SUMMER

Final report

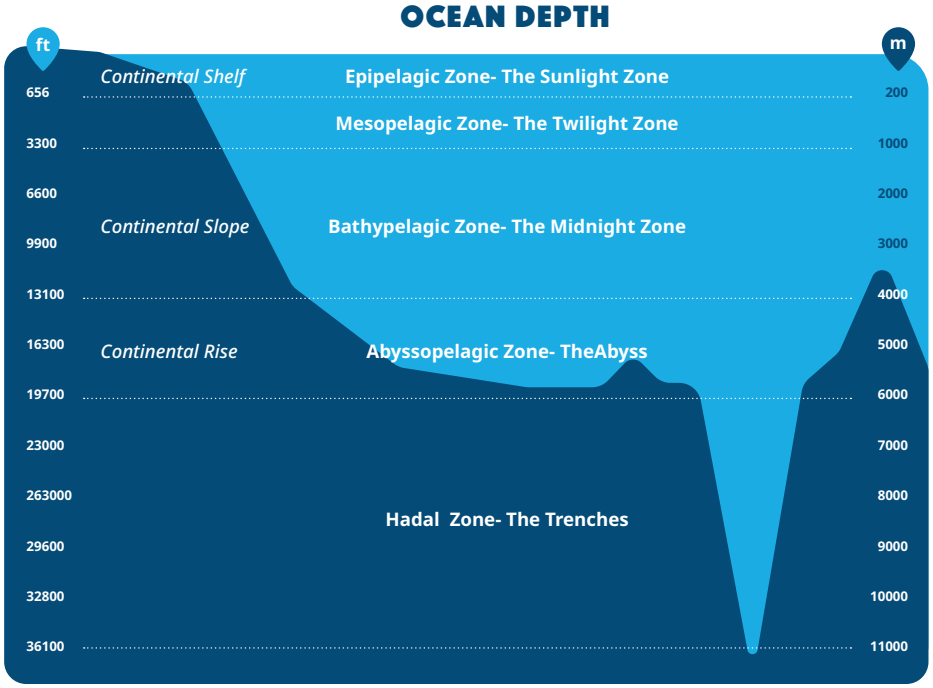
INTRODUCTION

The mesopelagic zone begins when only 1% of light reaches and ends where there is no light at all (200 to 1000m depth, depending on the zone of the world). It occupies about 60% of the planet's surface and about 20% of the ocean's volume and, although still uncertain, it is considered that it contains more than 75% of the pelagic biomass.

Constituting one of the largest yet least understood ecosystems of the earth system.

Biodiversity & Biomass

SUMMER aimed to reduce knowledge gaps of this zone, by assessing best methods for estimating biomass and biodiversity of mesopelagic communities, contributing to carbon transport and supporting ecosystem-based fisheries management. Key findings included the identification of dominant species in the northern Mid-Atlantic ridge and the development of a nested-bootstrapping method to reduce uncertainty in biodiversity estimates. The research demonstrated that net tows alone underestimate mesopelagic fish biomass, highlighting the **need for combined methods using eDNA, acoustics, and net sampling.** The project provided essential data on vertically migrating biomass and its role in active carbon flux, offering insights for future mesopelagic surveys.



Food web structures & Resilience

SUMMER highlighted the **complex biological interactions and ecosystem functioning within the mesopelagic zone.** SUMMER key advancements were made in identifying trophic interactions and energy flow among mesopelagic species, which are crucial for ecosystem modeling and management. Notably, SUMMER highlighted gaps in knowledge regarding certain species groups like crustaceans and cephalopods, emphasizing the need for further investigation due to their significant roles in the food web and their challenging nature to sample effectively.

INTRODUCTION

Carbon Storage & Climate Regulation

Regarding the role of mesopelagic fish in carbon storage and climate regulation through their diel **vertical migrations (DVM),** SUMMER demonstrated that these migrations significantly enhance carbon sequestration by contributing to the active flux, which is less attenuated than gravitational fluxes. The global NEMO-PISCES-APECOSM model estimated that mesopelagic fish migrations contribute to 1.39 PgC y-1 globally, accounting for a substantial portion of the total carbon flux.

High Value Produts

SUMMER also explored the **potential of mesopelagic organisms for high-value product development, such as fishmeal, fish oil, and novel antibiotics.** The findings indicated that mesopelagic fish, particularly *Maurolicus muelleri,* meet safety and quality criteria for fishmeal and fish oil production. However, the yields were insufficient for profitable processing. Furthermore, spoilage during on-board handling due to lipid oxidation was identified as a major issue. Recommendations included rapid refrigeration to prevent spoilage. Additionally, the **unique biochemical traits of mesopelagic microbial communities were highlighted as promising sources for new pharmaceuticals.**

Ecosystem Services & Management Evaluation

The economic and social feasibility and ecological sustainability of exploiting mesopelagic fish. Despite the large biomass, it was found that **commercial viability is limited** due to the fish's wide and thin distribution and the need for transformation into fishmeal and fish oil. The research emphasized the critical ecological role of mesopelagic fish in carbon sequestration and food webs, highlighting **significant risks of overfishing from the social perspective.**

Policy implications

Legal and regulatory frameworks are not yet in place, with the new Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ Agreement) expected to influence and collaborate with a future regional fisheries management organization for mesopelagic species. This is, however, in the event a fishery is deemed sustainable, where **the BBNJ treaty can contribute to sustainable management practices,** most specifically within the context of the development of potential area based management tools including potential marine protected areas and environmental impact assessments for other activities that may have an impact on a potential mesopelagic fishery, such as deep sea mining or other activities, known or future ones.

