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Mesopelagics–New gold rush or castle in the sky?

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ABSTRACT

The growing world population requires large, renewable sources of nutritional food. Fish and other marine resources are nutrient dense and rich in healthy marine omega-3 lipids (EPA and DHA) beneficial to humans and animals alike. However, only about 6% of current fisheries are underexploited. Although improvements in fisheries management can increase marine production, aquaculture and untapped marine resources may contribute to a greater degree. Mesopelagic fish have increasingly gained interest as a massive unexploited marine resource. We did a literature review considering the narratives of mesopelagics (especially fish) as a new source of marine resource and compared this to similar narratives about the zooplankton redfeed (*Calanus finmarchicus*) - another marine resource that was considered equal in terms of potential. We found that mesopelagics have the potential to contribute to food production through usage in fish feed, but more significantly by direct human consumption. However, proper markets and demand must be present for them to make harvest economically viable. In addition, a thorough knowledge base will need to be generated to understand all the risks and make the harvest sustainable, in order to avoid adverse effects on several important species relying on mesopelagics as food. As technological advancements and ecological knowledge are increasing, with a growing focus on sustainable resources and healthy oceans as per SDG 14 and the UN Ocean Decade, time will tell whether your future diet will consist of mesopelagic fish, granted we are able to find and sustainably harvest the elusive treasure hidden in the twilight depths.

1. Introduction

The developing and growing human population requires a constant supply of nutritional food. New commercially exploitable marine resources are a promising area of research to deal with this challenge. A recent assessment from FAO states that 60% of fish stocks are maximally sustainably fished, whereas only around 6% is underfished, leaving 34% fished above sustainable levels (overexploited). The state of marine resources has continued to decline since the FAO assessment begun in 1974 [15]. In addition to human pressure, climate change has also been identified as a major threat to marine resources [4,37,57]. As such, the food safety for the continually growing human population is further threatened given the importance of seafood as a major source of protein and nutrients for many vulnerable communities, representing a nutritionally dense and healthy food item containing long chain poly unsaturated fatty acids (LC-PUFAs); the omega-3 fatty acids EPA and DHA [63].

As growth in the wild fishing industry is challenged because of these stressors, aquaculture is pitched as a potential source of fish supply to fill the gap in nutritional needs [38] and alleviate pressure on wild resources [72]. However, aquaculture also requires input from marine resources for fish feed, especially in the farming of predatory fish like salmon and cod that require substantial marine lipids and proteins [54]. At present, fish feed uses feed ingredients from plant proteins and oils blended with marine ingredients, and there has been a considerable shift in the composition of the feed since the 1990 s [61,64,66]. Marine ingredients constituted 90% of the salmon feed in 1990, while this levels were reduced to around 30% in 2013 and further to 25% in 2016 [64, 66]. Blending marine oils with vegetable oils is a less expensive alternative – especially given the limited supply of marine oil coupled with the inexpensive production of vegetable oil. However, the negative consequence of reducing EPA and DHA levels in salmon fillet is that it essentially removes some of the health benefits humans get by eating the salmon fillet, as well as having lower digestibility [32,61]. Additionally, the effects of pressures on land-based ingredients for feed, such as soy beans from Brazil, has its own negative consequences [17,39]. These are some of the reasons for the urgency to find new and still un- or under-exploited sources of marine lipids in fish feed, as they could

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replace the plant oils if its economically viable to do so.

Considering this, mesopelagic fishes represent a promising alternative. Mesopelagic fish reside below the border of the deep sea, in the Mesopelagic zone also known as the Twilight Zone - the layer in the ocean between 200 m and 1000 m depth. The mesopelagic zone can be found in 60% of the worlds areas and fills a total of 20% of the total world's oceans volume. Given this, it is a large part of our biosphere, and possibly one of the least explored ecosystems on Earth. Mesopelagic fish is also believed to be the largest unexploited resource on Earth, with the most ambitious estimates suggesting the mesopelagic zone could contain around 10 Gt (10,000 million tonnes) of fish biomass. Mesopelagic fish were already likely to dominate total fish biomass at the previous estimates of 1000 million tons (1 Gt), but the recent estimates which suggest an increase of one order of magnitude, further strengthens this claim. If accurate, this will make mesopelagic fish the most abundant vertebrate in the biosphere [30]. Previous estimates were made with trawls, and were likely underestimating biomass due to multiple factors, especially trawl avoidance [33], poor catch equipment and technique. The new estimate of 10 Gt is 100 times the annual catch of commercial fisheries today, giving a scope of how large this potential resource is, as harvesting only 1% of this biomass would increase total global fishery landings by the double. Research efforts have increased, and there has been considerable effort in test fisheries, both in national and international waters, from a few Norwegian fishing companies the last 5 years.

