WORKING GROUP ON MARINE BENTHAL AND RENEWABLE ENERGY DEVELOPMENTS (WGMBRED; outputs from 2024 meeting)

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i Executive summary

The Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED) examines benthal and renewable energy related research, cause-effect relationships and develops guidelines to aid future research.

This report examines the ecological implications of offshore renewable energy infrastructure on benthic ecosystems, with a focus on developing scientific methods for assessment, monitoring, and management. The overall objectives were to improve understanding of the tools and frameworks necessary to assess ecological change and inform decision-making around marine renewable energy.

The report addresses five main questions: (1) how non-extractive monitoring methods can be used effectively for benthic surveys; (2) how energy emissions from offshore infrastructure affect benthic species; (3) how decommissioning of marine structures should be assessed ecologically; (4) how offshore infrastructure influences the provision of ecosystem services; and (5) how functional biological traits of benthic organisms can be used to assess ecosystem functioning.

Key conclusions include that non-invasive techniques (e.g., imagery, eDNA) offer complementary or alternative data to extractive methods, particularly when integrated into ecosystem modelling. However, comprehensive comparative datasets are still limited. The analysis of energy emissions such as noise, electromagnetic fields, and light revealed specific benthic groups and life stages likely to be affected, providing a scientific basis for further impact assessments. On decommissioning, the group identified technical, regulatory, environmental, and financial challenges, especially concerning habitat disturbance, waste recycling, and site-specific legislation. The report also introduced a novel framework linking offshore wind-related pressures to ecosystem service supply, supported by a semi-quantitative scoring system and an online tool. In addition, a trait-based database of 572 taxa associated with artificial structures was developed, allowing for functional assessments of ecological changes across natural and artificial substrates.

Scientific outputs include peer-reviewed publications, the BISAR database on benthic species, and an online tool for mapping ecosystem service pathways. These tools support cross-disciplinary integration and are designed for adaptation across regions and infrastructure types.

Future priorities include refining the trait-based approach through comparative analyses, further developing the ecosystem service linkage tool, and consolidating international case studies on non-extractive monitoring. These efforts aim to underpin evidence-based marine spatial planning and ensure ecological sustainability in offshore energy development.

ii Expert group information

Expert group name	Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED)
Expert group cycle	Multiannual
Year cycle started	2022
Reporting year in cycle	3/3
Chairs	Jan Vanaverbeke, Belgium
	Joop W.P. Coolen, the Netherlands
Meeting venues and dates	28 November – 1 December 2022; Den Helder, the Netherlands
	6–9 November 2023; Lisbon, Portugal
	4–7 November 2024; Newport RI, United States

1 Background and scoping of the group's work

The aim of the group is to increase scientific efficiency of benthal renewable energy related research, to specify the various cause-effect relationships resulting from the construction and operation of offshore renewable energy installations, and to develop guidelines and an overview of existing data for cumulative impact research by future international collaboration. The outcomes will assist in improving monitoring concepts in the context of offshore renewable energy constructions and will also be set within the context of marine spatial planning strategies and future ecosystem-based management approaches.

Renewable energy developments, in particular offshore wind farms, cause large-scale anthropogenic pressures which affect benthic communities over various spatial and temporal scales within coastal and offshore ecosystems over the next decades.

Benthic organisms have a fundamental place in marine ecosystems and are involved in processes supporting the supply of numerous ecosystem services (such as food provisioning, long-term carbon storage, clear waters….), which are intimately linked to the benthic system. Extensive renewable energy developments have the potential to initiate processes which are expected to affect benthic communities in numerous ways. The identification of these processes is the prerequisite for an efficient, hypothesis-driven approach towards the understanding of the various effects of marine energy developments on the marine benthos as well as on the whole ecosystem.

The work group consists of scientists from many European countries and North America. WGMBRED meets annually and meetings are hosted at one of the members institutes, aiming to visit a new country each year. Group members cooperate in research projects, by data exchange and in joint scientific publications.

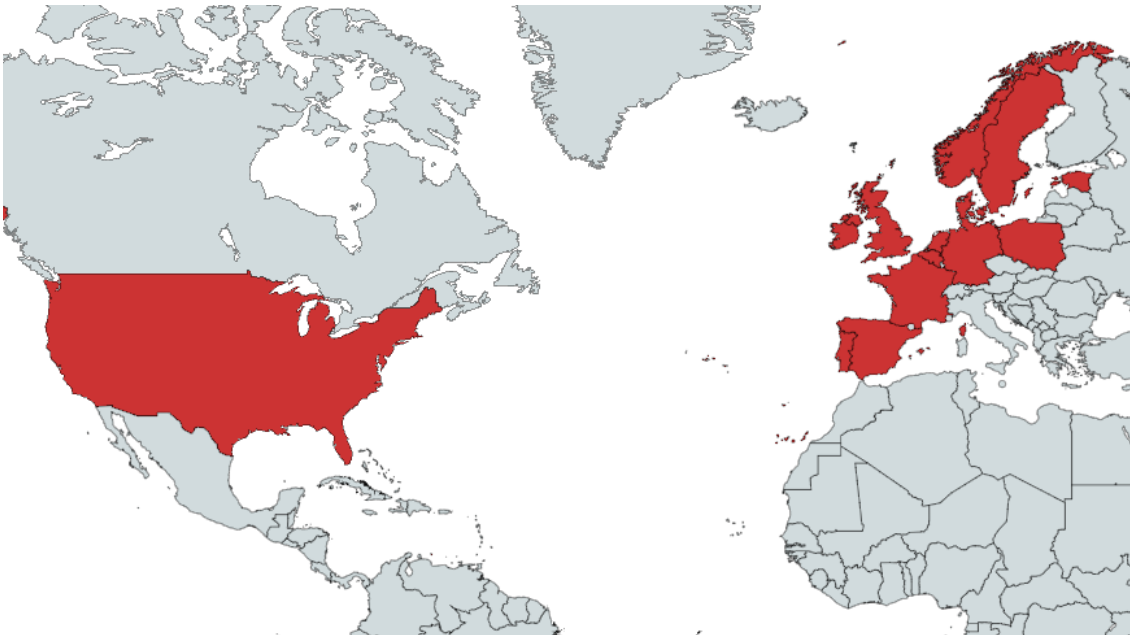

Figure 1.1. Geographic overview of the WGMBRED membership (in red).

2 Review the methods for non-invasive imagery benthic data collection and interpretation methods (ToR a)

2.1 Background

The working group recognised that the use of non-invasive (also referred to in this report as non-extractive) assessment methods of the benthos associated with marine renewable energy devices is a valuable addition to integrated analyses of the effect of such devices on the benthos on wider spatiotemporal scales. Development of a non-invasive data (visual, acoustic) interpretation framework that promotes incorporation into ecosystem models will provide expansion of existing efforts to wider application, facilitating joint analyses and international collaboration.

2.2 Objectives

The initiative had three specific aims:

1. Review the current use of non-extractive monitoring techniques to evaluate effects of offshore wind on benthic environments across the group of researchers, synthesize when and where these approaches could be useful and may exceed value from traditional extractive techniques (non-extractive benthic monitoring framework).
2. Assess the applicability of non-extractive monitoring approaches to inform ecosystem models and thus increase spatial and temporal inferences of the research priorities identified previously in Dannheim *et al.* 2020.
3. Assess the applicability of non-extractive monitoring approaches in addressing societal targets and values across regions of offshore wind development (e.g., United States, European countries) and thus turning off the DRIP (sensu Wilding *et al.* 2017).

2.3 Approach

Initial Discussions and Outline of the Framework (2022)

In 2022, the group discussed the policy and science-based motivations for benthic monitoring surveys to develop an outline for the non-invasive/non-extractive benthic monitoring framework that would be applicable across societies and regions of the world. The discussions occurred initially prior to the 2022 WGMBRED Annual Meeting, within a smaller subgroup over several virtual meetings (Tom Wilding, John Haplin, Joseph Marlow, Drew Carey, and Annie Murphy). It was recognized during these initial discussions that ToR A was very broadly defined and would require focussing in order to generate a useful outcome.

Non-invasive data collection spans a wide range of methodologies from visual to acoustic to molecular (e.g., eDNA approaches). During these initial discussions, a poll was designed to employ during the annual WGMBRED meeting to guide discussion and narrow down the terms of reference goals and outcomes and to create boundaries around the topic of interest. It was decided that we would use the 2022 annual meeting to develop more refined and focused objectives based on the current state of the science, which non-invasive techniques were currently being employed at windfarms by the researchers within WGMBRED, and to build on the outcomes of previous work conducted by WGMBRED in recent years (i.e., Wilding *et al.* 2017 and Dannheim *et al.* 2020).

Using the results of this 2022 poll, the group focused the discussion during the 2022 annual meeting on the need to match the monitoring methodology, whether extractive or non-extractive, to the survey objectives and monitoring targets, which ultimately are shaped by societal values. Societal values differ across countries and regions and therefore the adoption and acceptance of non-extractive techniques to monitor changes in the benthos will differ by region. This concept was fully explored through discussions in 2022 and is summarized in the Results section.

In 2022, the group identified biodiversity as the dominant endpoint in Europe. In contrast, a functional ecosystem assessment is the predominant endpoint in the United States. Further, the team identified publications that review and evaluate motivations for benthic monitoring in association with marine renewable device development and potential impacts (Dannheim *et al.* 2020, Wilding *et al.* 2017).

Clear parallels and common themes existed between the focus of the 2022 ToR A discussions, the "Turning off the DRIP" paper (Wilding *et al.* 2017), and the comprehensive published review of potential benthic impacts associated with offshore wind development (Dannheim *et al.* 2020). It was suggested that a framework should be developed building off the central table provided in Dannheim *et al.* 2020 that would integrate which non-invasive and invasive techniques could be employed to address the potential impacts listed in the table, and as grouped into the three regional scale impacts identified in this paper: 1. Food Resources, 2. Biodiversity, and 3. Biogeochemical Reactor. The outcome of these discussions and the framework is summarized in the Results below (Table 2.1).

Identifying Potential Case Studies across WGMBRED Research Groups (2023)

Following the analysis of the 2022 poll results and the discussions during the various meetings in 2022, a revised and more focused and informative poll was created for the 2023 annual meeting with WGMBRED members. The results of the 2022 poll were used to build a more comprehensive poll for 2023 to shape the ToR A. Key changes between the 2022 and 2023 polls, included 1) separate surveys for societal targets and non-extractive methods, 2) requesting a single submission for each country when evaluating societal targets, 3) exclusive ranks for societal targets, and 4) and explicit questions about modelling frameworks tied to specific methods. The 2023 poll questions are provided in Figures 2.1 and 2.2; results of the 2023 poll completed by the attendees of the WGMBRED during the 2023 annual meeting are described and illustrated in the Results section.

