, 2021). The spawning stock biomass of sprat only has limited influence on the recruitment strength (MacKenzie and Köster, 2004). The predation pressure on sprat is predominantly influenced by its main predator, i.e. the biomass of cod (Sparholt, 1994; ICES, 2021). Variation in the spatial overlap of sprat and cod and fluctuations of the cod biomass thus lead to interannual variation in the predation mortality (Eero, 2012). A mismatch in the spatial overlap between the cod and the sprat stock and a decrease in cod biomass led to a decrease in natural mortality in the last decade (ICES, 2021). The estimate of the cod stock biomass is used as an external variable to estimate the predation mortality. This is already an example where an indicator is included in the assessment. In contrast, the residual natural mortality is kept constant (ICES, 2020).

Recruitment

Recruitment success of sprat does not solely depend on the spawning stock biomass (MacKenzie and Köster, 2004 and reference therein; Voss *et al.*, 2012). Field samplings, laboratory experiments and modelling exercises stated that temperature and prey abundance as well as transport dynamics of larval cohorts as the main drivers for recruitment outcome (e.g. Nissling, 2003;

MacKenzie and Köster, 2004; Baumann *et al.*, 2006; Voss *et al.*, 2012). Laboratory experiments showed that temperatures <5°C caused an increased mortality for eggs and larvae produced by Baltic sprat (Nissling, 2003). Further, low temperatures can also lead to slower sprat growth and reduced gonadal development and thus influence recruitment negatively (Grauman and Yula, 1989, Parmanne *et al.*, 1994). Baumann *et al.* (2006) for example used a Lagrangian particle simulation and sprat spawning stock biomass to predict 82% of the overall recruitment variability between 1979 and 2008. Larval displacements from the central spawning basins to the south-eastern coastal areas were predicted to result in less productive recruitment output. Additionally, the study showed that temperature and recruitment highly correlated in the surface water in August (73%) with higher temperatures having a positive impact on recruitment. An indicator including temperature and drift modelling might be suitable to be included in the sprat assessment. The extension of the time-series to recent times could provide further insights for a potential recruitment index.

3.3 Evaluation

Several ecosystem indicators are currently operational for the Baltic Sea region. Most of these have been developed in relation to the Marine Strategy Framework Directive and the Baltic Sea Action plan, hence they have been developed to support marine environmental management generally. Most of the existing indicators can potentially support EBFAdvice by providing an integrated ecosystem assessment framing and some of them have a potential link to aspects of fish productivity, growth and natural mortality.

However, the existing set of indicators were not directly connected to the needs of EBFAdvice, based on a preliminary evaluation in relation to current advice processes and foreseen development work in WGBFAS. It is suggested that further work should focus on assessing to what extent selected existing indicators could be analytically linked to the developing EBFAdvice, and on proposing how to solve cases where this is not possible, such as establishing new indicators. This work strand would preferentially be integrated with the different steps in the proposed roadmap, as outlined below.

On a general level, there is a lack of food web indicators (to evaluate e.g. changes in productivity), climate indicators and indicators of recruitment areas. The workshop participants are aware of various ongoing initiatives to fill these gaps, and suggest that these aspects will be revised in an upcoming workshop so that WKEBFAB can take part in the development.

4 ToR iii) An evaluation of how of existing stock assessment and ecosystem models and their integration can be used to fill the gaps identified in ToR ii) and for giving advice on ecosystem-based catch options

4.1 Review of foodweb models in the Baltic Sea

27 foodweb related models were reviewed with different application areas in the Baltic Sea (Table 4.1 and Figure 4.1). This list is probably not exhaustive, but covers the different types of ecosystem models applied in the region. Bio-geochemical models without explicit substructures for fish that are management applicable are not included in this review.

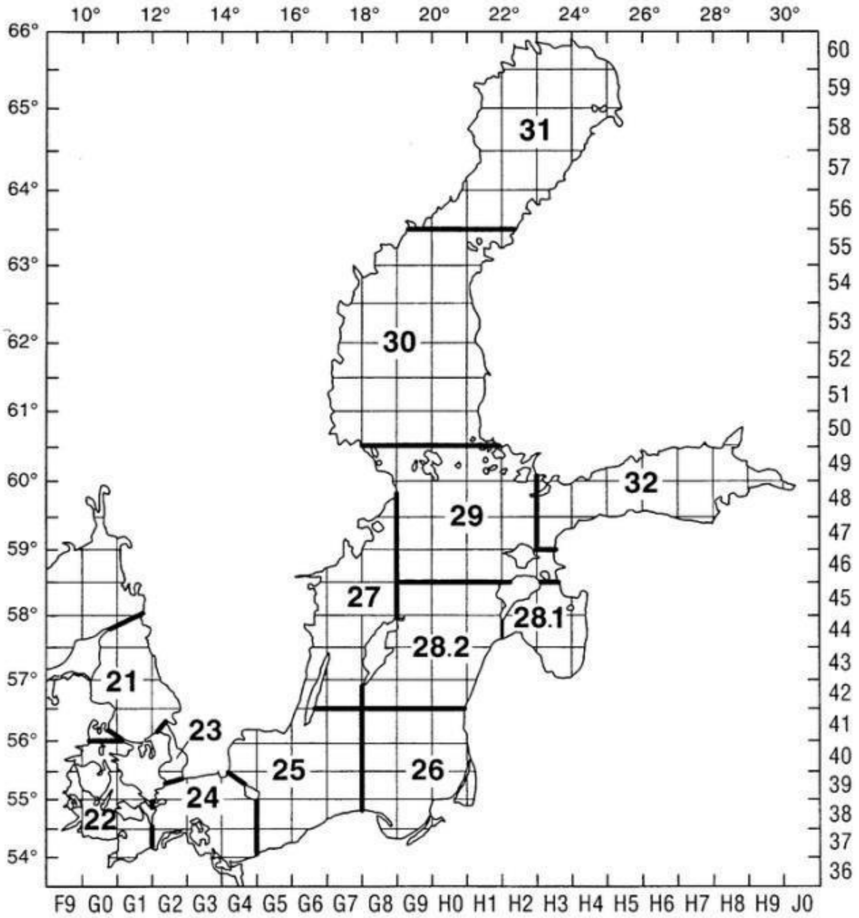


Figure 4.1 ICES subdivisions and statistical rectangles in the Baltic Sea

Table 4.1. Model applications by ICES subdivisions and purpose of the models.

