WORKSHOP ON PARTICIPATORY MODELLING (WKPARTICIPATORYMODELLING; outputs from 2024 meeting)

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International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44-46

DK-1553 Copenhagen V

Denmark

Telephone (+45) 33 38 67 00

Telefax (+45) 33 93 42 15

www.ices.dk

info@ices.dk

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Editors

Jacob Bentley • Benjamin Planque

Authors

Gillian Ainsworth • Darcie Anderson • Marta Ballesteros • Jacob Bentley • Ricardo Cavieses Adrien Chevallier • Martina Gaglioti • Maria Gamaza Márquez • Eirini Glyki • David Gyimah Katell Hamon • Alejandro Hidalgo Garrido • Stéphanie Hopkins • Erasmia Kastanidi • Tom Kisters Michael Kriegl • Sigrid Lehuta • Sarina Lincoln • Lis Lindal Jørgensen • Marcos Llope • Claire Macher Jelto Makris • Irene Martins • Erika Meerhoff • Samuel Morsbach • Fabien Moullec Mamadou Ndiaw Seck • Matthew Pace • Ualerson Peixoto • Holly Ann Perryman • Maria Pierce Benjamin Planque • David Reid • Alfredo Santiago Garcia de Vinuesa Gutierrez • Charlotte Scholte Nathalie Steins • Olivier Thebaud • Deutz Zafimamatrapehy

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i Executive summary

The Workshop on Participatory Modelling (WKParticipatoryModelling) was convened to advance the integration of participatory approaches into ICES science and advice. Its terms of reference included reviewing past participatory modelling experiences, identifying where its application could improve ICES processes, and developing a structured framework for future implementation.

The workshop addressed three questions: (1) How has participatory modelling been used inside and outside ICES, and what lessons can be drawn? (2) In which areas could ICES benefit from participatory modelling? (3) How to build a robust participatory modelling framework compatible with ICES workflows?

The workshop found that while participatory modelling improves the credibility, relevance, and acceptance of scientific outputs, its application within ICES is inconsistent. Some successes were achieved in integrated ecosystem assessment (IEA) groups and more specifically in the Workshop on an Ecosystem Based Approach to Fishery Management for the Irish Sea (WKIRISH) expert group. However, major challenges remain, including a lack of structured methods, limited training, and difficulties in balancing empirical science with experiential stakeholder knowledge.

The group identified high-priority areas for participatory modelling, including mixed-fisheries management, integrated ecosystem assessments, marine spatial planning, biodiversity conservation, and climate impact assessments. Participatory modelling is especially relevant when stakes are high, uncertainties are high, multiple views or interests are conflicting, and when models represent the behaviour of human groups.

A draft framework was developed to guide participatory modelling in ICES. It emphasizes clear justification for participation, rigorous stakeholder selection, co-development of models, robust facilitation, transparent communication, and systematic monitoring and evaluation. The framework is modular to allow adaptation across different projects and sectors. A practical method to guide, assess, and report participatory engagement is also provided as annex to the report.

Future work priorities include testing and developing the framework in selected case studies, training ICES scientists and stakeholders in participatory techniques, showcasing participatory modelling at ICES Annual Science Conference, and embedding participatory modelling practices into standard ICES advisory processes. The long-term goal is to institutionalize participatory modelling to enhance trust, transparency, and the real-world applicability of ICES science and advice.

ii Expert group information

Expert group name	Workshop on Participatory Modelling (WKParticipatoryModelling)
Expert group cycle	Annual
Year cycle started	2024
Reporting year in cycle	1/1
Chair	Jacob Bentley, UK
	Benjamin Planque, Norway
Meeting venue and dates	7 -11 October 2024, Copenhagen, Denmark (38 participants)

1 Introduction

Background

Participatory modelling is an approach that facilitates the integration of diverse experts and knowledge sources into environmental decision-making, with extreme relevance and applicability to the work and ambitions of the International Council for the Exploration of the Sea (ICES). By engaging a range of experts, including scientists, industry representatives, policymakers, and local communities, participatory modelling fosters transparency, legitimacy, and inclusivity in the development of scientific advice. It is widely recognized that stakeholder involvement in modelling can improve the credibility and usability of outputs, enhance shared understanding of ecosystem processes, and facilitate consensus-building in decision-making processes.

Within ICES, participatory modelling has been applied in some working groups and workshops, including integrated ecosystem assessment (IEA) groups and the Benchmark Workshop on an Ecosystem-based Approach to Fishery Management for the Irish Sea (WKIRISH). However, despites its recognized value, its use remains inconsistent, with no established framework guiding when and how participatory approaches should be implemented. In some cases, stakeholder engagement occurs at later stages of model validation, whereas best practices suggest that early involvement in model development enhances the co-production of knowledge and the applicability of model outputs to real-world decision-making. The development of a structured approach to participatory modelling within ICES is therefore necessary to support its more systematic and effective application in both scientific and advisory contexts.

Scope and Importance

The growing complexity of marine management challenges, including climate-driven shifts in species distributions, competing uses of marine space, and increasing demands for ecosystem-based decision-making using trade-off analyses, highlights the need for participatory approaches that integrate the multiple knowledge streams that should be used to inform decisions. Participatory modelling has been successfully applied in other fisheries and ecosystem management contexts, demonstrating its potential to improve decision-making processes by ensuring that models reflect the perspectives and experiences of those directly affected by management measures. Approaches such as ecosystem modelling, management strategy evaluation (MSE) with stakeholder-driven scenario testing, conceptual models, and Bayesian belief networks have been used to enhance the relevance and uptake of scientific advice. However, many of these approaches require structured facilitation, dedicated resources, and institutional support, factors that are not yet consistently embedded in ICES workflows.

Key challenges in implementing participatory modelling within ICES include defining when and how stakeholder engagement should occur, integrating different types of knowledge (empirical, analytical, and experiential), and ensuring that participatory processes are robust, well-facilitated, and consistently evaluated. There is also a need to align participatory modelling efforts with ICES existing advisory frameworks and governance structures to ensure that outputs are effectively incorporated into fisheries and ecosystem-based management and follow existing guidelines for stakeholder engagement. Without clear guidelines and mechanizms for

integrating participatory approaches into ICES processes, there is a risk that stakeholder engagement remains fragmented, limiting the potential benefits of participatory modelling to support evidence-based decision-making and uncover novel scientific and advisory opportunities.

Workshop Objectives

WKParticipatoryModelling was convened to review past experiences, identify opportunities for application, and develop a framework for participatory modelling within ICES. The workshop addressed three key objectives:

1. Review experiences of participatory modelling in marine science, both inside and outside ICES. This included an evaluation of how participatory modelling has been applied in ICES working groups and other scientific contexts, assessing lessons learned from both successful and unsuccessful case studies. The workshop examined different interpretations of participatory modelling and its role in various modelling frameworks, including IEAs, MSE, and mixed-fisheries modelling.
2. Identify candidate studies or assessments within ICES that would benefit from participatory modelling. The workshop assessed specific fisheries and ecosystem assessment processes where participatory modelling could enhance stakeholder engagement, improve model credibility, and increase the uptake of scientific advice. This included identifying key areas such as the development of ecological reference points and the integration of socio-economic considerations into advice for ecosystem-based management.
3. Develop a framework for participatory modelling within ICES. Drawing on international best practices and lessons learned, the workshop aimed to establish a structured yet adaptable framework to guide participatory modelling efforts within ICES. The framework includes recommendations for stakeholder identification and engagement, knowledge integration, model transparency, facilitation techniques, and evaluation mechanizms.

The outcomes of WKParticipatoryModelling aim to support the transition from ad-hoc applications of participatory modelling towards a structured and institutionalised process that enhances both scientific rigour and decision-making relevance. Moving forward, the recommendations outlined in this report aim to contribute to the development of participatory modelling as a valuable mechanizm for improving the implementation of ICES science and advice.

2 ToR a: Participatory modelling review

ToR a: Review experiences of participatory modelling in marine science, both inside and outside of ICES

2.1 Background to the ToR

ICES now has a Stakeholder Engagement Strategy which outlines the key principles of stakeholder engagement and defines the roles of stakeholders and scientists in the engagement. The recent Workshop on the Implementation of the Stakeholder Engagement Strategy (WKSTIMP) defined a suite of actions to make the ICES strategy work. Initiatives to reinforce the strategy include the development of guidelines for integrity and the accountability of stakeholder perceptions. Participatory modelling is well routed in the scientific literature and frequently occurs across ICES groups and workshops (e.g. IEA groups and WKIRISH). However, its application within ICES seems inconsistent. ToR a) of WKParticipatoryModelling explores 1) different definitions and interpretations of participatory modelling, 2) where and how participatory modelling has been applied within and external to ICES, learning from both positive and negative experiences (e.g. Sterling et al., 2019), and 3) which frameworks already exist and may be appropriate to use across ICES. We also aimed to assess the importance of participatory modelling and the existing demand for the approach from stakeholders (e.g. Voinov et al., 2016). The objective was to understand the experiences of researchers and stakeholders and use this knowledge to inform a framework for participatory modelling within ICES. Particular focus was given to the application of conceptual frameworks for integrated ecosystem assessments, as this is an area relevant to ICES where we have seen the greatest participation of stakeholders within ICES (ICES 2021) and elsewhere (e.g. Ingram et al., 2018).

2.2 Summary of presentations

MSE and participatory approaches

Marta Ballesteros

The use of management strategy evaluations (MSE) to support fisheries decision-making has increased worldwide over the last thirty years. Evidence shows that without a participatory angle to the process, there is a significant risk of the work being ignored or used inappropriately (Ditchmont and Fulton, 2017).

The presentation highlighted three aspects relevant to the workshop: 1. MSE entails more participation than in modelling. 2. Participatory process using modelling is not the same as

participation in modelling; 3. Participation in modelling has different levels (model framing, model evaluation, model use and model construction).

The Math4fish project (see details in presentation 3) allowed us to design a systematic process including seven steps: 1. Characterize the social-ecological system, including the attributes of the natural and human dimensions; 2. Characterize the models to be used and its current stage of development; 3. Assess the capability of the models to operate as boundary objects, providing common ground and facilitating the interaction and understanding of preferences, actions and consequences across stakeholder; 4. select the methods; 5. training natural scientists on participation; 6. Bargaining with policy-makers and 7. Learning by doing on structured dialogue. The steps were illustrated through three case studies (hake, anchovy and sole). The conclusions pointed to the potential of participatory modelling to discuss and improve the current advisory system.

EBM Participatory modelling in the Guadalquivir estuary and West Africa

Marcos Llope

Experiences and results from participatory modelling carried out in two socio-ecosystems (SES): the Guadalquivir estuary Gulf of Cadiz (GoC) and West Africa (WA): Mauritania, Senegal, The Gambia, were presented. Both case studies are multisectoral (agriculture, non-renewables, shipping, fishing, etc), data poor (at least for some of the relationships) and pose urgent challenges (risk of ecosystem collapses and massive migration). The techniques used to understand and conceptualise the social and ecological components of these two systems included semi-structured interviews, social network analysis, conceptual models and Bayesian belief networks.

In the GoC, the study was carried out in a structured way from the start. First, the social system was characterized, key actors were invited to three participatory workshops where we co-created three individual conceptual models (focusing on fisheries, water uses and shipping). These three models were merged into a comprehensive but simplified Bayesian belief network that will be used to assess trade-offs and, it is to be hoped, inform EBM in this SES.

In WA emerging (oil and gas developments) and urgent (loss of livelihoods leading to perilous Atlantic crossing) issues came after an exercise of integrated ecosystem assessment validation was carried out in a workshop with a diversity of stakeholders.

BioEcon4Fish - Bioeconomic modelling for the sustainable exploitation of fishing resources

Mari Gamaza

The Math4Fish project (https://math4fish.ieo.csic.es/) aimed to improve the stock assessment models for three species assessed by ICES in Spanish waters, and in particular, for the ICES anchovy stock in ICES Area 9.a. To do so, using an MSE approach, an evaluation model was developed in FLBEIA to demonstrate that a different HCR was better to accommodate the stock fluctuations whilst started to build first steps into participatory processes by communicating the results and getting feedback (more information in the website, though it is in Spanish, but also

in Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA), 2023-2024 reports). Stakeholders were very receptive with the information presented but also concerned that no socio-economics were included into the assessment so fishers could not really tell how the results of the models could affect their livelihoods. Therefore, based on this, a new project call **BioEcon4Fish** have been put together, aiming to incorporate socio-economic indicators into the model used for anchovy in Area 9.a by co-creating knowledge with all stakeholders involved in this fishery; the main difference with the previous project is that, although improving the model to incorporate the socio-economics is key, the model itself is not the focus of this project, but working together with all actors involved to define management strategies, what to include or not to include in the model, etc.

Regarding the Math4fish approach to participatory processes, there are two things worth highlighting; we were clear, honest and transparent from the beginning with everybody by clearly communicating our role, the project, the results, the good and the bad news. Therefore, moving from the three-dimensional cube that Marta Ballesteros presented (not to be shared), this presentation shows where math4fish was located compared to where our new project is, as mentioned earlier, we are now focusing more on co-creating knowledge and management scenarios that could feed into the model (and no the other way around).

Some of the techniques we are hoping to use in the co-creating of management strategies through participatory processes, include but are not limited to:

1. Clarify decision context: facilitation
2. Define management objectives and alternatives: conceptual models
3. Scenarios building: Brainstorming
4. Estimate consequences and explore trade-offs
5. Explore uncertainty and set management thresholds: opening the black box
6. Evaluate data: FLBEIA

Take home messages:

- Plowing the ground is key to improving understanding, trust, and relationships among stakeholders.
- Unlike Math4fish, in BioEcon4fish we are now ready to start working together and tuning the model based on stakeholders' input.

