WORKING GROUP ON MARINE BENTHAL AND RENEWABLE ENERGY DEVELOPMENTS (WGMBRED)

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Contents

i Executive summary

The aim of the Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED) is to increase scientific exchange and efficiency of benthal renewable energy related research.

In 2019–2021, the group discussed guidelines for data collection and methodologies and developed an integrated example dataset on benthos data of marine renewable energy devices. This database CRITTERBASE, currently contains data from Belgium, the Netherlands, Germany and Denmark on wind farms, gas platforms and a natural reef, based on 1969 samples collected during 92 expeditions with 710 benthic taxa. This dataset will be made publicly available to serve future research on the effects of the installation and exploration of renewable energy devices in the marine environment.

WGMBRED further investigated possible positive effects of renewable energy installations, developed the scientific basis for assessing the effect of different decommissioning scenarios and reviewed the available knowledge on the relationship between renewable energy installations and the provisioning of ecosystem services. The identified positive effects of the installation of offshore energy devices is linked with the removal of pressures in light of safety issues, rather than a direct protection of the marine environment, and therefore such installations can be considered as Other Effective area-based Conservation Measure (OECM). The group identified the most plausible decommissioning scenarios and tested whether the earlier published cause-effect relationships underlying the effect of the presence of renewable energy installations can be used – after slight modification – for assessing the (partial) removal of the devices.

Along the same lines, a structural review of the biodiversity – ecosystem functioning – ecosystem service links in the context of an operational phase of an offshore wind farm resulted in a conceptual framework and available knowledge base allowing formal semi-quantitative analyses. WGMBRED will continue along these lines and use the concepts and collective knowledge base for more formal assessments of the ecological consequences of installing, operating and decommissioning renewable energy structures from the marine environment. In addition, WGMBRED will review emerging non-invasive monitoring techniques and methodology to assess the effect of energy emissions on the environment.

ii Expert group information

Expert group name	Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED)
Expert group cycle	Multiannual
Year cycle started	2019
Reporting year in cycle	3/3
Chair(s)	Jan Vanaverbeke, Belgium
	Joop W.P. Coolen, the Netherlands
Meeting venue(s) and dates	12-15 February 2019, Brussels, Belgium, 19 participants
	20-23 April 2020, online meeting, 21 participants
	8-11 March 2021, online meeting, 27 participants

1 Background and scoping of the group's work

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

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 deliver numerous ecosystem services (such as marine biodiversity, long-term carbon storage and natural resources), 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 45 scientists from many European countries and North America (Figure 1.1). WGMBRED meets annually and meetings are hosted at one of the members institute, aiming to visit a new country each year. Group members cooperate in research projects, by data exchange and in joint scientific publications.

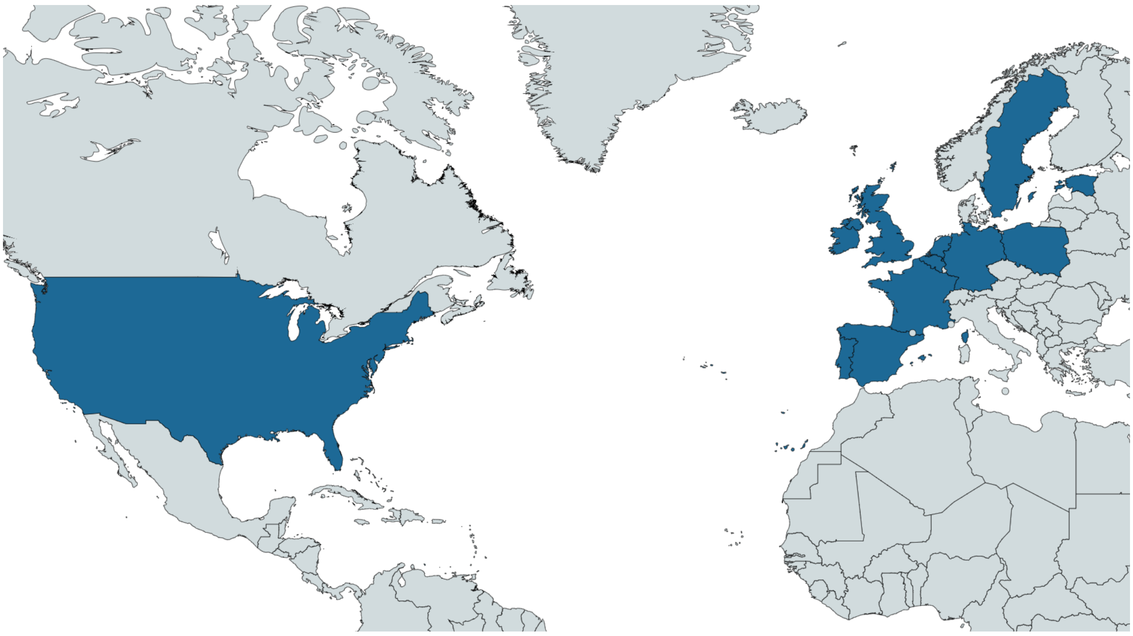

Figure 1.1. Overview of all counties with WGMBRED members (in blue).

2 Guidelines for data collection, methodologies, and integrated example dataset on benthos data of marine renewable energy devices (ToR a & b)

2.1 Background

The working group recognised that various organisations were collecting data on benthal communities at different sites, using similar but not identical methods. For example, scrape samples from the hard surfaces of offshore energy structures, have been collected via nets, plastic bags, and airlift samplers, and then processed in the laboratory to attain e.g. counted individuals, cover percentages, cover in cm^2, presence/absence records, identified to species, genus, family level, *et cetera* (Krone *et al.*, 2013; De Mesel *et al.*, 2015; Coolen *et al.*, 2020a, 2020b).

Furthermore, these data were stored using different systems, at open access sites or on organisation servers inaccessible to others. Some data had never been published before and no intention existed to publish the data (personal observations Joop Coolen, Wageningen Marine Research).