#	Authors	Year	Subdivisions													Purpose
			21	22	23	24	25	26	27	28.1	28.2	29	30	31	32	
1	Elmgren	1984														Overview over main carbon flows
2	Wulff & Ulanowicz	1989														Comparison of structure and function Baltic/Chesapeake Bay
3	Rudstam *et al.*	1995														Top-down control in the pelagic ecosystem
4	Jarre-Teichmann	1995														Seasonal energy flows
5	Horbowy	1996														Production model for commercial fish stocks
6	Sandberg *et al.*	2000														Updated carbon flows
7	Harvey *et al.*	2003														Interactions between fisheries and food web
8	Sandberg *et al*.	2004														Terrigene dissolved organic carbon as structuring factor for secondary production
9	Sandberg	2007														Comparison of pelagic food web structures in three main basins
10	Hansson *et al.*	2007														Management scenarios
11	Van Leeuwen *et al.*	2008														Apparent Allee effect
12	Tomczak *et al.*	2009						Coastal systems								Compared carbon flows in five south-eastern Baltic coastal ecosystems
13	Lindegren *et al.*	2009														demonstrate that in hindsight the cod collapse could only have been avoidable by adapting fishing pressure to environmental conditions and food-web interactions
14	Teschner *et al.*	2010														Impact of hypoxia on pelagic commercial fishes predation rates

#	Authors	Year	Subdivisions													Purpose
			21	22	23	24	25	26	27	28.1	28.2	29	30	31	32	
15	Tomczak *et al.*	2013														simulated the regime shift in the Central Baltic Sea of the 1980s
16	Gårdmark *et al.*	2013														Biological ensemble model
17	Lindegren *et al.*	2014														Meta-community model for source-sink dynamics
18	Gårdmark *et al*.	2015														Detecting mechanisms underlying alternative stable states
19	Norrström *et al*.	2017														Nash equilibrium for multispecies fisheries management reference points
20	Jacobsen *et al.*	2017														Ecosystem-level efficiency of fisheries in five large marine ecosystems (
21	Bauer *et al.*	2018														Simulating reduced eutrophication
22	Bossier *et al.*	2018														End-to-end model implementation
23	Uusitalo *et al.*	2018														Dynamic Bayes Network Implementation
24	Bauer *et al*.	2019														Food web and fisheries in the future Baltic
25	Bauer *et al.*	2019														Model uncertainty and simulated fisheries advice
26	Kulatska *et al.*	2019														Implementing GADGET multispecies model for commercial fish species
27	Karlson *et al.*	2020														Linking consumer physiological status to food web structure and prey food value

Elmgren (1984) was the first to model Baltic **energy flows** using a mass-balance model. He showed pelagic primary production to be the primary energy source with river input and benthic primary production to be important locally. Direct waste discharge of organic matter was only of minor importance. The paper suggests that most of the energy was utilised within the pelagic system, where the 'exudate-bacteria-microzooplankton-pelagic fish' food chain seemed to be more important, in terms of carbon transport, than the classic 'phytoplankton-mesoozooplankton-pelagic fish food chain. Energy reached the benthos passively by sedimentation and actively through suspension feeding by the macrofauna. Besides this first prioritisation of carbon pathways, Elmgren (1984) stressed the sensitivity of the Baltic Sea to anthropogenic impacts.

Wulff and Ulanowicz (1989) concluded in their comparison of the Baltic Sea to Chesapeake Bay, that there appears to be a real biological difference between the feeding habits of the planktivorous fishes in the two systems. In the Chesapeake the menhaden (*Brevoortia tyrannus*) acted in large part as herbivores consuming phytoplankton, whereas their Baltic counterparts fed exclusively on trophically higher zooplankton during the warm months and on benthic invertebrates during the winter. The Baltic Sea, in spite of its lower species diversity compared to the Chesapeake Bay, had furthermore a higher relative **diversity of flows**.

Rudstam *et al.* (1995) review evidence for and possible consequences of **top-down control** in the pelagic Baltic Sea ecosystem using partially a statistical approach. Two top-down control processes, cod predation on clupeids and clupeid predation on cod eggs, were considered important and tended to produce either a cod-dominated or a clupeid-dominated system. Several counteracting forces could prevent this from happening, including the side-effects of eutrophication, variable hydrographic conditions, cannibalism within species, the fishery, and separate spawning and nursing areas for herring. Top-down control of zooplankton was likely to be intense but variable with season. Zooplanktivores (primarily herring, sprat and mysids) were selective and consumed a large proportion of the estimated zooplankton production (50-93%). In addition, zooplanktivory was at a peak in late summer and early autumn when zooplankton populations declined. Therefore, a negative correlation was expected between clupeid and zooplankton biomass although this was not found in available datasets (1974-1988). The lack of correlation could be due to relatively small changes (by a factor 2) in planktivore biomass over this time period and compensatory increases in other zooplanktivores (e.g. mysids and juvenile clupeids). Less was known about the top-down control of primary production in the Baltic Sea. Available information suggested that grazing rates on algae is maintained as metazooplankton decrease by compensatory responses of protozooplankton.

Jarre-Teichmann (1995) presented four preliminary mass-balance models of **carbon flow by season**, based on estimates of standing stock and energy flow from the late 1980s and early 1990s. The construction of the models emphasized on the commercially most important fish species, herring (*Clupea harengus*), sprat (*Sprattus sprattus*), and cod (*Gadus morhua*). Further included were primary producers, several groups of planktonic invertebrates and benthos, as well as commercially less important fish. The models were analysed and compared by means of network analysis.

Horbowy (1996) developed a **multispecies stock-production** model and used it to estimate the dynamics of cod, herring, and sprat stocks from 1982 to 1992. Inputs to the model were estimates of the fishing effort, recruitment indices, mean individual weight of fish in the stock, von Bertalanffy's growth parameters, and residual natural mortality. The model's parameters that were not known in advance (e.g. food preference parameters, catchabilities, calibration coefficient for recruitment indices) were estimated by minimising the deviations of observed catches and food composition of cod from the values arrived at from the model. The standard errors of the fitted parameters of the model were evaluated using a bootstrap procedure. Sensitivity analyses showed that growth parameters had the largest influence on the model outcome. The model produced estimates of the population dynamics of Baltic fish stocks consistent with the estimates from age-structured models. In the period analysed, the biomass of cod decreased by about 80%, the biomass of herring was stable, and sprat biomass fluctuated, increasing finally to a record high level. The estimated decrease of cod biomass is reflected in a decreasing predation mortality of herring and sprat.

Sandberg *et al.* (2000) used the EcopathII software (ver 3.1) to analyse models of **carbon flow through the food webs in the three main areas of the Baltic Sea**; the Baltic proper, Bothnian Sea and Bothnian Bay. Elmgren (1984) was complemented with the data on respiration and flow to detritus from Wulff and Ulnowicz (1989) in order to present complete mass balance models of carbon. The purpose of re-evaluating previous models with new analytic tools was to check how well their carbon flows balance, and to provide a basis for improved mass balance models using more recent data, including nutrients other than carbon. The resulting mass balance networks for the Baltic proper, Bothnian Sea and the Bothnian Bay were shown to deviate from steady state. There was an organic carbon surplus of 45, 25, and 18 g C m-2 year-1 in the pelagic zones of the Baltic proper, Bothnian Sea and Bothnian Bay, respectively. The Ecopath network analysis confirmed that the overall carbon flow was highest in the Baltic proper, somewhat lower in the Bothnian Sea and much lower in the Bothnian Bay. The only clear differences in food web structure between the basins was that the average trophic level was lower for demersal fish in the Bothnian Sea and higher for macrofauna in the Bothnian Bay, compared to the other basins.

Harvey *et al.* (2003) created a food web model for the Baltic proper, using the Ecopath with Ecosim software, to evaluate **interactions between fisheries and the food web from 1974 to 2000**. The model was based largely on values generated by multispecies virtual population analysis (MSVPA), an earlier commercial fish centred model. Ecosim outputs closely reproduced MSVPA biomass estimates and catch data for sprat, herring, and cod, but only after making adjustments to cod recruitment, to vulnerability to predation of specific species, and to foraging times. Among the necessary adjustments were divergent trophic relationships between cod and clupeids: cod exhibited top-down control on sprat biomass, but had little influence on herring. Fishing, the chief source of mortality for cod and herring, and cod reproduction, as driven by oceanographic conditions as well as unexplained variability, were also key structuring forces. The model generated many hypotheses about relationships between key biota in the Baltic Sea food web and may ultimately provide a basis for estimating community responses to management actions.