However, be aware that changes in the socio—political context might affect the trust between stakeholders; nonetheless, we assume that will not be our case, as we are moving forward from a "strong" baseline, but this is to be seen! It is planned to present the results at ICES ASC 2025 in Lithuania.

Participatory modelling – Wageningen Economic Research perspective

Tom Kisters

In the Netherlands we have more than 20 years of Science Industry Research Collaboration. This collaboration has strongly focused on data collection and interpretation of the data. Participatory modelling is the next step; together we discuss how we use and understand the data in modelling.

Why should we do that? Due to many changes in the system (wind at sea, Brexit) we need to adjust our models and make sense of future scenarios and key drivers with the industry. So doing it collaborative – we make them more realistic, and we make sure (as they were involved) the outcomes will be more legitimate.

We see participatory modelling as including more stakeholders, both in shaping the assignment and model discussion, as can be seen in Figure 2.1. The decision-maker, the fisheries researcher and the fishers themselves have input into the formation of the assignment.

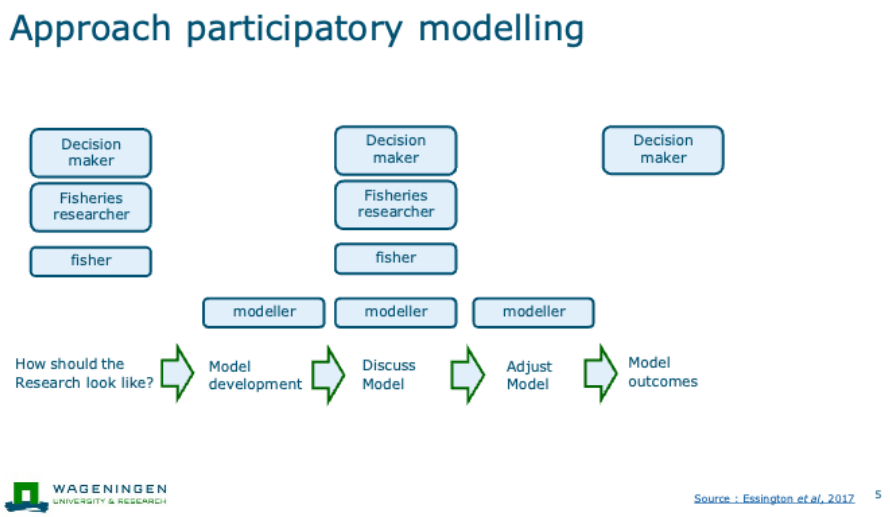

Figure 2.1 A schematic representation of participatory modelling that includes multiple stakeholders.

For WEcR, the common, non-participatory modelling approach often looks as Figure 2.2. For Wageningen Economic Research, the decision-maker is usually the Ministry of Agriculture, Fisheries, Food Security and Nature. This decision-maker has an assignment, somewhere halfway through development, the model is discussed with the decision-maker and at the end of the project we report back with the model outcomes.

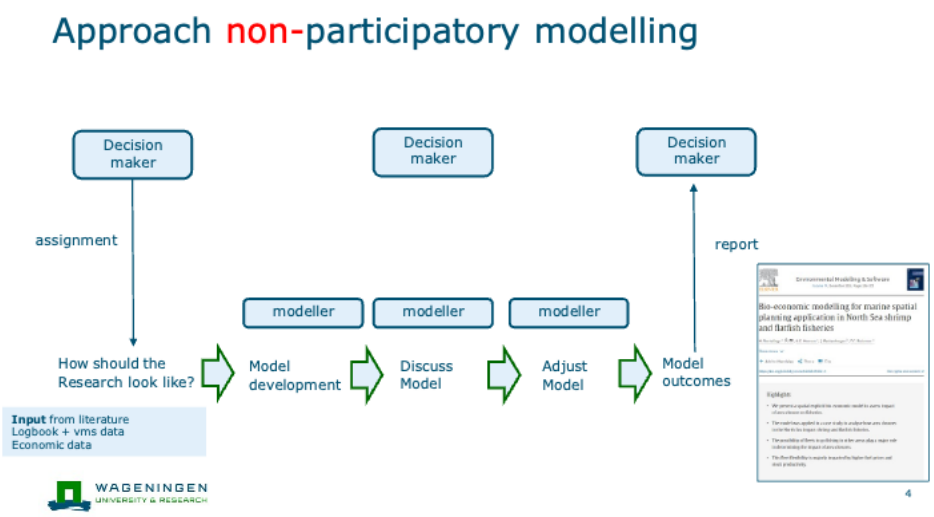

Figure 2.2 A schematic representation of modelling that excludes participation from multiple stakeholders.

Over time we had more projects where we have moved from the traditional approach, to what we consider participatory modelling (an overview of these projects can be found in the presentation). The latest example is the MONS project in Figure 2.3. Where both the decisionmaker and fisheries researchers are included in developing the assignment. In addition, we will also be including input from the fishers themselves. The input which we have gathered (solid lines) or will gather (dashed lines) can be seen in the red frames below; We had 5 scientists participate and observe on fishing vessels. In addition, one fisher was prepared to manually keep a "Change location logbook", where he wrote down where they were going and why, each time they went to a different location.

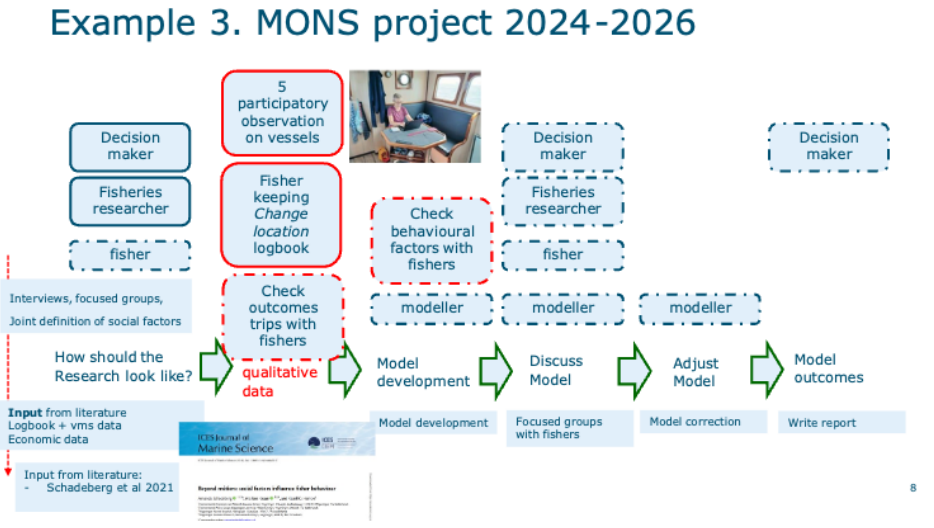

Figure 2.3 MONS project development including decisionmakers and fisheries researchers

One key point of participatory modelling is that there are different types of engagement. There are different ways of using qualitative data. 1) Qualitative methods for data gathering, such as participatory observation, interviews, and focused groups. 2) It also involves using qualitative research as input through full analysis. It is important to discuss certain aspects about the data, including potential biases and assumptions. Co-creation needs to be emphasized, where

outcomes are interpreted and adjusted collaboratively. The choice of engagement depends on time available, expertise, existing data (and considerations of stakeholder fatigue), political sensitivity of the project, and the level of trust among participants.

Working interdisciplinarity is also a "people" story. It requires a willingness to collaborate and bridge gaps between disciplines. This is also true for transdisciplinary work, which necessitates having boundary people; People who work on the boundary between the researcher and the industry or government, for example someone who worked on both sides. Furthermore, it is important that dilemmas are properly discussed. For example, whether the research that you are doing is not accidentally influencing your sample.

Part of participatory modelling deals with the question of how to incorporate behavioural variables into models. We feel that is important to include variables that we can reliably, objectively and repeatedly measure. Regrettably there are not many variables which qualify. As a result, we need to find creative ways to add to the data. As an example, we can use expert experience to distinguish between family businesses and other fishing companies. Dummy code them and see if a regression analysis shows markedly different behaviour between the business types. As another example, we can use VMS data to identify vessels that often cluster, to create subgroups, to account for network or norm effects.

Participatory modelling at the Benchmark Workshop on an Ecosystem-based Approach to Fishery Management for the Irish Sea (WKIRISH)

Jacob Bentley

Benchmark Workshops on an Ecosystem-based Approach to Fishery Management for the Irish Sea (WKIRISH) ran from 2015 to 2019. The workshops were requested by stakeholders following years of poor stock production (principally white fish) despite the implementation of management changes, such as fishing effort reduction. The workshops aimed to use a participatory approach to investigate drivers of stock production, including fishing, environmental change, and foodweb interactions. As part of this process, ecosystem models were co-developed for the Irish Sea. An Ecopath with Ecosim (EwE) model was constructed in close collaboration with the stakeholders, who shared their knowledge of foodweb interactions and fishing effort which was used to parameterize the model. Stakeholders and researchers co-created simulation questions and were able to provide ecosystem hypotheses for the failed recovery of many Irish Sea stocks. The model was reviewed for use in ICES advice by Working Group on Multispecies Assessment Methods (WGSAM), following which strategic ecosystem information was used to inform the development of an ecosystem reference point (Feco) in the catch advice for Irish Sea Cod. WKIRISH is continuously referred to as an example of successful stakeholder engagement within ICES and there ambitions to replicate its structure for other research questions and regions. Key reasons for WKIRISH success include: the initial ask came from stakeholders, trust was established prior to the process, stakeholders were involved at every stage, efforts were taken to make tailored products for dissemination, and knowledge was shared - not harvested.

Some feedback and perspectives from experiences in participatory modelling in support to fisheries or marine social-ecological system management

Claire Macher

While being more and more recognized for its salience and conceptually developed, participatory modelling still remains arduous and demanding for scientists. It requires a continuous reflective stance and questioning on added value and pitfalls of such approaches and a clarification of the methods and frameworks developed. Sharing feedback and experiences are thus a key issue to improve and foster the use of participatory modelling. The presentation gives some feedbacks and perspectives from three more or less recent approaches or projects developed along the last 15 years in Ifremer – AMURE lab in support to fisheries and marine social ecological systems management : (1) A participatory modelling approach called « The Partnership Bio-Economic Approach (PBEA)» developed by Ifremer since 2009 in the context of the last Common Fisheries Policy Reform and dedicated to the development of an operational participatory framework and protocol for multi-criteria impact assessment of scenarios (including TAC and quotas scenarios, fisheries management plans, selectivity, MSY, MEY objectives), (2) The PARTAGE initiative which try to foster reflexivity and experience sharing on collaborations between science-society and decision in a context where more and more people get engaged in participatory approaches for the social salience of their research but in a learning by doing approach and (3) the ongoing HOPOPoP project embedded in the sustainability sciences and based on Inter- and transdisciplinary consortium developed in the French Iroise Sea where we experiment new interactive methods based on companion modelling, simulations, gaming and virtual reality with models being considered here as intermediary objects aiming at fostering social learning and transformation towards sustainable marine social-ecological systems..

Feedback from these experiences highlight the particular interest found in collaborating on fleet-segmentations and appropriate model dimensions definition with regards to management issues addressed, on accounting for stakeholders' knowledge to identify potential behaviours and constraints operating in different scenarios (e.g. possible or impossible effort reallocation towards other fisheries) or in complementing the quantitative assessment with qualitative knowledge. Assessing the impacts of collaborations in the short and longer term in capacity and social learning still remains an issue as well as maintaining capacity and engagement along time or finding opportunities and arena to institutionalize the use of this kind of participatory framework.

When stakeholders build the ecosystem model: method and application to share common representation and uncertainties.

Sigrid Lehuta

The complexity of marine socio-ecosystems, combined with observations that are often indirect and incomplete, leads to stylized representations (models) that can be far from ecosystem actual functioning. The acceptance of models as a support to decision-making is conditional on their credibility with the different stakeholders. Identifying convergences and considering divergences in the visions actors have of the socio-ecosystem functioning is an essential

prerequisite to make pedagogy on these models. While most stakeholders are aware of uncertainties and used to consider them fully in their own decisions, model uncertainties are rarely presented to them. Not presenting uncertainties can make believe that models outcomes are certain and can lead to not well-informed decision. On the other hand, emphazing the uncertainty can reduce model credibility and therefore justifying inaction. A major issue of communicating on model uncertainties for making-decision is to develop tools for representing uncertainty that are accessible to stakeholders. The MIMI (Models, IMaginars and uncertaInties) project aims to contribute to the resolution of these challenges. In France, fishers representatives are involved in working groups with scientists from Ifremer to allow more fluent dialogue and requests. They recently asked for more information and training on models because they felt management heavily relied on them and they did not understand why they were many and so complex. Scientists saw the opportunity to increase credibility and acceptance of their models, and teach the inductry about uncertainty. That's how the MIMI project was launched with the objectives of demystifying models and share representations and knowledge of the socio-ecosystems. Two workshops gathering around 25 people mainly scientists and fishers representatives were held. The first one focused on models and the approach was « learning by doing ». Two groups of fishers representatives were asked to build a mental model aimed to project biomass and catches of a theoretical population in 5 years using an online post-it board. They were then asked to identify the most uncertain parts of their models. The second workshop focused on uncertainty with the representatives asked to define ranges for the uncertain parameters and processes identified previously and to vote for the graph (boxplot, enveloppes, risk…) that was conveying uncertainty the best for them.

