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The added value of participatory modelling in fisheries management – what has been learnt?

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ABSTRACT

How can uncertain fisheries science be linked with good governance processes, thereby increasing fisheries management legitimacy and effectiveness? Reducing the uncertainties around scientific models has long been perceived as the cure of the fisheries management problem. There is however increasing recognition that uncertainty in the numbers will remain. A lack of transparency with respect to these uncertainties can damage the credibility of science. The EU Commission's proposal for a reformed Common Fisheries Policy calls for more self-management for the fishing industry by increasing fishers' involvement in the planning and execution of policies and boosting the role of fishers' organisations. One way of higher transparency and improved participation is to include stakeholders in the modelling process itself. The JAKFISH project (Judgment And Knowledge in Fisheries Involving StakeHolders) invited fisheries stakeholders to participate in the process of framing the management problem, and to give input and evaluate the scientific models that are used to provide fisheries management advice. JAKFISH investigated various tools to assess and communicate uncertainty around fish stock assessments and fisheries management. Here, a synthesis is presented of the participatory work carried out in four European fishery case studies (Western Baltic herring, North Sea Nephrops, Central Baltic Herring and Mediterranean swordfish), focussing on the uncertainty tools used, the stakeholders' responses to these, and the lessons learnt. It is concluded that 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. However, when approaching real-life situations, modelling should not be seen as the priority objective. Rather, the crucial step in a science–stakeholder collaboration is the joint problem framing in an open, transparent way.

1. Introduction

How to link fisheries science with competent and fair governance processes? In EU fisheries management, mathematical and statistical modelling has long been the central analytical method used for producing scientific advice informing the European decision makers. Strong tensions have grown in some fisheries between scientists and industry, in particular around questions of credibility and legitimacy of scientific advice based on the use of such models [1,2]. This credibility crisis has been identified as an

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important issue hampering the Common Fisheries Policy (CFP) to provide biological and economic sustainability (e.g., [3–11].

Uncertainties challenge the 'good' governance in fisheries. Adequate handling and communication of uncertainty in fisheries science is still poorly addressed. Specific approaches or tools dealing with this are emerging, but are still insufficiently formalised, and underperformance in this field contributes to impairing scientific credibility [2,3,5–7,12]. Fisheries science and fisheries management are associated with various forms of uncertainty, which require approaches that go beyond the traditional quantification of uncertain parameters. For example, specific management measures may fail to fit the policy questions [13]. Questions to reflect on include: *Does the scientific method fit the policy problem?* (For example whether a single stock TAC approach is appropriate for a mixed fishery); *Does the choice of assumptions or scientific method potentially favour certain values at stake?* (For example, choosing the assumption of whether a unit of fish comprises one or two stocks may affect the fish and a fisherman in various ways); *What are the sources of uncertainty, and to what extent do they matter?* (A particular uncertainty may be substantial in itself, but may not affect the effectiveness of a particular management measure); *Can the uncertainty be reduced?* (Through data collection, other model approaches or other management approaches); *Do scientists communicate uncertainties in an understandable way?*

Scientists and practitioners in natural resource governance have highlighted the value of and the demand for integrating science and public participation [14, p. 148]. The European Commission (EC) has taken steps in this direction by actively promoting increased stakeholder involvement in fisheries management, for example through the Regional Advisory Councils (RACs). The RACs represent a forum within the CFP, where representatives of the fisheries sector and other interest groups affected by the CFP can be consulted [15]. However, their involvement is indeed mostly restricted to consultation, i.e., providing views on pre-defined management proposals, where scientific advice has already been incorporated [16]. The EC has also supported a number of collaborative research projects (e.g., JAKFISH,[1] EFIMAS,[2] MEFEPO,[3] PRONE,[4] GAP and GAP2[5]), and science–stakeholder partnerships that have investigated ways to effectively and legitimately combine scientific modelling with participatory processes in fisheries governance (Review in [17]) [18,19]. One flexible and innovative concept for combining modelling with stakeholder involvement is participatory modelling [20–22]. It can solicit input from a wide diversity of stakeholders, facilitate creating a shared vision of complex problems among scientific experts, policy-makers and stakeholders, and help to maintain substantial, structured dialogue between these groups [20,23,24], for an overview see [25].

The European FP7 research project JAKFISH (Judgement and Knowledge in Fisheries Involving Stakeholders) has explored tools to address quantitative and qualitative uncertainties in the models used for fisheries management and policy advice within a participatory modelling process with fisheries stakeholders. Participatory modelling is expected to enhance a common and advanced understanding of the current biological, fishery, socio-economic and management issues and their potential risks for stocks and fisheries. The JAKFISH approach to participatory modelling was mainly inspired by the concept of *post-normal science* [26,27]. A policy situation can be considered post-normal when stakes are high and scientific knowledge is uncertain (Fig. 1) [26,28], which often is the case for fisheries. In such situations, one cannot rely on textbook knowledge, and trust that scientists alone will be able to give the answers – because there is not one single answer due to the uncertainties and decision stakes involved. The different types of uncertainties have traditionally been dealt with insufficiently by the science, and some scientists have advocated to bring them to the centre of the policy debate [3,5,7]. A central element of post-normal science is *extended peer review*, where the scientific "peer review community" is extended to include stakeholders [27]. An extended peer review process extends beyond simply ensuring the scientific credibility of results to ensuring the relevance of the results for the policy process. Crucial for an extended peer review is that non-experts understand the implied uncertainties in scientific knowledge so that management actions can take them into account.

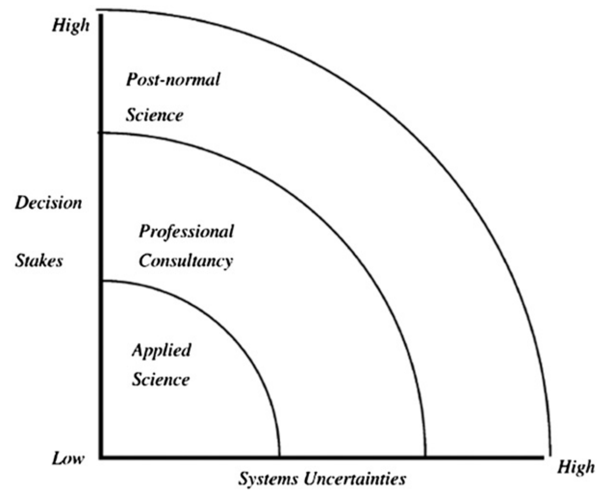

Fig. 1. Problem-solving strategies and the concept of post-normal science (from [27] p. 745).

Practical experience with participatory modelling for natural resource management and marine governance is still limited. JAKFISH explored the potential of participatory modelling in four case studies and in varied and flexible ways. Context and issues differed in each case study, thus representing different situations that can arise within the CFP. This diversity in case studies enabled us to learn about possible options and basic procedural and structural requirements of participatory processes that involve stakeholders in model-related activities.

This paper reviews the participatory processes carried out in the four JAKFISH case studies and synthesizes the achievements, failures and successes. In Section 2, an overview is given of forms of participatory modelling and ways of handling uncertainty. Detailed characteristics of the four JAKFISH case studies and their individual participatory modelling approaches are presented in Section 3. Section 4 reflects upon the lessons learned. The paper concludes with suggestions for the further integration of participatory approaches into fisheries management.