This is not the first time we have seen rhetoric about unexploited marine resources with enormous potentials, though. The current narrative around mesopelagic fishes finds itself reminiscent of a similar narrative regarding the abundant zooplankton *Calanus finmarchicus (*"redfeed*")*. This is a species of marine copepods, zooplankton, which at the adult state ranges from 2 to 3 mm in size. Redfeed is known as the most abundant of all species in Norwegian waters, with a standing biomass estimated at 33 and 28 million tons wet and dry weight in Norwegian and Barents Sea, respectively and a total annual production estimated at 190–290 million tons per year [8].

These zooplankton are furthermore lipid rich and rose to fame as an untouched marine resource for both human consumption and potential use in aquaculture feed. Therefore, similarly to mesopelagics, redfeed was heralded as the solution to ameliorate fishing pressures from already overfished stocks, as the zooplankton could replace fish meal and oil, and thereby indirectly contribute to food for humans as well via alleviating the challenges of feed for the aquaculture industry [14,43,55,56,58–60]. In addition, uses for direct human consumption as nutraceuticals seemed promising at the time as well, as the oil from redfeed were shown to provide a range of health benefits [14]. It would seem, in every aspect an underutilized marine resource, with great potential, just like the current narratives surrounding mesopelagics.

In light of this, the current paper looks at these two cases of "great potentials" in a commercial harvesting setting and compares the narratives around them. We also use the benefits of hindsight in assessing whether there are similarities in these two cases, and what the nascent mesopelagic industry can learn from the experiences of the redfeed fishery. We start by highlighting the methods used for this literature search, followed by a discussion of first the mesopelagic narrative followed by that of redfeed. We discuss the challenges of economics in both cases, given that neither has had an explicit human food market of large size yet. We then bring in the case of herring, which was a resource heavily targeted for the fish feed industry earlier, but which today is primarily going to the human consumption market. We argue that both mesopelagics and redfeed need to study the paths of herring to assess the potentials for accessing this market instead, to ensure that more fish is made available for the human consumption market and thereby ameliorating overexploitation pressures.

2. Methods

For this article, we specifically chose to compare the narrative of "new unexploited resource" for both mesopelagics and redfeed. Key topics for both narratives we investigated includes existing biomass, current and previous fisheries, current markets and values, potential usage areas of the resources, and the breadth of knowledge regarding the two resources. This was to compare them and find similarities and differences. In addition, we wanted to include information on forage fish with a focus on herring, to examine the history of herring usage to speculate the future potential high value usage areas of mesopelagic resources.

For the purposes of this study, we did a literature review. We wanted to find papers on mesopelagics, redfeed and herring, in terms of their resource potential and usage. To do this we employed the search engine Google Scholar, with different Boolean searches. The articles were then systematically read. Some papers were removed even at this stage, due to low relevance, in addition multiple papers being added due to high relevance by reading and going through the selected papers reference lists and adding them to the list of relevant literature. During reading and writing, we also talked to experts who gave input and direction for relevant content. To find statistical data on the harvest and economics of redfeed and other fished species in Norway, the Norwegian directorate of fisheries was accessed through fiskeridir.no accessing databases with fishery statistics. Two phone calls were also made to employees in the directorate to clarify statistics, and to request more information and relevant data.

