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Interim Report of the Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED)

6–10 March 2017

Gdynia, Poland

ICES International Council for the Exploration of the Sea

CIEM Conseil International pour l'Exploration de la Mer

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Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Executive summary

The 2017 annual meeting of the Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED) was attended by 19 experts, representing seven countries and was held in Gdynia, Poland during March. The meeting was co-chaired by Jennifer Dannheim (Alfred Wegener Institute, Germany) and Andrew B. Gill (Cranfield University, United Kingdom/Cape Eleuthera Institute, the Bahamas).

The question of Scale was the focus of ToR A. This ToR was determined as crucial to the work of the group following the first three years of WGMBRED. So we took previous case studies, which were set up at the last meeting and in sub-groups developed them in the context of defining their key elements associated with scale effects. From these case studies a conceptual model to show why scale matters has started to be developed.

The goal of the work on ToR B was to expand the matrices of effects to encompass those devices not considered in the knowledge publication (Dannheim, Degraer, Jackson *et al.* unpubl.) which considered fixed wind devices only. In order to progress, the knowledge base was updated in relation to specific marine renewable devices, i.e. floating wind, wave and tidal devices. Matrixes on the likely interactions between specific devices (i.e., floating wind, wave and tidal) were elucidated using the template on specific cause-effect relationship and the scoring system following the scheme presented in the ICES WGBMRED report in 2015 which accounts for the spatial and temporal scale of an effect, the sensitivity, the confidence and consistency. Matrixes and scoring of effects were summarised in tables for each marine renewable energy device.

With ToR C intersessional work using an online survey questionnaire provided some very interesting pilot data on a network analysis, which is being undertaken to create a map of interconnectivity between individuals, which when combined with information about individuals' membership of groups, generates new information on the way that groups interact, exchange knowledge and influence each other. During the meeting further contact details were sought to increase the number of respondents to the questionnaire for a more thorough analysis. This will form the basis of the main analysis and publishable outputs.

ToR D was addressed by looking at the cause-effect relationships in the conceptual scheme (see ICES WGMBRED report 2016), the functions that may be changed and to link these functions to specific services provided by the benthos. The group aimed at defining ecologically relevant indicators that are suitable to detect changes in functions and thus benthic services. Ecosystem services were identified following mainly Hattam *et al.* (2015, which basically is following CICES). The ToR D was tackled in three sub-groups related to the societal important issues: biogeochemical reactor, food resources and biodiversity

1 Administrative details

Working Group name

Working Group on Marine Benthal and Renewable Energy developments (WGMBRED)

Year of Appointment

2016

Reporting year within current cycle (1, 2 or 3)

2

Chair(s)

Jennifer Dannheim, Germany

Andrew B. Gill, United Kingdom

Meeting venue

Gdynia, Poland

Meeting dates

6–10 March 2017

2 Terms of Reference a) – z)

a) Critically assess relevant temporal and spatial scales in relation to the effects of MREDs on the benthic ecosystem and evaluate the consequences in relation to environmental policy and decision-making;

b) Review progress on filling knowledge gaps relating to the benthic ecosystem including differentiation among MRE technologies using e.g. reports of national activities;

c) Analysis of network and interactions amongst WGMBRED and other relevant groups including regulators, stakeholders, policy makers and scientists, in order to evaluate the impact of MBRED science;

d) Identifying and operationalising relevant indicators in relation to assessing ecosystem functioning and change in relation to MBRED at scales related to ToR A.

3 Summary of Work plan

Year 1 ToR – A, B, C, D

Year 2 ToR – A, B, C, D

Year 3 ToR – A, B, D

4 List of Outcomes and Achievements of the WG in this delivery period

WGMBRED considered several aspects in the WG and evaluated which will lead to publications, datasets, methodological developments and advisory products.

- Four main themes were discussed during the meeting, which address the main ToRs of the expert group
  - the importance of scale
  - knowledge improvement related to devices other than offshore wind farms
  - network analysis of the impact of WGMBRED expert group
  - the use of indicators
- Significant progress on these topics was made particularly in relation to potential publications and advisory products
- ToR A on scale issues and ToR D on indicators were related to each other and discussed in a complementary way

ToR A: Scale

Current activity:

- Developing further the work on the three case studies that the WG started in Delft in 2016: Southern North Sea - Plaice, Southern Baltic – Cod, and Southern Irish Sea – Blue Mussel farming. Using the three case studies the sub-groups focussed on the following aspects:
  - Define spatial boundaries of the system scale issues
  - Define food resources for species
  - Describe cause-effect relationships (C-E-R)
  - Describe change in C-E-R with different spatial scales: turbine – array – multiple arrays
  - How to maximize effects at these different scales

Expected output:

- Following from the DRIP paper, an outline for a new paper focussing on scale,
- The generic approach in the paper will be to set up a conceptual model (EcoPath style) for the ES 'Food provisioning', and how MRE will influence (improve where possible) this, and how scale is related to it (spatial ecology for the relevant species, upscaling of the MRE devices, and spatial management).
- It is important that the purpose of the paper is to indicate that scale matters not that we solve the puzzle.

Expected output (year 3):

- Review paper

ToR B: Knowledge improvement

Current activity:

- Review of progress on filling knowledge gaps related to the effects of energy devices on the benthic ecosystem, differentiation between different marine renewable energy device groups: tidal and wave energy devices, floating wind farm devices
- Scoring of the magnitude of the effect of the three device groups on benthic cause-effect relationships based on the temporal and spatial extent, as well as the sensitivity

Expected output:

- Overview of the effect magnitude of the cause-effect relationships of the three device groups on the benthos in comparison to offshore wind farms
- Analysis of potential knowledge gaps

Expected output (year 3):

- Matrices – updated knowledge base

ToR C: Network

Current activity:

- The ICES WGs on 'Marine Benthal and Renewable Energy Developments' and 'Marine Renewable Energy' have combined efforts to assess communication between individuals working across relevant sectors.
- Led by Tom Wilding (WGMBRED) and Raeanne Miller (WGMRE) data gathering is ongoing using an online questionnaire, this phase is scheduled to finish by the end of June, the analysis will then occur by the end of October.