2. The toolbox of participatory modelling and uncertainty handling

The following paragraphs sketch possible forms of participatory modelling and uncertainty handling with relevance for the JAKFISH case studies.

[1] Judgement and Knowledge in Fisheries involving Stakeholders (JAKFISH); EU FP7 project: www.jakfish.eu

[2] Operational Evaluation Tools for Fisheries Management Options (EFIMAS); EU FP6 project (project no.: SSP8-CT-2003-502516): www.efimas.org

[3] Making the European Fisheries Ecosystem Plan Operational (MEFEPO); EU FP7 project: http://www.liv.ac.uk/mefepo/

[4] Precautionary risk methodology in fisheries (PRONE); EU FP7 project: http://ec.europa.eu/research/fp6/ssp/prone_en.htm

[5] Bridging the gap between science, stakeholders and policy (GAP); EU FP7 project: http://www.gap2.eu/

2.1. Forms of participatory modelling

Participatory modelling is an emerging instrument of stakeholder involvement into scientific modelling for the governance of natural resources. It can take place at different stages of the modelling process, spanning from the construction to the actual use of a model [29]. Involvement of stakeholders in the process of model *construction* is referred to as direct stakeholder involvement. Indirect stakeholder involvement covers contributions to the *framing* of the modelling endeavour, model *evaluation* and model *use*. Various sub-forms of indirect involvement are conceivable. Stakeholders can be invited to review the design of the model, a process corresponding to the extended peer review concept. Stakeholders can also be asked to provide input to model use in form of scenarios (in terms of policy or management options), or in form of critical reflections over the causal logic of these inputs. The appropriate stage(s) for stakeholder input in the modelling process need to be identified at an early stage [21]. To stimulate the feeling of ownership and to increase legitimacy and effectiveness, stakeholders should be involved from the very first, the problem-framing, step.

Drakeford et al. [25] and Dreyer et al. [18] carried out a literature review of participatory modelling in natural resource governance. The synopsis of the results of this review offers, in short form, practical implementation assistance to such participatory exercises [29]. Drawing on main analytical distinctions provided by the literature screened, it sets out different purposes envisaged, specifies different modelling phases at which stakeholders could be involved [21], and points out how the timing of participation is linked to the degree to which stakeholders can influence model-based knowledge output. One basic design principle of participatory processes is clarity of purpose for all participants [14, p. 228]. A participatory process should be designed with a clear purpose in mind of both, modelling and deliberation, and sharing this understanding with all participants. Dreyer and Renn [29] highlight four purposes of participatory modelling in the context of natural resource governance [20,22,30–32]: (A) Collective learning for consensus-building and/or conflict reduction; (B) knowledge incorporation and quality control for better management decisions; (C) higher levels of legitimacy of and compliance with management decisions; (D) advancing scientific understanding of potential and implementation requirements of participatory modelling.

In fisheries, so far stakeholders have been involved in modelling activities only sporadically, mainly through research projects (e.g., EFIMAS, PRONE, GAP1), hence, with a focus on purpose D. The JAKFISH literature review found only few cases in Europe where participatory modelling aimed at directly supporting actual decision-making processes [33,34].

2.2. Handling different forms of uncertainty

The characterization of uncertainties is an important element of participatory modelling approaches. Traditional characterizations based on quantifiable uncertainties [35] tend to ignore uncertainties that are not amenable to quantitative analyses. Fisheries science and fisheries management are associated with various forms of uncertainty, which require approaches that go beyond the traditional quantification of uncertain parameters. Walker et al. [36] proposed the 'uncertainty matrix' as a tool to characterise uncertainty in any model-based decision support situation embracing both quantifiable and non-quantifiable uncertainties. The conceptual framework underlying this matrix classifies uncertainty along three dimensions: (1) location (sources of uncertainty), (2) level (whether uncertainty can best be described as statistical uncertainty, scenario uncertainty, or recognised ignorance), and (3) 'nature' (whether uncertainty is primarily due to imperfect knowledge or the inherent variability of the described phenomena). Additionally, three types of uncertainties can be distinguished [26]: inexactness, unreliability, and ignorance: Inexactness denotes quantifiable uncertainties and probabilities with known statistical distributions, therefore also called technical uncertainty. Unreliability represents methodological uncertainties, for example, in cases where a system is understood, but the uncertainty associated with the parameters cannot be precisely quantified (the "known unknowns"). Ignorance or "epistemic uncertainty" refers to unknowable uncertainties, such as indeterminacy (the "unknown unknowns"). These "deeper [epistemic] uncertainties" [37] (p. 2) reside in, for instance, problem framings, expert judgements, and assumed model structures.

Different types of uncertainty require differential treatment in the science–policy interface [5,26,38–43] [44, p. 76]. A review follows of three different approaches, used within the four JAKFISH case studies, to assess the different types of uncertainties.

2.2.1. Frequentist approach

Classical statistics rely on the quantification of technical uncertainties only, i.e., sampling variation of potential new data under the hypothesis that the true state of nature would be known. The frequentist approach to uncertainty is based on the frequency interpretation of probability. In fisheries science, frequentist statistics have been used widely [5], including in the recent developments around Management Strategy Evaluations (MSE) [45–47]. However, they cannot measure epistemic uncertainties about parameters, future events, or inappropriate modelling approaches [2,7,12]. The frequentist approach to assess uncertainty accounts for quantifiable uncertainties only. This approach alone is not appropriate for a complete investigation of uncertainty, but should be complemented by additional investigations.

2.2.2. Bayesian approach

Bayesian statistics offer systematic ways of quantifying and processing both technical and non-technical, epistemic uncertainties. In a Bayesian approach, the uncertainty related to a phenomenon is expressed as a probability distribution and the update of uncertainty in the light of new data is achieved using probability theory as inductive logic [48]. When data is not available, experts can assign probabilities to their uncertain knowledge claims [49,50]. A probability in Bayesian statistics is defined as a degree of belief [51], and current knowledge is represented as a joint probability distribution of all variables. This may also include different model structures, if there are alternative causal hypotheses. The future stock simulations include both: uncertainties in historical parameter estimates and uncertainty due to system variability. Both uncertainty expressions are typically used in fisheries science to learn about population dynamics and status of fish stocks [52–55].

2.2.3. Qualitative tools

Qualitative uncertainty tools, such as mental modelling, questionnaires, uncertainty or pedigree matrixes, offer a structure to systematically describe and classify sources and types of uncertainties. Qualitative descriptions of uncertainties can help to structure a discussion around uncertainties with stakeholders. In mental modelling, stakeholders are asked to list risks, indicate links between processes and quantify (or quasi-quantify) probabilities and hazards. Mental modelling can be combined with Bayesian methods [50,56,57]. Alternatively, questionnaires are useful to map broader sets of uncertainties [42,58]. "Pedigree matrices" [26] have been successfully applied to communicate the soundness of scientific knowledge in science for environmental policy [58–60]. They illustrate the quality of knowledge sources, including data, assumptions, types of models used and effectiveness in fisheries management, by scoring the knowledge quality from low (e.g., for an expert guess) to high quality knowledge. Such scores represent a simple way to assess qualitative uncertainties and indicate potentially problematic areas in a transparent way. Pedigree matrices can indicate how rigid a science-based conclusion is or compare the rigidity of two approaches, sub-models, data sources or parameters.

