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Fisheries economics, mesopelagic, pelagic fleet

Executive Summary
Exploitation of mesopelagic stocks of Myctophids and Sternoptychids has been around since the Soviet Union started exploiting these resources near Antarctica in the early 1980s. Limited exploitation and trial fisheries have also taken place off South Africa and in the Gulf of Oman in the 1990s. More recently (2009-2010) Icelandic fishing companies have conducted mesopelagic fishing trials. Most of the historical exploitation efforts have lasted no more than a few years due to the low profitability, but interest in these resources still exists and trial fisheries and surveys in the North Atlantic are still taking place. This raises the question whether a mesopelagic fishery could be viable, and if so, in what form and under what conditions. This report explores the economic characteristics of a mesopelagic fishery, focusing on relevant fishing fleets in Spain, Denmark, and The Netherlands. In Spain, the commercial viability of a mesopelagic fishery in the Bay of Biscay was explored focusing on Basque trawlers. A survey among ship owners was carried out to assess their willingness to engage in a mesopelagic fishery and to explore the most relevant potential regulatory and technological difficulties. Data from this survey were combined with logbook data, sales data, and public data from the EU Social, Technical, and Economic Committee for Fisheries (EU STECF) to identify the segment of the Basque trawler fleet most likely to engage in mesopelagic fishing. The findings suggest that although mesopelagic fishing is probably technically feasible for all the otter and pair trawlers considered in the analysis, it is financially feasible only for the cod trawling fleet. That is because all other fleets are occupied during the full year, and hence would have to give up other fishing activities, which

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implies an opportunity cost that currently outweighs the financial benefits from a mesopelagic fishery. The storage capacity is another key issue. Due to the potentially low price of the resource catches should be large in order to achieve profitable fishing trips. Moreover, trip length is severely limited as the catch deteriorates quickly onboard. Data about the potential operational costs were collected and will be included in the bio-economic model that will be developed during the life of this project.

In Denmark the commercial viability was assessed for the large vessel pelagic fishery. Data from logbooks, sales slips, Vessel Monitoring System (VMS) databases, and EU STECF databases were used to assess the economic performance, activity levels, behaviour, and fisheries dynamics of the Danish large vessel pelagic fishery. Fisheries representatives were interviewed to obtain their perception of the potential of a mesopelagic fishery and to develop scenarios of mesopelagic exploitation by the Danish fleet. The findings suggest that mesopelagic resources are commercially attractive due to their relatively high fat content, resulting in prices comparable to that of summer herring landed for industrial purposes. As regards the fishing patterns and the cost structure of the fishing trips, a Danish mesopelagic fishery is likely to resemble the blue whiting fishery as it is also a small-meshed deep-sea fishery, although substantial investments in gear modifications (especially smaller-meshed nets), or onboard storing, conservation, and processing methods, may be needed. Since the Danish large-scale pelagic fleet is currently occupied year-round, engaging in a mesopelagic fishery would imply either switching activities or investment into new fishing vessels. Both options result in substantial opportunity costs for the Danish vessels, but the costs were the lowest for the Norway pout fishery. Switching to mesopelagic resources could very well be profitable for these fisheries. In the Danish investigations different scenarios of potential mesopelagic fishery were evaluated in relation to different price levels, trip durations (in relation to conservation method limitations and storage capacity), and cost levels.

In The Netherlands analysis of EU STECF data and informal interviews with fishery representatives were used to assess the interest of the Dutch pelagic freezer-trawler fleet in a mesopelagic fishery. The Dutch pelagic freezer-trawler fleet consists of about six vessels with engine power between 3200 and 7920 kW, and this capacity is currently fully used. Therefore, engaging in mesopelagic fishery would involve substantial opportunity cost. Such opportunity costs are difficult to estimate from available data as the firms operating the vessels are highly vertically integrated so that the prices should be regarded internal prices rather than market prices. So far representatives of this fleet have indicated very limited interest in developing a mesopelagic fishery due to lack of experience and considerable uncertainties with respect to onboard storage and processing, particularly considering the possibly high water and salt content of the catch combined with the fact that this fleet typically freezes its catch for onboard storage.

Altogether, the results of these analyses suggest that a mesopelagic fishery could be commercially viable given adequately high ecological sustainable catch rates, but

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the scale is so far limited by the quick deterioration of the catch. Without facilities to preserve the catch, or to process it on the vessel, mesopelagic fishing trips will likely be limited to a maximum of four to five days. Factors limiting onboard preservation and processing include its high content of salt, water, and fat, and the small size of the fish. Other uncertainties with respect to mesopelagic fishing regard the regulations to be expected, particularly with respect to mesh size and quota; ecological impacts of the fishery, including bycatch and the food chain; and technological options such as onboard processing or preservation, or designing entirely new vessels. The availability and the seasonal behavior of the mesopelagic resources is another uncertainty that should be clarified in order to better understand the dynamics in a potential mesopelagic fishery.

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AUGUST

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Final report fisheries economics

The case study of the Basque Country

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1. INTRODUCTION

Until 2014, the mesopelagic biomass was estimated around 1,000 million tons, but in 2014 acoustic observations showed that mesopelagic biomass could be significantly large (Irigoien *et al.* 2014). Although the biomass is still being accurately assessed (SUMMER[1] & MEESO), the commercial exploitation of mesopelagic resource can be a new business opportunity for the fishery sector.

The commercial exploitation of mesopelagic resources existed in The Soviet Union (catches between 500 and 24,000 tons) but it was abandoned because of low commercial profits (ASOC, 1996; Kock, 2000). Icelandic fishers also conducted some fishing trials mostly in the period 2009 - 2011 for the mesopelagic species (including *Maurolicus. muelleri* (*M. muelleri)*) (MFRY, 2020), but this activity was abandoned in 2016 due to the poor catches (Prellezo, 2018). This background indicates that commercial exploitation of the mesopelagic resource needs to be assessed cautiously, considering the whole value chain from the biomass assessment, harvest control rules, resilience of the fishery, fishing activity, traceability of the product, transformation to the final product and to the final market.

The current case study is focused on the Bay of Biscay. The biomass of mesopelagic resource in this area is still uncertain but there are some preliminary figures that are used in this study (Boyra et al., 2019). Furthermore, there is a gap on the knowledge about how this resource would be managed, which lead uncertainties on the amount of harvest possibilities. Thus, the harvest possibilities were simulated considering several scenarios for the more suitable fleets to exploit the mesopelagic resource.

The economic viability of mesopelagic fishery in the Bay of Biscay was studied preliminarily (Prellezo, 2018) considering the demersal trawl fleet. But the same study explained that the pelagic trawler was probably the most adequate fishing gear. In this study the most suitable fleet has been selected as a combination of technical indicators (adaptability to a new fishery, the storage capacity, the potential onboard processing, and the vessels autonomy (Grimaldo & Grimsmo et al. 2020)), social indicator (willingness of the ship owners to exploit the new fishery) and economic indicators (net profit). The economic indicators were analysed for those fleets that are technical viable and expressed interest in the mesopelagic fishery. The economic viability was performed comparing the current profit against the potential profit of the mesopelagic fishery. In this analysis the data were calibrated with the results obtained from commercial trials in Norway and Iceland.

An important issue to consider in the mesopelagic fishery is the onboard conservation of this resource to be suitable for its final market. The target market is still undefined, but although some mesopelagic species are considered suitable for human consumption, mostly they are used as a raw material in the global fish mean market (Grimaldo & Grimsmo et al. 2020). Thus, one

[1] https://summerh2020.eu/

interesting possibility is to transform the resource into fish oil – fish meal to feed the aquaculture. Aquaculture, salmon among other species, is in great need of good quality balanced protein and lipid sources, particularly marine omega-3 (n-3) long-chain polyunsaturated fatty acids (LC-PUFA), to sustain a further development of the industry (Olsen, Strand et al. 2020). The protein content of mesopelagic resource is typically high and the amino acid composition deemed sufficient for use in feeds for farmed fish such as Atlantic salmon (Olsen, Strand et al. 2020). Thus, in the current study the final market for the mesopelagic resource is the fish oil – fish meal for the aquaculture. The whole value chain was explored to estimate the potential price of the mesopelagic catches that will be processed for the fish meal and fish oil. The profit of a potential mesopelagic fishery in the Bay of Biscay was estimated and compared with the actual fisheries. All the studied elements make up the framework to analyse if it is worth it or not to exploit the mesopelagic fishery in the Bay of Biscay.

This study analyses the viability of the mesopelagic fishery from the economic profitability of fishing fleets perspective, without considering some other important aspects such as the impact in the global carbon cycle or food webs. The current analysis is just one piece of the puzzle that is needed to assess a holistic impact of mesopelagic fishery commercial exploitation in the Bay of Biscay.

2. OBJECTIVES

The main objective is to select the fleet components in perspective of potential mesopelagic resource exploitation. This objective can be divided in the following sub-objectives:

- Select the most suitable fleets for the commercial exploitation of mesopelagic resource.
- Economic assessment of the selected fleets involved in the current fisheries.
- Economic assessment of the potential exploitation of mesopelagic resource considering different alternatives of the product transformation (on board or on land). In this way, a survey was carried out to better understanding from the fisher's perspective.
- Risk analysis. Given that it seems that the fishery was failed previously, the identification of the potential risks for the commercial mesopelagic fishery was studied.

3. MATERIAL AND METHODS

3.1. Mesopelagic fishery framework

For the assessment of the new commercial exploitation of the mesopelagic fishery in the Bay of Biscay there are some questions that need to be solved. The most significant gaps in knowledge are:

- **Biological data**: The biological data of the mesopelagic resource, its temporal seasonality, spatial distribution, and interannual variability need to be well defined.
- **Regulation**: Regulatory framework that will be drive the fishery need to be explored.
- **Harvest control rules**: This will give us the knowledge about the quantities that the fleet will be allowed to fish.
- **Technical issues**: The vessels that will exploit this fishery will tackle a new fishery very different from that they are already exploiting. Several technical issues need to be considered.
- **CPUE**: The catch per unit of effort (CPUE) is an important factor that will be drive the economic viability of the fishery. As in the Bay of Biscay there is no data about the CPUE for the mesopelagic fishery, an estimation should be based on the existing data in other mesopelagic fisheries.
- **Onboard conservation**: The fish conservation onboard will be set the fishing trip duration. *Maurolicus muelleri (M. muelleri)* is a fish that degrades rapidly.

3.2 Fleet selection

In this sense, when considering the exploitation of a new fishery, the fleet can be a new fleet or an existing one. There are restrictions to build new vessels for exploiting new fishery; any authorization for the construction of fishing vessel will require that the new vessel will replace one or more decommissioned ones. These actions need to be executed under strict conditions already established in the regulation (Reglamento (CE) n.º 2371/2002 , Real Decreto 1549/2009). Given the lack of knowledge and the uncertainties about the profitability of this new fishery, **we will focus our analysis only on existing fleets.**

The selection of most suitable fleet depends on several factors: the financial risks, fishing area, fishing gear, vessel size, opportunity costs, if the fleet will be strongly affected by Landing Obligation (LO), the age of the vessel and the ship owner willingness to exploit the new fishery (Figure 1).

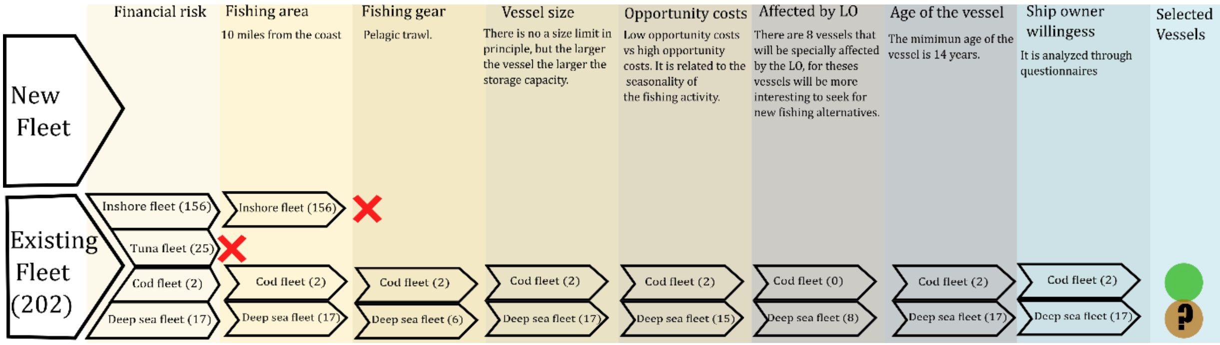

Figure 1: Scheme illustrating the steps for the selection or criteria of the Basque fleets for the commercial exploitation of the mesopelagic fishery. The red cross means that this fleet does not pass the specified criteria, the green point refers to the selected fleet, and the orange point indicates that it is uncertain.

3.3. Indicators

Technical indicators

Three technical indicators regarded the possibilities of the vessel to deal with the mesopelagic fishery were defined:

I. **VFG:** Viability of the use the fishing gear for mesopelagic fishery.

II. **SC:** Storage Capacity is referred to the minimum storage capacity to achieve profitable results in mesopelagic fishery was estimated for each fleet. If the actual capacity was larger than the estimated one, it was considered as viable in capacity terms.

III. **OP**: Onboard Processing was explored in case of being necessary to maintain the mesopelagic catches in good conditions onboard.

The values for the three indicators are categorized as **YES**, **NO** and **NA**.

Financial indicator

This indicator measures the difference between the profitability of the mesopelagic fishery and the current activity of the fleet. Following the analysis carried out by Prellezo (2018), the analysis was done based on operating day. The selected indicator was Net Profit (NP) of fishing mesopelagic species (*m*) instead of the traditional target species ($_0$) of the fleet (*f*) in one day (*d*). Since the trip for traditional target species and for mesopelagic species can differ, the basic unit considered in this study was the day. The income and cost of the days of the same trip were assumed constant. The profit (π) for each fishery is defined in equation *(1)* and *(2).*

$$\pi_{0,d,f} = (p_{0,d,f}h_{0,d,f})(1 - crew\ c) - fuel\ c_{0,d,f} - vc_{0,d,f} - fix\ c_{0,d,f} - cap\ c_{0,d,f} \quad (1)$$

$$\pi_{m,d,f} = (p_{m,d,f}h_{m,d,f})(1 - crew\ c) - fuel\ c_{m,d,f} - oth\ vc_{m,d,f} - fix\ c_{m,d,f} - cap\ c_{m,d,f} - \frac{Inv}{AP*days} \quad (2)$$

where *p* is the price of the catch (*h*), *crew c* is the crew remuneration system of the fleet. Fuel costs (*fuel c)*, other variables costs *(oth vc)* and fixed costs (*fix c)* and capital cost (*cap c) are* assigned to each day.

NP of mesopelagic fishery is the differences between both profits (equation *3*).

$$NP_f = [\pi_{m,d} - \pi_{0,d}] \quad (3)$$

Where $\pi_{0,d}$ is the profit of current fishery and $\pi_{m,d}$ is the potential profit of the mesopelagic fishery. The categorization of this indicator is:

- If $NP_f > 0$: **YES**, allocate effort to mesopelagic fishery is viable.
- If $NP_f < 0$: **NO**, allocate effort to mesopelagic fishery is not viable
- If $NP_f = 0$: NA, allocate effort to mesopelagic fishery is indifferent.

Social indicator

The social viability was evaluated considering the ship owner's willingness to embrace the new activity. This indicator measures the willingness of the ship owner to switch to a new mesopelagic fishery in case it is profitable. This information was obtained from interviews with shipowners. The values are:

- Willing: **YES**
- Unwilling: **NO**
- Neither willing nor unwilling: NA

All indicators are represented in a table with a colours code that indicates the viability of a new mesopelagic fishery for each fleet.

3.4. Data

The assessment of a new mesopelagic fishery in the Bay of Biscay requires great amount of data, but not all of them already exist. The analysis of the viability of the commercial exploitation of the mesopelagic fishery is done considering the framework illustrated in Figure 2 . The knowledge and data about the mesopelagic biomass, the existing fleets and the potential fishery information is needed to calculate the indicators.

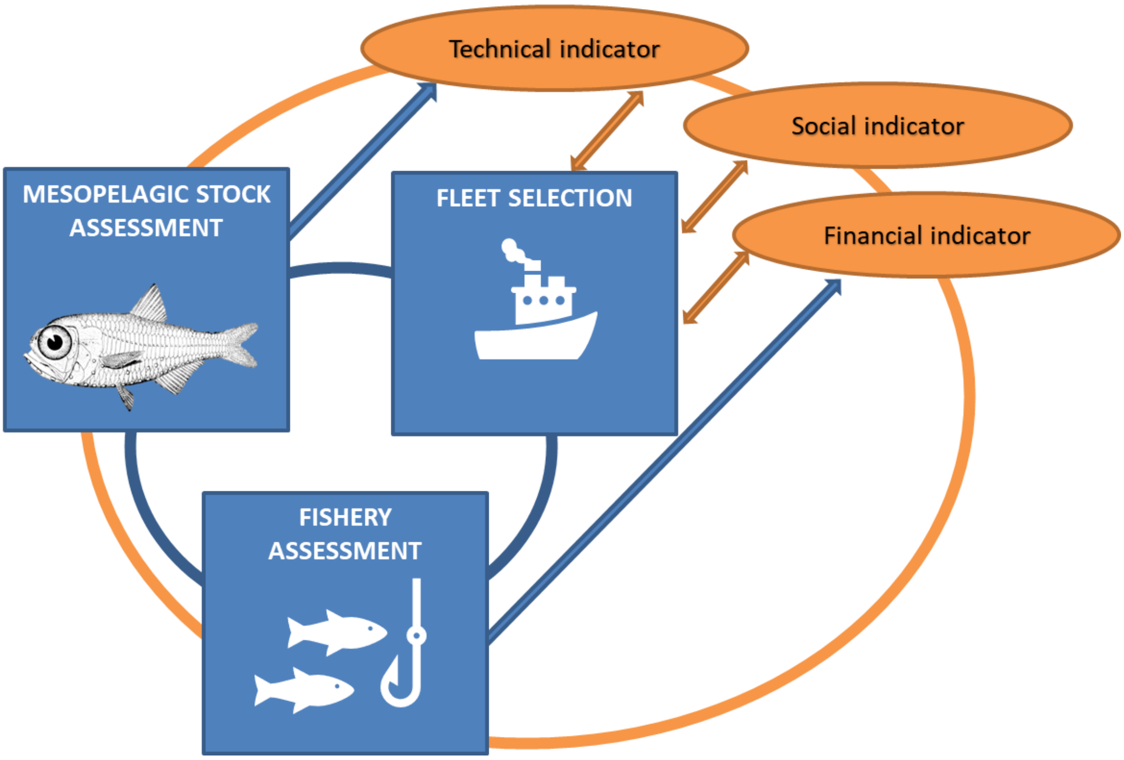

Figure 2: Framework of the analysis for the fleet selection. In blue the elements related to the potential exploitation of the mesopelagic fishery, in orange the indicators that will be used for the fleet selection.

Data used in this analysis are summarized in Table 1.

Table 1: Data sources summary.

Type of data	Data description	Source
Biomass estimation	Biomass in the Bay of Biscay	(Sobradillo, Boyra et al. 2019)
Fleet selection	Ship owner profile	Survey *
	Vessel technical adaptations requirements	Survey*, (Prellezo 2018), Naberan, (Grimaldo, Grimsmo et al. 2020)
Fishery	Willingness to exploit the new fishery	Survey*
	Effort dynamics	Survey*, logbooks, first sale note
	Onboard processing possibilities	Survey*
	Onboard processing plant and required investment	Fishmeal Processing Solutions (www.hedinn.com)
	Fishing gear issues	Fishing gears producers (Naberan), survey
	Commercial vessel to catch mesopelagic resources	Own estimation, survey
Ship owner willingness	Willingness of the ship owner to exploit mesopelagic resource	Survey
Fleet economic data	Current catches	Estimations from Loogbook and First sales notes & AER (Annual Economic Report of the STECF).
	Price	Estimations from and First sales notes & AER
	Costs	Survey, AER, local and national official statistics.

(*) The information regarding the fleet effort dynamics, fish owner profile, willingness to exploit a new resources and vessel adaptation requirements, has been obtained from a survey carried out through telephone interviews (see ANNEX 1).

4. MESOPELAGIC FISHERY IN THE BAY OF BISCAY

Biomass estimation: The biomass of *M muelleri* is yearly estimated in autumn during the acoustic survey JUVENA. In this area, this specie is the dominant mesopelagic specie, and its acoustic biomass was estimated in 2019 in 157,000 tons (Boyra *et al*, 2019). The mean size of this species was 3.8 cm and mean weight 0.5 gr. According to Juvena survey, the biomass of *M. muelleri* in the Bay of Biscay biomass ranged from 132,000 to 260,000 tons from 2014 to 2019 respectively (Table 2). Most of the specimens captured in autumn corresponded to juveniles born in spring of that year (age 0). Although there are no other surveys for this species beyond JUVENA, some prospective samplings carried out in spring and summer have collected larger individual than in autumn. These exemplars corresponded to spawning adults of 1 and 2 years old. Then the biomass estimation should be improved considering samples from other seasons. Accurate estimate of *M. muelleri* abundance is a cornerstone to evaluate the impact of its exploitation and establish the necessary management measures (Sobradillo *et al.*, 2019).

Table 2: Estimation of the M. muelleri biomass. Source: Boyra & Martinez, 2019

Year	Mean energy mn²	Mean weight (gr)	Mean size (cm)	Numbers of individuals ($x10^{11}$)	Biomass (tons)
2014	309.3	0.51	3.4	4.6	236,410
2015	630.8	0.58	4.0	3.6	211,510
2016	349.0	0.36	3.4	3.7	132,410
2017	511.3	0.53	3.7	5.0	268,377
2018	585.2	0.26	3.0	9.8	257,725
2019	257.0	0.53	3.8	2.9	157,042

Spatial distribution: In the Bay of Biscay the *M. muelleri* biomass was predominantly found off the shelf or at the outer part of the continental shelf, although it reached the 100 m isobath on the French self (Sobradillo *et al.*, 2019). In general, the campaign covers an area that goes from a minimum of 15-20 nautical miles (nm) to 300 nm offshore (Figure 3). Although the abundance of this species beyond this limit is unknown, information from other areas suggests that its presence could be also significant (Figure 3). It is well-known that *M. muelleri* migrate daily from deep to shallow waters to feed. It has been also observed in the Bay of Biscay. Thus, the vertical distribution of *M. muelleri* during daytime ranged from 50 m down to the maximum depth sampled in this study (500 m), with a clear maximum of biomass at 100-150 m depth (Boyra *et al.*, 2019). During night-time, however, the location of the acoustic detections in the water column varied with time being and although it can ascend to depth of 20-25 m, it has been often observed at on average of 50 m depth (Sobradillo *et al.*, 2019).

The resource is partially located in the Spanish Exclusive Economic Zones (EEZ), where is not allowed the use of pelagic trawl, but in French waters does. Then, the possibilities of using pelagic trawl for the mesopelagic fishery in the Spanish EEZ need to be explored.

According to Juvena Campaign results, scientific landings were 100% *M. muelleri*, without krill or bycatch. It seems that the probability of finding krill during the day in oceanic waters was quite low. The maximum biomass of *M. muelleri* was located around 150 meters depth where the temperature was around 11 - 12 degrees.

In conclusion, the results gained during the last 7 years of JUVENA campaigns suggest that **the best site to fish mesopelagic resource is during the day (less krill), in oceanic waters close to the continental shelf at 100 – 150 metres depth**.

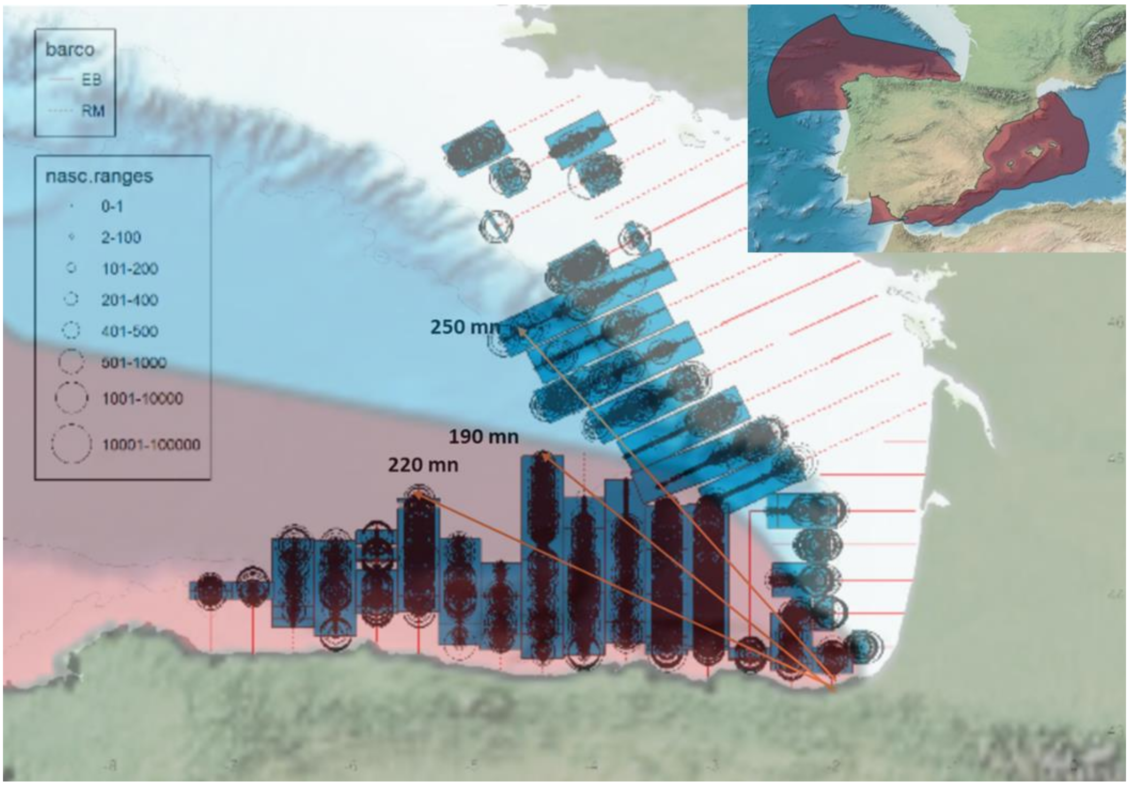

Figure 3: Fishing ground of M. muelleri s. In red Spanish Exclusive Economic Zone (EEZ). Source: Elaborated from (Boyra et al., 2019) and https://www.marineregions.org/gazetteer.php?p=details&id=5693

Technical Issues: The most suitable fishing gear is the '**pelagic trawl'** (Prellezo, 2018). Due to the size of the *M. muelleri*, the mesh size would be smaller than the current mesh size used by Basque fleets (70-mm). In the trials done by commercial vessels "Ligrunn" and "Liafjord" (Lie Gruppen AS) in Norway the **mesh size** was 11 – 12 mm; in other studies, considered a mesh size of 7 - 10 mm (Valinassab & Pierce, 2007; Sobradillo *et al.*, 2019). The legal mesh size depends on the fishery, and it is regulated by REGULATION (EU) 2019/1241. The **vertical opening** of the pelagic trawls carried out during JUVENA surveys were 15 m of vertical opening and fishing trawls were performed between 15 – 300 m depth at a mean speed of 4 knots (Sobradillo *et al.,* 2019). In de case of the trials executed by Lie Gruppen AS, the average bottom depth was 195 – 338 m, the trawl horizontal opening from 45 to 100 m, and the vertical opening from 36 to 80 m. Technical issues depend on the size of the vessels and also on the specific characteristics of the engine of the boat.

