Report of the MEESO modelling workshop held on 21 June 2022

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Ecologically and Economically Sustainable Mesopelagic Fisheries

Date
September 2023

Acknowledgements
The authors gratefully acknowledge all the helpful input from the workshop participants.

This report and the described workshop have been financed by the EU H2020 MEESO Project "Ecologically and Economically Sustainable Mesopelagic Fisheries" Grant Agreement No. 817669.

Contents

1. Introduction

As a follow up of the two stakeholder meetings that were held in MEESO (March and September 2021), a third workshop was organised on Tuesday 21 June 2022. The goal of the workshop was to discuss whether the expected outcomes of the models addressed the concerns of the stakeholders expressed by the stakeholders in the previous two workshops. Modellers in MEESO were invited to the workshop, whom came from Wageningen University and Research, World Maritime University, DTU Aqua, MI, AZTI and the University of Strathclyde. And a diverse group of stakeholders were invited to the workshop, coming from industry, policy, NGOs and science, and whom had been invited to the previous 2 workshops. We were curious to know whether science, by taking the approach outlined, would answer to the right questions according to these stakeholders: will they address the major concerns, and if not, what is missing and can we address those?

The workshop was hosted online on Microsoft Teams and had a duration of 2 hours. The outcomes of this workshop will help the MEESO project partners with the modelling and scenario development and will also be major input to inform and develop scenarios based on which management strategies can be evaluated and potentially developed. For the stakeholders the workshop was an opportunity to understand the developments in the scientific approach and give input into this process. MEESO aims for a transdisciplinary approach to ensure the relevance and legitimacy of the scientific work.

In total 24 people participated in the workshop: 10 stakeholders and 14 project partners who prepared the workshop and/or were involved. Of these, 11 are modelers and 3 participated out of interest.

The agenda of the meeting was as follows:

15.00-15.30	Presentation	
15.30-16.00	Q&A	
16.00-16.45	Break out groups	
	1. Fishing, Economics, Food Security	*Marga, Rolf, Francois, Berthe*
	2. Governance and the interplay between concerns; i.e. carbon flux	*Mary, Anna, Maartje, Amanda*
	3. Ecology	*Douglas, Rasmus, Marloes*
16.45-17.00	Plenary and closing	

The introductory presentation outlined the MEESO project and the previous stakeholder engagement workshops, gave a short introduction to the ten models used in the project (see section 2), and presented the gap analysis that was made (see section 3). Section 4, 5 and 6 in this report presents what discussed the break out sessions, with conclusion being drawn in section 7.

2. Short summary of the models

The models used in the MEESO project are presented in Table 1 below. What follows is a short description of each model, written by the model developers.

DISPLACE	WP 6 Social cost-benefit analysis
TROPFISH R / S6 model	SEAPODYM
FLBEIA	Strathspace
WP 7 Spatial (toolbox)	NORWECOM
WP 7 SD DMDU	Acoustic Data Geostatistical Mode

Table 1. List of all models used in MEESO

DISPLACE – The DISPLACE model is an individual-vessel based dynamic model, which simulates the decision making process of fishing vessels, their movement in space and time and their interaction with fish populations. This model was developed to support Management Strategy Evaluation (MSE), where we create mathematical models of the full fisheries system & represent each step of the management process with its own set of equations to provide output on fisheries economic indicators. We then create feedback to the fish population model by using the results of the management decision in the fishing model to provide output on biological population dynamic indicators. The individual-vessel based approach allows for the estimation of the uncertainty of the indicators according to the variability between vessels. In the MEESO project we do a case study to investigate the economic viability of a mesopelagic fishery performed by the Danish large-scale pelagic fleet. The vessels and their economics are parametrized with input data from VMS, logbooks, sales slips and cost structure to parametrize the vessels and their economics. The mesopelagic fish stocks are parametrized with abundances from MEESO surveys and biological parameters (e.g. growth and mortality) as estimated with the TropFishR model. Simulations then result in time series of biological indicators such as recruitment (R), fishing mortality (F), spawning stock biomass (SSB) for fisheries management, and economic indicators such as cost, profits, fuel use. We will investigate the fish prices necessary for an economically viable fishery, taking into account the biological uncertainty of the stocks.

TropFishR is a length-based model designed for data-limited situations where fish length frequency distributions are used to estimate *fish growth*, *natural fish mortality*, *selectivity* and the uncertainty of those parameters. The model can also be used for length-based assessment of abundance relative to maximum sustainable yield (MSY). Information on growth and mortality is essential input for stock assessment models (e.g. s6model) and ecosystem models (e.g. StrathSPACE), that are used to investigate the sustainability of potential mesopelagic exploitation. In MEESO we use TropFishR to investigate spatial variability in population dynamic parameters, e.g. growth and mortality, as well as selectivity according to stock specific patterns of *Maurolicus muelleri* and *Benthosema glaciale.*

S6 is another model designed for the stock assessment of data-limited stocks, which uses fish size (body weight) instead of length. In the MEESO project, s6 will be used to estimate natural mortality and reference points for *Maurolicus muelleri* and *Benthosema glaciale.* It will take as input life-history information (e.g. growth) from TropFishR and/or from the literature. Extensions of the model are being implemented to accommodate for non-exploited fish stocks and to estimate the uncertainty of all important estimates – most importantly the fishing mortality reference point FMSY.