3. Results

3.1. Mesopelagic narratives

Mesopelagic fish species have been subject to several commercial attempts since the 1970 s [16]. They are generally small (2–15 cm), planktivorous fish that perform diel vertical migration (DVM). They migrate as such near the surface during the night to feed in a more nutrient rich environment and back to the dark depths of the twilight zone during the day as to avoid predators [25]. A wide range of organisms inhabit the mesopelagic zone in the Northeast Atlantic, with krill, jellyfish and fish being examples. Catches of mesopelagics in these waters often vary significantly in terms of catch composition [26,40]. It is the mesopelagic fish however, that we consider as the largest potential resource. Many fish species are considered mesopelagic, but the families Myctophidae (Lanternfish) and Gnostomatidae (Bristlemouth/Lightfish) are the dominating fish families based on sampling, out of a total of about 30 fish families inhabiting the sampled zone [25]. Together, the large mass of mesopelagic organisms collectively forms what is known as deep scattering layers (DSL). These are dense and dynamic layers consisting solely of marine creatures observable by acoustic sampling [25].

The most striking aspect of mesopelagics is their massive biomass. In 1972 an experiment was conducted in tropical regions at the coast off Northwest Africa and the Arabian Sea, where productivity is high. It was estimated to contain several million tonnes of mesopelagic fish between 16 N and 27 N, with a pelagic trawl yielding a catch rate of 6 tonnes/hour [24]. Recent estimates based solely on acoustic sampling of the mesopelagic zone in higher latitudes towards the Arctic (in the Northeast Atlantic, Norwegian Sea) suggested high densities of mesopelagic organisms, even though no specific sampling of biomass or abundance were made. This showed that at high latitudes the biomass in the mesopelagic layer exceeds what we find in the epipelagic layer, a pattern similarly observed in tropical and subtropical waters [49]. In fact, biomass estimates from Southern Norway and West of the British Isles over a period of 1971–1976 with both echosounders and trawls estimated the stock size of the most abundant species, the Mueller's pearlside (*Maurolicus muelleri),* commonly called "pearlsides", to be between 20,000 and 1,600,000 tons [23]. The echosounder estimate from 2014 (Irigoien, Klevjer et al.) even suggested the possibility of a global mesopelagic fish biomass of 10 Gt, where the previous estimate was 1 Gt based on trawling [34]. More recent estimates employing food web models suggested a global mesopelagic fish biomass of 2,4 Gt [3].

The results from 2014 however, of potentials of a 10 Gt of biomass could be an overestimation. In this estimate, all acoustic backscatter was assumed to be attributed to mesopelagic fish, even though it could also have been copepods, squid, jellyfish and siphonophores [47]. Siphonophores, like fish, have gas filled bladders which cause large amounts of backscatter – but the fishing of these has no commercial value. It is especially hard to quantify siphonophores contribution to mesopelagic biomass as they are gelatinous and fragile animals, breaking up when trawled [47]. In addition, small fish (e.g., larvae) are stronger scatterers compared to larger fish. This may also cause overestimation of biomass by acoustic sampling as it doesn't necessarily reflect biomass, but rather positions of strong scatterers [11]. Biomass estimates taking into consideration various scenarios of siphonophore inclusion spanned between the lower quantile 1,8 Gt and the upper quantile 15,9 Gt [47]. Needless to say, both previous and current estimates of mesopelagic biomass have large uncertainty gaps, which will likely need to be filled in before commercial large-scale harvesting can occur.