In the four JAKFISH case studies, all of the uncertainty tools mentioned above were used; not every tool was applied in each case study, though. Details about how the different uncertainty tools were used are presented in the next chapter.

3. Participatory modelling in the four JAKFISH case studies

Although dealing with different stakeholders, fish stocks, fisheries and regions, the four case studies had several characteristics in common: a situation characterised by high uncertainties inherent to the fisheries science and management; different interpretations about the resource situation; and conflicts arising due to the distribution of the fish resources. In three of the four case studies the issue of managing a complex of sub-stocks was critical. There was thus a potential that all case studies could benefit from extra scientific effort and enhanced science–stakeholder collaboration. Furthermore, each case study had to deal with quantitative and qualitative uncertainties, and in particular, to assess epistemic uncertainties. The stakeholders in each of the case studies were invited to evaluate the participatory process and the outcome, i.e., to carry out an extended peer review.

The case studies differed in terms of the foci of the participatory modelling purpose; the starting point of the JAKFISH activities within the broader policy and decision making processes; and the specific design of the participatory process (cf. Table 1). Sections 3.1–3.4 describe the specifics of each of the four case studies in more detail, addressing in particular the rationale for choosing the case study, objectives of the participatory modelling approach, actual form of the participatory modelling, form of handling uncertainty, form of extended peer review, main lessons learned and outlook. For simplicity, the case studies are referred to as the pelagic (Section 3.1), Baltic (Section 3.2), Mediterranean (Section 3.3), and the Nephrops (Section 3.4) case studies.

3.1. *Western Baltic spring spawning herring (pelagic case study)*

Western Baltic spring spawning herring is managed within a complex governance scheme, despite its relatively small stock size and relatively low economic value. Various stocks and sub-stocks of herring co-exist, originating from both the Western Baltic and the North Sea; these different stocks intermingle on fishing grounds, following migration patterns of variable magnitude [61]. One single total allowable catch quota (TAC) is applied on the whole area for this stock mixture and for both industrial and human consumption fisheries; it is shared across the various fisheries units on a sometimes lose basis. Moreover, two different Regional Advisory Councils (the Pelagic RAC and the Baltic Sea RAC) deal with WBSS management advice representing different fisheries in different areas.

The European Commission (EC) officially chose Western Baltic herring as a candidate for the implementation of a long-term management plan (LTMP) [47], together with other pelagic stocks in the Baltic Sea. The development of a LTMP offered potential for simplification; it should provide predictability and stability to all parties. This official development accelerated and framed the participatory modelling process [62], because the EC requested action from scientists and stakeholders.

3.1.1. *The participatory modelling approach in the pelagic case study*

Initially, the main scientific issues were considered the mixing between the North Sea and the Western Baltic herring stocks, the variable selectivity of the fleets and their variable spatial patterns, aiming to build an innovative and integrated modelling framework. The original objectives shifted towards evaluating and communicating the risks and sources of uncertainty linked to the EC initiative to establish a LTMP for this stock. This included (i) creating a common understanding of the process and the implications of simulation-based Management Strategy Evaluation on a single-stock basis, (ii) evaluating a number of alternative management scenarios, and (iii) reaching agreement and commitment on a preferred Harvest Control Rule (HCR).

The main participatory modelling purposes were to improve the knowledge base and quality control and increase legitimacy of and compliance with management decisions (cf. Section 2.1, Table 1). Additionally, participatory modelling contributed to collective learning for consensus-building/conflict reduction and advanced scientific understanding of participatory modelling, even though these were not the primary objectives. The process focused on problem framing, model evaluation and model use.

The level of stakeholder involvement into the modelling was indirect: Scientists and stakeholders jointly selected scenarios and evaluation criteria, which ensured a broad scope and high relevance of the evaluation process (see [62] for a complete description of the process). The process contributed to getting acquainted with each other, understanding the framework and terms of the EC LTMP initiative, the basics of the Management Strategy Evaluation approach and Harvest Control Rules (HCR), and a better common understanding about scientific knowledge, uncertainties and risks. Finally, a HCR consensus was reached among stakeholders, based on latest scientific simulations.

In this case study, the JAKFISH scientists took a pragmatic approach, focussing on achieving the operational objective of recommending a HCR for a future LTMP. Moreover, the flexibility of the participatory process resulted in a common understanding of the possibilities and limitations of the scientific model.

3.1.2. *Forms of handling uncertainty in the pelagic case study*

To quantify "standard" technical uncertainties (inexactness), frequentist uncertainty metrics were used in the modelling, such as error distributions on stock recruitment relationships, on the assessment error and on TAC implementation. This part relates to statistical outcomes of the model, i.e., the source of uncertainty is restricted to the data [62].

To tackle uncertainties relating to unreliability and ignorance, questionnaires, pedigree matrices and a series of science–stakeholder meetings were used to discuss any additional issues that might influence the soundness and the relevance of the scientific input to the policy problem [62, chapter 3]. Three pedigree matrices helped to identify, assess and discuss both quantifiable and non-quantifiable uncertainties: The un/certainty of all data and assumptions used in the models was scored. As a result of applying the various qualitative uncertainty tools, three major uncertainty issues were identified (e.g., lack of trust in the stock assessment outcomes) and possibilities for their future handling discussed. The effect of a fourth uncertainty issue (the effect of cod abundance on natural mortality) was acknowledged, but nonetheless neglected, arguing that scientists were currently not able to quantify this.

Table 1
Overview and schematic synthesis of the participatory modelling approaches in the four JAKFISH case studies.

Case study	Pelagic (Western Baltic spring spawning herring)	Baltic central Basin herring	Mediterranean swordfish	North Sea Nephrops
Main objective	Recommend a harvest control rule for a future long-term management plan	Integrating knowledge of six stakeholders to evaluate drivers of stock dynamics and consequences for management options.	Recommend appropriate management measures	Design a long-term management plan "from scratch"
Purpose of participatory modeling				
(A) Collective learning for consensus-building and/or conflict reduction	xx	xxx	x	x
(B) Broader knowledge base and quality control for better management decisions	xxx	xxx	xxx	xxx
(C) Higher levels of legitimacy of and compliance with management decisions	xxx		x	x
(D) Advancing scientific understanding of potential and practice of PM	x	xxx	x	x
Participatory modelling Type				
Timing	Problem framing, model evaluation and model use	Problem framing, model construction, model evaluation	Problem framing, model evaluation and model use	Problem framing
Level (form of involvement)	Indirect	Indirect/direct	Indirect	Indirect
Type (types of uncertainty)	Review of model assumptions Suggestion on scenarios Suggestion on evaluation criteria	Model design based on stakeholders belief Review of models assumption	Suggestion on scenarios Suggestion on evaluation criteria	
Methodological approach				
for problem framing	Informal/roundtables during meetings	Bayesian influence diagrams	ICCAT scientific documents	Port meetings
for models for management scenarios	Management Strategy Evaluation with FLR	Bayesian metamodel	Management Strategy Evaluation with FLR	Draft documents, FLR
Tools for uncertainty				
Quantifiable uncertainty	Error distributions on stock–recruitment relationship, assessment error, Total Allowable Catch implementation	Integrated Bayesian framework	Error distributions on stock–.recruitment relationship, catch misreporting	
Un-quantifiable uncertainty	Pedigree matrix		Pedigree matrix	(Pedigree matrix)
Feedback obtained	Collective publication/ stakeholder's presentation in closing symposium	Final workshop gathering all 6 stakeholders/ questionnaires	Questionnaires	Stakeholder's presentation in closing symposium
Final outcomes				
Model results	Consensus around one preferred scenario	Successful test of Bayesian model averaging to take into account stakeholder knowledge in stock assessment	Summer closure most appropriate	-
Uptake by stakeholders	Recommendations sent to the EC	Depends on uptake of method by ICES	ICCAT decision	No results to take up
Political role	Yes	No	Yes	?
References	Ulrich et al. [62]	Haapasaari et al. [65], Mäntyniemi et al. [50]	Tserpes et al.[80], Tserpes et al. [79]	