FLBEIA is a simulation model to carry out bio-economic impact assessments of fisheries management strategies. It is a tool that follows the management strategy evaluation (MSE) approach and as such it allows the simulation of the whole fisheriy management process, from data collection to stock assessment to advice and finally, implementation. Users can assess management strategies, from both the biological and economic perspectives, facilitating decision-making in the medium and long-term. In the MEESO project, the *Maurolicus muelleri* fishery in the Bay of Biscay is analysed to assess the potential viability of this fishery for selected fleets.

For the **WP 7 spatial models for trade off analysis** we use maps generated by the other models in the MEESO project and by external collaborators (Pinti et al, 2022). The maps of the ecological models showing carbon sequestration can be overlaid with maps of governance indicators to see which are areas of concern, e.g. which areas are covered by the convention for biodiversity

WP 7 System dynamics model with biological carbon pump function of mesopelagic fish and perception of the state of the resource and climate change by public and policy makers that feeds back into management. The model is a set of coupled ordinary differential equations. We use participatory methods to find main variables and policy concerns to construct the model. We use decision making under deep uncertainty methods to run the models over a range of parameter and structural uncertainties and find possible clusters of scenarios and extreme outcomes.

WP 6 The social cost-benefit analysis in WP 6 assesses the economic viability of a mesopelagic fishery from a public perspective, i.e., taking into consideration public costs of the fishery such as climate impacts. The analysis considers at two broad scenarios. In the first scenario we assume that only existing fishing capacity is being used, so we focus on the marginal costs of fishing (labour, fuel, other variable costs). We estimate break-even curves from the point of view of a private company and from that of society, so including impacts on the climate. In the second scenario we explore more long-term perspectives where current capacity is not limiting: What is then the natural limit on this fishery? Is it resource availability, market saturation, or something else?

SEAPODYM (Spatial Ecosystem and Population Dynamics) is a numerical model to simulate the distribution and dynamics of key marine species. It is composed of 2 modules: MASS (Migratory and Aged Structured Stock) for predators, and LMTL (Low and Medium Trophic Level) for their prey, namely zooplankton and micronekton. The LMTL module was used here to model the distribution of *Maurolicus muelleri*. It takes as input currents, temperature and NPP. Equations of the model are solved in each cells of a grid, at every time step. Here it is a daily time step, at 1/12°.*Maurolicus*, such as other micronectonic organisms perform diel vertical migration. Modelling those intermediate levels of the trophic chain will enable to quantitatively account for the carbon pump which is particularly important in the context of increase CO_2 in atmosphere and climate change.

StrathSPACE models a single species in space. Growth, mortality, and movement are driven by a physical environment – ocean currents and temperature – from the UK National Oceanography Centre's NEMO model. Key outputs are population length structure, recruitment, and biomass, and how these change with time (including climate change). The animations shows modelled adult biomass from 1988-2050. Imposing fishing mortality on the model will allow us to generate yield curves (catch at different levels of fishing effort) and to explore spatial management strategies.

NORWECOM is an individual-based ecosystem model, which traces carbon flows through the marine ecosystem. The model has now included the dynamics of *B. Glaciale*. The whole life cycle of the species is dynamically implemented (movement, foraging behaviour, growth, mortality and reproduction). The vertical movement of *B Glaciale* is based on their light comfort zone. Horizontal movement occurs by drift. Foraging and growth of the species are based on principles of their visual range and bioenergetics (e.g. metabolic rates, based on e.g. temperature in their locations in the spatial model).

Acoustic Data Geostatistical Model - In the analysis of the west of Ireland acoustics surveys, we used geostatistical analyses to improve our knowledge on the distribution, and potentially the abundance of mesopelagic resources. Using the newly developed acoustic analysis algorithm on historical survey data allows us to access time series of acoustic abundance on which geostatistics can be applied to focus on two aspects of the abundance distribution in time and space. The first is unveiling the spatial pattern characterizing mesopelagic fish distributions. Minimum-Maximum Autocorrelation Factor (MAF) is an exploratory analysis aiming at finding the spatial structures summarizing annual distributions. The analysis is a PCA applied on spatial data where the principal components are maps ordered using variograms. The defined structures can then be used to correlate fish distributions with environmental parameters (e.g. temperature, water depth or sea surface elevation). While the approach to this first aspect is mainly descriptive, the second focus is to use variographic analysis (i.e. a linear model of coregionalisation) to determine how the fish biomass might interact with the environment. Biomass-environment relationship can be scale dependent, meaning the factors structuring the biomass variance at a regional scale may not be seen at more local scales or may affect the biomass differently. Unveiling these scales is necessary to better understand the relationship between the mesopelagic biomass and the ecosystem, and to design future acoustic surveys (e.g. transect spacing or Elementary Distance Sampling Units – distance over which acoustic data is integrated).