Regulation: The 'pelagic trawl' means a trawl designed and rigged to operate in midwater (REGULATION (EU) 2019/1241). But the use of **pelagic trawl fishing is restricted** by the regulation. At national level, according to the Art. 1 of the regulation (Orden de 10 de mayo de 1988; Real Decreto 1441/1999) the use of pelagic or semi-pelagic trawl is forbidden to Spanish vessels in the national sea of Northwest and Cantabrian Sea for the exercise of maritime fishing. Note that this is only for the national fishing ground, that is to say that trawlers with permission to fish in fishing grounds other than this can use pelagic trawling. At European level there are also limitations, for example, directed fishing for anchovy using pelagic trawls in ICES division 8c shall be prohibited. Depending on the geographical dimension, the meso-pelagic fishery may

be more or less restricted by regulation and need to be explored the possibility to modify the regulation and the procedures.
The regulation on the conservation of fisheries resources and the protection of marine ecosystems through technical measures (REGULATION (EU) 2019/1241) establishes the conditions in relation to mesh size specifications, and the percentages of the species shall be without prejudice to the obligation to land catches in Article 15 of Regulation (EU) No 1380/2013. The regulation of the bycatch could also limit the commercial exploitation of the mesopelagic fishery because in the selected area for mesopelagic fishery there could be dolphins.

Management: As a new mesopelagic fishery may be conducted either as a new and additional season for today's deep-sea pelagic fleet or by specialized vessels for a year-round mesopelagic fishery, the alternatives represent different capacity adaptations and institutional implications for the management regime (Standal & Grimaldo, 2020). While most commercial fish stocks in the north Atlantic are regulated with TAC's (total allowable catch), access regulations and IVQ's (individual vessel quotas), harvesting mesopelagic resources, such as *M. muelleri* represents a clear exception. Neither TAC's nor rules for bycatch are implemented (Standal & Grimaldo, 2020). The mesopelagic resource management need to be addressed before the economic analysis. But the reality is that to regulate a commercial exploitation of a resource that has never been exploited regularly and whose knowledge is still limited is it not a simple task. This evaluation comes from WP5.

5. FLEET SELECTION

The large-scale industrial actors outside the traditional fisheries domain are paying attention to the potential commercial exploitation of the mesopelagic resources. In this context it is expected the future fleet structure and industrial operations of a mesopelagic fishery to be comparable to that of the krill fishery in Antarctic waters (Standal & Grimaldo 2020). According to Aker BioMarine[2], exploitation of this fishery should be carried out by huge factory trawlers with full-fledged on-board processing plants for fishmeal, oil, etc. If this kind of new vessel is built, the investment will be around 9.7 billion EUR, with a daily catch rate of 500 tonnes, 200 operating days per year and a total catch of 100,000 tonnes per year and vessel (Standal & Grimaldo 2020). While the exploitation of the mesopelagic in Norway is oriented towards an industrial fleet, the Basque fleet it is not necessarily industrial and the onboard processing it is not always possible. The Basque fleets is composed by a total of 200 vessels[3], and operates over the whole world. The Basque fleet segments main characteristics are described in Table 3.

[2] https://www.akerbiomarine.com/
[3] https://en.eustat.eus/elementos/ele0000300/Characteristics_of_the_fishing_fleet_in_the_Basque_Country_by_type_of_fishing_according_to_province/tbl0000377_i.html

Table 3: Basque fleet main characteristics and suitability for the exploitation of mesopelagic fishery.

Fleet (nº vessels in 2018)	**Fishing Gears**	**Main target species**	**Vessel Length (m)**	**Area**
Inshore fleet (156)	Purse seiner, troll lines, vertical lines, set longlines & gillnets.	Mainly pelagic species (anchovy, mackerel sardine, etc)	[13, 37]	8abdc & 7
Deep sea fishing (17)	Bottom otter trawl, pair trawl, longlines & gillnets	Mainly demersal species (hake, megrims, etc) and to a lesser extend cephalopods and some pelagic species.	[17, 42]	6, 7 & 8abd
Tuna freezer fleet (25)	Purse Seiner	Tuna (Skipjack, yellowfin tuna and bigeye)	[50, 55]	Indian and Atlantic ocean
Cod Fishing (2)	Trawls	Cod and haddock	[48, 56]	1 & 2

OTB_COD operates in Norwegian and Barents Sea (corresponding to areas 1 and 2), OTB & PTB operates in Bay of Biscay, Northwest Coast of Scotland and North Ireland (corresponding to areas 8 and 6) and inshore fleet operates mainly in the Bay of Biscay (area 8) (Figure 4). Assuming that mesopelagic biomass in the Bay of Biscay is located at 10 nautical miles (after the continental shelf), at that location not all vessels are allowed to operate, so the selection of the fleet must be restricted. Basque OTB & PTB operate in national and in non-national (but EU) fishing grounds. In both fishing grounds operate Bottom Trawlers and Pair Trawlers, and those are the fleet that this study is focused on. Additionally, fleets involved in the Cod fishery are also able to operate in this target mesopelagic area.

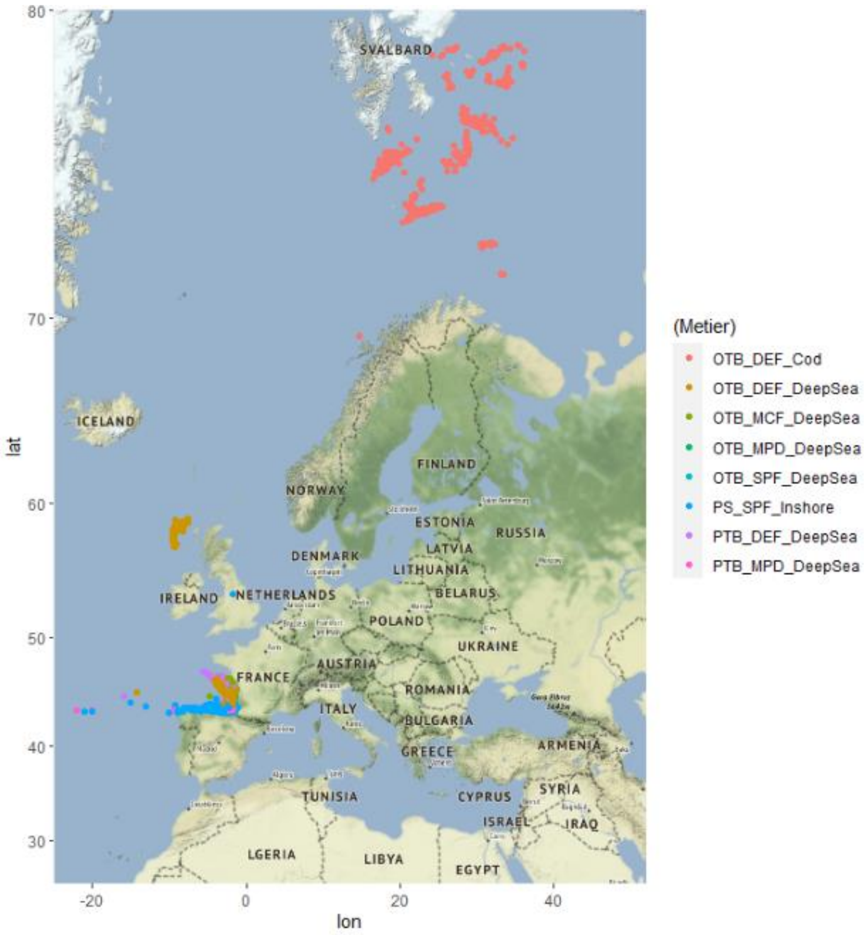

Figure 4: Location of the Basque fleet fishing operation from 2016 to 2018. OTB_DEF refers to Bottom otter trawl directed to demersal fish; OTB_MCF refers to Bottom otter trawl directed to demersal fish, OTB_SPF refers to Bottom otter trawl directed to Small Pelagic fish, PS_SPF refers to Purse Seiner directed to Small Pelagic Fish, PTB_DEF refers to Bottom pair trawl directed to demersal fish, and PTB_MPD refers to Bottom pair trawl directed to mixed pelagic and demersal fish. The numbers after de metier names refer to the vessel length in meters. Source: AZTI.

All those segments can be retrofitted to target mesopelagic resource, but those with a lower initial investment requirement are the trawler segment (Deep Sea fishing and Cod Fishing). To select which one is the most suitable to allocate effort to mesopelagic fishery, the fishing area, fishing gear, capacity of the vessel and seasonality of the fisheries was assessed[4]:

- Tuna Freezer fleet (Purse Seiner Freezer PS_F): On average the freezer tuna vessels have 25 crew members per vessel. The average tonnage is 1 566 GRT and the average power is 4 358 Kw. The main target species are yellowfin (*Thunnus albacares*), bigeye (*Thunnus obesus*), skipjack (*Katsuwonus pelamis*) and albacore (*Thunnus alalunga*). Their activity is carried out in the tropical waters of the Atlantic Ocean (in the area of the Gulf of Guinea) and the Indian Ocean (from the East coast of Africa to the Chagos Islands). **PS freezer operates outside the case study area**, and the license for fishing in European Watters should be explored. Additionally, although being big industrial vessels, the **type of vessel is not suitable for the use of pelagic trawl**. A high investment should be do for adapting this fleet to mesopelagic fishery. Thus, due to the **high financial risk,**

[4] https://www.europarl.europa.eu/RegData/etudes/note/join/2010/431583/IPOL-PECH_NT%282010%29431583_EN.pdf

unsuitable fishing gear and unsuitable fishing area, Purse Seiner Freezer fleet is discarded from this study.

- Inshore fleet (Purse Seiner: PS): On average, the inshore fleet has seven crew members per vessel. Although there is a great deal of diversity, the average tonnage is 64 GRT and its average power is 305 HP. The most important method is 'surface fishing', which catches migratory pelagic species with purse seines, or 'cacea' with troll lines. The main target species for surface fishing are mackerel, anchovy, sardine, albacore and bluefin tuna, and a great variety of other coastal species. Around 75 % of the inshore fleet is dedicated to small-scale fishing. The gear used by the small-scale fishing is quite selective and includes troll lines, vertical lines, set longlines or gillnets. The target species for the small-scale fleet are quite diverse. This fleet it is **not suitable for the pelagic trawl**, and the required investment for retrofit the vessels would be very high. Thus, due to the **unsuitable fishing gear, Inshore Purse Seiner is not suitable for mesopelagic fishery exploitation**.

- Deep sea fleet (Otter and Pair trawlers: **OTB & PTB**)**:** The average crew of the deep-sea fresh fleet is 12 per vessel. The average tonnage is 207 GRT and the average power is 595 HP. This sector is among those that have been affected by the adverse circumstances in recent decades. It has been directly affected by the limitations of access to resources. Traditionally they fished in Gran Sol, the Irish Sea and the 58th Parallel North. In 1977, with the extension of the EEZs (Exclusive Economic Zones), their activity was very much restricted. The gears are 'Bakas', trawls, 'pair trawling' and into a lesser extent longlines or gillnets. The main target species are hake, monkfish, megrim, mackerel, and other species. This fleet can use the pelagic trawl with a lower investment than aforementioned fleets, and the impact of the recent regulations (landing obligation) on this fleet will drive to this fishery to seek for solutions. Then, the **viability of this OTB & PTB for the mesopelagic commercial fishery is explored**.

- Cod Fleet (Otter trawlers: **OTB_COD**)**:** On average, the cod fleet has 25 crew members per vessel. The average tonnage is 825 GRT and its average power is 1,800 HP. Its activity is essentially focused on Arctic cod and haddock in waters of the northwest Atlantic. The Basque cod fleet has seen a decline in line with the state of resources and the reduction in quotas. It is now no more than a shadow of what it was decades ago, and it currently only has two vessels. It should be considered that in 1973 there were 73 cod boats in the port of Pasajes. Before the crisis in cod resources, there was a great deal of concentration in terms of businesses in the cod fleet. At the end of the 1960s, Pesquerías y Secaderos de Bacalao de España (PYSBE) (Spanish Cod Fisheries and Curing Businesses) owned a fleet that represented more than 23 % of the tonnage of the fleet of the port of Pasajes. It also had its own wharf and cod curing factories. The crisis began at the end of the 1960s with a drastic reduction in catches. The PYSBE vessels were specialised in cod salting with few or no possibilities of focusing their activity on other target species. As a result, PYSBE issued a statement of financial difficulties in 1974 and suspended its activities. The wharf franchise went back to the State and the facilities were destroyed. Subsequently, when Norway and Canada extended their EEZs in 1976, the situation deteriorated. In addition, the increase in purchasing power in Spain at the end of the 1970s meant that consumption could be directed towards other products. The price of cod fell and stocks of 'unfinished' cod (salted but not dried) accumulated. The decline in this sector manifested itself in both ageing and lack of renovation in this sector of the fleet and in the decline in fishing activity in ports such as Pasajes. Currently activity in the sector has considerably reduced to only three – five months per year. Although the fleet has a Northwest Atlantic Fisheries Organisation (NAFO) quota for Greenland halibut in the Northwest Atlantic, its activity is essentially focused on Arctic cod and haddock in waters of the northwest Atlantic (Martín, 2010). This fleet can use the pelagic trawl with a lower investment than purse seiner fisheries, and the size of the vessel are larger that deep sea fleet, the **viability of this OTB_COD for the mesopelagic commercial fishery is explored**.

Seasonalitiy: The fishing activity of the selected fleet (OTB, PTB & OTB_COD), in terms of days of active fishing days, is lower during summertime (June, July and August) (Figure 5).

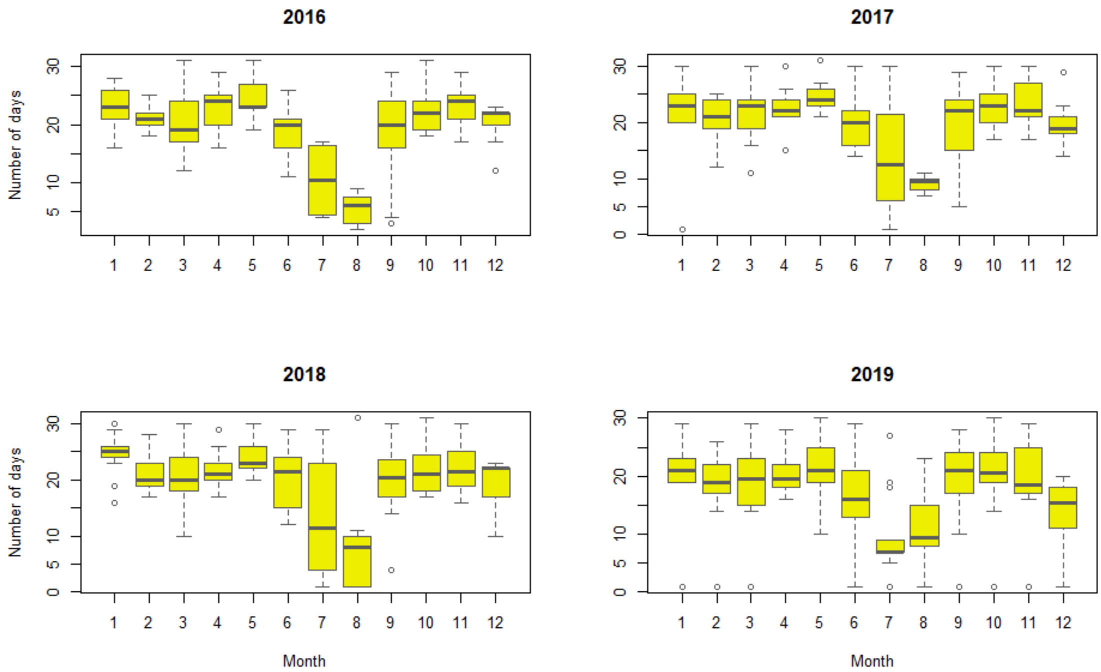

Figure 5: Fishing effort by month and year of the selected fleet (TF & CF). Source: Estimated from AZTI database.

- **Gross tonnage and storage capacity**: the gross tonnage and storage capacity will limit the amount of catch in each fishing trip. The storage capacity of the OTB is around 50 tonnes (Prellezo, 2018), for the PTB is also approximately 50 tn each vessel (100 tonnes both), for the OTB_COD the storage capacity is estimated to be more than 500 tonnes. The storage capacity is lower than the storage capacity considered in Norway (Standal & Grimaldo, 2020). In the case of Bay of Biscay, the mesopelagic resource is located close to the coastline, then fishing trips could be shorter thus a lower storage capacity is required (lower than the fisheries of Iceland or Norway).
- **Affected by the landing obligation**: If the vessel is highly affected by LO, they can exhaust the quota rapidly leaving time for the exploitation of new fishery. On the contrary, if the LO does not limit the fishing effort of the fleet, they could not be interested on changing to a new activity because the opportunity costs would be high.

- **Opportunity costs:** The higher opportunity costs the lower willingness of ship owner to change the activity. The seasonal definition of the mesopelagic fishery is conditioned by the opportunity costs. Mesopelagic fishery could perform during the whole year or only during one season of the year. It will depend on the seasonal availability of the resource and the current effort dynamics of the selected fleet. If the selected fleet is inactive for some months a year, they can allocate the fishing effort to mesopelagic fishery only those months because the opportunity costs are low. It is the case of OTB_COD, that operates 5 months a year and they have no fishing activity for 7 months a year.

A prior filter was carried out to select the most suitable vessels for each select fleet segment (OTB, PTB and OTB_COD). The selection of the most suitable vessels has been done on the basis of gross tonnage, length, age of the vessels, if the vessel performance is affected by the landing obligation and additionally, an expert opinion (technical expert that know the ship owner and the vessel operations) and the number of months without fishing activity, as Table 4 shows.

Table 4: Prior filter to select the most suitable vessel of each fleet segment. Colour code denotes suitability degree from highest (in green) to lowest (in red).

Vessel ID	Metier1	Metier Code	Gross Tonnage (GT)	Length - metres	Age of the vessel (in year 2020)	Affected by LO (1 =Low; 2 = Medium; 3 High)	Expert opinion	Number of months without activity
1	PTB_MPD	1	195	26	25	3	1	1
2	PTB_MPD	1	254	29	20	3	1	1
3	OTB_DEF	2	429	38,5	14	2	3	0
4	OTB_DEF	2	960	56,2	32	1	2	5
5	PTB_MPD	1	254	29	20	3	1	1
6	OTB_DEF	2	835	47,75	14	1	2	5
7	OTB_DE	2	387	37	16	3	2	1
8	PTB_MPD	1	195	26	25	3	1	1
9	PTB_DEF	1	432	39	12	2	2	2
10	OTB_SPF	2	432	39	14	2	2	2
11	OTB_DEF	2	441	40	19	3	2	1
12	OTB_MCF	2	476	42,5	17	1	2	2
13	PTB_DEF	1	372	37	14	1	2	0
14	PTB_DEF	1	372	37	14	1	2	0
15	OTB_DEF	2	409	38,5	17	2	2	1

Ship owner willingness to exploit a new resource is vital for selecting a specific vessels. The assessment of the willingness is analysed through a survey done to the fisher (see ANNEX I). This survey conducted to OTB & PTB and OTB_COD fleet segments. In the case of **OTB, the 100% of the surveyed sample showed a low willingness** regarding to the mesopelagic fishery (sample that represents the 20% of the selected vessels of this fleet). The **PTB** fleet segment would not catch a resource if the first sale price is about 0.7 EUR/kg since the average price of their fish landings is currently around 2.7 EUR/kg. In summary, **PTB fleet segment willingness is conditioned to the market price of the mesopelagic resource**. The surveyed ship owners of the **OTB_COD** fleet segment (the sample represent the 100% of the fleet segment) **showed willingness** only if the fishery is profitable, but they express that there are a lot of uncertainties that should be solved.

The selected fleet segments are OTB_COD and PTB.

6. CURRENT ACTIVITY OF SELECTED FLEET SEGMENTS

In this section the actual activity of the selected fleets segments is described.

- **Segment 1 – OTB_COD**: In this case there are only two vessels operating in the Basque Country. Due to the rules on statistical confidentiality, economic data of this fleet segment cannot be presented. Then, data regarded to this fleet is an estimation derived from data of similar vessels from the AER (equivalent to OTB_DEF_>=120_0_0[5] fishing Cod fleet segment) and Regional[6] and National statistics.

- **Segment 2 – PTB**: Effort and catches are derived from the Loogbook data, economic data from the AER (equivalent to PTB_DEF >=70_0_0 fleet segment) and Basque Official statistics and prices from sale notes.

Data in this section is based on average vessel.

6.1. Effort & catches

OTB_COD: the shipping autonomy of these vessels are 60 days, so it will be their longest trip, but they usually last from 20 to 45 days per trip. This fleet segment operates 5 months a year. The rest of the year these vessels do not have fishing activity (Figure 6). Then, it seems reasonable to allocate around 5 or 6 moths to the mesopelagic fishery. The main target species of this fleet segment is cod, but they also catch other species such as GHL (*Reinhardtius hippoglossoides*), HAD (*Melanogrammus aeglefinus*), PLA (*Hippoglossoides platessoides)* and REB (*Sebastes mentella*).

[5] See page 8 for metier definition: https://datacollection.jrc.ec.europa.eu/documents/10213/891027/2018_Workshop_DCF+Metiers.pdf/6b928c8a-c2ac-4507-840c-98155e0f07d9?version=1.0

[6] https://www.euskadi.eus/estadistica/cuentas-economicas-macromagnitudes-del-sector-pesquero/web01-a2estadi/es/ -> Data of COD fishery only before 2000.

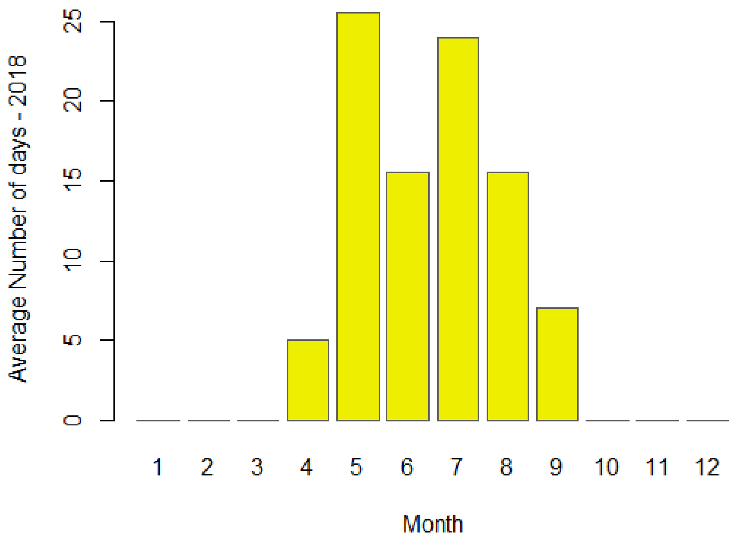

Figure 6: Estimation of effort (measured in days) and catches by species of the OTB_COD fleet segment. Source: Estimation from AZTI data base from Logbooks.

PTB: The main target species of this fleet are HKE (*Merluccius merluccius*), WHB (*Micromesistius poutassou)* and MAC (*Scomber scombrus).* This fleet segment has activity in all the months, or around 11 months a year, so the mesopelagic fishery would replace another fishery. In this case, they have two options: allocate all its effort to mesopelagic fishery or just some months a year.

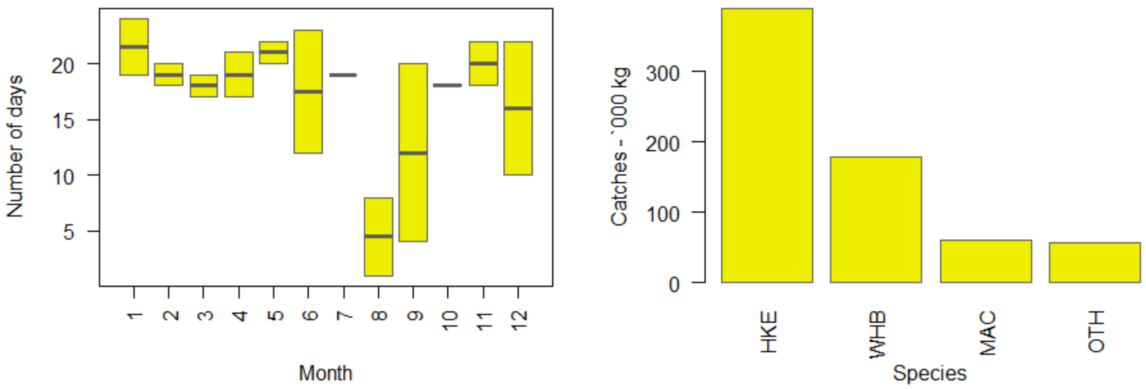

Figure 7: Effort (measured in days) and catches by species of the PTB fleet segment. Source: AZTI data base from Logbooks.

6.2. Prices & income

OTB_COD: The OTB_COD fleet segment will exploit the mesopelagic fishery only that period when this fleet is not fishing. In this period catches are null, so that it is not required prices for the analysis because the income in this period is 0. In any case, the minimum price according to the survey ranges from 0.7 to 1 EUR/kg. According to (Sogn-Grundvåg & Zhang, 2020), the cod ex-vessel price can reach the 3 EUR/kg, but this reference is for another fleets. If the mesopelagic fishery is related to this season without fishing activity, the current income of this fleet is 0, no income, so they only incur in cost (fixed costs).

PTB: The average prices of the main target species are shown in Table 5. The average income by month is around 200,000 to 300,000 EUR/month/vessel. In August and September, the income is lower because the crew need to rest for summer holidays (Figure 8).

Table 5: Average prices (years 20017 – 2019) of the main target species of PTB fleet. Source: Estimation fron the First Sales Notes.