Stakeholders ended up building very complex models which allowed to explain why complex models are sometimes needed to be more accurate. They were specifically complex when describing the management links, other activities than fishing and environment influence on stocks. The identification and propagation of uncertainties on the opposite showed why sometimes models were too simplistic or have to be simple in order to limit uncertainty. Models built by different groups were quite different, demonstrating that several models may coexist to answer the same question without one being less credible than the others. The need to adapt model features to the particular objective at stake was stressed multiple times by chairs to challenge the components participants proposed to include but it seems that the models obtained represented basically the full system, possibly because it was felt that everything was important in projecting biomass and catches. We then showed them a representation - using the same post-it board - of the model we would use for the purpose at stake, which was much more simple and highlighted the subjectivity of the decisions made when building a model and the need for transparency and collaboration. The models built that day were focused on current issues the industry was facing, which made us realize the need to do iterations and set it in a long-term perspective (depending on the objective).

A shrimp's tail: advancing lessons learned from formally reviewing end-to-end marine ecosystem models

Holly Perryman

Holistic approaches to managing living marine resources, which consider the suite of ecological and environmental interactions affecting a population, are becoming increasingly common. Often, these approaches utilize predictive models that include ecosystem dynamics. However, the application of marine ecosystem modelling tools is generally limited due to the lack of formal

reviews of the model's utility and performance, despite these practices being commonplace for single-species stock assessment models. Herein, we provide an account of our experience undergoing a formal review of a Gulf of Mexico end-to-end marine ecosystem model. Guided by lessons learned from the "guinea pigs" preceding us, described by Kaplan and Marshall (2016), we crafted and implemented a two-phase project timeline consisting of an informal review with regional experts and a formal review with independent experts. While the outcome of our review was that the model was not yet ready for use, a list of necessary model refinements provided by the reviewers offered a clear path for the model toward operational use. We reflect upon the practical challenges, successes, and setbacks encountered during our experience, offering insights into structuring a marine ecosystem model review for future applications. Additionally, building upon previous recommendations, we provide a list of baseline standards for reviewing marine ecosystem model performance. Addressing the inherent challenges in the review of marine ecosystem models is crucial to unlocking their potential contributions to ecosystem-based management, and our recommendations outlined herein offer guidance for future reviews.

Numerical modelling with uncertain knowledge and multiple expertise – an example with foodweb modelling

Benjamin Planque

Foodweb modelling is one tool available to investigate trade-offs in marine ecosystems and can be used to support ecosystem-based advice and management. Developing foodweb models in a participatory context is warranted because knowledge of foodwebs may be uncertain, it may be distributed between multiple knowledge holders, and because some modelling issues may not be easily resolved without deliberation among different experts. The contribution of non-modellers to foodweb modelling is also expected to help interpreting the model results outside "model land" and in the context of real world issues.

This presentation reports on a participatory modelling exercise conducted with the goal to reconstruct the dynamics of marine mammals, fish, and fisheries in the Norwegian and Barents seas. The participatory modelling process followed three main phases: 1) model preparation, 2) model implementation, and 3) model outputs. These were broken down into more specific steps: identification of the pool of participants (1.1), formulation of the model objective (1.2), identification of relevant species (1.3), and of the relevant temporal and spatial dimensions (1.4); collation of model input parameters (2.1) and of other model input knowledge and data (2.2) that can be used to constrain the model behaviour (2.3). This step (2.3) is critical as it specifies how multiple types of information, knowledge, and data – that can be uncertain – are used to constraint the model outputs. The model is then built (3.1) and if there is a solution (= if the multiple information provided by experts in steps 2.1-2.3 are not incompatible) the set of model solutions is sampled (3.2) and then jointly interpreted (3.3). Steps 3.1 and 3.3 can lead to the revision of all other steps of the modelling process (e.g. bringing new experts, revising the model structure, adding or revising input knowledge, etc.).

In the Barents-Norwegian seas example, model "failures" or "misbehaviour" were used to initiate discussions between participants and the resolution of these issues was achieved through deliberation. For example, some stock assessment data used as input were recognized to be unrealistically low and this was assigned to the individual stock assessment methodology. Another example involved consumption (=feeding) rates that were lower than suggested by

previous studies. The experts that conducted the earlier studies were invited and acknowledged that the lower estimates coming out of the foodweb model were reasonable and could not be ruled out.

In this example, the iterative development of the foodweb assessment model can be understood as a journey to advance system understanding, reveal knowledge uncertainties, and improve the model credibility.

This participatory modelling exercise did not involve non-academic stakeholders, but the principles of the modelling process (steps 1, 2, 3, deliberations and model revisions) should be possible to generalize to situations that involve institutional or sectoral stakeholders, in which knowledge is distributed and uncertain, and where some issues remain to be resolved before the model results can be accepted by all parties involved.

More details about the model structure and results are available from https://doi.org/10.1016/j.pocean.2024.103361.

Balancing stakeholder interests in participatory modelling

Erasmia Kastanidi

Participatory modelling is an iterative process that requires balancing scientific rigor with experiential knowledge. Stakeholder involvement can range from consultation in model conceptualization to full empowerment, influencing decision-making and model outcomes. However, broader participation raises expectations, making careful planning essential. Stakeholder mapping helps define involvement levels, ensuring realistic expectations and meaningful engagement.

Researchers act as facilitators, ensuring inclusivity while managing power dynamics. They must prevent dominant voices from overshadowing marginalized perspectives and maintain trust and transparency. Striking a balance between qualitative and quantitative approaches is crucial, as stakeholders often prioritize lived experiences over statistical validation. Managing expectations is key—avoiding over-promising results while ensuring genuine participation.

Group system mapping is a widely used approach to develop conceptual models transparently. This methodology includes multiple perspectives and supports social learning. Mental modelling helps identify key variables and relationships within a system, creating a qualitative representation of stakeholders' views. However, challenges arise as each participant interprets reality through their own cognitive and cultural lens, increasing complexity and potential conflicts. Despite this, qualitative system mapping is valuable in capturing diverse perspectives and guiding the modelling process. To reduce power imbalances, stakeholders can be grouped based on economic sectors or their interests in modelling outcomes. However, transitioning from qualitative to quantitative modelling is complex and requires compromises, such as model simplification and deciding on stakeholder inputs included in the final model.

A key challenge is model validation. Scientists emphasize quantitative validation to ensure accuracy and reproducibility, while stakeholders assess models based on how well they reflect lived experiences. This creates tension: scientists prioritize empirical robustness, whereas stakeholders seek qualitative relevance. The complexity of quantitative validation can alienate stakeholders, leading to trust issues. Addressing this requires continuous feedback, transparent

decision-making, and, in some cases, simplifying models for accessibility while maintaining scientific credibility.

While participatory modelling aims to reduce power imbalances, researchers ultimately control stakeholder influence over model structure. The challenge remains in balancing scientific accuracy with inclusivity, ensuring participatory methodologies align with empirical modelling. Bridging this gap requires adaptability, communication, and commitment to both rigorous science and meaningful stakeholder engagement.

Models as thinking tools

Maria Pierce

Non-modelling scientists, such as ecologists and field-researchers, are a valuable stakeholder group, particularly in the context of increasingly dynamic ecosystems and the necessary shift towards ecosystem-based advice. However, there is currently no clear path of including their knowledge in the immediate Advice pipeline and additionally no established scientific workflow to align and consolidate the many different contributing perspectives with regards to management implications.

With the Eastern Baltic Cod as an example the breadth of facets relevant to investigating the observed reduction in growth and condition was evaluated using a mechanistic individual-based model. In the end six facets (physiology, abiotic environment, prey, reproduction, parasitic infestation, and behaviour) were required to exhaustively model the established hypothesis regarding its decline (poor oxygen conditions, reduction in prey, high levels of parasitic infestation). Consolidating such a broad array of expert knowledge using a modeller as a conduit is highly inefficient and does not align with the time frame of managing dynamic ecosystems.

An alternative proposition is to facilitate group modelling as an approach, not only for building a model which allows to test hypotheses and contrast the relative impact of different mechanizms, but also as a way in which the different mental models individual scientists hold can be aligned and updated. Additionally, there are three ways in which this approach can directly feedback both into classic single species and ecosystem-based management advice workflows. First, any updated understanding of relevant quantitative, or even semi-quantitative factors can be directly included in the running of the stock assessment models, at least after the next benchmark. Second, any updated understanding of relevant qualitative factors can be included as text in the Advice. Third, any identified gaps in knowledge which could improve the quality of the advice can feedback into monitoring and experimentation.

Working towards approaches and tools that can aid in understanding the ecology of stocks and supporting ecosystems not only once but unremittingly is becoming a necessity as their dynamics continue to accelerate. Only with access to a scientific workflow that can provide uninterrupted insight and foresight will we be able to provide consistent guidance for use and stewardship.

An organization which can provide potentially useful tools in future, in this case in the form of standards for modelling and simulation, is the Standards working Group of the OMF – Open Modelling Foundation (https://www.openmodelingfoundation.org/).

The cephalopod food system framework: a socio-ecological model to foster transformations towards sustainable seafood systems

Gill Ainsworth

We present a novel market-based adaptation of the IPBES conceptual framework – our 'cephalopod food system framework', to represent how the cephalopod food system functions as a qualitative socio-ecological model and how it can inform processes to improve sustainability and equity of the cephalopod food system.

Our global literature review examined what is known about cephalopod food systems, value and supply chains, and associated market drivers. We followed the IPBES conceptual framework to build a map of the links between cephalopod market drivers, nature's contributions to people (NCP) and good quality of life. Then we mapped cephalopod food system dynamics onto IPBES (in)direct drivers of change relating to catch, trade and consumption.

Our model facilitates knowledge of key factors relating to cephalopods that can support transitions towards increased food security: the value of new aquatic food species; food safety and authenticity systems; place-based innovations and empowerment of communities; and consumer behaviour, lifestyle and motivations for better health and environmental sustainability along the food value chain. Based on the model outputs, we outline requirements for a sustainable, equitable cephalopod food system policy landscape that values NCP, considers UN Sustainable Development Goals and emphasizes the role of seven IPBES (in)direct drivers of change: Economic, Governance, Sociocultural and Socio-psychological, Technological, Direct Exploitation, Natural Processes and Pollution.

This synthesized knowledge provides the basis for diagnosing opportunities and constraints to be considered regarding the role of cephalopods in transformations towards a resilient and more diversified seafood production system. This social-ecological systems approach could apply to other wild harvest commodities with implications for diverse marine species and ecosystems and can inform those working to deliver marine and terrestrial food security while preserving biodiversity.

Can Participatory modelling resolve stakeholder conflicts in mixed fisheries?

Matthew Pace

Mixed fisheries catch more than one species in a single fishing operation. When multiple quota-managed stocks are caught by mixed fisheries, full compliance with the management procedure requires that fishing stops when the first quota is fully consumed. This is referred to as fishing effort 'choking'. Hence, performance evaluation of catch-based management procedures should consider mixed fisheries interactions when stocks are caught as part of a mixed fishery.

However, despite the development of sophisticated mixed fisheries models, mixed fisheries interactions are rarely formally integrated into the fisheries advice generation process. One important reason for this is that large irreducible system uncertainties prevent the adoption of a single 'true' model structure to inform catch advice. These uncertainties may be due to limited

data but may also represent uncertainty around fleet activity and behaviour patterns that lead to choking, as well as behavioural responses to choking.

Management strategy evaluation (MSE) provides a partial solution, by accommodating alternative plausible model structures as hypotheses against which management performance is simulation-tested. For instance, alternative assumptions about fleet behaviour following choking may be represented as distinct models within a set of 'operating' models (OM). It is important that the OM set captures the range of plausible uncertainty within the system.

Stakeholder participation from the early stages of model development is therefore critical to elicit a set of mutually agreed-upon hypotheses that could be modelled, and to ensure buy-in from both policy and industry. This participatory modelling approach is especially important when there are stakeholders have conflicting views about the structure and behaviour of the mixed fishery that must be accommodated. However, important questions remain. How should results from contrasting operating models be reconciled when evaluating management performance? How should reviews for exceptional circumstances incorporate changes in fleet behaviour and activity distribution?

Development of participatory modelling 'best practices' for the application of MSE to management of mixed fisheries is urgently needed to resolve these questions and ensure success of the MSE process. This will allow explicit consideration of mixed fisheries interactions during advice generation and allow evolution of management from the current single-stock focus toward management of mixed fisheries.

Setting the scene: Stakeholder Engagement Strategy, STIMP, and WGENGAGE

Marta Ballesteros

The presentation summarized the history of ICES opening up to stakeholder engagement (described in Dickey-Collas and Balleros, 2021) and the process developed from the Position Paper on the ICES Stakeholder Engagement Strategy in 2020 to the approval of the Strategy (ICES, 2023a) and the Workshop on Implementation of the ICES Stakeholder Engagement Strategy (ICES, 2023b).

The Strategy departs from conventional approaches in using roles instead of profiles (e.g. a fisher or a representative of an NGO) to ensure the credibility, legitimacy and relevance of ICES science and advice (see Ballesteros and Dickey-Collas, 2023). The roles are defined by the aim and focus of the processes within which the stakeholders are involved (Figure 2.4). The duties and responsibilities of those engaged and those who engage were analysed and are described in the Strategy.