2.1 Comparing the models

We (the organising team) summarized the stakeholder concerns from the previous workshops into broad categories and then assessed which MEESO models addressed these categories. All categories from the stakeholders are addressed at least once, but no model is able to address all concerns.

Models related to concerns

Models	fishing	governance	economics	ecology	Food security	Carbon flux
DISPLACE	■		■			
TROPFISH R / S6 model	■			■		
FLBEIA	■		■			
WP 7 Spatial	■	■				■
WP 7 SD DMDU		■	■		■	■
WP 6social cost benefit analysis	■		■		■	■
SEAPODYM	■			■		■
Strathspace	■			■		
NORWECOM	■			■		■
Acoustic Data Geostatistical Model				■		

Table 2. List of all models used in MEESO and which topics they address (marked green)

We also mapped the spatial applicability of the models, which shows that some models assume global applicability, whereas others are linked to case study areas.

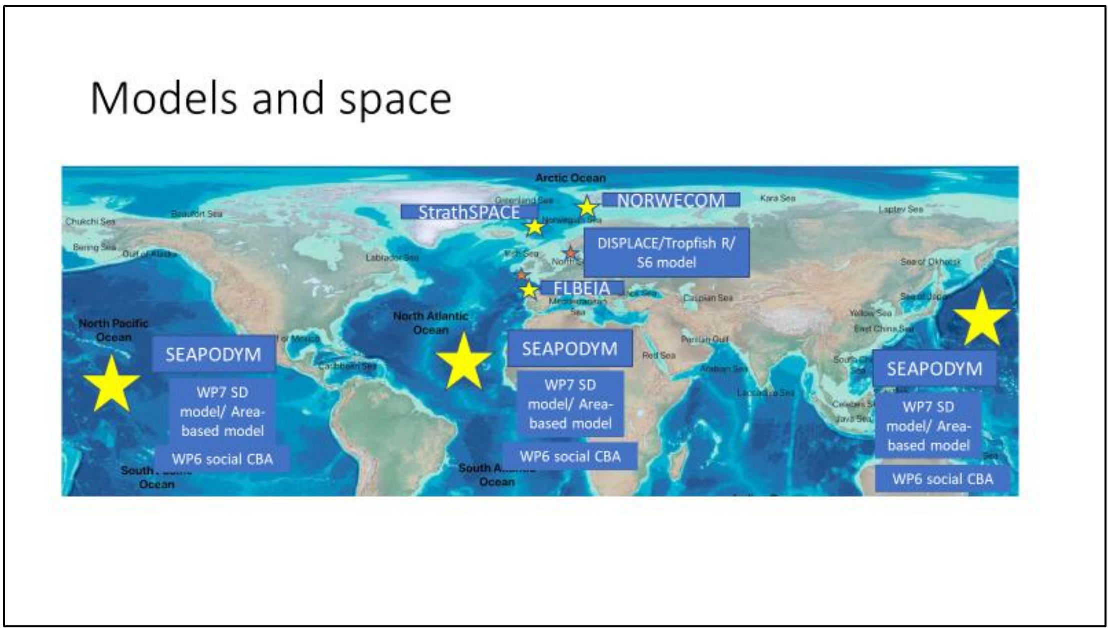

Figure 1. Models used in MEESO and how they are applicable spatially.

The next section outlines in more detail how the expected output of the models can connect to stakeholder concerns.

3. The gap analysis

Table 3 contains stakeholder interests that were identified in the two previous MEESO workshops. We grouped these concerns into six overarching topics (fishing/fisheries management, economics, food security, ecology, governance and carbon flux), as indicated in the left column. The middle column contains the subtopic of interest and the column on the right shows which models of the MEESO project can address the stakeholder concerns. Green is used when the model(s) fully address the concern, while yellow is used for models that partly address the concern, and red is used when the topic is not addressed with the models. These research gaps are indicated below each sub-topic in a blue box.

Overarching topic	**Stakeholder concern**	**MEESO models address**
Fishing/fisheries management	Risk of stock collapse	DISPLACE TROPFISH R / S6 model FLBEIA NORWECOM STRATHSPACE SEAPODYM SDDMDU
	Bycatch	NORWECOM (possibly)
	1% catch of the mesopelagic biomass already extremely interesting (abundance/viable catch)	DISPLACE TROPFISH R / S6 model FLBEIA MODEL NORWECOM STRATHSPACE SEAPODYM SDDMDU
	Scientifically backed quota and adequate enforcement in the fishery	DISPLACE FLBEIA
GAP: Bycatch (possibly, if NORWECOM will not address it)		
Economics (incl. fisheries GHG emissions)	Jobs, income, profits from a fishery	DISPLACE SDDMDU *SCBA WP6* FLBEIA
	Who will gain– who has access?	
	Effects on other fisheries through markets, bycatch, and ecological relations	
	At what scale it will be economically viable, considering the investments needed and the market	DISPLACE SDDMDU *SCBA WP6* FLBEIA
	Large CO2 from fishing	DISPLACE WP7 SD DMDU model *SCBA WP6* FLBEIA
GAP: Jobs (partially, e.g. DISPLACE and FLBEIA have FTE), indirect effects, markets (partially), who will gain, who has access		
Food security	MP fish available for the poor and nutrient-deprived people. mesopelagic fish could be suitable for human nutrition (e.g. in soups or fortifying noodles). Protein and calcium can also be extracted for supplements for both humans and animal feeds. fish for feed via aquaculture rather benefit the wealthier people impact indirect; indeed these species fish for feed, but would thereby alleviate other fish for feed fisheries (anchovy) rather than opening a new fishery it would perhaps be better to make food systems less wasteful	WP7 SD DMDU model *SCBA WP6*
GAP: Release of pressure on other fisheries, general wastefulness of food system, only thing addressed really is the possible scale/nutrition of mesopelagic fisheries. Both WP6 SCBA and WP7 SD DMDU address seafood supply and possible scale of fishmeal supply but neither model is addressing where this supply is ending up and who will be fed.		