Expected output:

- A map of interconnectivity between individuals, which when combined with information about individuals' membership of groups, generates new information on the way that groups interact, exchange knowledge and influence each other.
- A paper will be submitted for publication by the end of the 2017

Expected output (year 2):

- Network map and associated publication

ToR D: Indicator

Current activity:

- Linking cause-effect relationships to functions and specific services provided by the benthos
- Defining ecologically relevant indicators that are suitable to detect changes in functions and thus benthic services

Expected output:

- Specified indicators for specific cause-effect-relationships caused by renewable energy devices on the benthos related to benthic ecosystem services and goods

Expected output (year 3):

- Review paper

5 Progress report on ToRs and workplan

5.1 Current work status of the expert group on marine benthal and renewable energy developments

At the start of the meeting, Andrew B. Gill (co-chair) and Jennifer Dannheim (co-chair) welcomed the 19 participants representing seven countries and thanked Urszula Janas (Institute of Oceanography, University of Gdańsk) for hosting the meeting.

Jennifer Dannheim and Andrew Gill summarised the work of WGMBRED of the last meeting and gave an outlook on the expectation for this meeting concerning scale issues, knowledge improvement, and the impact of the expert group's science and the identification of indicators. All this was to be facilitated by the structured agenda, but leaving room for open conversations and discussions. The topics during the meetings are driven by the four multi-annual ToRs (2016–2018):

a) Scale topic which aims at assessing relevant temporal and spatial scales in relation to MREDs effects on the benthic ecosystem and evaluating consequences in relation to environmental policy and decision-making;

b) Knowledge improvement which includes a review progress to fill knowledge gaps related to the benthic ecosystem particularly differentiation among MRE technologies;

c) Network and interactions analysis amongst WGMBRED and relevant groups (regulators, stakeholders, policy makers, scientists to evaluate the impact of MBRED science;

d) Indicator identification and operationalisation to assess ecosystem functioning and changes in relation to MBRED at scales defined through the scale topic.

Andrew Gill summarised the research priorities (and sub priorities) of the ICES Science plan to which the WGMBRED makes a significant contribution. These are:

- 1.1: Climate change processes and predictions of impacts
- 1.3: The role of coastal zone habitat in population dynamics of exploited species
- 2.3: Influence of development of renewable energy resources (e.g. wind, hydropower, tidal and waves) on marine habitat and biota
- 2.4: Population and community level impacts of contaminants, eutrophication, and habitat changes in the coastal zone

This was followed by a summary of the intersessional activities relating to the WG:

- Monitoring paper - submitted and accepted (following major revisions)
- Knowledge paper -ready to submit
- Network analysis – pilot questionnaire and outputs

And intersessional activities outside of WGMBRED

- ICES ASC 2016 in Riga, Andrew presented WGMBRED activity within the open session 'What are the implications for marine ecosystems of interactions between multiple stressors?'

- Marine Renewable Energy session, European Geosciences Union Assembly (EGUA) in Vienna, Austria, 17-22 April 2016, Degraer *et al.*
- Contributions to the North Sea Open Science Conference, Ostend, Belgium from WGMBRED experts: Steven Degraer, Silvana Birchenough, Ilse de Mesel, Jennifer Dannheim, Ed Willsteed, Jan Vanaverbeke
- Upcoming event: Theme session K at ICES ASC 2017: Introducing man-made structures in marine systems: assessing ecological effects, knowledge gaps and management implications which is chaired by two WGMBRED experts (Silvana Birchenough, Jennifer Dannheim)

Finally, the group discussed the agenda that had been drafted prior to the Gdynia meeting.

5.2 National updates

Germany: Currently, 11 wind farms are operational with 694 turbines, 25 were authorised comprising another 1440 turbines. A minimum of 36 wind farms with 2134 turbines in total will be installed in the German Exclusive Economic Zone (EEZ). Further applications for 76 wind farms (6706 turbines) are under progress for approval. While the offshore wind farm industry is continuously increasing, other marine energy devices such as floating wind farms, tidal and wave energy devices are not planned for the German EEZ.

The Alfred Wegener Institute (AWI) in collaboration with the Federal Maritime and Hydrographic Agency (BSH), i.e. the approval authority for offshore wind farms in Germany, are establishing an information system on benthic invertebrates and demersal fish from environmental impact assessments (EIA) and research projects. The information system is the core of the project ANKER which has the aim of cost reduction approaches and increase in efficiency of monitoring data surveys of offshore projects by this information system. ANKER is establishing use cases, user stories and products for different stakeholders and decision makers (e.g. OWF industries, regulators, authority). The products of the information system comprise, among others, species distribution maps, biodiversity maps, comparisons of OWF areas and references areas over time for different parameters. Study outcomes from analysis based on the information system are directly retrievable via the systems internet page (GeoSeaPortal, Marine data infrastructure-Germany MDI-DE) and are thus public and long-term available as a service for the different stakeholders.