Sandberg *et al.* (2004) quantitatively assessed the **relative importance of terrigenous dissolved organic material** (TDOC) as a carbon source for secondary producers (e.g. bacteria) and as a structuring factor for the pelagic food web in the Gulf of Bothnia, northern Baltic Sea. The 3 study sites, situated in Bothnian Bay (BB), the Öre Estuary (ÖE) and the Bothnian Sea (BS), had markedly different freshwater loads and water-residence times. In Bothnian Bay, bacterial biomass and production were higher than expected from the levels of phytoplankton biomass and productivity there, suggesting an uncoupling of bacterial productivity from phytoplankton production. Phytoplankton size structure and size-fractionated production were, however, relatively similar among areas. A simplified carbon budget model suggested that bacterioplankton dominated organic carbon consumption in all of the food webs studied, but was most marked in BB. The model showed that the available autochthonous primary production could not alone support the heterotrophic carbon demand in BB. The most likely explanation of this discrepancy was that the total annual input of terrigenous dissolved organic carbon was bioavailable, resulting in a budget closer to balance with the heterotrophic carbon demand. BB, receiving 38% of the carbon input from land, was consequently a net heterotrophic ecosystem. A sensitivity analysis showed that the bacterial carbon demand, and growth efficiency in particular, had the greatest influence on the resulting budget. TDOC was the dominant carbon source in ÖE, but the losses of carbon through advection to offshore areas and sedimentation was high. The evidence of net heterotrophy in ÖE was therefore weaker than in BB. In BS the input of TDOC was less important, and the carbon used for secondary production originated mainly from autochthonous primary production. The results suggested that the supply of TDOC is of great importance for the abundance of plankton and as a structuring factor for the aquatic food webs in the Gulf of Bothnia.

Sandberg (2007) compared Ecopath models of mass flow of carbon through pelagic food webs in the three major basins of the Baltic Sea: Bothnian Bay (BB), Bothnian Sea (BS) and the Baltic proper (BP) including the Gulfs of Finland and Riga. The carbon flows in the models were estimated indirectly based on monitoring data of bacterial and primary productivity as well as on literature data on predator's diets and size-fractionated primary production. Analysis of the carbon flows suggested that in order to present a good balance between inputs and losses of carbon to each system, the most sensitive factor in the models, e.g. averaged monitoring data on bacterial productivity had to be lowered for the BB and BS, whereas it was raised for the BP basin. The final model configuration resulted in fairly realistic productivity estimates and carbon demands for individual compartments in each area. The supply of carbon via autochthonous primary production was highest in the Baltic proper (192 g C m-2 year-1), whereas it was estimated 3 and 11 times lower in the BS and the BB, respectively. The input of allochthonous sources, via terrigenous dissolved organic carbon as well as advection between basins was relatively higher towards the north, being 7.4, 11.6, and 22 g C m-2 year-1 in the BP, BS, and BB, respectively. Along with the higher allochthonous supply there was a gradual increase in bacterial production relative to particulate primary production since that ratio was 20%, 60%, and 160% in the BP, BS and BB, respectively. The relatively higher bacterial production as compared to primary production towards the north of the Baltic Sea resulted in systematic differences in carbon flow between basins. The flow from particulate primary production to the classic food chain (zooplankton and Mysids) and the microbial food web was fairly similar between areas. However, the demand for particulate primary production by the microbial food web was 79%, 54%, and 29% in the BP, BS and BB, respectively. The study thus gave further indirect support to the view that **the carbon flow through the microbial food web** is enhanced in less productive aquatic systems with relatively high input of allochthonous carbon such as the Bothnian Sea and the Bothnian Bay.

Hansson *et al.* (2007) explored possible effects of different **management scenarios** for the Baltic Sea, based on an earlier published ecosystem model. The scenarios include an oligotrophication of the system, a drastic increase in the number of seals, and changes in the fishery management. From these simulations they concluded that fisheries, seals, and eutrophication all have strong and interacting impacts on the ecosystem. These interactions call for integrated management. The modelling highlighted the potential for conflicts among management mandates such as flourishing fisheries, rebuilt seal populations, and substantially reduced eutrophication. The results also suggested that fisheries management reference points have to be adjusted in response to changes in the presence of natural predators or ecosystem productivity.

Van Leeuwen *et al*. (2008) explored whether the lack of cod recovery can be ascribed to an **emergent Allee effect**, which is a mechanism intrinsic to the community in contrast to explanations involving environmental factors. They formulated a stage-structured biomass model for the cod-sprat interaction in the Baltic Sea, paying special attention to the size-dependent prey preference of differently sized cod. The model predicted that alternative community states can occur under the same environmental conditions, in which cod is either present or absent. In a stable equilibrium with its main prey cod has a strong effect on the prey size distribution, resulting in larger densities of preferred prey sizes for cod than in the absence of any predation. Cod thus shapes its food environment to its own benefit. Furthermore, in response to increased exploitation cod biomass and yield tended to increase unless a stock collapse is imminent. After a cod stock collapse and the consequent drop in predation the prey size distribution becomes stunted and offers insufficient food for cod to grow and recover. These results were consequences of the indirect effects of predation and harvesting, whereby increased mortality relaxed competition among surviving individuals, leading to an increase in food intake and hence increased somatic growth and reproduction. The paper observed community changes following the collapse of the cod stocks in the North West Atlantic and the Baltic Sea in the light of model predictions. In line with the model predictions growth in body size of cod had slowed down after the collapse, despite high densities of prey biomass. Furthermore, estimates of total prey population fecundity in the Baltic Sea identified the emergent Allee effect as a potentially important mechanism contributing to the lack of cod recovery.

Tomczak *et al*. (2009) **compared carbon flows in five south-eastern Baltic coastal ecosystems** (Puck Bay, Curonian Lagoon, Lithuanian coast, Gulf of Riga coast and Pärnu Bay) on the basis of ECOPATH models using 12 common functional groups. The studied systems ranged from the hypertrophic Curonian Lagoon to the mesotrophic Gulf of Riga coast. Interestingly, they found that macrophytes were not consumed by grazers, but rather channelled into the detritus food chain. In all ecosystems fisheries had far reaching impacts on their target species and on the food-web in general. In particular, benthic food-webs were partly affected by indirect fisheries effects. For example, fisheries tended to change the biomass of piscivorous fish, causing a cascading effect on benthivorous fish and macrozoobenthos. These cascades were ecosystem specific and needed to be considered when using benthic invertebrates as productivity and eutrophication indicators. Odum's maturity attributes allowed a ranking of coastal ecosystems according to their maturity. Namely, the community development decreased in the following order: Pärnu Bay > Gulf of Riga coast > Lithuanian coast > Puck Bay > Curonian Lagoon.

Developing ecosystem-based fisheries management (EBFM) to prevent catastrophic fisheries collapses in the future requires ecological models incorporating both internal food web dynamics and external drivers such as fishing and climate. Using a **stochastic foodweb model** for the Baltic Sea, Lindegren *et al.* (2009) we were able to reconstruct the history of the Eastern Baltic cod stock. Moreover, they demonstrated that in hindsight the collapse could only have been avoidable by adapting fishing pressure to environmental conditions and food-web interactions.

Teschner *et al.* (2010) investigated the **effects of oxygen deficiency on** cod consumption rates and how these translate to **stock size estimates in multi-species models**. Based on results from laboratory experiments, a model was fitted to evacuation rates at different oxygen levels and integrated into the existing consumption model for Baltic cod. Individual mean oxygen corrected consumption rates were 0.1-10.9% lower than the uncorrected ones.