CONTENT

1
Biodiversity & Biomass

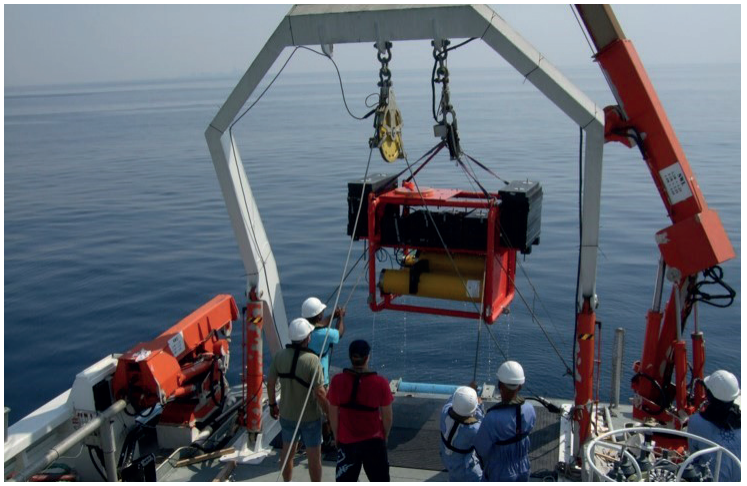
1

Biodiversity & Biomass

Currently, the **estimates of global mesopelagic fish biomass vary widely** between the different model and observation methods, ranging from 1 to 20 billion tonnes. The uncertainty is largely due to **trawl sample bias** (fish avoid and escape the net) and uncertainty in **active-acoustic species identification** e.g., it was highlighted in a recent study that the unknown contribution of **gas-bladdered siphonophores,** which are strong acoustic targets, to the observed mesopelagic backscattering intensity is the most significant source of uncertainty in estimates of mesopelagic biomass.

In SUMMER we have created a **"how to" manual for assessing mesopelagic biomass.** By combining samples and observations of mesopelagic fish obtained by multiple methods, the uncertainty in biomass estimates (both relative and absolute) can be reduced. Lowered **echosounders** provide crucial information on fish density that can help estimate the capture probability of the **trawl net,** which is a requirement of absolute biomass estimation. Collecting additional information on species ID using **cameras, nets and eDNA** samples can also help reduce uncertainty. The main challenges reside in developing suitable sampling protocols that facilitate spatial and temporal overlap in observations.

In the year 2020 a **CSIC-SUMMER cruise** was carried out. In here, a total of **70 mesopelagic fish taxa, ca. 70 crustacean and 20 cephalopod taxa were recorded.** The total number of species caught in the Mediterranean Sea (22) was lower than in the Atlantic (67). In all zones the community was dominated by the small bristlemouth fish *(Cyclothone spp),* followed by some lanternfish *(Benthosema glaciale* and *Ceratoscopelus maderensis* in the Mediterranean, and *Benthosema. suborbitale* and *Ceratoscopelus warmingii* in the Atlantic. The crustacean data, indicated that the community was numerically dominated by euphausiids and decapods. Among decapods, in Mediterranean region the *Dendrobranchiata, Gennadas elegans* and *Eusergestes articus* were the most abundant and frequent, while the *Caridea Systellaspis* debilis and *Pasiphaea sivado* dominate in the Atlantic.



Echosounders. Photo: University of Oslo.

1

Biodiversity & Biomass

Additionally SUMMER also used **modelling techniques to upscale "ground-truthed" regional fish biomass to global scale,** by simulating mesopelagic community dynamic over the period 1948-2016.

A global estimate of 1.3 billion tonnes or 87% of total pelagic biomass was obtained.