Ecology	We need a full understanding of what mesopelagic species exist, there: • reproductive /lifecycle info	SEAPODYM Strathspace NORWECOM TROPFISH R / S6 model
	understanding of food web interactions, and	NORWECOM
	processes that they contribute to	NORWECOM SEAPODYM
	abundance	SEAPODYM Strathspace NORWECOM Acoustic Data Geostatistical Model TROPFISH R / S6 model FLBEIA
GAP: None in relation to models, but lack of data		
Governance	Lack of adequate institutions	WP7 SD DMDU model (strength of governance/institutions)
	Collaboration & enforcement in international waters	
	Sequential exploitation	
	The challenge for governance is that pending more knowledge about the ecosystem decisions need to be made (either fish for food or the role in carbon sequestration).	WP7 SD DMDU model (strength of governance/institutions)
GAP: Sequential exploitation, distinction inside & outside international waters		
Carbon flux	Quantify carbon flux before exploitation MSY+C approach financially evaluate this ecosystem service define mesopelagic areas as marine protected areas based on either biodiversity or carbon maps indicating areas with priority Will fishing really impact this function?	WP7 SD DMDU model (magnitude, fishing impacting C, financially evaluate ES) *WP 7 Spatially explicit models (MPA's with carbon)* SEAPODYM (magnitude, fishing impacting C) NORWECOM (magnitude, fishing impacting C) *SCBA WP 6 (*magnitude, fishing impacting C, financial evaluation)
GAP: MSY+C		

Table 3: The GAP analysis, linking the overarching topic to specific stakeholder concerns and reporting whether or not this is addressed (in some way) by the models. If not, the specific gap is mentioned per topic.

4. First Break out session : Fishing, economics and food security

In this breakout session we discussed the stakeholder's questions and concerns related to a mesopelagic fishery, the economics and the contribution to food security. The session consisted of a total of 12 participants, all of whom were scientists. The majority (9) were affiliated to the MEESO project. All participants indicated a high level of uncertainty in relation to what is known. Not only are there still many information gaps, also it is uncertain what is actually already known but not (sufficiently) communicated. Fishers hear mixed messages from science. Some studies and scientists make notion of high volumes of mesopelagic fish, others stress the ecological uncertainty with regard to stock abundances, distributions and the ecological and climatic processes that will be affected by exploitation. The main concerns are the large but variable biomass estimates, and the high uncertainty regarding the volumes and the variability of the possible catches. Further there are questions regarding the ecological impact of fishing, but also about the cost of developing a new fishery, the required investments and potential fuel consumption.

4.1 Economic viability, fishing costs and fish prices

The main concern identified in this session was the costs of a mesopelagic fishery, and what fish prices and catchable quantities would be realistic to account for those. This is a key factor in the feasibility of the fishery, but defining the market and the fish prices for mesopelagic species is a chicken-and-egg story: while it remains unclear how much biomass can be extracted, it is difficult for the processing industry to give an indication of the prices. On the other hand, without a certain market there is high uncertainty limiting the investments in this new fishery. Fish prices will also depend on the (micro-)nutrient content and water content of the species, which is currently still uncertain. A participant suggested the possibility of modelling the establishment of a fishery over time, to understand the factors affecting the start of a potential fishery and what fish prices would be necessary to account for the current uncertainty.

Modelers pointed out that such analyses can only be performed on a local scale: the current bio-economic models such as FLBEIA or DISPLACE can only model specific fleets. Even though the market for mesopelagic fish species would likely be global, it is still suitable to perform such analyses on a regional scale due to seasonality of the fishery and to the distributional patterns of the species. With the current uncertainty in biological and ecological knowledge of the mesopelagic species under investigation, researchers are still working according to different scenarios rather than with actual estimates of e.g. regional and seasonal catchability or the life history of the species.

The boarfish fishery in Ireland (Egerton et al., 2017) could be used as an example. Here, similarly to the mesopelagic case, fishers were looking for new opportunities in order to maximize profits, diversify and reduce costs.