Tomczak *et al.* (2013) **simulated the regime shift in the Central Baltic Sea** of the 1980s that has been associated with food-web reorganisation and redirection of energy flow pathways. The long-term dynamics from 1974 to 2006 have been simulated here using a food-web model forced by climate and fishing. Ecological network analysis was performed to calculate indices of ecosystem change. The model replicated the regime shift. The analyses of indicators suggested that the system's resilience was higher prior to 1988 and lower thereafter. The ecosystem topology also changed from a web-like structure to a linearized food-web.

Natural resource management requires approaches to understand and handle sources of uncertainty in future responses of complex systems to human activities. Gårdmark *et al.* (2013) presented one such approach, the "**biological ensemble modeling approach**," using the Eastern Baltic cod as an example. The core of the approach was to expose an ensemble of models with different ecological assumptions to climate forcing, using multiple realisations of each climate scenario. They simulated the long-term response of cod to future fishing and climate change in seven ecological models ranging from single-species to food web models. These models were analysed using the "biological ensemble modelling approach" by which they (1) identified a key ecological mechanism explaining the differences in simulated cod responses between models, (2) disentangled the uncertainty caused by differences in ecological model assumptions from the statistical uncertainty of future climate, and (3) identified results common for the whole model ensemble. Species interactions greatly influenced the simulated response of cod to fishing and climate, as well as the degree to which the statistical uncertainty of climate trajectories carried through to uncertainty of cod responses. Models ignoring the feedback from prey on cod showed large inter-annual fluctuations in cod dynamics and were more sensitive to the underlying uncertainty of climate forcing than models accounting for such stabilising predator-prey feedbacks. Yet in all models, intense fishing prevented recovery, and climate change further decreased the cod population.

The degree to which metapopulation processes influence fish stock dynamics is a largely unresolved issue in marine science and management, especially for highly mobile species such as Atlantic cod and herring. The Baltic Sea comprises a heterogeneous oceanographic environment that structures the spatial and temporal distribution of the dominant species cod, herring, and sprat. Despite local differences, the stocks are traditionally managed as homogeneous units. Lindegren *et al.* (2014) presented a **metacommunity-perspective on source-sink dynamics of Baltic Sea fish stocks** by using a spatially disaggregated statistical food web model. The model was fitted to area-specific time-series of multiple abiotic and biotic variables using state-space methods. Their analysis revealed pronounced net fluxes between areas, indicative of source-sink dynamics, as well as area-specific differences in species interactions (i.e. density dependence, competition, and predator-prey) and the degree of fishing and climate impact on survival and recruitment. Furthermore, model simulations showed that decreasing exploitation pressure in the source area for cod (without reallocating fishing effort) produces an increase in neighboring sink habitats, but a decline of prey species in response to increased predation.

Many marine ecosystems have undergone ‘regime shifts’, i.e. abrupt reorganisations across trophic levels. Establishing whether these constitute shifts between alternative stable states is of key importance for the prospects of ecosystem recovery and for management. Gårdmark *et al.* (2015) showed how **mechanisms underlying alternative stable states caused by predator-prey interactions** can be revealed in field data, using analyses guided by theory on size-structured community dynamics. This was done by combining data on individual performance (such as growth and fecundity) with information on population size and prey availability. They discussed and distinguished two types of mechanisms, ‘cultivation depensation’ and ‘overcompensation’, that can cause alternative stable states preventing the recovery of overexploited piscivorous fish populations. Importantly, the type of mechanism can be inferred already from changes in the predators’ body growth in different life stages. Their approach aimed to be applied to monitored stocks of piscivorous fish species, for which this information often can be assembled. However, these findings are only valid, if environmental impact can be assumed constant.

Norrström *et al.* (2017) stated that the current fisheries management goals set by the European Commission to deliver maximum sustainable yields (MSY) and simultaneously take ecosystem considerations into account creates unsolved trade-offs for the management of the stocks. They suggested a definition of a multi-species-MSY (MS-MSY) where no alternative fishing mortality (F) can increase yield (long term) for any ecologically interacting stock, given that the other stocks are fished at constant efforts (Fs). Such a MS-MSY can be solved through the **game theoretic concept of a Nash equilibrium** and they explored two solutions to this conflict in the Baltic Sea. They maximised the sustainable yield of each stock under two constraints: first, to harvest the other stocks at a fixed F (FNE); second, to keep the spawning stock biomasses of the other stocks fixed [biomass Nash equilibrium (BNE)]. As a case study, they have developed a multi-species interaction stochastic operative model (MSI-SOM), which contains a SOM for each of the three dominant species of the Baltic Sea, the predator cod, and its prey herring, and sprat. For the Baltic Sea case, MS-MSYs existed under both the FNE and the BNE, but there was no guarantee that point solutions exist. They found that the prey species' spawning stock biomasses are additive in the cod growth function, which allowed for a point solution in BNE. In the FNE, the herring MSY was found to be relatively insensitive to the other species' fishing mortalities (F), which facilitated a point solution. The MSY targets of the BNE and the FNE differed slightly where the BNE gave higher predator yields and lower prey yields.

Weighing objectives becomes increasingly challenging when managers have to consider opposing objectives from different stakeholders. Jacobsen *et al*. (2017) offered an alternative view on dealing with trade-offs: An alternative to weighing incomparable and conflicting objectives was to focus on win–wins until Pareto efficiency is achieved: a state from which it is impossible to improve with respect to any objective without regressing at least one other. They investigated the ecosystem-level efficiency of fisheries in five large marine ecosystems (LMEs), including the Baltic, with respect to yield and an aggregate measure of ecosystem impact using a **novel calibration of size-based ecosystem models**. They estimated that fishing patterns in three LMEs (North Sea, Barents Sea and Benguela Current) were nearly efficient with respect to long-term yield and ecosystem impact and that efficiency has improved over the last 30 years. In two LMEs (Baltic Sea and North East US Continental Shelf), fishing was inefficient and win–wins remained available. They additionally examined the efficiency of North Sea and Baltic Sea fisheries with respect to economic rent and ecosystem impact, finding both to be inefficient but steadily improving. Their results suggest the following: (i) a broad and encouraging trend towards ecosystem-level efficiency of fisheries; (ii) that ecosystem-scale win–wins, especially with respect to conservation and profits, may still be common; and (iii) single-species assessment approaches may overestimate the availability of win–wins by failing to account for trade-offs across interacting species.

Bauer *et al*. (2018) investigated, if eutrophication management has the potential to substantially affect which areas are going to be most suitable for commercial fishing in the future. They used a **spatial ecosystem model (ecospace)**, forced by a coupled physical-biogeochemical model, to simulate the spatial distribution of functional groups within a marine ecosystem, which depends on their respective tolerances to abiotic factors, trophic interactions, and fishing. They simulated the future long-term spatial developments of the community composition and their potential implications for fisheries under three different nutrient management scenarios and changing climate. The three nutrient management scenarios resulted in contrasting developments of bottom oxygen concentrations and phytoplankton abundance, with substantial effects on fish production. Nutrient load reduction increases the spatial extent of the areas suitable for the commercially most valuable demersal fish predator and all types of fisheries.