From the scientists' point of view, the pedigree matrices assisted the different scientists to understand each other and facilitated the communication with the stakeholders about scientific uncertainties in an open, transparent way. The pedigree matrixes met the purpose "to reflect the status of knowledge related to the simulations of the long term management plans" [38, p. 28]. To the stakeholders, the matrices' usefulness was less obvious, depending on their prior level of knowledge [62]. For those stakeholders regularly involved in the political process and familiar with ICES advice and the scientific basis, the matrices did not reveal new information. The matrices were acknowledged as "a very useful tool in standard ICES advice" to communicate uncertainty, however, their use would still require a lot of explanation to be understood [62]. In summary, it seems to be a matter of getting familiar with such a visualization tool.

3.1.3. Forms of extended peer review in the pelagic case study

Through questionnaires, JAKFISH enquired the stakeholders' views and reflections on the relevance and quality of the JAKFISH approach, whether JAKFISH has given information on the relevance and quality of the proposed LTMP and covered the stakeholders' concerns and objectives. The questionnaire return was poor, probably because for most stakeholders, the main purpose of the project was to reach consensus around a LTMP, rather than to reflect on a participatory modelling process. Also, stakeholders admitted that they were not fond of filling in questionnaires. Instead, they were eager in writing a collective publication, which was presented at the ICES Annual Science Conference [62]. In general stakeholders appreciated the collaboration that had developed. Some stakeholders attended the final JAKFISH symposium, where they reflected on the process and achievements. They emphasized the necessity to realize and acknowledge that stakeholders' objectives usually differ from scientists' objectives: Their primary aim was to develop a management plan. It was secondary, to learn about the process of participatory modelling and contribute to an improved knowledge base on how best to organise it.

3.1.4. Main lessons learnt and outlook in the pelagic case study

The participatory process lasted one year and most of the time was spent on explanations and discussions (getting acquainted with each other and problem framing). A final consensus was reached on a preferred Harvest Control Rule, which was submitted to the European Commission. Later on, though, it became clear that there were still unresolved political issues around the sharing of the TAC across areas and fleets. This was addressed more specifically during a broader scale ICES workshop [63]. One important lesson learned from the WBSS case study is the need to discuss all potentially conflicting issues, also the politically sensitive ones, early in the process. Mutual comprehension of each other's – possibly diverging – motivations, concerns, wishes and expectations for participation in a modelling exercise is key to a successful collaboration. If scientists consider the discussion of scientific uncertainties important, then effort should be made to reach this mutual comprehension. At the same time, stakeholders should also be open about their expectations from the beginning.

The impact of the collaborative JAKFISH process on the actual management decisions is not yet known. No LTMP has been implemented yet. However, from the perspective of both the involved stakeholders and scientists, the process was perceived to have contributed greatly to the sense of ownership and mutual understanding between scientists and different stakeholders.

3.2. Central Baltic herring (Baltic case study)

According to ICES [61], Central Baltic herring is exploited outside of safe biological limits, suffering from small fish size and decreasing stock biomass. Different well-justified hypotheses exist about the reasons behind this reduced growth and the variable productivity of the stock; these competing hypotheses can lead to totally different management conclusions (e.g., advised increase or decrease of fishing pressure). The Baltic case study aimed at testing alternative probabilistic models and exploring issues around model uncertainty in discussions with stakeholders. Explicitly, the participatory modelling objectives of the Baltic case study were to:

- integrate stakeholders' knowledge into the modelling of Baltic herring population dynamics
- formalise this integration
- explore the consequences of alternative management options based on this knowledge
- examine structural uncertainty related to management of the herring stocks.

3.2.1. The participatory modelling approach in the Baltic case study

Six stakeholders (representing managers, scientists, fishers and environmental NGOs) from four Baltic Sea countries shared their knowledge related to the stock assessment and management of the Central Baltic herring. The stakeholders were treated as experts, and everyone built an own model in a separate workshop, independently of the others.

Six conceptual biological models (graphical causal system models) were built based on assumptions of the individual stakeholders about causalities and factors influencing the natural mortality, growth, and egg survival of the Central Baltic herring. The estimated strengths of the assumed causalities were expressed as probabilities [64]. The six individual stakeholder models were afterwards pooled by the researcher into a large meta-model using the techniques of Bayesian model averaging, and further combined with scientific data [50].

A parallel modelling task aimed at a better framing of the herring fishery management problem. The stakeholders were asked to extend their biological model by including additional factors they considered important for the Central Baltic herring stock assessment, management objectives, and measures to reach these objectives [65]. The logic of Bayesian influence diagrams [64] was used to build a qualitative graphical model on herring fishery management with each stakeholder.

The stakeholders participated in two workshops. The first was arranged for each stakeholder separately, to build the model independently of the others. The second took place at the end of the project, to present the analysed models to all stakeholders together, to discuss them, and to get systematic feedback.

3.2.2. Form of handling uncertainty in the Baltic case study

The Baltic case study focused mainly on structural uncertainties, i.e., the basic ignorance about the nature of a complex system, by acknowledging that there are alternative beliefs about the components, dynamics, and inherent internal interactions in the fishery [66]. A Bayesian approach [67,68] was used to structure and pool the views of the stakeholders on the relevant causalities and their estimated strengths. The Bayesian approach produced (1) graphical models to explore and communicate structural uncertainty, and (2) probabilistic information that explicitly quantified the uncertainties. The approach could be called a graphical "risk register", illustrating how a large proportion of uncertainties, risks and stakeholders' concerns can be covered by the current scientific activities.

3.2.3. Form of extended peer review in the Baltic case study

Two questionnaires were distributed to the six stakeholders in order to collect feedback: the first one after the completion of the modelling work, and the second one after the final workshop. All stakeholders participated in the final meeting, and all returned carefully filled in feedback forms. The purpose of the first questionnaire was to learn how the stakeholders felt about the participatory modelling exercise, and what kind of benefits or disadvantages they saw in this approach. The second questionnaire was to enquire about the Central Baltic herring fishery in general, the continued process, and the results.

3.2.4. Main lessons learnt and outlook in the Baltic case study

The Bayesian modelling facilitated discussion and structuring of the complex issues around Central Baltic herring, and it enabled an explicit treatment of uncertainty. The participatory exercise revealed diverging views of different stakeholders about factors influencing the population dynamics of the herring. Despite this disagreement on influencing factors, there can be agreement about management actions. The approach is valuable to analyse and illustrate consequences for management advice of different management objectives and different assumptions about system dynamics.