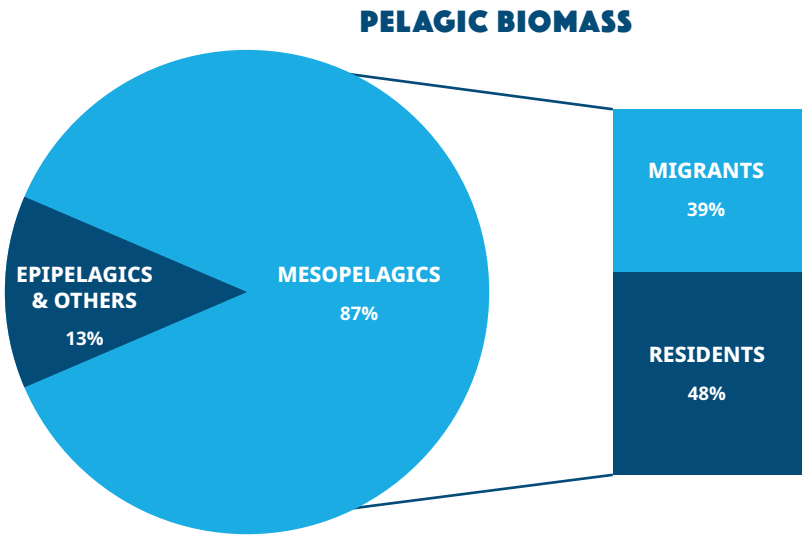


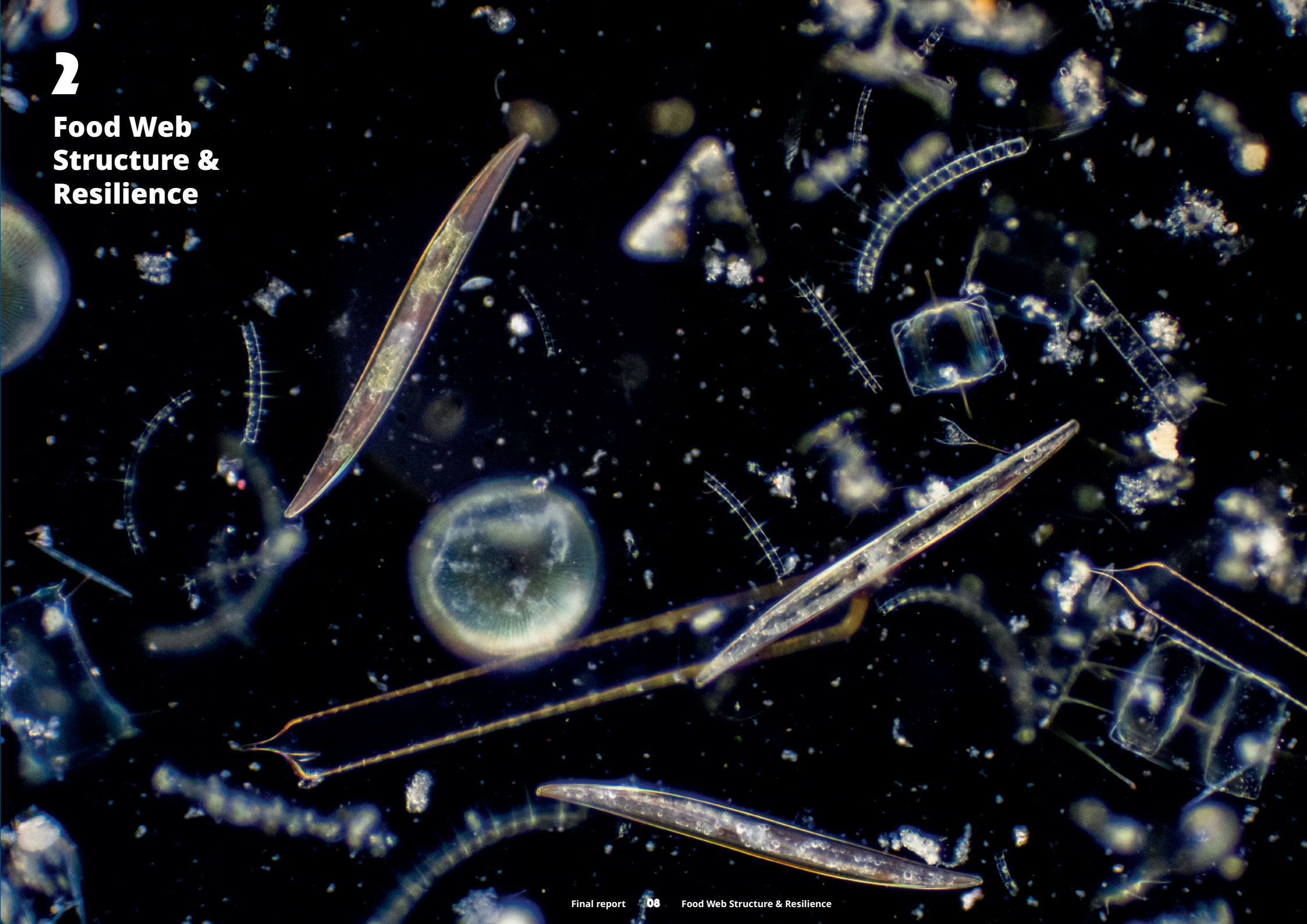
Photo: Leif Grimsmo (SINTEF Ocean).

To put this biomass estimation in context,

in 2022 the oceanic fisheries accounted for 81 million tonnes, that is almost 15 times less than all the mesopelagic biomass worldwide.

2

Food Web Structure & Resilience



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Food Web Structure & Resilience

Photo: Séverine Tourbot-Pau / IFREMER.

Analyses of existing and novel samples conducted within SUMMER, provided additional datasets on stable isotopes, stomach contents, trace elements, energy density, lipid classes, and estimates of trophic levels, diets, and feeding rates. SUMMER generated data include **9128 data records from 52 different sampling periods/locations from the Atlantic Ocean and Mediterranean Sea obtained from 2002 to 2021.** 95.6% of the records were of mesopelagic organisms, 3.5% zooplanktonic and 0.6% to cetaceans. Overall, SUMMER generated an impressive amount of data of great value for trophic ecology and food web studies within the project, as well as for future research in the mesopelagic region.

SUMMER revealed that far from being a homogeneous whole, mesopelagic fish species can feed on a high diversity of resources, and numerous trophic interspecific segregations appear to structure oceanic food webs. Sometimes **unexpectedly, species that are close taxonomically or morphologically appear to have adopted different feeding strategies.** Segregation can also occur at an intraspecific level. The dependence of predators on certain mesopelagic resources was also quantified. **All top predators depend to varying degrees on mesopelagic resources,** specifically, meso- and bathypelagic cephalopods appeared to be crucial for various predators.