Achieving good environmental status in the Baltic Sea region requires decision support tools which are based on scientific knowledge across multiple disciplines. Such tools should integrate the complexity of the ecosystem and enable exploration of different natural and anthropogenic pressures such as climate change, eutrophication and fishing pressures in order to compare alternative management strategies. Bossier *et al.* (2018) presented a new framework, with a **Baltic implementation of the spatially-explicit end-to-end Atlantis ecosystem model** linked to two external models, to explore the different pressures on the marine ecosystem. The HBM-ERGOM initialises the Atlantis model with high-resolution physical-chemical-biological and hydrodynamic information while the FISHRENT model analyses the fisheries economics of the output of commercial fish biomass for the Atlantis terminal projection year. The Baltic Atlantis model composes 29 subareas, 9 vertical layers and 30 biological functional groups. The balanced calibration provides realistic levels of biomass for, among others, known stock sizes of top predators and of key fish species. Furthermore, it gives realistic levels of phytoplankton biomass and shows reasonable diet compositions and geographical distribution patterns for the functional groups. By simulating several scenarios of nutrient load reductions on the ecosystem and testing sensitivity to different fishing pressures, they showed that the model is sensitive to those changes and capable of evaluating the impacts on different trophic levels, fish stocks, and fisheries associated with changed benthic oxygen conditions.

Ecosystems are known to change in terms of their structure and functioning over time. Modelling this change is a challenge, however, as data are scarce, and models often assume that the relationships between ecosystem components are invariable over time. **Dynamic Bayesian Networks** (DBN) with hidden variables have been proposed as a method to overcome this challenge, as the hidden variables can capture the unobserved processes. In Uusitalo *et al.* (2018), a series of DBNs with different hidden variable structures were fit to the Baltic Sea food web. The exact setup of the hidden variables did not considerably affect the result, and the hidden variables picked up a pattern that agrees with previous research on the system dynamics.

Bauer *et al.* (2019a) developed numerical simulations of potential future ecological states of the Baltic Sea ecosystem at the end of century under five scenarios. They used a **spatial foodweb (ecospace) model, forced by a physical–biogeochemical model**. The scenarios were built on consistent storylines that describe plausible developments of climatic and socioeconomic factors in the Baltic Sea region. Modelled species diversity and fish catches were driven by climate- and nutrient load-related changes in habitat quality and by fisheries management strategies. Their results suggest that a scenario including low greenhouse gas concentrations and nutrient pollution and ecologically focused fisheries management results in high biodiversity and catch value. On the other hand, scenarios envisioning increasing societal inequality or economic growth based on fossil fuels, high greenhouse gas emissions and high nutrient loads result in decreased habitat quality and diminished biodiversity. Under the latter scenarios catches are high but they predominantly consist of lower-valued fish.

Different ecosystem models often provide contrasting predictions (model uncertainty), which is perceived to be a major challenge impeding their use to support ecosystem-based fisheries management (EBFM). The focus of Bauer *et al.* (2019b) was to examine the extent of model disagreements which could impact management advice for EBFM in the central Baltic Sea. They **compared how much three models (EwE, Gadget and a multispecies stock production model) differ** in 1) their estimates of fishing mortality rates (Fs) satisfying alternative hypothetical management scenario objectives and 2) the outcomes of those scenarios in terms of performance indicators (spawning stock biomasses, catches, profits). Uncertainty in future environmental conditions affecting fish was taken into account by considering two seal population growth scenarios and two nutrient load scenarios. Differences in the development of the stocks, yields and profits existed among the models but the general patterns were also sufficiently similar to appear promising in the context of strategic fishery advice. Thus, they suggested that disagreements among the ecosystem models will not impede their use for providing strategic advice on how to reach management objectives that go beyond the traditional maximum yield targets and for informing on the potential consequences of pursuing such objectives. This was especially true for scenarios aiming at exploiting forage fish sprat and herring, for which the agreement was the largest among models. However, the quantitative response to altering fishing pressure differed among models. This was due to the diverse environmental covariates and the different number of trophic relationships and their functional forms considered in the models. This suggested that ecosystem models can be used to provide quantitative advice only after more targeted research is conducted to gain a deeper understanding into the relationship between trophic links and fish population dynamics in the Baltic Sea.

Size of predator and prey determines, to a large extent, predator-prey interactions in aquatic systems. **Understanding the relationship between predator and prey size** in the individual predator's food selection process is a cornerstone of ecological modelling. Stomach content data are used to inform such models, as they provide prey species specific information about the predator diet in the wild. These data are strongly relevant as direct observations of species trophic interactions, but they have limitations, and are costly. Kulatska *et al.* (2019) developed and tested a model which is able to predict changes in the Baltic cod diet by reconstructing the dynamics of cod and its prey, herring and sprat, populations, their length distributions, and parametrizing trophic interactions between them. They analysed time-series of cod stomach data and built an age-length structured multispecies model using **Gadget**. Both observed and predicted diets of smaller (juvenile) cod consisted mainly of benthos, while larger cod fed mostly on fishes (herring and sprat). Their model could predict the main patterns in species and length composition of cod diet. They also identified important knowledge gaps, especially on benthos dynamics and processes affecting prey availability and predator preference.

Karlson *et al.* (2019) investigated changes in the physiological status and population/community traits of six consumer species/groups in the Baltic Sea (1993–2014), spanning four trophic levels and using metrics currently operational or proposed as indicators of food-web status. They asked whether the physiological status of consumers can be explained by food-web structure and prey food value. This was tested using **partial least square regressions** with status metrics for grey seal, cod, herring, sprat and the benthic predatory isopod *Saduria entomon* as response variables, and abundance and food value of their prey, abundance of competitors and predators as predictors. They found correlations implying that the physiological status of cod, herring and sprat is influenced by competition, predation, and prey availability; herring and sprat status also by prey size.

4.2 Model applicability for indicating food web status and model gaps in relation to this application

The trophic models represent a wide range of applications in the Baltic Sea. Each model has been designed for a specific purpose, and contains some key assumptions (Table 4.2). The key assumptions have been chosen to illustrate the gaps in the models and are selected in relation to determine the extent to which the models can be applied to represent status and dynamics of the Baltic Sea food webs.

Table 4.2. Model applications by model type and basic assumptions

#	Model type	Key assumptions
13,17,18,19, 27	Multivariate statistics	Stable relationship between variables also on the non-sampled future
5,16, 26,14	Commercial fish species multispecies	Food selection according to constant size preference and predator-prey overlap
1, 2, 3, 4,6, 7,8,9, 10,12, 15,16,21, 24, 25	Mass-balance	Mass has to be scaled up/down using a vulnerability parameter to reach mass balance. This parameter is not measurable
22	End-to-end	Many untested, deterministic sub-models
20	Size spectra	Size is the only parameter determining species interactions
11,18,	Theoretical	Several model specific assumptions; in general, difficult to falsify
23	Dynamic Bayesian Network	Graphical formalism for representing joint probability distributions, causality is not investigated

Classical foodweb metric include for example **link density** (the Number of trophic interactions (links) per species), **connectance** (the proportion of directed links realised out of the maximum number of possible links), **modularity** (describes how densely sub-groups of species interact with one another compared to species from other sub-groups), or **clustering** (describes the probability that two taxa that are linked to the same taxon are also linked together). For a more exhaustive list see Kortsch *et al.* (2019). These food web metrics are not especially well represented in any ecosystem model, because the selection of species in all mentioned models, and the subsequent aggregation into guilds or functional groups, is not emerging from the models, but has to be given as input. Hence, these types of metric cannot be considered well-represented since they are input rather than output of the models.