4.2 Fuel consumption and associated costs

Potential fuel consumption was also identified as a concern. The fuel use and associated costs are expected to be high in a mesopelagic fishery, due to distant fishing grounds and large, small meshed nets that will need to go to large depths. This is not only a concern in terms of economics, but might also affect the fishery's environmental footprint. In addition (high) fuel consumption more often is a societal concern, especially when subsidised. Therefore having a better understanding of the ranges of fuel consumption, depending on the spatio-temporal distribution of the target species and the fishing gear, would be useful.

4.3 Market, and contribution to global food security

Another concern posed was the contribution of a mesopelagic fishery to the global food security and sustainability of the food chain in developing countries. Even though the market for mesopelagic fisheries is expected to be global, products originating from the North-Atlantic region first be used for European fishmeal products. The representative from the fishmeal and fish oil sector indicated that even though the European aquaculture sector is expected to grow 5% during the next years, this growth is limited by resource availability. As the current fisheries are exploited optimally, no more fishmeal and fish oil can be produced from current resources.

If the products based on the mesopelagic fishery will also be available for the global market it might also contribute to the food security on other continents and developing countries, where the aquaculture industry is also growing. The use of mesopelagic products would then allow for other marine resources to be used for direct human consumption rather than to produce aquaculture feed.

4.4 GAPS identified in this sub-session:

- How will the fishery be established over time?
- Can we reduce the uncertainty in the fish prices?
- What will be the fuel consumption and associated costs?
- Will this fishery also contribute to higher sustainability of other fisheries?

5. Second Break out session: Governance and Carbon sequestration

This break out session was split into two parts, which have important overlaps. The first part of the break out covered governance questions and the second part of the break out covered questions related to carbon sequestration in the mesopelagic zone. The session consisted of 7 participants, with two NGO representatives and two representatives from the fishing industry (both from Ireland) and three scientists who were involved with facilitating and participating.

5.1Governance

Before the workshop the conveners made a very short list of very broad policy options (coloured text, left column, Table 1). These policy options were in part identified from interviews (Oostdijk et al., 2022), where we interviewed different stakeholders on policy options for oceanic blue carbon governance/mesopelagic zone. Other policy options emerged from an extreme outcomes workshop in September (Kraan et al., 2022). Finally, one policy option was not mentioned in the interviews nor extremes workshop but was mentioned in the MEESO grant proposal, and therefore also included.

During the breakout session we filled in Table 1, starting with the question ”Which of the policy options is the most likely to be implemented as a policy?”

5.1.1 Quota management

Stakeholders in the workshop agreed that a (precautionarily small) quota (within EEZs) would be the likeliest initial policy implemented for mesopelagic fishing.

The stakeholder operating a fishing business noted that a quota (even a small, precautionary quota) would be the most likely management option for a starting, experimental mesopelagic fishery: ”*Just a comment coming from a fishing background, I think the natural start place is quota management. If the fishery is going to go ahead and going to take place you need to have a fishing cap, even if it’s just a small cap.*”

5.1.2 Area-based approaches

Another stakeholder (working for a non-profit organisation) mentioned that the MSY+C approach (setting quota based in order to avoid undermining the ecosystem processes that support carbon sequestration, taking carbon sequestration into consideration for fishery management) may not be very commonly used in fisheries management *(”Depending on how common it is to include carbon sequestration* (into stock assessments and reference fishing mortalities RED), *that could be something that is not likely in the short term.”).* However, they mentioned that ecosystem-based management (in combination with quota management) may be able to consider ecosystem services of biodiversity (e.g. including the carbon sequestration services).

Area-based management was seen as unlikely, at least with the current state of knowledge and there not being a fishery. The fishing industry stakeholder noted that the area that is occupied by mesopelagic fish is vast so area-based management is unlikely: *”I think it’s a massive area, so I’m not so sure what you’d do with that.”* Other stakeholders present agreed with this observation. Moreover, there are large uncertainties with implementing marine protected areas (MPAs) for mesopelagic fish as we do not know their distributions very well: ”*With this fishery there is so much unknown, where is the best protected area, Bay of Biscay, west coast of Ireland? These are massive areas, where is the biomass, where is the biggest abundance? There’s just so much of it that is really unknown. That’s why I’d think that quota would be the only effective cap at the moment.”*

Another caveat for MPAs was the question of whether the mesopelagic species move around a lot? The fisheries stakeholder mentioned that he heard from a survey that they would catch a lot of mesopelagic fish somewhere and then no more in the same region two years later. The ecosystem modeler present explained that the biomass is also really patchy, so the shifts in distribution, even if it’s just 10 miles or so, can be very noticeable when fishing, saying "*Because you will find a lot of Maurolicus in one spot, but next week they'll be 10 miles away, still in the same grid cell in the model but you won't find them on the fishing vessel.*".

5.1.3 Other policy options

BBNJ agreement (Biodiversity in areas Beyond National Jurisdiction)was mentioned as less likely due to the large uncertainties in its implementation. It's not clear whether this will be an incremental process, or whether there will be some momentum to actually put in place processes and funding for strategic assessment.