Despite the ambitious estimates, though, results from commercial trial fisheries in the Northeast Atlantic indicate significant variations in mesopelagic catch rates, as well as catch composition and amounts of bycatch. During 2009–2010, Icelandic pelagic trawlers caught 46,000 and 18,000 tons of pearlsides (*Maurolicus muelleri*) respectively. Despite a TAC (Total allowable catch) of 30,000 tons pearlsides being established in 2010, the quota was not fished, due to overlapping seasons from other more valuable pelagic fisheries [50]. During summertime in 2019, the commercial trial fisheries within the Norwegian EEZ landed a total of 1693 tons of mesopelagic species, of which 1223 tons were pearlsides. The amounts of bycatch from krill, blue whiting, saithe and mackerel from the fishing trials, showed significant variations. Krill species (*Euphauciacea sp.*) are the dominating bycatch which, (on average) constituted 18% of the total landed catch of mesopelagic species. Other bycatch species, such as saithe, blue whiting and mackerel, constituted only minor proportions, 1.7%, 5.5% and 0.05% of the total catches, respectively. In 2020 and 2021, the commercial trial fishery within the Norwegian EEZ landed 50 and 121 tons of mesopelagic species respectively, of which pearlsides was the most dominant fish species in the catch. Based on resource availability, technical feasibility, and economic break-even analysis for the trawler fleet, Prellezo [46] found that harvesting is technically possible, however it would not constitute an economically viable fishery. The lack of economic viability is a challenge for new marine resources such as mesopelagics and redfeed. Some mesopelagic fish species have been fished for human consumption, but this is not common. This is because, though the potential usage areas of mesopelagics are many (food, nutraceuticals, personal care products), they centre on reduction into fish meal and fish oil. This is because mesopelagic fish are currently still considered a low value fish, and as such, it requires large catches to be economically viable per trip [53]. Coupled with this is the low catch rates among other Norwegian fisheries.

Between 2018 and 2021, for example, only 1,895 tons[1] were reported caught by Norwegian vessels. These fish were caught for industrial purposes and pearlsides were the only species fished at substantial rates. The main usage area for mesopelagic fish as industry is still to produce meal and oil [20] and its low value is reflected in the average price of 329 euro per ton, placing it at the bottom price compared to both herring and even redfeed. In 2018, only 31 tons were caught. This increased in 2019–1,693 tons, in 2020 it went down to 50 tons, and up to 121 tons again in 2021. Biomass estimation along the Norwegian continental shelf were carried out in March 2020 and March 2021 and indicated a total biomass of 15,000 tons of pearlsides in the study area [35].

3.2. *Calanus finmarchicus narratives*

While mesopelagic fisheries are in a nascent stage right now, the rhetorics around "new" resources is not, nor is the challenges of uncertainty and lack of economic viability. In the early 2000 s, redfeed was heralded as the promises of lower trophic level feed for future food security of humans. The Calanus species (not exclusively the finmarchicus genus) has been shown to contribute around 80% of the total mesozooplankton in the Barents Sea alone. They are low on the trophic food web, live as herbivores (primary consumers), and are extremely abundant with high lipid contents [65]. The current estimates of *Calanus finmarchicus'* biomass are 290 million tons of new production per year in the Norwegian Sea alone [8]. From an ecological perspective, early research showed great promise as well with simulations demonstrating that the redfeed's growth rate was inversely related to their standing stock – meaning that large depletions of their biomass would likely grow back fast [51].

This potential was argued for both through narratives on it being a new and promising resource for the aquaculture industry as well as for direct human consumption – a striking similarity to the narrative surrounding mesopelagics today. Similar to mesopelagic fish, it was before this also a largely ignored species, and likely considered non-exploitable. After the krill fishery collapse in the early 1990 s though, and the concurrent data on new estimates that concluded that there may be a huge standing biomass of redfeed, the interest increased [1]. This led to more focus, at first scientifically in the form of new PhDs and projects on the subject, and a little later, industrially as well, with commercial redfeed trawling and the foundation of Calanus AS (processing plant, 2002). Since 2003, redfeed has been harvested in a small-scale fishery, based around one experimental license only though (of 1000 tons). In 2015, this resulted in a catch of 513 tonnes, followed by 660 tonnes the following year. The same year, an official fisheries management plan (MP) for redfeed was proposed by the Norwegian Fisheries Directorate, finalized in 2016 and officially accepted and implemented in 2019 [12]. In 2018, ten licenses for commercial harvesting redfeed had been issued by the Norwegian Directorate of Fisheries.