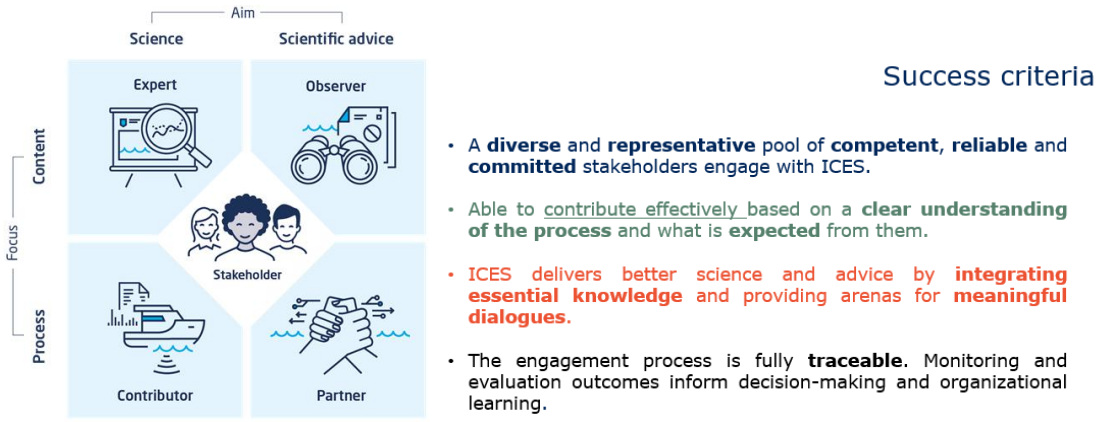

Figure 2.4 Role of Stakeholders within ICES. Source: ICES, 2023a; and Success criteria for the ICES Stakeholder Engagement Strategy (ICES, 2023b).

The implementation of the strategy includes 35 time-based priority actions (ICES, 2023b): immediate (22%), short-term (39%), mid-term (29%) and exploratory (10%), available in the WKSTIMP report. One of those actions is the creation of Working Group on Stakeholder Engagement (WGENGAGE, ToRs available here).

Within this context, several insights on the role of Participatory modelling within ICES were shared. ICES operates across issues, scales and knowledge action boundaries within multiple audiences. In developing science and advice, there are multiple entry points for stakeholder that call for a multi-level approach. Remarkably, the development of the European Digital Twin of the Ocean allows new applications for participatory modelling.

Modelling marine social ecological systems with participatory modelling

Olivier Thébaud

As part of the ecosystem approach to managing fisheries and other uses of marine ecosystems, there has been a growing call for the development of integrated assessment tools to support the provision of both tactical and strategic management advice. Of particular importance in this domain is the development of models that capture the dynamic interactions between social and economic systems, and marine ecosystems. In February 2013, a workshop jointly organized by the ICES Working Group on Integrative, Physical–biological and Ecosystem Modelling and researchers attending the "Mathematics of Bio-economics" initiative, a contribution to the international event "Mathematics of Planet Earth 2013", brought together experts to discuss advances and key methodological challenges posed by this field of research. The presentation focused on how participatory modelling can help address these challenges.

2.3 Discussion points following from the presentations

Clarifying **"who" are the participants** when we talk about participatory modelling is central. Fisheries stakeholders are obvious candidates, but not the only ones. Some of the presentations presented other types of participants (including scientists that are not modellers). The selection of participants is noted (in the existing literature) to greatly affect the process. One needs to go beyond the usual suspects and keep notes of who isn't there.

Clarifying **"where" and "to what extent" the participants join the modelling process** is also central. A good starting point to to identify and map participation, as for example in the proposition by Vaughn and Jacquez (2020, Figure 2.5). The ICES Stakeholder Engagement Strategy is highly relevant in this context.

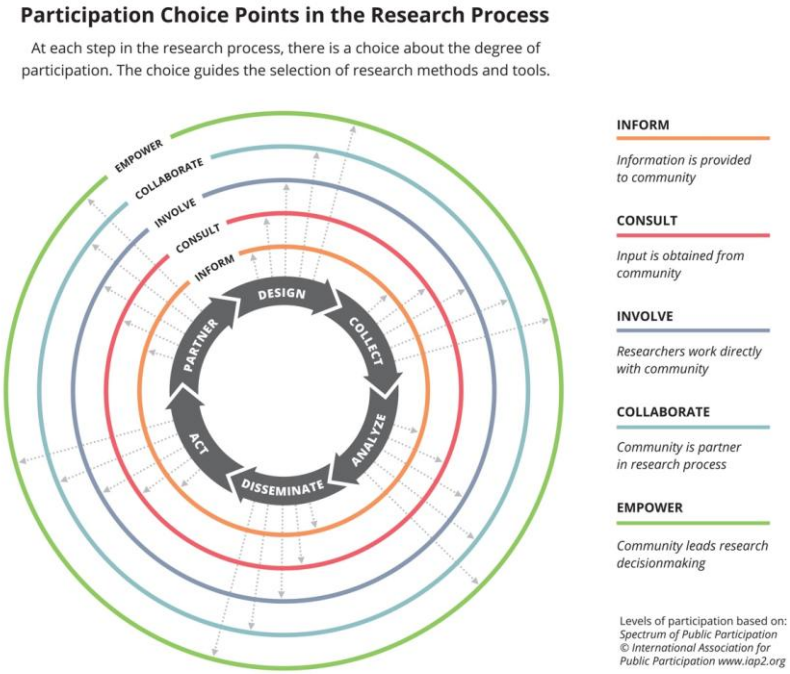

Figure 2.5 Participation choice points in the research process. Reproduced from Vaughn and Jaquez (2020).

Participation is context dependent. The approach that was successful e.g. in WKIRISH may not work in other contexts. Failure to characterize the social-ecological system, lack of contact with relevant stakeholders, reluctance to engage, political context, etc. can hinder effective participatory modelling.

One needs to be just as **rigorous with how to handle stakeholder knowledge**, as with how to handle empirical data. Stakeholder knowledge evaluation may need to be performed in specific ways, and there exist mechanizms to evaluate different forms of knowledge.

Models come in multiple shapes and forms and it is challenging to identify the suitable model(s) upfront. Choosing inappropriate modelling tools can have long lasting consequences (it's hard to revert to another model), and can degrade collaboration between modellers and non-modellers. Creating a **community of practice within ICES** could help identify what model(s) should be considered and who should be involved in different processes. Creating a family tree for the models that can be used in the participatory approaches (what are their applications) would be useful.

It is important to understand **what drives a participatory modelling** exercise and to analyse the features of the human and biological systems before we start designing the participatory approaches. It is critical to discuss **objectives** with the stakeholders at the outset of model development, rather than setting a wishlist of things that could be done with the model(s). The

models are not the objective of the participatory modelling, rather these are tools to address objectives and support the collaborative process. These early discussions will affect the model choice, the participatory process, and its outcomes.

Participatory modelling appears highly relevant in situations where there are **large irreducible system uncertainties** that prevent the adoption of a single 'true' model structure. These uncertainties may be due to limited data but may also represent uncertainty around ecological or human patterns and behaviour. When stakeholders hold **conflicting views** about the ecological and fisheries system, participation from the early stages of model development is critical to elicit a set of mutually agreed-upon hypotheses and to ensure buy-in from both policy and industry. The case of **MSE for mixed fisheries** appears to be a strong candidate for developing participatory modelling within ICES.

Participatory modelling can (should) be an integral part of "**action research**" or "**living lab**", that is user-centred environment where researchers, stakeholders, and communities collaborate, following an iterative process of intervention, reflection, and adaptation, to create change, not just knowledge.

Stakeholders and end-users should be prepared to participatory modelling resulting in unfavourable outcomes.

2.4 Report from break-out group

Question 1: What have been the most significant successes and caveats in participatory modelling from the case studies presented? And why?

An important aspect of **success** refers to the benefits of the participatory dimension: broadening of perspectives, inclusion of multiple actors, identification of relevant actors, trust building, supporting long-term interactions between actors. In some cases participatory modelling also offered a *safe space* for actors to interact. Participatory modelling helped in identifying trade-offs (west Africa CS), clarifying assumptions (Bay of Biscay CS), defying more salient advice (Bay of Biscay CS), communicating between actors (visualization, Gulf of Cadiz CS), and supporting informal institutional engagement (Gulf of Cadiz CS). Participatory modelling also contributed to assembling greater knowledge and data available from multiple sources.

Some **caveats** are related to the participatory process proper, including limitation in the inclusion of various actors (is everyone who should be present actually present); difficulty to consider cultural identities and practices; trade-offs between engagement and workload/availability of actors; fear of instrumentalization from all sides; epistemic (knowledge) imbalance between hard core modellers, natural and social scientists (non-modeller), and non-scientists. Clarifying expectations, objectives, and roles from the start of the participatory process remains a difficult task. Models can be too complex to be fully discussed in a participatory framework. Identifying and qualifying input data, parameters, assumptions, and model structure may require multiple iterations and consensus-building which are resource demanding. It can be difficult to consider actors' qualitative feedback on quantitative models. There is no easy pathway to incorporate many model results within the current ICES advisory system. Actors' knowledge is not always treated fairly, because knowledge that is highly relevant to some actors, may not be easy (or even possible) to implement in a given modelling approach.

Question 2: Who are the key stakeholders/end-users that should be involved and what are the challenges in building and maintaining effective participation?

The list of relevant stakeholders is context dependent. It can be wise to combine participation of small (focus) groups and of larger stakeholder groups, starting with few engaged individuals that have a fair level of trust and share a common set of values and objectives. It can be useful to follow a snowball approach, i.e. ask those few stakeholders already identified if they miss anyone. Reed et al. (2009) provide a useful review of methods to define who should be in and why. Structured analyses that consider the different categories of stakeholders - (different typologies - e.g. academics- NGOs- fishing industry- consumer- citizen - deciders- managers), their impact, and their influence, can help elucidate who should be in.

Creating a safe space can be challenging. Some individuals may not get to the table because they do not trust the process, are unhappy with other stakeholders, feel unfavoured regarding power dynamics, or have other concerns. People may also disengage along the process which reflects that the process might not properly incentivise them. Identifying who is absent or disengaging is as important as identifying who is present. Identifying shared values and goals is important to build and maintain trust and engagement.

Question 3: What unique approaches have emerged that could be adapted for use in other regions or modelling approaches?

Participatory modelling exercises within groups of natural scientists (modellers and non-modellers), i.e. without stakeholders. The examples presented for the Eastern Baltic Sea (Maria Pierce) and the Norwegian-Barents Sea (Benjamin Planque) illustrate the capability to **improve modelling through collective intelligence**.

Mind modelling and **Domain Specific Languages** (DSLs) or APIs have been shown to help communicate and disseminate modelling processes.

Stepwise approach for model co-construction with stakeholders looks transferable: 1. **Scoping**- identify stakeholders to engage, issues at stake- available data-knowledge. 2. **Share representation** of the system - Model the system according to issue- choose dimensions- fleets-species to be accounted for…3. **identify scenarios** and assumptions 4 **Simulate and explore** scenarios 5 **discuss** - qualify results with expert knowledge -.

Social network analyses to map the social systems (connections among stakeholders/sectors) as already done by e.g. Working Group on Maritime Systems (WGMARS) could also help.

Interactions in the form of **living labs**, where stakeholders agree to engage in the project for a number of consecutive years through an iterative process to refine the approach collaboratively.

Comparative studies can help methodological development and evaluation.

Policy-driven participatory modelling.

Question 4: How do the shared participatory modelling experiences align with or differ from ICES current modelling efforts?

Current ICES modelling efforts generally overlook the participatory dimension, but some forms of participation are emerging in several places (Feco, mixed-fisheries, ecosystem overviews, ecosystem assessment models).

Single-stock assessment advice accounts little for the interplay between stakeholders' experiences and the structure of mixed fisheries, thereby limiting the effectiveness of participatory modelling in this context.

The reported participatory modelling examples were often one-off exercises rather than done in a periodical cycle (1-2 years) that would be more typical of ICES modelling work.

The shared participatory modelling experiences reflect the Ecosystem Based Management approach, can inform on trade-offs, explore scenarios, support uncertainty and risk communication, support visualization and management of social conflicts, deal with qualitative and quantitative data, be problem oriented and address CS specific issues, help aligning with policy framework, all of which are relevant to ICES work.

Question 5: What modelling approaches or experiences do you think might be missing from our discussions so far?

Missing from the discussion were examples of participatory modelling that addresses restoration of fisheries and more generally fisheries management, cumulative impact assessments (e.g. Offshore wind farms), multi-scale advice and governance (local, regional, state, multiple states).

Missing from the discussion were examples of participatory models that are based on the following modelling tools: agent based models, use of art and humanities, simulation and gaming for transformative research, serious games and machine learning, and generally new tools and softwares.

Missing from the discussion were examples of participatory modelling that address the following issues with regards to participation: handling conflict of interests (not just identifying them), mixing non-participatory and participatory modelling approaches, including the cultural and psychological dimensions of stakeholders, tool to better understand and decide how different knowledge holders can contribute in different ways (what are their roles) to models.

Additional comments

No stakeholders outside science attend this workshop, which is a concern.

There is a need for **coordinating mechanizms** (across projects and institutions) to avoid duplication, stakeholder fatigue, etc.

A major objective for participatory modelling in ICES seems to be to support better assessment and advice. What is the space for more transformative **action research** where the objective would be more about **social learning and empowerment**?

There is a need to put effort in explaining to the stakeholders and to the modellers the added value of the participation to the modelling process, to engage both parties in this approach.

A clear **definition** of what participatory modelling is and isn't, **training** on participatory modelling, and **tools** to support engagement in participatory modelling are needed.

A comprehensive review of **existing structures and workflows within ICES** is required to make sure we are not replicating efforts and considering what it is already there.

2.5 Discussion points following from the break-out groups

A major contribution of participatory modelling can be to support the building and maintenance of trust between participants. Continuity is important, and so is managing expectations from the start. The process should be simple and well understood by all participants. Participants should identify where, in the modelling process, participation is most critical.