Specie	Average price EUR/kg
Hake	2.6
Atlantic John Dory	11.1
Mackerel	1.5
Other speciese	2.9

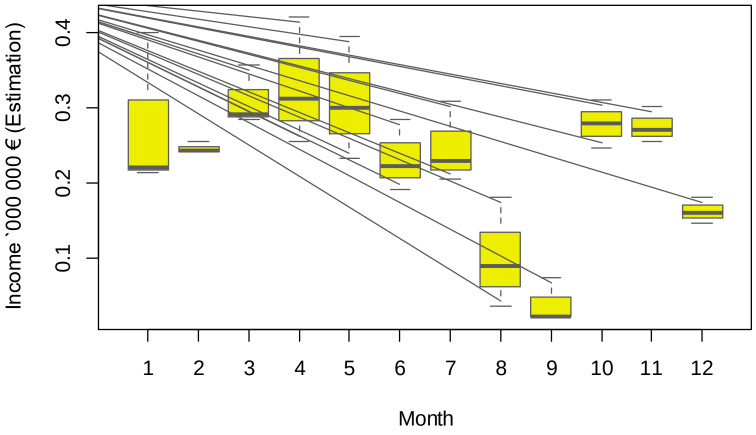

Figure 8: Estimation of monthly income of fishing activity of PTB fleet segment. Source: Estimation from Azti database.

6.3. Costs

OTB_COD: In the case of this fishery, the costs in the considered period are fixed costs and capital costs. Cost is estimated from AER for the segment DTS_VL40XX operating in supra region 27. Note that variable costs are assigned only to those days with fishing activity and fixed and capital are assigned to each day of the year (with and without fishing activity) to estimate the cost of that period without fishing activity (Table 6).

PTB: Cost data of these fleet segments are the average of years 2014 – 2016 from the AER. As far as effort is concerned, data source is data base of AZTI (logbooks).

Summary table

The income of the fishing activity is divided by fishing days because is when the value is generated. In the case of other income, the unit is EUR/365 days, because the allocation of this value is assumed homogeneous throughout the year. In the case of variable costs, they are allocated homogeneously only between fishing days, but fixed costs and capital costs are allocated homogeneously along the year. This distribution in done to ease the allocation of costs in those seasons that some segments does not have fishing activity (Table 6).

Table 6: Estimation of income, cost, and employment of by fleet segment for the actual fisheries in the period that the mesopelagic fishery could carried out.

	OTB_COD	PTB	SOURCE
Effort (nº fishing days)	150	200	Survey/AER
Income (€/fishing day)	0	14,000	AER + Survey + First sales notes
Other income (€/day (365))	0	89	AER
Crew share (% over the income)	30	33	Survey/AER
FTE	0	12	Survey/AER
Energy costs (€/fishing day/vessel)	0	895	These data are included in variable costs
Variable costs (€/fishing day/vessel)	0	591	AER
Fixed costs (€/days(365)/vessel)	2,456	486	AER
Capital costs (€/days(365)/vessel)	1,167	133	AER

Note that the fishing trip for PTB last 6 days and in the case of OTB_COD the trip last 20 to 45 days (with a maximum of 60 days that it is the maximum autonomy of the vessel). The effort allocation to the new mesopelagic fishery can be done considering the year round or just a season of the year, it depends on the fleet. Regarding OTB_COD, it seems reasonable to consider only those months (6 – 7 months a year) when the fleet is halted. In the case of PTB, vessels operate the whole year, and they only rest 10 days for Christmas holidays and 30 days in summertime, the average effort is considered 200 days/year.

7. POTENTIAL COMMERCIAL EXPLOTATION MESOPELAGIC FISHERY

7.1. Exploitable biomass and CPUE

Exploitable biomass: The historical estimation of biomass of *M. muelleri* goes from 132 000 to 260 000 tn (Boyra et al., 2019). The exploitable biomass and the quota allocation will define the fishing season duration for each fleet. At this stage there is no knowledge about the quota or the amount of exploitable biomass. Then, assumptions need to be done. In line with the storage capacity (SC), the following scenarios have been defined:

- **Scenario SC1**: The vessel can fill the 100% of the storage capacity in each fishing trip.
- **Scenario SC2**: The vessel can fill the 75% of the storage capacity in each fishing trip.
- **Scenario SC3**: The vessel can fill the 50% of the storage capacity in each fishing trip.

7.2. Description of fishing operation

Fishing season duration: The required time to reach to the fishing ground can last 18[7] hours (assuming an average speed of 10 knots). Depending on the duration of the fishing season, the conservation of fish onboard will be different:

- **From 1 to 3 days**: Considering a fishing trip duration being a maximum of 3 days from the first harvest, the mesopelagic resource can be conserved in refrigerated sea-water tanks at 1.5 degrees of temperature or in boxes with ice, and then the landings need to be transported immediately to the processing plant. The problem in this case

[7] 1 knot = 1.1508 miles/hour; The vessel can be reach the 10 knots, then it can sail 11.5 miles/hour. For 200 miles the boat need 18 hours.

arises whenever the mesopelagic resource is captured together with, for example, krill, the mesopelagic fish can break down in only one day (*Pers. Comm*). In the case of the Basque Country, in waters outside the platform, the *M. muelleri* was the predominant species in the layers where it was distributed, being either isolated or mixed with krill (*Meganyctiphanes norvegica*) in smaller proportions (Boyra *et.al*, 2019).

- **More than three days**: In this case other methods of preserving *M. muelleri* should be explored.
  - **Silage** system on board. Fish silage is defined as a liquid product made from whole fish or parts of fish that are liquefied by the action of enzymes in the fish in the presence of an added acid. The enzymes break down fish proteins into smaller soluble units, and the acid helps to speed up their activity while preventing bacterial spoilage. Silage made from white fish offal does not contain much oil, but when it is made from fatty fish like herring it may be necessary to remove the oil at some stage. There are methods of making liquid fish protein, for example by adding enzymes or bacteria (FAO[8]). The hull-integrated silage solution that does not require a big boat, but instead capitalizes on available tank capacity by first creating silage of mesopelagic fish, separating the fish oil, and thereby evaporating the liquids that does not represent any economic value (Flow Solutions). Silage is an intermediate step between the raw material and fish meal – oil production. Fish silage is a brown liquefied product by the action of enzymes prepared by acidifying finely grounded whole fish or parts of fish.

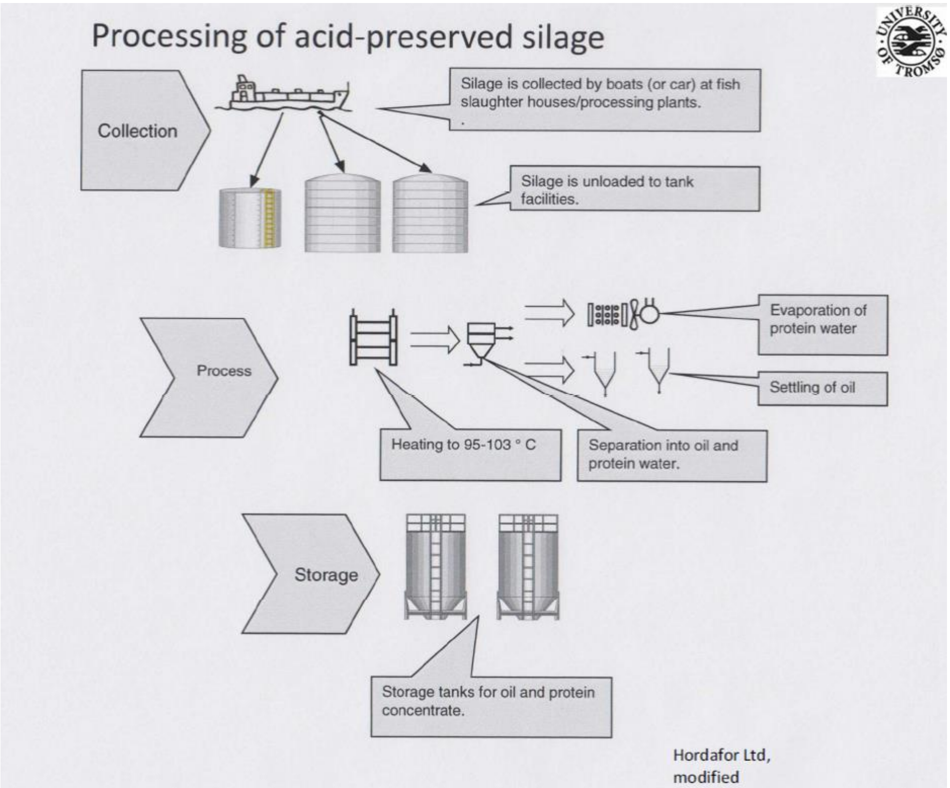

Figure 9: Silage: processing of acid preserved silage scheme.

[8] http://www.fao.org/3/x5937e/x5937e01.htm

The silage process results in a stabile product, which is usable as ingredient for livestock. However, during long term storage (longer than a week) the degree of hydrolysis is increasing strongly. This results in a low abundance of polypeptides, having the effect that no bioactivity is present. The product then has a lower added value in livestock feed application, in comparison to e.g., soy protein. The manufacturing process of fish silage needs lower investment costs than onboard fish oil and fish meal process, uses lower technology and lower energy and is more economical than that of fish meal. Stabilised fish silage can be kept at room temperature without the need of cooling. Fish silage is a convenient protein-rich ingredient used locally, but its high-water content makes long distance transport uneconomic. It can be produced in smaller places than fish meal plants. Fish silage is produced from fish of low commercial value, not suitable for consumption or further processing, and from by-products from fish processing (Rurangwa *et al.,* 2015). Then, if the oil is of high value, it may not be the best option

- **Onboard fish meal and oil process**: To process fresh raw material into valuable products like fish meal and fish oil, a processing equipment is needed. Fishmeal and oil normally have much higher value that the product derived from silage. Additionally, storage and transport are easier for fishmeal and fish oil. The required space and initial investment are described in Table 7, and in Figure 10 shows an example of fish meal and oil plant.

Figure 10: Example of onboard system to process fish oil and fish meal. Source: Hedinn.

Table 7: Onboard fish meal and oil investment estimation (Price estimate is without installation). Source: Hedinn.

	Capacity Ton/day	Rough budget for equipment €	Space for equipment W x L x H (m)
HPP-1000	25	1.700.000	5 x 8 x 5
HPP-2000	50	2.100.000	5 x 10 x 5
HPP-5000	125	4.200.000	6 x 12 x 5.5
HPP-10000	250	6.000.000	12 x 18 x 6
HPP-15000	350	7.000.000	15 x 20 x 7

One of the main problems of both types of onboard processing (silage and fish oil and meal process) is the space. The selected vessels of the Basque Fleets are not very large vessel, and those vessels may not have enough space for these facilities. Another problem is that in case of allocate the effort to mesopelagic fishery only one season a year (not during a year-round), the installation and deinstallation of this machinery may be costly.

For OTB_COD fleet segment it could be possible to install HPP-2000, but the problem is how to inset it in the hold. According to the survey, it is preferable not to do any investment on transformation plant in the first stage because the uncertainties of the fishery.

The simplest solution is to maintain the sea-water tanks at 1.5 degrees of temperature but given the environmental temperature at these latitudes (the sea water temperature in the fishing ground can range from 10 to 15 degrees), cooling water could be necessary, and this process is costly. The alternative and more suitable option is to **preserve the specimens in boxes with ice**. The **silage system** onboard can be used, and this option should be further explored for larger vessels than Basque ones. In general terms, it seems that to process fish – oil or fish – meal onboard requires a physical space that the Basque fleets do not have, then, this option is discarded.

The duration of fishing operation is determined by the method of the preservation onboard. If the conversation is done without onboard processing (i.e., in water or on ice), the first catches of the trip cannot spend more than three days without processing.

CPUE

To estimate the Catch Per Unit of Effort (CPUE) of a non-existing fishery, data from other commercial vessels which conducted mesopelagic fishing trials have been taken as a reference. The first commercial fishery in Iceland (MFRY, 2020), the Huginn vessel (Length = 75.21 m & Gross tonnage = 2724) exploited mesopelagic resource during 2009 – 2011. During this period, intermittent attempts have been conducted to fish for *M.muelleri* and the CPUE was estimated to be from **0 to 40 tn/hour** approximately. A second reference was the trials carried out by a pelagic trawl vessel with 62 metres length in Norway (estimation from Lie Gruppen AS data provided by Sintef). In the latter, the CPUE average was around 1 - 102 tn/set (**0.4 -16 tn/hour).** In one set the tow duration ranged from 2:25 to 9:09 hours (average of 5.5 hours) (see Table 8 for more details). Applying a tow duration of 6 hours, a vessel can perform about 3 sets/day, reaching a maximum catch of *M.muelleri* of **216 tn/day** (3 sets x 6 hours x 16 tn/hour). In Iceland catches the CPUE ranged from 5 – 25 tn/hour, with a maximum of **275 tn/day** (3 sets x 6 hours x 12 tn/hour). It is clear that the CPUE depends on the biomass abundance and the typology of vessel, parameters still uncertain for the Bay of Biscay case study.

Table 8: Data of Lie Gruppen AS and Iceland mesopelagic fishery. Source: Estimation from data of Lie Gruppen AS provided by Sintef.

	Lie Gruppen AS		Iceland	
	Min	Max	Min	Max
Tow duration	2:27	9:09		
Average bottom depth	193,5	337,5		
Trawl horizontal opening	45	100		
Trawl vertical opening	36	80		
Average sampling depth	90	222,5		

Average speed	2,5	3,6		
Total catch (kg)	1,010	102,225		
Catch (kg)/hour	412	15,567	5,000	25,000
Catch (kg)/hour - *M.muelleri*	364	12,183		

The estimation of the **CPUE** of selected **Basque fleet segments** has been done considering that a vessel spends approximately 18 hours to arrive to the fishing ground, and the vessel can spend 50 hours fishing (72 hours (3 days) – 18 (hours needed to return) – 4 hours (error)). From those 50 hours, the tow time is estimated to be 45 hours approximately[9]. Catches of *M. muelleri* by hour (CPUE) ranges **from 0.4 to 16 tn/hour** (we took the reference of Lie Gruppen AS, because the vessels of Iceland were much larger than selected fleet - Table 8). This means that **a vessel can catch from 18 to 720 tn per trip.** The scheme of the fishing operation is shown in Figure 11. These data should be used with caution because in this case study are not trials with our own commercial vessels, but we used trials from other areas to estimate the costs and catches.

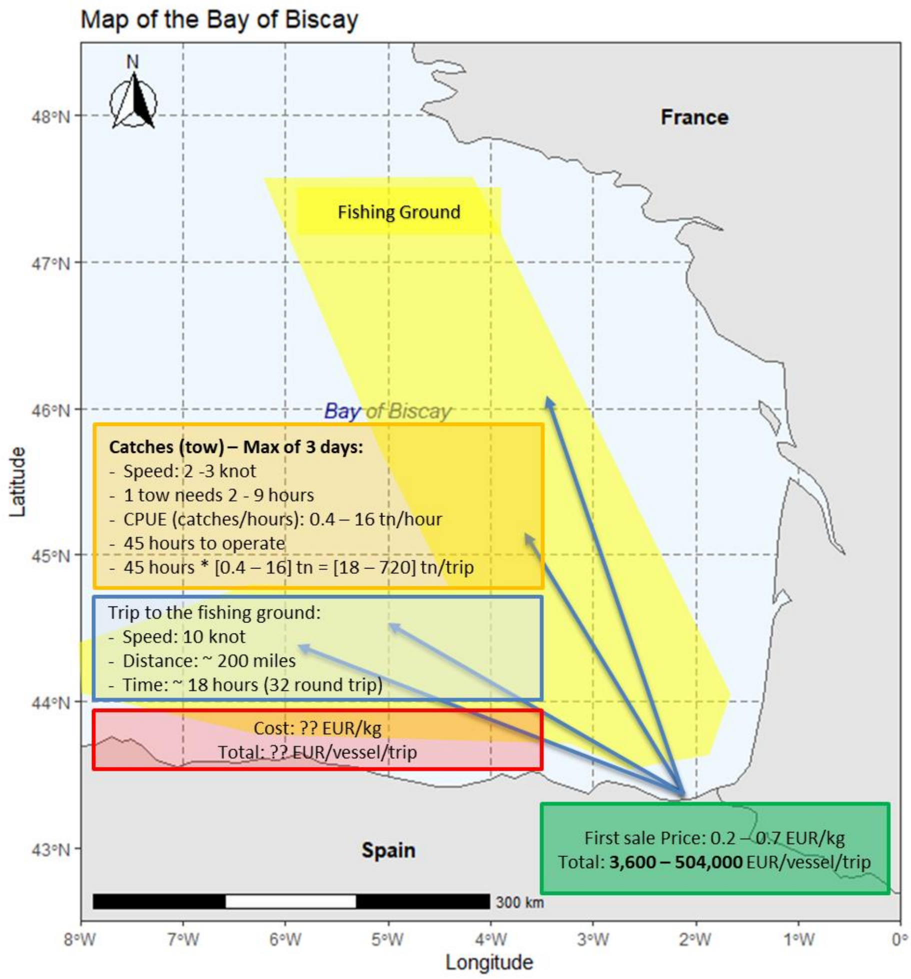

Figure 11: Scheme of the fishing operations to the Bay of Biscay basis on the existing data provided by Lie Gruppen AS and Iceland .

[9] Three set of 6 hours of tow, 3 set/day during 2 days and half result into 45 hours.

Storage capacity and CPUE:

<u>OTB_COD</u>: The fishing trip for this fleet last from 20 to 40 days currently, with and storage capacity of 40 - 50 tn/day (data from survey). The estimation of storage capacity is approximately 1,400 tn. If we divide this figure between 3 days (maximum days to maintain the resource in good conditions), the catch per day can reach a maximum of **<u>470 tn/day</u>**. Considering all estimation of the catch per day, in this analysis the harvest scenarios for the OTB_COD fleet are:

- **OTB_COD_SC1**: Catches of 470 tn/day (fishing day).
- **OTB_COD_SC2**: Catches of 350 tn/day (fishing day).
- **OTB_COD_SC3**: Catches of 230 tn/day (fishing day).

<u>PTB:</u> The storage capacity of this fleet is about 50 ton per vessels, as the bottom trawling operate in pair, then the total storage capacity is double and estimated about 100 tn (33 tn/day in mesopelagic fishery trip). Then, the scenarios that will be explored are:

- **PTB _SC1**: Catches of 30 tn/day (fishing day).
- **PTB _SC2**: Catches of 20 tn/day (fishing day).
- **PTB _SC3**: Catches of 10 tn/day (fishing day).

According to the estimation of CPUEs, the total catches by fleet segment in each scenario are shown in Table 9.

Table 9: Scenarios of catches for each scenario and each fleet.

Scenario	OTB_COD *(*)*	PTB *(**)*
SC1	470 tn/day * 75 days ~ 35,000 tn/year/vessel	30 tn/day*157 days ~ 5,000 tn/year/pair of vessels
SC2	350 tn/day * 75 days ~ 26,000 tn/year/vessel	20 tn/day*157 days ~ 3,000 tn/year/pair of vessels
SC3	230 tn/day * 75 days ~ 17,000 tn/year/vessel	10 tn/day*157 days ~ 1,600 tn/year/pair of vessels

(*) Days for OTB_COD: 5 month a year ~ 150 days. The fishing trip is around 4 days, and we consider two days for rest, thus the total fishing trips are 25 trip/year, and the effective fishing days are 75 days/year.

*(**) In the case of PTB, in 3 days they can catch a maximum of 100 tn. Then, in three days a maximum of 33 tn. Considering the whole year, 365 days minus 10 days of holidays in winter and 30 days in summer is 315 operating days. Fishing trips is 4 days, and capturing days are 3, and then they rest two days results in 157 fishing days a year ([315/6 (trip + rest)]*3 fishing days).*

7.3. Retrofit of the vessel

For the exploitation of mesopelagic resources, existing vessels need to be retrofitted. On the one hand, the fishing gear need to be adapted to the new fishery, and on the other and in the case of onboard processing, the processing plant need to be acquired. In this study, the onboard processing has not been considered due to the space constraints and the high initial investment required.

- **Fishing gear**: The mesh size would be chosen as a compromise between maximizing the trawl's catch area and reducing the total drag of the trawl (Grimaldo and Grimsmo, 2020). To fish the mesopelagic species, a mesh size of 10 mm should be used. The price of such net is the same as for the currently used ones (circa 6000 EUR) (Prellezo *et al.*, 2018). But the design of such a net should be carefully studied because the technical characteristics of the net will impact on the fuel consumption during the fishing operation. Note that 10 mm mesh size is much smaller than the size that the selected fleets are presently using, and the resistance to the water is higher due to the lower water filtration. The towing cable length will depend on the depth at which the resource inhabits, and in this case that the resource is located from 300 to 50 metres depth, the cable should be about 300 to 1,800 metres (with a proportion of 1 metre depth x 6 metre cable length). The investment in net is estimated to be around 10.000 EUR (pers. Comm). According to the consulted fishing gear designer (NABERAN, pers. comm.), investment in the new gear can reach **250,000 EUR for OTB_COD**, this figure includes the net and the complementary equipment for the fishery. The investment will be **125,000 EUR/vessel for PTB**.

- **Suction pump** to haul the fish aboard. The new gear and the suction pump are considered a new investment (Inv) with an amortization period (AP) of 10 years and the same depreciation scheme as for the previous capital investment (Prellezo et al., 2016). This new investment is approximately 20,000 EUR[10].
- **Acoustic system** to identify where the resource is located. The standard multiband scientific acoustic equipment would cost about 250,000 euros including the range of useful frequencies (in the attached budget it would include all frequencies except the highest one (333 kHz), which does not reach the range in which mesopelagic ones inhabit). Several vessels have its own acoustic system, and it can be not necessary to invest in a new one. **No investment in acoustic system.**
- **Training of crew:** According to the survey done to the ship owners, **the fishers will not need any additional training.**
- **Other:** The **5% over the total investment** is applied to 'other investment'.

Total initial investment is summarized in Table 10:

Table 10: Initial investment estimation for the mesopelagic fishery for each fleet segment; PTB_Cod and PTB.

	PTB_COD (EUR)	PTB (EUR)
Fishing Gear	250,000	125,000
Suction pump	20,000	20,000
Acoustic system	0	0
Initial training	0	0
Other	14,300	7,300
Total	**~ 285,000**	**~ 152,000**

7.4. Costs

Fuel costs: Considering OTB_COD, the fishing trips for mesopelagic fishery are shorter than the fishing trips for the cod fishery, but they need to make the trip every 6 days. Additionally, given the smaller mesh size that is required to capture the mesopelagic resource, the fuel cost of the tow is expected to increase. It is assumed that the fuel costs can vary from 0% to 100% with respect to the current costs.

Variable costs: Regarding OTB_COD, while the cod is processed onboard, the mesopelagic resource will not, and it will be stored in boxes with ice. Variable costs may be lower than for the cod. The variable costs for mesopelagic fishery are not easy to measure, so we will assume

[10] http://www.acuinuga.com/es/producto/bomba-de-extraccion-de-peces/

the same variable costs as current cost per day, but this figure must be accurate with a practical trial for this fishery. The same happens with the PTB fleet segment.

Crew costs: According to the survey, in the case of OTB_COD, their crew is 26, but in the case of mesopelagic fishery without any onboard processing, the crew can be reduced to 9, which is the minimum number of crew for this typology of vessel. Concerning PTB, the same crew costs are assumed.

Fixed costs: Fixed costs are assumed the same costs as the current fisheries for both fleets.

Transport: Since fish spoils quickly, the capture should be transported immediately to the processing plant after landing. The cost of this transport can be assumed by the fisher or by the transformation company. At the moment, it has not been established who will pay for this transport, thus we will not consider this cost.

Table 11: Estimation of income, cost and employment by fleet segment for the potential mesopelagic fishery.

	OTB_COD	PTB	SOURCE
INITIAL INVESTMENT	285,000	152,500	Estimation
EFFORT (Nº FISHING DAYS)	75	157	Survey/AER
INCOME (EUR/FISHING DAY)			Estimation
- MIN (0.2 EUR/KG)	46,000	2,000	
- MAX (0.7 EUR/KG)	94,000	23,100	
OTHER INCOME (EUR/DAY (365))	250	89	AER
CREW SHARE (% OVER THE INCOME)	30	33	Survey/AER
FTE	9	12	Survey
ENERGY COSTS (EUR/FISHING DAY/VESSEL)	2,364	895	Included in variable costs
VARIABLE COSTS (EUR/FISHING DAY/VESSEL)	3,861	1,388	AER
FIXED COSTS (EUR/DAYS (365)/VESSEL)	2,456	483	AER
CAPITAL COSTS (EUR/DAYS (365)/VESSEL)	1,167	132	AER

7.5. Value chain & Price

To estimate the potential price of the mesopelagic resource, the value chain of the actual substitutive product needs to be analysed. The price of the catches should cover all the costs (including opportunity costs) and the product price should accepted by the market. For that, the value chain of the potential final product was assessed considering the products that are already in the market such as Peruvian anchovy or krill. The current value chain of the fish meal and fish oil can be divided in three phases:

- Phase 1: Raw material (fisheries).
- Phase 2: Marine ingredients (transformation).
  - Phase.2.1: Fish meal and fish oil
  - Phase 2.2: Omega 3.
- Phase 4: Aquaculture feeds.
- Phase 3: Distribution to final consumer (aquaculture producers).

Phases 1 and 2.1 are often vertically integrated in the same company. Phase 2.2. is usually differentiated since there are companies like BASF[11] that process and refine the oils, producing food supplements or pharmaceutical products. However, an increasing vertical integration is

[11] https://www.basf.com/

taking place, for example, TASA[12] in 2015 has included an Omega 3 processing line. Another large company, Austevoll Seafood ASA[13], also has phase 1 and phase 2 (only phase 2.1) vertically integrated, that is, the company has its own vessels, captures the raw material, transforms it into fish meal and fish oil and commercializes these products for animal feed and aquaculture, and also commercializes it for the production of Omega 3 (Figure 12). Regarding phase 3 and 4, companies such as BASF distribute their products to parapharmacies, supermarkets, etc., and these, in turn, distribute it to the final consumer.

Figure 12: AUSS value chain. Source: AUSS.

Considering the business model of the existing fleets and producers of fish meal and fish oil, the potential price for the raw material (i.e. mesopelagic resource) has to cover the operational costs and the opportunity costs of the Basque fleet. To estimate the potential income for each kilogram captured, we analyse the margin obtained in each productive phase from one kg of mesopelagic biomass to its transformation into fish oil or fish meal. The cost of extraction must not exceed the cost of the raw materials plus the margin of the fish meal and fish oil processing industry. From one kilogram of mesopelagic biomass, it is estimated that 0.3 kg of fish meal and 0.06 kg of fish oil can be produced (Table 12).

Table 12: Conversion rates of fish into fishmeal and fish oil.