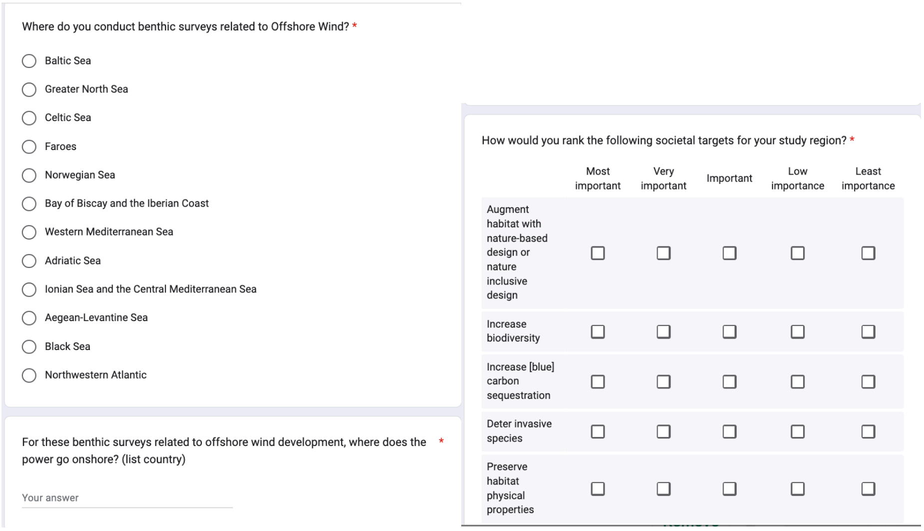

Figure 2.1. Example poll questions completed by attendees during the 2023 WGMBRED annual meeting – Ranking Societal Values.

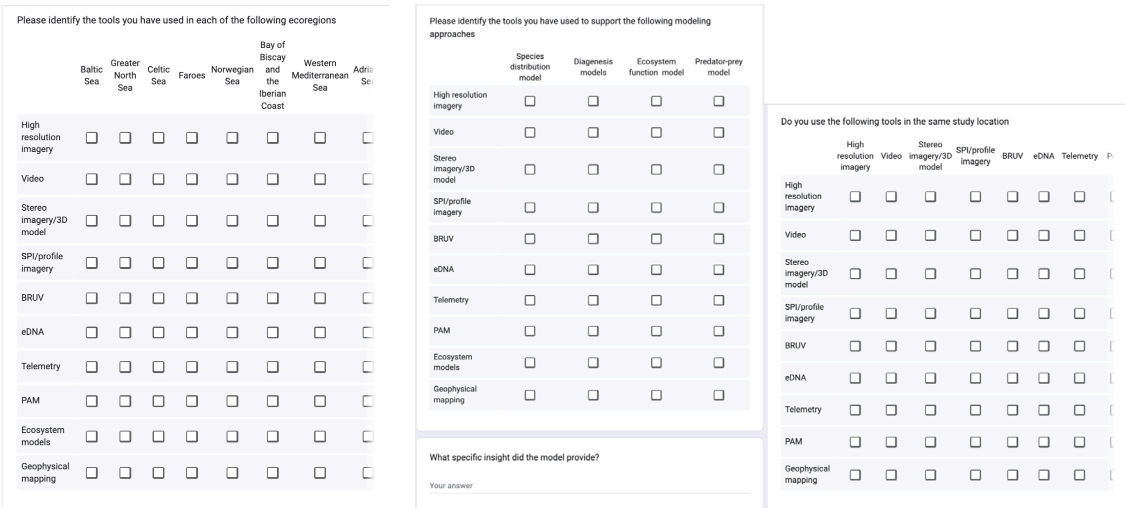

Figure 2.2. Example poll questions completed by attendees during the 2023 WGMBRED annual meeting – Identifying commonly employed non-invasive tools.

The results of the 2023 poll, highlighted the viability of a case study approach to ToR A, as there were several individuals in the group that indicated they could share non-extractive data coupled with conventional extractive data for a meta-analysis to support the development of a benthic monitoring framework for non-extractive methodologies and metrics. The goal of the case study approach would be to review which components of monitoring programs could be addressed using non-extractive techniques and discuss if there was anything lost as a result of using a non-extractive approach. It was thought that perhaps these case studies could show that anything that was lost by using non-extractive techniques was not substantive or important within the context of addressing societal targets because, for example, models do not necessarily require high taxonomic resolution or data obtained from a single turbine spatial scale.

It was agreed by the group that exploration of the non-extractive techniques needed to be assessed across different spatial and temporal levels and determine if these approaches are also fit for the purpose of particular ecosystem models. The group discussed the value of taking a top-down and bottom-up approach, and the possibility of using both to identify data gaps: the top-down approach identifies the full suite of desired targets, and the bottom-up approach illustrates the current landscape of data and methods and how these address various targets. Case studies could highlight method efficiency and accuracy. However, the framework need not rank methods. Instead, the framework could emphasize the value of combining tools to meet survey objectives. For example, a field survey could combine extractive and non-extractive tools at frequencies to optimize the strengths while minimizing costs. For another example, a survey could combine multiple complementary non-extractive methods (e.g., BRUV, telemetry, PAM) to meet policy and science objectives.

Literature Review to Broaden the Available Case Studies (2024)

Despite positive interest and enthusiasm to share datasets for example case studies during the 2023 annual WGMBRED meeting, there was limited follow up from the group with those datasets. Therefore, in 2024, an initial, more comprehensive, literature review was conducted to identify studies with more than one sampling approach (coupled extractive and non-extractive techniques) with the intention of collating relevant data and performing a comprehensive meta-analysis. The literature review included peer-reviewed publications involving the assessment of offshore wind development on benthic and fisheries resources and was narrowed to papers that included results obtained from both extractive and non-extractive approaches to answer a similar question. Initially the search for publications was limited to studies that investigated benthic habitat and community change as a result of added infrastructure projects. The criteria were then expanded to encompass fisheries resource monitoring to broaden the studies to ensure sufficient case studies could be identified that utilized both extractive and non-extractive techniques.

Initially the identified papers were screened using the following information noted for each publication in the review:

- Sampling Location
- Sampling method: Extractive, Non-extractive, or both
- Sampling tools: Scrape, Grab, Imagery, Trawl, Edna etc.
- Number of Species: yes or no
- Species Types: Invertebrates, Fish, Algae, Microbial
- Abundance parameters
- Other opportunistic data

Publications were screened to include only those studies that included data or results derived from “Both Methods” (i.e., extractive and non-extractive techniques). The following information was then gleaned from these papers to summarize and determine the feasibility of each paper as a case study for ToR A:

- Raw Measurement
- Estimated Parameters
- Diversity Indices
- Independent Variables
    - By depth
    - By time interval
    - By season
    - By turbine / site
    - By year or month

Data were then extracted from a select number of studies including the following, as applicable:

- Percent Cover
- Percent Composition
- Abundance
- Occurrence
- eDNA reads
- Diversity via Shannon Wiener H′ and Hill's N2
- Phylogenetic Diversity
- Functional Diversity
- Evenness via Pielou's J′
- Richness via Margalef's d
- Dominance via Simpson's λ

This initial literature review was discussed during the annual 2024 WGMBRED meeting. The majority of studies obtained during this literature review coupled molecular sampling and analysis with more conventional extractive approaches (e.g., trawl surveys). Therefore, the discussion during the 2024 annual meeting centered a lot on considerations of molecular approaches to assessing biodiversity and shifts in biodiversity. The 2024 discussion also revisited the use of existing datasets within the research groups of WGMBRED to use as case studies. These datasets were compiled by the group and reported in results below.

2.4 Results

Initial Discussions and Outline of the Framework (2022)

The discussions in 2022 linked the objectives of ToR A to the previous work conducted by WGMBRED including Wilding *et al.* 2017 and Dannheim *et al.* 2020. Specifically, the group built off the three broad pathways of change described in Dannheim *et al.* 2020 and linked non-extractive tools that could be used to measure response variables associated with these pathways (Table 2.1). Further, the conventional extractive methods were included in this table and highlighted where there could be potential areas or studies that utilized both extractive and non-extractive approaches to measure the same broad pathway of change or response variable. These studies could be used as examples within ToR A to highlight where and when non-extractive sampling could be beneficial as an efficient and well-calibrated means to track change.

Table 2.1. Summary of Outline of ToR A Framework – Linking non-extractive methodology with Pathway of Change.

Broad Pathways of Change (sensu Dannheim et al. 2020)	*Metrics or Response Variables*	*Non-extractive Tools to measure these variables versus conventional tools* *Case Studies*	*Ecosystem Model Application*
Biodiversity	Number of species per unit area Non-indigenous species presence	Scraping vs Panels vs HD imagery eDNA vs grabs/scraping	Population Distribution Models
Biogeochemical Reactor	Biomass distribution Respiration Rates Primary Production Carbon stocks	Scraping vs 3D photogrammetry SPI aRPD vs organic matter content vs flux measurements	Diagenesis models Ecosystem models
Food Resources	Biomass distribution Secondary Production Rates	BRUV vs. stomach content studies (stable isotopes) BRUV vs. trawling/nets	Ecosystem models (trophic dynamics)

Results of Group Poll to Develop Focused Case Studies (2023)

The group conducted an initial poll during the 2022 annual meeting, which was completed by the WGMBRED attendees; however, there were clear limitations in how the poll results could be interpreted and therefore a revised poll was designed to further explore the non-invasive techniques being used across research groups at the 2023 WGMBRED annual meeting. In 2023, the group completed the updated poll and discussed the results for societal targets and non-extractive tools. The 2023 poll aimed to explore what types of non-extractive data were being collected across the research groups present at the meeting. A summary of the findings of the 2023 poll is provided here.

The results of the 2023 poll highlighted the diversity of non-invasive methodologies employed by the researchers across WGMBRED to monitor impacts of offshore wind devices on benthic environments (Figure 2.3). In general, more individuals (>10 respondents) indicated they used video as a tool compared to the other non-invasive techniques, followed by eDNA (Figure 2.3).

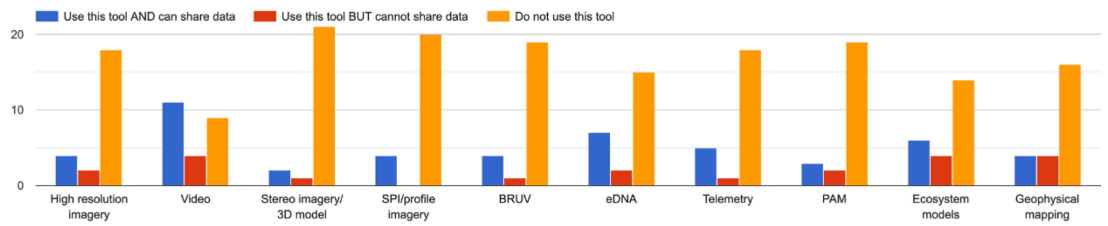

Figure 2.3. 2023 Poll Results for the Questions: Do you use the following tools? And can you share the data you collected using these tools?

In terms of results of the societal values poll, Figure 2.4 summarizes the results of how various targets or societal values were ranked based on importance. The data are coded based on the location (i.e., society) that the respondent was actively conducting studies. The poll included the following five broad societal targets to rank, individually: (1) Augmentation of benthic habitats with nature-based or nature inclusive design; (2) increase biodiversity; (3) increase blue carbon sequestration; (4) deter invasive species; and (5) preserve habitat physical properties. The poll participants identified mainly from the North Sea, with several other European study systems noted as well as the United States. Results showed the majority of participants ranked increasing biodiversity as "Very Important", while deterring invasive species target varied in rank with several respondents noting as "Little importance".