Contact: Jennifer Dannheim, Alfred Wegener Institute, Bremerhaven

Germany: Research on adequate environmental compensation measurements, restocking of European oyster and lobster

As a precondition, the permission for the installation of subsea cables and transformer stations within the German EEZ and coastal waters has to include compensation measures in the context of nature conservation. Wind farms inside the German EEZ which are approved in 2017 and later, will also have to apply for compensation measures in the future. The creation of new natural substrates, i.e. destroyed or modified substrates during the construction process, is regarded as unsuitable compensation measure. Therefore, alternative measures which aim at improving the affected benthic ecosystem are required. In 2013, a pilot field study started to test the settlement of lobsters inside an offshore windfarm. Within the last two years, two additional concepts considered as potential compensation measures have been planned and will be tested in the field.

Offshore windfarms as habitats for European lobsters (*Homarus gammarus*)

From 2013 until 2015, a lobster settlement project was carried out inside the offshore wind farm Riffgat. The first inspection in 2015, one year after the *H. gammarus* release, revealed that a reasonable number of lobsters occurred at the four stocked turbines. Difficulties arose in differentiating wild lobster from those of the hatchery because the systematic design of the pot fishery survey was very difficult to implement fully due to safety requirements (Schmalenbach *et al.*, 2016). In the summer 2017, the inspection will be extended over up to 17 wind-turbine scour protections to gain information on the lobster distribution across the entire wind farm and to distinguish the share of wild individuals. Future field studies will be conducted by a standardised diving method.

The quantification of mobile demersal megafauna within the lobster project (baseline study in the second year after deployment of the turbines) revealed that approximately 40% of edible crab (*Cancer pagurus*) might be produced at the turbines at this site, as they are max. 2 years old (Krone *et al.*, 2017). This is a first approach to distinguish between production and aggregation of crabs at German Bight wind farms.

Restoration of locally extinct European Oyster (*Ostrea edulis*)

The native European oyster is considered a keystone species with special ecological functions in its typical species community and habitat. The historical distribution covered wide areas of the North Sea. Today *O. edulis* is functionally extinct in the German North Sea due to extensive overfishing over several decades. A feasibility study revealed the potential for the restoration of oyster beds which would re-establish not only the species but also its characteristic biocoenosis and essential ecosystem services.

The current project develops strategies for a sustainable restoration of the native European oyster *Ostrea edulis* in the German North Sea. Methods and procedures are tested at experimental scales at different locations in the field (Pogoda *et al.* 2011), e.g. in offshore wind farms of the EEZ. Results of this investigation will support the future development and implementation of a German native oyster restoration program to re-establish a healthy population of this highly endangered oyster species in the German North Sea.

Restocking of *Homarus gammarus* stock at the reefs of Helgoland

In the middle of the last century, *H. gammarus* stocks decreased dramatically along North Sea coasts. At the island of Helgoland lobster landings of local fishermen decreased down to less than one percent. Environmental requirements seem to be appropriate for lobster development at present. However, most probably the stock has not been able to achieve its critical size to increase further by its own capabilities. As a compensation measure for offshore constructions, it is proposed to release at least 360,000 juvenile lobsters in a time span of six years, to support the wild stock. This will include a comprehensive long term monitoring of the lobster and the entire mobile demersal reef fauna.

We assume that *H. gammarus*, as the largest invertebrate predator, regulates the remaining reef fauna. The baseline study will start in autumn 2017. The first lobster release is scheduled for spring 2018.

What is coming next?

Previous results from offshore windfarm Riffgat showed that scour protections of turbine foundations might serve as permanent habitats for lobsters and other reef fauna. So far, no data are available on how lobsters respond to operating turbines and how lobsters and crabs behave and move inside wind farms. Furthermore, no quantitative data are available so far on movement patterns of *H. gammarus* on different time scales in the German Bight. A five-year research project is in its planning stage: Lobsters and other large demersal reef fauna will be tracked via transmitters. These results will support protection measures and rate the suitability of offshore wind farms as artificial reef fauna habitats.

Krone R, Dederer G, Kanstinger P, Krämer P, Schneider C, Schmalenbach I (2017) Mobile demersal megafauna at common offshore wind turbine foundations in the German Bight (North Sea) two years after deployment - increased production rate of Cancer pagurus. Marine Environmental Research 123: 53-61.

Schmalenbach I, Krone R, Janke M, Franke HD (2016) Hummeransiedlung im Offshore-Windpark Riffgat - Maßnahmen zur Erhaltung und Stabilisierung der bedrohten Art in der Deutschen Bucht und Grundlagenforschung zur Ökologie des Hummers. NLWKN. 107 pp.

Contact: Roland Krone, Alfred Wegener Institute, Bremerhaven

Poland: Marine renewable energy developments in Poland

At the time of writing the report, there are no offshore wind farms in Poland. Initial plans for development of offshore wind farms in the country’s marine areas assumed that the capacity of installed wind power is going to be at least 0.5 GW in year 2020 and may reach 6 GW until year 2025. Currently due to ongoing delay in the preconstruction process, it is obvious that these goals will not be achieved. Commissioning of the first two wind parks in Polish EEZ – Middle Baltic 3 and Middle Baltic 2 - has been scheduled for years 2022 and 2026 respectively. It is worth noting that these wind parks form only a small part in plans for offshore wind farms development in Poland. In total 23 sites have been chosen and approved for wind farms construction in three regions: Oder Bank, Słupsk Bank and Middle Bank. Total area of chosen sites comes to 1880 square kilometers.