Formulating the stakeholder views as a mixture of multivariate normal distributions simplified the modelling task and increased the possibility of taking the stakeholder views into account in practice. However, such a simplification naturally reduced the chance to account for relationships that are difficult to linearize by using simple transformations. It is also worth noting that the approach used here results in a mixture of stakeholder views and the views of the analyst. The variables to be used and statements about their relationships come from the stakeholders but the rest of the structure depends on the analyst. This balance could be changed by increasing the time to be used for interviewing the stakeholders. The interviews for the three parameters of interest lasted from two to four hours in total. In some cases it was evident that the interviewee got tired of thinking, especially about the uncertainty in the effect strength, towards the end of the interview. This suggests that if priors for means and variances would be asked from the stakeholders, the interview should be divided to multiple sessions.

The interview process was challenging for the interviewer. Some of the stakeholders picked up the idea of graphical modelling very quickly and gave direct instructions on how to draw the graph. However, some stakeholders preferred to talk about the subject without using the language of graphical modelling, which then required that the interviewer expressed the spoken information as a graphical model. Consequently, the interviewer then posed more elaborate questions about the subject and had to back-translate the resulting graphical model to ensure that it represents the views of the stakeholder. Successful widespread use of the interview methods probably requires more methodological research and a training programme for the interviewers.

Concluding from the feedback questionnaires (extended peer review), the six stakeholders saw several benefits in the participatory modelling approach, highlighting the potential of the approach to

– improve stock assessments and management by enabling to account for factors that have not necessarily been taken into accounted in other assessment methodologies
– help people understand and commit to management
– integrate different objectives and analyse trade-offs among them
– demonstrate and raise awareness of the complexity of fisheries systems
– make explicit and enable combination of different views, expertise and priorities
– facilitate communication, cooperation, understanding and consensus between stakeholders.

Challenges or pitfalls that the stakeholders saw in the approach relate to

– the subjective approach of the Bayesian method
– the small sample size and definition of "minimum" necessary input
– "calibration" of the models against the historical catch data, which can be flawed to an unknown extent
– complexity and slowness of the method for practical use
– avoidance of "noise" coming from the involvement of too many factors
– lack of knowledge of individual stakeholders and a need to prepare for the modelling.

Some of the challenges pinpointed by the stakeholders indicate that properties of the Bayesian reasoning and purpose of the modelling may not have been understood correctly. References to small sample sizes and noise from inclusion of too many factors reveal that the Bayesian approach was assumed to work in the same way as classical statistics. Seeing the subjectivity of the method as a challenge in participatory modelling is surprising, since it is the inherent subjectivity of the knowledge that is the motivation for any participatory modelling. If there existed an objective way to make inductive inference, knowledge of experts of any kind would not be relevant.

Future impact of the work achieved depends on whether the ICES working group dealing with Baltic herring stock assessment is willing to take the ideas and results into account.

3.3. Mediterranean swordfish (Mediterranean case study)

The Mediterranean swordfish stock is considered to be overexploited; current spawning stock biomass levels are $>40\%$ lower than those that would support maximum sustainable yield [69]. The biological and management situation is complex: Mediterranean swordfish is assessed as a single stock but there are indications that it consists of several independent sub-stocks with unknown rate of mixing. The stock–recruitment relationship is not well defined; catch misreporting of undersized fish is considered to be a problem; and there is a large amount (50–70%) of juveniles in the catches [70]. The exploitation pattern of swordfish fisheries is complex and difficult to manage, with several small- and medium scale fisheries from various EU and Non-EU Mediterranean countries.

The International Commission for the Conservation of Atlantic Tunas (ICCAT, the relevant management authority) asked for an evaluation of the impact of different recovery measures, such as temporary closures, effort control (e.g., capacity reduction) and quota management schemes. ICCAT and various EU groups have discussed the potential application of various management measures. Several Mediterranean countries have imposed specific technical measures aiming to improve the stock exploitation pattern and ICCAT has established seasonal fishery closures. Nonetheless, there is a lack of a harmonised management plan that would support stock recovery, resulting in various conflicts among the different fishing fleets.

The objective of the Mediterranean case study was to develop and evaluate management scenarios (including bio-economic modelling) for the Mediterranean swordfish, based on the recommendations of ICCAT and interactions with Greek stakeholders. The case study investigated options of an operational management system for this particular situation where scientific knowledge is relatively poor, various stake conflicts exist, and harmonised management practices are generally lacking.

3.3.1. The participatory modelling approach in the Mediterranean case study

Different management scenarios were developed and evaluated using simulations. ICCAT was considered the main stakeholder, particularly the ICCAT Scientific Commission. Apart from ICCAT, fishers and local managers in Greece were involved in a series of interactive meetings to discuss scenario objectives, uncertainties and discuss results.

Preliminary results of management strategy evaluations were presented and discussed in four ICCAT Scientific Commission meetings. Additionally, popularized presentations were given in three meetings with fishers. The feedback from both types of meetings facilitated the final development of scenarios, the incorporation of uncertainties and the definition of risks.

3.3.2. Form of handling uncertainty in the Mediterranean case study

Management scenarios addressed uncertainties of biological parameters (assessment estimates and stock/recruitment models), fishery data (catch misreporting), and implementation of management measures. Through a risk analysis the danger of stock collapse within 4–5 generations (about 15–20 years) was assessed. Scientists filled three pedigree matrices to schematically reflect the state of knowledge and uncertainties about the stock and the fisheries. One matrix focused on the status of knowledge concerning biological parameters, the second one on data, the third one on fisheries related aspects (e.g., regulations, compliance, bycatch). The matrices were presented to stakeholders (ICCAT, fisher groups and local managers) at intermediate meetings, i.e., they served as a tool to discuss uncertainties. Stakeholders suggested minor changes that were incorporated in the final versions of the matrices. Scenario projections and risk analysis estimates were included in the latest report of the ICCAT Scientific Commission and utilized for drawing management recommendations [69].

A few questions concerning uncertainties were raised by fishers that were not incorporated in the evaluation models, such as effects of climate change on fish migration routes. The lack of relevant scientific knowledge did not allow the identification of meaningful assumptions or even speculations about those uncertainties.

3.3.3. Form of extended peer review in the Mediterranean case study

The ICCAT stakeholders involved assessed the participatory approach and the contribution of the project to scenario evaluations by filling in questionnaires. Fishers and local managers received a slightly modified version of the original questionnaire: questions dealing with technical specifications of the models were omitted. Also, one questionnaire was prepared and distributed to the stakeholders after the completion of the modelling work (management scenario evaluations) asking them to review and evaluate the accomplished work.

3.3.4. Main lessons learnt and outlook in the Mediterranean case study

The timing of the JAKFISH process fitted well in the formal ICCAT process: At about the time the JAKFISH project started, the ICCAT Scientific Committee had pointed out the necessity for the establishment of a long-term management plan for the Mediterranean swordfish stock. When collaboration was agreed, the Scientific Committee provided a general outline of the management scenarios that should be evaluated in the JAKFISH process. This facilitated a quick, focused and pragmatic start of the case study in terms of model selection tools and model building. Uncertainties and risks were defined at a later stage during the process. The regular time frame of ICCAT specific species-group meetings facilitated the presentation and discussion of intermediate results and consequently the overall planning of the JAKFISH work.