RFMOs (Regional Fisheries Management Organisations) were mentioned to likely only get involved once a significant fishery would take place (in international waters.) One of the participants mentioned that some of these agreements may also collaborate on the topic of management of mesopelagic fish/fisheries: *"The collaboration with a new agreement (i.e. BBNJ) of just sort of putting it on the radar is maybe more likely. And discussing whether it's a thing for RFMOs, or some other process."*

Policy options	**Most likely to be implemented as policy?**	**Most effective for conservation?**
Area based management (ABNJ) (MPA zoning, etc.) (P,EOWS)	We are talking about a huge area and therefore area based management is not likely nor likely to be very effective, BBNJ is about integration and is getting a narrow focus.	This has a high priority, but depends where, many uncertainties
Area based management (EEZ) (MPA, zoning, etc.) (P, I, Ex)	Fishing industry: EEZ's are promising as a management boundary	This has a high priority but depends where, many uncertainties
Quota management- MSY, (P, I, Ex)	Fishing industry: this most promising Academic: agree first	This has a high priority, especially for a new fishery, quota/cap is most effective/sufficient.
Quota management- MSY + C (P, I, Ex)	NGO: agree step 2 after setting quota with MSY	Not addressed in workshop.
Strategic environmental impact assessment (SEA BBNJ) (P, I, Ex)	High level of uncertainty. Not clear if it's going to be an incremental process. if SEIA will be implemented or resources are being made available.	Not addressed in workshop.
International fisheries management (RFMOs under UNFSA) (P, I, Ex)	RFMOs are unlikely to do get involved until the fishery is established (potentially with experimental/exploratory fishery on high seas?)	Not addressed in workshop.

A collaboration between RFMOs and BBNJ agreement to address multiple management (.e.g C & fishery management) (P, I, Ex)	RFMOs are unlikely to get involved until the fishery is established. This may be more likely, but this is uncertain depending on what the BBNJ would look like.	Not addressed in workshop.
valuation of carbon sequestration -> carbon market UNFCCC (P, I, Ex)	Not addressed in workshop.	Not addressed in workshop.
Precautionary: Moratorium on mesopelagic fishing (P, I, Ex)	We are starting from a new fishery- so precautionary (quota) management is the starting point.	Not addressed in workshop.
Other precautionary management (examples?)	Not addressed in workshop.	Not addressed in workshop.
innovation oriented governance P	Fisheries gear is decisive for the establishment of a new fishery.	Not addressed in workshop.

Table 4. Management options section 1 of break out. The policy options were added by the session conveners (MSW and MO) and the questions (Most likely to be implemented as policy; most effective for conservation) were answered during the session break out. The policy options are colored based on if they were mentioned in previous stakeholder interactions, or if they were only mentioned in the MEESO proposal: (P) = MEESO Proposal, (Ex) = Extreme outcomes workshop (Kraan et al., 2022), (I) = Interviews reported in (Oostdijk et al., 2022), 20 interviews between 05-2021 and 08-2021

5.2 Carbon sequestration

5.2.1 Level of detail needed from the models

On the question if it would be of interest to assess the carbon storage capacity of the mesopelagic zone in each EEZ, for different spatial areas, and for different fishing scenarios, one of the stakeholders (working for the non-profit) answered that if it's within the capabilities, it may not hurt to add this information. Given the uncertainties, the fisheries stakeholder mentioned that erring on the precautionary side when starting fishing would be a good approach to deal with this uncertainty.

5.2.2 Fishing scenarios

When asked about fishing scenarios (e.g. with Catch Per Unit Effort, if there will be a season and if gear would likely change during the season) the fisheries stakeholder suggested that the first attempt may be to bring along a small trawl net on board of the vessel and try a net that would also catch mesopelagic fish. They suggested that researchers could make more use of them when they are at sea, with the real time information that they have: "*We are at sea, and I think we should be made more use of when we are at sea. At the minute we don't have more information. We have some pictures and times that I could send to you but a lot of the time I don't know what we're looking at, but we're not trying to catch it. But we could, if we had a small net aboard we could take samples.*" This indicates a willingness for fishers and researchers to cooperate on collecting relevant data.

5.2.3 Specialised fishery vs. using current equipment

A second fishery stakeholder (trawl designer) suggested that any mesopelagic fishery would be a specialised: *"The gear would have to be designed specifically for that, also for the bycatch side of it. Grids, small mesh cod-ends."* Some of the discussion then continued to cover the end product: the mesopelagic fish could be used for higher value products than simply aquaculture feed, for example for its protein and calcium (e.g. in fortified noodles).

Finally the fishery stakeholder mentioned that it's only when there are no other valuable fishing opportunities that this fishery may actually take off:

"*In other cases where fishers caught mesopelagic fish, e.g. Iceland they say the fishery didn't succeed, but what I think happened is that whenever they caught mackerel or herring or something more valuable they'd turn their attention away from it. So now in Ireland we're sort of tied up and we have plenty of boats that aren't fishing. So that's why you'd probably see more Irish fishers be interested in these kind of things, as we're twiddling our thumbs most part of the year. We've only fished 35 days this year, so even if we'd double that with mesopelagic fish that would still be ok*."