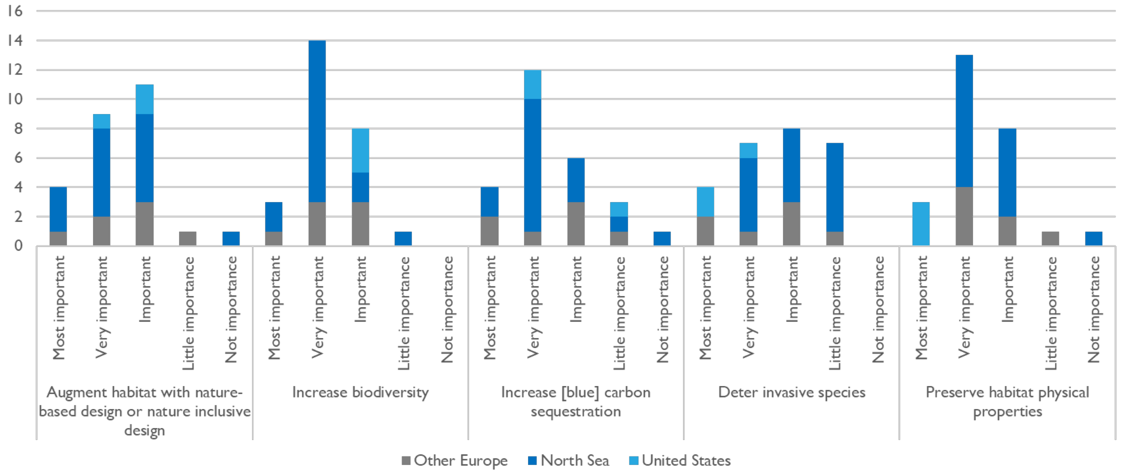

Figure 2.4. 2023 Poll Results for the Question: How would you rank the following societal targets for your study region?

Following the 2023 poll and discussion of the poll results, volunteers from the working group outlined their potential cases and agreed to share additional information throughout the year to support the review. Suggested case studies discussed during the 2023 meeting included:

1. imagery versus settlement plants (INSPIRE/RODEO),
2. multiple types of imagery and 3D models (INSPIRE),
3. 2D assessment versus physical removal (Pedro),
4. eDNA, grabs, photos (Silvana),
5. eDNA versus trawls (Zoe),
6. eDNA versus trawls (Jolien),
7. camera, visual, scrapes, grabs, water samples for eDNA, BRUV (Joop),
8. two types of vehicles carrying a magnetometer (Pedro).

Results from the 2024 Literature Review for Case Studies

Despite the momentum garnered during the 2023 WGMBRED annual meeting, the enthusiasm and availability of datasets dwindled over the following year. Therefore, the ToR A participants turned toward the published literature to identify potential candidate case studies. The goal was to identify studies that included both non-extractive and extractive techniques to measure similar targets (or parameters, response variables). Table 2.2 provides the list of 27 recent publications identified during the literature review. Of these studies, ten publications included a description of both non-extractive and extractive techniques.

Given resource availability, this effort was limited to a preliminary review of the literature and available data. Nevertheless, this effort identified the following conclusions, which could inform a more thorough literature review and meta-analysis.

This preliminary review focused on studies of offshore renewable energy structures. The majority of these studies either did not report comprehensive results from both types of sampling techniques or, more often, the studies used the two types of techniques to measure different response variables. In other words, it was not often that studies reported results, and specifically the same metrics, obtained from both extractive and non-extractive approaches. More often the studies used an extractive technique to answer one specific question and the non-extractive technique to answer a separate targeted question. Therefore, a meta-analysis would require the inclusion of: 1) a broader set of marine environments, 2) an alternate effect size that allows the inclusion of studies that only include a single response metric, 3) additional resources.

ToR A was not formally continued for the next phase of WGMBRED due to the lack of a 'hero/heroine' to lead the ToR. However, there was substantial interest in the topic and numerous suggestions to develop a publishable short note by reviewing existing data in the context of ecosystem model requirements and consider proposing a new ToR in the future. Specifically, a suggestion was made to address ICES Standards with 'tales from the frontline' in relation to evolving non-extractive techniques. Because WGMBRED participants are actively engaged in a variety of non-extractive approaches, this topic will likely have future relevance.

Table 2.2. A summary of publications identified during the literature review in 2024.

First Author	Publication Year	Abbreviated Title	Sampling Location	Extractive, Non-Extractive, or Both	Sampling Tools
English *et al.*	2023	Field Observations RODEO CVOW	CVOW, Virginia	Both	Physical Sample (e.g., scrape), Imagery
INSPIRE	2024	Marine Growth Survey	CVOW, Virginia	Non-Extractive	Imagery
Fonseca *et al.*	2024	Block Island Wind Farm Benthic Epifauna	Block Island Wind Farm	Both	Imagery, Scrape, Grabs
Spielmann *et al.*	2023	Decommissioning Benthic Ecology	Multiple	Non-Extractive	Database Query
Li *et al.*	2023	Marine Biodiversity Life Cycle	North Sea	Extractive	Physical Sample (e.g., scrape)
Kingma *et al.*	2024	Nature Inclusive Scour Protection OWF Benthic Diversity	North Sea	Extractive	Physical Sample (e.g., scrape), Imagery
Jech *et al.*	2022	Fish Distribution at BI OWF using Echosounders	BI	Both	Physical Sample (e.g., scrape)
Zupan *et al.*	2023	Succession of OWF and Species Interactions	North Sea	Extractive	Physical Sample (e.g., scrape)
HDR	2023	Benthic Monitoring of BIWF Operation	BI	Both	Physical Sample (e.g., scrape), Imagery
Guarinello & Carey	2022	Multi-modal Benthic Assessment BIWF	BI	Non-Extractive	Imagery
Coolen *et al.*	2020	Benthic Biodiversity on Different Substrates	North Sea	Extractive	Physical Sample (e.g., scrape)
Cruz-Marrero	2019	Benthic Community in Maryland OWF	Maryland	Both	Imagery, Trawl
HDR	2019	Field Observations RODEO BI WF, RI	BI	Non-Extractive	Imagery
Huang *et al.*	2021	Fish Aggregations at Wind Turbines in Taiwan	Nanlong Wind Farm Area	Non-Extractive	Echo Sounder, Scuba Diving

First Author	Publication Year	Abbreviated Title	Sampling Location	Extractive, Non-Extractive, or Both	Sampling Tools
Raoux *et al.*	2017	Benthic and Fish Aggregations in OSWF	Normandy, France	Non-Extractive	Modeling
Schutter *et al.*	2019	Artificial Substrate Biodiversity	North Sea	Non-Extractive	Imagery
Wilber *et al.*	2022	Fish and Invertebrate Catches at BIWF	BI	Extractive	Trawl
Glarou *et al.*	2020	Artificial Reef Fish Abundance and Diversity	Lit Review	Non-Extractive	systematic literature review protocol developed by Pullin and Stewart
Stoeckle *et al.*	2021	Trawl and Edna Assessment of Fish Abundance and Diversity	NJ	Both	Trawl, EDNA
Veron *et al.*	2023	EDNA complements Trawling for Biodiversity	France	Both	Trawl, eDNA
Thomsen *et al.*	2016	EDNA vs Trawl Catch Correlation	SubArctic	Both	Trawl, eDNA
Cornelis *et al.*: https://onlinelibrary.wiley.com/doi/epdf/10.1002/edn3.575	2024	EDNA vs Trawl in OWF	North Sea	Both	Trawl, eDNA
Iguchi *et al.*	2024	EDNA vs Imagery on Seamount	northwestern Pacific Ocean	Non-Extractive	Imagery, eDNA
Lefaible *et al.*	2023	Macrobenthic Community Monitoring OWF	North Sea	Extractive	Grab
Hutchinson *et al.*	2020	Offshore Wind Energy and Benthic Habitat Changes	BIWF	Both	Grab, Drop Camera, Divers

First Author	Publication Year	Abbreviated Title	Sampling Location	Extractive, Non-Extractive, or Both	Sampling Tools
de Mendonca and Metaxas	2021	ROV, Drop Camera, trawl deep-sea epifaunal abundance and diversity	Southwest coast of Newfoundland CA	Both	ROV, Drop Camera, Trawl
Schramm *et al.*	2019	stereo-BRUV, diver and remote stereo-video	Geographe Bay, Western Australia	Non-Extractive	comparison BRUV, ROV, diver video, towed video

Table 2.3 A summary of projects provided by WGMBRED members during the 2024 annual meeting that included non-extractive techniques to monitor benthos.

Contact(s)	Project Name	Infrastructure Type	Year(s) of data collection	Sampling Location	Sampling tools	Response Variables	Other notes, key metadata
Caterina Coral	ReViFES (North Sea vitalisation for ecosystem services)	Natural subtidal reefs (biogenic, geogenic)	2022, 2023	Voordelta (NL, SNS); Noss Head (Scotland, NNS)	BRUVS, eDNA	Biodiversity, abundance of fish in and out reefs	data have not been published and are part of PhD thesis Caterina Coral
Tom Wilding	North Sea 3D	All man-made structures	~2010 to present	North Sea	Inspection ROV video	marine growth	machine-based (AI) identification of key taxa
Lea Kornau	JIP LIFE	Wind	2021/2022, 2024	Southern North Sea, Hollandse Kust Zuid	eDNA, video	Species absence/presence	
Joop Coolen	Multiple projects in Hollandse Kust Zuid OWF	Wind turbines	2023	Southern North Sea, Hollandse Kust Zuid	ROV Marine Growth Sampling Tool on single foundation, BEEX video inspection on some of the other foundations in the same OWF	Macrofauna abundance in the scrapes from MGST, some form of counts (not sure, not my project) from the BEEX video	This is the same wind farm as Lea's JIP LIFE
Andrew Want	FLEDGE - Biofouling	Waverider buoys, marinas, harbours	2015	Orkney and Pentland Firth	Rapid assessment survey	Community composition	
Andrew Want	BioFREE	Wave and Tidal MRE test sites	2018-2021	Orkney	Settlement panels; still	Community composition; biomass	

Contact(s)	Project Name	Infrastructure Type	Year(s) of data collection	Sampling Location	Sampling tools	Response Variables	Other notes, key metadata
					image analysis		
Joop Coolen / Caterina Coral	ReViFES (North Sea vitalisation for ecosystem services)	Natural subtidal reefs	2020	Borkum Reef Grounds NL	Box corers, cod pots, drop camera video	macrofauna abundance	data have not been published and are part of PhD thesis Caterina Coral
Joop Coolen	North Sea reefs	Gas platforms	2014-2016	Multiple offshore gas platforms in Dutch part North Sea	Scrape samples & ROV inspection videos supplied by industry	Macrofauna abundance for scrape samples and SACFOR type of scale for video analysis	The two methods were not part of the same campaign, but some of the platforms were analysed in both papers. The video originated from a few years before the scrape samples were taken, but the platforms were already 20-30 years old so we may assume that variation between years is low. the comparison between the two methods have not been done. The raw data are available, the scrapes are in BISAR

3 Energy analysis (ToR b)

Review existing methods assessing the effects of energy emissions

There is increasing evidence that multiple forms of energy emissions (namely Electromagnetic Fields -EMFs, underwater sound (sound pressure and particle motion), vibrations, heat from ORE infrastructure can affect several benthic taxonomic groups and this may lead to impacts on the species or the community. The information on effects on benthos is currently lacking or patchy and what does exist is scattered and generally based on specific experiments and therefore difficult to integrated.

The reason why energy emissions are a focus is that increasingly, Stakeholders raise questions on their effects. From a policy perspective there is a requirement under the Marine Strategy Framework Directive (MSFD), article descriptor 11: energy, to address energy emissions. Furthermore, there is a requirement under Article 12: known disturbance of (habitat of) protected species is prohibited, to take into account energy emissions.