Because participatory modelling is not standard practice in ICES, this would require training of all participants, modellers and stakeholders alike.

Participatory modelling development in ICES would benefit for application on test case studies to establish proof of concept (Offshore renewable energy, multisectoral trade-offs, mixed fisheries, biodiversity, etc.)

Having a Participatory modelling framework ready will be particularly useful for new modelling initiatives which can be structured within this framework from their onset.

2.6 Priorities and statements

Identifying participants – Defining who participates is crucial. Stakeholders, scientists (non-modellers included), and other relevant actors must be carefully considered. Identifying who is missing is as important as identifying who is present.

Structuring participation – It is essential to clarify not only who participates but where and to what extent stakeholders engage in the modelling process. Existing frameworks, such as Vaughn and Jacquez (2020) and the ICES Stakeholder Engagement Strategy, provide valuable guidance. Annex 4 of the current report, which was developed in the months following from the WKParticipatoryModelling workshop, provides a practical tool to guide, assess, and report participation.

Handling stakeholder knowledge with rigor – Stakeholder knowledge must be evaluated with the same level of rigor as empirical data. Mechanizms exist to assess and integrate diverse knowledge sources effectively.

Selecting modelling tools that are fit for purpose – Choosing inappropriate modelling tools can have long-term consequences and degrade collaboration. Establishing a community of practice and a model "family tree" within ICES would improve model selection and integration.

Fostering participation when modelling uncertain systems – When large system uncertainties prevent a single 'true' model, participatory modelling can help reconcile conflicting views among stakeholders and ensure buy-in from end-users, e.g. policy and industry.

Recognizing engagement challenges – Key barriers to effective participation include trust issues, disengagement, power imbalances, and epistemic differences between modellers, scientists, and non-scientists. Identifying absences and maintaining incentives for engagement are critical.

Integrating participatory modelling in ICES Workflows – Current ICES modelling efforts generally lack structured participation. Aligning participatory modelling with ICES existing science, assessment, and advisory processes would enhance its impact.

2.7 Knowledge gaps relating to this ToR

Training and capacity building – There is a lack of formal training, resources, and tools for modellers and stakeholders to engage effectively in participatory modelling.

Framework for evaluating stakeholder knowledge – There is a lack of established methodologies to systematically assess, validate, and integrate different types of stakeholder knowledge (experiential, qualitative, quantitative) into participatory models.

Criteria for selecting modelling tools – There is no structured approach to determining which models are best suited for different participatory contexts, leading to uncertainty in model choice and potential mismatches between models and stakeholder needs.

Mechanizms for integrating participatory and non-participatory models – There is limited understanding of how to merge participatory modelling insights with traditional fisheries models, particularly in handling qualitative inputs within quantitative frameworks.

Long-term institutionalization of participatory modelling – There is no clear knowledge of how participatory modelling can be embedded within existing advisory and governance structures (e.g. ICES), ensuring it becomes a sustained and formalized process rather than one-off exercises.

3 ToR b: Participatory modelling opportunities

ToR b: Identify candidate studies or assessments within ICES that would benefit from participatory modelling

3.1 Background to the ToR

WKParticipatoryModelling used discussions and lessons from ToR a) to identify case studies where participatory modelling may be needed to (i) enhance science and advice, (ii) increase transparency in the provision of advice and ultimately (iii) increase buy-in by relevant end-users. Participatory modelling has the potential to facilitate and structure discussions between scientists and stakeholders about uncertainties and the quality of the knowledge base. It can also contribute to collective learning, increase legitimacy, and advance scientific understanding (Röckmann et al., 2012). ToR b set out to identify a set of case studies in existing ICES expert groups which were expected to directly benefit from the application of participatory modelling approaches.

3.2 Summary of presentations

Holly Perryman

Holistic approaches to fisheries management, which take into consideration the suite of ecological and environmental interactions affecting a population, are becoming common. Often, these approaches use predictive modelling tools that simulate ecosystem interactions. Although marine ecosystem models offer environmentally informed predictions, their application in the development of fisheries management advice is generally limited. This limitation has been attributed to the general uncertainty surrounding the utility and credibility of these models. Independent peer reviews are commonly conducted on stock assessment models, serving to convey technical details to stakeholders, assess the methodology, and ensure the model furnishes the best available insights for effective management. This process, however, has not been well developed for marine ecosystem models. The objective of our project was to carry out an independent peer review of the Gulf of Mexico Atlantis ecosystem model with the intention of advancing its capabilities to offer strategic recommendations, particularly within the framework of supporting ecosystem-based fisheries management for Gulf of Mexico shrimp (penaeid) stocks. Guided by the lessons learned from the "guinea pigs" preceding us, described in Kaplan and Marshall (2016), we crafted and implemented a two-phase project timeline. In the initial phase, the Gulf of Mexico Atlantis model underwent an informal peer review with regional experts from the National Oceanic and Atmospheric Administration's National Marine Fisheries Service. Conducted through six webinars spaced approximately one to three months apart, these were highly interactive sessions that allowed for open, detailed, and dynamic discussions on model parameterization and diagnostics. In the subsequent phase, the Gulf of Mexico Atlantis

model underwent a formal peer review with a panel of experts provided by the Center of Independent Experts. This review was conducted through a three-day public meeting, similar to peer review workshops conducted for single-species stock assessment models. Herein, we reflect upon our experience and provide insight into structuring an independent peer review of an ecosystem model. Additionally, we build upon previous recommendations by providing a revised list of standards for evaluating ecosystem model performance.

3.3 Report from break-out group

Question 1: Are there current ICES modelling areas where stakeholder/end-user involvement is particularly critical, i.e. for which modelling approaches or situations should participatory modelling be a priority, and where might it not be so important?

Participatory modelling should be prioritized in situations where stakes and uncertainties are high, as stakeholder involvement can enhance model acceptance, quality, and decision-making support. This is particularly valuable in cases where stakeholders are in direct conflict, as joint participation can help build trust and foster a shared understanding of model implications. Breakout group discussions identified several priority areas for participatory modelling:

- **Mixed-fisheries modelling:** A key area for participatory modelling, as it integrates multiple species and gear types while requiring assumptions about fleet structure and behaviour. Stakeholder input can improve the realism and credibility of these assumptions.
- **Integrated ecosystem assessments (IEAs) and ecosystem-based management (EBM):** These processes, including ecosystem overviews and social-ecological system modelling, would benefit from participatory approaches, as they involve synthesising diverse knowledge sources and balancing competing interests.
- **Areas of conflict or uncertainty:** When there are conflicting pieces of evidence, participatory modelling can help clarify discrepancies, strengthen coherence in information, and refine shared representations of ecological and fisheries dynamics.
- **Marine spatial planning (MSP) and cumulative impact assessments:** These approaches should integrate stakeholder knowledge, particularly in qualitative assessments such as risk evaluation.
- **Species-specific examples:** In Spain, small-scale common octopus fisheries operate outside quota regulations, making fishers' ecological knowledge critical for stock assessments. Similar engagement could be beneficial for other regionally managed species.
- **Climate change impact assessments:** Given the long-term uncertainties and cross-sectoral implications, participatory modelling can help bridge scientific projections with local and industry perspectives.

In contrast, participatory modelling may be less critical for well-managed, stable stocks, where routine assessments already provide reliable management guidance. However, economic assessments related to these stocks may still benefit from stakeholder input.

While some technical modelling applications may not require extensive stakeholder engagement, transparency and clear communication with stakeholders should always be prioritized. Even where participatory modelling is not essential, ensuring that stakeholders understand the implications of modelling outcomes should remain a key consideration for ICES processes.

Question 2: Given the scope of ICES science and advice, which marine management issues or evidence requests would most benefit from participatory modelling?

Participatory modelling would be particularly valuable in marine management issues and evidence requests where multiple sectors, stakeholders, and complex trade-offs must be considered. Breakout group discussions highlighted several priority areas where participatory approaches could enhance the quality, relevance, and acceptance of scientific advice.

- **Offshore wind farms (OWFs) and marine spatial planning (MSP):** As competition for marine space increases, participatory modelling can support multi-use planning and conflict resolution between sectors such as fisheries, renewable energy, and conservation. Stakeholder involvement is also essential to monitoring and data access, particularly for high-resolution environmental and fisheries data collected during OWF construction and operation.
- **Trade-off assessments:** Multi-sectoral decisions, particularly those balancing environmental, social, and economic factors, would benefit from participatory approaches. This includes evaluating the impacts of climate change and sustainability pathways, as well as assessing the trade-offs between conservation and resource use.
- **Biodiversity and conservation:** Effective conservation strategies require integrating stakeholder perspectives on biodiversity protection, particularly in Marine Protected Areas (MPAs), Vulnerable Marine Ecosystems (VMEs) in Areas Beyond National Jurisdiction (ABNJ), and exclusion zones for fisheries management.
- **Emerging issues:** Novel and rapidly evolving areas of marine management, such as deep sea mining, mesopelagic ecosystems, and increased shipping activity, present significant uncertainties. Participatory modelling can facilitate early stage discussions, ensuring that stakeholders contribute to monitoring strategies and impact assessments.
- **Global commons and iconic ecosystems:** Decisions affecting marine areas beyond national jurisdiction (ABNJ), such as deep-ocean environments, seamounts, and hydrothermal vent ecosystems, require broad international collaboration. Participatory approaches can help integrate diverse perspectives and align management decisions with global conservation priorities.
- **Fisheries management and bycatch reduction:** Participatory modelling can improve fisheries advice and management strategies, particularly for mixed fisheries, recreational fisheries, and evaluation of management measures through MSE (management strategy evaluation). It is also essential to identifying alternative management measures, technical gear innovations, and strategies for reducing bycatch of Endangered, Threatened, and Protected Species (ETPS).
- **Ecosystem-based management (EBM) and social-ecological linkages:** Effective marine management should connect ecosystem-based approaches with human welfare considerations, including socio-economic assessments and links to the UN Sustainable Development Goals (SDGs). Participatory modelling can facilitate the integration of ecological, economic, and societal factors into decision-making processes.
- **Aquaculture and climate mitigation projects:** Stakeholder involvement is crucial in the placement of aquaculture sites and emerging climate mitigation projects, such as plankton farms or bivalve bed restoration efforts. These activities have significant ecological and socio-economic implications, necessitating participatory approaches to ensure balanced and informed decision-making.

Participatory modelling is particularly valuable in issues that involve trade-offs, competing interests, and emerging uncertainties. While some areas of marine management may require less

stakeholder involvement, ensuring transparent communication and inclusive decision-making remains a fundamental priority across all ICES advisory processes.

Question 3: How and where can ICES integrate participatory modelling into its existing structures and workflows?

Integrating participatory modelling into ICES structures and workflows

ICES can integrate participatory modelling into its existing structures and workflows by embedding it within specific working groups, case studies, data collection processes, training initiatives, and decision-making frameworks. A key approach is to include participatory modelling in the ToRs of relevant ICES groups, ensuring that stakeholder engagement becomes a structured part of scientific and advisory activities. A case study and problem-oriented approach can also be used to demonstrate the value of participatory modelling, particularly in areas such as mixed-fisheries workflows, where stakeholder input is essential. However, it is important to recognize that participatory modelling can be time-consuming and resource-intensive, and if requests for certain types of advice are no longer active (e.g. Mixed-Fisheries Advice), there may be insufficient human or institutional capacity to sustain participatory efforts.

Embedding participatory modelling in scientific and advisory processes

Participatory modelling could be integrated into annual stock assessments, stock assessment benchmarks, and the qualitative aspects of catch advice sheets. By improving understanding of ecosystem dynamics and fishery interactions, participatory approaches could enhance assumption-setting in stock assessment models, providing an early warning system for new knowledge and emerging trends. Additionally, participatory modelling insights could point to new opportunities for data collection and process transformation, making advisory processes more adaptive. Contributing institutes, such as those involved in Data Collection Framework (DCF) activities, could be mobilized to support participatory initiatives. However, the current lack of structured opportunities for participatory modelling within ICES suggests that dedicated workshops, which offer more flexibility than traditional working groups, could serve as an initial entry point.

Building capacity and supporting implementation

To embed participatory modelling more effectively within ICES, collaborative frameworks and capacity-building initiatives should be established. This includes hosting multi-actor workshops (e.g. WKSTIMP, WKAFPA, WGENGAGE) and developing training sessions for stakeholders and ICES scientists on participatory modelling techniques. Training efforts should target both natural scientists and modellers, equipping them with the skills to conduct effective stakeholder workshops. Digital tools and platforms could be developed to facilitate ongoing stakeholder involvement, making participatory modelling more accessible and scalable.

Expanding participatory modelling in decision-making

ICES should encourage its working groups to adopt participatory modelling approaches in research projects, ensuring that stakeholder engagement is embedded within their methodologies. Additionally, regular evaluations of participatory modelling efforts, for example through participant feedback and surveys, could help to refine best practices and improve future engagement strategies. Workshops with industry and policy partners could also be expanded, such as through the development of management strategy evaluation (MSE) initiatives (e.g. an

expansion of WKNSMSE, WKECOMSE), to review and test the effectiveness of fisheries management advice.

Question 4: How and where can ICES integrate participatory modelling into its existing structures and workflows?

Breakout groups discussed how participatory approaches are most beneficial in the framing of model objectives, model evaluation, and the communication of model outputs, though engagement in other stages, such as model design and implementation, can also enhance transparency, trust, and usability. Discussions highlighted that the level and timing of stakeholder involvement should be tailored to the specific modelling context, ensuring that participation is meaningful and effective.