2

Food Web Structure & Resilience

SUMMER used modelling techniques to understand the consequences of mesopelagic fishing on food web stability. We obtained **some divergent results.** Results from one model setting showed that fishing on mesopelagic fish has no negative indirect effect on the stock sizes or the yield of other pelagic fish or fisheries. Rather, the depletion of mesopelagic fish results in a **reduction of the competition for zooplankton prey for the epipelagic forage fish, to the benefit of the forage fish (and fishery)** and to a smaller degree of large pelagic fish.

However, other models showed that under **intensive fishing rates decreases in phytoplankton (37%) and mesopelagic fish biomass (95%) and increases in zooplankton (26%) and non-mesopelagic biomass (25%),** the latter mostly because of the increase in biomass of small epipelagic fish. The biomasses of some commercially important **tuna species also decreased.**

Other models showed that given that mesopelagic fishes are key prey in the food web, reduction of their biomass would lead to **declines in biomass of their predators.**

In conclusion,

simulations show a great variation in the capacity of food webs to support fisheries across fishing grounds, and that food webs are particularly sensitive to catch of mesopelagic fish.

3

Carbon Storage & Climate Regulation

Carbon Storage & Climate Regulation

Photo: AZTI (JUVENA 2020).

Carbon storage and climate regulation are related to the link between the biological carbon pump (BCP) and atmospheric CO_2. The BCP is formed by a suite of processes exporting organic carbon from surface to deep waters. The depth at which this carbon is converted back to carbon dioxide—known as the remineralization depth—influences the rate at which it is returned to the surface ocean and, ultimately, the partitioning of carbon dioxide between the atmosphere and the ocean.

This active carbon sequestration is due to the fact that daily movement of mesopelagic organisms, including fish and zooplankton, **is the largest daily migration by biomass on the planet. This daily, or diel, vertical migration (DVM)** is motivated by the benefits to individuals of 'hiding' from visual predators in the dark at depth during daylight hours and feeding near the surface (where primary production occurs) under the cover of darkness.

SUMMER illustrated both **(1)** that there is **very strong regional variability in the relative magnitude of the three fluxes** (the active flux, the gravitational flux associated with sinking particulate material and the passive flux associated with downward mixing of dissolved organic carbon (DOC)) and **(2)** that there **are places where the active flux appears to be a major component of the biological carbon pump.**

Although the observations at multiple locations and idealised modelling give insights to the variability and interactions of mesopelagic fish in the flux of carbon, there remains the question of how significant their role is at the global scales that matter to carbon budgets. SUMMER found that, worldwide,

of the approximately 1.3 billion tonnes of mesopelagic organism, 39% of them performed these daily excursions.

3

Carbon Storage & Climate Regulation

Based on that SUMMER estimated that the

active carbon flux associated with the vertical migrations of mesopelagic fish below 150 m is 1.39 PgC y-1, globally.

Relative to the total export of carbon to the mesopelagic (i.e. including gravitational, active and DOC fluxes) this is equivalent to 9-28% of the total, with the largest component of this active flux associated with basal respiration (56%). As context,

this active flux represents 1.5 times all the Co_2 emissions of the cars worldwide.

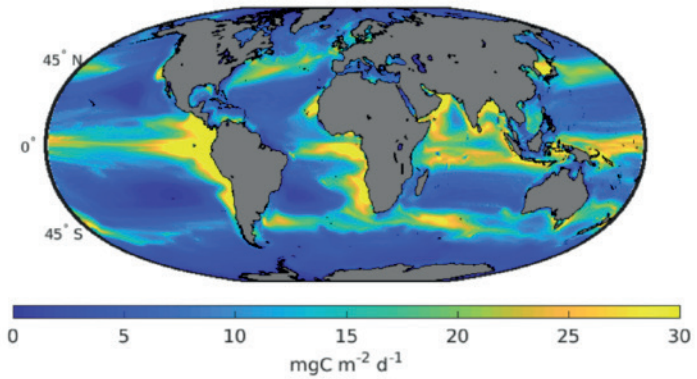
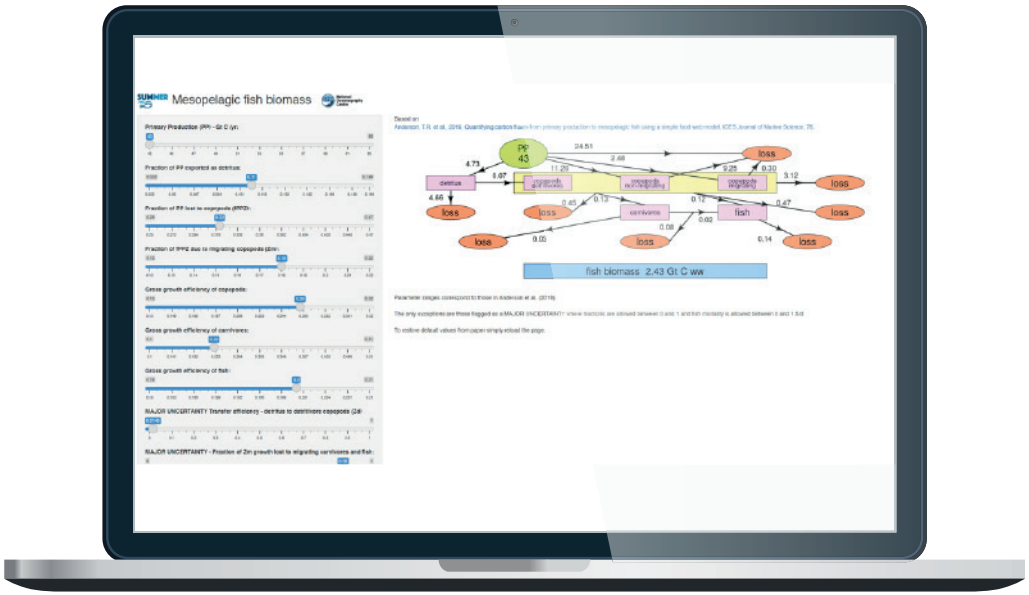