5.3 GAPS identified in this sub-session:

- Uncertainty with governance frameworks (e.g. BBNJ or RFMOs)
- What "end product" would the mesopelagic fish be used for?
- Uncertainties in distributions and patterns of occurrence, high uncertainties for area based management (e.g. mobility of the species)

6. Third Break out session: Ecology

In this breakout group we discussed with stakeholders what their main questions were related to understanding the ecological system of the mesopelagic zone. The session consisted of 6 participants, one scientist working with the Irish fishing industry, one Irish gear manufacturer and one NGO representative. The format of the session was open: all stakeholders were given the floor to ask some questions to the modelers which lead to engaged discussions on the state of progress in the MEESO project, discerning what the project is looking at, what the models can and cannot (yet) address, and how the models work.

6.1 Data availability

One of the first topics that was discussed was the availability of data to use as input to the models. The models that were discussed were: TropFishR, s6, Strathspace (all single-species models), and NORWECOM and SEAPODYM (both ecosystem models). In WP4 of the MEESO project, data is collected during scientific surveys. Other data and parameters originate from literature surveys and from trial fisheries. Data and parameters necessary to parametrize the single species models are related to the life history of the species, e.g. fecundity, recruitment, growth rates, reproduction and mortality. The ecosystem models are parameterized using information on nutrients and other components of the ecosystem. The MEESO project focusses on 2 species: *Maurolicus muelleri* and *Benthosema Glaciale*. Some single species models could give an indication on the presence of single or multiple stock units, e.g. by the identification of regional differences in population dynamic parameters.

6.2 Genetic data

One of the stakeholders, the scientists working with the fishing industry, suggested to collect genetic data:

"So before, trying to do the genetics and the population genetics of any species was kind of a shot in the dark, but now that we can access the whole genome, if there is a difference between different populations you can find that. There is no limitation to actually discovering that."

As of now in the MEESO project we do not collect genetic information. The stakeholder argues that it is the best way to define the stocks we would want to assess. Ideally the biological unit in the stock assessment area is one, but one can only be sure when this is tested. The argument he uses in fact has been mentioned before by stakeholders in earlier meetings and boils down to, this time (with still a pristine, or at least unfished stock) we should do it right:

"You should be assessing based on the population level rather than one some geographic or political stock."

The scientists of the MEESO project agreed that this was a good idea, but that this was not part of the project, probably because it would never have been possible to sample the whole area. We currently work with data from areas around Norway, Iceland and Spain, which does not cover the whole North East Atlantic. The workshop participant explained that collecting genetic data in that somewhat limited area would nevertheless still be valuable. Perhaps a follow-up project would be able to assess the data:

'It is just that, if you do have the opportunity to start collecting samples, my recommendation I suppose is to start collecting them and just archiving them. It is very cheap to actually collect them in the first place and just have them there for the future."

The stakeholder stressed that ideally this would be done sooner rather than later, to avoid a situation in which a stock gets defined without rigorous knowledge of the underlying population dynamics. This is a concern because once this is done, it will be a reality in practice and very difficult to change:

"So once these things get set up to stock assessments, it is very difficult to change them afterwards. That is what we found with the herring […]. So I[…] at least to note that and have that as a kind of caveat that goes with any stock assessment, or with any attempts to estimate the biomass, just to make people aware of that and that this could change then, if you ultimately go and identify the populations. It would be great to get those samples banked anyway for the future."

The stakeholder referred to the European Reference Genome Atlas, where perhaps space was available to add 1 or 2 additional species. Adding one of the species studied in the MEESO project would be a great opportunity.

6.3 De facto governance

This discussion is also a nice example of how scientists play a *de facto* governance role in their work on the mesopelagic zone (Schadeberg *et al* 2023). Scientists make justifiable and defensible choices during their work, but the discussion above (on how to define a stock vs a population and the choice of words) shows how these choices can have long-term impacts on management decisions.

6.4 Food web interactions

The second topic that was discussed for some time was the understanding of the food web interactions and how a potential fishery might impact that.

"[…] how important is this stock in a food web context and what is eating it and what is reliant on it? And then how important is that in the trophic structure of the other species that maybe we exploit or are wanting to conserve or protect and maybe would interact with the fishery directly as bycatch but also maybe the dependency of certain populations […] feeding on mesopelagics and carry that food from the low level of energy up into the high level?"

The MEESO scientists responded that what was known was that there were high natural mortality rates for these species, as they are generally short-living, allowing for a fishery as it could probably sustain some level of fishing mortality. On the other hand, a high natural mortality indicates that there is predation and thus a food web function, thus cascading effects could potentially be high. This is exactly one of the questions that can be explored in the ecosystem models. In addition, reference was made to the SUMMER project, which is running in parallel with MEESO. It was expected that more information on the topic of natural mortality would be coming out of that project. In the discussion it did become clear that for the scientists in the room it was unclear how close cooperation was between the two EU H2020 projects (MEESO and SUMMER). In addition, there was acknowledgement of the different mandates of the two projects – SUMMER looks at trophic level phenomena and not at species level, which is what would be required for MEESO scientists to effectively study food web interactions in their models. The models are used to estimate growth and mortality, taking the selectivity of the fishery into account. Yet, as said before, no model is better than the data put into it. Time series sampled from different areas are limited, so there is a lot of uncertainty. Species-specific growth and mortality parameters are essential input in single-species stock assessment models and in larger scale ecosystem models, and therefore limiting the evaluation of the sustainability of a fishery targeting *Maurolicus muelleri* and *Benthosema glaciale*. Because these species play some function in the biological carbon pump it is important to understand the trade-offs between X and X.