Therefore during meetings of the working group, it was decided to start exchanging data between the different members via a joint database with the long term intention to perform joint meta-analysis and publish findings at higher levels than possible using single datasets. The initiative was led by Jennifer Dannheim from AWI and Joop Coolen from Wageningen Marine Research.

2.2 Aims

The initiative had two aims:

1) To create a joint database capable of ingesting data collected by working group members, allowing comparison of the data and joint data analysis (ToR b).
2) To learn from the experience with the database, assess whether the database could be further optimised to facilitate joint data analysis and provide a prioritisation of variables that could be collected by the members in their scientific research to facilitate joint data analysis (ToR a).

2.3 Methods

In the 2019 group meeting, Jennifer Dannheim presented the CRITTERBASE system that was being developed at AWI and suggested it was a good opportunity for the group to exchange data. CRITTERBASE is a data-warehouse on marine benthos. As a biological information system it provides quality-controlled and taxonomically standardised occurrence and biomass data of benthic species. Data quality controls are unique compared to other information systems and are thus major components of CRITTERBASE. The quality management ensures high quality standard of imported data. This includes basic quality components such as the data model itself but also several routines (i.e. related to taxonomic information, logical checks on data scenarios related to sampling areas and occurrence/abundance of data) that detect and flag mistakes by a number of logical checking routines before, during and after data import. It was agreed to use the CRITTERBASE facilities and perform a test by ingesting data collected from oil and gas installations, rocky reefs, and wind turbine foundations in the Netherlands (Coolen *et al.*, 2020a) and evaluate the process of data preparation and ingestion. This was performed intersessionally and results were presented during the 2020 meeting. Based on the experience, the ingestion template was improved, and additional datasets collected in Belgium (De Mesel *et al.*, 2015), the Netherlands (Coolen *et al.*, 2020b), Germany (Krone *et al.*, 2013; Schröder *et al.*, 2013; Gutow *et al.*, 2014) and Denmark (Leonhard and Frederiksen, 2006) were collected intersessionally before the 2021 meeting.

In the 2020 meeting, the group discussed the variables that were present in CRITTERBASE with the aim to identify variables that might be important for MBRED related research but missing from CRITTERBASE. Any variable that was missing and potentially important, was added to a long list of all variables present in CRITTERBASE. Within the long list, variables related to station code, sample number, sampling gear type, sampling coordinates, date, sampled area and scientific name of the sampled species were marked as essential. These variables were not scored in the next exercise performed by the group: The long list was then scored by each member independently, by valuing every variable as either 2 (very important), 1 (important) or 0 (not important). All long lists were then combined, and total scores calculated for each variable in CRITTERBASE as well as for each variable suggested by the group.

2.4 Results

After ingestion of all data from Belgium, the Netherlands, Germany, and Denmark CRITTERBASE contained 748 stations with 1969 samples collected during 92 expeditions, 710 benthic taxa which were found in seven windfarms, at one research platform, at nine oil and gas rigs and one natural reef (Borkum reef).

CRITTERBASE contains customised templates for data import and links directly to WoRMS (www.marinespecies.org, Figure 2.1) for taxonomic quality control. The ingestion of data contains several quality management steps in order to harmonise and standardise data. The database is SQL-based on the PostgreSQL programme and will be linked to web services (under development). Exploration tools are under development, but extraction of data for our purpose was already developed (see Figure 2.1 data download for own scientific analysis).

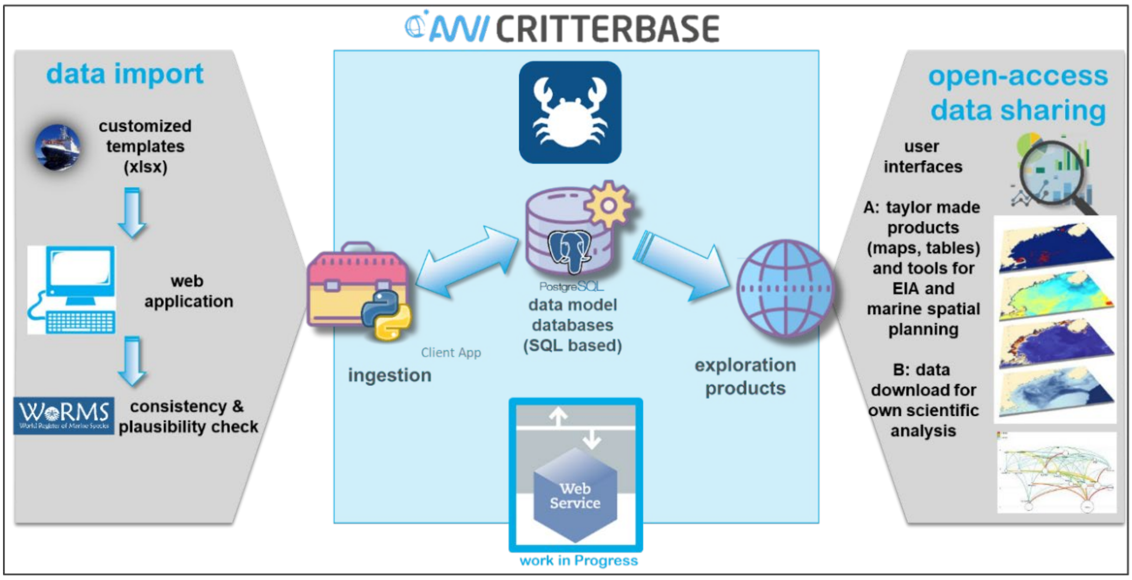

Figure 2.1. Presentation of functions and workflow of the biological information system CRITTERBASE, showing the data import routines with taxonomic quality management linked to WoRMS, quality management of data ingestion with Python, the data model developed in PostgreSQL and exploration and data sharing of products by user interfaces.

The WGMBRED international joint database will be published open access together with a data paper.