Figure. Annual-mean daily active flux of carbon induced by DVM of mesopelagic fish (in mgC m-2 d-1), predicted using the fully coupled NPA model.

Regarding this active flux, SUMMER provided a **tool to support management decisions on exploitation of mesopelagic organisms** by allowing stakeholders to get a first-hand experience in the impacts of DVM on the BCP in an interactive way. It can be found in https://summer-mesopelagic.shinyapps.io/summer/



Model tools for quantifying role of mesopelagic fish in influencing the BCP.

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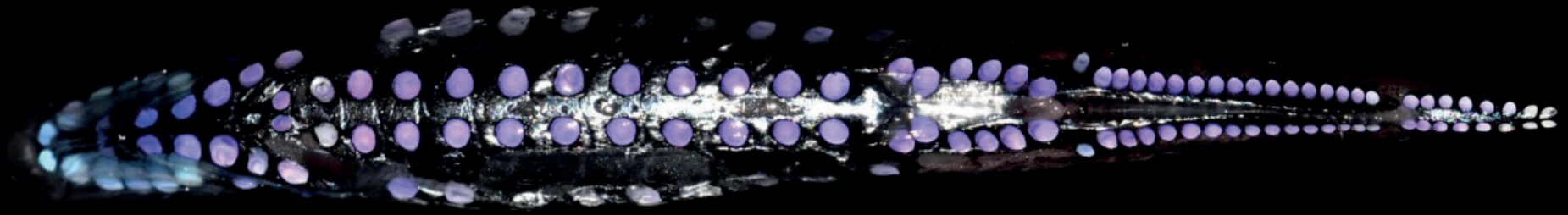
High value products



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High value products

Worldwide there is a growing need for sustainable sources of high-value products like fishmeal and fish oil, as well as new antibiotics due to increasing antibiotic resistance. Mesopelagic organisms, in the ocean's depths, offer a unique opportunity due to their abundance and diversity. **The extreme conditions of the mesopelagic zone have driven the evolution of microbial communities with unique biochemical traits, making them promising sources of novel molecules.**

SUMMER showed that mesopelagic fish, such as ***Maurolicus muelleri,*** **comply with the safety and quality criteria for production of fishmeal and fish oil** and other food grade applications. However, the yields foreseen with analytical data reveal poor processing output that will result in **non-profitable processing** and therefore, will lead to low purchasing prices for such landings.

Regarding handling conditions of the biomass on board, that main source of spoilage of *Maurolicus muelleri* is related to lipid oxidations. Protein degradation occurs but it doesn't exceed tolerable limits. Based on the results of the lipids deterioration analyses, it is recommended to store the raw material within 30 minutes in fridge to avoid the spoilage.

As an alternative, SUMMER studied the possibility of producing fish protein hydrolysates. It was concluded that ***Maurolicus muelleri*** **is a potential source of bioactive peptides.** However, it appeared that the profitability of building a new plant to process this mesopelagic species will be very dependent on fishery operational costs and the resulting selling price of these catches.

After selecting, cultivating and extracting the microbial isolates, **SUMMER established a microbial extract library containing approximately 700 extracts.**

These extracts were evaluated for their antimicrobial activities against various human and fish pathogens, as well as human cancer cell lines. The findings highlighted the **potential relevance of mesopelagic microorganisms for pharmaceutical applications.**

The mesopelagic zone is a largely untapped resource, rich in microbial diversity capable of producing unique bioactive compounds.

SUMMER also assessed the microbial community by culture-independent techniques associated with mesopelagic fish. A metagenome analysis of the global ocean detected marker genes of the microbial polyketide synthase pathway involved in omega-3 fatty acid synthesis in bacteria inhabiting the mesopelagic zone. In addition, by metabarcoding, bacteria from genera typically producing **omega-3 fatty acids, which are relevant in the fields of nutraceuticals and aquaculture, have been found in mesopelagic fish guts.**

Overall it was found that the low processing yields and profitability challenges associated with obtaining fish oil require careful evaluation of mesopelagic fish for commercial viability. However, targeted microbial bioprospecting in the mesopelagic zone presents a promising and sustainable avenue, highlighting its microbial and chemical diversity for potential pharmaceutical advancements.