Product/Source	[1]	[2]	[3]
Fish (kg)	1	1	1
Fish meal (kg)	0.30	0.2	0.225
Fish oil (kg)	0.06	0.06	0.058

[1] IFFO, 2015. The Marine Ingredient Organisation. Issue 267. Narch 2015. UPDATE. http://www.iffo.net/system/files/Update%20-%20March%202015%20-%20267.pdf
[2] The Fish meal and Fish oil Industry, 2004.
[3]http://www.infopesca.org/sites/default/files/complemento/articulossel/49/Nro_49%20Cuanto%20pescado%20consume%20la%20acuicultura.pdf

To assess the maximum acceptable price of mesopelagic resource two approaches have been followed:

[12] https://www.tasa.com.pe/
[13] https://www.auss.no/

Approach 1

The literature indicates that the price per kilogram of fish-meal ranges from 1,1 to 1,6 EUR/kg (average 1,35 EUR/kg) and fish-oil price ranges from 1.8 to 2.1 EUR/kg (see Table 13). Following the conversion factor in Table 12, for each kilogram of raw biomass, the processing companies can have an income of 0.38 – 0.54 EUR (0.33 – 0.48 EUR of fish oil and 0.054 – 0.063 EUR of fish meal). The fish oil and fish meal processing costs are estimated between 0.11 to 0.24 EUR (Cotano *et al.*, 2016). Then, subtracting the **maximum price under this approach ranges between 0.14 – 0.43 EUR/kg** of raw material. This is the price in the case of zero margin of the processing industry.

Table 13: Price of fish meal and fish oil.

Concept	Price	Year	Source
Price – Fish-meal (€/kg)	2,1 (Super -Prime)	2014	AUSS
Price – Fish-meal (€/kg)	1,6	2014	AUSS
Price – Fish-oil (€/kg)	1,8	2014	AUSS
Price – Fish-meal (€/kg)	2,1 (Super -Prime)	2014	Globefish
Price – Fish-meal (€/kg)	1,3	Promedio 2014	The fish site
Price – Fish-oil (€/kg)	1,8	Promedio 2014	The fish site
Price – Fish-meal (€/kg)	1,2	2011	TASA
Price – Fish-oil (€/kg)	1,1	2011	TASA
Price – Fish-meal (€/kg)	1,4	2015	BROKER 1
Price – Fish-oil (€/kg) 28% EPA / DHA	2,5	2015	BROKER 1
Price _ Fish-oil to produce omega 3 (€/kg)	4	2015	News

Approach 2

The raw material costs (resource to produce fish – oil or fish meal such as anchovy or mesopelagic resource), for vertically integrated companies is estimated to be around 0.11 to 0.6 EUR/kg (the costs of raw materials account for between 70% - 80% of the total production costs) (Cotano *et al.*, 2016). In Denmark, the fish used to obtain oil can be paid at 0.62 and 0.7 EUR/kg, while in Chile the price is around 0.22 EUR/kg[14]. In general terms, the cost of the raw material (which can be an approximation of the price paid to fisher) can vary between 0.11 and 0.7 EUR/ kg (Table 14), figure that is in line with the price assumptions given in the literature (Prellezo, 2018).

Table 14: Estimation of the cost of the raw material to produce fishmeal and fish oils.

	€/kg	Year	Source
Raw material	**0,12**	**2015**	Avadí, 2015
Raw material	**0,24**	**2014**	Austral S.A.A. (Grupo Auss). Annual accounts AUSS.
Raw material	**0,11**	**2011**	Informe de TASA
Raw material	**0,12**	**2007**	TASA
Raw material (Krill)	**0,7**	**2006**	Luten, 2006.

Summarizing, and considering both approaches, the market price of mesopelagic resource can be between **0.2 and 0.7** EUR/kg.

[14] http://www.fao.org/docrep/003/x6899e/x6899e10.htm

8. SCENARIOS

There are several variables whose values are uncertain, so several scenarios are defined for catches, price and fuel costs (Table 15).

Table 15: Definition of scenarios.

Scenario	Fleet segment	Catches (tn/day)	Price (EUR/tn)	Fuel costs (%▲)
OTB_COD_CAT1_P1	OTB_COD	470 tn/day	200	0%, 1%, 2%.... 100%
OTB_COD_CAT1_P2			700	0%, 1%, 2%.... 100%
OTB_COD_CAT2_P1		350 tn/day	200	0%, 1%, 2%.... 100%
OTB_COD_CAT2_P2			700	0%, 1%, 2%.... 100%
OTB_COD_CAT3_P1		230 tn/day	200	0%, 1%, 2%.... 100%
OTB_COD_CAT3_P2			700	0%, 1%, 2%.... 100%
PTB_CAT1_P1	PTB	33 tn/day	200	0%, 1%, 2%.... 100%
PTB_CAT1_P2			700	0%, 1%, 2%.... 100%
PTB_CAT2_P1		20 tn/day	200	0%, 1%, 2%.... 100%
PTB_CAT2_P2			700	0%, 1%, 2%.... 100%
PTB_CAT3_P1		10 tn/day	200	0%, 1%, 2%.... 100%
PTB_CAT3_P2			700	0%, 1%, 2%.... 100%

9. RESULTS

9.1. Indicators

From the technical perspective, in the Basque Country there are three fleet segments that can be adapted (in terms of fishing gear) for the mesopelagic fishery (**OTB, PTB and OTB_COD**). But, given the potential low market value of the mesopelagic resource, there is only one fleet segment that could have enough storage capacity (**OTB_COD**), but there are doubts about the storage capacity of the other two fleets (**OTB and PTB**). Regarding to onboard processing, for **OTB and PTB** would be really difficult to install any onboard processing installation, but in the case of **OTB_COD** it could be possible.

From the social perspective, according to the survey there is only one of the fleet segments that showed interest in the mesopelagic fishery (**OTB_COD**), **PTB** showed limited interest (the price of 0.7 EUR/kg it is really low for them) and **OTB** showed no interest due specially to the size of the vessel and the difficulty for towing the net. The potential low price of the mesopelagic resource, the size of this fish and the knowledge gap of this fishery are the main drivers for the ship owners to that make the mesopelagic fishery unattractive to the sector.

Finally, the financial indicators were assessed only for those fleet segments that showed interest. Results indicate the net profit for **OTB_COD** is positive for all tested scenarios, which means that for this fleet could worth fishing mesopelagic species in those months that they currently do not have fishing activity. On the contrary, for **PTB** the mesopelagic fishery does not worth financially because the opportunity costs are higher than the profit of the new mesopelagic fishery. In the case of PTB, an additional simulation was carried out to estimate the required minimum price of mesopelagic resource to be the fishery financially viable, and the price should reach 1000 EUR/tn (see Figure 13).

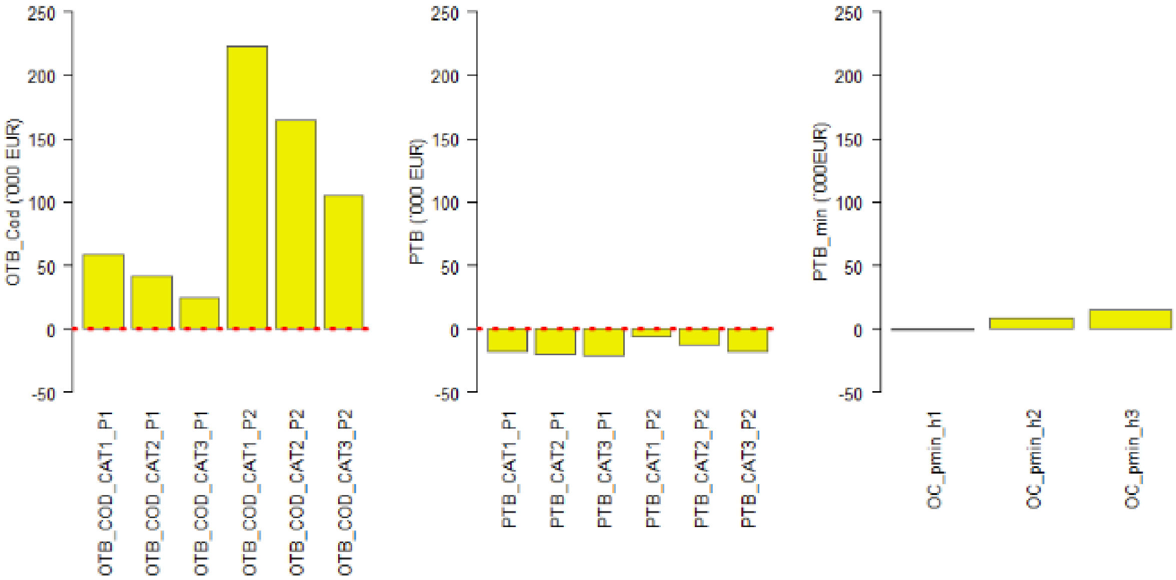

Figure 13: Net profit of the mesopelagic fishery (financial indicator). The plot on the left represents the scenarios for OTB_COD fleet segment, the plot in the middle represents scenarios for PTB. The plot on the right represents PTB fleet with the minim price of 1000 EUR/tn for each harvest scenario.

The Table 16 shows the summary of the indicators used to select the fleet segment. The technical issues limit greatly the potentiality of the fleet segments to deal with the mesopelagic fishery. Additionally, the social indicator shows how the uncertainties of the mesopelagic fishery and the low price of this resource disincentives the participation in this new fishery. Finally, the financial indicators are related to the storage capacity of the fleet segment, thus, only the OTB_COD gives a positive financial indicator to allocate its effort, to the mesopelagic fishery, but just during a season a year.

Table 16: Summary of the indicators.

Fleet segment	Technical (*)			Social	Financial
	VFG	SC	OP		
Purse Seiner Freezer (PS_F)	NO				
Inshore fleet (Purse Seiner: PS):	NO				
Deep sea fleet (Otter and Pair trawlers: OTB):	YES	NA	NO	NO	
Deep sea fleet (Otter and Pair trawlers: PTB):	YES	NA	NO	NA	NO
Cod Fleet (Otter trawlers: OTB_COD):	YES	YES	NA	NA	YES

(*) VFG: Viability of the fishing gear; SC: storage capacity: OP: Onboard processing. Colour codes: red refers a low viability, orange not low not high and green a high viability.

9.2. Risks

Risks of exploiting a new fishery, whose biomass and management measures are still unknown, cannot been neglected. Moreover, in the Bay of Biscay there has not been any commercial trial, so the catch per unit of effort it is still uncertain. For this reason, we have opted for fleets that require less initial investment, ruling out the construction of new vessels adapted to the mesopelagic fishery. In the short term it is unlikely that a ship owner to make a high investment in such an uncertain fishery. If the fishery would be profitable, then, a new vessel can be acquired. Even choosing the option that requires the least initial investment, there are several risk factors to take into consideration:

- The initial investment represents around 0.5% - 4% of the annual income from landing in the case of OTB_COD and PTB respectively. For PTB the percentage of the initial investment is higher, which in case of a not successful business, the sunk costs for this cannot be neglected.

- In the selected framework, costs of switching back have been minimized because we have considered short fishing trips without onboard transformation plant. In the case of OTB_COD the change of metier is temporal (i.e., the metier is switched during just one period a year, and then the traditional fishing gear is again applied), so if the fishery is not profitable, they just would not switch to the mesopelagic fishing gear anymore.

- Regarding to the metier, it is still under research what could be the optimal design of the mesh, so the design of the metier needs to be investigated for the selected fleet to optimize the fishing operation.

- The existing regulation it is another factor of risk for the fishery profitability. The optimal mesh size should be accepted by regulation.

- Regarding to the logistic, once the mesopelagic resource would be landed, the traceability to maintain the resource in a good condition need to be stablished and the transformation plant should be close to the harbour. If the logistic system would not be well established, the resource could deteriorate losing market value, with its associated risk for the fishing fleets.

- Management scenarios are uncertain, then, the catches are uncertain. How to regulate a resource that has never been regulated before and neither exploited continuously is an issue that need to be clarified to assess the commercial fishery from the economic perspective.

- The potential bycatch should be study, note that in the target area there can be protected species, and they can be affected by the mesopelagic fishery profitability.

9.3. Main conclusions

- Results gained during the last 7 years of JUVENA campaigns suggest that **the best site to fish mesopelagic resource is during the day (less krill), in oceanic waters close to the continental shelf at 100 – 150 metres depth**.
- The most suitable fishing gear is the '**pelagic trawl'** and the mesh size between 7 - 12 mm.
- There are regulations that need to be explored to outline the regulatory framework of mesopelagic fishery (legal mesh size, the use of pelagic or semi-pelagic trawl in the Bay of Biscay).
- The selected fleet segments, from the technical perspective, to exploit the mesopelagic resource in the Bay of Biscay are OTB_COD and PTB.
- In the short term, the investment in a new vessel is not contemplated due to the knowledge gaps make the perception of a large investment being highly risky.
- In that sense, we focused into short fishing trips that do not require onboard investment for onboard processing, which is possible for the Basque fleets due to the location of the biomass.
- The net profit of the mesopelagic fishery is positive for all simulated scenarios in the case of OTB_COD fleet segment, but for PTB the net profit is negative.
- The net profit for the PTB fleet segment would be positive only in the case that the price of the mesopelagic resource reaches 1 EUR/kg.

10.DISCUSSION

This study shed light on the main features to define and to shape the mesopelagic fishery in the Bay of Biscay and to identify all the information needed to overcome the uncertainties of this potential fishery.

There are studies that suggest that while mesopelagic exploitation is technically possible, it is not a viable alternative to the existing commercial fisheries because of the lower profitability of the landings (Hidalgo and Browman 2019). However the landing obligation regulation will limit the fishing effort leaving the possibility for excess capacity to be used to harvest mesopelagic species (Hidalgo and Browman 2019).

In that sense, in a first stage, is it important to select those fleets that could exploits mesopelagic resource with a minimum investment requirement to minimize the risks of a fishery with a high knowledge gap. Thus, it seems reasonable to consider (at least in the short run) existing fleet for a seasonal mesopelagic fishery with a fishing trip of 4-5 days without onboard transformation. If the profitability of this fishery would be enough to make additional investments in new vessels or new onboard transformation plant, it will be done in the medium

– long term. This fishery framework differs from other studies that expect to develop huge factory trawlers with full-fledged on-board processing plant for fish meal and fish oil (Standal and Grimaldo 2020).

It is important, when developing the framework for a profitable mesopelagic fishery business model, to consider not only the fishing activity, but also the whole value chain of the product including fishery managers, the fish-oil and fish-meal producers, aquaculture farmers and research and development institutions.

This assessment of a non - existing fishery has several points that need to be clarify for a realistic evaluation. A priory, the theoretical framework built here is useful to discards some options, but there are several questions that must make clear before starting commercial fishery.

The first question is the regulation framework. It is not obvious that the required fishing gear is allowed in the target area. Additionally, the mesh size is small, and the bycatches could be a problem.

The second question is about the management measures, how to manage a fishery that has not been exploited before? The impact of the fishery on the stock status is uncertain, and without this information sets up harvest control rules can be complicated.

Third, in this report we have done the analysis considering exclusively the existing vessels and proposing their retrofit. But the most efficient vessels should perhaps be new ones built especially for this fishery. This option will be risky, and it is unlikely that an investor decides to invest in this fishery unless the existing knowledge gaps are not clarified.

The fourth question is the hand processing onboard. In this study the selected fleet is composed by smaller vessels than the those in Norway or Iceland. No onboard processing is expected in the short term, but the onboard conservation of a such delicate resource needs to be examined. And additionally, the port facilities and the transport to the transformation plant are aspects that need to be also evaluated. Note that this kind of fisheries, whose catches are for fishmeal and fish oil production, are usually designed for large and industrial vessels which are integrated vertically into a big transformation company.

In any case, the mesopelagic fishery can be a new business opportunity. But according to Europe's new agenda for sustainable growth, the EU's transition to a circular economy will reduce pressure on natural resources and will create sustainable growth and jobs, achieving the EU's 2050 climate neutrality target and halt biodiversity loss[15]. Thus, the European Commission ("Blue Growth Strategy") is currently open to the exploitation of new ocean horizons such as the mesopelagic[16] and support the development of the EU aquaculture sector that ensures the supply of food with a low environmental and climate footprint. Accordingly, the mesopelagic commercial fishery will be a sustainable business or otherwise, it won´t exist.

[15] https://ec.europa.eu/environment/strategy/circular-economy-action-plan_es
[16] European Commission, 2018

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ANNEX I: Questionnaire of the survey.

MESSO: Ecologically and economically sustainable mesopelagic fisheries.
ENTREVISTAS A LA FLOTA SELECCIONADA PARA UNA POTENCIAL EXPLOTACIÓN DE LA PESQUERÍA MESOPELÁGICA

OBJETIVO GENERAL: El objetivo es entender la estructura de costes de una posible pesquería mesopelágica para las pesquerías vascas.
DESTINATARIOS: Se ha preseleccionado la flota que se considera más idónea para explotar esta pesquería. En concreto, Bakas (Bottom Otter Trawls) y Parejas (Bottom Pair Trawls).

¿DEFINICIÓN DE POTENCIAL PESQUERÍA MESOPELÁGICA?
Los organismos mesopelágicos viven a profundidades de entre 200 y 1000 metros de profundidad. Han existido otras pesquerías mesopelágicas (por ejemplo, en Islandia, que capturaban a 500 metros de profundidad). Se estima una biomasa de entre 132 000 a 206 000 toneladas, aunque todavía está bajo estudio. La pesquería se realizaría probablemente a 10 millas naúticas (después de la plataforma continental). El arte de pesca idóneo para la explotación de los recursos mesopelágicos (ej: *Maurolicus muelleri)* es la red de arrastre pelágica, con un tamaño de malla de unos 10 mm. Según las pesquerías mesopelágicas que han existido, los lances pueden durar entre 2 - 3 horas ó 4 – 5 horas.
Las especies mesopelágicas irían directamente a su transformación para la producción de Omega 3 y harinas de pescado, por lo que una relación directa con una empresa de procesado en puerto sería interesante. Si bien las estimaciones del precio de especies que van directamente a su procesado para la producción de Omega 3 y harinas de pescado se puede situar entre 0,2 y 0,7 €/kg, se precisará un gran volumen de capturas por marea para que su explotación sea viable desde el punto de vista económico.

CONFIDENCIALIDAD:

	SI	NO
Doy mi consentimiento voluntario para participar en este estudio y entiendo que puedo negarme a responder preguntas y puedo retirarme del estudio en cualquier momento, sin tener que dar una razón.		
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Estoy de acuerdo en que la información proporcionada por mí puede citarse en resultados de investigación, como publicaciones científicas y presentaciones en conferencias.		

CUESTIONARIO

Perfil encuestado	Respuesta
Rol (armador, patrón, etc)	

¿Cuánto tiempo ha estado ejerciendo ese rol?	
¿Edad?	

Características de la flota seleccionada	Respuesta	Unidades
¿Cuál es la capacidad máxima de almacenamiento del buque/s en este momento? ¿Se podría aumentar? ¿Cuánto? ¿Qué inversión necesitaría?		Toneladas
¿Cuántos días al año, aproximadamente, está el barco operando?		Días operativos
¿Existe alguna temporada en la que el barco no esté operativo? ¿Por qué?		
¿Realizan procesado a bordo? ¿Qué tipo de procesado?		
¿Cuántos tripulantes suele llevar a bordo? ¿Cuál es el sistema de remuneración?		FTE
¿Precio mínimo por kilogramo pescado para salir a pescar?		Euros/kilo
¿Qué duración tiene un lance en promedio?		Horas
¿Cuánto dura la marea en promedio?		Días

Intencionalidad de dedicarse a la pesquería mesopelágica	Respuesta	Unidades
¿Estaría dispuesto a explotar la pesquería mesopelágica? ¿Por qué? Poco conocimiento, adversidad al riesgo, etc…		
¿Hasta dónde estaría dispuesto a desplazarse para acceder a la pesquería mesopelágica?		Area ICES
¿Se podría realizar algún tipo de procesado a bordo? ¿Cuál?		
¿Cuáles serán los principales factores que determinarán a dónde irán a pescar los barcos (densidades de recursos, precios del pescado, capacidad física del barco, legislación, bienestar, etc.)	Densidad de recursos: Precios de mercado: Capacidad física del barco: Bienestar: Legislación: Otros:	Responder del 1 (no influye) a 5 (influye totalmente)
La estacionalidad de la pesquería mesopelágica probablemente estará dependerá de la distribución estacional de los recursos meso pelágicos, pero también estará influenciada por la estacionalidad de las otras pesquerías actuales. ¿Cómo cree que se podría asignar el esfuerzo de pesca a lo largo del año?		

Operativa pesca mesopelágica	Respuesta	Unidades
¿Cuáles podrían ser los factores limitantes para la duración del viaje? ¿La distancia de los caladeros?		

¿O la demanda del mercado determinará la duración del viaje?		
¿Habrá un volumen máximo alcanzable por arrastre? ¿Podría estimar el volumen máximo?		
¿Cuáles y cuántos puertos podrían usar para desembarcar capturas y procesarla?		Nombres de los puertos
¿Existe algún período del año en el que la flota esté parada? Motivo (vacaciones, falta de cuota, otros…)		
El consumo de combustible será de gran importancia al considerar los costos de las pesquerías mesopelágicas debido a la fuerte fuerza de fricción experimentada por la red más fina. ¿Cuáles serán los principales factores que determinan la velocidad de pesca (combustible, probabilidad de captura, artes)?		

Características del buque y equipamiento técnico	**Respuesta**	**Unidades**
¿Qué tecnología se necesitará para pescar los recursos mesoplágicos a tales profundidades? (nuevo equipo de búsqueda de peces / dispositivo de detección? P.ej. Sondas específicas ¿) a. En Prellezo, se sugiere una nueva red con un tamaño de malla de <10 mm y una bomba de succión para recoger la captura. En el caso islandés, se modificó la red y se sustituyeron algunas piezas de acero con plástico y se modificaron tamices para separar los peces del agua.		
¿Cree que el motor actual podría ajustarse o necesitaría ser reemplazado?		
¿Cómo ve la opción de construir nuevas embarcaciones sería una opción? Aquí hablar de la regulación, posibilidad de aumentar la capacidad de pesca?? O se refiere a sustituir??		

RRHH, economía y regulación	
¿Necesitarán los pescadores capacitación y educación adicional para la práctica de la nueva pesquería?	
¿Crees que pueden surgir nuevos problemas de seguridad surge en la pesquería? ¿Qué nuevos riesgos deben tenerse en cuenta y qué mejoras serán necesarias para garantizar los estándares de seguridad?	
¿Cuántos miembros de la tripulación estarán típicamente a bordo? ¿Cómo y cuánto se les paga?	

¿Tendrán un salario fijo, recibirán una parte de los ingresos o una combinación de ambos?		
¿Crees que su tripulación estaría dispuesta a ir a pescar aquellos periodos en los actualmente el barco está parado?		
¿La duración de los viajes será factible con condiciones de trabajo, horas de trabajo y días libres? ¿O la duración mínima del viaje rentable estará en conflicto con las necesidades de dicho empleado?		
¿Crees que la nueva pesquería tendrá un impacto en los salarios de la tripulación?¿Positivo o negativo?		
¿Crees que la pesquería mesopelágica aumentará o disminuirá el conflicto entre las actividades de los buques y las partes interesadas involucradas?		
A pesar de que todavía no hay muchas reglamentaciones vigentes para este tipo de pesquería, ¿cree que las reglamentaciones y las leyes se potenciarán fácilmente sobre este tipo de pesquería?		
¿Cree que la pesquería será económicamente estable y confiable en el futuro?		
Finalmente, de acuerdo con su definición de sostenibilidad, ¿cree que las pesquerías mesopelágicas podrían ser ecológica, económica y sociológicamente sostenibles?		

Grimaldo, E., L. Grimsmo, et al. (2020). "Investigating the potential for a commercial fishery in the Northeast Atlantic utilizing mesopelagic species." ICES Journal of Marine Science.

Hidalgo, M. and H. I. Browman (2019). "Developing the knowledge base needed to sustainably manage mesopelagic resources." ICES Journal of Marine Science **76**(3): 609-615.

Olsen, R. E., E. Strand, et al. (2020). "Can mesopelagic mixed layers be used as feed sources for salmon aquaculture?" Deep Sea Research Part II: Topical Studies in Oceanography **180**: 104722.

Salmon aquaculture is in great need of good quality balanced protein and lipid sources, particularly marine omega-3 (n-3) long-chain polyunsaturated fatty acids (LC-PUFA), to sustain a further development of the industry. One possibility is to harvest mesopelagic marine layers. Therefore, the current project analysed mesopelagic hauls from three cruises (November 2015 to October 2016) collected from the inner fjord systems around Bergen and in open-waters off Tromsø and Ålesund, Norway. Jellyfish, krill, shrimps and small amounts of the mesopelagic fish, Maurolicus muelleri and Benthosema glaciale, dominated the mixed mesopelagic hauls. Lipid content ranged between 35-40% of dry matter with two samples from autumn being 21 and 13%, with the latter haul being almost exclusively krill. In contrast, M. muelleri and B. glaciale had lipid contents of around 54 and 47% respectively. Overall, lipid was a relatively good source of marine n-3 LC-PUFA, EPA and DHA, being in the range of 15–20% of fatty acids which increased in lean samples. However, many of the trawl hauls contained wax esters (7 out of 9 hauls), equivalent to 40% or more of the lipid, with B. glaciale containing almost 90% wax esters of lipid. This presents a challenge if used in salmon diets, as their utilisation is limited. Protein contents ranged between 45-50%, increasing in lean samples. The essential amino acid content was well above the requirements for Atlantic salmon (Salmo salar) with B. glaciale generally containing higher levels compared to M. muelleri. Leucine, lysine and valine levels were particularly high. Hauls from open-waters contained mixtures of amphipods resulting in cadmium levels exceeding the maximum allowable level in feedstuffs. Arsenic levels were high or borderline. Reducing crustacean mix in hauls appear to be the only option to reduce these levels, whereas mesopelagic fish contained low levels of all heavy metals. In summary, the mesopelagic layer contains protein and lipid sources that could supply raw materials to the salmon aquaculture industry. However, high levels of wax esters, cadmium and arsenic needs to be addressed.

Prellezo, R. (2018). "Exploring the economic viability of a mesopelagic fishery in the Bay of Biscay." ICES Journal of Marine Science **76**(3): 771-779.

Sobradillo, B., G. Boyra, et al. (2019). "Target Strength and swimbladder morphology of Mueller’s pearlside (Maurolicus muelleri)." Scientific Reports **9**(1): 17311.

Standal, D. and E. Grimaldo (2020). "Institutional nuts and bolts for a mesopelagic fishery in Norway." Marine Policy **119**: 104043.