Ingesting the data into CRITTERBASE was a bigger challenge than expected. The combination of different datasets, deriving from many countries, having been processed by different people using multiple methods was laborious. Furthermore, scientists from different countries, institutions, and fields (e.g. IT, biology, taxonomy) often define stations, subsamples, *etc*. in different ways, which resulted in multiple discussions about how to follow the CRITTERBASE structure and its rules.

After ingesting all the data into CRITTERBASE, data exploration was conducted by three scientists working on different research questions. These scientists identified missing information that could be ingested in CRITTERBASE and facilitate multiple research studies. Examples of information that have not been incorporated into CRITTERBASE yet include: (a) the age of the structures during sampling, which can be useful for community succession studies; (b) the type of platform sampled, e.g. offshore wind farm, oil and gas platform; (c) the type of foundation from which samples were collected, e.g. jackets, monopiles, gravity-based foundations, which might have different community compositions; and (d) the size of the rocks of the scour protection layer that were sampled or from which scraped samples were collected. The country of origin of the samples is currently included in a separate sheet in CRITTERBASE, while it should be integrated within the raw data to facilitate the data analysis.

The group discussions of the variables missing in CRITTERBASE resulted in an addition of 22 variables to the long list (Table 2.1). Since CRITTERBASE was designed to ingest data from benthic monitoring programmes, the initial list of variables already included any essential variable for this type of research. WGMBRED related variables that were added by the group included distance to the nearest structure, where seabed samples were taken around an installations, age of the structure that was studied, electromagnetic field levels, structure type, substrate type and surface orientation.

Table 2.1. Variables added to the scoring long list by WGMBRED members, with name, description, and score (percentage of maximum possible score), variables ordered by decreasing score.

Name	Description	Score %
Distance to nearest structure	Distance to nearest structure (AR, Turbine, platform etc.)	97%
Structure material artificial	e.g. steel, concrete, scour protection	94%
Structure type artificial	e.g. platform, wind turbine	94%
% coverage of attached species	Determined visually	83%
Orientation of sample	e.g. horizontal, vertical, diagonal, ceiling (up-side-down)	75%
tracks, trails, burrows	description of biological bed features from visual data collection	69%
Turbidity bottom water	Turbidity of sea water near seabed	67%
Chl-a bottom water	Chl-a concentration of sea water near sea bottom	64%
Grain size major mode	Grain size major mode estimated from SPI image	61%
EMF level	Magnetic field level at defined distance from subsea cable (also electric field level) - sea bed surface often most relevant for benthic species	58%
Sound level	Received level of sound by receptor (measured as Sound Pressure level and/or Sound particle motion level for most benthic species) - [SPL expressed in units of decibels relative to 1 μPa, or alternatively dB re 1 μPa., for animals that detect sound pressure]	58%
bedforms	description of bedforms from visual data collection	56%
aRPD	Depth of apparent Redox Potential Discontinuity collected with SPI	56%
Chl-a surface water	Chl-a concentration of sea water near water surface	56%
Water current direction bottom water	water current speed near seabed	53%
Water current speed bottom water	speed of water current above the sediment	53%
Turbidity surface water	Turbidity of sea water at water surface	50%
Successional Stage	Successional stage cf. Pearson and Rosenberg determined with SPI	47%
Methane bubbles	Number of methane bubbles in SPI image	44%
Age	Age of the organism, determined by otolith or vertebrae inspection	42%
Water current speed surface water	speed of water current at sea surface above the sediment	36%
Water current direction surface water	water current speed near water surface	28%

The scoring by the group showed that the experts valued MBRED specific variables very high. The following variables all scored at least 90% of the maximum score:

- Sampling depth
- Distance to nearest structure (variable not in CRITTERBASE)
- Structure type of the installation under study (monopile / gravity based / jacket structure; variable not in CRITTERBASE)
- Structure material of the installation under study (steel / concrete / rocky scour protection; variable not in CRITTERBASE)
- Sieve mesh size
- Number of individuals per species in sample, with sub sample factor
- Biomass weight (in variable forms such as wet weight, dry weight, ash free dry weight

Three of these highest scoring 7 variables are currently not present in CRITTERBASE and could be considered an important extension to the database.

3 Assessing the potentially positive ecological interactions of Marine Renewable Devices that exclude destructive fishing activities and create habitat (ToR c)

3.1 Background

By introducing structure into marine environment, offshore Marine Renewable Energy installations, which exclude bottom towed fishing have the potential to aid the recovery of degraded seabed habitats and deliver a range of ecosystem services (Gill 2005, Inger *et al.*, 2009, Witt *et al.*, 2011, Sheehan *et al.*,2018). This *de facto* Marine Protected Area (MPA) effect was explored by the working group, who recognised that other offshore Blue Growth industries could also have wider ecosystem benefits, such as offshore bivalve and seaweed mariculture (Sheehan *et al.*, 2019, Mascorda *et al.*, 2020). This effect could also be formally acknowledged as an OECM. OECM stands for Other Effective area based Conservation Measure. Sites that deliver marine protection that increases biodiversity unintentionally that are not designated as an MPA. Listed alongside MPAs in Aichi Target 11, governments can claim OECMs along with MPAs as part of their 30% seas protected by 2030 commitment (Global Ocean Alliance: 30 by 30 UK led commitment). In cases like offshore Marine Renewables and offshore Mariculture, by introducing structure and food, they will arguably be more effective at protecting areas of seabed than those MPAs where trawling is still permitted. Organisations such as IUCN, CBD and ICES are in the process of testing international OECM guidance (Garcia *et al.*, 2020) as part of a workshop WKTOPS (https://www.ices.dk/community/groups/Pages/WKTOPS.aspx). WGMBRED members joined this workshop to formally link this working group and the aims of ToR c and presented the only case-study to consider whether Blue Growth industries could be considered an OECM. The resulting publication will inform the development of ToR c and is due to be published in May 2021.

During the meetings of the working group, it was decided to write an evidence-based opinion piece on the potential positive ecological interactions of Blue Growth industries with a focus on offshore marine renewable installations. The initiative was led by Emma Sheehan from the University of Plymouth and Arjen Boon from Deltares (currently AVANS Hogeschool).