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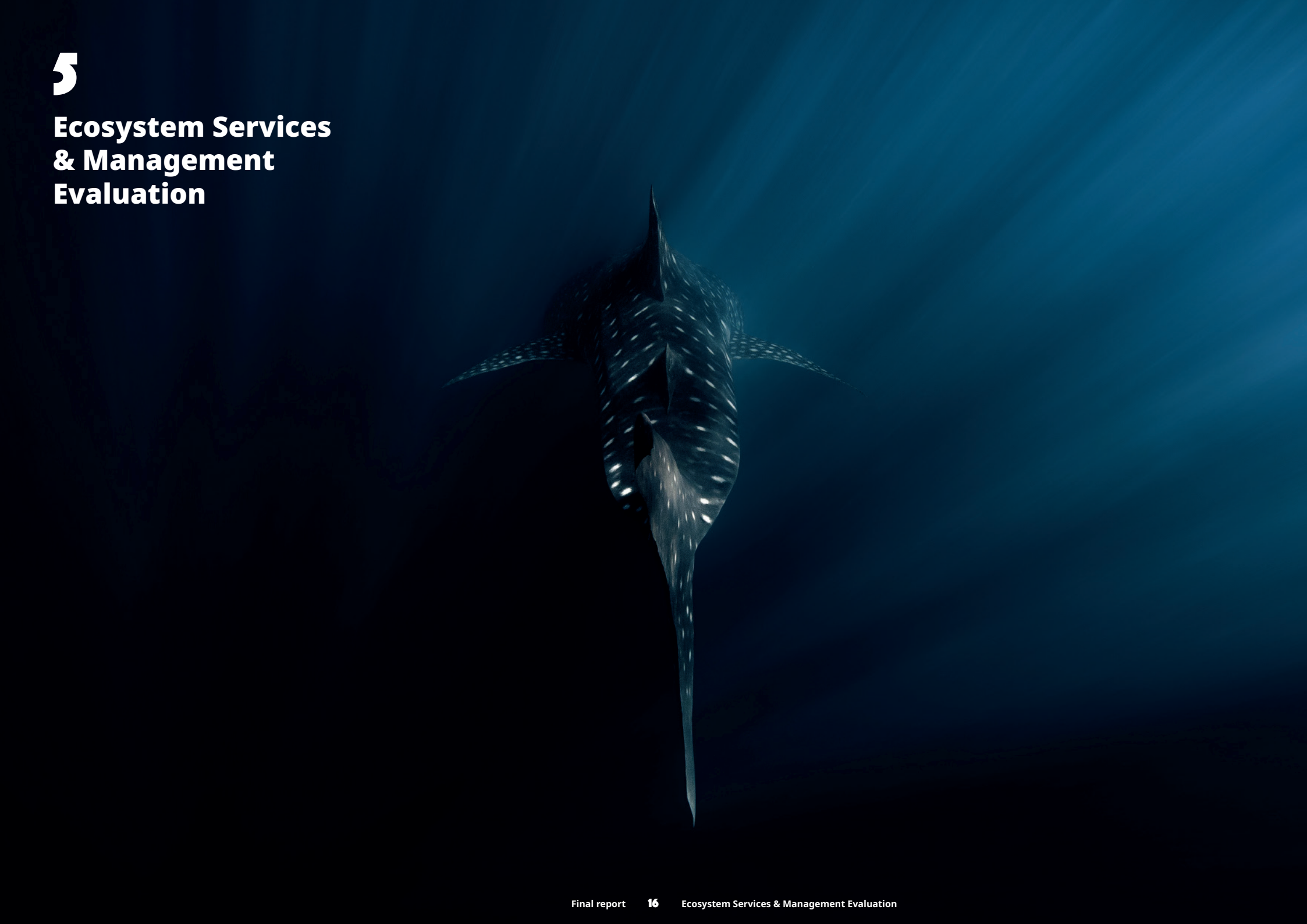
Ecosystem Services & Management Evaluation



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Ecosystem Services & Management Evaluation

Mesopelagic organisms are part of the functioning of the ecosystem as an important food source for predators and contribute to the provisioning and the economic activity of many fisheries in the world. Furthermore, they provide climate regulation services, related to the link between the BCP and atmospheric CO_2.

On the feasibility and sustainability on the use of mesopelagics, SUMMER has shown that while it is likely net tows are grossly underestimating the biomass of mesopelagic fish (by missing larger animals due to size-selective bias), vessel-based acoustics show that this biomass is so widespread, and relatively thinly spread, across the oceans, that **finding places where the biomass is dense enough to make fishing profitable under the current economic conditions is highly unlikely**. Importantly, whilst a large mesopelagic fish biomass of ca. 1.3 billion tonnes was estimated, it must be considered that mesopelagic fish have a slow metabolism and low productivity and are therefore highly vulnerable to over-fishing.

Additionally, community stability is strongly related to species diversity, and any loss of species richness triggered by commercial fishing will modify species trophic interactions that may endanger the mesopelagic populations and in turn the pelagic ones. Mesopelagic resources have the potential to contribute to food security either through usage in fish feed or by direct human consumption. However, proper markets and demand must be present for them to make harvest economically viable.

Fishing mesopelagic species implies favouring SDG 8 (growth) and SDG 2 (food security) through aquaculture and/or production of fishmeal and fish oil and may impede SDG 13 (climate change) and SDG 14 (life below water).

SUMMER simulated a potential commercial fishing and evaluated the trade offs among SDGs. It was discovered that on average, the benefits obtained on fishmeal and fish oil from the transforming of mesopelagic fish, would be outweighed by the cost in terms of climate regulation and loss of other commercial and non-commercial species.