Previous and ongoing research

Natural hard bottom is very rare in the southern part of the Baltic Sea. Therefore, artificial structures such as offshore wind farms should be concerned as a significant change in the local marine environment. Large-scale research of soft sediment benthos was carried out in the past but current Polish monitoring sites are situated far away from the areas planned for wind farm construction. As there are no offshore wind farms in Polish EEZ yet, any research in the area is limited to other artificial hard substrata such as shipwrecks and inactive offshore structures left after the World War II. Experimental hard substrata such as settlement plates are also used during the research. Ongoing research is focused on fouling communities and their ecological functioning in comparison to assemblages associated with natural hard bottom. Samples for the research were collected at foundations of two World War II offshore watchtowers as well as at two natural boulder fields in the Gulf of Gdańsk. At the same time, the organic enrichment of natural soft bottom around one of the artificial structures in the Gulf of Gdańsk is investigated. Samples for the research are collected in a similar manner as described by Coates *et al.* (2013) in the report "Environmental impacts of offshore wind farms in the Belgian part of the North Sea: Learning from the past to optimise future monitoring programmes". Collecting the samples around the 70-year old foundations will allow us to study fully developed effects of organic enrichment on benthic communities associated with natural soft bottom.

Contact: Radek Brzana & Urszula Janas, Institute of Oceanography, University of Gdańsk, Gdynia

France: Trophic webs comparison of two future Offshore Wind Farms in the English Channel: the Courseulles-sur-mer and the Dieppe-Le Tréport case studies

The French government has planned the construction of three offshore wind farms in Normandy at the end of 2000. The planning of these sites was very long. The public debates are ongoing and several conflicts have arisen from fisherman and local landscape associations which have delayed the beginning of the construction. The first offshore wind farms will be built in early 2020. These offshore wind farms will integrate into an ecosystem already subject to a growing number of anthropogenic disturbances such as fishing (dredges, trawls and whelk pots and crab traps), sediment deposition in the Bay of Seine and sediment extraction. The possible effects of these cumulative stressors on ecosystem functioning are still unknown, but they could impact their resilience, making them susceptible to changes from one stable state to another.

Nowadays, a holistic and integrated view of ecosystem impacts through the use of trophic webs modelling tools has been developed in the framework of two PhD theses (Dieppe - Le Tréport and Courseulles-sur-Mer (CSM) planned offshore wind farms) and ANR TrophiK Project. Ecopath with Ecosim models allow a description of the trophic link between biological compartments at different trophic levels and are based on quantifying the flow of energy and matter in ecosystems. They allow the application of numerical methods for the characterization of emergent properties of the ecosystem, also called Ecological Network Analysis (ENA) which has already been used to assess stress in coastal ecosystems. A comparison between the two coarse sediments zones of CSM and Dieppe-le Tréport shows a lower total living biomass at the site of CSM than at the other site. In addition, the Dieppe-le Tréport site shows a higher system activity, ascendancy and recycling were higher than in the CSM zone. At the end of two PhD, advices for hard-bottom and soft-bottom monitoring should be proposed to offshore wind farm owners.

In addition, the benthic habitats of the Raz de Blanchard, a potential site for tidal turbine development were prospected by the laboratory M2C. The zone is characterised by hard bottom, pebbles and rocks with a low number of species. Conversely, the coarse sediment patches show a high diverse small interstitial fauna adapted to live in such hydrodynamic environment.

Contact: Jean-Claude Dauvin, Jean-Philippe Pezy & Aurore Raoux, UNICAEN

United Kingdom: Current status of MRED in UK waters

The UK continues to plan, consent and install offshore wind farms, principally monopile foundation type. Floating wind farms remain at the concept stage with one or two test devices being planned. Wave energy has suffered many set-backs over the past couple of years and its future remains uncertain. Tidal stream energy is moving ahead more positively and the first array has been deployed in the Pentland Firth (Maygen, 4 devices).

An overview of those operational, under construction and planned for each main device type is shown below:

Offshore wind – fixed:

- in use: 1578 devices (27 projects)
- under construction: 362 devices (5 projects)
- planned: 1944 devices (22 projects, includes planned & consented)

Wave:

- in use: 4 devices (4 projects)
- under construction: 2 projects
- planned:
- 28 devices (13 projects)

Tidal stream:

- in use: 5 devices (5 projects)
- under construction: 1233 devices (22 projects)
- planned: 398 devices (17 projects) (inc. in planning, scoping, consented)

MRED Related Research

MAGNETlse (USA) – Electromagnetic field impacts on Elasmobranch (shark, ray and skates) and American lobster movement and migration from D.C. cables. Bureau of Ocean Energy Management (BOEM), University of Rhode Island, Swedish Defence Agency. The project has completed field experiments of acoustically tagged lobster and skates and is moving into the data analysis phase with an end date for the project being March 2018 (Contact: Zoe Hutchison and Andrew Gill).

Biodiversity and offshore structures – EPSRC REMS PhD (Paul Causon), in the 2nd year of research on 'Epibenthic community dynamics in relation surface orientation on offshore wind turbine substructures'. The project is collaborating with Joop Coolen and Roland Krone through using their extensive datasets to assess benthic community colonisation on sub-sea structure. Furthermore, experiments using colonisation cubes to understand the effect of surface orientation on benthic species colonisation are being planned for deployment at the Westermost Rough wind farm off the Humber estuary in collaboration with Hull University and the Holderness Fishing Industry Group, Bridlinton (Contact: Paul Causon).

Cumulative environmental change – NERC Industrial Case PhD with Cefas (Ed Willsteed). The PhD research is now in its 3rd and final year. The focus is on trialling a method that Ed has developed to undertake a cumulative environmental effects assessment using existing data and GIS capabilities at Cefas (the industrial sponsor). The research has had one paper published:

- Willsteed, E., Gill, A.B., Birchenough, S.N.R. & Jude, S. (2017). Assessing the cumulative environmental effects of marine renewable energy developments: Establishing common ground. Science of the Total Environment, 577, 19–32.