Therefore, the main aim for ToR B was to review the topic of energy emissions that are associated with marine renewable energy developments and their potential effects on the benthos. Then structure the information to identify the benthic species groups that are or could be affected by multiple pressures related to energy emissions. Finally, to make recommendations for addressing knowledge gaps.

The intention when considering the environmental impact of energy emissions associated with MRED is that they will not affect the marine environment. There are some specific sources of energy emissions, which were considered:

- Noise and vibrations from ORE construction, operations and maintenance, decommissioning
- Noise and vibrations from UXOs (Unexploded Ordnance)
- Electromagnetic (EMF) emissions from subsea power cables
- Heat from subsea power cables
- Navigation and lights

Expert evidence to support the ToR

During the ToR we identified experts who were invited to present to the group to ensure that WG members gained some insight into the different energy emissions. This was important in the context of interpretation of effects on benthic and demersal species.

We also noted several projects that are ongoing or are planned, which the WG members should keep in mind as the ToR develops. Some of these are:

- SafeWAVE project from WAvEC https://www.safewave-project.eu/marendata/?lang=pt-pt
- Substrate-Borne Vibroacoustic Disturbances from Offshore Wind Construction: Measurements, Physical Characteristics, and Propagation (NT-23-11). Woods Hole Oceanographic Institution (WHOI) and Pacific Northwest National Laboratory (PNNL), ends December 31, 2026. BOEM funded project.

- FLOWERS - Floating Offshore Wind environment response to stressors. Cefas and Marine Scotland, ends April 2025. The Crown Estate funded project.
- Benthic-Offshore Wind Interactions - BOWIE - ECOWind. United Kingdom Research and Innovation (UKRI) funded project.

Assessment of the relationship between energy emissions and the benthic community

To use the combined expertise of the WG members we undertook an exercise to consider different types of energy emissions scenarios in relation to the types of benthic organisms and life stages. Figure 3.1 shows the different scenarios that were considered by the sub-groups.

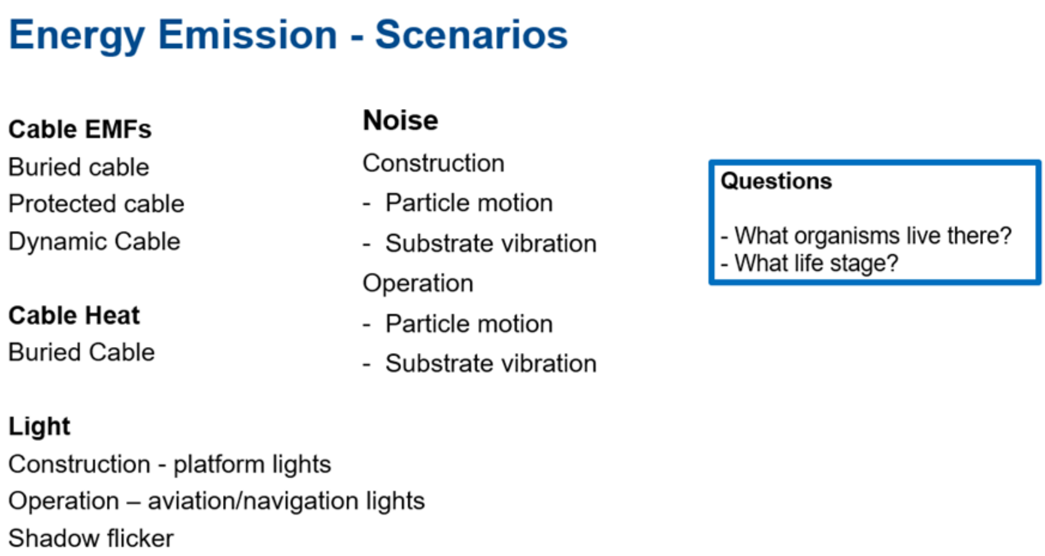

Figure 3.1. Scenarios for energy emissions arranged by sub-groups.

The subgroups set out the benthic fauna into relevant groupings and scored each group in relation to the energy types. The scores were compiled and used to highlight which benthic group was expected to be most affected by each energy type and scenario.

Figure 3.2 shows that for EMF the most affected groups are expected to be burrowing fauna, bivalves and polychaetes. For EMF associated with cable protection, it is expected to be megafauna, such as large crustaceans and demersal fish, and colonising anemones and mussels. When considering dynamic cables, amphipods, anemones, mussels and fish are expected to be affected the most.

Noise was separated into water borne particle motion and substrate borne vibrations for the construction and operation phases of renewable energy development (Figure 3.2). Burrowing fauna, and mobile megafauna, such as crustacea, fish and echinoderms were considered the most likely to be affected by the noise for other construction and operation. The vibrations are expected to affect organisms either on or in the substrate. Water-borne noise was most likely to affect bivalves, and mobile fish and crustacea.

The predominant expected effect of light for all three scenarios was on zooplankton and other crustacea (Figure 3.2).

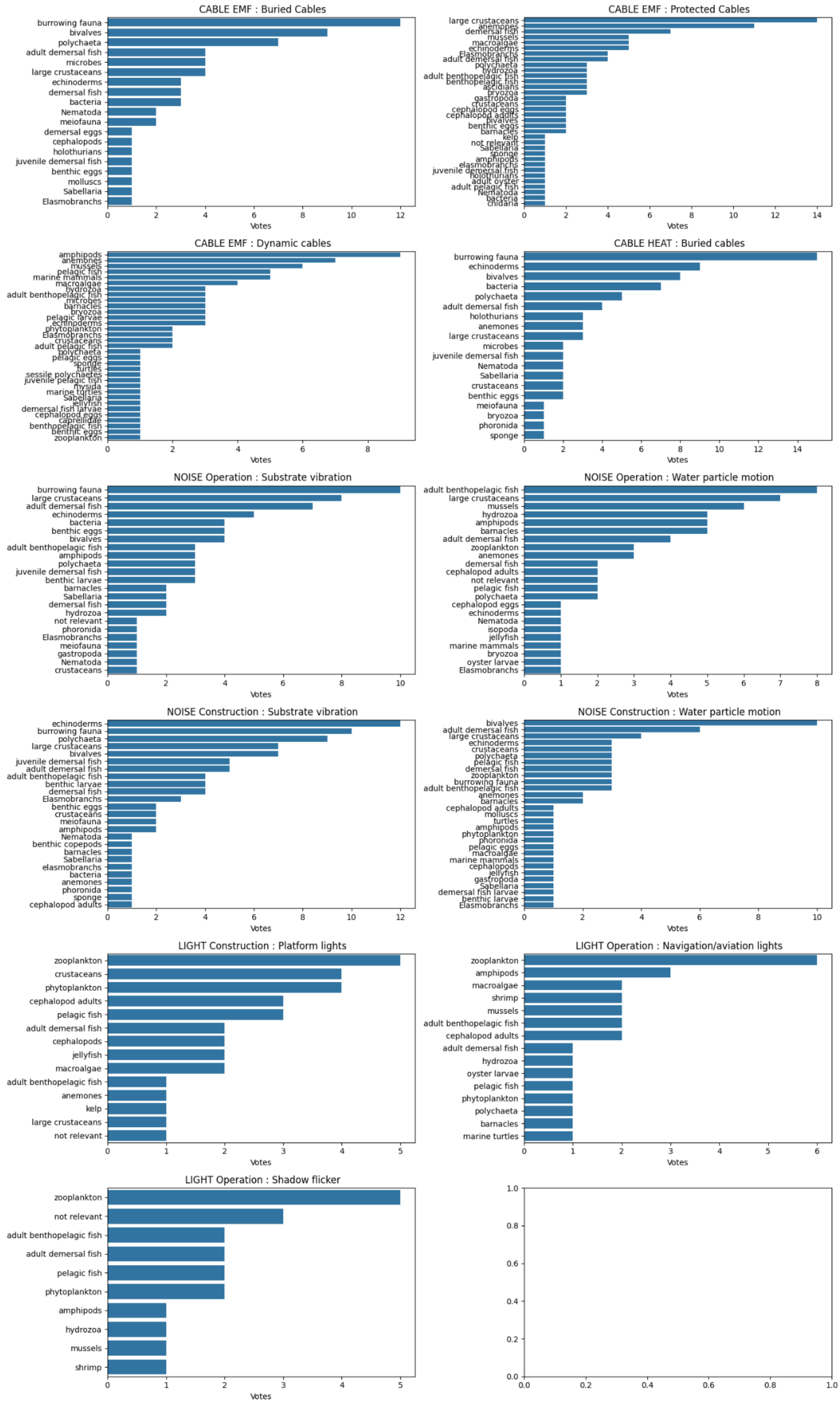
CABLE EMF : Buried Cables
burrowing fauna
bivalves
polychaeta
adult demersal fish
microbes
large crustaceans
echinoderms
demersal fish
bacteria
Nematoda
meiofauna
demersal eggs
cephalopods
holothurians
juvenile demersal fish
benthic eggs
molluscs
Sabellaria
Elasmobranchs
Votes
CABLE EMF : Protected Cables
Votes
CABLE EMF : Dynamic cables
Votes
CABLE HEAT : Buried cables
burrowing fauna
echinoderms
bivalves
bacteria
polychaeta
adult demersal fish
holothurians
anemones
large crustaceans
microbes
juvenile demersal fish
Nematoda
Sabellaria
crustaceans
benthic eggs
meiofauna
bryozoa
phoronida
sponge
Votes
NOISE Operation : Substrate vibration
Votes
NOISE Operation : Water particle motion
Votes
NOISE Construction : Substrate vibration
Votes
NOISE Construction : Water particle motion
Votes
LIGHT Construction : Platform lights
zooplankton
crustaceans
phytoplankton
cephalopod adults
pelagic fish
adult demersal fish
cephalopods
jellyfish
macroalgae
adult benthopelagic fish
anemones
kelp
large crustaceans
not relevant
Votes
LIGHT Operation : Navigation/aviation lights
zooplankton
amphipods
macroalgae
shrimp
mussels
adult benthopelagic fish
cephalopod adults
adult demersal fish
hydrozoa
oyster larvae
pelagic fish
phytoplankton
polychaeta
barnacles
marine turtles
Votes
LIGHT Operation : Shadow flicker
zooplankton
not relevant
adult benthopelagic fish
adult demersal fish
pelagic fish
phytoplankton
amphipods
hydrozoa
mussels
shrimp
Votes

Figure 3.2.

Based on the activities undertaken above, the WG members highlighted that there are some key aspects that should be addressed when considering energy emissions and the potential impacts on the benthos.

1. The characteristics of the energy emission should be understood in terms of intensity, frequency and duration and how the emission propagates into the environment, whether the water column or the seabed.
2. The assessment of energy emissions scenarios and the identification of faunal groups most likely to be affected provides a focus for research into the future.
3. Different life stages should be included, with consideration of how they interact with respect to the presence of the energy emission source.
4. Any assumptions should be clearly stated and justified.
5. Real world interactions are required to ensure that the energy emission being investigated is representative of the environment that the receptor species are exposed too.
6. There may be cumulative effects from several energy emissions.

These considerations are proposed to be taken forward in the continuation of ToR b).