5

Ecosystem Services & Management Evaluation

At regional level,

SUMMER found that there was, in mean, a social cost of 17 euros per tonne of mesopelagic fish caught,

although the big uncertainty around this calculation was also acknowldeged. To consider and assess the effects of this uncertainty an interactive tool https:// aztidata.es/BayesNetVis/ was created.

A parameterized interface (Bayesian network) to determine the trade-offs and overall change in the value of the ecosystem services.

6

Communication & Dissemination

6

Communication & Dissemination

During the development of the SUMMER Project, various materials, events, and activities were created to disseminate the project and its results to all stakeholders, including the scientific community, industry, policymakers, civil society and other key actors.

Among the actions aimed at the **scientific community, the *Mesopelagic Symposium*,** held in Norway, stood out with 42 presentations and 3 posters, showcasing scientific work across various disciplines focused on the mesopelagic zone of the ocean. In addition, **97 scientific papers** and **84 open data series** have been published. The project's researchers also disseminated their advances and results by participating in more than **31 international scientific events.**

Networking has been essential for SUMMER, which is part of the international **JETZON** *(Joint Exploration of the Twilight Zone Ocean Network),* acting as an international coordinator and focal point for studies of the ocean's twilight zone. Additionally, SUMMER collaborated closely with the **MEESO project,** expanding the scope and impact of the research in this area.

A significant effort was made to communicate the project to society at large, as **a lack of knowledge about the mesopelagic zone was identified among the general public** at the beginning of the project. To address this, three **videos** were developed: the first one introducing the project, the second explaining the techniques used to estimate biomass, and the third showcasing the creatures inhabiting the mesopelagic zone, accumulating more than 3,000 views.

In addition to the 2D videos, an adaptation of the final **video (on mesopelagic creatures) was made in 3D and shown to students of different ages** from various educational centers, allowing them to discover this mysterious oceanic zone in a special way.

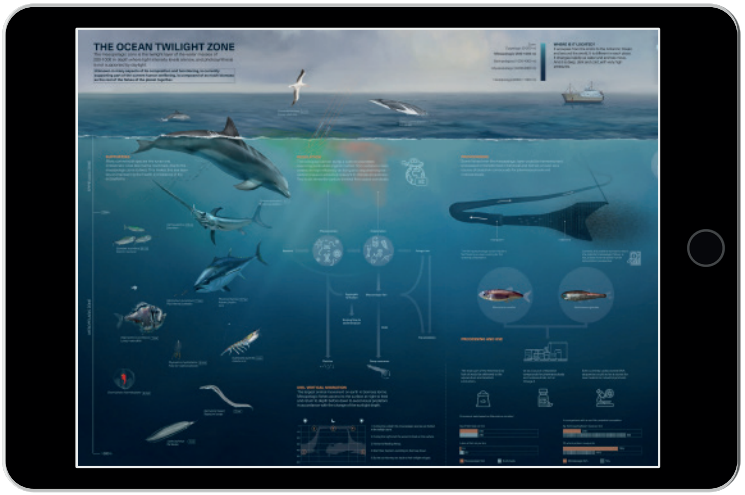
Students from Haizeder eskola (Ea, Biscay) watching the 3D video about mesopelagic creatures.

6

Communication & Dissemination

Since the mesopelagic zone is accessible to very few, mainly fortunate scientists, **an immersive experience was created where participants could "dive" into the mesopelagic in a submarine** and observe phenomena such as marine snow, bioluminescence, lantern fish, siphonophores, deep-sea anglerfish, and other never-before-seen species through virtual reality glasses. This innovative experience was showcased at the ICES Annual Conference 2023 in Bilbao, where it was met with great enthusiasm.

Illustrator Alazne Zubizarreta, in collaboration with project coordinator Raúl Prellezo, created an **infographic** that summarizes the various ecosystem services provided by the mesopelagic zone, emphasizing its importance. The infographic has been displayed at several partner institutions and is also available for download online.



METROPELAGIC exhibition in the Bilbao Metro.

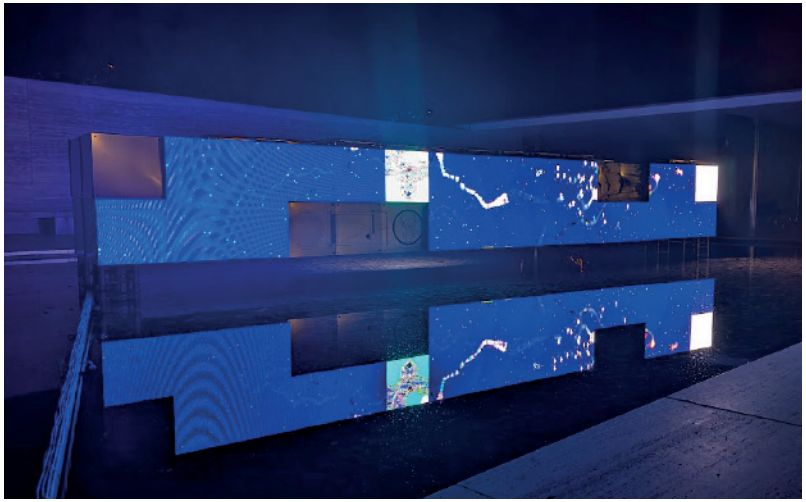
Working alongside "Metro Bilbao and the **Woods Hole Oceanographic Institution, the METROPELAGIC** exhibition was organized, featuring photos of various mesopelagic species at several Bilbao subway stations. Passengers "descending" into the stations could immerse themselves in the dark world of the mesopelagic zone and enjoy its creatures. The exhibition was held at **5** stations, with **more than 800,000** people passing through. To promote these exhibitions, a social media campaign was launched, resulting in over **14,000 impressions.** Additionally, a **press release** was issued, generating 13 media placements across various local outlets, including radio interviews and a two-page feature in a Basque newspaper. Along with this press release, two others have been distributed throughout the project, achieving together, according to the Onclusive Platform, an estimated audience reach (opportunity to see) of **more than 27 million people.**