Future research is planned in proposals that have been submitted for funding:

2 x H2020 Blue Growth proposals submitted:

- Reducing barriers & consenting risk; innovative solutions
- Multi-use platforms

2 x UK-China ESPRC/NERC/NSFC:

- Multi-use platforms
- Scaling up with arrays

CEI – Cape Eleuthera Institute – Andrew Gill gave an overview of the new institute where he has taken the role of Director from 1 February 2017. Whilst CEI is based overseas in the Caribbean working on MBRED interactions with the environment very much remains at the heart of the research activity. A visit is planned for WGMBRED members following the ICES ASC in Florida in September, 2017.

Contact: Andrew Gill, Zoe Hutchison, Ed Willsteed, Paul Causon, Cranfield University, Cranfield, UK

United Kingdom: The EU Horizon 2020 CEFOW (Clean Energy From Ocean Waves) is now out of suspension and has moved its deployment site from Wave Hub in SW UK to EMEC in Orkney. One device has been connected and has successfully generated electricity into the national grid off the west coast of Orkney. This summer, annual environmental monitoring surveys will commence by a collaborative team from the Universities of Exeter, Plymouth and Uppsala.

Contact: Emma Sheehan, Plymouth University

Ireland: The following table details the status of current offshore renewable projects in Ireland.

Table **on the** current status of offshore renewable energy projects in Ireland:

Project	Resource Type	Status
Arklow-Banks, Wicklow	Wind	Lease Granted – 7 turbines
Codling-1-Banks, Wicklow	Wind	Lease Granted – no turbines
Oriel, Louth	Wind	Lease Application (on hold)
FST Sceirde, Galway	Wind	Lease Application (on hold)
Codling-II-Banks, Wicklow	Wind	Lease Application (on hold)
Kish-Banks, Dublin/Wicklow	Wind	Lease Application (on hold)
Bray-Banks, Wicklow	Wind	Lease Application (on hold)
Gaelectric, Louth/Meath (Investigation)	Wind	Site Investigation licence Approved
Marine.Institute-Smartbay, Galway	Wave (test site)	Lease Granted
Pandion Ocean Energy Ltd., (Investigation) Mayo	Wave	Site Investigation Consultation
Westwave Clare, (Investigation)	Wave	Site Investigation licence Granted
SEAI-AMETS, Mayo	Wave (Test Site)	Lease Granted
CETO Wave Energy Ireland Ltd. (Investigation), Clare	Wave	Site Investigation Licence Granted

While one existing lease site (i.e. Arklow) is currently operational with 7 x 3.5 MW turbines, there are no other operational marine renewable developments currently active. A number of leases for testing of devices are operational. In addition, a number of site investigation licences have also been issued in the last few years. However, consideration of foreshore lease applications for full offshore energy developments are currently 'on-hold' pending a review in the context of the implementation of the Offshore Renewable Energy Development Plan[1] and other relevant policy developments. There is no timeline as to when this review might be concluded.

Contact: Francis O'Beirn, Marine Institute

[1] http://www.dccae.gov.ie/energy/en-ie/Renewable-Energy/Pages/OREDP-Landing-Page.aspx

Belgium: The recent research activities and findings with regards to the Belgian monitoring programme are summarised in:

Degraer, S., Brabant, R., Rumes, B., Vigin, L. (Eds.) (2016). Environmental impacts of offshore wind farms in the Belgian part of the North Sea: Environmental impact monitoring reloaded. Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management Section. 287 pp.

The report can be downloaded from:
http://odnature.naturalsciences.be/downloads/mumm/windfarms/winmon_report_2016.pdf

The report starts with the lessons learned from the application of the monitoring design during the first 7-8 years of monitoring and how that informed the outline of the renewed basic monitoring programme. The renewed monitoring programme particularly strives for a better focus on meaningful changes and a higher level of integration between the monitoring programmes of the different ecosystem components under consideration (i.e. soft sediment and hard substrate invertebrates and fish, birds, bats and marine mammals). The bulk part of the 15 chapters' report touches upon all ecosystem components investigated. Basic and targeted monitoring results are presented. The report finally presents an update on the state of affairs with regards to the offshore renewable energy developments in Belgian waters, and a view on the current perception and use of offshore wind farms by recreational fishermen.

Contact: Steven Degraer, RBINS

Belgium: PERSUADE: ExPERimental approaches towards Future Sustainable Use of North Sea Artificial HarD SubstratEs

Coastal areas are increasingly affected by a mixture of global and local pressures. At the global scale, global change, including the combination of both warming and acidification is a well-known phenomenon. According to the business-as-usual scenario from IPCC, sea-water temperature will have increased by 3°C, and the pH will have decreased with 0.3 units by the end of the century. Research on the effects of such changes has revealed that both food-web interactions and nutrient cycling will be affected. While warming and pH decrease are primarily effects measured in the water column, there is growing evidence that organisms in sediments and sedimentary processes are affected as well.

In addition to the pressures acting at the global scale, local pressures are often induced by a localized human activity. In coastal areas around Europe, there is an increasing trend towards the installation of offshore wind farms (OWFs) to meet the requirements for renewable energy. The installation of OWFs results in change in the marine environment, through the introduction of large surfaces of hard substrate in an otherwise sandy environment. This hard substrate is rapidly colonized by large quantities of fouling fauna, including non-indigenous species. The new members of the local fauna affect the local food web, by introducing new trophic and non-trophic links, which affects stability and resilience of the trophic network. On top of this, the presence of large quantities of fouling fauna can result in increased emissions of the important climate gas N_2O through the activity of a specific microbiome that is present on shells of fouling bivalves. As such, the planned development of blue mussel (*Mytilus edulis*) aquaculture within wind-mill farms can further increase the production of N_2O, while at the same time affecting the trophic and non-trophic links in the food web. On the other hand, the harvestable biomass yield of mussel farms within an OWF will depend on such changes in the N-cycle, affecting local primary production and hence competition with zooplankton.