To get some more understanding of the role in the food web, another source of information would be dietary studies. This is another topic where the SUMMER project's outputs will provide useful insights.

6.5 When might there be a fishery?

The last question that was asked, by the net manufacturer, was when the scientists expected that there would be a fishery. The scientists supposed that if trial fisheries would be able to get feasible catch rates, fishing would pick up. Practice has shown that catch rates were quite variable. The question that the MEESO project needs to deal with is what would sustainable harvest levels be in the case that fishing would pick up. Due to data limitations the scientists do not expect, however, to be able to give robust estimates of how much can be harvested but they rather expect to evaluate scenarios and look at risks. The net manufacturer shared information on how he had heard that MP fisheries have been explored elsewhere and that that looked promising:

"*I also know from working with another customer that we have down in Namibia (fishing for horse mackerel) that they believe that there's a very viable source down there, because they're seeing it quite* *consistently. They're exploring options on how to- I think there's a lot of shore site facility infrastructure that would have to be set up."*

6.6. GAPS identified in this sub-session:

- The gaps identified are related to lack of data: on diets, genetics and general biological data
- These data gaps lead to a gap in food web interaction studies

7. Conclusions

The workshop centred around the question: does MEESO address the main concerns of stakeholders regarding the mesopelagic system and if not, what is missing and can we address those?

By looking at the concerns stakeholders had expressed in 2 previous workshops (March and September 2021) we could identify six overarching topics (fishing/fisheries management, economics, food security, ecology, governance and carbon flux) that are of concern to stakeholders. We performed a GAP analysis by comparing these concerns with whether or not the models used in MEESO (DISPLACE, Social cost benefit analysis WP 6, TropFishR/s6 model, SEAPODYM, FLBEIA, Strathspace, WP 7 Spatial (toolbox), NORWECOM, WP 7 SD DMDU, Acoustic Data Geostatistical Model), would address these concerns.

The gap analysis showed that all 6 overarching topics were covered but that some specific concerns would not be addressed, notably 1) bycatch, 2) employment, 3) effects on other fisheries through markets, bycatch, and ecological relations, 4) markets, 5) access to the resource, 6) release of pressure on other fisheries, 7) general wastefulness of food system, 8) sequential exploitation, 9) distinction inside and outside international waters, and 10) climate impacts and 11) data availability (on ecology). These concerns are all very much related to governance questions around a mesopelagic fishery: who has access, how will it be organised, who will benefit, whose problems will it solve, what cumulative impacts can be expected, and which management tools could be used to ensure that a possible mesopelagic fishery will be sustainable? For instance quota were mentioned as a possible policy option, yet for the fishing practice it makes big difference whether it these will be individually transferable or not, and also how they will be divided (as there is no historical catch record).

The gap analysis in the workshop identified additional concerns, questions, and gaps: 1) How will the fishery be established over time? 2) Can we reduce the uncertainty in the fish prices? 3) What will be the fuel consumption and associated costs to fishers be? 4) Will this fishery also contribute to higher sustainability of other fisheries? 5) How can data availability issues (dietary data, genetic data and general biological data) be solved? 6) What governance frameworks (e.g. BBNJ or RFMOs) would govern a potential fishery in the mesopelagic zone? 7) What "end product" would the mesopelagic fish be used for? and 8) How can we deal with uncertainties in distributions and patterns of occurrence for mesopelagic fish, especially in relation to area-based management?

In addition some specific recommendations were made in relation to ecology:

- Collect genetic information whilst sampling. If this cannot be analysed in the project at least it can be banked and analyses at a later stage.
- Note the caveats clearly when doing a stock assessment (i.e., "we do not fully understand the underlying population dynamics of this stock. Our assumptions are …")
- Discuss the de facto governance implications of defining a stock
- Follow up on connecting the outputs of MEESO and SUMMER with one another
- Follow up on the European Reference Genome Atlas project
- Follow up on the Namibian mesopelagic fisheries

It should be noted that workshop was attended by a limited number of stakeholders, and many of them were scientists. It is imaginable that with more and more diverse stakeholders additional concerns, questions and gaps might be identified. We also acknowledge the necessary choices that project partners have to make as to which issues can and which cannot be addressed by this project with its limited timeline, budget, and personnel capacities. However, we argue that it would be good to have explicit considerations and documentation of such choices.

The outcomes of this stakeholder discussion will be presented to the MEESO consortium at the 2022 Annual Meeting, where members of the project will also discuss the question of the extent to which the MEESO project addresses these stakeholder concerns. In other words this input from the stakeholder consultation will be taken further in the MEESO project and exert some influence over the final year of the project, as the models continue to be refined and applied to the project's aims.

8. References

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