4 Develop the scientific basis to support decision making processes regarding decommissioning of marine benthal renewable energy installations (ToR c)

4.1 Background

Globally, the increasing quantities of Man-Made Structures (MMS, hereafter) populating the marine and coastal environments to enable and support the generation of clean energy sources has moved to the top of the agenda for environmental monitoring and management (Birchenough and Degraer, 2020). The presence of MMS includes cables, offshore renewables, oil and gas, wrecks, etc. The full cycle of MMS includes planning, construction, operation and decommissioning (Alexander *et al.*, 2025; Birchenough and Degraer, 2020). The final step, e.g. decommissioning has been considered under the general principles of the licensing and overall application. However, little details of successful examples exist to date. In the case of offshore renewable energy projects, the decommissioning process is now being under consideration as it is a complex and evolving process (Knights *et al.*, 2024). The work primarily, involves the regulatory guidelines, which have been drafted and published (e.g. Scotland, Belgium, England). However, the application of such guidelines remains still under discussions.

Over the last three years, our ICES WGMBRED sub-group has dedicated discussions and exchanges to fully document and understand the decommissioning debate and likely issues. The work has been centred on discussing ongoing efforts in Germany, Belgium and the UK. Substantial advancements from oil and gas and cables have been used to support the current knowledge based (Watson *et al.*, 2023). Whilst information from other industries and efforts remains valuable, it is clear that offshore renewable energy projects will have to consider dedicated strategies and planning.

The group has agreed to continue with this work over the next set of ToR (2025–2027). The work will be also summarised into a position paper (e.g. *Quo Vadimus category to advance the current field and provide thought provoking opportunities*) to submit with the current knowledge gained and future ecological recommendations for consideration between industry, regulators and the scientific community.

The group discussed what will be the ecological considerations from previous studies available to date, to ensure all aspects are considered. There are several levels of uncertainty, as current legislative frameworks are general and there is a need for site-specific, types of structures (e.g. tripod, monopile, floating and blades) to be considered. Similarly, the need to distinguish between oil and gas platforms from offshore windfarms is also needed. Whilst there are some commonalities between industries, there are clear differences in both processes (e.g. footprint of the structure, scales, time framework, presence of contaminants, size and life of the structure).

Several challenges need to be addressed, ranging from technical, environmental concerns to financial and regulatory issues. Some of these considerations are outlined below:

1. Environmental Impacts concerns:

- **Marine Ecosystem disturbances**: The decommissioning process can disrupt marine life and ecosystems, especially if these structures have been in place > than 10 years. Therefore, there are important considerations for removal and disposal of these parts and/or full structures. Any removal processes will cause sediment disturbance (from the base to the extraction of the foundations and cables). If one or many turbines have been in place for longer than 10 years, then these effects could affect fish habitats and marine biodiversity.
- **Waste Disposal**: Some materials used in offshore wind turbines, such as fiberglass in blades or concrete in foundations, may be difficult to recycle. Finding sustainable methods to manage this waste, especially in terms of disposal at sea or recycling on land, will be a challenge. Similarly, logistics, for example finding suitable vessels and cranes to dismantle, transport these parts to dedicated recycling sites could also pose challenges in the overall process.

2. Technological challenges:

- **Removal of Offshore Structures**: The large and often deep-water location of offshore renewable installations makes decommissioning costly and technically challenging. Offshore turbines can be located in very harsh conditions, and removing heavy structures like turbines, foundations, and subsea cables will be logistically difficult. The need to use large vessels and removal equipment will need careful consideration (e.g. cost, carbon footprint and cumulative effects if the work is to take place over other ongoing sites).
- **Complexity of Foundations**: Different offshore projects will have adopted different foundation designs (e.g. monopiles, jackets, or floating structures). Decommissioning these varied foundation types requires different techniques, vessels and waste management strategies, to ensure H&S, economic and environmental footprint of effects are monitoring and minimised.

3. Costs implications:

- **Financial Improbability**: Decommissioning offshore renewable projects could be expensive. The long-term financial planning and the allocation of funds for decommissioning are uncertain, especially when decommissioning costs may exceed initial estimates and/or in some instances there has not been initial budget allocations at the planning stage.
- **Lack of Funding Mechanisms**: Unlike other industries, offshore wind and renewable projects often lack clear financial mechanisms to ensure that enough funds are set aside for decommissioning. There may be concerns about whether operators will have sufficient funds for decommissioning once their projects reach the end of their operational life. It is an important license condition to cover with financing mechanisms and regulators.

4. Regulatory and Legal Frameworks

- **Uncertainty in Regulations**: The regulatory frameworks for decommissioning offshore renewable projects are still being developed globally. In some cases, broad guidelines are evolving. However, rules for decommissioning may not be well-defined or could continue to evolve over time, creating further uncertainty for project developers during different stages.
- **Permitting challenges**: the need to secure and access the necessary permits for decommissioning could be time-consuming, costing and challenging. This aspect could present

further challenges and delays if the decommissioning plan involves activities that will have repercussions for marine habitats or local communities.
- **Liability Concerns**: There can be legal and liability concerns if decommissioning if the process is not done properly, with potential lawsuits or fines related to environmental damage or non-compliance with regulations.

5. Renovating and Repurposing Materials

- **Challenges with Material Reuse**: Offshore wind turbine blades, which are typically made of composite materials, will be difficult to recycle. Finding cost-effective ways to repurpose or recycle turbine materials will be an ongoing challenge.
- **Waste Management**: There is limited infrastructure for recycling offshore turbine components. The disposal of large turbine blades, for example, will be an issue, as landfills are typically not equipped to handle such large and composite materials.

6. Capacity for New Opportunities

- **Repowering, Repurposing or Reuse structures**: some offshore renewable energy assets might be repowered (i.e., replacing old turbines with new ones) rather than decommissioned. This could reduce the overall environmental and economic costs of decommissioning, but it depends on the specific project's viability.
- **Additional opportunities**: decommissioning can create opportunities for companies to develop new business models around repurposing structures, such as transforming old wind farms into artificial reefs (e.g. rigs to reef approaches) or other beneficial uses (e.g. ecotourism and diving).

7. Technological Development and Innovation

- **Lack of Proven Decommissioning Technology**: there are limited examples of decommissioning offshore wind farms at scale in which these developments are currently operating. Many projects are still in operation or at early stages. Therefore, the industry and regulators are still developing reliable and cost-effective decommissioning technologies and guidelines.
- **Research and Development**: More targeted research is clearly needed to identify ways to improve the longevity of offshore renewable projects. It is important to assess the ecological integrity of these sites prior to adopting and rolling a suite of decommissioning measures. The need to consider what are the needs and methods for decommissioning, including improved technologies for dismantling turbines and managing waste, will make further benefits for the marine environment, industry and regulators.

Addressing these issues requires collaboration between governments, industry stakeholders, environmental organizations, and technology developers to create sustainable, cost-effective, and environmentally responsible decommissioning strategies (see Birchenough and Degraer, 2020).

4.2 Objectives

The main research question is as follows: What effects of OWFs will change during and after decommissioning under different scenarios, taking account of the new baseline?

The discussions took the form of sub-groups, helping to document current knowledge, main gaps and some of the ecological considerations. The discussion and new ideas resulted in a manuscript structure, and it is currently under development.

4.3 Methods and results

A series of presentations and working documents have been considered during the evidence gathering. There is ongoing work in Belgium with stakeholder consultation to canvass needs and concerns. Some examples, see Elliott and Birchenough (2022) postulated a series of steps when considering the current knowledge and effects resulting from additional artificial substrate. Relevant literature sources have been used to inform the current process and available knowledge.

In short, as many installations will likely reach the end of their operational life. The approach of removal MMS will be subject to different legislation, region, and structure type. In some instances, the decommissioning options will include full removal, partial removal, or repurposing. In the North Sea, approximately 10% of oil rigs have undergone full removal, with 95% of the removed materials being reused or recycled.

Ongoing work is now focusing on optimizing the recycling of decommissioned materials. In ecological sense, some of these considerations have shifting to repurposing with ongoing investigations. Recent studies have suggested that leaving structures in place as artificial reefs may offer limited long-term ecological advantages, especially in sandy seafloor areas. As the science surrounding decommissioning impacts continues to evolve for MMS, this knowledge remains a critical area of study along North Sea and worldwide.

It is important to consider local ecosystems, often functioning as artificial reefs over soft sediment, creating vertical habitat complexity from the seafloor to the surface. This dedicated complexity supports diverse communities of marine life, including encrusting organisms like barnacles and mussels, mobile invertebrates, and various fish. In some instances, some structures have been found to host higher biodiversity than natural reefs in the vicinity. The concern is that complete removal of these structures could lead to a significant loss of established habitats and the species they support. Further challenges will consider the influence of MMS in ecosystem functioning with wider repercussions for food weed dynamics. Further work will help to understand and disentangle these effects.

4.4 Conclusion

The scientific basis for supporting decision-making in marine benthic renewable energy decommissioning involves a comprehensive understanding of environmental, physical, ecological, and socio-economic factors. Through the use of monitoring, modelling, stakeholder engagement, and adaptive management, decision-makers can ensure that decommissioning strategies are both effective and responsible, minimizing negative impacts while promoting ecosystem recovery and societal benefits. Similar decommissioning frameworks for oil and gas have considered the whole cycle of considerations (Watson *et al.*, 2023).

4.5 Future work

The work under this ToR will continue for the next 3 years. The intention will be to synthesise and continue to document the ongoing developments under this evolving knowledge base with direct relevance to biodiversity needs, as some work is looking to repurposing and new horizons (Herbert-Read *et al.*, 2022). This work will ensure that a wider collaborative assessment is conducted with a plethora of industries and stakeholders.

5 Review the methodology to assess the role of benthos associated with benthal marine energy devices on the provisioning of ecosystem services to society (ToR d)

5.1 Background

The presence of offshore wind farms (OWFs) in the marine environment leads to changes in the physical and biological characteristics of the originally mainly sandy habitat. The turbines and – when present - scour protection layers (SPL) act as artificial reefs (Degraer *et al.*, 2020) as they get colonized by many suspension feeding organisms (Coolen *et al.*, 2022; Zupan *et al.*, 2023, 2024) attracting higher trophic levels, including species of commercial importance such as cod (Gimpel *et al.*, 2023), plaice (Buyse *et al.*, 2022) and large crustaceans (Krone *et al.*, 2013, p). At the same time, the sedimentary environment within an OWF gets enriched with organic matter (De Borger *et al.*, 2021), which is partly explained by a continuous supply of faecal pellets produced by turbine-inhabiting organisms (Mavraki *et al.*, 2022). As such, it is clear that the presence of offshore wind farms affects the capacity of the marine ecosystem to supply ecosystem services (ES) to society (Hooper *et al.*, 2017; Galparsoro *et al.*, 2022). However, the cause-effect relationships between the multiple pressures associated with the presence of offshore wind farms and the changes in ecosystem service supply often include multiple steps (Dannheim *et al.*, 2020) including biotic and abiotic changes affecting ecosystem processes supporting ecosystem services. A framework for incorporating these steps is currently unavailable.

5.2 Objectives

The aim of this ToR was

(1) to establish a generic framework that allows the mapping of cause-effect relationships linking the pressures associated with the presence of OWF to the capacity of the marine ecosystem to supply ecosystem services
(2) to develop a tool that allows for a semiquantitative analysis of the effects of OWFs on the ES supply.