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Potential for Mesopelagic Fishery Compared to Economy and Fisheries Dynamics in Current Large Scale Danish Pelagic Fishery

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Mesopelagic fish species represent a large potentially unexploited resource for the fishing industry and the fish meal, oil, nutraceutical, and pharmaceutical production. However, thorough investigation on ecological sustainability and socio-economic viability are fundamental prerequisites for potential exploitation. The current study explores the economic viability of a potential mesopelagic fishery investigating minimum catch rates, under the assumption of previous assessments of biological sustainability of such exploitation. We analyzed fishery data from the North-East Atlantic fisheries of the Danish large pelagic fleet from 2015 to 2019, by comparing the combined data on fishing dynamics and cost-structures with data from interviews of key pelagic producer organization representatives to develop scenarios of profitability. The results show full year-round fleet occupation with the ongoing fisheries, exposing the need of switching from existing activities, or investing into new vessels for conducting potential mesopelagic fishery. Economic analyses revealed that the minimum revenue to break even (zero profit) by trip varies among métiers between 60,000 and 200,000 euro showing strong positive correlation with vessel sizes. High profitability was discovered for herring, Atlantic mackerel and blue whiting fisheries while low profitability was observed for the Norway pout fishery. Due to the lack of mesopelagic fishery data, different scenarios of profitability were investigated as informed by the pelagic catch sector stakeholder perceptions of prices and costs and compared to current economic dynamics. A high break-even revenue per trip was forecasted given the increased perceived costs for fuel, modifications of gears and on-board processing methods and potential new vessel investments. High profitability may be reached if the catches exceed 220–1,060 tons per trip depending on costs and vessel storage capacity. If the conservation methods are improved from current refrigerated sea water, fishing trips could last longer than 5 days, being the major limiting economic factor for potential mesopelagic fishery. Future investigations on realistic mesopelagic catches, trip durations and spatio-temporal distribution of fisheries in relation to location, resource abundance, fishing rights, storage and conservation methods will be essential to test the robustness of the scenarios proposed in this study, and will in turn benefit of the economic requirements evaluated herein.

Keywords: catch and effort dynamics, cost structures, economic break even point, fleet occupation, fisheries economics, fishing equipment, pelagic fishery dynamics, potential mesopelagic fishery

INTRODUCTION

Capture fishery represents an estimated global value of USD 151 billion corresponding to roughly 97 million tons of wild caught fish per year (FAO, 2020). Approximately 3.3 billion people are dependent on this food source for 20% of their daily intake of animal protein, and more than 38 million people have direct employment in fisheries activities in 2018 (FAO, 2020). The models by the United Nations Food and Agriculture Organization (FAO) show that around 66% of exploited fish and shellfish stocks are currently fished sustainably and around 34% are fished above biological sustainable limits in 2017 (FAO, 2020). However, due to a growing human population, the demand for human food, resources, and employment continues to increase (Costello et al., 2020).

Mesopelagic (200–1,000 m depth) marine living resources in the world oceans represent a large unexploited biomass (St. John et al., 2016). Preliminary investigations suggest that there may be a potential for capture fishery exploitation of some mesopelagic species, specifically targeting the Myctophid *Benthosema glaciale* (Glacier lanternfish) and the Sternoptychida *Maurolicus muelleri* (Mueller's pearlside). Both species are small (50–80 mm) and perform diel vertical migration (Ishihara and Kubota, 1997; Sutton et al., 2008; Eigaard et al., 2012; Hudson et al., 2014; Prellezo, 2019; Grimaldo et al., 2020). The high levels of lipid and fatty acid contents found in *B. glaciale* and *M. muelleri* (Phleger et al., 1999; Lea et al., 2002; El-Mowafi et al., 2010; Koizumi et al., 2014; Grimaldo et al., 2020) make the species commercially and economically interesting for industrial, neutraceutical, and pharmaceutical purposes (Gjosaeter and Kawaguchi, 1980; Gjosaeter and Tilseth, 1983; Gjosaeter, 1984; Johannesson, 1991; Lamhauge et al., 2008; Tacon and Metian, 2009; Irigoien et al., 2014; Olsen and Torrisen, 2015; Grimaldo et al., 2018, 2020; Davidson et al., 2019). Some trial fisheries and surveys on mesopelagic species have already been conducted in different parts of the world; in the Gulf of Oman, the Indian Ocean, the California Current, and the Northeast Atlantic (Valinassab, 1998; Lamhauge et al., 2008; Sebastine et al., 2013; Davison et al., 2015; Grimaldo et al., 2018, 2020; Malvarosa et al., 2019). But before such potential large-scale exploitation the ecological and the economic sustainability of the fishery needs to be thoroughly assessed.

A comprehensive investigation of the ecosystem and biological sustainability is necessary, evaluating the potential target and by-catch stocks, food web interactions, and biodiversity to assess whether such exploitation is at all ecologically precautionary and sustainable, also in the long-term (Hall, 1999; Branch et al., 2010; Hilborn et al., 2015; Gascuel et al., 2016). Among other, the effects of mesopelagic exploitation on the ecosystem functioning have to be considered. The mesopelagic community provides several essential ecosystem services: the community inhabiting this layer is part of the marine food chain with significant supply to the epipelagic trophic levels and ecosystem, it represent high biodiversity, its extensive biological production and distribution of biomass in the sea, and finally, its important role in carbon sequestration and transportation of carbon to the deep ocean (Gartner, 1993; Ishihara and Kubota, 1997; Lea et al., 2002; Sutton et al., 2008; Branch et al., 2010; Hudson et al., 2014; Irigoien et al., 2014). As such, the resilience of the stocks to future harvesting and climate change scenarios needs to be evaluated as well.

If there is a biomass that could be exploited, such potential exploitation will need assessments of options to sustainably manage and govern the exploitation to establish robust governance systems. Here, the complexity and key interactions of the ecological, economic, social, and governance systems involved needs to be understood (Holling, 2001; Garcia and Rosenberg, 2010; Nielsen et al., 2018). The social acceptance in potentially exploiting new mesopelagic resources will depend on the biological and ecosystem sustainability herein, but it will also depend on analyses of the economic, social, governance, and biological trade-offs and risks involved in mesopelagic exploitation and management (Holling, 2001; Mullon et al., 2009; Ostrom, 2009; van Dijk et al., 2013; Hicks et al., 2016; Soma et al., 2018).

Similar to the ecological sustainability, the economic sustainability of the potential fishery needs to be thoroughly assessed to investigate if the fishery is at all economically viable (Valinassab et al., 2007; van Putten et al., 2012; Malvarosa et al., 2019; Prellezo, 2019). Adaptations or new developments in catch and processing methods will be necessary to efficiently exploit the potential resource, including vessel investments, and gear modifications (e.g., Grimaldo et al., 2018, 2020). The design and development of new fishing methods fit for mesopelagic resource harvesting may lead to efficient fishery, but thorough investigations in fishing patterns and the needed and investments are crucial as it will influence the fishing costs (Grimaldo et al., 2018, 2020; Bigné et al., 2019). Investments into the fishery will among others be more profitable on-board processing methods to deal with the high fat content of the species and their fast deterioration after harvest (Olsen and Torrisen, 2015). This makes the catching methods, catch handling, on-board processing, and conservation methods essential to assure a cost-efficient yield of high-value components (El-Mowafi et al., 2010; Vang et al., 2017).

Pilot studies have been done to investigate the economic viability of a potential mesopelagic fishery, focusing on the fishing costs of such potential fishery compared to current fisheries (Valinassab et al., 2007; Prellezo, 2019). But to date detailed analyses of the economic performance of current large-vessel pelagic fisheries and the economic preconditions necessary for the implementation of a potential mesopelagic fishery have been lacking. Here we investigate the economic performance and dynamics of the current large scale Danish pelagic fishery, and compare it to evaluations of the economics of the potential exploitation of *M. muelleri* and *B. glaciale* according to different scenarios of cost and price dynamics and fishing trip length.

The overall objective of the present study is to analyze current fishing patterns, activity levels, and economic performance in the Danish large vessel pelagic sector to investigate the potential of a mesopelagic fishery, either by using new vessels or switching activities from pelagic fisheries to mesopelagic fisheries in the future. We analyze and describe (i) the economic performance and dynamics of the current Danish large vessel pelagic fisheries based on existing fisheries economic, catch and effort data and (ii) evaluate the economic performance of a potential future mesopelagic fishery according to different likely scenarios. The second part of the analyses links the analyses of current fishery to interview investigations conducted under this study. The interviews with main representatives of the Danish Pelagic Producers Organization (DPPO), cover the broader pelagic catch sector and industry perceptions of the key drivers in the current pelagic fishery and the necessary conditions and changes with focus on costs, prices, trip duration and needed equipment for a potential mesopelagic fishery.

The study investigates the following zero hypotheses:

- The large pelagic vessel fleet does not have time available and is fully occupied to perform additional mesopelagic fishery without switching from other fisheries;
- All current pelagic fisheries are economically efficient;
- The expected increased costs compared to likely prices/earnings and thus the expected larger break-even points (BEP) of mesopelagic fishery are too extensive
    - to obtain an adequate profitability to switch to or conduct new, additional mesopelagic fishery with current fleet, i.e., to fill in no activity periods (gaps) of current large pelagic fishing fleet or substituting current activities with mesopelagic fishing;
    - or to obtain an adequate profitability to invest in new vessels to initiate a mesopelagic fishery;

given different scenarios of economic BEPs (covering among other prices, catch amounts, and costs per unit of effort).

MATERIALS AND METHODS

Analysis of Current Danish Large Vessel Pelagic Fleet and Fisheries

Data Extraction on the Current Danish Large Vessel Pelagic Fleet

The extracted data covers the time period from 2015 to 2019. Only data for larger vessels were selected to cover the pelagic fishery with potential to switch to offshore, mesopelagic fishery. We selected only Danish vessels larger than 24 m which have been involved in pelagic activities (i.e., which have conducted typical pelagic métier fishery) at least once during 2015–2019.

Data of fisheries dynamics of the Danish fleet used in this study originates from the merging of logbooks, sales slips and Vessel Monitoring System (VMS) databases hosted and made available by the Danish Fishery Directorate[1], following the standards of the EU CFP Data Collection Framework (EC, 2016, 2017). Vessel specific information is obtained from the Danish fishing vessel register[2], the Danish logbook database, the Danish Sales Slips database and through the national VMS logbook-coupled fisheries data (see text footnote 1). The distribution of vessel-specific effort was coupled to the catches following the procedure given in Bastardie et al. (2010).

Data on the economics of the selected vessels was obtained from the EU Scientific, Technical and Economic Committee for Fisheries (Scientific, Technical and Economic Committee for Fisheries (STECF), 2018a,b). This database provides information on the economics of the Danish fleet segment selected in this study: the fleet segment capacity (number of vessels), effort (total fishing days, days at sea, and fishing trips), and total expenditures and incomes divided into categories informing individual vessel features (see details below and in STECF AER Economic and Transversal data tables in https://stecf.jrc.ec.europa.eu/reports/economic).

Data Description

The selection included 37 large demersal trawlers, pelagic trawlers and purse seiners, active to different extents between 2015 and 2019 with vessel sizes between 27.7 and 90.5 m, corresponding to an engine power range from 514.7 to 5431.7 kW. An average of 26 vessels was active each year. The selection covered 3,722 fishing trips during the 5-year period for a total of 21,557 days at sea (**Table 1**). On average 744 $\pm$ 91 number of trips and 4,309 $\pm$ 222 days at sea were spent each year, for an average of 29,910 $\pm$ 2,456 fishing hours per year. The overall mean trip duration of large scale pelagic fisheries was 5.79 $\pm$ 2.90.

The logbooks are a compilation of individual vessels, fishing trips and fishing operations logged with unique ID and spatio-temporal information. Each fishing trip of an individual vessel performed during a certain year is registered with vessels features (length, tonnage, and engine power), starting date and harbor, landing date and harbor, and combined with a disaggregated fishing operations list. Each operation (haul) is cataloged with start-end time stamps, start-end coordinates, ICES statistical

[1] https://fiskeristyrelsen.dk/

[2] https://fiskeristyrelsen.dk/erhvervsfiskeri/krav-og-reguleringer/fiskefartoejer/

TABLE 1 | Fleet capacity and effort allocation of the selected fleet obtained from logbook information and VMS analyses.

Year	No vessels	Days at sea	No trips	Mean trip duration (days) ± SD	Fishing hours
2015	27	4,694	828	5.67 ± 2.89	27,843
2016	29	4,149	797	5.21 ± 2.77	28,651
2017	26	4,245	797	5.33 ± 2.63	29,973
2018	25	4,267	688	6.20 ± 2.80	28,997
2019	26	4,101	612	6.86 ± 3.20	34,084
Total	37	21,557	3,722	5.79 ± 2.90	149,236

rectangle, gear, mesh size, landing catches, and prices per kilogram. Timestamps and latitude and longitude coordinates are informed by the VMS present onboard of every operating vessel above 12 m in length which continuously records the location of the fishing operation and the spatial coverage of the entire fishing trip. The information on total catches and revenues derived from each trip are collected at the sales auction after landing and are registered in sales slips merged with logbook events. Sale slips recorded each species weight (kg) and price (€/kg) landed at the end of each fishing trip. The data from the logbook and sales slips databases are available from the Danish Fishery Directorates web site as dynamic tables[3].

We formed groups of 3 to 4 vessels with similar physical characteristics (e.g., vessel size and engine power) and similar fishing patterns and behavior for confidentiality reasons (**Supplementary Table 1**). The resulting grouping was used to describe the fishing units in all further analyses. Similarly the dataset was classified according to métier. The set of fishing activities were grouped into 9 métiers identified by the target species and the observed gears and mesh sizes (**Table 2** and **Supplementary Table 2**). The trip métier and the target species are inferred from the dominant species landed in the logbook (**Table 2**). The métiers were used as units in all the analyses and comprise fisheries for industrial purposes and fisheries for human consumption.

The data from logbooks, sales slips, and VMS were combined in R (Bastardie et al., 2010; RStudio Team, 2020) to assess: (i) the temporal occupation of the Danish large vessel pelagic fleet in terms of fishing operations among seasons and years; (ii) the spatial coverage of the fleet activities among the ICES ecoregions; (iii) the effort allocation of the fleet in time and space; and (iv) the fishing patterns (métiers) and the catch composition of current Danish pelagic fisheries.

Methods for Economic Analyses

The sales slips gave incomes from landings per trip and prices per species. When the catches are destined for industrial processing, the landings are not sorted, and the same price per kilo is applied to any non-targeted landed species. When the catches are destined for consumption, prices per kilo are informed per species. We estimated the average catches per métier, and we considered the observed maximum catches per métier as a proxy

[3]https://fiskeristyrelsen.dk/fiskeristatistik/dynamiske-tabeller/

TABLE 2 | Classification of fishing activities into 9 métiers according to gear and target species.

Métier	Gear/s	Mesh size range (mm)	Dominant (target)Target species
OTB Demersal fish species	Otter bottom trawl	16–120	Demersal mixed species
OTB Sandeel	Otter bottom trawl	10–16	Sandeel (*Ammodytes* spp.)
OTB Norway pout	Otter bottom trawl	16–31	Norway pout (*Trisopterus esmarkii*)
OTM/PTM Sprat	Mid-water trawls, pair pelagic trawls	16–69	Sprat (*Sprattus sprattus*)
OTM Pilchard	Mid-water trawls	16–31	Pilchard (*Sardina pilchardus*)
OTM/PS Herring	Mid-water trawls and purse seine	16–69	Herring (*Clupea harengus*)
OTM/PS Atlantic mackerel	Mid-water trawls and purse seine	32–69	Atlantic mackerel (*Scomber scombrus*)
OTM Horse mackerel	Mid-water trawls	32–69	Horse mackerel (*Trachurus trachurus*)
OTM Blue whiting	Mid-water trawls	32–69	Blue whiting (*Micromesistius poutassou*)

for maximum vessel storage capacity. Fish price fluctuations over a 5 years period could be observed per species. Trip landing revenues were calculated from the product of the volume of catches and prices per species.

The EU STECF database provides the information on total yearly costs (fixed and variable costs) together with the fleet size and total trips and days at sea, although the information was not available for all. We considered the costs of demersal trawlers between 24 and 40 m, demersal trawlers above 40 m, and pelagic trawlers above 40 m, and assumed the costs of pelagic trawlers between 24 and 40 m to be similar to the demersal trawlers between 24 and 40 m and the purse seiners to have similar costs as the pelagic trawlers above 40 m. As a single cost estimate was available for any vessel above 40 m, a posthoc correction was applied to scale fixed and variable costs proportionally to the vessel lengths for all vessels > 40 m using simple linear regression models:

$$\text{Fixed costs}_{\text{OTB, trip}} = a + b * \text{Vessel length}_{\text{OTB, trip}} \quad (1)$$

$$\text{Fixed costs}_{\text{OTM, PTM, PS, trip}} = c + d * \text{Vessel length}_{\text{OTM,PTM,PS, trip}} \quad (2)$$

$$\text{Variable costs}_{\text{OTB, day}} = e + f * \text{Vessel length}_{\text{OTB,day}} \quad (3)$$

$$\text{Variable costs}_{\text{OTM,PTM,PS,day}} = g + h * \text{Vessel length}_{\text{OTM,PTM,PS,day}} \quad (4)$$

With linear regression parameters a–h being vessel specific. Fixed costs (i.e., costs that do not vary along the year or the effort deployed) cover the consumption of fixed capital, the repair and maintenance costs, the value of unpaid labor, and other non-variable costs. We evenly dispatched the annual fixed costs among trips to assume a fixed cost per trip. Variable costs are proportional to fishing effort and cover the payment of quotas, the energy consumption, the personnel costs, and other variable costs. We estimated the daily variable costs from the annual variable costs over the total number of days at sea. The same procedure was applied to fixed and variable sources of income which are not coming from landings. Following this, total costs, total revenues, and profits are expressed at the trip level as:

$$\text{Total costs}_{\text{trip}} = \text{Fixed costs}_{\text{trip}} + \left(\text{Variable costs}_{\text{day}} * \text{Days at sea}_{\text{trip}}\right) \quad (5)$$

$$\text{Total revenues}_{\text{trip}} = \text{Landing revenues}_{\text{trip}} + \left(\text{Fixed income}_{\text{trip}} + \left(\text{Variable income}_{\text{day}} * \text{Days at sea}_{\text{trip}}\right)\right) \quad (6)$$

$$\text{Profit}_{\text{trip}} = \text{Total revenues}_{\text{trip}} - \text{Total costs}_{\text{trip}} \quad (7)$$

The BEP was estimated for each métier, except for the pilchard fishery (because the pelagic species is an occasional catch only) and the demersal mixed species fishery (whose target species are variable and do not fall in the intent of the study). The BEP represents the minimum revenue and catch per trip necessary to cover the trip-based costs and obtain a zero profit trip, corresponding to the crossing point of the revenue and cost regression functions (**Figure 1A**). The area for which each métier conducts a profitable fishery is deduced by projecting the BEP on the demand-supply trade-off graph (**Figure 1B**). **Figures 1C,D** show the theoretical BEP and profitability for a very profitable fishery, and **Figures 1E,F** show the theoretical BEP and profitability for a very costly fishery. The BEP may derive from an infinite combination of prices per kilo and harvested resources, but we expect that only a certain range of prices will be observed on the market in accordance with interview information. We also expect the volume of resources harvested during one trip to be limiting, lowering the possible profitable area. Hence, the BEP curve was obtained as follows:

$$\text{BEP}_{\text{trip, species}} = \text{Landing weight}_{\text{trip}} * \text{Price per kg}_{\text{species}} \quad (8)$$

Analysis of the Economic Performance of Potential Future Mesopelagic Fishery Based on Scenarios of Price, Cost, and Activity Dynamics

Sources of Information for the Analyses

To investigate the economic performance of a potential mesopelagic fishery, we developed and analyzed several future scenarios. We used the parametric dataset and analyses from the current Danish pelagic fleet described in section "Analysis of current Danish large vessel pelagic fleet and fisheries," and supplemented this information with additional assumptions about the perceived changes and conditions necessary for a potential mesopelagic fishery. The mesopelagic scenarios and assumptions were based on interviews with the director and the chief scientific advisor of the DPPO, who are representatives of the Danish large vessel pelagic fleet. The DPPO represents 10 recently-built large pelagic trawlers out of the 37 selected pelagic vessels and purse seiners. The members of DPPO account for one-third of the Danish fish landing values, and hold the majority of the Danish quotas for key pelagic and industrial target species. On this basis, the DPPO is a valid representative of the Danish pelagic sector, and it has a well consolidated role with insight in the economy of the sector. The organization also represents a key potential investor into a mesopelagic fishery and the DPPO has explicitly expressed interest herein. The interviews followed a pre-prepared questionnaire which covered (1) the structure, the patterns and the behavior of the current fishing activities, and (2) the technical, economic and social challenges that the potential mesopelagic fishery would bring to the sector. A summary of the topics discussed can be found in the **Supplementary Table 3**. The questions were covering the following main topics:

- Current spatial coverage of pelagic fisheries, the maximum physical range covered within a trip and factors affecting trip duration.
- Current fishing depths, number of hauls, and achievable catch volumes.
- Current storage, processing, conservation methods, and capacity on board.
- Reasons for the investment in or switching to mesopelagic fishery.
- Perceived drivers of fishing patterns, spatial coverage, and catches of a mesopelagic fishery (e.g., distance to fishing grounds, behavior and conservation of target species, market demands, and prices).
- Fishing depths, number of hauls per day, maximum achievable volume per haul, and minimum needed catch for the profitability of a new mesopelagic fishery.
- Expected prices per kg of mesopelagic resources given conservation methods and comparison with possible similar fisheries.
- Cost structure of a mesopelagic fishery, including additional costs due to fuel consumption changes, gear adaptations, storage, processing and conservation changes, in comparison to possible similar current fisheries.

Methods and Parameters for Economic Analyses

We built potential profitability scenarios for mesopelagic fisheries, informed and constrained by fishermen perception of potential mesopelagic fishery fishing costs, fish prices, maximum catches achievable per trip and trip feasible durations dependent on the conservation method adequate for mesopelagic species.

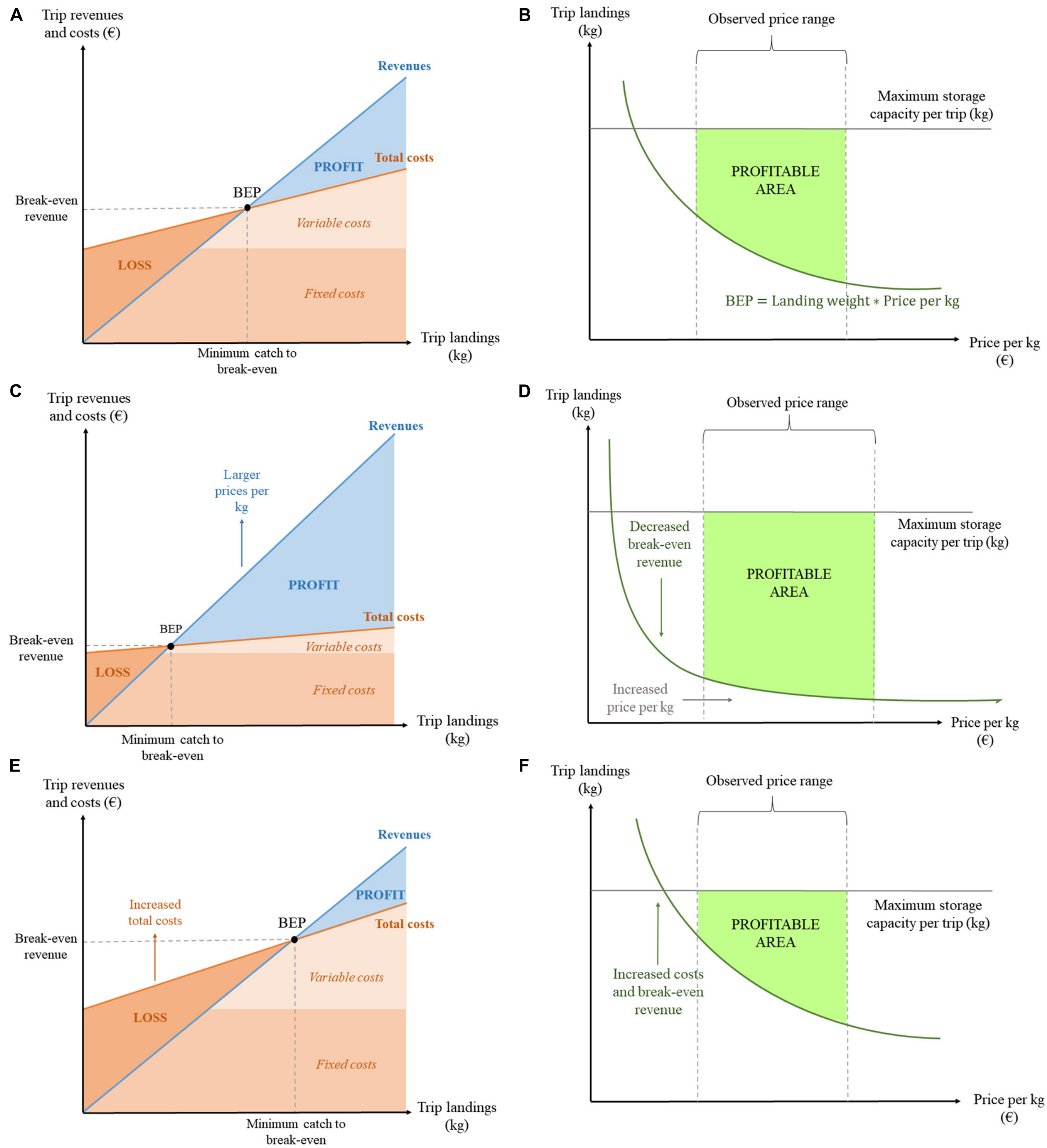

FIGURE 1 | Graphical representation of the economic performances of a fishery. **(A)** Theoretical break-even point (BEP) derived from the intersection of revenues and costs functions over landing weight at the trip level. **(B)** Theoretical profitability identified as the area exceeding the break-even function and constrained by observed prices and storage capacity of the vessel. **(C)** Theoretical early break-even point (BEP) for the case of a very profitable fishery where revenues far exceed the costs. **(D)** Theoretical profitability of a very profitable fishery with a lower break-even function and a larger area of profit. **(E)** Theoretical break-even point (BEP) for a costly fishery with increased costs and limited profits. **(F)** Theoretical profitability of a costly fishery with a higher break-even point (BEP) and a shrunk area of profits.