3.2 Aims

The aim of this initiative was to:

Review the knowledge on changes in the benthos associated with environments where marine renewable energy devices are located and relate them to the presence of these structures and the changes to other human activities (e.g. fisheries).

3.3 Methods

In the 2020 and 2021 group meetings, Emma Sheehan presented the group's intersessional progress on the writing of a report for ToR c. The group collaboratively scoped a paper for submission to the ICES Journal of Marine Science for consideration as a "Food For Thought" article. They agreed the key sections of the paper, content, and co-authors. With the help of Emma's research fellow, Pete Davies, the target of the group is to submit the manuscript by September 2021.

4 Develop the scientific basis for assessing the conservation of benthic habitats beyond the exploitation phase of marine renewable energy installations (ToR d)

4.1 Introduction

In 2015, Lindeboom *et al.* concluded that the overriding lesson from more than a decade of monitoring of environmental impacts of European offshore wind farms (OWFs) is that OWFs do change the local environment. These changes span all ecosystem components, and some can be regarded as (potentially) undesirable, e.g. avoidance and collisions of birds and some (potentially) desired, e.g. increased biodiversity and enhanced local fish populations (e.g. Wilhelmsson *et al.*, 2010; Lindeboom *et al.*, 2011; Bergström *et al.*, 2014). To enable distinguishing between desired and undesired effects a fundamental understanding of the effects is needed. Contrary to basic monitoring, targeted monitoring and research as adopted by the Belgian WinMon.BE and the Dutch WOZEP programs, directly contribute to such understanding by investigating the underlying ecological processes (or cause-effect relationships) behind (a selected set of) observed impacts (Hutchison *et al.*, 2020).

Much is already known about the cause-effect relationship at the basis of OWF effects, as reviewed for the benthos by Dannheim *et al.* (2020). They identified the cause-effect relationships between different activities related to OWF construction and operation, and three impact types of societal relevance, i.e. impacts on biodiversity, food resources and biogeochemistry, comprising abiotic and biotic ecosystem features and their interactions. The science-base for each of these cause-effect relationships is elaborated in their supplementary material.

While Dannheim *et al.* (2020) covered the impacts of activities related to OWF construction and operation, they did not cover the impacts of activities related to decommissioning. However, OWFs are temporary constructions most often allowed to occupy marine space only for a limited period of time after which they are to be decommissioned (Birchenough and Degraer, 2020). In the Northeast Atlantic, the present-day commitment under the OSPAR Convention is to fully remove the OWFs when they are decommissioned. However, derogations from the general principle of complete removal may apply.

The expected ecological effects of removal practices comprise, e.g. the removal of the established artificial hard substrate community, elevated turbidity, elevated underwater sound and/or an increased risk of ship collisions and pollution, which are considered to be detrimental to marine ecosystems (Birchenough and Degraer, 2020). On the other hand, the removal of OWFs will allow restoration of the natural habitat, reversing the artificial reef effect, but at the same time also the protection by the *de facto* fisheries exclusion. A new challenge hence is the planning of decommissioning scenarios for OWFs. This will have to be judged by whether it is e.g. environmentally beneficial to apply derogation (e.g. "rigs-to-reefs"), or to partially or completely remove these structures. To date, there are substantial gaps in the knowledge base needed to support science-based decisions on this topic. These knowledge gaps include how the (partial) removal of the artificial reef and fisheries exclusion effect may further affect the marine ecosystem.

4.2 Objective

Our study targeted the assessment of what effects of OWFs will change during and after decommissioning under different scenarios of decommissioning, taking account of the new baseline.

The following definitions were adopted for the sake of this initiative:

- Decommissioning: a formal process to remove something from an active status (Wikipedia) (for our purpose "to remove" is widened to from leaving the structure in place over redevelopment to full removal)
- Change: no longer take place, strengthen/weaken, or even newly show up
- Baseline: the ecosystem as it has developed with the OWFs in place

Note that to tackle what effects of OWFs will change during and after decommissioning, as is targeted in this study, does not equal to tackle what the direct effects of decommissioning are. In practice, we analysed for a selection of decommissioning scenarios:

- What cause-effect relationships (CERs) are likely to disappear?
- What CERs are likely to change in effect size (in space and time)?
- What CERs are likely to newly appear?

4.3 Research strategy

First, we identified realistic decommissioning scenarios, after which we revisited the CERs as described in Dannheim *et al.* (2020). Decommissioning scenarios were based on an interview with Vanessa Spielmann (Hohschule Bremen) engaged in a German project investigating decommissioning scenarios for OWFs, and a discussion within WGMBRED. Revisiting the Dannheim *et al.* (2020) CERs comprised (1) the qualitative identification of obsolete and missing activities and CERs during decommissioning and after decommissioning, and (2) a quantitative (i.e. effect size and direction) assessment of change of CERs. During this exercise we have only tested the applicability of revisiting the CERs (i.e. proof-of-concept) without executing a comprehensive analysis of change which will be done in a next step. Proof-of-concept exercises were executed for the partial decommissioning scenario and two impact types, i.e. impacts on biodiversity and impacts on food resources. The comparison made is from the pre-decommissioning baseline to the post-decommissioning status 5 years on. Therefore, the deconstruction activities were not under consideration at this time. Additionally, we only considered the effects in relation to a single turbine, not the whole wind farm and only wind farm related effects, not those relating to the use of the space after decommissioning.

4.4 Results

Decommissioning scenarios

Four decommissioning scenarios were considered representing realistic future decommissioning strategies: (1) do nothing, (2) partial removal (leave the lowest 5 m in place, incl. scour protection layer and cable), (3) full removal (turbine cut below the seafloor, scour protection layer and cables removed), and (4) redevelopment (construct new wind farm at same lease area, with full removal of old wind turbines). Only the first three scenarios were further considered in this study because the fourth scenario will ultimately lead to the same CERs as in Dannheim *et al.* (2020) (Figure 1).