Fishers raised questions about certain epistemic uncertainties that were not considered in the existing evaluation models due to lack of relevant scientific knowledge. Hence, the case study did not zoom in on those uncertainties raised by the stakeholders, and one could argue that in this respect the science did not entirely follow a "post-normal" approach, which would have meant to focus on a different problem framing. Instead, the case study stuck to its foreseen modelling approach, producing various management strategy simulations. This suggests that there is always the possibility that stakeholders can raise questions that cannot be addressed – independently of the modelling tools used.

Through the participatory modelling process, ICCAT member states reached consensus on one specific technical measure (seasonal closure). This method emerged as having an evident link with the biology of the stock, and it was felt that it could be agreed on between the different countries and enforced over all fishing sectors. The model simulations indicate that it can lead to stock recovery.

3.4. North Sea Nephrops (Nephrops case study)

The Nephrops case study was chosen based on two major issues: (1) differing objectives of stakeholders, and (2) high uncertainties in the science/scientific advice.

1. The Nephrops sub-group of the North Sea RAC were in the process of drafting a long term management plan (LTMP) for the fishery, which could subsequently assist in efforts to gain accreditation from the Marine Stewardship Council (MSC), whose "pre-assessment" process had highlighted the need for a formal management plan). However, the different fishery stakeholders have been struggling with agreeing on objectives for the fishery. Discussion about potential future structures of the fleet resulted in the final consensus that the plan should not seek to determine a particular structure, but rather that the current fleet structure was satisfactory and should be allowed to evolve naturally.
   The different stakeholders have different views and objectives:
   - Small coastal fishers: Prevent competition with bigger boats in "their" coastal Nephrops fishing grounds. Keep current employment level.
   - Larger more offshore fishers: Ensure high profits by keeping the spatial fishing flexibility, i.e., keep whole area Total allowable catch (TAC) instead of introducing TACs per functional unit.
   - Policy makers, managers: Quickly implement a LTMP and ensure sustainable fisheries.
   - Scientists: Improve the modelling structure by including spatial dynamics, fleet dynamics and size-based population dynamics.
2. There are large uncertainties in the science and management [71]. Management advice by ICES is provided at the level of eight functional units (FUs; areas with suitable grounds for Nephrops in the North Sea) though management is applied through a single area TAC. Also, there are diverse fleet segments (eight nationalities, different gears) that can move freely between the FUs. This flexibility in fishing pattern was considered essential for operational reasons by the fishing industry but it concerned scientists as the system did not offer protection from overfishing to the separate stock units.

Hence, there was potential for JAKFISH to help the stakeholders finding common objectives and move forward with improving the LTMP draft. And there was the scientific challenge to work on something new, a size based population and fleet dynamics model. The original objective of the Nephrops case study had been to improve the Nephrops stock assessment modelling, such that the management and a future LTMP could be based on better scientific results. The original main purposes of the PM approach were thus:

A. Collective learning for consensus-building and conflict reduction.
B. To improve the knowledge base and quality control for better management decisions

Initially, specific scientific goals had been listed relating to a spatial framework for TAC setting, rules for effort distribution, fleet structure, and management schemes to be tested. The scientists perceived the biggest challenge in the FLR programming [72], namely to simultaneously use several dimensions (time, length, sex, area), to solve the ''age and length'' modelling dilemma, to produce alternative growth models for crustaceans, and to establish a link between fishing mortality and effort for gear types.

3.4.1. The participatory modelling approach in the Nephrops case study

The Nephrops case study had a very slow and difficult start. Neither stakeholders nor scientists knew what could be expected from each other, and in particular the scientists felt stuck not knowing what the stakeholders wanted to be evaluated and modelled. In addition, major staff changes at one scientific institute and inadequate internal communication led to delays and misunderstanding. As a result, stakeholders and scientists have not managed to fully engage around model development, and the case study failed to establish a structured work plan early in the project. Only at a late stage in the project did the case study start to actively engage in problem framing with the stakeholders. These were RAC representatives as well as grass rooted fishers. Triggered by the Nephrops sub-group of the North Sea RAC and co-funded by the JAKFISH project, stakeholders organised meetings in various ports to set out clear objectives and a range of management options, and aiming at a management plan that would have industry ''buy in''. Those meetings enhanced the understanding of the main issues and requirements to account for in the future management plan. The JAKFISH scientific input to these discussions focused on technical modelling challenges and mapping out uncertainties.

3.4.2. Form of handling uncertainty in the Nephrops case study

The JAKFISH scientists prepared pedigree matrices for North Sea Nephrops to reflect on three areas of concern: the status of knowledge concerning (1) biological parameters, (2) the data, and (3) fisheries related aspects (e.g., regulations, compliance, bycatch). In the end, the pedigree matrices were not used in discussions with stakeholders; timing was considered to be too early in the process because of the internal disagreements among the stakeholder groups. Nonetheless, filling the matrices had helped the scientists with mapping uncertainties in a structured way and facilitated the communication among the scientists.

3.4.3. Form of extended peer review in the Nephrops case study

As the participatory work had mainly been driven by the stakeholders themselves, the extended peer review was not carried out using a questionnaire. Instead, two of the main RAC-stakeholders presented their impressions and reflections of the collaborative work in the JAKFISH final symposium.

3.4.4. Main lessons learnt and outlook in the Nephrops case study

The Nephrops case study is an example of lack of communication and mutual understanding between scientists and stakeholders. Comparing the extended peer review with reflections of JAKFISH Nephrops scientists, there had been different perceptions about the work progress: From a JAKFISH perspective, the case study experienced significant delays and problems, which affected negatively the project outcomes. The case study did not progress in terms of the scientific goals and the expected FLR development. From the stakeholders' perspective, the evaluation proved much more positive: e.g., ''Almost all the fishers believed that it was right to protect the stocks via long term management plans'', and ''Importantly – Fishers felt they had been listened to'' [73]. The main lessons learnt therefore relate to ways of problem framing, communication, education, and planning.

Mutual problem framing in an open, transparent, truthful and flexible way is crucial in a participatory modelling process to identify the real stakes, problems, and needs. Internal conflicts, e.g., between different stakeholder groups (here: small coastal versus larger offshore fleets) can block a collaborative process [74]. Hanssen et al. [74] suggest that science should focus on reducing societal dissent in complex unstructured situations where scientific uncertainties abound and different interests play a role. In the Nephrops case study, focussing on the ''facilitation'' strategy from the beginning could have been more rewarding, i.e., instead of continuing with a poorly defined participatory modelling goal, scientists should focus on resolving the societal conflict first, keeping in mind that consensus is not always possible in international settings with several stakeholder groups in different countries. It is concluded that one should only start modelling, once the need to model has been stated and a goal for modelling has been identified. In the Nephrops case study, it appears that initially, the JAKFISH scientists had perceived the modelling as too much centre-stage, and participation was secondary.

Mutual trust benefits from open and transparent communication. The historical relationship between fisheries and science has left some legacies of mistrust amongst parties. The ability to overcome these is crucial to the success of mutual problem framing. The Nephrops sub-group of the NS RAC comprises a majority of fisheries representatives who have interacted with policy and science for many years. There was a general good rapport between all parties. However, when discussing the LTMP also with other stakeholders (e.g., fishers directly) there was a general mistrust of both fisheries science and fisheries management. Time is required to develop a common language, thus fostering mutual understanding. Moreover, all parties need to develop an understanding of each other's viewpoints and stakes.