5.3 Methods and Results

We developed a linkage framework (Armoškaitė *et al.*, 2020; Baulaz *et al.*, 2023) to map interacting links between nodes of a system. We adopted the approach of Armoškaitė *et al.* (2020) where 'components' reflect species groups occupying a certain habitat. Our benchmark OWF reflects an OWF set in a soft sediment environment, as operational in Belgium, the Netherlands, Denmark and Germany, and consists of an array of monopiles, surrounded by a SPL, where fishing is prohibited. Nodes (Table 5.1) in the framework consist of:

1. pressures on the underwater environment, induced by the presence and operation of OWF
2. components – groups of species living on a certain part of the OWF habitat ("domain")
3. ecosystem functions (defined according to de Groot *et al.*, 2002)
4. ecosystem services (based on CICES classification - https://cices.eu/)

Table 5. 1. Nodes in the WGMBRED linkage framework.

PRESSURE	COMPONENT	DOMAIN	Ecosystem Function	Ecosystem Service
Loss of soft sediment	blue mussel (Mytilus edulis)	Turbine	Biodeposition	Food from wild macroalgae
Increase of hard substrate	Other calcifying suspension feeders	Turbine SPL	Bioirrigation	Material from wild macroalgae
Sediment Deposition	Non-calcifying suspension feeders	SPL	Bioturbation	Food from wild animals
Fining of Sediment	Macroalgae	Turbine	Calcification	Material from wild animals
scouring	Large crustaceans – commercial value	Turbine SPL	Dead shell accumulation	Genetic material from animals
Underwater Noise	Other foraging predators - invertebrates	Turbine SPL	Extraction of inorganic particles	Filtration/Sequestration/ Storage/Accumulation
Electromagnetic Fields	Foraging vertebrate predators – commercial value	Turbine SPL	Flow perturbation	Nursery and habitats
Removal of abrasion	Forgaging vertebrate predators – no commercial value	Turbine SPL	Organic matter decomposition	Amelioration of eutrophication
reduced selective extraction of marine species	Microbes	Turbine SPL Sediment	Primary production (macroalgae)	Sequestration of greenhouse gasses
	Foraging scavengers	SPL	Primary production (phytoplankton)	Aesthetic experiences
	Demersal Fish-commercial value	Sediment	Reef building	Active recreation
	Demersal Fish-No commercial value	Sediment	Removal of dissolved reactive nutrients	Passive recreation
	Mobile epibenthos on sediment	Sediment	Secondary production – organisms with commercial value	Cultural resonance
	Sessile epibenthos	Sediment	Secondary production – organisms without commercial value	
	Deep-burrowing infauna	Sediment	Attraction of marine mammals	

	Shallow-living in-fauna	Sediment
	Round fish – commercial value	Water
	Round fish – no commercial value	Water
	jellyfish	Water
	Mussel Spat	Water

Following Duncan *et al.* (2015), pressures can be linked to ES supply following different types of pathways (Figure 5.1):

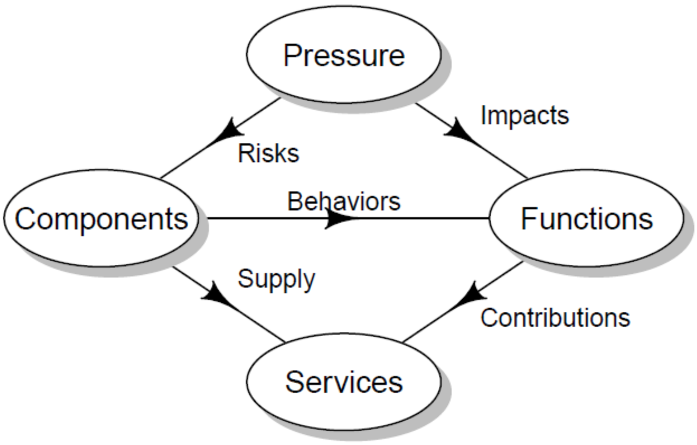

Figure 5.1. 'Diamond Diagram', linking pressures to ES following different types of pathways.

1. The Pressure – Component – Function – Service (PCFS) pathways
2. The Pressure-Components-Service (PCS) pathways
3. The Pressure-Function-Service (PFC) pathways

We reviewed 239 peer-reviewed papers and reports to score the links between the components. Given the variety of research fields to be covered, we did not perform a structured review but started the process based on expert knowledge and snowballing from the list of originally retrieved papers (Hooper *et al.*, 2017). An existing OWF-related literature study scoring system (Dannheim *et al.*, 2020) was used to score magnitude of effect size, spatial impact and degree of confidence. Effect size scores included 0 (no effect), 1 (moderate effect) and 2 (strong effect). A negative effect, i.e., in the sense of a negative correlation, was scored similarly, but on a negative scale (-2 to 0). Effect size was based on reported significance level where possible (effect in paper reported as p<0.01 scored as 'strong'; p<0.05 scored as 'moderate", p>0.05 as 'no effect), or on expert judgement when p-values were not available. Spatial scale scores were ranked as 1 (effect limited to the vicinity of turbine), 2 (OWF scale) or 3 (beyond OWF scale). Confidence scores ranged from 1 (low certainty) over 2 (no information on specific link, but based on analogue research) to 3 (high certainty, based on specific research on considered link). All scores and supporting information is available online (https://owf-pressure2service.naturalsciences.be/). The complete framework consists of 1129 pathways (Figure 5.2).

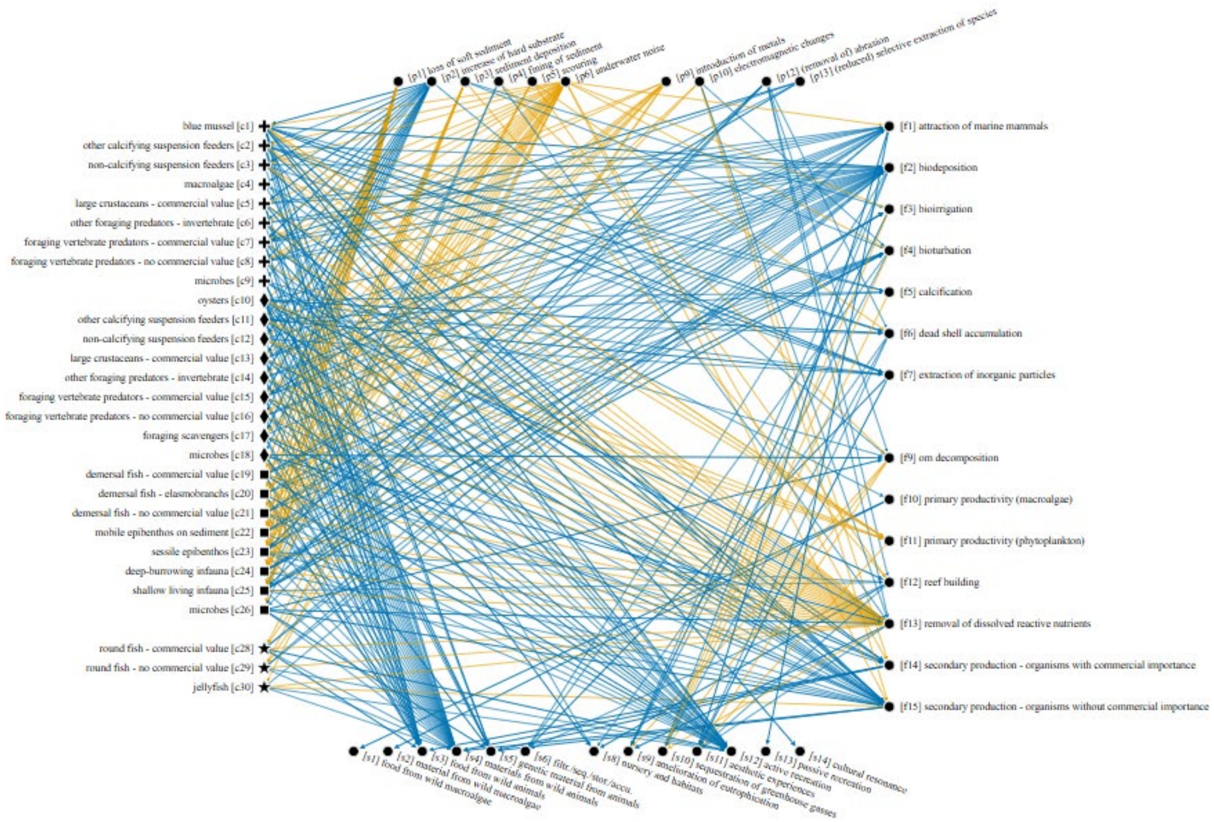

Figure 5.2. Full linkage framework linking OWF-related pressures to marine ES supply.

To allow a semi-quantitative analysis of the linkage framework, a set of linkage metrics were developed. A path score is calculated as the geometric mean of the absolute value of all links withing a path. The sign of the path score is derived from multiplying the individual path signs (Table 5.2).

Table 5.2. Examples of calculations of path effect scores and signs for hypothetical paths and associated link scores. P= pressure; C=component; F=function; S = service. Link score 1 characterizes the link from a pressure to a component. Link score 2 reflects the score of a link including a function. Link score 3 reflects the score of a link including a service. The path effect is calculated as the geometric mean of the individual scores, the path sign is derived from the product of the individual signs.

Path type	P-C-S	P-C-F-S	P-C-F-S	P-F-S	P-F-S
Link 1 score	1	-2	-2	NA	NA
Link 2 score	NA	1	1	1	1
Link 3 score	2	2	-1	1	-1
Path Sign	+	-	+	+	-
Path Effect	$(1x2)^{1/2}$=1.4	$(2x1x2)^{1/3}$= 1.58	$(2x1x1^{1/3}$= 1.26	$(1x1)^{1/2}$=1	$(1x1)^{1/2}$=1

Path collections are defined as subsets of paths sharing a common feature (e.g., involving a single pressure, component, function or ES). For each of these path collections, the path scores can be summed to estimate the contribution of the collections to the total 'weight' in the linkage framework, allowing a semi-quantitative analysis of the established network.

To facilitate the analysis of the framework, an online tool is being developed (test version: https://owf-pressure2service.naturalsciences.be/) and currently hosted at the Royal Belgian Institute of Natural Sciences. We stress that this is a beta-version that will be checked by WGMBRED members and will be adapted where needed. The tool allows the user to select pathway collections and/or confidence levels (example in Figure 5.3).