On the other hand, all models represent the dynamics of species or functional groups (guilds). To that end, they can not only be used to show food web status in terms of guild biomasses, but also allow to infer about the dynamics between functional groups and hence good environmental status (GES), as well as feeding conditions for predators and potential for food competition. This knowledge can form the basis for scaling existing F(MSY) values to ecosystem state.

Spatial aspects of population- and ecosystem dynamics are getting increasingly important in marine management, including conservation issues, which are becoming an integral part of the overall spatial planning. Especially in a multispecies and food web context, when several species interact in a system, it is of fundamental importance to describe the spatial patterns of different species and understand the causes and consequences of their distribution changes. Within species, information on the spatial population structure is pivotal for sustainable management.

The match and mismatch of natural populations with their management units, the existence of source-sink systems, local density dependence and migrations interact and affect estimates of natural and fisheries-induced vital rates, such as somatic growth and mortality. One mass balance model (Ecospace) and the end-to-end model Atlantis (Table 4.1) have been applied that potentially can account for such issues. However, both the implementation of spatial heterogeneity and the model setup have to be carefully considered before they are applied for management decisions. Such considerations include the spatial units in the modes, redistribution mechanisms at each model iteration as well as the representation of biomass or biomass-equivalent (e.g. nitrogen) flows between model compartments and the impact of spatial predator-prey overlap on predation rates.

5 Tor iv) Roadmap on steps to utilise ecosystem information in fish stock assessment and advice in the Baltic Sea based on ToRs i) to iii), including consideration of the need for revising threshold reference points.

A roadmap on steps to utilise ecosystem information in stock assessment and advice for the Baltic Sea was drafted during the WK and then worked on after the meeting. The roadmap is presented below. The roadmap consists of four steps over 2022-2023 (see 5.1 -5.4) with relevant actions (Table 5.1): workshops, intersessional work, work at the ICES EGs and the ICES Benchmark process. As part of the roadmap, we propose a working framework, i.e. in which ICES groups work collaboratively. Because part of the preparation process depends on individual work and expertise, intersessional work to select indicators and use of models need to be carried out. One part of the roadmap refers to the ICES advisory process, where a number of changes to the process are suggested to support the operationalization of EBFAdvice and avoid hindering EBFAdvice application due to a formalised process (Table 5.2). It should be noted that the work required to eventualize this road map is dependent on further funding, in particular towards two more workshops (WKEBFAB 2 and 3). he benchmarks and some intersessional work are covered by other sources of funds. In addition, the working group for integrated assessment (WGIAB) has already proposed as part of their meeting 3-year ToRs for 2022-2024 to assist in the work of WKEBFAB.

5.1 Feco

As a product of the ICES WKEBFAB a test of the Feco approach for the Baltic was agreed. The methodology, developed at the WKIRISH and published by Howell *et al.* (2021) and Bentley *et al.* (2021) (see above), needs to be refined and adjusted for the Baltic stocks. It was identified that it would be as part of the ICES Benchmark process, where the approach would be tested and accepted. According to the ICES ACOM/SICOM plan, the next benchmark for Baltic stocks may cover some of the small pelagic stocks i.e. Central Baltic Herring, Baltic sprat and Gulf of Riga herring, which thus creates the first window of opportunity to test Feco for those stocks. The critical step at the method development is to develop indices/indicators required by Feco - survey-based or model-based. Model-based indices can be used from available ecosystem models (see section above) as i.e. EwE (Tomczak *et al*., 2012; Bauer *et al*. 2019) or Atlantis (Bossier *et al*., 2018) as originally proposed by Howell *et al.* (2021); available bio-economic (Nielsen *et al*., 2018) and biogeochemical models, environmental datasets and ecological knowledge also allows to use a broad spectra of indices from other sources to inform Feco. Work on indicators/indices at relevant EG (i.e. WGIAB) are required.

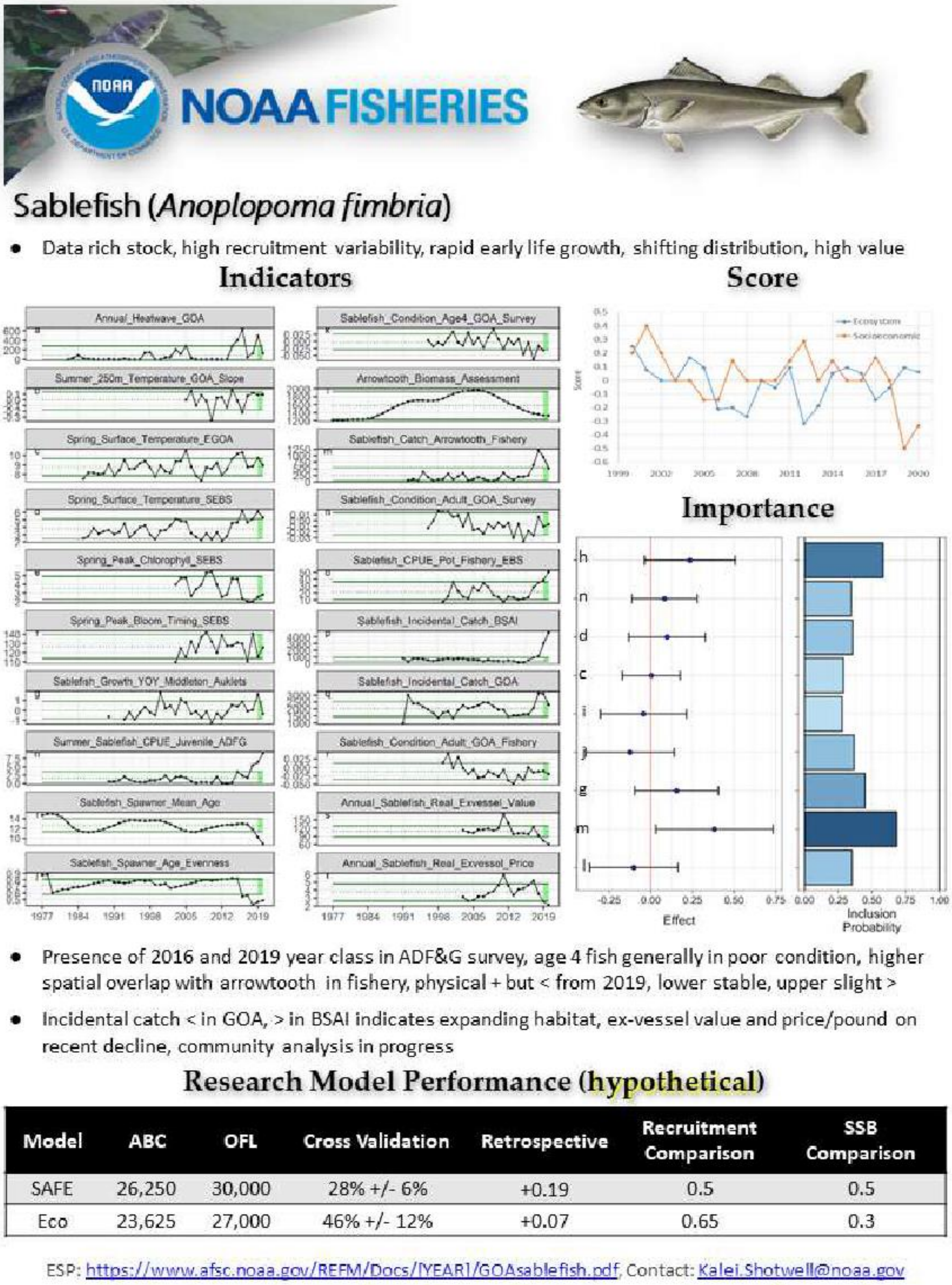
Table 5.1. Roadmap – EBAdvice implementation exercise for Baltic example (plan with the assumption that external/available funds cover parts of the work)