Mutual education from all sides is often necessary to create a common knowledge basis and understanding of what is required/possible/desirable. One-way education (e.g., scientists ''teaching'' the stakeholders) should be avoided. Rather, all parties need to be open to learn from each other. This will help to jointly develop a realistic view of goals: What can be done? In the Nephrops case study, the initial scientific modelling goals had been too ambitious and not realistic. The toolbox, proposed by the scientists, was not suitable, and time was wasted unsuccessfully trying to modify the model to suit the situation. The stakeholders were unsure what modelling questions could be asked. Hence, an iterative process of balancing requirement with practicality was not reached.

Timing and planning of meetings is crucial and it is interlinked with commitment. Time available for Nephrops meetings was limited, both for scientists and stakeholders; hence, agreeing on mutually convenient meeting opportunities proved problematic. Additionally, commitment might have been lacking, as JAKFISH had not been able to fully engage in the process of developing the Nephrops LTMP. The JAKFISH process was not a driving force but rather seen as an adjunct to the NS RAC process, and therefore had limited influence.

In conclusion, the Nephrops case study's participatory approach has dealt with the problem framing stage, but only at a late stage in the JAKFISH project. The actual participatory modelling (as carried out in the pelagic or Mediterranean case studies) could be a next logical step.

4. Discussion

The four case studies followed individual approaches, developed along different paths and had different successes (cf. Table 1), but all served – to different degrees – the four purposes of participatory modelling as identified by Dreyer and Renn [29] (cf. Section 2.1). Referring to the practical implementation assistance to participatory modelling again [29], here the lessons learnt from the four case study experiments/experiences are synthesised and the usefulness of participatory modelling in general discussed. Has the participatory modelling approach itself contributed to the successes and/failures? The following practices, relating to participatory process design [29], are reflected and expanded upon: purpose/objectives, timing, model complexity, knowledge integration, communication tools and user friendliness.

4.1. Purpose – Diverging objectives

Concluding from the JAKFISH scientists' experiences and the stakeholders' feedback received through the extended peer review, the stakeholders' purposes of participating in modelling are likely to diverge from purely scientific objectives [75]. Stakeholders have an agenda, and at the same time, scientists have scientific agendas or at least personal scientific ambitions. This dilemma of possibly diverging objectives should be realized and clearly acknowledged. Scientists need to be flexible with their methods and willing to apply non-traditional approaches in post-normal situations, otherwise applied sciences might not target the real problem and thus fail to help solve real-world problems. Also, collaborative projects should be integrated with broader political and societal processes or agendas. This can prevent "stakeholder fatigue" in future collaborative projects. After all, the ultimate aim of collaboration and participatory modelling is to help solve a real world problem.

The pelagic and Mediterranean case studies were exemplary in terms of aligning the participatory modelling work into the "real world" processes. Apart from the JAKFISH project's scientific objective to learn about participatory modelling, both case studies linked up with official processes of developing LTMPs. They simulated and helped develop realistic management scenarios, which were supported by stakeholders. This is expected to increase legitimacy and stakeholder compliance [65]. The case studies' objectives had been discussed in meetings with key stakeholders prior to or at the start of the project, and the stakeholders had thus been involved from the very beginning.

The Baltic case study was very transparent in stating its purpose, which was mostly academic: studying and modelling different stakeholder views of herring population dynamics. The timing and level of stakeholder involvement had been carefully planned well ahead of the beginning of the study, and the process followed the original work plan. Stakeholders were well informed and did not develop unrealistic expectations that the study would serve their own needs. However, at the end of the JAKFISH project, the stakeholders are left with the suspense of what will happen with the results. Already during the process they raised their concerns over the practicalities of incorporating such an approach into management structures. It would be desirable that the results influence management actions in the future. It was clear from the beginning, though, that such goals are outside of the scope and power of the case study.

At the start of the Nephrops case study, scientists and stakeholders had completely different agendas in mind, and a clear work purpose was lacking. It could have been much more time- and effort efficient to follow a "facilitation" strategy [74] to reduce societal dissent from the very beginning, instead of attempting to achieve a purely scientific modelling goal. Ultimately, the time allocated for the participatory modelling was mainly used for improving communication to clarify the situation and establish long-term goals instead of dedicated modelling.

4.2. Be aware of the timing and time frame

Literature studies pointed out the importance of early stakeholder involvement – preferably during the initial, problem framing stage, in order to achieve the purpose of increasing legitimacy of and compliance with management measures (cf. Section 2.1) [29]. The four JAKFISH case study experiences confirm that early stakeholder involvement becomes a necessity, i.e., this requirement is now based on empirical observations, and not on value judgments anymore.

All case studies pointed clearly to the problem of time and timing, and, as a direct consequence of this, to the problem of financial resources to sustain this time. Participatory modelling implies by essence working with a group of people with different background and knowledge. As such, the process confronts the participants with the steps of forming (get to know each other), storming (frame the problem, express ideas, map conflicts and misunderstandings etc.) and norming (develop common understanding and agree on main objectives) before it can reach the performing step, i.e., the modelling phase itself [76,77]. Depending on the context, the starting point and the persons involved, the initial phases of getting acquainted can be very time-demanding. In most cases, this time is hardly reducible, as it also covers the time for deliberation and maturation of the issues being discussed. There is therefore an evident risk of failure if the time is not carefully monitored, as illustrated – unintentionally – by the Nephrops case study. Only towards the end of the project, people finally got acquainted and progress was achieved in terms of problem framing, but no time was left for the participatory modelling itself.

A factor that helps steering time and ensuring that concrete and timely achievements are produced is the inclusion of the participatory modelling process within broader political and scientific agendas, such as in the pelagic and Mediterranean cases. Regular milestones and political requests for advice were set up externally by ICES/ICCAT, respectively. This enforced the scientists and stakeholders to keep on track and deliver operational outcomes – and not least – maintain stakeholders' motivation and commitment to the participatory modelling project at a high level.

4.3. Model complexity

Participatory modelling techniques in fisheries are considered as a way forward in developing transparent procedures for generating and using knowledge, in a process which usually appears as a large black box. However, computer-based models are becoming increasingly large and complex. The quest for more holistic, integrated approaches, which account better for uncertainties, conflicts with the quest for greater transparency.

The four JAKFISH case studies illustrate different ways of handling this conflict. The pelagic and Mediterranean case studies used a fairly standardised management strategy evaluation approach, based on single-stock projections with available stock assessment data; in these cases the assumptions and issues hidden in the models could be explained in simple terms, because the problem was framed to fit such standard approaches. Although the scientists did not address every single issue that the stakeholders brought up, the discussions were open and flexible. The scientists enriched their expertise with additional, new and innovative research questions. The Nephrops and Baltic cases represent situations, where standard modelling approaches are not suited, requiring new, non-standard approaches; both cases focused on comprehensive and time-consuming model development. In the Nephrops case study, the scientists focused on developing an innovative model that fits the specifics of Nephrops biology, population and fleet dynamics, but the model has not been useful so far in the participatory process with the involved stakeholders. In the Baltic case study, the participatory model development had been the explicit objective. Ultimately, such an innovative, integrative model could be used for operational management advice. Despite direct stakeholder participation in model construction, here, science partly pre-framed the problem by pre-defining a core-model structure (around herring growth).