6

Communication & Dissemination

The depths of the ocean, particularly its acoustics, were also featured at the renowned **Sónar Festival** which in 2024 attracted **more than 150,000 attendees.** Through **an art installation that creatively and experimentally transformed scientific data, visitors could transpor into the depths of the sea where the sound and visual pulse of the unknown mesopelagic ecosystem resonated.**

The installation was presented as part of *Sónar+D,* a section dedicated to science, innovation, and creative industries, at the iconic Mies van der Rohe Pavilion, offering a unique setting for this fusion of art and science.



An audiovisual installation 'Diving Into Liquid Strata' at the Mies van der Rohe Pavilion as part of the Sónar+D festival.

SUMMER Virtual experience at ICES Annual Science Conference.

To further enhance the understanding of the mesopelagic zone, a SUMMER project video, incorporating characteristic of this enigmatic oceanic layer, was included alongside the art installation.

The main goal of these actions was to raise awareness about the importance of this marine ecosystem,

as it is impossible to protect what is not known.

All the material generated, including scientific articles, promotional content and videos, as well as information on events and communication actions, has been compiled and is available on the SUMMER website. This website has registered 44.000 page views throughout the project, largely driven by the 104 articles published in the news section. As for the project's social networks (Instagram, LinkedIn, Twitter, YouTube), these have achieved 660 followers in total, reinforcing the visibility and impact of SUMMER's results.

7

Policy implications

7

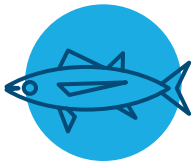
Policy implications

In the EU the legal framework does not encompass a mandate to manage mesopelagic resources. However, SUMMER examined conservation and management measures of the Northeast Atlantic Fishery Commission (NEAFC) and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and identified **elements for ad hoc management of new fisheries that could serve as precedents for the management of mesopelagic resources.** Adaptation of these instruments by the concerned Regional Fisheries Management Organisations (RFMOs) to the characteristics of the mesopelagic resources may imply regulating the fishing gears and the operations to address the likely occurrence of bycatch provided the role mesopelagics have as prey species.

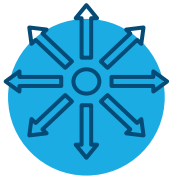
In the EU, **there are institutional structures in place to address the particular needs of managing these resources,** i.e. a solid network of research institutes with ongoing data collection programmes, well established scientific cooperation, and research funding programmes.

The main difficulties for the management of these resources at international and EU level seem to be:

To estimate biomass effectively, as scientists must overcome significant technical challenges related to acoustic methods.



To prevent large bycatches of fish and other animals associated with mesopelagic species—given the technical complexities of a new fishery and the unique characteristics of these resources.



To ensure the equitable distribution of benefits derived from the resource.

To prevent potential impacts of such exploitation on the ecosystem and environment.

7

Policy implications

The Biodiversity Beyond National Jurisdiction (BBNJ) Agreement under United Nations Convention on the Law of the Sea (UNCLOS) on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (ABNJ) was approved by the parties in June 2023 after ongoing discussions since 2004 and in formal negotiations since 2018. The entry into force of this agreement, **will also be critical to ensure that** the Kunming-Montreal Global Biodiversity Framework, under the Convention on Biological Diversity, with deadline 2030, has a viable chance **of reaching the goals of 30x30 – 30% protection and restauration of both land- and marine areas.**

The agreement will only have indirect implications for the fishing of mesopelagic fish, though, precisely through RFMOs. This is due to, Part II of the agreement (MGR), which deals with genetic resources and equitable sharing of benefits, excludes fishing activities and marine organisms caught in fishing operations regulated under relevant international law from the scope of the provision of Part II.

Nonetheless, **these organisms can be regulated by this part of the agreement if they are employed as genetic resources. Part III,** in turn, **is more relevant since it deals with the protection of marine ecosystems and of the services they provide to the environment, including the carbon cycling services.**

The use of area-based management tools in the high seas is described as one of the main mechanisms for protecting ecosystems.

Additionally, **it is expected that in the future the agreement will have implications for new fisheries** and in particular with those with strong environmental implications like mesopelagic fish. Environmental impact assessment (EIA) will furthermore be mandatory under this agreement and thus any new fisheries will be subject to in-depth environmental analysis.

Overall, it can be considered that

SUMMER research outputs will be critical in informing EIAs for new fisheries, the Scientific and Technical Board (STB) that will be established under the COP when the treaty enters into force, as well as RFMOs in general.

www.summerh2020.eu

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