Even though mesopelagic fish and redfeed are different species and constitute a different position in the trophic level, both fisheries need fine-meshed harvesting technologies, relative to harvesting from higher trophic levels. Such similarities also apply to technological development, as both fisheries are guided towards pelagic trawling with fine-meshed trawls-systems and the need for acoustic instruments to detect low-trophic species. Key information from the MP for redfeed which is relevant for the development of a mesopelagic MP are for instance the estimation of total biomass. The total stock biomass of redfeed in the Norwegian sea has been estimated to be of approximately 33 million tonnes [8,12]. Based on the stock assessment, a TAC of redfeed is set to 254,000 tonnes, up from 165,000 tonnes within the Norwegian EEZ [18, 36]. The redfeed TAC is considered low, representing 0.5% of the estimated total biomass, and therefore well within safe biological limits. Most of the total quota of 254,000 tons must be harvested outside the 1000 m depth zone - only 3000 tons are allowed harvested close to the coastline.

Currently, redfeed is being harvested for its oil in Norwegian waters. The oil is mainly used for health- supplements, but has also been experimentally tested in feed for the aquaculture industry in Norway, as supplement to fish oil in their diet, incorporating up to 30% Calanus oil in the feed [6,7]. Successful experiments were also performed incorporating Calanus meal in the feed of halibut [9]. However, zooplankton oils are considerably higher in cost than fish oils, making them unviable in fish farming [14,42]. Its limited main usage area has therefore been in the nutraceutical market [14], with multiple documented health effects. It has been shown effective to reduce heart disorders, heal damaged arteries, and prevent oxidative damage, for instance [21].

As great as the redfeed resource is, it does not appear to have lived up

[1] 2018: 31 tons; 2019: 1693 tons; 2020: 50 tons; and 2021: 121 tons

to the initial hopes and dreams the industry had for it as a supplementary resource with high economic benefits. This is despite the fact that it contributes to 80% of total meso-zooplankton in Barents Sea [65]. In fact, currently, almost no pelagic fishing of redfeed occurs in the Norwegian sea, but its rather fished closer to the coastline. A possible reason for this may be that the large pelagic fleets choose to fish for different species than redfeed incentivized of larger economic gains. Lack of proper harvesting technology and gear seems to be the most limiting factor for efficient capture, this is especially true for harvesting outside the 1000 m depth zone. As the trawls to catch redfeed are very finely meshed, bycatch of young fish larvae can be a problem, and if catches consists of > 10% larvae the fleets are required by law to change their geographical position or equipment [19] possibly leading to even more monetary loss and waste. In fact, statistics show that in 2017, only 760 tons of redfeed were caught, even though the research quota was set to 1500 tons. There was a catch record in 2018 at 1362 tons, but a rapid decline again in 2019 with only 352 tons caught. In 2021 the reported catch were 1156 tons, and this was the amount that the industry at that time was able to process in their factory [20]. When harvesting below the processing capacity, the industry keeps their catches frozen until they have enough to process, as such it is still viable when their catches are low. In addition, a new factory was recently built with the capacity of processing 10,000 tons of redfeed raw material, displaying growth in the market for redfeed nutraceuticals.

The annual quota for redfeed in Norwegian waters is 254,000 tons. However, during the last 4 years only a total of 3 630 tons has been harvested. When we compare the last 4 years' worth of redfeed catches, to other commercially landed species like herring and cod, both around 1,5 million tons – redfeed has still not lived up to its' potentials, especially in light of the estimated annual biomass production of 290 million tons. As previously mentioned, this is likely due to it being non-profitable, making fisheries with redfeed licenses rather opt for more profitable harvest like cod and herring. Since the harvesting season is short, typically 2–3 months– it is not likely that highly specialized fishing- and processing vessels will be developed (as developed for Antarctic krill), at least in a short term. It is more likely that boats with flexible fishing gear for harvesting different species will take part in the fishery, but this should not overlap with the existing fishing seasons for other species.

Considering the growing global market for both omega-3 nutraceuticals expected to grow by compound annual growth rate (CAGR) 7.8% from 2020 to 2028 [70] and that of aquaculture feed and pet food expected to grow by CAGR 5–6% from 2022 to 2029 [67,68], coupled with the good nutritional profile of redfeed, it is still a highly relevant marine resource, and the next years will show if the research initiatives for technology development for sustainable fishing of *Calanus finmarchicus* will increase the amount of redfeed harvested.