It is to be expected that the resulting effects on the coastal ecosystem will be an integrated non-linear response to multiple changes. PERSUADE will investigate the integrated effect of both global and local pressures on the resilience of the coastal ecosystem and the production of greenhouse gases. Global change will be assessed according to IPCC scenario RCP 8.5 (current emission trajectory), which predicts a 3°C increase in water temperature coinciding with a decrease in pH of 0.3 units by the end of the century. Local pressures are related to the installation of OWFs, and the planned blue mussel farming within OWF concession zones.

We will use a combination of ecosystem-wide and model-species experiments, modern genomic tools and modelling to investigate the response of the coastal ecosystem to the anticipated multiple pressures. Using large holding tanks (4 m^3), in combination with acidification and warming equipment, we will incubate the dominant fouling communities above sediments, in current (control), and 2 future scenarios. A first future scenario will mimic the presence of OWFs in a coastal sea environment as predicted by IPCC (temperature, pH), while the second future scenario adds blue mussel farming to the same predicted climate change setting.

We will investigate how the combined local and global pressures affect the resilience of the ecosystem, and the production of the greenhouse gas N_2O. Resilience will be investigated through the assessment of structural and functional food-web properties, which are well-accepted proxies for resilience. This will be complemented with a quantitative assessment of the C-flows in the various settings, to relate the structural and functional changes to secondary production, which is of importance for aquaculture related activities. We will take into account both trophic and non-trophic interactions within the network as their relative importance is expected to change with climate change and the introduction of aquaculture activities.

While climate change is known to affect the coastal pelagic nitrogen cycling, the effect is expected to be modulated by the microbiomes associated with the fouling fauna on the OWF. We will focus on three model species, dominant within the fouling communities of OWF in the Belgian part of the North Sea: the blue mussel *M. edulis*, the amphipod *Jassa herdmani* and the non-indigenous tunicate *Diplosoma listeranium*. *J. herdmani* lives in tubes partly made of organic material, while *Diplosoma* sp. forms large encrusting sheets. Hence, their presence results in additional large surfaces of biologically generated hard substrate that can affect the N-cycle in a similar way as in the presence of the blue mussel. Therefore, we will conduct detailed experiments and genomic research that will allow for quantification and a mechanistic understanding of the effects of the fouling organisms on the pelagic N-cycle, with a focus on N_2O production. Along the same lines, the effect of climate change on the sedimentary N-cycle will be investigated. We will combine whole-community incubations with detailed investigations on behavioural responses of selected key species (the invasive clam *Ensis directus*, the bivalve *Abra alba*, and the tube-building polychaete *Lanice conchilega*) to quantify and understand the effect of climate change on the benthic N-cycle.

The integration of ecosystem-wide and species-specific experiments, both on food-web topology and N-cycling, in a pelagic and benthic environment, will be done through the development of an ecological model. This 2D-model will integrate the detailed measurements listed above, to investigate how climate change and the introduction of hard substrate fauna interact with respect to the production of N_2O by coupling biological models for the three selected fouling species, with a physical and biogeochemical model estimating turbulence, water temperature and biogeochemical properties of the water column on the one hand, and a diagenetic benthic model on the other. This model will allow predictions of how the coastal ecosystem will respond to the complicated changes in the feedback links between organisms and their environment that are expected when cumulative pressures affect the ecosystem simultaneously. On the other hand, the model will allow for estimations in variation of harvestable mussel biomass in different aquaculture scenarios (climate, mussel farm configuration). As such, our results will be directly applicable for policy measures (MSFD, maritime spatial planning) and society (Blue Growth initiatives).

Contact: Jan Vanaverbeke, Steven Degraer, RBINS

The Netherlands: Current state of offshore wind farms in the Netherlands: The fourth Dutch OWF GEMINI (ca. 80 km north of Groningen province) has begun producing power. It is expected to be fully commissioned before mid-2017. This is the last OWF from the second round of licensing. The third consenting round has started, with licenses being awarded to DONG Energy for Borssele 1 and 2 (excluding the grid, which is the responsibility of the Dutch state-owned company TenneT). Borssele 3 and 4 are awarded to a consortium of Shell, Van Oord dredging, Eneco and Mitsubishi. Borssele 5 is an innovation plot, targeted for projects to demonstrate new technologies at a high readiness level (TRL8). Other areas to be further developed are Hollandse Kust (Holland Coast) around Prinses Amalia and Egmond aan Zee wind farms, and around Luchterduin wind farm; tenders are planned for 2017 to 2019. Other tenders are expected later as part of the so-called Energy Agenda 2050 for further reduction of greenhouse gases, with a planned installation of 1 GW per year for 2024 to 2030.

At the end of 2016, a multi-annual monitoring program for assessing the ecological impact of offshore wind farms has been set up for the period 2017 to 2021[2]. This monitoring plan puts (like in earlier years) the emphasis on birds and marine mammals, but adds monitoring for bats, fish and benthos to the program. The benthos program identifies important knowledge gaps, research questions, and derives several research projects for the period of 2016 to 2021. The projects are:

1) Long-term monitoring of the soft-sediment benthos (survey in 2017 and 2021), following the set up in 2007 and 2011 in Egmond aan Zee and Prinses Amalia;
2) Long-term monitoring of the hard-substrate benthos with a focus on invasive species;
3) Pilot for biogenic structures with multibeam sonar and towed camera.

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2 https://www.noordzeeloket.nl/images/Offshore%20wind%20ecological%20programme%20(Wozep)%20-%20Monitoring%20and%20research%20programme%202017-2021_5284.pdf (in English)

Also at the end of 2016, two projects on the potential for recovery of protected species using wind farm areas started. The first describing the potential for European flat oyster reintroduction, the second describing how scour protection may be optimised to attract a diverse set of species, including benthic species, among which there are species protected by OSPAR.