Framing of model objectives

Stakeholder participation is particularly valuable in the early stages of model development, especially in defining model objectives and identifying key questions. Different stakeholders often have diverse perspectives on the system being modelled. Bringing them into the process early can help ensure that models are addressing relevant, real-world concerns and are aligned with the needs of decision-makers.

Model design and implementation

Participatory modelling can enhance model design, particularly in ensuring that models can accommodate different stakeholder views, behaviours, and real-world operational factors. Stakeholders can also provide valuable input on assumptions and data sources, improving model credibility. However, while some engagement in model implementation may be beneficial (e.g. refining assumptions or integrating knowledge), the group considered that this stage may be less crucial to stakeholder participation compared to other phases.

Model evaluation and validation

Model evaluation is another critical stage where stakeholder involvement helps assess whether the model accurately represents reality. Participation in this phase can ensure that the model matches the mental models, experiences, and expectations of those affected by its outputs. Additionally, stakeholders can help validate model assumptions and dynamics, particularly in scenario simulations and alternative management measures, ensuring that model outputs are practically relevant and usable for decision-making.

Communication of model outputs

Clear and accessible communication of model results is essential to building trust, engagement, and understanding. Participatory approaches can be used to co-develop communication tools, such as interactive apps (e.g. Shiny apps) or visualization techniques, that make model outputs more understandable for non-technical audiences. Stakeholders should be engaged throughout the process to bridge the gap between complex model outputs and real-world applications.

Ensuring effective participation

For participatory modelling to be effective, simplification of the modelling process is crucial: stakeholders must be able to easily understand and engage with different steps. Training scientists in participatory methods and engagement strategies could improve the integration of

stakeholder input across modelling workflows. Additionally, a model family tree could help guide decisions on which types of models would most benefit from participatory approaches at different stages.

Question 5: How could we handle differences in knowledge types and are there areas where combining knowledge types might pose challenges? How can we overcome them?

Integrating diverse knowledge types into participatory modelling can pose challenges due to differences in scale, trust, uncertainty, and the nature of information. However, structured frameworks, inclusive facilitation, shared terminology, and knowledge co-production strategies can help bridge these gaps, ensuring that multiple perspectives are equitably represented in ICES science and advice:

Establishing a clear framework for participatory modelling

WKParticipatoryModelling recommends that a framework for participatory modelling should be developed. This would provide structured guidance on knowledge integration. Inclusive facilitation techniques, such as workshops, interactive dialogues, and safe spaces, are essential to foster mutual respect and trust among participants. Creating an environment where stakeholders feel comfortable sharing knowledge is key to successful integration.

Developing a shared terminology and knowledge database

One challenge in integrating different knowledge types is the lack of a common language between disciplines and stakeholder groups. Establishing a shared terminology, potentially through an international database of terms, participants, and knowledge equivalencies, could facilitate clearer dialogue and improve mutual understanding. This database should be regularly updated to reflect evolving scientific and stakeholder perspectives, helping to bridge gaps in communication.

Addressing challenges in scale, trust, and knowledge types

A common difficulty in integrating knowledge types arises from differences in scale. Scientists often work at larger geographic or ecosystem scales, whereas small-scale fishers and local stakeholders operate at finer spatial resolutions, leading to misalignments in perception and applicability. To address these concerns, knowledge co-production strategies should be implemented as a foundation for participatory modelling, ensuring that different knowledge holders contribute equitably and that their insights are valued.

Leveraging existing expertise and building communities of practice

One way to enhance knowledge integration is by leveraging individuals with broad expertise across different knowledge domains. Many experts already have long-term relationships with stakeholders, which can facilitate trust-building and knowledge-sharing. For example, in the BioEcon4Fish project, a social expert supports participatory processes, but the team also includes scientists with 10–30 years of industry experience, allowing them to act as knowledge brokers. Given the limited availability of social scientists, using existing networks and communities of practice is crucial to ensuring effective engagement.

Exploring narrative-based approaches and cross-sectoral tools

Incorporating qualitative knowledge, such as stakeholder narratives, into modelling frameworks is another way to integrate diverse perspectives. The Breakout Groups discussed how the medical sciences have developed advanced tools for integrating narratives into evidence-based frameworks, which could be adapted for use in marine science and participatory modelling. Additionally, in Wageningen Economic Research, challenges have emerged in translating field observations into measurable, empirical data. Learning from these experiences could help develop better methodologies for quantifying qualitative insights, ensuring that local knowledge is not only acknowledged but also meaningfully incorporated into decision-making.

3.4 Discussion points following from the break-out groups: priorities and evidence gaps

The post-breakout group discussion focused on several core themes related to the questions tackled by the groups for ToRb:

Building trust and managing expectations

The discussion highlighted the importance of recognizing diverse perspectives and maintaining trust in participatory modelling processes. However, challenges such as a lack of generalizability and reproducibility in methodologies were noted, along with the need for better stakeholder training to manage expectations effectively.

Key marine management issues

Participatory modelling was identified as beneficial for mixed fisheries, offshore wind farm operations, marine spatial planning, and conflicts in resource use. Emerging concerns such as deep sea mining, mesopelagic ecosystems, and shipping were also highlighted as areas where participatory approaches could add value.

Integration into existing structures

To integrate participatory modelling into existing structures, a transparent, case study-driven approach was recommended. The mixed fisheries workflow was suggested as a potential entry point, though concerns were raised about resource constraints and the time-intensive nature of these processes.

Stages for participation in modelling

Participants saw the greatest value in participation during model framing, evaluation, communication, and assumption-making. Ensuring models are simple and accessible was emphasized as key to fostering broad engagement and understanding.

Avoiding stakeholder fatigue

A more coordinated approach to engagement was recommended to avoid overwhelming stakeholders. The risk of repeated, unstructured requests for input was flagged as a potential barrier to effective participation.

Participatory modelling as a training tool

Participatory modelling was proposed as a training tool within ICES, particularly for social science education aimed at natural scientists. A suggestion was made to integrate it into existing ICES training courses to familiarise researchers with participatory methods.

Application to emerging issues

The group discussed the benefits of applying participatory modelling to emerging issues from the outset. Establishing best practices early in new initiatives was seen as a way to prevent later difficulties in integrating stakeholder input.

4 ToR c: Participatory modelling framework

ToR c: Develop a framework for participatory modelling within ICES by building on experiences and literature

4.1 Background to the ToR

To encourage further instances of participatory modelling which are in line with ICES Stakeholder Engagement Strategy and consistent application, ToR c focused to the development of a framework which ensures that (i) a participatory approach is justified, (ii) models are communicable an transparent to stakeholders (e.g. in their function and assumptions), (iii) approaches are robust and appropriately facilitated, (iv) co-production principles are applied (i.e. engagement early and often), and (v) instances of participatory modelling are effectively monitored and evaluated.

4.2 Report from break-out group

Question 1: What should be the primary objective(s) of the ICES participatory modelling framework?

Overarching objectives

Breakout groups suggested that an ICES participatory modelling framework should enhance both the science and advisory processes within ICES. In the advisory context, the developed participatory modelling framework should improve the relevance of ICES advice to the needs of requesters and observers and therefore its uptake, while in scientific applications, it should facilitate shared representations of systems, capacity building, social learning, and knowledge exchange through interactive modelling. A key objective should be to increase transparency, legitimacy, trust, quality, and thus acceptance of ICES science and advice.

By integrating diverse stakeholder knowledge, the framework can enhance the credibility and usability of models, ensuring they incorporate both experiential and local insights. Additionally, participatory modelling should function as an early warning system, anticipating challenges and opportunities that could arise when implementing advice. It should also support the development of more salient and politically aware advisory processes while promoting innovative approaches to data collection and modelling. Ultimately, the framework should contribute to more comprehensive, adaptive, and effective ecosystem-based management.

Specific objectives and applications

The participatory modelling framework should allow ICES to address knowledge gaps at regional and localized (e.g. national) scales while leveraging its extensive networks to scale up expertise and stakeholder engagement. It should be able to serve as a testbed for multiple contexts and case studies, allowing flexible and adaptive applications of participatory modelling.

The framework would benefit from the strengthening of ICES connections with the broader participatory modelling community (including experts beyond the marine sector) to facilitate the exchange of tools, training, and expertise. To ensure longevity and adaptability, the framework should follow a modular design, allowing updates to specific components while maintaining a stable foundation.

A critical aim is to make participatory modelling both useful and applied within ICES processes, particularly by improving data and information sharing among scientists.

Question 2: How could an ICES framework for participatory modelling capture the below points through different approaches, recommendations, and objectives (may be useful to think short, medium, and long term):

- The participatory approach is justified (clear, need, objectives, and problem definition)
- Stakeholders/end-users are included (stakeholder/end-user identification and engagement)
- Co-development of models (knowledge integration, interaction, dissemination)
- Models are communicable and transparent to stakeholders and end-users(visualization)
- Participatory approaches are robust and appropriately facilitated
- Instances of participatory modelling are effectively monitored and evaluated to adapt the framework
- Other important components?

Justification for the approach

To ensure participatory modelling efforts are well-founded, the framework should begin with a clear justification for the approach. This should involve defining the need, objectives, and problem statement to guide the participatory modelling process. For example, a decision tree could be developed to help practitioners determine when participatory modelling is appropriate, structuring a stepwise process that aligns with different modelling approaches. Additionally, an ICES model family tree could provide an overview of different model types and their suitability for participatory approaches.

In the short term, this requires developing clear guidance that helps users to define and justify the participatory need and objective. In the medium term, linking the decision-making process to an ICES-wide engagement strategy will help ensure alignment with existing advisory and stakeholder engagement mechanizms. Long-term efforts should focus on refining the framework through continuous feedback and lessons learned from real-world applications.

Stakeholder and end-user identification and engagement

Breakout groups recommended that a successful participatory modelling framework should include a structured engagement strategy that defines clear entry points for different stakeholders. The ICES Stakeholder Engagement Strategy should inform this process, ensuring that engagement is not only inclusive but also contextually relevant. Identifying expertise and

skills across the community of practice is crucial, as well as recognizing training needs related to facilitation, communication, and modelling.

In the short term, the framework should outline different formats of interaction, from informal discussions to structured workshops, to ensure accessibility and inclusivity. The medium-term goal should be the development of a structured stakeholder panel, where scientific committees manage model development while stakeholder panels review progress and provide feedback. Long-term objectives should focus on embedding a culture of equal participation, ensuring participatory modelling is not simply modellers explaining concepts to stakeholders, but rather a shared, iterative process.

Co-development of models: knowledge integration, interaction, and dissemination

For participatory modelling to be meaningful, co-development must be built into the process rather than added as an afterthought. The framework should encourage a formal "stop sign" checkpoint where modellers should pause to engage with stakeholders before proceeding with model development. This ensures that models are co-framed and co-developed, rather than pre-designed by scientists and later presented to stakeholders.

In the short term, the focus should be on developing protocol steps that clarify who is involved, how they contribute, and what outcomes are expected. The medium-term objective should be to integrate participatory approaches into ICES working groups, ensuring that model co-development becomes standard practice. Long-term efforts should include fostering cross-sectoral learning by bringing in experts from outside the marine sector (e.g. agriculture, climate science) to share best practices in participatory modelling.

Communicating and ensuring transparency in models

Ensuring that models are transparent and accessible to stakeholders requires effective visualization techniques. The framework should provide an overview of different visualization methods, such as storytelling, role-playing, gaming, cartoons, and art and humanities approaches, to make complex model outputs more digestible. Involving ICES Communications teams in participatory modelling processes will ensure that outputs are well-presented and that there is a clear feedback mechanizm to engage stakeholders.

In the short term, the framework should establish a graphical representation process to track stakeholder inputs and ensure that contributions are reflected throughout the modelling process. The medium-term objective should be to formalize communication channels that ensure transparency and feedback loops between model developers and stakeholders. Long-term efforts should focus on embedding visualization best practices across ICES advisory and assessment processes, ensuring that participatory modelling is accessible to diverse audiences.

Robustness and facilitation of participatory approaches

Participatory modelling processes must be robust and well-facilitated to ensure their credibility and effectiveness. This requires a focus on engaging with facilitators and training facilitators, ensuring redundancy in expertise (i.e. at least two trained individuals should be able to run the process from start to finish). The framework should also emphasize the traceability of participatory processes, including documentation of who was invited, who participated, and what decisions were made.

In the short term, training modules on facilitation, communication, and participatory techniques should be developed for ICES scientists and working groups. The medium-term objective should be to establish a community of practice for participatory modelling within ICES, ensuring knowledge exchange and continuous skill development. Long-term efforts should focus on institutionalising participatory modelling processes within ICES structures, ensuring they become standard practice across relevant working groups.

Monitoring and evaluation of participatory modelling instances

For participatory modelling efforts to improve over time, a structured monitoring and evaluation process must be embedded into the framework. This includes tracking participation, evaluating stakeholder engagement, and assessing the usability and impact of model outputs. Lessons learned from past applications should inform continuous refinement of the framework.

In the short term, the participatory modelling framework should benefit from the basic ICES tracking mechanizms to document participatory modelling efforts. The medium-term objective should be to develop standardized evaluation criteria for participatory modelling, ensuring that each instance is assessed for effectiveness and inclusivity. Long-term efforts should focus on using evaluation results to adapt the framework dynamically, ensuring it remains relevant and responsive to emerging needs.

Additional considerations and recommendations

The ICES participatory modelling framework should not be overly prescriptive but should provide guiding principles similar to the IEA (integrated ecosystem assessment) loop. Additionally, participatory modelling should be recognized as a spectrum of engagement, where not all processes require full transdisciplinary collaboration - sometimes, simply sharing model outputs and gathering stakeholder feedback is a valid and useful approach.