The average minimum landing per trip necessary to break-even was estimated from the intersection of the BEP revenue curve and the range of price selected. We investigated three BEP values that represent the minimum, the average and the maximum BEPs that were observed as the range among the current pelagic fisheries analyses; the smallest BEP represents the current sprat fishery; the intermediate BEP represents the current herring fishery for human consumption; and the highest BEP represents the current blue whiting fishery. The mesopelagic fishing costs were perceived similar to the current blue whiting fishery (the fishery with the highest BEP observed), but two scenarios were added to account for the range of

BEPs estimated for the current large scale pelagic fisheries. Because the cost structure of the new fishery is unknown we forecasted a 50% increase and a 100% increase in both fixed and variable costs from the baseline scenarios within perceived realistic ranges of fish prices and landing amounts. Further details on the economic analyses are given in section "Outcomes from the interviews with representatives from the DPPO."

RESULTS

Evaluation of Current Danish Large Vessel Pelagic Fisheries and Fleets

Fishing Patterns, Activity Levels and Behavior

All vessels in the different vessel groups are highly occupied all year round during the 5 year period (2015–2019; **Figure 2A**).

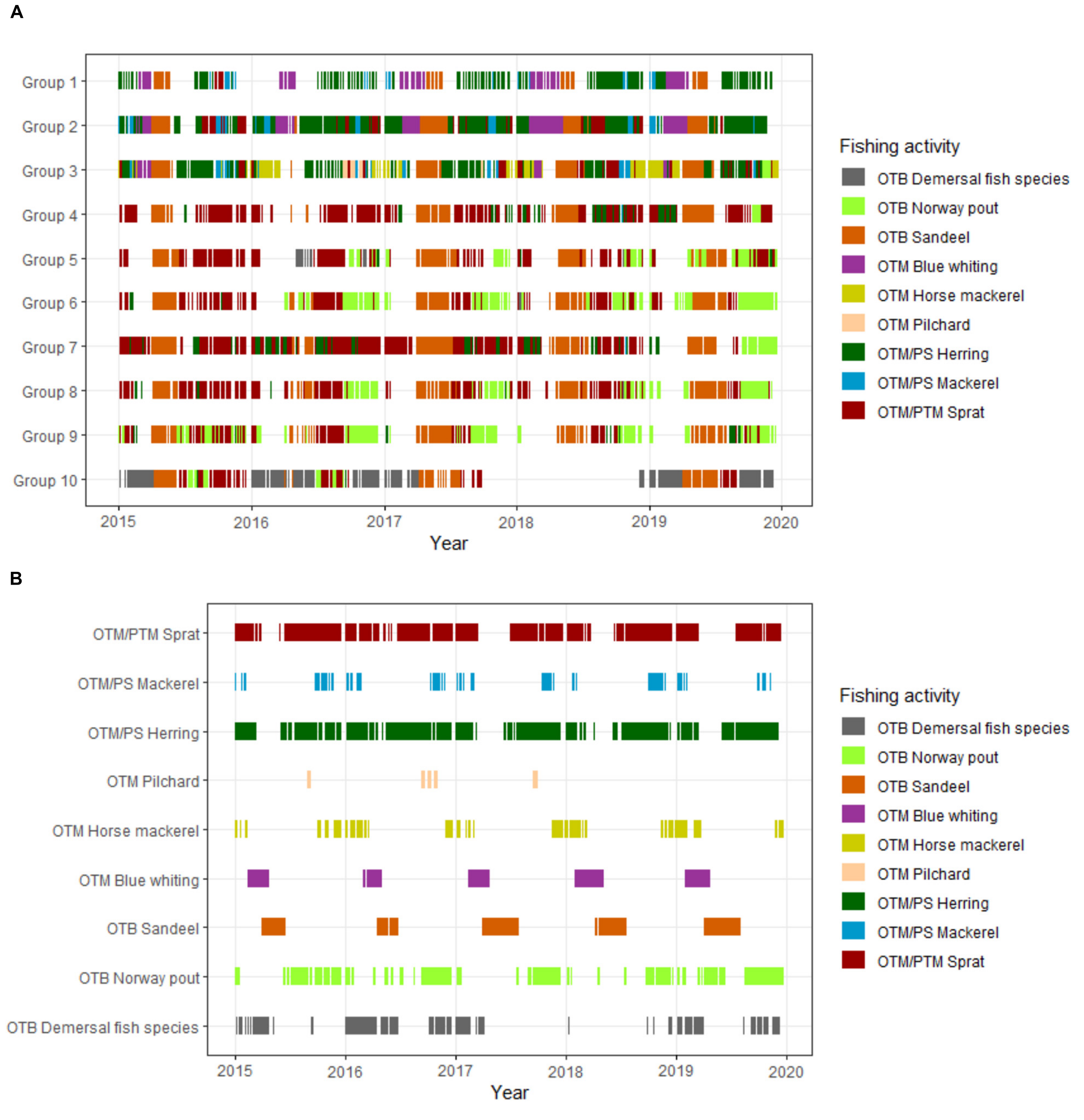

FIGURE 2 | Timeline of fishing activities along 5 years period of time (2015–2019). **(A)** Temporal distribution of fishing trips among vessel groups by métier. **(B)** Temporal distribution of fishing operations (haul-to-haul basis) by métier.

Main fisheries in the pelagic sector according to yearly occupation are sprat and herring fisheries (**Figure 2B**) which are performed all year round differently from the other fisheries that have strong seasonal patterns and are undertaken in specific quarters of the year. The largest vessels of the selection are grouped in Group 1, 2, and 3, and are extensively involved in herring fishery, interspersed with blue whiting fishery, horse mackerel fishery, and Atlantic mackerel fishery, which are not performed by any of the smaller vessels. Most of the other vessels displayed a seasonal alternation among sandeel fishery, sprat fishery and Norway pout fishery. Only the smallest vessels of the selection engaged in some demersal mixed species fishery in alternation with pelagic fisheries. The yearly, seasonal and geographical patterns in the behavior of the different groups are described below.

Trip Duration and Seasonality

A range of trip duration from 1 to 16 days and maximum trip length between 13 and 16 days were observed among all métiers during 2015–2019. Specific mean trip durations were highlighted by métier (**Figure 3**). Among the métiers using bottom trawl gears the sandeel fishery had an average trip duration of 7 days, the Norway pout fishery had an average trip duration of 8 days, and the demersal fish species fishery had an average trip duration of 4 days. Among the métiers using mid-water trawls for industrial purposes, an average

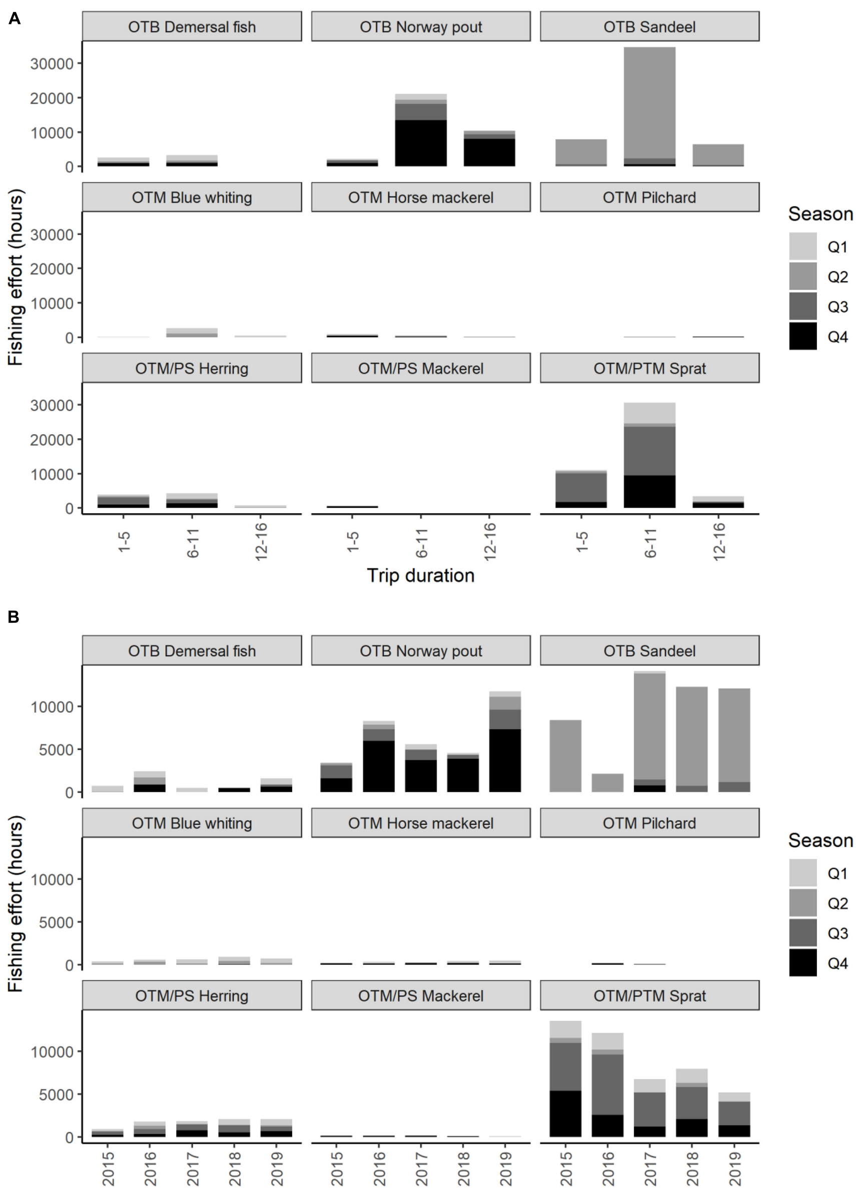

FIGURE 3 | Fishing effort allocation among vessel groups by métier with **(A)** fishing effort as fishing hours among quarters and years by métier during the period 2015–2019, and **(B)** seasonal allocation of fishing hours by trip duration intervals in days.

trip duration of 6 and 8 days was found for the sprat and the blue whiting fishery. Among the métiers for consumption purposes, average trip durations of four, 4, 10, and 5 days were observed for the Atlantic mackerel, the horse mackerel, the pilchard and the herring fisheries, respectively. However, the trip duration was mainly dependent on catches and storage capacity (**Figure 3A**).

When looking at the distribution of trip durations per métier, 86% of the time, fishing for blue whiting was during trips lasting 6–11 days. Furthermore 89% of the time fishing for Atlantic mackerel was at trip durations below 5 days, and 70% of the time, fishing for pilchard was during trips longer than 13 days. Similarly, 60% of the herring fishery was emplaced in trips less than 6 days, and 60% of the time, fishing for horse mackerel was during trips less than 5 days. In the sandeel fishery 63% of the effort was emplaced in trips between 6 and 12 days. The sprat and the Norway pout fishery had the fishing effort distributed over two-thirds of the trip duration range, with 94% of the sprat trips between 1 and 12 days, and 89% of the Norway pout trips between 6 and 16 days long. Finally, the demersal fish species fishery had fishing effort distributed evenly in trips no longer than 11 days.

Fishing for Norway pout, sandeel and blue whiting constituted seasonal distinct fisheries as shown by the seasonal allocation of the fishing hours (**Figure 3B**). The Norway pout fishery was mainly conducted in the fourth quarter of the year while the sandeel fishery was designated to the second quarter of the year where the sandeel fishery typically is associated to the sandeel feeding period. Sprat and herring were harvested all year round, less extensively during the second quarter of the year. Both blue whiting and horse mackerel were targeted during the first quarter of the year, while Atlantic mackerel is mainly harvested during the fourth quarter of the year. Fishing effort distribution by ICES ecoregion is displayed in the **Supplementary Figure 3**.

Spatial Fishing Patterns

The spatial coverage in the North East Atlantic of the Danish large vessel pelagic fleet is quite widespread and the full, extensive geographical coverage expressed as haul observations per vessel group and fishing effort distribution expressed in fishing hours are shown in the **Supplementary Figures 1**, **2**. The geographical distribution of the métiers in main sea areas by vessel group is shown in **Figure 4**. The majority of the activities took place within the Greater North Sea area and the Baltic Sea. However, the three largest vessel groups regularly engaged in fisheries that took place in distant ICES regions such as the Norwegian Sea, the Celtic Sea and the West of Scotland sea, and sometimes down to the Bay of Biscay (**Figure 4**). The geographical distribution of the métiers and their concentration in specific quarters of the year are to a large extent driven by distribution and densities of the targeted species (**Figure 5**), but also by access to third country EEZs and specific geographical regulations, i.e., closures such as the sprat box (ICES, 2020a,b) and the Norway pout box (Bigné et al., 2019). The blue whiting fishery, the horse mackerel fishery and the Atlantic mackerel fishery were located furthest away and were consequently undertaken only by the three largest vessel groups.

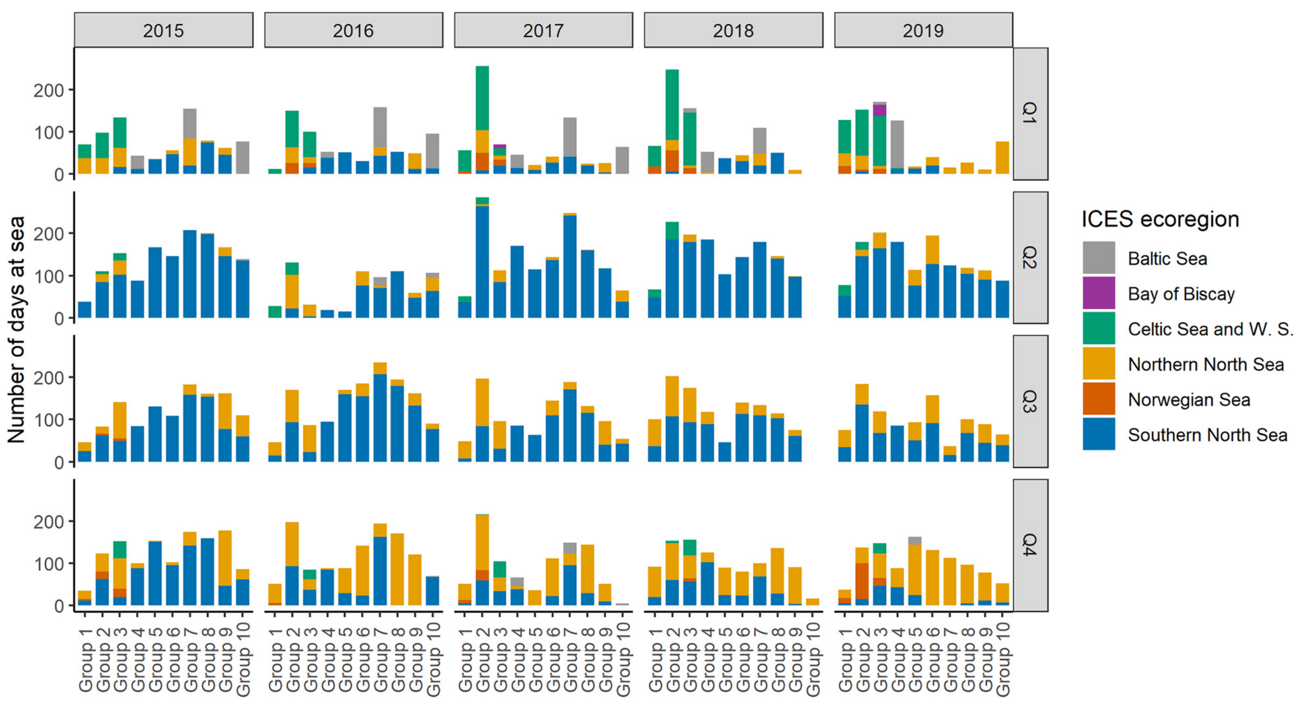

FIGURE 4 | Days spent at sea by each vessel group among quarters and years, distinguished by the ICES ecoregion they were spent in during the period 2015–2019. The vessel groups are detailed in **Supplementary Table 1**.

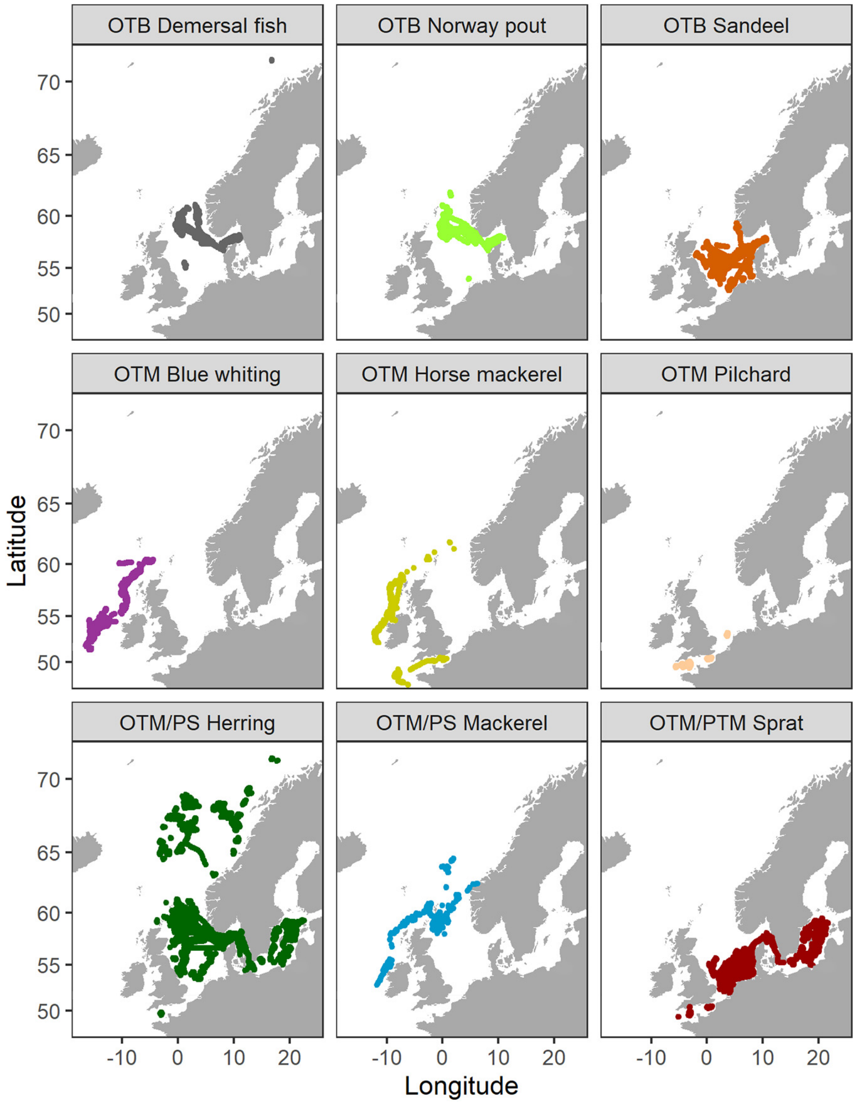

FIGURE 5 | Geographical distribution of VMS points indicating fishing operations by métier along the North East Atlantic during the period 2015–2019 for the Danish large pelagic vessel catch sector.

Species Targeting and Catch Composition

The relative species composition in the catch derived from landings and sales slips for each of the métier performed by the Danish large vessels pelagic fleet is shown in **Figure 6** for the period 2015–2019. Besides the demersal mix species métier which targets multiple species, the other métiers had catch compositions dominated by the single target species, except for the sprat and herring fisheries which showed mixed catches of herring and sprat, respectively. Another noticeable mixed fishery and by-catch percentage was within the horse mackerel fishery which often harvested Atlantic mackerel and other collateral species (mainly boarfish; *Caproidae*).

Economic Dynamics and Performance in Current Pelagic Fisheries

The analyses of the sales slips displayed that the dominant species in landing weight were sprat, herring, and sandeel (**Figure 7A**). However, different market prices make herring, Atlantic mackerel and sprat the most important harvested species in terms of landing revenues (**Figure 7B**). The comparison of catches and revenues among the 5 years period of time (2015–2019) revealed a certain price fluctuation over the years for most of the species which indirectly appears from **Figure 7** as well. According to the insights from the DPPO interviews (see also section "Evaluation of economic performance of potential future mesopelagic fishery") the price fluctuations for industrial species

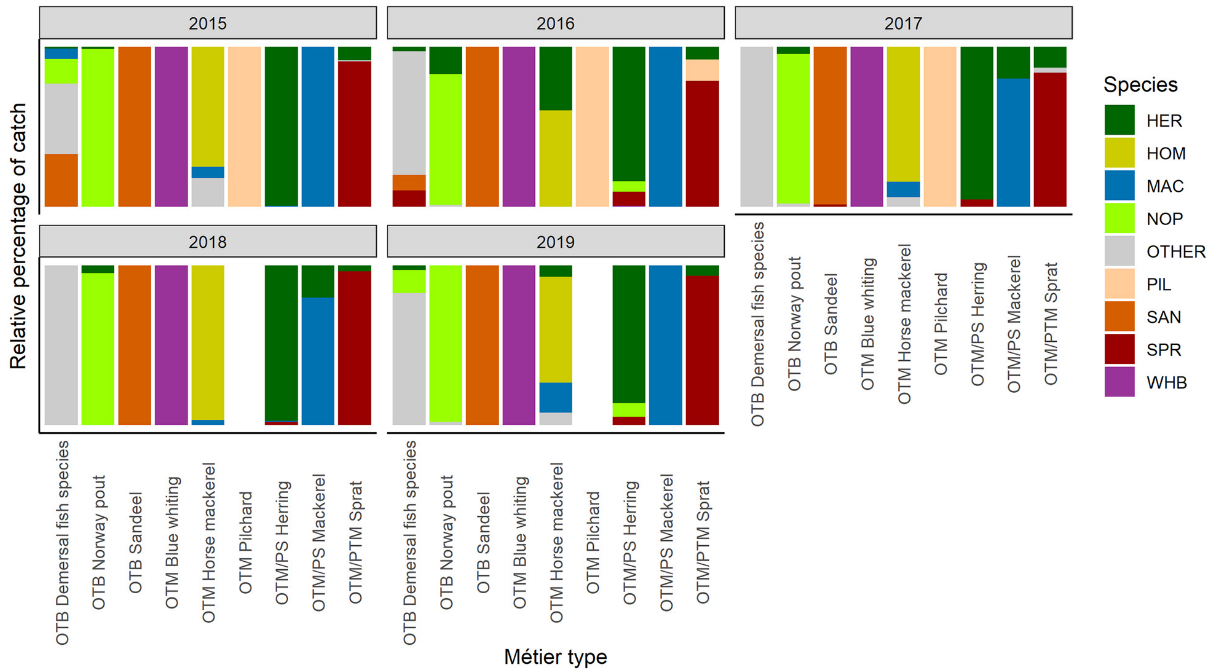

FIGURE 6 | Relative species composition in the catch of each métier by year during the period 2015–2019, distinguishing main targeted species from other collateral species.

relate mainly to fluctuations in world market demands and price variability for soya beans, another resource for livestock feed (Rana et al., 2009).

The fishing trip BEP, defined as the minimum revenue to break-even the cost, was estimated for each métier from the intersection point of the revenue and cost linear functions within each métier (**Figure 8**). Linear regressions between costs, revenues and landings were made for different resolutions of vessel categories selecting the top three represented vessel groupings by trip number in **Figure 8**. The specific BEP estimates for size classes (vessel lengths) and estimates of average trip BEP by métier are shown in the **Supplementary Table 4**, specific BEP estimates for different vessel groups and years are given in the **Supplementary Tables 5**, **6**. A strong linear proportionality between the BEP and the size of the vessel was demonstrated with high correlation coefficient (**Supplementary Figure 4**). This positive vessel size dependency in the BEP also appears by métier (**Supplementary Table 4**).

As both fixed and variable costs increase with vessel size and catch volume, the net profit showed more variability across size classes. The total estimated profit over the selected 5-year period indicated that the métiers targeting herring and Atlantic mackerel for consumption were the most profitable in the Danish large vessel pelagic catch sector. The métiers targeting sprat, sandeel, and blue whiting displayed similar profitabilities, however, the Norway pout fishery was indicated as only a marginally profitable métier.

The demand-supply graph highlights the estimated profitable area for each métier (**Figure 9**). The shape and the distance to the origin of the trade-off curve between catches (kg) and prices (€/kg) determine the size and shape of the profitable area, and hence the profitability of the given métier. The trip catches and prices are averaged per métier over the 5-year period (2015–2019). Prices of target species vary both between seasons and years and is included in the vertical price range limit per métier in the graph. The observed prices vary according to the landing site, the processing plant, the quality of the catch and their oil/fat content. Larger scale price variability is also driven by demand of fish meal and soybeans and world market prices in general. The economy portrayed for each métier were in accordance with what observed in the BEP graphs (**Figure 8**). Average catches well above the trade-off curve generate revenues above the break-even value by trip and are linked to métiers that have positive net profit for every trip undertaken. This was observed especially for the blue whiting and the Atlantic mackerel fisheries. On the other hand, average catches closer to the trade-off curve lead to zero profit trips and to a smaller overall net profit as was observed for the Norway pout fishery.

Evaluation of Economic Performance of Potential Future Mesopelagic Fishery

Outcomes From the Interviews With Representatives From the DPPO

The interviews provided insights, perspectives, and factual economic information into which will be the main challenges, factors, and incentives influencing the potential switching to or the initiation of new mesopelagic fishery activities for the Danish large vessel pelagic fleet. The difference in fishing effort (days spent fishing) among current pelagic métiers that we

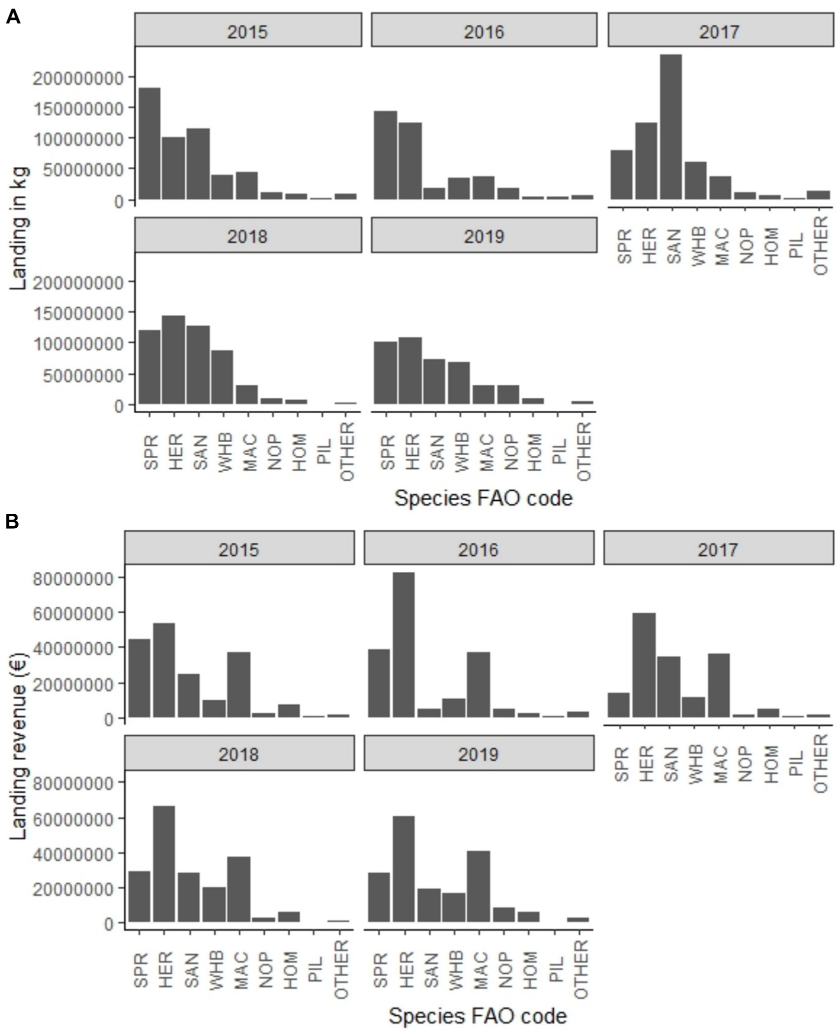

FIGURE 7 | (A) Total landing weight and **(B)** Total landing income from landings by targeted species in recent years from 2015 to 2019. The yearly relative differences between the two panels reveal price variability.

observed above were explained as being linked to the targeted species distribution and its conservation possibilities. Potential mesopelagic fisheries will likely be performed by the métiers that make fishing trips of approximately five fishing days. The interviewees informed that exploratory trips in distant areas (e.g., up to East Greenland or along the African coasts) can occasionally and will likely occur.