In 2017, Dutch OWF will be opened for vessels < 24 meter length overall, no exact date has been set yet.

Studies we were involved in pertaining to offshore wind farms:

- Set up of monitoring plan for ecological impacts of offshore wind farms
- Study into the possibility of admission to OWF for various user types.
- Set up of (Integrated) Cumulative Effect Assessment framework and methodology (together with WMR), report published.

Relevant publications:

van Walraven L, Driessen F, van Bleijswijk J, *et al.* (2016) Where are the polyps? Molecular identification, distribution and population differentiation of Aurelia aurita jellyfish polyps in the southern North Sea area. Mar Biol 163:172. doi: 10.1007/s00227-016-2945-4

Coolen JWP, Lengkeek W, Degraer S, *et al.* (2016) Distribution of the invasive Caprella mutica Schurin, 1935 and native Caprella linearis (Linnaeus, 1767) on artificial hard substrates in the North Sea: separation by habitat. Aquat Invasions 11:437–449.

Contact: Arjen Boon, Deltares Research Institute and Joop Coolen, Wageningen Marine Research

5.3 ToR A: Scale

ToR A – Critically assess relevant temporal and spatial scales in relation to the effects of MREDs on the benthic ecosystem and evaluate the consequences in relation to environmental policy and decision-making

The ToR A was introduced by Andrew Gill and Jennifer Dannheim. The recently published WGMBRED paper (referred to as 'DRIP', Wilding *et al.* 2017) focussed on the issues with collecting monitoring data and its utility to the decision making process for those determining whether MREDs will affect the environment and in particular the benthic ecosystem. One major factor was the scale at which an effect was considered, i.e. the need for ToR A to directly address the question of scale. At the outset it has to be recognised that as a WG, our task is to scale up from small-scale effects (in space and time) and determine if and at what scale this becomes relevant for policy and management.

The group discussed this aspect and the consensus was to use our judgement within the group and apply to case examples, working towards ecosystem services to tackle spatial and indicator issues for the three societally relevant groups that we have defined previously, namely: biodiversity, biogeochemical reactor and food resources.

Tom Wilding presented a decision-tree from the recently published DRIP paper and how scale is relevant to it. Societally relevant questions: So what is the basis for the issues around scale such as the increases in blue mussels, jelly fish, and polychaetes.

It was decided to work further on the three case studies that the group started in Delft in 2016: Southern North Sea - Plaice, Southern Baltic – Cod, and Southern Irish Sea – Blue Mussel farming.

The following aspects were specifically addressed:

- Define spatial boundaries of the system scale issues
- Define food resources for species
- Describe cause-effect relationships (C-E-R)
- Describe change in C-E-R with different spatial scales: turbine – array – multiple arrays
- How to maximize effects at these different scales

Case studies:

(A) Define Boundaries

- Hydrographic/Bathymetric
- Geographic
- Geopolitical
- Wind farm footprint

(B) Define Food production

- Ecosystem services
- Species parameters (refs) that will plausibly change ecosystem service

(C) USE: Cause effect pathways to ID changes relevant to

- Species w.r.t a turbine
- Species w.r.t. a windfarm
- Species w.r.t. national/Geopolitical/hydrographic boundaries defined in A
- Maximise effect

Based on the approach and case studies of the subgroup work (see below), Andrew Gill and Arjen Boon proposed to set up an outline for (and lead) the paper on scale The case studies need to fill in further details in intersessional work, guided by Silvana Birchenough for the Irish Sea, Urszula Janas for the southern Baltic Sea and Arjen Boon for the southern North Sea.

The generic approach will set up a conceptual model (EcoPath style) for the ES 'Food provisioning', how MRE will influence (improve where possible) this, and how scale is related to it (spatial ecology for the relevant species, upscaling of the MRE devices, and spatial management). It will highlight the ability to select indicators for the issue of interest but also the spatial and temporal scale. Linkages can be made to the need for and use of indicators along the causal chain, specifically pertaining to the scale-related ones. It is important that the purpose of the paper is to indicate that scale matters not that we solve the puzzle. Literature on the specifics for the case studies (especially on the relationships between the relevant species and MRE) will be uploaded to the WGMBRED SharePoint.

Literature cited:

Wilding TA, Gill AB, Boon A, Sheehan E, Dauvin J-C, Pezy J-P, O'Beirn F, Janas U, Rostin L, De Mesel I (2017). Turning off the DRIP ('Data-rich, information-poor') – rationalising monitoring with a focus on marine renewable energy developments and the benthos, Renewable and Sustainable Energy Reviews 74: 848–859

5.3.1 Southern North Sea

The case study centred on a monopole-based offshore windfarm. The conditions in the Southern North Sea are well characterised and mapped (there is relatively good quality/high resolution data on sediment type and faunal populations). The environmental characteristics the group considered typical were – depth: 20 m, sediment: medium sand, relatively homogenous (not the German Bight), well oxygenated, low organic content, mobile, characterised by ripples or dunes, seasonally stirred (storms) with some tidally induced mobilisation, ecology: species poor, low biomass, low density, water column: clear, oligotrophic, 7–18 °C, high and stable salinity. When considering a device the group focused on a 5 m diameter monopole with 12.5 m scour-protection either side (~500 m^2 individual footprint).