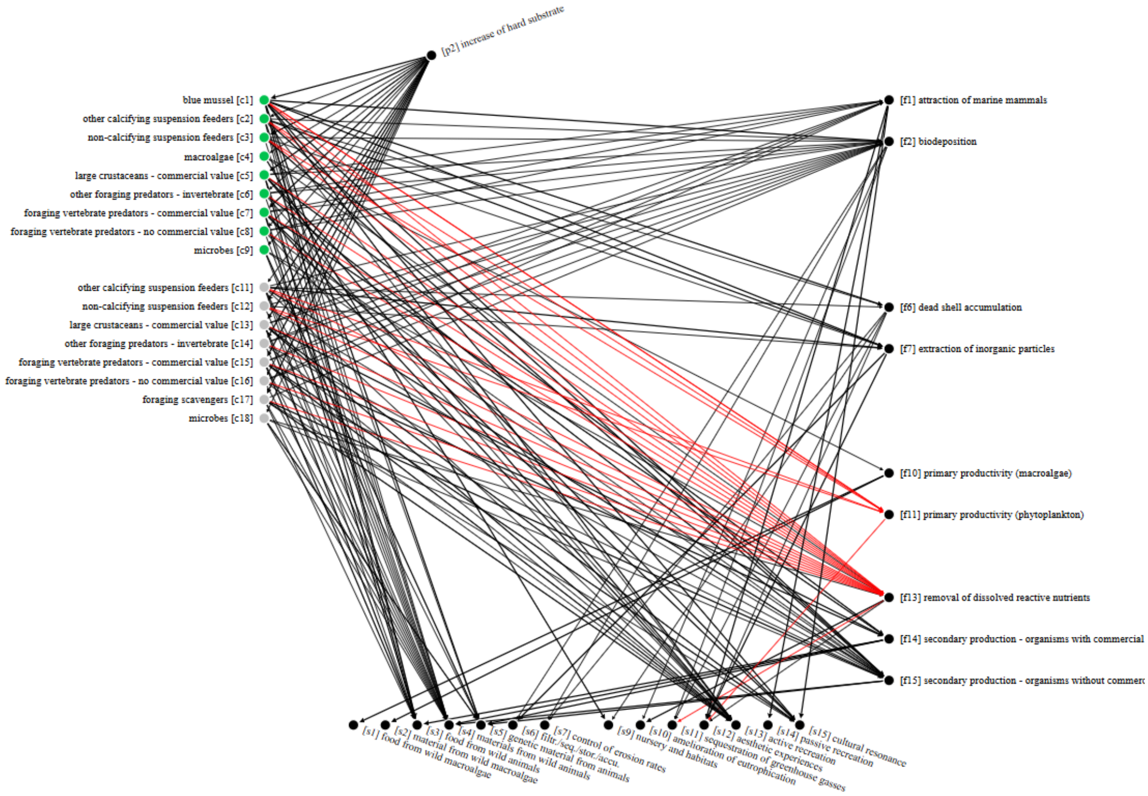

Figure 5.3. Path collection starting from a single pressure and involving all relevant components, functions and ecosystem services. Black and red links represents positive and negative links, respectively.

The tool offers additional possibilities to generate a variety of graph types (example in Figure 5.4) and download the selected data, allowing the user to analyze the data or to generate user-specific graphics (Figure 5.5).

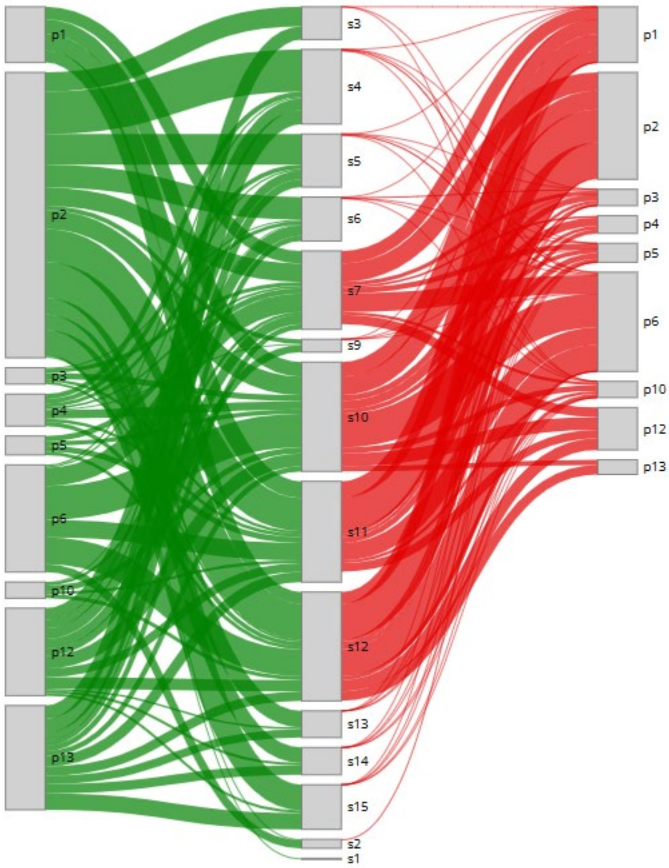

Figure 5.4. Example of graph generated by the online tool. The graphs shows the relative weight (thickness) of the path collections linking the pressures with the ES. Green pathways have a positive sign, red pathways have a negative sign.

Export data as CSV

Search

		Positive pathways						Negative pathways					
Service ID	Pressure ID	Number of paths	Mean effect	Total effect	Mean confidence	Mean area effect	Total area effect	Number of paths	Mean effect	Total effect	Mean confidence	Mean area effect	Total area effec
s3	p1	0		0.00			0.00	3	1.86	5.59	1.55	2.00	6.00
s4	p1	0		0.00			0.00	14	1.52	21.25	1.51	1.67	23.42
s5	p1	0		0.00			0.00	7	1.71	11.94	1.71	2.02	14.11
s6	p1	0		0.00			0.00	15	1.30	19.55	1.78	1.56	23.33
s7	p1	8	1.42	11.39	2.05	1.74	13.94	9	1.26	11.34	1.67	1.44	12.98
s9	p1	0		0.00			0.00	2	1.59	3.17	2.08	1.79	3.59
s10	p1	8	1.59	12.70	1.60	2.00	16.00	16	1.44	23.03	1.70	1.75	28.04
s11	p1	10	1.46	14.56	1.99	1.83	18.35	14	1.26	17.64	1.59	1.52	21.24
s12	p1	8	1.30	10.41	1.17	1.64	13.11	7	1.49	10.46	1.62	2.00	14.01
s13	p1	0		0.00			0.00	5	1.65	8.24	1.25	1.65	8.24

1–10 of 72 rows   Previous 1 2 3 4 5 ... 8 Next

Figure 5.4. Screenshot showing selected data and download option.

5.4 Future work

This ToR is considered finalized. After some further testing, the network will be analyzed and the results will be summarized in a manuscript for the peer-reviewed literature. We also intend to submit an abstract for ASC 2025. The linkage diagram, and associated tool for semi-quantitative analysis – including the knowledge base- will be made publicly available.

6 Using biological traits to assess functional effects of renewable energy devices on the marine ecosystem (ToR e)

6.1 Background

The introduction of offshore artificial structures (e.g. offshore wind farms, oil and gas platforms, etc.) induces multiple changes to the marine environment. The most prominent impact is the provisioning of new habitat (Petersen and Malm, 2006; Andersson and Öhman, 2010; Degraer *et al.*, 2020), which is rapidly colonised by fouling fauna. The community composition of fouling organisms colonising artificial structures in the North Sea differs from the natural (mainly soft-sediment-related) biodiversity, leading to changes in functional diversity and ecosystem functioning (Boutin *et al.*, 2023). The functional impacts of introducing artificial hard substrates into the marine environment are mediated by the activities of the fouling fauna that colonises them. Assessing the generality of these effects requires research based on functional biological traits since the functional trait-based approach may address a wide range of ecological issues, including human impacts (Boutin *et al.*, 2023).

Biological trait analysis (BTA) is a method introduced to describe ecological functioning (Dolédec and Statzner, 1994). It employs a range of life history, morphological and behavioural characteristics of species within assemblages as proxies for their ecological roles. This approach moves beyond merely identifying taxa within communities and instead emphasizes their contributions to ecosystem functioning (Bolam *et al.*, 2016). Additionally, because taxonomically distinct organisms can share similar biological traits (Clare *et al.*, 2022), BTA can be applied across various taxonomic groups. This flexibility makes this method suitable for use across broad geographical scales where species composition gradients challenge traditional species-based approaches (Bolam *et al.*, 2016).

The working group understood the need for a BTA approach to better understand the impacts of marine renewable energy devices on the ecosystem functioning and, therefore, created a dataset on functional traits of the taxa occurring on artificial structures.

6.2 Objectives

This term of reference had as aim to review the available literature on biological functional traits of fouling taxa occurring on artificial structures in the southern North Sea.

6.3 Methods

To reach our objective, we first created a taxa list with taxa occurring on artificial hard substrates in the southern North Sea as they are inserted in BISAR (Dannheim *et al.*, 2025). Taxa occurring on offshore wind farms in Denmark, Germany, the Netherlands and Belgium, as well as taxa from oil and gas platforms and one natural reef in the Netherlands were included in our analysis. After we acquired our taxa list, we assembled information on functional traits by reviewing the existing literature. Based on our research, we decided to collect functional trait data on the genus level since (a) entries at the genus level account for any variation in trait expression present at the species level, while entries at the family level capture variation occurring at both genus and species levels, (b) members of the same genus generally exhibit consistent trait expression for the categorical traits, and (c) apparent interspecific differences can often be attributed to context-specific trait expression shared across all members of a genus (Clare *et al.*, 2022).

Furthermore, we conducted a trait selection to get traits that would provide us with information on how offshore artificial structures can influence the wider marine environment. We, therefore, chose six traits: (1) feeding mode, (2) larval development, (3) production/biomass (P:B) ratio, (4) body shape, (5) longevity, and (6) living habit (Table 6.1). Each taxon from our list was assigned to one or more trait modalities based on the fuzzy coding approach (Chevene *et al.*, 1994), since taxa can exhibit diverse behaviours depending on the specific conditions and available resources (Bolam *et al.*, 2016). We used the biological traits dataset originally published by Clare *et al.*, (2022) as a baseline for data collection and adapted it and extended for the offshore structures included in this analysis.

We noticed that mainly infauna taxa have been investigated for their biological functional traits, making the search for trait information for epifauna taxa more challenging. In the cases where we could not find any information on one or more of the selected traits for a specific taxon, we left the cells blank. Since some traits/trait modalities seemed to be explicitly defined to describe infauna, we created our own definitions that fit better to epifauna taxa. This was to be able to explain better how fouling epifauna could further impact its surrounding environment.

Table 6.1. Traits and trait modalities used in the present study, as well as relevance of the traits to the study.

Trait	Trait modalities	Relevance to the study
Feeding mode	Suspension Deposit Scavenger Predator Parasite	Provide information on how taxa on artificial structures feed, and thus whether they would affect the wider marine environment by consuming particles from the water column.
Larval development	Pelagic planktotrophic Pelagic lecithotrophic Non-pelagic	Larvae that can disperse farther away and for a longer period of time can easier be attached on new substrates, such as offshore wind farms (i.e. pelagic planktotrophic), while larvae with limited or no pelagic phase can disperse for a limited amount of time (i.e. pelagic lecithotrophic) or not at all (i.e. non-pelgic).
P:B ratio	0 - 1.58 1.59 – 2.46 2.47 – 3.45 3.46 – 5.20 > 5.20	This is a valuable trait for assessing productivity in different organisms, comparing growth strategies across species and understanding ecosystem-level energy dynamics.
Body shape	Erect and flexible Erect and non-flexible	Provides information as to whether a taxon can provide substrate for other taxa to attach

	Tube-building Encrusting and flexible Encrusting and non-flexible Other	on and what type of substrate that would be.
Longevity	< 1 year 1 – 3 years 3 – 10 years > 10 years	This trait shows for how long a taxon can potentially colonise a hard substrate.
Living habit	Free-living Crevice-dwelling Tube-dwelling Burrowing Epi-endozoic or epi-endophytic Attached to a substrate	Provides information on the mode of living, showing which species are more vulnerable to change (i.e. attached) and which can move from the one to the other substrate easier.