The removal of monopiles will likely happen making use of jack-up vessels similar to the ones used for piling activities. Removal will take place after the monopiles are cut loose about 1 m below the sediment surface either by water jet cutting (high pressure water jet mixed with sand; most likely scenario) or diamond sawing from the inside of the monopiles or the use of targeted (fine-scale) explosives. To cut the monopiles, sediments need to be flushed from around the turbine to get access to ~1 m below seabed with consequent impacts on suspended matter concentrations in water column and on the surrounding scour protection layer (cf. flushing will most likely affect the full extent of the scour protection layer). No information on how to remove gravity-based foundations is available as yet, but it is evident that prior to removal, the sand added to achieve "gravity" will have to be taken out and deposited somewhere prior to removal of the structure, increasing suspended matter concentrations in the water column. The removal of the scour protection layer (not applicable for jacket foundations) will be executed making use of caterpillars (see e.g. Goliath Van Oord) which will impact suspended matter concentrations in the water column. The removal of cables will be done by "reversed" cable laying vessels, pulling cables out instead of digging in after the end of the cable has been freed from the sediment. Some dredging may be or is needed to free up the end of the cable, including a possible removal of the scour protection layer. Deviation from this methodology is expected at locations of cable crossings. Shipping during (partial) removal works are likely going to be similar to what may be expected during construction works.

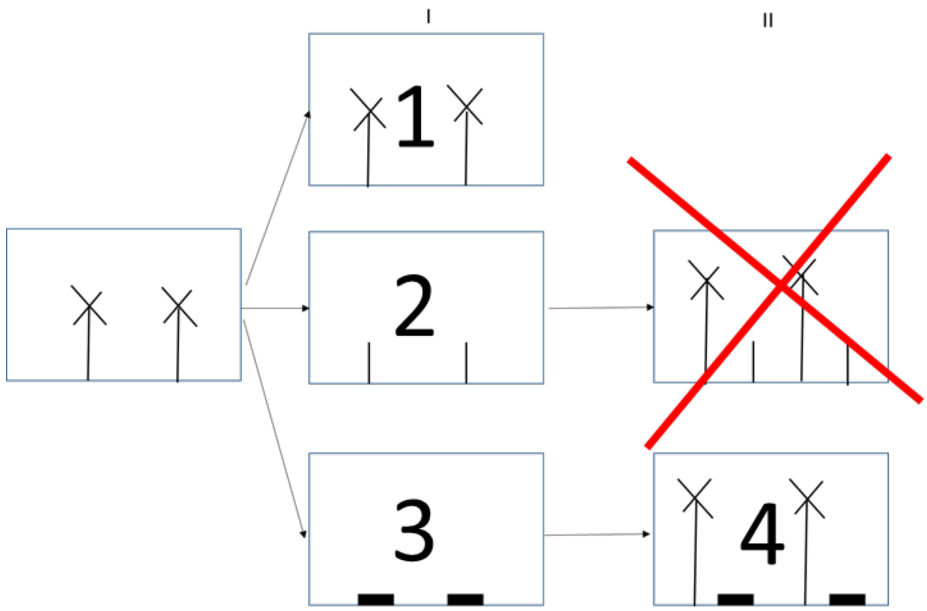

Figure 4.1. Illustration of the four decommissioning scenarios as analysed in this study.

Revisiting Dannheim *et al.* (2020) cause-effect relationships: proof-of-concept

Both proof-of-concept exercises demonstrated the anticipated methodology worked and hence is worth pursuing (draft technical reports available upon request). For all CERs, both proof-of-concepts succeeded in addressing the questions whether CERs changed (0/1) and if yes, in what direction (+/-) and how much (--/--/0/+/++).

Considerations relevant for future work are:

- The questions of realism of making assessments of the CER when not considering the use of the space after decommissioning, e.g. change in fishery use or shipping/transport routes.

- The comprehensiveness and correctness of literature documenting that requires checking.
- That some CER pathways were described in the main text of Dannheim *et al.* (2020), rather than the supplementary material.

4.5 Suggestions for future work

With proof-of-concepts having been successful, we propose to run the full assessment of decommissioning effects in a next cycle of WGMBRED.

5 Review and provide an empirical overview on the role of benthos associated with marine renewable energy devices in the maintenance of important ecosystem processes (ToR e)

It is now accepted that human activities at sea affect the provisioning of ecosystem services in direct and indirect ways and through multiple – cascading – pathways), including effects on biodiversity and ecosystem functioning (Duncan *et al.* 2015, Figure 5.1).

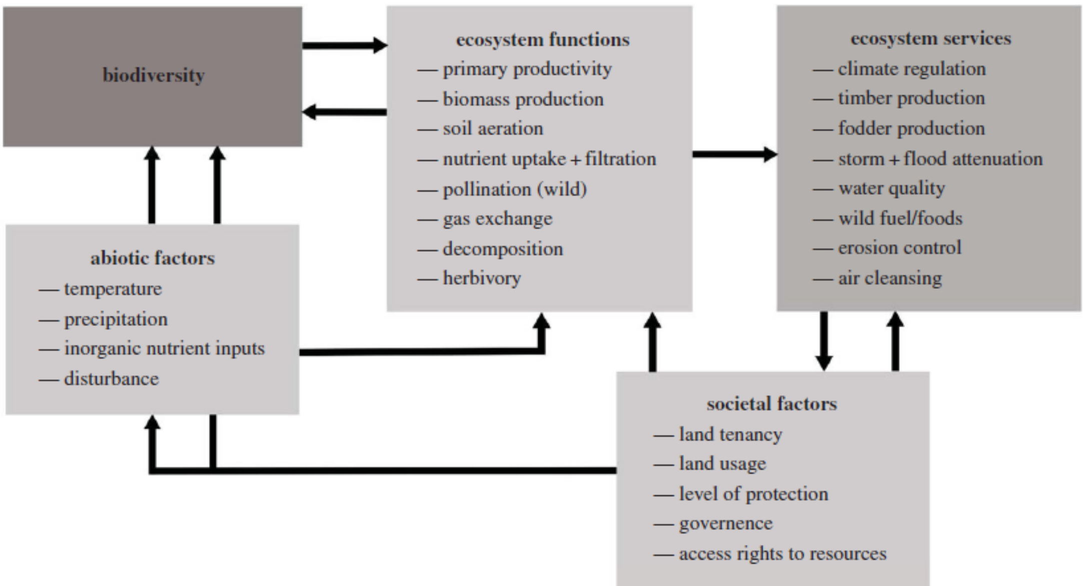

Figure 5.1. Schematic of the complex linkages involved in the consequences of human activities (societal factors) in the provisioning ecosystem services (Duncan *et al.* 2015).