The DPPO representatives indicated that mesopelagic resources are particularly interesting because of their perceived relatively high fatty contents, which has been supported by experiences from previous Norwegian and Icelandic experimental fisheries for *Maurolicius muelleri*. By experience, the prices will increase with higher relative fat content of the resources (Rana et al., 2009). Landing prices will likely be similar to summer herring prices landed for industrial purposes because of a similar fat content, and hence would head toward the upper end of the current observed prices range for pelagic fish resources used for industrial purposes between 3.5 and 6 NOK/kg (corresponding to 0.30–0.55 €/kg). The price depends not only on the total high oil content and relative amount of lipids in the resources, but also upon the composition of the fatty acids (omega three acids) which will determine the price for fish meal and fish oil. In 2019–2020, prices in Norway have been between 3.5 and 4.5 NOK (corresponding to 0.30–0.40 €) for landed *Maurolicus* in trial fisheries which is better paid than blue whiting also used for meal and oil production. Such economically interesting resources with high fat content will according to the fishers inevitably bring new opportunities and challenges. None of the selected vessels currently owns any parts of or in the fish processing industry, neither for the purpose of consumption not fish mean/oil production. Thus, there is no ownership or membership that could influence the behavior of the fishery sector and its willingness to invest into a potential mesopelagic fishery, even at a lower expected profit. The DPPO representatives expressed that the behavior observed in the current pelagic

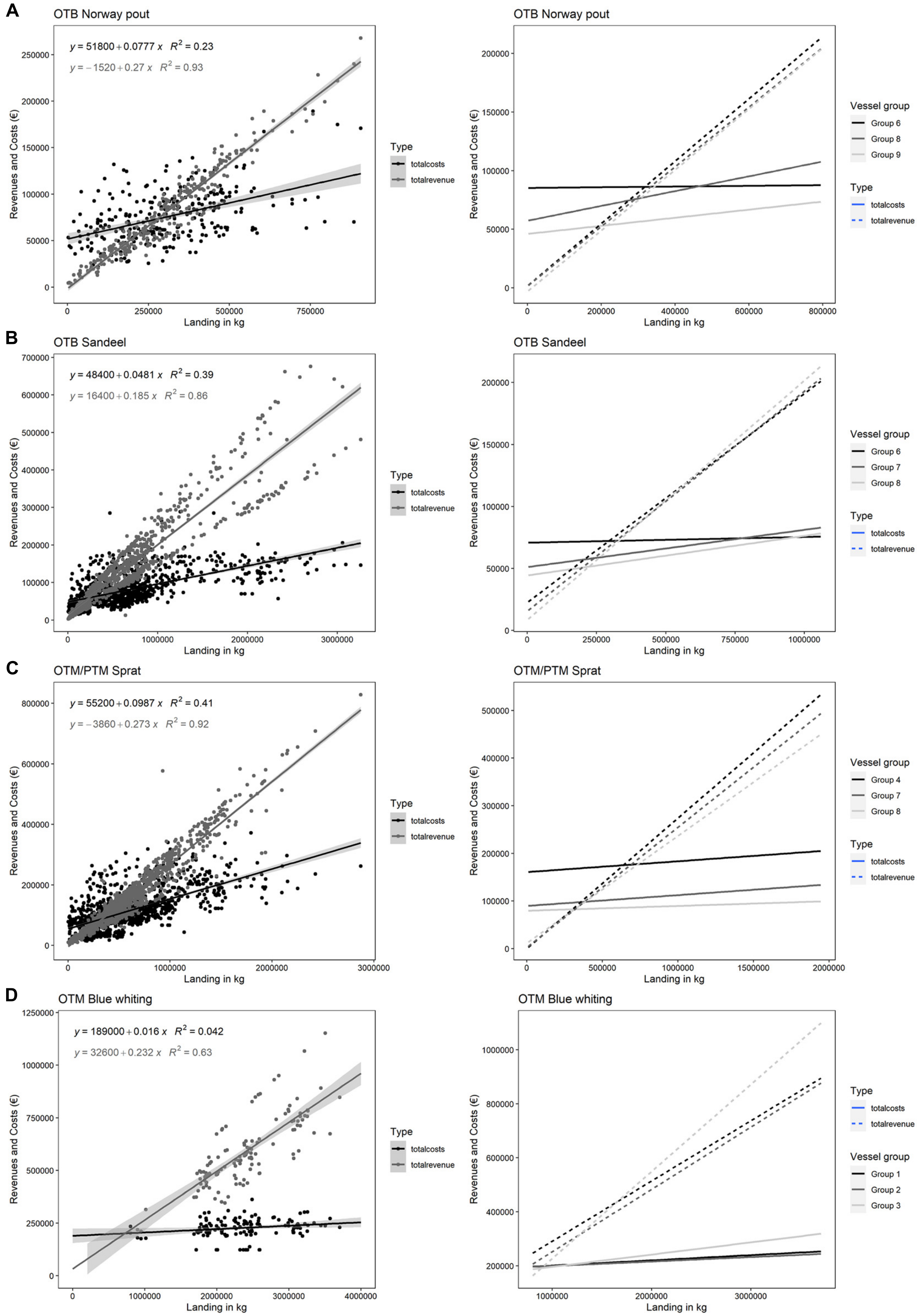

FIGURE 8 | Continued

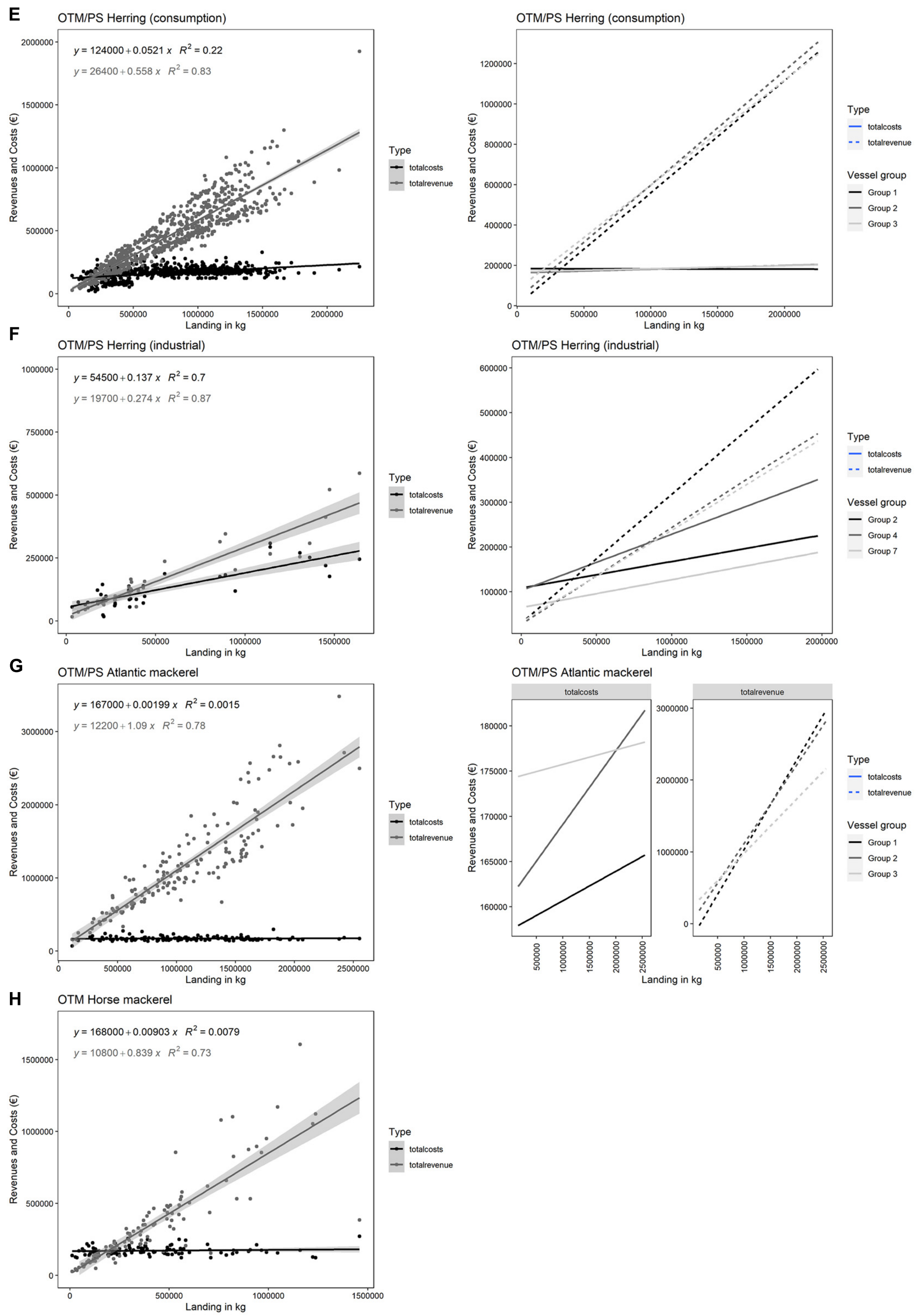

FIGURE 8 | BEP graphs by métier for the Danish large vessel catch sector with **(A)** OTM Norway pout, **(B)** OTB Sandeel, **(C)** OTM/PTM Sprat, **(D)** OTM Blue whiting, **(E)** OTM/PS Herring (consumption), **(F)** OTM/PS Herring (industrial), **(G)** OTM/PS Atlantic mackerel, and **(H)** OTM Horse mackerel, for the period 2015–2019.

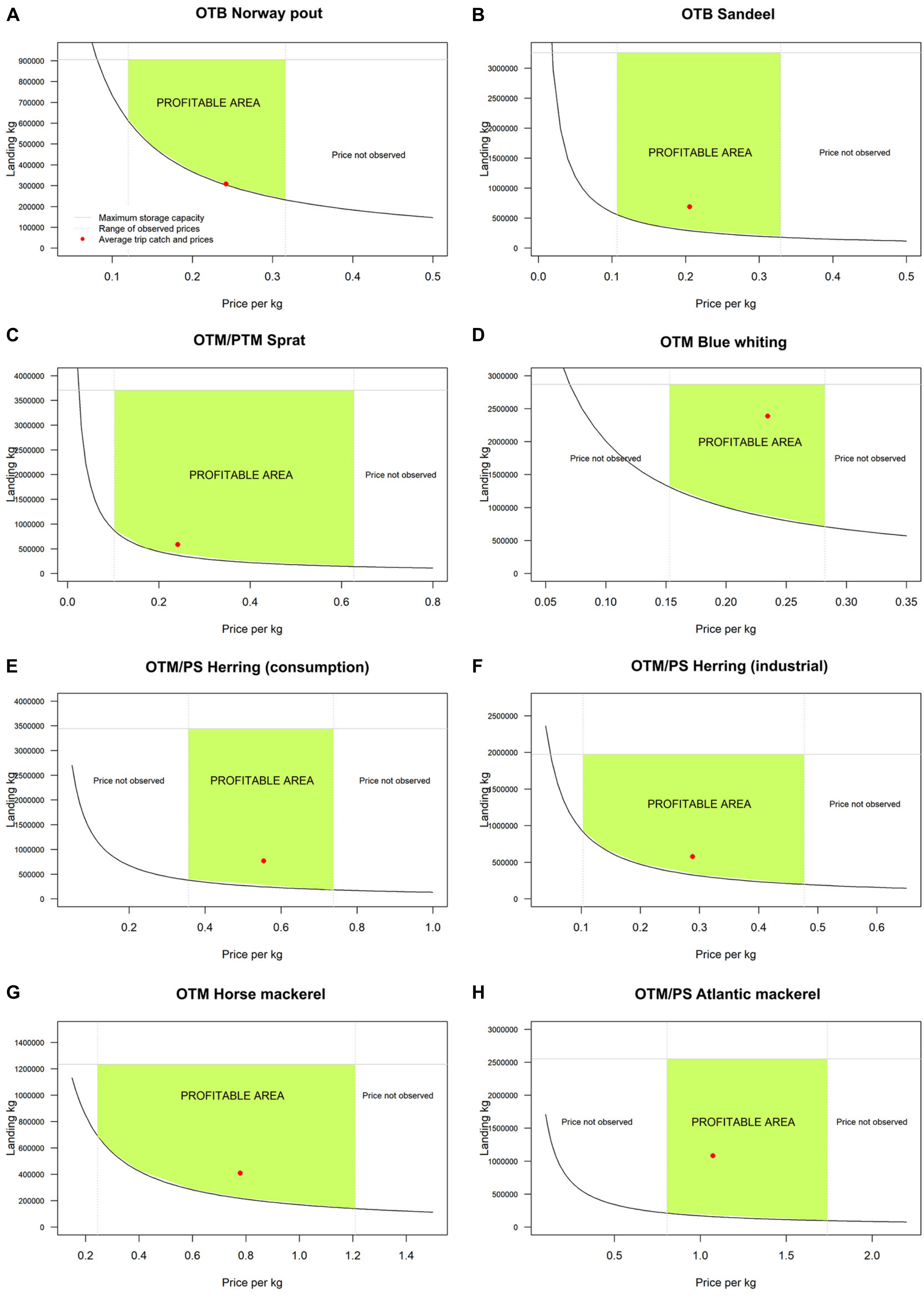

FIGURE 9 | Potential profitability of main pelagic métiers for the Danish large vessel pelagic catch sector during the period 2015–2019 delimited by the bio-economic variables, with **(A)** OTB Norway pout, **(B)** OTB Sandeel, **(C)** OTM/PTM Sprat, **(D)** OTM Blue whiting, **(E)** OTM/PS Herring (consumption), **(F)** OTM/PS Herring (industrial), **(G)** OTM Horse mackerel, and **(H)** OTM/PS Atlantic mackerel.

fisheries and the willingness to invest into a new activity are driven by its biological sustainability and profitability within the catch sector.

Conservation is, however, a main issue. With the current conservation method (RSW), the trips where the duration between the day of first catch and the first landing needs realistically to be 3–5 days before losing significant quality of the stored resources on board. This observation is also supported by experiences from previous Norwegian and Icelandic experimental fisheries for *Maurolicius*. That is the period from the first catch being taken on board to the actual landing in harbor. Trips with longer steaming time and shorter concentrated fishing time are possible, but once the first catch is stored it will need to be landed within 3–5 days when using refrigerated sea water (RSW), which is the dominating conservation method on board in current fishery. In accordance with the literature results given in the introduction, the interviews also put emphasis on that the conservation method is inversely proportional to the fat content of the targeted species. If the method is improved to conserve species with high fat content, e.g., freezing, or the vessel adds, e.g., a fish meal processing facility on board, the fishing trip duration may be increased and become comparable to other current pelagic fisheries. Among new conservation methods the silage production, freezing, acids, thermic separation, and enzymatic hydrolysis may be considered. Consequently, the trip duration is not only dependent on the storage capacity, but also on the concentrations (densities) of the resources in relation to the fishing capacity, i.e., needed fishing time to fill the storage, but also on the distance between the fishing areas and landing harbors with necessary processing facilities determining the needed steaming time for landing in relation to a trade-off in quality – and accordingly prices – of the catch. Currently all ten large pelagic vessels organized by the DPPO have RSW systems on board where species are cooled down and maintained in sea water between 0 and −1 degrees to preserve the best quality. The storage capacity depends on the vessel length, where currently the largest pelagic vessels store up to 3,000 tons per trip. Landings by the DPPO occur both in national and foreign harbors, including Norway, Scotland, the Faroe Islands, and Germany besides Denmark.

From the interviews it appeared that fishing patterns and trip cost structure would mostly resemble the blue whiting fishery among the current large pelagic vessel fisheries which is also a small meshed deep sea trawl fishery. As such, it would be a relatively heavy fishery, fishing at large depths that require high fuel consumption and extensive engine power due to the large, small meshed trawl gears hauled and filtering large water masses through fine mesh sizes, as well as heavy weight gear from among other the long wires used. However, no avoidance reaction to the fishing gear is expected by mesopelagic species contrary to traditional blue whiting fishery. The interviews confirmed that schooling species are targeted with shorter duration but more frequent fishing operations, where the fishermen skills and expertise come extensively into force (e.g., the blue whiting fishery), while non-aggregating species were targeted with longer duration hauls deployed fewer times (e.g., the Norway pout fishery). Mesopelagic species undergo a diel vertical migration as observed by the DPPO at sonars and echosounders at around dawn and dusk, which vertical migration patterns are also supported by literature (Ishihara and Kubota, 1997; Sutton et al., 2008; Hudson et al., 2014). A fishing pattern conducted by two long tows per 24 h diurnal period will likely be most efficient to target species with such diurnal migration. That is, 1 day haul and one night haul, and then heaving and setting at dusk and dawn when the resources are migrating and changing depth distribution. According to the DPPO perception, then catch amounts per tow will most likely resemble the sandeel fishery, with tow weights typically ranging between 200 and 500 tons per haul.

Based on the interviews, additional costs could not be quantified precisely before further investigation in the DPPO databases was conducted, but according to the DPPO it would surely include the development of new gears and storage facilities. With respect to new gear, it would be central to find the right relative proportion of mesh sizes of the different panels down through the trawl to the very fine mesh sizes in the cod end in order to increase catch and reduce fuel costs. That is, to increase catch rates according to fish behavior and at the same time reduce fuel costs by not pushing unnecessary much water by the trawl, i.e., to reduce the water resistance. Under all circumstances there will be an increased fuel consumption compared to the current small meshed pelagic fisheries for industrial purposes conducted by the DPPO. Investments in the construction of a new vessel were also considered very realistic by the DPPO also considering the current activity levels of the existing fleet and in order to quickly establish historical fishing rights according to future quota allocation. This should according to the DPPO certainly be considered in relation to the fishery break-even and profitability considerations.

Economic Performance of Potential Mesopelagic Fishery Integrated From Current Fishery Analyses and Outcomes From the Interviews With Representatives of the DPPO

Potential profitability scenarios by trip for mesopelagic fisheries were developed given the information obtained from the interviews (**Figure 10**). The first row of scenarios was established using approximations of the smallest (sprat fishery; ∼90,000 €), the intermediate (herring fishery for consumption; ∼150,000 €), and the largest (blue whiting fishery; ∼200,000 €) BEP revenues estimated among the current strictly pelagic fisheries and represent a realistic range for potential mesopelagic fisheries. Current observed price ranges of 3.5–6 NOK/kg (0.30–0.55 €/kg) for pelagic resources as explained above vertically delimited the profitable areas, while the maximum expected catch per trip as perceived by the DPPO delimited the areas horizontally. The maximum expected catch per trip was estimated as follows:

$$\text{Max. catch}_{\text{trip}} = \text{Max. catch}_{\text{tow}} * \text{Number of tows}_{\text{day}} * \text{Fishing days}_{\text{trip}} \tag{9}$$

where realistic indications according to current conservation and storage possibilities were considered 500 tons of maximum expected catch weight per tow, two number of tows per day, and

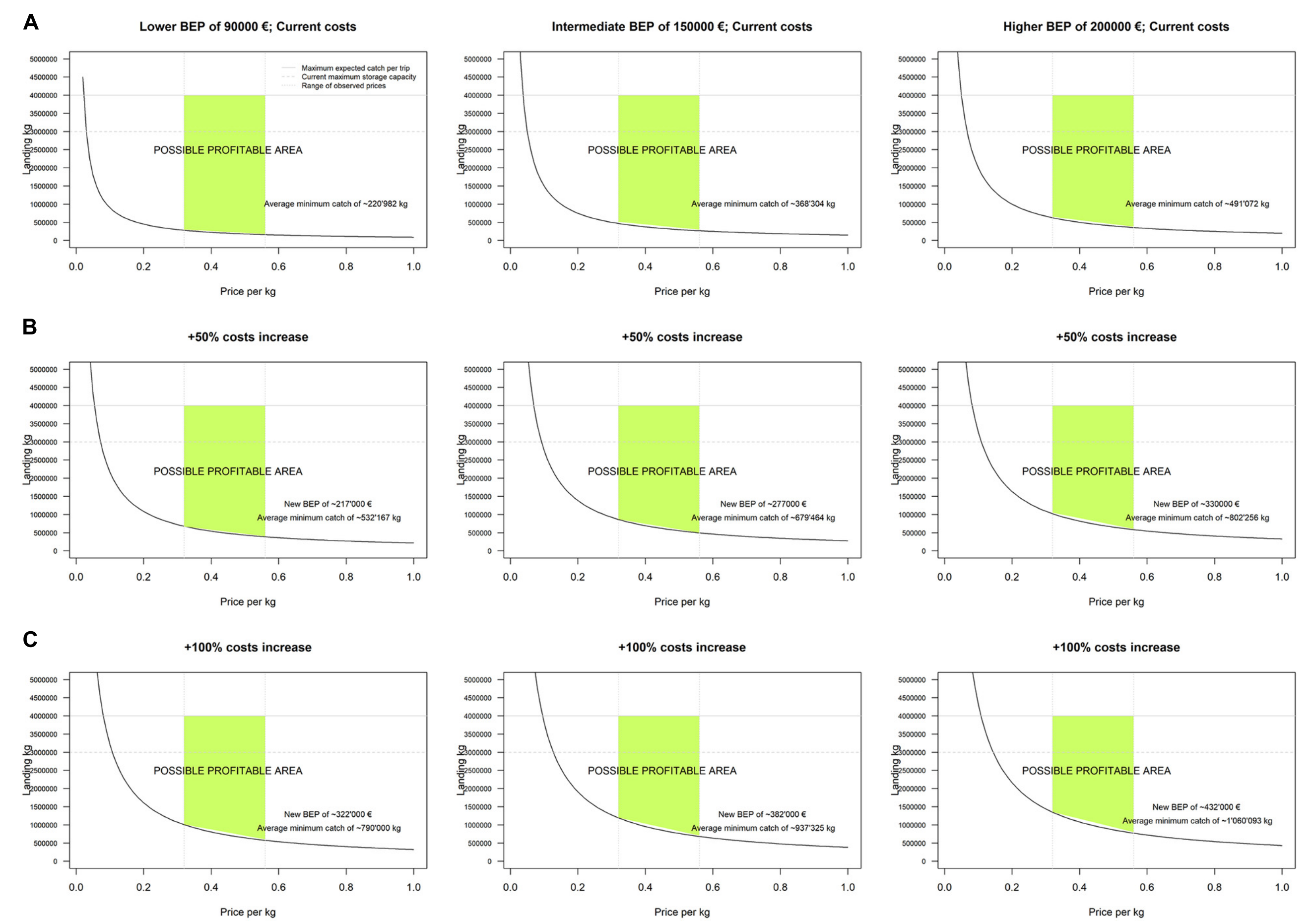

FIGURE 10 | Potential profitability scenarios by trip for mesopelagic fisheries as perceived from current Danish large vessel pelagic fish sector activities and results from interview investigations of the DPPO representing this catch sector. Dotted lines indicated the current maximum storage capacity, solid lines indicate realistic future storage capacity, e.g., new vessels. **(A)** Different BEP scenarios were chosen to build the trade-off curves and display the corresponding profitable areas under current costs similar to the blue whiting fishery. **(B)** BEP and profitability changes under costs scenarios increased by 50%. **(C)** BEP and profitability changes under costs scenarios increased by 100%.

four effective fishing days, for a maximum expected catch per trip of 4,000 tons. Two other rows of scenarios displayed the changes in BEPs and profitability when, respectively, a 50% and a 100% increase in both fixed and variable costs are considered (estimated) from the cost-structure of the perceived most similar current pelagic fishery, i.e., the blue whiting fishery.

The break-even revenues gradually increased given increasing total costs (**Figure 10**) because of the lifting and steepening of the cost function in relation to the revenue. The increase in the break-even revenue lifts the demand and supply curve from the origin and drives the shrinking of the potentially profitable areas. For all scenarios developed, the results indicate a maximum profit between 1,560,000 and 1,208,000 euro (€) per trip given current maximum storage capacity of 3,000 tons for a trip of 3–5 days (limit set by the dotted line) but may be higher if the storage capacity is improved and the catches are maximized to 4,000 tons per trip (limit set by the solid line). The range of maximum potential profits can be estimated as the maximum potential revenue of 1,650,000 € (right corner at the limit set by the dotted line) subtracted of each scenario specific BEP. Within a trip the range of minimum catches to break-even goes from an average of 220,982 kg (average of the bottom corners of green area in the first panel) to 1,060,093 kg (average of the bottom corners of green area in the last panel). The highest break-even revenue forecasted is 432,000 € (last panel).

DISCUSSION AND PERSPECTIVES

In this study, detailed information of fishing effort, catches, revenues, and costs of vessels and métiers of the Danish large vessel pelagic fleet over the period 2015–2019 were investigated and integrated with information and perspectives from interviews with key stakeholders. Interviews with main representatives of the DPPO, including the director and their chief scientific advisor that represent an important part of Danish pelagic fishing vessel owners, gave insights into necessary changes, potential revenues, and additional costs in a potential mesopelagic fishery. Based on this information we have analyzed the current fishing dynamics, providing new insights into the pelagic fisheries at national level, and into the economic conditions and incentives related to the development and investment into a new potential mesopelagic fishery in the North East Atlantic.