In the short term, efforts should focus on identifying and documenting reusable tools that can support participatory modelling across different contexts. The medium-term objective should be to promote ICES-wide discussions on participatory modelling, including through keynotes or sessions at major conferences such as ICES ASC. Long-term efforts should ensure that participatory modelling is embedded into ICES governance structures, aligning with broader ICES advisory and engagement strategies.

4.3 Key discussion points

Implementing a framework for participatory modelling within ICES can support the transition from focusing on delivering 'the model', towards recognizing the importance of multiple models that tackle different aspects of a system and that can jointly address complex questions. It is also a way to better account for uncertainties, to recognize multiple perspectives, and to support participatory approaches in a broad sense.

A first step can be to ensure that new modelling initiatives consider the opportunity for participatory approach from the start, evaluate potential benefits and costs of engaging into PM, and define where in the modelling process would participation be most beneficial.

Implementation would require the involvement of ICES MIRIA and MIACO, a broad discussion on participatory within ICES, the development of training courses for modellers and non-modellers, and the identification of case studies that can serve as proof of concept.

4.4 Priorities and statements

To implement more instances of participatory modelling within ICES, WKParticipatoryModelling recommends the development of a structured and adaptable framework that builds on existing examples (both within and external to ICES) and ensures applicability across different modelling areas while remaining flexible to regional and research needs. Immediate priorities include refining the justification and decision-support elements within the framework, such as developing a decision tree to guide when and how participatory modelling should be applied, aligned with ICES stakeholder engagement strategy. The framework should also incorporate structured mechanizms for stakeholder identification and engagement, ensuring inclusivity and relevance in both advisory and scientific contexts. In the short term, efforts should prioritize the development of training materials for facilitators and modellers to enhance capacity within ICES, alongside the establishment of clear guidance on co-development processes and knowledge integration. Opportunities for training were noted as a particular gap which may be supported by the forthcoming work of WGENGAGE.

The long-term aspiration is to embed participatory modelling as a standard practice within ICES, fostering collaboration with stakeholders and establishing ongoing monitoring and evaluation mechanizms to refine and improve participatory approaches over time. The success of participatory modelling within ICES, as demonstrated in groups such as WKIRISH, will likely depend on its ability to enhance transparency, legitimacy, and usability of scientific advice.

4.5 Knowledge gaps relating to this ToR

There are several gaps in our capacity and understanding which require further investigation and support. Knowledge and process gaps include:

- Understanding when participatory modelling is most beneficial and making sure those opportunities are identified and communicated.
- Limited knowledge across disciplines on best practices for identifying and integrating diverse knowledge systems in a way that enhances model credibility and legitimacy.
- Understanding the role of facilitation in participatory modelling and how different facilitation styles might impact or influence stakeholder contributions and the overall effectiveness of co-development processes.
- How to effectively evaluate participatory modelling efforts: what are the metrics for success, how can we track engagement over time, and how do we quantify or capture the benefits of participatory modelling through real-world impact.
- A need for a better understanding of how participatory modelling can be aligned and evaluated with existing ICES advisory processes.

Addressing these knowledge gaps will require interdisciplinary collaboration and trial applications across different case studies.

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Annex 1: List of participants

Name	Institute	Country (of institute)
Gillian Ainsworth	University of Santiago de Compostela	Spain
Darcie Anderson	University of Cape Town	South Africa
Marta Ballesteros	Technological Centre of the Sea	Spain
Jacob Bentley	Natural England	UK
Ricardo Cavieses	Oceanological Research Institute	Mexico
Adrien Chevallier	University of Montpellier	France
Martina Gaglioti	International Union for Conservation of Nature	International
Maria Gamaza Márquez	Spanish Institute of Oceanography	Spain
Eirini Glyki	ICES	International
David Gyimah	Flanders Research Institute for Agriculture, Fisheries and Food	Belgium
Katell Hamon	Wageningen University & Research	Netherlands
Alejandro Hidalgo Garrido	Spanish Institute of Oceanography	Spain
Stéphanie Hopkins	National Institute for Ocean Science - Ifremer	France
Erasmia Kastanidi	Hellenic Centre for Marine Research	Greece
Tom Kisters	Wageningen University & Research	Netherlands
Michael Kriegl	Leibniz Center for Tropical Marine Ecology	Germany
Sigrid Lehuta	National Institute for Ocean Science - Ifremer	France
Sarina Lincoln	Stockholm Resilience Centre	Sweden
Lis Lindal Jørgensen	Institute of Marine Research	Norway
Marcos Llope	Spanish Institute of Oceanography	Spain
Claire Macher	National Institute for Ocean Science - Ifremer	France
Jelto Makris	Unaffiliated	NA
Irene Martins	Interdisciplinary Centre of Marine and Environmental Research	Portugal
Erika Meerhoff	Clemente Estable Institute of Biological Research	Uruguay
Samuel Morsbach	University of Gothenburg	Sweden

Fabien Moullec	Royal Netherlands Institute for Sea Research	Netherlands
Mamadou Ndiaw Seck	Spanish Institute of Oceanography	Spain
Matthew Pace	Cefas Lowestoft Laboratory	UK
Ualerson Peixoto	University of the Azores	Portugal
Holly Ann Perryman	University of South Florida	United States
Maria Pierce	Thünen-Institute of Baltic Sea Fisheries	Germany
Benjamin Planque	Institute of Marine Research	Norway
David Reid	ICES	International
Alfredo Santiago Garcia de Vinuesa Gutierrez	Institute of Marine Science	Spain
Charlotte Scholten	Royal Netherlands Institute for Sea Research	Netherlands
Nathalie Steins	Wageningen University & Research	Netherlands
Olivier Thebaud	National Institute for Ocean Science - Ifremer	France
Deutz Zafimamatrapehy	UMR MARBEC	France

Annex 2: Resolutions

2023/MT/HUDISG04 The **Workshop on Participatory Modelling (WKParticipatoryModelling)**, chaired by Jacob Bentley (UK) and Benjamin Planque (Norway) will be established and will meet in Copenhagen, Denmark, 7 to 11 October 2024 to work on the following Terms of Reference (ToRs):

a) Review experiences of participatory modelling in marine science, both inside and outside ICES; (Science Plan codes: 7.5, 7.7);
b) Identify candidate studies or assessments within ICES that would benefit from participatory modelling; (Science Plan codes: 7.5, 7.7);
c) Develop a framework for participatory modelling within ICES by building on experiences and literature; (Science Plan codes: 7.5, 7.7).

WKParticipatoryModelling will report for the attention of ACOM and SCICOM.

Priority	Very high. The current activities of this Group will lead ICES into issues related to marine ecosystem services, integrating fisheries management and transformative changes towards ocean equity. Consequently, these activities are considered to have a very high priority.

Scientific justification	**Term of Reference a)** ICES now has a Stakeholder Engagement Strategy which outlines the key principle of stakeholder engagement and defines the roles of stakeholders and scientists in the engagement. The recent Workshop on the Implementation of the Stakeholder Engagement Strategy (WKSTIMP) defined a suite of actions to make the ICES strategy work. Initiatives to reinforce the strategy include the development of guidelines for integrity and the accountability of stakeholder perceptions. Participatory modelling is well routed in the scientific literature and frequently occurs across ICES groups and workshops (e.g. IEA groups and WKIRISH). However, its application within ICES seems inconsistent. ToR a) will explore 1) different definitions and interpretations of participatory modelling, 2) where and how participatory modelling has been applied within and external to ICES, learnin from both positive and negative experiences (e.g. Sterling et al., 2019), and 3) whicl frameworks already exist and may be appropriate to use across ICES. We will also aim to assess the importance of participatory modelling and the existing demand fc the approach from stakeholders (e.g. Voinov et al., 2016). The objective is to understand the experiences of researchers and stakeholders and use this knowledg to inform a framework for participatory modelling within ICES. Particular focus will be given to the application of conceptual frameworks for integrated ecosystem assessments, as this is an area relevant to ICES where we have seen the greatest participation of stakeholders within ICES (ICES 2022) and elsewhere (e.g. Ingram e al., 2018). **Term of Reference b)** We will use lessons from ToR a) to identify case studies where participatory modelling is needed in order to (i) enhance science and advice, (ii) increase transparency in the provision of advice and ultimately (iii) increase buy-in by relevant end-users. Participatory modelling has the potential to facilitate and structure discussions between scientists and stakeholders about uncertainties and the quality of the knowledge base. It can also contribute to collective learning, increase legitimacy, and advance scientific understanding (Röckmann et al., 2012). ToR b will identify a set of case studies in existing ICES expert groups that are expected to directly benefit from transitioning to participatory modelling. **Term of Reference c)** To encourage further instances of participatory modelling which are in line with ICES Stakeholder Engagement Strategy and consistent application, ToR c will propose a framework which ensures that (i) a participatory approach is justified, (i models are communicable and transparent to stakeholders (e.g. in their function and assumptions), (iii) approaches are robust and appropriately facilitated, (iv) co-production principles are applied (i.e. engagement early and often), and (v) instances of participatory modelling are effectively monitored and evaluated. **References** ICES. 2022. Joint ICES/EUROMARINE Workshop on Common Conceptual Mapping Methodologies (WKCCMM; Outputs from 2021 meeting).

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Resource requirements	Hybrid meeting (online component only in mornings)
Participants	This workshop will be of interest to participants who are involved in modelling, social science, stakeholder engagement, local ecological knowledge, and transdisciplinary methods. Members from IEASG and HUDISG may be particularly interested. Chairs intend to reach out to a list of participants who are heavily involved in this work area (also open to nominations from SCICOM), with wider attendance being driven by advertising of the WK on the ICES website and social media.
Secretariat facilities	Meeting facilities (in person and online), registration support
Financial	No financial implications.
Linkages to Advisor Committee	ACOM, SCICOM
Linkages to oth committees or groups	HUDISG, WKSTIMP, ICES Stakeholder Engagement Strategy, WKAFPA, WGSOCIAL, WGMARS, WGIPEM, WGSAM, IEASG, HAPISG, ASG, FRSG
Linkages to oth organizations	NGOs, marine sectors (e.g. fisheries and OFW), advice requesters

Annex 3: A tool to guide, assess, and report engagement in participatory modelling

This document was prepared in the months following the ICES workshop on participatory modelling by Maria Pierce, Benjamin Planque, Claire Macher, Marta Ballesteros, Stephanie Hopkins, Erasmia Kastanidi, and Irene Martins.

Background

Participatory modelling (PM), the practice of including non-modellers in a modelling process, can provide invaluable data, information and knowledge, contribute to a shared understanding of a given system, and result in a high degree of consensus and investment among the involved parties.

Participatory modelling can benefit modellers by improving the conceptual basis of models based on participants input, by gaining new knowledge and data that can inform models, by making their models more transparent and better communicated, and by building trust between modellers and model-users. Participatory modelling can support broader participatory processes by providing models as boundary object that facilitates dialogue between parties, by using the models as tools for the elicitation of concepts and assumptions held by different participants, and as tools to identify consensus, discord, and uncertainties.

These benefits come at the price of requiring an additional dimension of planning and awareness. Managing expectations, fostering good relationships, coordinating to avoid stakeholder fatigue, allocating sufficient time, providing appropriate feedback, considering specific features of research ethics (consent, knowledge use) etc. are additional tasks which are not part of the standard modelling and simulation life cycle. For this reason, it is not always easy to plan, conduct, and finalize a PM exercise.

One central issue to PM is the clarification of the role played by different participants. Who are the participants? Where/when should they engage in PM? How should they contribute?

This document presents a simple operational tool that can support responsible and sustainable participatory modelling in practice, by eliciting the engagement of participants in a PM exercise. The document uses concepts (e.g. boundary object or engagement) in a way that eases the understanding and facilitates the usability. Readers are warned that such use neither capture nor are intended to deny the complexities and nuances associated with each of them.

Purpose of this document

This document provides a practical tool for mapping the engagement of participants throughout the life cycle of a participatory modelling exercise.

1. It is designed to help **prepare for upcoming PM exercises** by identifying who the participants should be and at what level they are expected to be involved in the successive steps of modelling.
2. It can be used to **track an ongoing PM exercise**, by refocusing the purpose of each modelling step, and by clarifying and monitoring the role of each participant at each modelling step.
3. It can support the **reporting of a completed PM exercise** by showing, which level of engagement has been achieved, by who, and where.
4. It can support the **assessment of a PM exercise** by providing a systematic understanding of the steps and layers, as well as the implications of the choices made during implementation on performance and outcome.

Framework and definitions

We start by defining 1) **what** are the modelling **steps**, 2) **who** are the **participants**, and 3) **how** do they engage, i.e. what is their **level of engagement**.

Steps of participatory modelling

We identify 7 sequential modelling steps for PM:

1. **SCOPING**: motivation for developing the model, purpose and expected use

- This step should answer questions such as: Why should the model be developed? Will the model be used for pedagogical, explanatory, or predictive purpose? What conditions must be met to consider the exercise a success? What is this exercise not about? Who will use the finished model? How will the model results be used?
  From a modelling perspective this step can be understood as the 'problem definition' step in non-PM modelling life cycles.

2. **DESIGN**: selection of the model type and of its main components

- This step takes a close look at the system and subsystems the model will be about. Where are the systems boundaries drawn, i.e. what will be included in the model and what will be intentionally left out? Which assumptions are going to be part of the model? What type of model is this going to be? Is it going to look at interactions, is it going to be descriptive? Is it a mathematical model, will it produce numerical simulations? Will it include different scenarios?
  Here a lot of time and patience could be required to align participants mental models, modellers experience with a diversity of model types, and technical restrictions.
  From a modelling perspective this step can be understood as working out the conceptual model and deciding on its future implementation.