Currently, the bulk of marine renewable energy is delivered by offshore wind farms (OWF), which are abundantly present and proliferating in Europe and are gaining momentum in other continents as well (https://www.4coffshore.com/offshorewind/). Therefore, WGMBRED decided to use offshore wind farms as a model to review the effect of benthos associated with renewable energy installations on ecosystem processes. As the effect of the presence of OWFs on the marine environment can be location dependent, the model OWF was defined as a an OWF consisting of monopiles and associated scour protection layers, situated in a sandy environment (no presence of natural hard substrates in the vicinity) in a fully mixed water column thereby reflecting the situation in many of the currently operational coastal OWFs in European waters.

In order to guide the review of the role of benthos in the OWF-Ecosystem processes, the conceptual diagram suggested by Duncan *et al.* (2015) was adapted towards an operational concept (Figure 5.2).

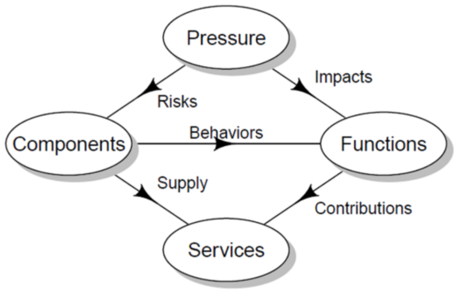

Figure 5.2 Diagram showing relations between pressures, components, functions and ecosystem services associated with the exploitation phase of offshore wind farms.

Adapting the EU Marine Strategy Framework Directive, operational OWF induce certain pressures on the environment, which can either directly act on the organisms ('Components') or affect ecosystem functions ('Functions). 'Components' or 'Functions' then affect the provisioning of ecosystem services ('Services').

The organisms affected by OWF both live on the turbines or scour protection layer, or inhabit the surrounding water column or soft sediment (Degraer *et al.* 2020). To facilitate detailed analyses in the future, organisms from all domains were included in the review.

A full understanding of the role of benthos required a detailed understanding of the relevant ecosystem services and ecosystem functions/processes cascade. Following Armoškaitė *et al.* (2020), the generic Common International Classification of Ecosystem Services (CICES, https://cices.eu/) was adapted to facilitate an OWF-oriented assessment of the role of benthos in ecosystem service provisioning, resulting in 12 relevant ecosystem services (Table 5.1).

Table 5.1. Relevant OWF-associated ecosystem services and associated ecosystem service sections (modified from CICES).

Ecosystem Service Section	Ecosystem Service
Provisioning (biotic)	Food from wild macroalgae
Provisioning (biotic)	Material (i.e. fibres) from wild plants
Provisioning (biotic)	Food from wild animals
Provisioning (biotic)	Material from wild animals
Provisioning (biotic)	Genetic material for maintaining a population
Regulation and maintenance (biotic)	Filtration, sequestration, storage by wild plants and animals
Regulation and maintenance (biotic)	Control erosion rates
Regulation and maintenance (biotic)	Hydrologic cycle and water flow regulation
Regulation and maintenance (biotic)	Maintaining nursery populations and habitats
Regulation and maintenance (biotic)	Sequestration of carbon and other greenhouse gasses
Regulation and maintenance (biotic)	Amelioration of eutrophication
Cultural (biotic)	Enabling aesthetic experiences

In a next step, ecosystem processes were specified as the result of complex interactions between biotic (living organisms) and abiotic (chemical and physical) components of ecosystems through the universal driving forces of matter and energy, whereas ecosystem functions were defined as capacity of natural processes and components to provides and services, either directly or indirectly (de Groot *et al.* 2002). Based on expert judgement, relevant ecosystem processes and ecosystem functions were determined (Table 5.2).

Table 5.2. Relevant ecosystem processes and functions affected by the presence of OWF.

Ecosystem process	Ecosystem function
Biomass production	Primary productivity
Biomass production	Secondary productivity
Biomass production	Attraction
Organic Matter Transformation	OM decomposition and removal
Organic Matter Transformation	import/export OM
Organic Matter Transformation	deposition of OM
Inorganic Matter Transformation	Extraction of inorganic particles
Ecosystem metabolism	O2 consumption
Ecosystem metabolism	C mineralisation
Nutrient Cycling	nitrogen removal
Nutrient Cycling	nutrient excretion
Nutrient Cycling	phosphorous removal
Nutrient Cycling	nitrification
Nutrient Cycling	denitrification
Nutrient Cycling	nitrogen fixation
Nutrient Cycling	exchange of limiting nutrients (i.e. silicate)
Allogenic engineering	bioturbation
Allogenic engineering	bioirrigation
Allogenic engineering	biodeposition
Habitat Creation	reef building
Habitat Creation	flow perturbation
Habitat Creation	sedimentation
Habitat Creation	dead shell accumulation

Finally, a list of relevant pressures was identified through adaptation of pressures identified according to the Marine Strategy Framework Directive. While generally, pressures are perceived as having a 'negative' impact on the environment, some of these pressures are removed from an OWF environment as certain human activities with associated pressures (i.e. bottom trawling) are not allowed in OWF due to safety regulations

In order to assess the role of benthos ('components' in Figure 5.2) in the linkage chain, a set of linkage matrices were compiled summarizing effect magnitude and spatial extent according to pre-defined scoring criteria. Scoring criteria were based on Environmental Impact Assessment procedures where magnitude scales are used within impact evaluation and prediction matrices the following table and definitions for magnitude are suggested:

Magnitude is defined as a qualitative/semi-quantitative measure of the level of change expected or demonstrable (via literature) to cause benefit/enhancement of ecological component, process, or function (+ve) or dis-benefit/hindrance of the defined ecological component, process, or function (-ve).