Action	Implementation how?	When Time framework	Who – working framework	Product
WKEBFAB	Concept clarification and examples	February 2022	WGIAB/WGBFAS	WKEBFAB report and recommendation.
Intersessional work	Cooperation with WKIRISH on Feco to select indicators, test models, run Feco framework	2022	WGBFAS/WGIAB	Prepared model, model-based indices and stock related indices for Feco approach
WKEBFAB 2	Method testing and establishing working example and process	Before benchmark for chosen stocks (2022-2023)	WGBFAS/WGIAB workshop participants	Run test on Feco on Baltic stocks. WKEBFAB 2 report
Stocks benchmark	Final method testing and establishing working example and process	Benchmark (2022-2023)	Benchmark participant	Runs of Feco on Baltic stocks. Benchmark report
Intersessional work	Develop Ecosystem and Socioeconomic Profile for stocks. ESPs drafts	After benchmark intersessional (2023)	WGBFAS/WGIAB	ESP draft
WKEBFAB 3	Establish a methodology for Baltic Feco and Final draft of ESP or EO changes	2023	WGBFAS/WGIAB/ WKIRISH	Feco implementation and ESPs draft submitted
WKEBFAB_MSE	Establish a methodology for Baltic MSE (with Feco)	intersessional and workshop at 2023	WGBFAS/WGIAB	Implement MSE-based risk assessment into ESPs (multiannual)

5.2 Ecosystem and Socioeconomic Profile (ESP)

ICES WKEBFAB agreed and suggests that an advice according to Feco needs to be supported by additional integrated analyses - inspired by NOAA's Ecosystem and Socioeconomic Profiles, but adjusted for the ICES process and the specificities of the Baltic stocks.

An Ecosystem and Socioeconomic Profile (ESP) is a standardised framework that facilitates the integration of ecosystem and socioeconomic factors within the stock assessment process and acts as a proving ground for operational use in management advice (Figure 5.1). WKEBFAB proposes that the ESPs for the Baltic should play the role of anon-ramp tool for next-generation stock assessments and as such, they provide the necessary tools for implementing the ecosystem approach to fisheries management. ESPs in contrast to Ecosystem Overviews and Fisheries Overviews, will re-calculate/present data on the stock-specific scale to explore the stock-relevant ecosystem and socioeconomic trends. These indices can then be used for Feco and, if the assessment methods allow, quantify risks and trade-offs.



Model	ABC	OFL	Cross Validation	Retrospective	Recruitment Comparison	SSB Comparison
SAFE	26,250	30,000	28% +/- 6%	+0.19	0.5	0.5
Eco	23,625	27,000	46% +/- 12%	+0.07	0.65	0.3

Figure 5.1. Draft example of the ESP one-page template for providing a rapid communication of the sablefish stock status, Ecosystem State report and full Socioeconomic Profile (ESP). See text above about NOAA ESP, Ecosystem state reports and model use.

Based on NOAA's experience the Ecosystem and Socioeconomic Profiles (ESPs) make up a structured framework to facilitate the inclusion of ecosystem and socioeconomic data in the stock advice process (Figure 5.1). Generally, ESPs consist of three components:

1. Stock metrics: information about the stock
2. Ecosystem and socioeconomic indicators: relevant information about the ecosystem and human dimensions, including the Feco indices
3. Analysis: Correlation and other modelling of relationships between stock metrics and ecosystem and socioeconomic indicators; summaries of current conditions and determination as to qualitative "favourability" for the stock.

Within this general framework, ESPs will have a flexible structure that allows for both quantitative and qualitative data and a variety of tailored analyses depending on the stock details. This flexibility makes ESPs a practicable method for implementing Ecosystem Based Fisheries Advice the Baltic. ESP fosters communication of ecosystem aspects of the ecosystem-based advice in fishing opportunities. It is crucial to present the data and knowledge, as a form of the product on stock level, especially linked to fishing opportunities, if Feco will be presented/used as a catch option. ESP might be quantitative or descriptive depending on the stock category, information and data available. The profiles should not describe ecosystem and ecosystem changes as in the ICES ecosystem overviews, but at the stock level focus on ecosystem/fisheries interactions influencing the stock assessment, short-term predictions and advice through Feco, scenarios etc.

For a detailed explanation of the EPS framework see:
*https://www.youtube.com/watch?v=kYi1SAI-Xtk

5.3 MSE as part of the process

WKEBFAB identified that Management Strategy Evaluations under changing environmental conditions is one aspect particularly lacking in the EBFAdvice of the Baltic, what is the. As stated in the ICES ecosystem overview of the Baltic, it is an environmentally driven ecosystem with strong trophic interaction. We see MSEs as a necessary tool that allows quantifying the risks levels of an EBFAdvice under changing climate and in reference to environmental management actions i.e. Baltic Sea Action Plan.

5.4 Implementation of an EBFAdvice within the ICES structure and advice framework

WKEBFAB discussed the implementation of an EBFAdvice within the ICES advice structure and issues that may hamper the operationalization of the approach. For the EBAdvice to be fully operational and implemented in the recurrent ICES advice process, a clear organisation structure and work-flow with the defined mandate, responsibility and resources are needed. This issue was already recognized by the ICES Study Group On The Scientific Basis For Ecosystem Advice In The Baltic [SGBEAB] in 2000 and discussed during the ICES Report of the Workshop on DEveloping Integrated AdviCE for Baltic Sea ecosystem-based fisheries management (WKDEICE) 2017 (see Figure 2.2)

During the WKEBFAB discussions on the Implementation of the Feco approach and ESP's as a part of the integrated advice, several questions and issues were raised regarding the ICES institutional processes and responsibility:

1. Where in the fisheries assessment and advisory process the Feco and ESP needs to be placed?

2. Which EG's could be responsible for ecosystem analysis/assessment and preparation of indices for Feco, and in which ICES pillar (ACOM or SCICOM) should it be placed?
3. How to allocate resources for the Feco framework annual/multiannual implementation and ecosystem assessment as a necessary part of the process
4. How to solve the annual ecosystem data availability, update and preparation for Feco and ESPs
5. Which EG's (or how often at benchmark) should perform multi annual MSE for Baltic fish stocks?

Below in Table 5.2 we present potential ICES advisory process structure changes and discussed issues raised above.

Tabel 5.2. Current (orange) and proposed (blue) advisory process for Baltic Sea stocks with identified crucial steps important for implementation EBFAdvice - the roadmap for ICES process. EG'- Expert Group, DG'- Drafting Group.