In all four case studies, scientists had invited stakeholders to participate in framing the research questions. An open invitation to participate and communicate with each other seems to be essential for jointly framing the problem and the research question. This should involve the willingness of all participants to reframe the issue at stake dependent on the inputs of other participants. Structural issues around model complexity can confine participatory modelling to stick to rather standard modelling approaches. A participatory approach inspired by post-normal science is not about answering to all (unanswerable) questions. The key is to jointly reflect on and identify knowledge gaps that matter in the real world, taking into account an achievable, realistic time frame.

4.4. Integrating different forms of knowledge

Participatory modelling is sometimes expected to "integrate all types of knowledge (empirical, technical and scientific) from a variety of disciplines and sources" [22]. The incorporation of experiential, local, indigenous, and folklore knowledge and the accumulated expertise of practitioners is considered necessary to take account of the specific features around a particular problem, in particular in "post-normal" situations [27,76]. However, practical implementation is difficult. The Investinfish South West project [34] faced methodological difficulties when trying to integrate stakeholders' non-scientific knowledge into a bioeconomic model at the model development stage [78]. The Baltic case study pushed forward this exercise of knowledge integration successfully, developing formalized approaches (mental modelling and conditioning of stakeholder-models on various sources of available data [50]). The approach could theoretically be applied to any other situations. However, the costs in terms of scientific time and skills are high. Also, the low number of stakeholders included (only six) decreases the level of commitment to the results among all stakeholders. Each of the stakeholders had a different conception/perspective, implying that more stakeholders would likely mean more complexity to be added. However, in this case the ultimate conclusion from the model averaging in terms of selecting appropriate management policies was little sensitive to this inclusion of stakeholders' knowledge. This was mainly caused by the fact that the participatory modelling considered different views about the biological processes but not the different views about how the fishery data should be interpreted. It was evident from the stakeholder feedback that extending the modelling to cover these aspects would have led to more diverging management views.

More pragmatically, in the pelagic and Mediterranean case studies, the main differences in perception among stakeholders and scientists were not accounted for as structural uncertainty (as in the Baltic example), but rather as irreducible sources of uncertainties. These were translated into large confidence intervals around the corresponding biological parameters in the simulation models. As a consequence, lower fishing mortality targets were required to maintain pre-agreed stock levels with a certain probability than if no uncertainty was considered [62,79,80]. These approaches brought probabilities and risks about biological issues at the heart of the modelling and management discussions.

4.5. Communication tools and user-friendliness

Van der Sluijs [28,81] evaluated that the usefulness of complex computer-based models was rated higher by non-scientific stakeholders if, among others, the following information and communication tools were used: (i) a comprehensible and detailed user manual; (ii) an understandable model presentation; (iii) an interactive and attractive user interface; (iv) a comprehensible account of uncertainties; and (v) an adequate model moderation. This checklist seems appropriate if the stakeholders are expected to be directly involved in the model use, i.e., if part of the purpose is capacity-building and training in the understanding of scientific modelling. However, none of our four cases provided all of these five requirements. In particular, points (i) and (iii) were not focused on. The stakeholders did not use the models themselves in any of the cases. All communication processes were articulated around points (ii), (iv) and (v).

Good examples of the development of user-friendly interfaces for non-technical (expert) users are models such as Investinfish South West [34], TEMAS [82,83] or ISIS-Fish [84]. However, stakeholders have not used these models on their own, often due to lack of time and capacity. Instead, in reality, stakeholders would more likely ask the scientists to provide the answers to their requests. The usefulness of an interactive and attractive user interface (iii) will increase, if it is tailored to the potential user group and their needs. If many scenarios and hypotheses are to be explored, it seems more adequate to have a model interface targeted at scientists rather than stakeholders, i.e., it should be flexible, generic, compute fast, and generate synthetic and clear output. A model interface with buttons, menus, etc. obliges the modelling to follow some fixed and pre-defined lines set up by the original model developer, and this may come at costs in terms of flexibility to address new thoughts and ideas, and may create parameterization issues if data is lacking to fit the model frame [82].

Three out of our four cases (pelagic, Mediterranean, Nephrops) made use of the FLR modelling framework [72]. Based on the R freeware (R development Core Team 2010), this framework is far from what could be considered a user-friendly interface, and requires advanced technical skills and an initial steep learning curve. However, its modular "Lego blocks" approach, where various small pieces of standard code can be put together by individual modelers within a loose modelling framework, has proven to be flexible and efficient to address widely different questions (cf. e.g., tutorials and publications list on www.flr-project.org). JAKFISH scientists also tested other types of communication tools, developing innovative types of graphs and figures to describe the results and their uncertainties (e.g., Bayesian influence diagrams), and using clear model description tools such as the pedigree matrices. The Baltic case study built on an integrated Bayesian framework, which did include an interactive and attractive interface (Hugin) for the initial conceptual phase of mental modelling [85]. For this particular purpose, the interface proved appropriate and appreciated. Despite its attractiveness, the interface was not operated by the stakeholders themselves but served only to support the discussion around model development.

In summary, there are many ways to communicate around modelling issues within a participatory modelling process; different tools have emerged. It is recommended to follow guidelines, or formalized approaches, to facilitate a structured dialogue, because a functioning communication between modelers and stakeholders is important. Although being time-consuming and beyond the traditional scientific tasks, functioning communication constitutes an absolute requirement for successful participatory modelling.

5. Conclusion

So far, participatory modelling is a relatively new approach in European natural resource governance with only few exercises that have been carried out. It is foremost an object of research, not an approved method. The four JAKFISH case studies shed light on possible ways, their pros and cons to put the concept into practice. A variety of types, forms and tools of participatory modelling were identified and tested in case studies over a one to three year time frame. Thanks to the available project funds and scientific working time, the case studies could maturate and develop within their own context. Some stakeholders had only limited time available. It is likely that lack of time and money limits any operational version of the participatory modelling methodologies.

A synthetic summary of the participatory modelling endeavours within each of the four case studies is given in Table 1. The precise details of how the uncertainties were addressed varied by case study, but in all cases extensive discussions between scientists and RAC/ICCAT stakeholders were found to be an important precursor to creating the atmosphere of goodwill required to openly address the uncertainties in a participatory, transparent, clear and understandable manner. Globally, the pelagic and the Mediterranean case studies turned out to develop along fairly similar, pragmatic tracks and are largely comparable, while both the Baltic and the Nephrops cases followed their own paths. The models used (standard as well as the non-standard approaches) were open for modifications based on stakeholder input; each model contained some core elements, though, that had been preframed by scientists only.

A final reflection about successes and failures based on our participatory modelling experiences: Transparent two-way communication (involving respectful listening) is considered a key factor for an effective extended peer review process where scientists and stakeholders acknowledge uncertainties, mutually reflect on knowledge gaps that may really matter, and take into account a realistic time frame. As already pointed out by Kraak et al. [7] and others [3,74,76,86–89], the authors believe that the best way to reach sustainability is to ensure stakeholders' participation in the process. This requires time, trust, transparency and efficient steering. To conclude, 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 contribute to collective learning, increase legitimacy, and advance scientific understanding. However, when approaching real life problems, modelling should not be seen as the priority objective. Rather, the crucial step in a science–stakeholder collaboration is the joint problem framing in an open, transparent way, in order to ensure that scientists tackle the relevant problems. Where people communicate with each other, it improves people's ability to understand each other.

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