Table 5.3. Scoring criteria for 'Magnitude of the effect'.

Magnitude score (Code)	Magnitude of effect or change definition
+2	Moderate to large positive effect on ecological component, process, or function
+1	Slight to small positive effect on ecological component, process, or function
0	No effect/neutral effect on ecological component, process, or function
-1	Slight to small negative on ecological component, process, or function
-2	Moderate to large negative on ecological component, process, or function

The spatial scale was scored from 1 to 3:

- 1: Local effect: turbine + scour protection layer
- 2. OWF scale : within the OWF array
- 3: regional: effect ranges outside the OWF

All scores were supported by literature. If no literature was available, expert judgement was noted downs as a statement (Hooper *et al.* 2017) and a level of uncertainty was associated to each score.

A preliminary analysis indeed reveals the central role of benthos in the OWF-ecosystem service relationships. Most pathways, linking the pressures associated with the presence of an operation OWF with ecosystem services include the ‘Components – Functions’ link (Figure 5.3) and stress the importance of detailed research along well-defined cause effect relationships rather than assessing change in biotic or abiotic descriptors of the environment in routine monitoring programmes (Wilding *et al.* 2017, Dannheim *et al.* 2020)

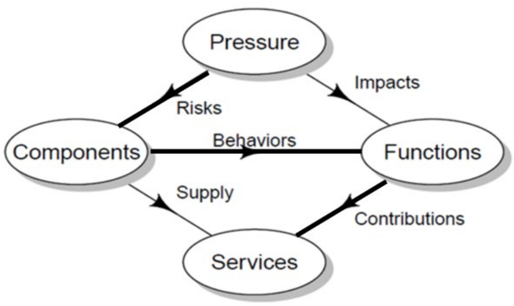

Figure 5.3 Main pathway linking OWF pressures with ecosystem services: thick arrows.

A detailed analysis of the available data is ongoing and will be submitted as a manuscript for a peer-reviewed publication. At the same time, the available dataset will support the new Terms of References of the ICES WGMBRED.

6 Review the current state and knowledge of studies into the deployment and environmental impacts of wet renewable energies and marine energy storage systems (ToR f)

This ToR was published in the ICES Scientific reports series as follows:

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6.1 Summary

This report provides an overview of the state of affairs (1) with regards to the deployment of wet renewables and (2) marine energy storage systems; (3) how they affect abiotic and biotic components of the marine ecosystem and (4) developments and concepts on cumulative impact assessments related to marine renewable energy devices and (5) future perspectives.

This report provides the scientific basis to address the OSPAR request for advice on the current state and knowledge of studies into the deployment and environmental impacts of the following wet renewable energies and marine energy storage (floating, coastal infrastructure), tidal stream (screws, kites), tidal flow (barrage, lagoon) and others. Advice should cover the status of wet renewable developments in the OSPAR region, future prospects, potential environmental problems (sea bed habitat loss/disturbance, fish, marine mammals, birds, seascape/ public perception, and cumulative impacts), potential benefits, next steps and conclusions". The request was directed towards the Working Group on Marine Benthal Energy Developments (WGMBRED) and the Working Group on Marine Renewable Energy (WGMRE).

A pre-meeting chaired by Jan Vanaverbeke, Belgium (WKWET, 15–16 January 2019) at ICES Headquarters, was attended by 11 participants from 4 countries, including members of WGMBRED and WGMRE and additional experts. The group analysed the OSPAR request, agreed on a structure for the report, and certain experts volunteered to conduct a literature review and provide the necessary knowledge base for the report.

WGMBRED met from 12–15 February 2019 in Brussels, Belgium. The input from WKWET participants was compiled, quality checked and adapted where needed; when relevant expertise was represented in the group. WKWET experts, not present at WGMBRED, reviewed text, where needed, and a first version of this report was delivered to WGMRE.

WGMRE met in Oostende (Belgium) from 26–28 February 2019. Participants reviewed the WKWET report following input from WGMBRED, quality checked, and adapted where necessary. Relevant experts contributed additional text and data to tables on MRE developments in ICES areas and provided text on public perceptions and future prospects of MRE.

This report presents an overview of the currently known "wet renewables" (all marine renewable energy devices, excluding offshore wind devices) and how their deployment will likely change in the future. It further provides an overview of the concepts and techniques of related to marine energy storage devices. Given the conceptual and experimental stage of marine energy storage devices, and the absence of data on how these devices affect the marine environment, the report is limited to a description of these marine energy storage devices.

This report provides a receptor-based summary of how the wet renewables can affect the marine environment. Receptors are either abiotic (hydrodynamics, physical seabed, and sediment transport) or biotic (benthos, fish, marine mammals, birds, sea turtles, otters, and polar bears). To avoid repetition, effects on these receptors were grouped according to pressure-inducing components (static component of the device, dynamic component of the device, cables) of wet renewables or consequences of their presence.

The report further discusses the developments on cumulative impacts assessments associated with wet renewables deployment in addition to many other human activities, and the need to move away from "data rich – information poor" monitoring of structural aspects of the marine ecosystem to hypothesis-driven functional research at the relevant spatial and temporal scales. This will require cross-border coordination in data collection, data storage and exchange and the development of a joint research agenda.