3. **DATA**: provision of knowledge and data that inform the model

- This step assembles, evaluates, and preprocess available knowledge and data from multiple sources. Knowledge and data might come in qualitative and quantitative forms, and a manner of formalization might be needed. Data might be biased and if so it should be decided how to handle this. Data might need to be processed to comply with technical

requirements. Data issues related to uncertainties, traceability, accessibility, privacy, or licensing should be explicitly considered here.

4. **IMPLEMENTATION**: technical implementation of the model, e.g. computer code, and production of model outputs.

- During this step the actual model is built. If the model is a board game, the actual board game is constructed and the game is played. If the model is a conceptual drawing, the sketch is realized by e.g. an graphical artist. If the model is a statistical model, the computer code for the model is written and the parameters are estimated. If the model is a simulation model, simulations are run and the results extracted, etc. for different model types.

5. **INTERPRETATION**: selection of relevant model outputs and their interpretation.

- During this step the results of the model will be discussed. A first step is to agree on the selection of model outputs that are most relevant given the objective identified in the scoping phase. This step includes evaluating both expected and unexpected outcomes, associating the results with the knowledge, expectations, or lived experience of participants and honing in on an aligned interpretation of the outcomes.

6. **EVALUATION**: assessment of the model adequacy for purpose

- This step links back to the scoping and design steps. Have the conditions that define success been met? Can the model results be used for their intended purpose? Did the set system boundaries turn out to be appropriate? Were the input knowledge and data sufficient to inform the model adequately? Should the model be revised in some way? From a modelling perspective this step can be considered part of model evaluation or evaluation (Augusiak et al., 2014)

7. **LEARNING**: lessons learned from the modelling process, for future participatory modelling.

- This step is unique to PM, due to its focus on collaborative learning and promotion of system understanding (Voinov et al., 2018). How was the interaction with participants? How did researchers experience the interaction? How did participants experience it? Were there any features that affected the PM performance (facilitating it or making it difficult)? If applicable, were there ways to present the model outputs (e.g. selected indicators) that work better or worse? If starting the same exercise from scratch, is there something to be done differently?
- From a modelling perspective, this step reflects on creating, retaining and transferring knowledge of the participatory component of the exercise.

Participants

There are no standard methods for choosing the participants of a PM exercise, but conscious consideration of relevant participants at each step of the process can guide this selection.

In addition, initiators of a PM exercise can ask the following questions:

Who knows about the system that will be modelled? Who has experience in the modelling techniques that could plausibly be selected? Who is a potential end-user of the model results? Who might be affected by decisions based on the model results? Is the behaviour of certain human groups included in the model? Is there an existing participatory process that can/does host the PM exercise? Who has sufficient time? Who is willing to participate? Might the inclusion of one group exclude the likelihood that another group will want to participate? Has a particular group already devoted time and energy to another PM exercise? Has any group been usually excluded or particularly "hard-to-reach"?

Levels of engagement

Recognizing that the steps of the PM process are very different in nature, it is expected that the same participants can have different levels of engagement at different steps. For example, some participants may be heavily involved in scoping, interpretation, and learning but much less so in providing data or contributing to model implementation. Conversely, some participants that hold specific expert knowledge may contribute to the data and interpretation steps, but less so to e.g. scoping and design.

We provide below four archetypes of levels of engagement: inform, consult, collaborate, and empower. The level of engagement can be define for each participant and for each modelling step.

1. **INFORM**: participant receives information.

- This level of engagement is one-directional with the participants receiving information about the modelling step, but not contributing to the modelling step otherwise.
- Two examples:
  During the SCOPING step, the participant is informed how the success of the exercised will be judged but s/he is not asked for input on criteria.
  During the DATA step, the participant is informed about which data will be included in the model but s/he is not asked to provide data.

2. **CONSULT**: participant provides input.

- This level of engagement is mainly one-directional with the participant providing input to the respective step of the PM exercise.
- Two examples:
  During the DESIGN step, the participant provides information, knowledge and understanding that can help defining the system boundaries. The participant is not involved in the decision on how this input is used in designing the model.
  During the EVALUATION step, the participant provides an assessment of the models' fitness for purpose, but s/he is not involved in the discussion on a shared perception of the model fitness-for-purpose.

3. **COLLABORATE**: Participant contributes through dialogue.

- This level of engagement is bi-directional with both sides entering into a dialogue of equal standing.
- Two examples:
  During the DESIGN step, the participant shares his/her mental model of a given subsystem. This is discussed among all participants (including modellers that can

provide feedback on technical feasibility) and iterated until a satisfactory path to implementation is jointly developed.
During the INTERPRETATION step, the participant provides expertise for the selection and interpretation of specific model results. This expertise is considered jointly with other expertise (including that of modellers) and valued equally to reach a consensus on model interpretation.

4. **EMPOWER**: Participant drives the step.

- This level of engagement puts the participants in charge.
- Three examples:
  During the IMPLEMENTATION step the participants decide what should be part of the model and how it should be implemented. This is often the case in stakeholder driven group modelling exercises: a causal loop diagram (decided upon as part of the DESIGN step) is built, exclusively to the specifications of the participants and the modellers act merely as technical enablers.
  A participant leads the SCOPING step by chairing the discussion about motivations for model development, expected model use, criteria for model success, etc.
  A participant leads the EVALUATION step by collecting information and coordinating discussions relevant to the evaluation of model fitness-for-purpose. The participant also steers discussions on possible future model revisions.

Reference list

Augusiak, J., Van den Brink, P. J., and Grimm, V. 2014. Merging validation and evaluation of ecological models to 'evaludation': A review of terminology and a practical approach. Ecological Modelling, 280: 117–128.

Voinov, A., Jenni, K., Gray, S., Kolagani, N., Glynn, P. D., Bommel, P., Prell, C., et al. 2018. Tools and methods in participatory modeling: Selecting the right tool for the job. Environmental Modelling & Software, 109: 232–255.

Operational tool: the onion of engagement

The information about engagement is organized along the three dimensions above: what, who, how? This complex information can be compiled into a table with, for example, modelling steps and participants as rows and columns and level of engagement written in each cell. Though this tabulation of the information is complete, it is not particularly intuitive, we therefore promote a graphical representation that is inspired from earlier work on stakeholder engagement and that is likely easier to grasp than a table. It has the added advantage of being able to convey a narrative when presented step by step (as in an animated power point).

This representation is based on a circular mapping of the modelling process combined with multiple layers of engagement. The resulting Figure A3.1 resembling a stylized onion with the radial wedges denoting the seven steps of the PM process and the four concentrical layers indicating the four levels of engagement. By placing each group of participants, either as a text-field or an icon, on the level of engagement for each respective step the overview of the PM exercise is completed.

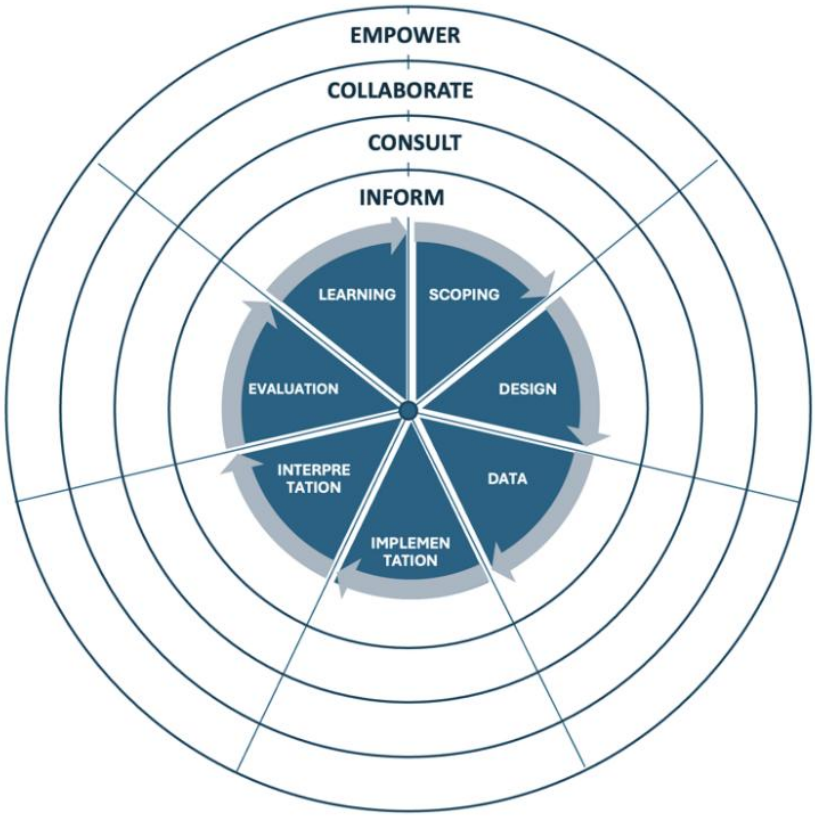

Figure A3.1 The graphical template. The two dimension of the "onion" are: 1) the seven wedges that refer to the seven steps of the participatory modelling process, and 2) the four layers that refer to the four levels of engagement.

Where to find the mapping template?

The link to the onion template can be found at:
https://www.ices.dk/community/groups/Pages/WKParticipatoryModelling.aspx

Example of application:

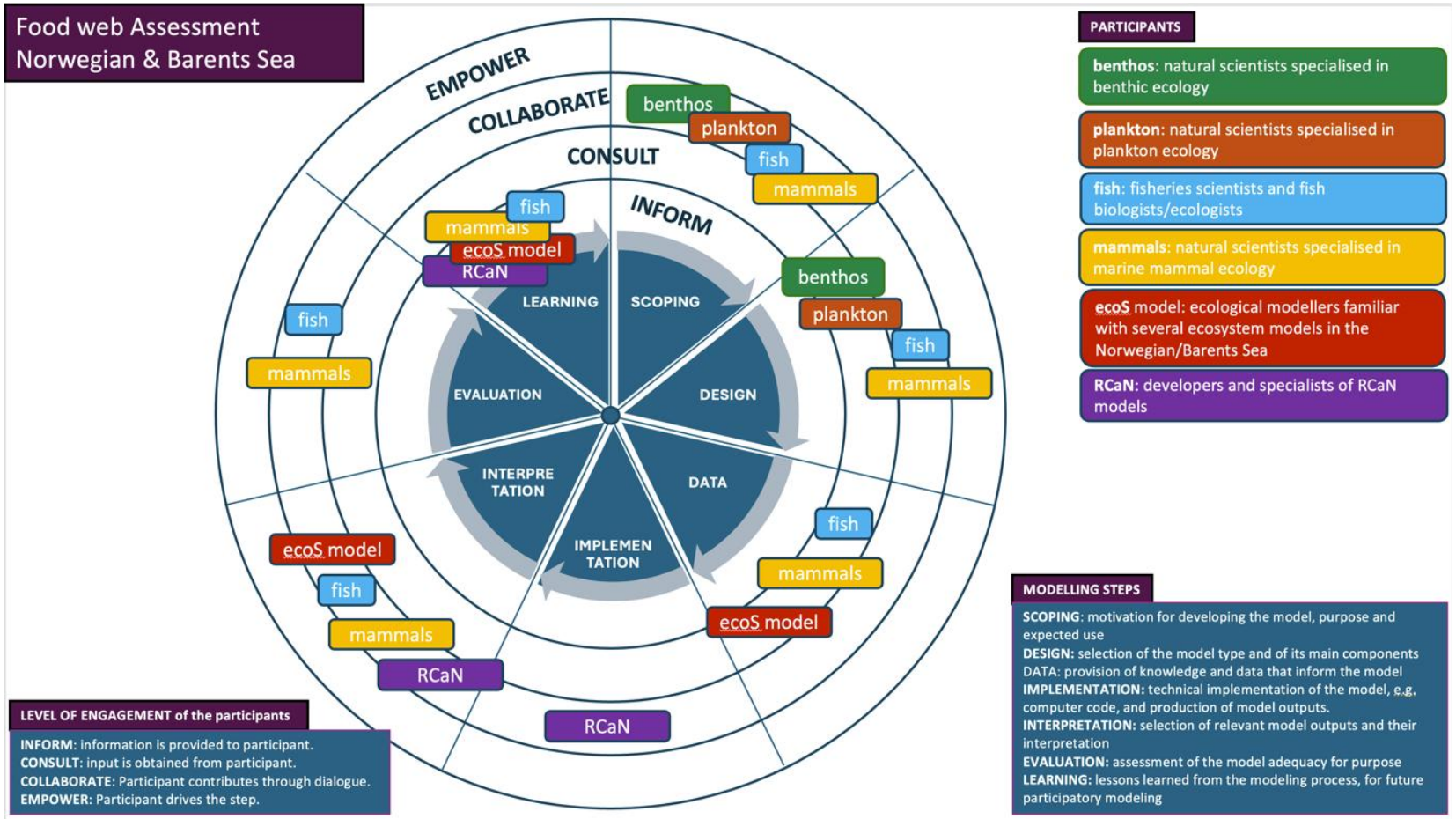

Figure A3.2 An example of mapping for the foodweb assessment model in the Norwegian and Barents Sea. The identified participants are listed on the top-right and identified with specific colours. The level of each participant at each modelling step is represented by the placement of the coloured boxes in the onion. For example: benthos specialists were involved as collaborators in the scoping step and were consulted in the design step but were absent from the PM later on. Fish and marine mammal specialists were involved as collaborators in most steps but did not contribute to the model implementation. The definitions of the levels of engagement and of the modelling steps are reminded in boxes (bottom left and right).