4. Discussion

Sustainability is a key element in the Norwegian management of marine resources, and includes biological, social, and economic sustainability. Biological sustainability focuses on marine resources being harvested in a manner that allow us to continue exploiting it in the future as well. Social sustainability, on the other hand, moves away from the biological resource to the human distribution of access to harvesting them, and economic sustainability in turn addresses the profitability of the fishery for these fishers. In this context, the total allowable catch (TAC) production secures biological sustainability, the resource allocation keys secure social sustainability and harvesting licenses deal with economic sustainability of the fishery. These three elements represent the main pillars of the overall management regime. While for redfeed, long time series of biomass estimations, a management plan, an annual TAC and 10 harvesting licenses all exist, for mesopelagic species, none of these do.

Nowadays, the bottleneck for economic sustainability in the redfeed fishery is as such not on the governance side, but on the low energy efficient harvesting technology and the low prices for raw material that disable the profitability of the fishery. As such it is tied to economic sustainability, in that the challenges are financial. Several products have been produced from the resource since its harvest became possible, but only nutraceuticals are still relevant today, provided consumer willingness to pay a premium for a more expensive alternative to traditional fish oil supplements given that lower priced alternatives already exist in the market. In addition, originally, the largest potential for redfeed was arguably in the fish feed market as high-volume ingredients. However, there too, with zooplankton oils bearing considerably higher costs than traditional fish oils, its usage in fish farming for example has also decreased [14]. Still, there is potential today, with the sidestreams of the production of marine oils already being used as protein ingredients in fish feed for both marine fish and salmon. Any increase in harvested redfeed volume will therefore in the short-term likely be employed by the marine ingredient or feed industry, but there is no doubt that there needs to be research and development to find more cost- and energy efficient harvesting methods of redfeed for it to be an economically viable product as a feed ingredient.

When comparing the stories about mesopelagics with redfeed, as such, there are some resemblances in the narratives that are important to keep in mind – and some lessons to be learned (or not). In both cases, there was a story about a huge, estimated biomass previously unexploited, with a great potential to expand fishery landings by harvesting a fraction of their total biomass. In both cases too, there was the potential for ameliorating overexploited fisheries, and for use in the salmon aquaculture fish feed industry to ensure its expansion. So, is that it? Is the mesopelagic fairy-tale just that? A castle in the sky? Or does it have characteristics that differentiate it from the narratives and actualities around the redfeed fishery?

First of all, mesopelagics and redfeed vary significantly in estimated biomass. When using the historical biomass estimation of mesopelagics at 1Gt global biomass [25], the Northeast Atlantic was estimated to hold 14,6 million tons of mesopelagic fish [41]. Redfeed in the NEA on the other hand, has an estimated biomass over 33 million tons in the Norwegian sea. However, the mesopelagic resource estimate is one of worldwide distribution, compared to redfeed which is primarily found in the North. Interestingly to note however, is that by calculating the density of mesopelagics in the NEA (tons biomass per km^2) it turns out to be the marginal 0,4 ton/km^2. If we compare this to the density of redfeed in the Norwegian sea, which is 24,8 ton/km^2, we see that the density of mesopelagics is comparably small, and much smaller if we estimate it terms of ton/km^3. In the Peruvian EEZ however, mesopelagics have a density of 2,5 ton/km^2, which is incredibly dense. Even though a gigaton of biomass sounds huge, mesopelagic fish can be widely spread out in the ocean causing a dilution of biomass, given that the mesopelagic zone is such a spacious environment. As such, it is arguably, yes, a castle in the sky.

In addition, large enough catches to ensure economic viability of harvesting mesopelagics is a problem, since there is currently a large knowledge gap in our understanding of the mesopelagic zone as a biological system, and its resultant ability to produce such large catches to be harvested sustainably [52]. We do know, however, that mesopelagics play important ecological roles in the ocean ecosystems worldwide, and it could pose serious consequences following reduction in their biomass. Importantly, we know that mesopelagic layers perform diel vertical migration (DVM) and are as such likely acting as key players in the global carbon pump. Carbon is constantly transported into the deep oceans from the surface, in a process known as the biological carbon pump. This transport is due to gravitational forces, and planktonic consumers which perform DVM [48]. Mesopelagic species transport carbon from the epipelagic (upper ocean zones) by foraging here during the night, then migrating back to the mesopelagic zone during the day and excreting it to the depths [10]. The organic material can then sink deeper into the bathypelagic zone, ending up sequestered in the deep sea. This carbon flux export from the epipelagic- towards the mesopelagic zone indicate the importance that the mesopelagic species may constitute in the organic carbon (POC) flux [10,29,31].