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Annex 2: Resolutions

The **Working Group on Marine Benthos 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 2019	12–15 February	Brussels, Belgium		Meeting in association with WGMRE
Year 2020	20–23 April	by corresp/ webex		physical meeting cancelled - remote work
Year 2021	8–11 March	by corresp/ webex		physical meeting cancelled - remote work

ToR descriptors

ToR	Description	Background	Science Plan codes	Duration	Expected Deliverables
a	Develop guidelines on standardised data collection methodologies and criteria for metadata to enable integration of benthos data of marine renewable energy devices into wider international frameworks	WGMBRED recognises the fact that data on the benthos of marine renewable energy devices are collected and stored according to different standards, hampering in integrated analyses of the effect of such devices on the benthos on wider spatio-temporal scales. Standardisation of data collection and storage methodology will overcome this problem, facilitating joint analyses and international collaboration.	3.1	Year 1–3	Synthesis report to ICES on review of existing standards and methodologies including guidelines for setting criteria of metadata facilitating integration and analysis of marine renewable energy devices benthic data.
b	Provide an integrated example dataset based on benthos data of marine renewable energy devices from various sources	To date, data on the effect of marine renewable energy devices are scattered in national or institutional databases. This lack of integration hampers the understanding of the general effects in space and time of renewable energy devices on the marine benthos. WGMBRED will therefore provide a prototype of an integrated database (based on publicly available data) that can be used for scientific purposes by the international scientific community	2.1; 3.1	Year 1–3	Prototype database on the benthos of renewable energy devices, submitted to a database repository.
c	Review the knowledge on changes in the benthos associated with environments where marine renewable energy devices are located and	Earlier WGMBRED work, showed a locally increased habitat diversity in areas where renewable energy arrays are in function. This results in increased diversity of	2.1; 2.2; 6.1	Year 1–3	Report to ICES on the assessment of the evidence of whether marine renewable energy device arrays can be

	relate them to the presence of these structures and the changes to other human activities (e.g. fisheries)	the benthos (including non-indigenous species). At the same time, many fisheries activities are excluded from these areas. As such, marine renewable energy device arrays could act as de facto conservation areas for benthos, adding to the existing network of designated Marine Protected Areas. This is of high importance and should be taken into account during marine spatial planning processes where multiple activities within concession zones for marine renewable energy devices are being planned for.			considered as de facto marine protected areas.
d	Develop the scientific basis for assessing the conservation of benthic habitats beyond the exploitation phase of marine renewable energy installations	Based in the current knowledge, WGMBRED realises that the local and regional biodiversity of the benthos may be positively affected in areas where marine renewable energy devices are exploited. This results from a combination of the provisioning of habitat, food and shelter for a number of marine organisms. These effects need to be taken into consideration in the decision making process for locating and the possible decommissioning of marine renewable energy devices sites.	6.1	Year 1–3	Manuscript to be submitted to peer-reviewed journal
e	Review and provide an empirical overview on the role of benthos associated with marine renewable energy devices in the maintenance of important ecosystem processes.	WGMBRED aims to provide the knowledge base to support the implementation of the Ecosystem Approach to Management with respect to marine renewable energy devices. This requires moving towards a process-driven understanding of how the changes to the structural and functional composition of the benthos (including non-indigenous species) associated with marine renewable energy devices) contributes to ecosystem functioning and the provisioning of ecosystem services (such as nutrient cycling and food provision via fisheries species).	2.2	Year 1–3	Manuscript submitted to a peer-reviewed scientific journal
f	Advice on the current state and knowledge of studies into the deployment and environmental impacts of the following wet renewable energies and marine energy storage systems: wave energy (floating, coastal infrastructure), tidal	Advisory Requirements: ICES has received a special request from OSPAR to advice on the current state and knowledge of studies into the deployment and environmental impacts of wet renewable technologies and marine energy storage systems. Given its expertise, WGMBRED will contribute to the advice with	6.1	Year 1	Report to ICES according to the advisory request

	stream (screws, kites), tidal flow (barrage, lagoon) and others. Advice should cover the status of wet renewable development in the OSPAR region, future prospects, potential environmental problems (sea bed habitat loss/disturbance, fish, marine mammals, birds, seascape/ public perception, and cumulative impacts), potential benefits, next steps and conclusions.	data and expertise on the benthic component of the marine realm. A subgroup will meet in ICES headquarters 15-16 January with experts from WGMRE to draft a first version of the advice. The draft advice will be finalised during WGMBRED (11-15 February 2019) and WGMRE meeting (25 February- 2 March 2019).

Summary of the Work Plan

Year 1	Begin reviews to start to address ToRs a, c, d and e; make inventory of data availability for compilation and integration for ToR b; develop and set out opinion matrix for ToR c. Contribute to advisory request from OSPAR (ToR f).
Year 2	Continue review activity to address ToRs a, c, d and e; Develop structure and populate integrated database for ToR b, further develop opinion matrix ToR c
Year 3	Finalise reviews ready for submission for ToRs a, c, d and e; make integrated database publicly available (ToR b), finalise expert opinion table ToR c;

Supporting information

Priority	The activities of the EG will lead ICES into a structural and functional understanding of how the marine benthal community of marine renewable energy devices contributes to the functioning of the marine ecosystem, and how they can act as areas where benthal biodiversity can be promoted. 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 or marine renewable energy devices are planned, and will be of directly use in marine spatial planning initiatives. Hence, the activities can be considered to be of very high priority.
Resource requirements	No specific resource requirements beyond the need for invited members to prepare for and resource their participation in the meeting. . Additional resources are required to respond the request for advice from OSPAR. A subgroup of experts from WGMRE and WGMBRED will meet in January in Copenhagen to draft a first response to the advice.
Participants	The Group is normally attended by 15–20 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	None.
Financial	Additional resources covered by OSPAR special request.
Linkages to ACOM and groups under ACOM	There are no obvious direct linkages. However, some contributions could be made to under 'pressures' as part 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 Marine Renewable Energy (WGMRE), the Working Group for Marine Planning and Coastal Zone Management (WGMPCZM) and the Working Group on Biodiversity Science (WGBIODIV).
Linkages to other organizations	OSPAR ICG-CUM