Specifically, we defined body shape and its modalities to match with epifauna taxa. Body shape can provide significant information on how organisms are shaped and the way they can further influence the community composition around them. Some taxa can function as ecosystem engineers, being able to directly or indirectly alter the resource availability for other species by changing the physical properties of abiotic or biotic materials (Jones *et al.*, 2020). Having this in mind, the body shape trait is a measure to capture how a taxon can provide secondary habitat for other taxa.

Collecting all the data was a big challenge, especially because trait data are mainly available for infauna, leading to multiple blanks in the database. Since some traits/trait modalities are explicitly targeting infauna taxa, we created new modalities (see body shape trait), or excluded some modalities during the trait selection (e.g. surface or subsurface deposit feeding which were merged to deposit feeding).

6.4 Results

In total 572 taxa were included in this study. Trait information is as complete as possible, with some NAs due to the lack of relevant information in the literature.

All the trait modalities were represented across the taxa included in the database (Figure 6.1). In some traits, some modalities occurred more often compared to others. For example, there is a higher representation of suspension feeders compared to deposit feeders. Most taxa produce pelagic planktotrophic larvae, while less taxa produce pelagic lecithotrophic or non-pelagic larvae. The taxa with body shapes characterised as “other” were the most frequent, indicating that mainly taxa that do not form any type of substrate can be found on artificial hard substrates in the southern North Sea. Most of the taxa have longevities spanning from 1 to 10 years, and most of the taxa have a free moving capability.

6.5 Future work

This ICES working group recognises the importance of functional traits to understand the effects of man-made structures (or other human impacts) on the marine ecosystem. An advanced data analysis of this dataset is ongoing having as aim to compare natural and artificial hard substrates in the southern North Sea using BTA.

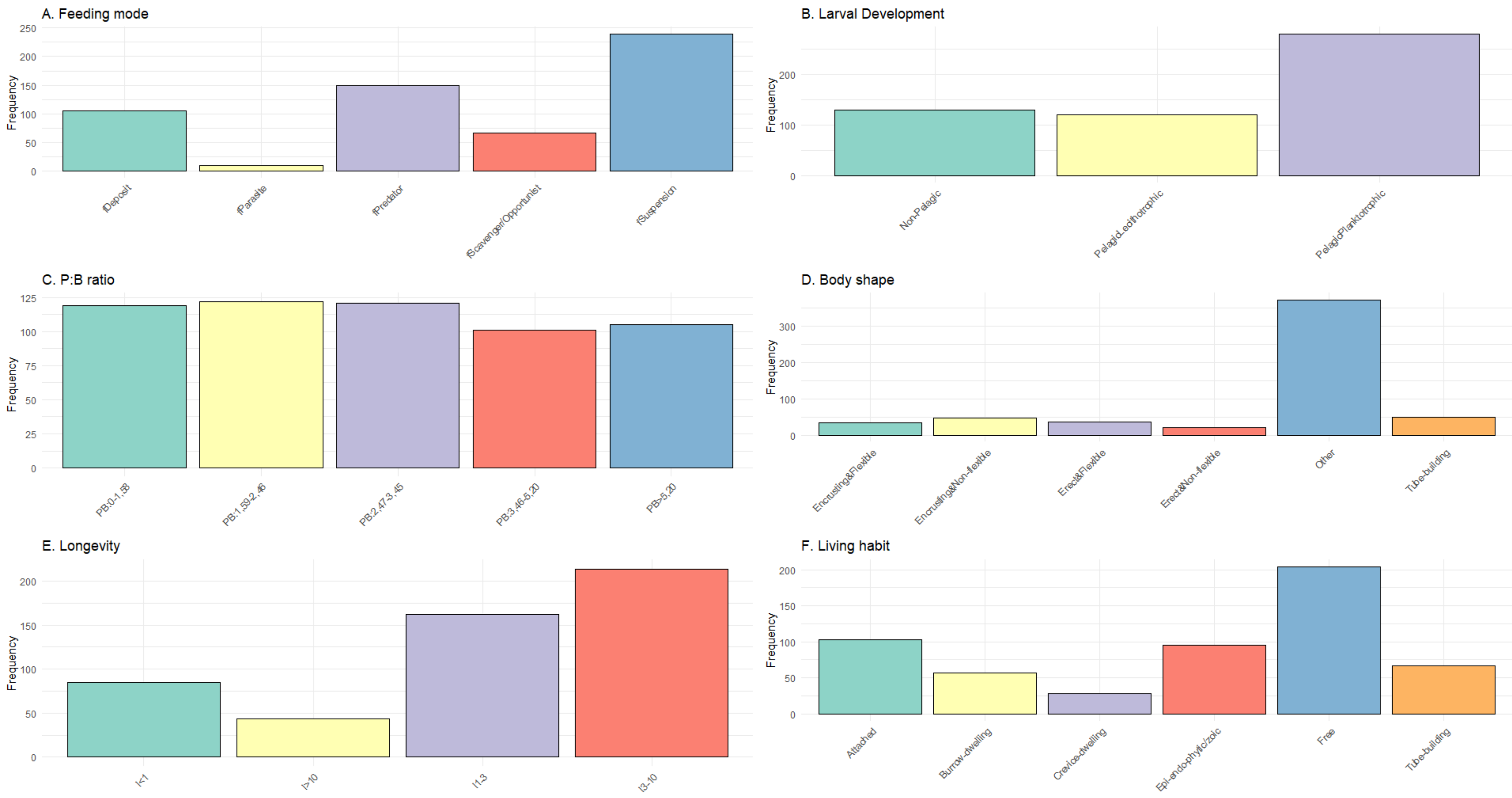

Figure 6.1. Frequency of occurrence of the different trait modalities across all the taxa included in the dataset: A: Feeding mode, B: Larval development, C: P:B ratio, D: Body shape, E: Longevity and F: Living habit.

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Annex 2: WGMBRED resolution

The **Working Group on Marine Benthal and Renewable Energy Developments** (WGMBRED), chaired by Jan Vanaverbeke, Belgium; and Joop Coolen, the Netherlands, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2022	28 November - 1 December	Den Helder, Netherlands		
Year 2023	6–9 November	Lisbon, Portugal		
Year 2024	4–7 November	Newport, Rhode Island, US	Final report by 15 December 2024 to SCICOM	

ToR descriptors

ToR	Description	Background	Science Plan Codes	Duration	Expected Deliverables
a	Review the methods for non-invasive imagery benthic data collection and interpretation methods.	WGMBRED recognises the fact that use of non-invasive assessment of the benthos of marine renewable energy devices is a valuable addition to integrated analyses of the effect of such devices on the benthos on widerspatio-temporal scales. Development of a non-invasive data (visual, acoustic) interpretation framework that promotes incorporation into ecosystem models will provide expansion of existing efforts to wider application, facilitating joint analyses and international collaboration.	3.2, 3.3, 4.4	Year 1–3	Report to ICES, reviewing existing imagery data collection, including who is collecting what data, what techniques are used, for what purposes, challenges and options for further streamlining.
b	Review the existing methods assessing the effects of energy emissions from benthal	The present knowledge base informing the effects of MRED energy emissions on the	2.1, 2.2, 2.7	Year 1–3	Manuscript to be submitted to peer-reviewed journal.

	marine renewable energy devices (MRED) to make recommendations for addressing knowledge gaps.	benthos is either lacking or patchy. The derived knowledge comes from a variety of methods (e.g. free-ranging, mesocosm, aquarium-based studies) with a diverse range of energy emission exposure characteristics which makes informed impact assessments for the receptive species difficult. Focussing on the understudied aspects of MRED energy emissions (e.g. EMF, particle motion, vibrations, heat) the group will assess the suitability of study methods used to date and their outputs. Critical reviews of methods used to assess responses to energy emissions will identify the best approaches to address the existing knowledge gaps.			
c	Develop the scientific basis to support decision making processes with regard to decommissioning of marine benthal renewable energy installations.	It is now clear that arrays of marine renewable energy installations affect structural and functional aspects of the marine environment, at both the local and regional scale. These effects largely stem from of organisms colonising the structures in large densities. Decisions on full or partial decommissioning will hence lead to a full or partial removal of these colonising organisms, and hence will modify the effect on the environment. As some of these effects are considered as ‘positive’, understanding the consequences of different decommissioning scenarios will be	2.1, 2.2, 6.1	Year 1–3	Manuscript to be submitted to peer-reviewed journal.

		important to inform future decision-making processes.			
d	Review the methodology to assess the role of benthos associated with benthal marine energy devices on the provisioning of ecosystem services to society	Marine benthal renewable energy devices serve the desire of society to combat climate change. The presence of the structures themselves, and the numerous marine organisms associated with these devices affect a set of ecosystem functions at various spatial scales, including biogeochemical cycling and food production, cascading into the provisioning of ecosystem services. WGMBRED will review the available methodology to assess the role of organisms in the biodiversity-ecosystem functioning-ecosytem services linkage and use the available knowledge base from previous WGMBRED cycles to test selected assessment frameworks.	1.3, 7.2	Year 1-3	Report to ICES on the methodoloy to assess the effct of marine benthal energy devices on the biodiveristy-ecosytem services link.
e	Review available literature on biological traits for application in assesments of the functional effects of renewable energy devices on the marine ecosystem	The functional effects of the introduction of renewable energy devices in the marine environment are channeled through the activities of the fauna associated with these devices. Assessing the generality of these effects in space and time requires research based on functional biological trait analysis. While	1.3, 2.1	Year 1-3	Report to ICES on the use of functional traits to investigate the effect of benthal renewable energy installations on ecosystem functioning

	structural response traits are available, this is not the case for functional effect traits.	

Summary of the Work Plan

Year 1	Literature compilation for all ToRs
Year 2	Structure review of compiled literature for all ToRs
Year 3	Finalise reviews and produce reports/manuscripts for all ToRs

Supporting information

Priority	The activities of the EG will provide a structural and functional understanding of how the marine benthal community of marine renewable energy devices contribute to the functioning of the marine ecosystem, and how they can act as areas where benthal biodiversity can be promoted or maintained after the lifetime of the devices. The objectives addressed for this group are therefore considered of high relevance in the context of ecosystem-based management of coastal areas where an increasing number of marine renewable energy devices are planned, while some need to be decommisioned and will be of direct use in marinespatial planning initiatives. Hence, the activities can be considered to be of very high priority. The WGMBRED work and ToRs are aligned with the ICES Science Programme and are of high priority. The WGMBRED are active contributors and aim to report their outcomes directly to ICES in their final report, Ecosystem Overviews, ICES ASC, and in parallel as peer reviewed literature.
Resource requirements	No specific resource requirements beyond the need for invited members to prepare for and resource their participation in the meeting.
Participants	The Group is normally attended by 20-30 members and guests working with the effects of marine renewable energy developments on the marine benthal communities (i.e. algae, invertebrates, and demersal fish). Participation from current ICES member countries and also from countries where marine renewable energy developments have started recently (Spain, Portugal) to develop knowledge on these activities.
Secretariat facilities	Standard EG support.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	There are no obvious direct linkages. However, some contributions could be made to ‘pressures’ section of ICES Ecosystems Overviews
Linkages to other committees or groups	There is a very close working relationship with Benthos Ecology Working Group (BEWG), the Working Group on Offshore Renewable Energy (WGORE), and the Working Group on Offshore Wind Development and Fisheries (WGOWFD)
Linkages to other organizations	OSPAR ICG-CUM