Mesopelagic species also hold key roles in the ocean food webs by linking primary consumers and predators. They constitute the diet for a multitude of important predators, including cetaceans (dolphins and whales), seabirds, and commercially important fish species such as tuna and swordfish [45,69,75]. By removing mesopelagic biomass, one could risk disrupting the natural balance in these food webs. An effect such as this is already seen in Antarctica, by the harvest of krill (together with unfavorable climate conditions) negatively impacting the population of marine mammals and penguins [71,76]. As such, a removal of mesopelagic biomass could lead down a similar path of consequences. This highlights the importance of gaining more ecological and biological knowledge on the mesopelagic zone before any commercial harvest is to occur.

Potential usage areas of mesopelagic fish differ do in fact differ from redfeed, albeit maintaining some similarities. Inhabitants in the mesopelagic zone aren't only a single specie like redfeed, as the fauna is diverse with multiple fish families (30 +) along with microorganisms, ctenophores, cephalopods, siphonophores etc[40]. The mesopelagic zone, being one of the least explored ecosystems, is likely to hold a wide range of undiscovered species. Thus, the potential range of mesopelagic usage areas are greater, and are not only limited to being used in fish feed and human nutrition like redfeed, but could also contribute in terms of pharmaceuticals, personal care products, enzymes, and other potential extractable resources. Notably, several promising anti-cancer drugs have already been discovered in deep sea [74], so the increased investigation and research into the ocean is not unlikely to lead to further discoveries and pharmaceutical products. Mesopelagics can also replace the already in use "forage/industry fish" to produce fish meal and oil, thus relieving pressure of these other heavily fished stocks, and at the same time potentially making these fish (herring, anchovy, blue whiting) more available for human consumption. In this regard, harvesting mesopelagics could help ameliorate already overexploited fish stocks, in the long run leading to larger and more efficient fisheries management and production.

Furthermore, the high levels of wax esters in redfeed are a challenge since humans have limited ability to digest these [13]. Even though mesopelagic fish are small, oily, and bony, thus appearing uncharismatic to the eye, the potential of producing direct human food from the fish is still present. Thus, instead of being used as ingredients for fish feed only, mesopelagics could be incorporated directly into the human diet, avoiding the intermediate of feeding to a fish in which a lot of the allocated energy will be lost. Direct consumption of mesopelagics will also make it available as food for a larger part of the human population, as salmon aquaculture especially is more of an upscale market. In fact, a human consumption market for eating mesopelagic fish already exists for *Argentina silus,* being one of the main ingredients in store-bought Norwegian fishcakes. Redfeed on the other hand is less likely to enter the human consumption market due to a lack of demand for eating zooplankton directly, compared to the market of eating fish which already exists. In addition, harvested mesopelagic raw material has been shown to contain very low quantities of unwanted substances (heavy metals, pesticides, etc.), making it more promising as both a feed- and food resource [5]. This represents a step towards a higher potential resource, and less of a castle in the sky.

This is especially relevant when we compare to the history of some former forage fish as well, such as Atlantic herring (*Clupea harengus*). Herring is a small (usually 20–25 cm) pelagic fish species, among the world's most numerous fish with a long history of exploitation and human consumption by Northern Europeans since medieval times. However, during the 1970 s, the Norwegian aquaculture needed large amounts of fish meal and oil to feed their Atlantic salmon, and herring was chosen for this use. This reduced the portion directly consumed by humans. The stock was then overexploited due to increased demands for meal and fish feed, while at the same time other fisheries sought it for direct consumption. Together with unfavorable natural conditions, this caused a total population crash, leading to disappearance of both types of fisheries for quite some time [44]. Recently, though, during the last 10–15 years, demand for herring as a direct food product for human consumption has increased, causing a shift in the utilization of herring from feed to food again, and today most catch of herring in Norway is indeed used for human consumption where the surplus is used to produce fishmeal and oil. In fact, the EU has actually prohibited the use of herring for fishmeal and fish oil thus promoting human consumption [62], though these restrictions do not apply to Norway and Iceland, the two largest producers of fishmeal in Northern EU [2]. In light of this, mesopelagics could enter the market of direct human consumption, just like the herring has done, instead of being used purely for reduction and fish feed.