Current advisory process	By whom?	Proposed process for EBFAdvice	By whom?	Comments and questions
Administrative agreement	ICES Secretariat	Administrative agreement	ICES Secretariat	Administrative agreement to be redefined with the client
EU Request	ICES Secretariat	EU Request	ICES Secretariat	EU Request need to be redefined to include EBAdvice
Stock assessment data call	ICES Secretariat, ICES member countries	Stock assessment data call Environmental and Ecosystem data call	ICES Secretariat; ICES member countries	Expanded call for data at the same way as stock assessment data are requested.
Data preparation for stock assessment	ACOM EG ICES Secretariat;	Data preparation for stock assessment and Environmental and Ecosystem assessment	ACOM EG ICES Secretariat	The ecosystem assessment EG should become ACOM EG', equally eligible to funding as fisheries assessment EG'
Stock Assessment	ACOM EG	Stock Assessment	ACOM EG	
Stock Prediction	ACOM EG	Ecosystem Assessment and indicators preparation	?	Work can be done at the new ACOM EG or WGIAB as ecosystem assessment but need to be redefined as a ACOM EG and work same way as i.e. WGBFAS
(Benchmark)	ACOM EG	(Benchmark and MSE)	ACOM EG	
Catch option	ACOM EG	Stock prediction	ACOM EG	
Advice drafting fisheries opportunities	ACOM DG	Ecosystem based stock prediction – Eco Catch option	ACOM EG	WGBFAS
EO preparation (data and text)	WGIAB (SCICOM)	ESP preparation	?	Work can be done at the new ACOM EG or WGIAB as ecosystem assessment but need to be redefined as a ACOM EG and work same way as i.e. WGBFAS

Current advisory process	By whom?	Proposed process for EBFAdvice	By whom?	Comments and questions
EO drafting	ACOM DG; ICES Secretariat;	Advice drafting catch opportunities + Ecosystem catch options	ACOM DG	Elements of advice linked together into Integrated Ecosystem Advice
FO preparation (data and text)	WGBFAS (ACOM)	ESP drafting	ACOM DG	Elements of advice linked together into Integrated Ecosystem Advice
FO drafting	ACOM DG; ICES Secretariat;	EO drafting	ACOM DG	Elements of advice linked together into Integrated Ecosystem Advice
Advice	ACOM; ICES Secretariat;	FO drafting	ACOM DG	Elements of advice linked together into Integrated Ecosystem Advice
		Integrated Advice - four elements above	ACOM; ICES Secretariat;	Elements of advice linked together into Integrated Ecosystem Advice

6 Conclusion

6.1 (i) Aspects to be included for an ICES EBFAdvice

WKEBFAB proposes the following ecosystem aspects to be added to the fisheries advice provided by ICES.

1. *Scaling factors* for the species-specific F(msy) derived catch options (similar to the idea of WKDICE and WKIRISH). These scaling factors can be used to scale F(msy) between upper and lower limits of F-ranges for category 1 stocks. The scaling factors can be derived as a combination of observations and hydrodynamic-, biogeochemical and ecosystem models, but should constitute the key factors influencing the stock in question. We are aware that ultimately, the ranges should be biologically derived and relevant to the specific stock, but until these have been estimated the existing F-ranges may be used. We are furthermore aware that the high frequency of re-estimating reference points, together with careful selection of the time range applied, covers a great deal of ecosystem changes and their impact on stock productivity. However, if key factors influencing stock productivity show parallel trends over a time range shorter or equal to the period between reference point estimations, or environmental change cannot be accounted for by selecting the time range for spawning stock biomass to recruitment relationships, then scaling factors should be applied.
2. *Ecological and socio-economic profiles (ESP)* of the specific stocks. These profiles should identify quantitative indicators/factors for ecological processes that can be used to scale the species-specific F(msy) described in point 1. Factors can be derived from a combination of observational data and model estimates and include, available food densities, changes in spatial distributions, habitat suitability, abundance of predators; but also stock development and in the longer term socio-economic indicators, as well as a narrative on the productivity regime (see point 1). Expectations for the development of indicators in the near- (2 yrs), medium (10 yrs), and long-term (>10 yrs) should also be included. The Ecosystem consequences (point 3), might be included in the EPS. Furthermore, where relevant, the ecosystem consequences for good environmental status can be discussed with HELCOM.
3. Ecosystem consequences / *Ecosystem risks* based on the specific fishery. These could include biomass caps on advice for forage fish to secure food for higher trophic level predators, bycatch, sediment destruction, multispecies effects and so forth. The ecosystem consequences should be derived by an ensemble of existing multispecies- and ecosystem models for the Baltic Sea, including SMS, Gadget, Ecopath with Ecosim and Atlantis.

The topics should in the first phase be based on applying existing single species assessment and stock-prediction models. Ecological information can be incorporated to both the assessments and predictions at a later stage, and is considered necessary in order to define ecologically-based F-ranges.

6.2 (ii) Next steps for implementation

We propose to focus on Central Baltic herring, Gulf of Riga herring and Baltic sprat as case studies for these topics. All three stocks are likely to be benchmarked in 2023 (with a data compilation in fall 2022). We furthermore propose to have a follow-up EBFAB workshop before the benchmark, where initial proposals for topics 1) - 3) will be defined.

We also propose to establish a benchmark and key-run acceptance process for ecosystem and higher trophic level models, supporting the information for F-scaling and EPS.

Finally, we propose to establish a data preparation process, based on data-calls and ICES oceanographic databases, supporting the information for F-scaling and EPS.

6.3 (iii) Integration into ICES advice formats

We are aware that ICES provides several types of advice, such as, the advice on fishing opportunities, the ecosystem-overview and the fisheries overview. We recommend that topics 1) – 3) are formulated and formatted in such a way that they can be integrated in this structure. The advice on fishing opportunities would be a candidate for 1), however, we do not consider it constructive to have the scaling factor hidden between a lot of different catch options, but rather in the main headline. *Ecosystem risks* could be part of an annual update of the ecosystem overview, while the *Ecological and socio-economic profiles* probably fit best in the Ecosystem overviews, but would also serve their purpose as stand-alone sheets from which the FO and EO can derive information.

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Annex 2: Resolution

2021/2/FRSGxx The **Workshop on Ecosystem Based Fisheries Advice for the Baltic- (WKEBFAB)** chaired by Mikaela Bergenius Nord*, Sweden, Maciej Tomczak*, Sweden, and Stefan Neuenfeldt*, Denmark, will meet on 10-12 November 2021 in Stockholm, Sweden[5], to:

Initiate work towards an operational Ecosystem Based Fisheries Advice for the Baltic stocks, including;

i) A review of international ecosystem-based fishery management approaches (by ICES, NOAA etc.), including MSEs, relevant to the Baltic Sea;

ii) A review and gap analysis of ecosystem-indicators for the Baltic Sea, relevant for advice on future fishing opportunities;

iii) An evaluation of how of existing stock assessment and ecosystem models and their integration can be used to fill the gaps identified in ToR ii) and for giving advice on ecosystem-based catch options;

iv) Development of a roadmap on steps to utilize ecosystem information in fish stock assessment and advice in the Baltic Sea based on ToRs i) to iii), including consideration of the need for revising threshold reference points.

WKEBFAB will report by 15 December 2021 for the attention of ACOM and SCICOM.

Supporting information

Priority	This workshop is considered to have a high priority since the integration of ecosystem aspecs in single stock assessments is a key area of interest fo ICES.
Scientific justification	This workshop will constitute an initial step to develop a roadmap to improv ecosystem based management in the Baltic Sea.
Resource requirements	None, apart from Secretariat support.
Participants	The workshop will be attended by 15-20 persons with expertise in stock assessment as well as ecosystem modellers.
Secretariat facilities	None.
Financial	Additional resource requirements will be facilitated by the Swedish Agency for Marine and Water Management.
Linkages to advisory committees	ACOM, SCICOM
Linkages to other committees or groups	WGBFAS, HAWG, WGIAB, FRSG, IEASG, WBBAST
Linkages to other organizations	HELCOM

[5] ACOM and SCICOM are considering guidance on meeting locations (20/09/2021). This meeting is planned to be held in Stockholm in November and will adhere to the respective national and institutional regulations for mitigation of Covid 19.