The majority of the activities of the Danish pelagic fishery takes place within the Greater North Sea and the Baltic Sea. However, large vessels also engaged in fisheries in more distant areas such as the Norwegian Sea, the Celtic Sea and the West of Scotland sea. Most métiers mainly focused on one single target species. Exceptions are the demersal mix species métier which targets multiple species, the sprat and herring fisheries and the horse mackerel fishery, which often also harvested Atlantic mackerel and other collateral species.

The initiation of a new fishery will most likely require switching from on-going fisheries and activity patterns or need for fleet expansion, since the temporal distribution of the fishing activities of the current Danish pelagic fishery showed that each vessel group is managed and organized to be fully active and occupied year round for all vessel groups. Seasonal métiers are currently alternated, and reveal no major gaps in the fishing activities performed by the full fleet capacity. Accordingly, we cannot reject our zero hypothesis that the large pelagic vessel fleet does not have time available and is fully occupied to perform additional mesopelagic fishery without switching from other current métiers.

We evaluated the economic efficiency and sustainability of the current métiers based on economic BEPs and profitability (Prellezo, 2019), to investigate the switching possibilities in more detail. The Norway pout fishery showed the smallest window of profitability and estimated net profits, likely due to high costs because of long distance fishing grounds and long hauling times, and should be considered when contemplating potential switching from existing activities. The high average trip catches and prices in the Atlantic mackerel, blue whiting, herring and sandeel métiers results in larger windows of possible profitability which may generate economic possibilities for new investments into new vessels, equipment and processing facilities. According to those results we cannot reject the zero hypotheses that all current pelagic fisheries exemplified by the Danish large vessels pelagic fleet are economically efficient and would not have incentives to switch to mesopelagic fishery. In the Norway pout fishery for some trips the costs were higher than revenues, resulting in a negative net profit. However, over the entire time frame the Norway Pout fishery is still profitable when all the trips are summed up.

The interviews indicated that the potential revenues and costs associated to fishing trips targeting mesopelagic resources would likely not differ extensively from the current economics observed for ongoing pelagic métiers. They were specifically foreseeing similarities between the current herring fishery for industrial purposes and the potential mesopelagic fishery in terms of revenues because of the relative high lipid/fatty acid contents of the mesopelagic resources, with a similar order of magnitude as summer herring (Phleger et al., 1999; Lea et al., 2002; Hamre et al., 2003; El-Mowafi et al., 2010; Koizumi et al., 2014).

Fishing costs will likely be similar to the current blue whiting fishery as this is also a mesopelagic resource and is fished with large small-meshed trawls. However, considerable additional costs might arise with needed vessel modifications or investment into new vessels to conduct an efficient mesopelagic fishery. These modifications include storing capacity, conservation and processing methods, as well as changed fishing gear. Sustainable trawling praxis and methods have to be developed to conduct both deep fishing (day fishing) and shallow fishing (night fishing) according to the vertical distribution patterns of mesopelagic species (Grimaldo et al., 2020) and sustainable herding mechanisms to improve the catch rates and to reduce by-catches. New trawls and fishing methods will be developed to ensure the methods are applicable to a larger fleet and to reduce the energy consumption and costs during mesopelagic trawling in relation to drag resistance of the small meshed fishing gears (trawl cod-end mesh size <10 mm; Valinassab et al., 2007; Lamhauge et al., 2008; Eigaard et al., 2012; Sebastine et al., 2013; Trenkel et al., 2013; Grimaldo et al., 2020). This is much smaller than for typical trawls used in the current small meshed pelagic fishery for industrial purposes (Eigaard et al., 2012; Bigné et al., 2019). Furthermore, trawl design and fishing methods will adapt in relation to species-specific behavior of target species and their response to herding methods (Grimaldo et al., 2018, 2020). With respect to the latter different frequencies and intensities of light and ultrasound could also be considered as alternative herding methods for concentrating mesopelagic fish. Also, introduction of continuous cod-end pumping systems to minimize trawl setting and heaving time and operations could be considered.

Given the necessary technical upgrades vessels and the full-time occupation of the current Danish pelagic fleet, the interviewees confirmed that it will likely be necessary to invest into building new vessels dedicated to a potential mesopelagic fishery. Nevertheless, the additional starting and investment costs were not necessarily perceived as a deterrent for this investment. The initial establishment phase of the fishery would likely be free of quota costs, allowing the investor to cover the costs and reach the BEP in shorter time. A strong incentive in participating in the start of a new fishery is to achieve historical fishing rights and accordingly perceived quota rights. There are naturally alternatives to such "olympic quota allocation" in relation to establishing historical fishing rights, however, some competition among fleets on the access to the resources can be foreseen. Therefore the governance of mesopelagic resources needs investigation prior to potential exploitation (Standal and Grimaldo, 2020).

The BEPs estimated for the new potential mesopelagic fishery highlighted different scenarios of profitability. For all scenarios investigated, the results indicate a maximum profit between 1,560,000 and 1,208,000 € per trip given current maximum storage capacity of 3,000 tons for a trip of 3–5 days but may be higher if the storage capacity is increased and the catches are maximized to 4,000 tons per trip. That means that per trip an average of 150,000–200,000 € of revenue should be made with a minimum average catch of 220–1,060 tons. High profitability may be reached if the catches exceed 220–1,060 tons per trip depending on costs and storage capacity.

This could be economic feasible; mesopelagic trial fisheries in Southwest Iceland in 2009–2011 indicated catch rates between 5 and 25 tons/h dependent on the season (MFRI, 2020, personal communication). Larger vessels with better on-board processing and conservation facilities may increase the upper horizontal constraint given by the vessel maximum storage capacity and the limit in conservation duration.

With the current RSW conservation method, fishing trips targeting mesopelagic resources may not be able to last longer than 3–5 days from the first harvest being stored without compromising the quality of the catches. However, with the introduction of new on-board conservation methods, e.g., freezing, silage production, thermic separation, and enzymatic hydrolysis, fishing trips could last longer. Mesopelagic species deteriorate easily after harvest, a process dependent on tissue degradation caused by endogenous enzymes and autolysis releasing low amino acid, nucleotide, and fatty acid contents, i.e., promotion of microbial degradation (Samuelsen and Oterhals, 2016; Vang et al., 2017). Future investigations on spatio-temporal mesopelagic resource abundance, fishery effort allocation, catches, trip durations, and fishing rights, together with more investigations on storage and conservation methods, will be essential to test the robustness of the proposed scenarios, and will in turn benefit of the economic requirements evaluated in current study. Furthermore, realistic prices for mesopelagic resources are still not fully known and may increase given the perceived high percentage of fatty acids. The prices do not only depend on the relative fatty acid and lipid content but very much also on the fatty acid composition (FAO, 1986).

Consequently, based on the current studies, we can reject the third hypothesis that expected increased costs (compared to likely prices/earnings), and thus the expected larger BEP of mesopelagic fishery, are too extensive to obtain an adequate profitability to conduct potential mesopelagic fishery with either current fleet or investment into new fleet capacity given different scenarios of economic BEP (covering among other prices, catch amounts, and costs per unit of effort). The current results indicate relatively high profit in most of the current pelagic fisheries as well as similar level of profits in potential mesopelagic fishery. There may be adequate profitability and a potential economic interest in either switching mesopelagic fishery from certain current fisheries or to investing into new vessels to conduct mesopelagic fishery based on the economic indicators considered in this study.

The above evaluations have not included potential impacts of the effects of other European management measures such as Brexit on the fishing patterns of the Danish large vessel pelagic fisheries, as it is currently impossible to predict how Brexit exactly will influence both the existing fishing patterns and the development of potential new mesopelagic fishery. Brexit measures might cause changes in current quota shares and induce a potential trade of quotas between vessels and countries, which we have not included here. Besides the unknowns in relation to fishing rights and quota trade between vessels and countries caused by Brexit also the fishing distribution and seasonal changes herein might change according to the United Kingdom EEZ and the EU EEZ of the different pelagic resources, and accordingly national/EU specific quota settings.

CONCLUSION

In conclusion, our study investigated the viability of a mesopelagic fishery within the Danish pelagic sector exclusively from an economic point of view, assuming that thorough investigations on the biological and ecosystem sustainability of such activity have priorly set the base for its existence. Therefore, based on the conducted scenario analyses, the expected increased costs in relation to the revenues and, thus, the expected larger BEP of mesopelagic fishery will not be too extensive to partly obtain an adequate profitability to conduct additional mesopelagic fishery with the current fleet. However, we can reject that potential new mesopelagic fishery will fill in activity periods (gaps) of current large pelagic fishing fleet or substitute current profitable activities with mesopelagic fishing. Our results indicate that potential new mesopelagic fishery would likely be profitable to invest into new vessels – or switch from the least profitable current fisheries – to initiate such potential new fishery, i.e., expand the capacity of the Danish large vessel pelagic fleet given the different scenarios of economic BEP we investigated taking into account pelagic fishers perceptions and results from investigations of ongoing pelagic fishing activities.

However, as explained in the introduction of the current paper the ecological sustainability of potential mesopelagic fisheries first of all have to be investigated in relation to the target species role in among others biodiversity, ecosystem functioning and ecosystem services before starting to conduct such potential fishery. This concerns not only the mesopelagic target species, but also as the potential by-catch species. Since fine-meshed trawl gears will be used, potential bycatch includes vulnerable species as well as other juvenile fish that might have commercial importance. Accordingly, the distribution patterns and overlap of potential target species with other species need thorough investigations to assess and predict catch compositions more precisely taking the selective properties of the gears into consideration.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

JRN and SP: conceptualization, funding acquisition, and writing – original draft. SP, JRN, CS, and FB: data curation. SP, JRN, and BV: formal analysis, resources, and project administration. SP, JRN, BV, CS, and FB: investigation, methodology, validation, visualization, and writing – review and editing. SP, FB, and BV: software. JRN and FB: supervision. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Table of Contents

1 Introduction

This report explores whether a mesopelagic fishery is economically attractive for the Dutch fishing sector. Using public data from the Fleet Capacity Report (2019), the Social, Technical, and Economic Committee for Fisheries, literature, and informal conversations with the Dutch fishing sector, we describe the cost structure, main target species, and fishing areas for the Dutch pelagic trawler fleet, and assess whether mesopelagic species, particularly *Mauroliccus muelleri* or *Benthosema glaciale*, can be an attractive target species for this fleet.

The structure of the report is as follows. Chapter 1 briefly describes the Dutch fishing fleet. Chapter 2 describes the main technical characteristics of the Dutch pelagic trawler fleet. Chapter 3 explains the main expenses and sources of revenue. Chapter 4 makes a preliminary assessment of the prospects for a mesopelagic fishery for Dutch pelagic trawlers. Chapter 5 concludes.

2 Composition of the Dutch fishing fleet

The Dutch fishing fleet consists largely of coastal and/or demersal fishing vessels that are unsuitable for a mesopelagic fishery (Table 1). The exception to this are the pelagic trawlers.

Table 1: Number of vessels in the Dutch fishing fleet 2012-2019. Source: Netherlands Fleet Capacity Report (2019)

	2012	2013	2014	2015	2016	2017	2018	2019
Small scale and coastal	248	254	248	232	231	219	210	206
Small beamtrawlers	169	171	176	174	174	178	184	171
Large beamtrawlers	84	86	79	77	83	85	88	86
Demersal trawlers	35	27	32	36	32	35	33	49
Pelagic trawlers	12	13	10	7	7	8	7	6
Total	548	551	545	526	527	525	522	518

With six to eight vessels in the last few years the Dutch pelagic fishery seems a small part of the Dutch fishing fleet, but due to the size of the vessels it represents a substantial part of the total landed value by Dutch vessels, i.e. roughly a quarter of the total landed value.

Table 2: Landing value in the Dutch fishing fleet 2012-2018 (mln 2015 EUR). Source: STECF (2020).

	2012	2013	2014	2015	2016	2017	2018
Small scale and coastal	14.9	10.9	11.2	12.0	16.1	3.8	7.1
Small beamtrawlers	64.3	86.0	76.0	70.3	126.7	101.5	99.6
Large beamtrawlers	141.3	139.7	134.4	148.4	171.3	165.9	166.4
Demersal trawlers	35.5	26.3	32.4	42.6	44.9	43.9	41.4
Pelagic trawlers	114.2	106.6	124.4	102.8	110.2	123.2	118.2
Total	370.2	369.4	378.5	376.1	469.3	438.2	432.8

The remainder of this report will only consider the pelagic fleet because this is the only fleet suitable for mesopelagic fishing.

3 Technical description of the Dutch pelagic trawler fleet

In 2019 the Dutch pelagic fishing fleet consisted of six freezer-trawlers with length varying between 95 and 143 m and engine power varying between 3200 and 7920 kW[1]. Main target species are Atlantic herring, blue whiting, Atlantic horse mackerel, Atlantic mackerel, European pilchard, and greater argentine (Table 3).

Table 3: Main species in the Dutch pelagic trawler fleet by value, 2012-2019 (mln 2015 EUR). Source: STECF (2020).

	2012	2013	2014	2015	2016	2017	2018	2019
Atlantic herring (*C harengus*)	31.6	31.8	31.2	27.3	37.2	32.5	39.1	28.4
Blue whiting (*M poutassou*)	9.4	17.1	10.5	16.9	17.5	24.1	35.0	21.1
Atlantic horse mackerel (*T trachurus*)	0.0	0.1	16.9	15.3	15.4	10.6	15.1	15.9
Atlantic mackerel (*S scombrus*)	16.6	13.3	30.8	24.2	22.9	26.3	17.2	13.7
European pilchard (*S pilchardus*)	10.9	2.0	13.8	4.3	11.4	9.2	5.1	4.7
Greater argentine (*A silus*)	1.1	0.8	1.3	1.1	1.3	1.7	1.4	2.2
Other species	46.4	40.7	18.8	13.4	4.7	12.3	2.6	2.9
Total	116.0	105.7	123.3	102.4	110.4	116.8	115.4	89.0

Fish are caught with pelagic trawls with an opening of between 30 and 60 m, a horizontal spread between 80 and 120 m, and a mesh size in the cod end of 4 cm (Couperus et al., 2004). Trawling depth for the main species is 50-200 m (herring and North Sea horse mackerel), 100-400 m (mackerel and western horse mackerel), 300-500 m (blue whiting), and 600-800 m (greater argentine). Catch is pumped out of the codend and frozen in blocks of 20-25 kg.

The pelagic fleet is currently used at or slightly above its full capacity (Netherlands Fleet Capacity Report, 2019). Target species and region vary by month, by year, and by company (Couperus et al., 2004). Although average trip length is between three and four days (Table 4), especially the larger vessels do make trips of five weeks or more (Couperus et al., 2004).

Table 4: Number and length of fishing trips and catch weight in the Dutch pelagic trawler fleet, 2012-2019. Source: STECF (2020).

	2012	2013	2014	2015	2016	2017	2018	2019
Days-at-sea	2566.4	2069.6	2211.1	1787.3	1825.3	2059.4	1883.3	1608.2
Number of fishing trips	693	662	636	487	577	581	618	507
Average trip length (days)	3.7	3.1	3.5	3.7	3.2	3.5	3.0	3.2
Average days-at-sea per vessel	213.9	159.2	221.1	255.3	260.8	257.4	269.0	268.0
Catch weight (mln kg)	259.7	258.0	296.0	242.7	275.3	295.3	315.8	239.5
Catch per day-at-sea (ton)	101.2	124.7	133.9	135.8	150.8	143.4	167.7	148.9

Spatial distribution of fishing activity varies from year to year, but the majority (64%-95% of days-at-sea) takes place in the Northeast Atlantic (Table 5). Within this area the ICES subareas 27.4 (North Sea), 27.6 (Rockall, Northwest Coast of Scotland and North Ireland), and 27.7 (Irish Sea, West of Ireland, Porcupine Bank, Eastern and Western English Channel) account for between 60% and 90% of total days-at-sea. There is also substantial fishing activity near the

[1] EU Fleet Register (https://webgate.ec.europa.eu/fleet-europa/search_en).

coast of northwest Africa (ICES subarea 34.1), which typically accounts for 5%-20% of total fishing days. Fishing activity in this area particularly takes place near the coast of Mauritania (Couperus et al. 2004).

Table 5: Days-at-sea of the Dutch pelagic trawler fleet by ICES subarea, 2012-2019. Source: STECF (2020).

ICES subarea	2012	2013	2014	2015	2016	2017	2018	2019
27.4	1236.6	412.7	535.2	397.7	619.2	925.3	612.8	483.9
27.6	87.2	334.6	344.7	294.0	405.7	364.9	521.0	551.3
27.7	770.4	982.7	410.4	536.5	394.8	475.5	471.9	379.2
34.1	403.0	59.0	444.9	247.7	221.3	94.6	127.6	130.8
Other	69.2	280.6	475.8	311.4	184.4	199.0	150.1	63.2
Total	2566.4	2069.6	2211.0	1787.3	1825.3	2059.4	1883.3	1608.2

4 Economic return in the Dutch pelagic trawler fleet

Major expenses in the Dutch pelagic trawling fleet are personnel (20%-30% of total costs), repair and maintenance (15%-20% of total costs), and energy (15%-20% of total costs) (Table 6). About half the engine power is used for propulsion, and the rest for freezing (Couperus et al., 2004).

Table 6: Economic return in the Dutch pelagic trawler fleet, 2012-2018 (mln 2015 EUR). Source: STECF (2020).

	2012	2013	2014	2015	2016	2017	2018
Repair & maintenance costs	32.9	19.0	24.0	33.9	19.4	21.9	22.8
Consumption of fixed capital	24.0	36.0	21.6	17.4	18.3	15.0	13.6
Other non-variable costs	7.4	7.8	9.0	11.2	14.0	15.1	13.3
Total fixed costs	64.3	62.7	54.7	62.5	51.7	52.0	49.8
Personnel costs	32.2	30.9	34.4	30.0	28.3	32.0	36.8
Energy costs	31.5	27.9	26.7	15.5	13.4	17.9	18.2
Lease/rental payments for quota	0.7	0.0	8.5	0.1	1.1	1.5	0.0
Other variable costs	14.5	13.5	15.5	15.5	8.9	11.1	11.0
Total variable costs	78.8	72.3	85.1	61.2	51.7	62.6	66.0
Total costs	143.1	135.0	139.8	123.7	103.4	114.6	115.8
Gross value of landings	114.2	106.6	124.4	102.8	110.2	123.2	118.2
Other income	0.0	0.0	0.0	0.3	0.1	0.3	0.1
Total revenues	114.2	106.6	124.4	103.1	110.3	123.5	118.3
Net returns	-28.9	-28.4	-15.3	-20.6	6.9	8.8	2.5

Economic returns were very negative in 2012 and have improved since. It must be noted, however, that the Dutch pelagic fishing companies are vertically integrated (Netherlands Fleet Capacity Report, 2019). The official landing prices are therefore internally used transfer prices rather than auction prices. The revenues and net returns of the pelagic fleet should therefore be interpreted with caution. The same caution applies to the prices estimated from catch weight and landing value (Table 7), which should only be taken as indicative of the market price.

Table 7: Estimated prices for the six main species in the Dutch pelagic trawler fleet, 2012-2019 (2015 EUR). Source: STECF (2020).

	2012	2013	2014	2015	2016	2017	2018	2019
Herring	€ 0.38	€ 0.36	€ 0.37	€ 0.36	€ 0.36	€ 0.36	€ 0.35	€ 0.34
Blue whiting	€ 0.35	€ 0.33	€ 0.27	€ 0.30	€ 0.30	€ 0.30	€ 0.29	€ 0.27
Horse mackerel		€ 0.45	€ 0.47	€ 0.51	€ 0.51	€ 0.50	€ 0.50	€ 0.50
Mackerel	€ 0.66	€ 0.64	€ 0.67	€ 0.63	€ 0.63	€ 0.62	€ 0.61	€ 0.66
Pilchard	€ 0.40	€ 0.44	€ 0.30	€ 0.33	€ 0.33	€ 0.33	€ 0.32	€ 0.31
Greater argentine	€ 0.63	€ 0.59	€ 0.46	€ 0.51	€ 0.51	€ 0.50	€ 0.50	€ 0.50

The costs of a day-at-sea varies between 30 and 40 thousand euro in price levels of 2015 (Table 8). Over the last decade personnel costs have increased while energy costs have decreased.

Table 8: Variable costs per day-at-sea in the Dutch pelagic trawler fleet, 2012-2018 (thousands of 2015 EUR). Source: STECF (2020).

	2012	2013	2014	2015	2016	2017	2018
Personnel costs	12.5	14.9	15.6	16.8	15.5	15.5	19.5
Energy costs	12.3	13.5	12.1	8.7	7.3	8.7	9.7
Other variable costs	5.6	6.5	7.0	8.7	4.9	5.4	5.9
Lease/rental payments for quota	0.3	0.0	3.8	0.1	0.6	0.8	0.0
Total variable costs	30.7	34.9	38.5	34.2	28.3	30.4	35.0

Most landed value is caught in ICES subareas 27.4 (North Sea), 27.6 (Rockall, Northwest Coast of Scotland and North Ireland), and 27.7 (Irish Sea, West of Ireland, Porcupine Bank, Eastern and Western English Channel), which usually account for 65%-95% of total landed value (Table 9).

Table 9: Value of landings by the main ICES subareas for the Dutch pelagic trawling fleet, 2012-2019 (mln 2015 EUR). Source: STECF (2020).

ICES subarea	2012	2013	2014	2015	2016	2017	2018	2019
27.2	2.3	2.0	6.8	6.0	7.3	7.5	5.1	2.0
27.4	55.1	26.2	40.0	30.9	45.7	52.5	41.4	31.3
27.6	4.3	20.2	19.3	18.4	23.5	25.2	33.3	30.7
27.7	38.9	43.1	20.8	28.9	23.1	23.4	27.5	21.5
34.1	14.7	1.8	19.4	7.7	7.5	3.1	5.0	3.2
Other	0.6	12.4	16.9	10.5	3.3	5.2	3.1	0.4
Total	116.0	105.7	123.3	102.4	110.4	116.8	115.4	89.0

The value of landings per day-at-sea is between 50 and 70 thousand euro in 2015 prices in the four most prevalent fishing areas (Figure 1).

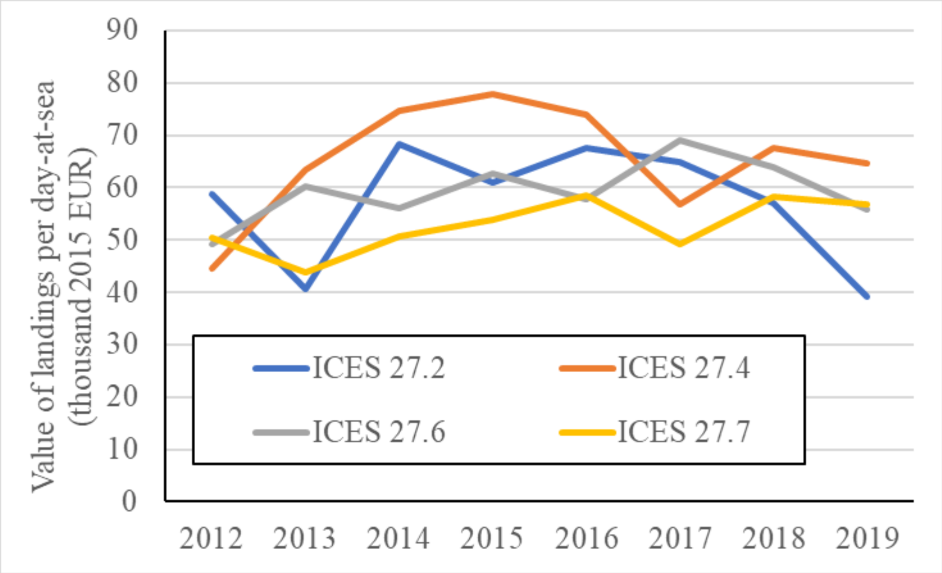

Figure 1: Value of landings per day-at-sea for the four most prevalent ICES subareas in the Northeast Atlantic (thousand 2015 EUR)

5 Prospects for involvement in mesopelagic fisheries

At present the fleet is operating at its full capacity (see also Netherlands Fleet Capacity Report, 2019), so that involvement in mesopelagic fisheries has a substantial opportunity cost. If we rule out big investments in onboard processing, i.e. we assume that catch of *Maurolicus* or *Benthosema* is frozen on board like the current target species, the market price of these species should exceed that of current species by a sufficient amount to offset possible higher fuel costs and investments in finer-meshed fishing nets. We have not been able to estimate the costs of such nets, but if we assume that fuel use during hauls will be twice current fuel use (which may be an overestimate), the extra fuel costs would amount to about €5,000 per day. At a catch of 100 tons per day (at the lower end of the range for current target species), this would require a price premium of €0.05 per kg. Considering the price estimates by Paoletti et al. (Part B of this Deliverable) of €0.30-€0.55 per kg, this is highly uncertain but not impossible.

This estimate, however, comes with considerable caveats. Current market prices are unavailable for the Dutch pelagic trawler fleet because the companies are vertically integrated and prices should be considered transfer prices. Therefore it cannot be said with certainty how Paoletti et al.'s estimate compares to the prices of current target species. The catch rate of *Maurolicus* or *Benthosema* is yet highly uncertain and could be much lower than that of current target species. Lastly, it is also unknown how easily these species can be frozen on board.

Informal conversations with the industry have so far indicated limited interest in developing a fishery on *Maurolicus muelleri* or *Benthosema glaciale*. Although the Dutch pelagic fleet is active at mesopelagic depths for blue whiting (*Micromesistius poutassou*) and greater argentine (*Argentina silus*) (Couperus et al., 2004), informants from the industry have indicated that for the time being they are not seriously considering it. Concerns include the industry's lack of experience with fishing the mesopelagic and considerable uncertainties regarding the market price and the required technological investments. The technical uncertainties include the question whether the high content of water and salt of *Maurolicus* and *Benthosema* limits the possibilities for freezing.

6 Conclusions

Within the Dutch fishing fleet the large-scale pelagic fleet is the only fleet segment that could potentially get involved in a mesopelagic fishery. Because this fishery is currently operating at its full capacity, however, a mesopelagic fishery would have to offer considerable benefits to the fishery to offset forgoing current profitable target species.

Given the vertical integration of the fishing companies it is difficult to judge to what extent *Mauroliccus muelleri* and *Benthosema glaciale* can generate higher revenues than current target species, but neither can it be ruled out. Major uncertainties exist, however, with regard to the expected market price, catch rate, and suitability of the species for freezing.

Informal conversations with the industry have so far suggested that there is very limited interest in this fishery. The main concerns of the pelagic trawler fleet with mesopelagic fishing are the lack of experience with the fishery; the high uncertainties in the market price, catch rate, and suitability of the catch for onboard freezing; and the fact that the fleet is currently operating at its full capacity.

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