5. Conclusion

We have looked at two great "new" marine resource potentials, mesopelagics and redfeed, that have both experienced ebbs and flows in terms of the narratives around their potentials, owing to a developing and growing human population globally, and a current and future need for a constant supply of nutritional food. Mesopelagic fish are estimated to be the world's largest unexploited natural resource with a global biomass of 1 gigaton. This narrative is similar to the one of zooplankton redfeed in the early 2000's with a staggering estimated production of 290 million tonnes annually in Norwegian waters. However, the current state of knowledge on mesopelagic resembles the state of knowledge on redfeed in the early 2000's, meaning with this that there still a long way to go before we could even talk about a sustainable mesopelagic fishery in the NEA.

The United Nations Sustainable Development Goals (UN SDGs) seeks to improve life, of our planet and all people living there within 2030. SDG 2: "Zero Hunger" and SDG 14: "Life Below Water" are especially central to the exploitation of these new resources. In addition, 2021–2030 is the UN Decade of Ocean Science, where a sustainable and healthy ocean is in great focus. As most fished stocks are fished at either maximum levels or above (94%), new marine resources, and better fisheries management plans are sorely needed to increase the potential output of our oceans and reach these ambitious global goals. Sustainable management of ocean resources is vital in order to increase fisheries production and combat malnutrition for future generations. Arguably, harvesting large biomass resources further down the food web could alleviate pressures higher up, and help solve some of our future food security challenges.

The link between these new resources is often linked to the aquaculture industry, by being a resource for feed ingredients that allows the industry to produce more fish. However, a more sustainable option would be for humans to eat the marine resource, whether it is mesopelagics or redfeed, directly. Mesopelagic fish and redfeed show some similarities but are arguably on two different scales. Even though redfeed has a huge standing biomass in Norwegian waters, mesopelagics can be found worldwide. Mesopelagics are also speculated to having broader usage areas compared to redfeed. They are both however, rich in the health promoting lipids EPA and DHA, and have been successfully incorporated into fish feed – although not economically feasible yet. In fact, today, the only economically feasible way of harvesting and employing redfeed is as a nutraceutical. This may be due to lack of efficient capture and processing technology not developed yet, making redfeed products expensive. However, recent research efforts have been launched to hopefully unlock redfeed's full potential.

Moreover, there are significant difference between the status of knowledge of redfeed and that of mesopelagics. The redfeed biomass, including its spatial and temporal variability, is well understood and there is a management plan in place for its governance. This is not the case for mesopelagics. In addition to uncertainty regarding biomass estimations of mesopelagics, there is also uncertainty regarding the ecology of the zone as a whole. Food web structures, species interactions, and diversity is lacking in terms of knowledge, as it has been historically hard to study and received little attention [27]. We do know that the mesopelagic fishes' role in the food web is complex, comprised of dozens of different species and that they act as prey items for multiple marine mammals and predatory fish, some of which are commercially important stocks like tuna and swordfish [22,28,73].

Once enough knowledge is available to sustainably harvest mesopelagics, though, we expect that it could either be a primary substitute for industry fish for fish feed, thereby ameliorate the overexploitation pressure of these species (e.g., herring, anchovy, blue whiting) or follow the route of herring and transition into direct human food allowing more industrial fish to copy the route of herring by promotion from feed to food. As for now this castle stands tall on a hill, grazing the skies, and time will tell whether we are able to reach the high expectations we have of the untapped mesopelagic resource.

CRediT authorship contribution statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the journal of Marine Policy.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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