The approach to the scale-relevant interactions was to consider a food-web for the location. The focus was on the societally relevant fishery group 'flatfish'. The group constructed a simple pre-deployment food-web, based around the diet /predators/parasites of flatfish and their likely interactions. The relevant scale was a device array (e.g. 200 monopoles) because, at this scale, it would be expected to be relevant to fishers. The scale-relevant questions were: to what extent are fishery catches likely to change over the scale of the array or the scale of the 'ranges' of the fishers using the area? The group also raised the issue of the likely larger-scale consequences and considered the Southern North Sea as a defined water body (i.e. Southern North Sea gyre) in which broader fishery-related issues should be considered. The major unknowns in this considerations were the spawning areas for some species (current location and following development), distributional patterns/habitat preferences and the degree to which biomass distribution will change following the intervention (i.e. wind-farm construction). The group considered that changes occurring in the food-web, primarily fuelled by monopole-based *Mytilus* sp. and macrophytic production, was an important known-unknown and the manner by which this carbon is redistributed to the food-web is a key knowledge gap.

5.3.2 Baltic Sea

Case study – Southern Baltic Sea Cod

Spatial boundaries relating to offshore wind farms

In assessments for fisheries, cod living in the southern Baltic Sea are subdivided in two populations: a western Baltic population (around the Danish islands), and an eastern Baltic population, living mainly south of Gotland and east of Bornholm. Spawning areas are mainly in the deeper waters, nursery areas are mainly at the hard substrate coastal areas, such as the shallow coastal Polish waters. Any scale effects of OWF will need to take this spatial –population- scale into consideration.

Cod migrate from their feeding grounds to their spawning grounds, and larval and juvenile cod migrate to shallower areas and when ageing, migrate to deeper waters again.

Cause-effect relationships, food resources

As with many fish species, cod eat different prey items depending on their size. Juvenile cod eat mainly small crustaceans, adult cod eat next to larger crustaceans also small fish such as herring and sprat.

The C-E-R studied here is the so-called attraction-production hypothesis: fish are attracted to offshore hard structures for shelter from currents and predators, and can feed from the organisms growing on the hard substrate. This combination provides relatively good conditions for growth, which improves the chances for survival of cod living around these structures, their individual fitness and may therefore contribute to the cod population fitness and stock improvements.

Since adult cod mainly feed on herring and sprat, and as these species are not known to aggregate around hard structures, the relative advantage for adult cod is deemed to be small. On the other hand, gobies are also a prey item for adult cod, and these may profit from shelter in and food on OWF. Juvenile cod however, may have a larger benefit from the OWF structures than adult. Whether the Polish OWF are planned in important nursery areas for cod is not known; the assumption is that when juvenile cod migrate from the coastal nursery areas to deeper areas, or when migrating from the deeper spawning areas to the coastal nursery areas, they pass the areas where the Polish OWF are planned. The assumption therefore is that OWF will mainly contribute to the juvenile cod life stage survival and to a lesser extent to that of adult cod. Hence, Polish OWF may improve the fitness of juvenile and adult cod, and at some point add to cod stock regeneration.

Scale changes in OWF

According to rough estimates, the first planned Polish OWF may add a few percent of hard substrate to the shallow offshore Polish waters. The increase in food production is assumed to be linear to the surface of hard substrate added to these waters. Thus, also the increase in individual cod fitness is expected to be linear with the surface of hard substrate added.

Another assumption is that fisheries will be prohibited within OWF; the benefit from going from one turbine to an array is therefore expected to be linear as well. From fishers' behaviour in the southern North Sea, it can be expected that they will fish closely around OWF to profit from any 'spill-over' effects of OWF. The assumption therefore is that any increase in individual, adult, cod growth will benefit the individual fisherman, but not add to the chances of stock fitness.

Juvenile cod may escape from fisherman fishing for spill-over, since the cod fishery will be a single-species fishery, following mesh-size rules closely. The assumption is that regulated mesh size will catch cod (females?) at 50% fecundity. Hence, some fertile adult cod will escape being caught, and may add to the fitness of the stock.

A more than linear increase is expected to come from a scaling up of OWF in the southern Baltic: at some point, the fishing pressure will not 'keep up' with the number of OWF, and an increasing number of fertile cod will escape the fishing pressure.

Maximisation of OWF scale effects

It should be noted that there are two main limitations currently known hampering cod stock recovery of the eastern Baltic cod:

- Spawning areas of cod are in deeper, often hypoxic waters. Only after an influx of North Sea water, the spawning areas of cod are refreshed and a good recruitment of juvenile cod is possible.
- Herring and sprat in the Baltic is currently mainly distributed in the mid-Baltic, and only a limited amount of herring is present in the southern Baltic.

Next to this, the increase in common seals in the southern Baltic may exert an extra predation pressure on cod.

5.3.3 Irish Sea

Case study – Walney Extension, eastern Irish Sea

The sub-group chose to focus on an existing wind farm and a consented extension in the eastern Irish Sea. The area was spatially delimited using the ICES Rectangle VIIa – Irish Sea. This area has a significant amount of bivalve culture in the form of the Blue Mussel (*Mytilus edulis)* bottom culture – i.e. colonisation of hard surfaces (as opposed to rope culture). The sub-group assumed that this type of culture could have effects on local population abundance and distribution. Any effect at the population level would in part be determined by the existing location and extent of the naturally occurring mussel beds and the prevailing hydrographic conditions affecting dispersal, up and downstream of the beds.

As a hard surface MRED structures would provide an ideal opportunity for colonisation which is supported by studies from many wind farms in the Irish and North Sea where colonisation of the turbine foundation is high. To consider the scale of effects it was assumed that there would be even coverage of the turbine. Another assumption was that the predominant water currents were from south to north and west to east. The number of wind turbine foundations already existing and the increase with the extension were regarded as likely to cause a meaningful change in the mussel occurrence and abundance. The mussel early life history stage time in the water column would likely be short owing to increased encounter rate with hard surfaces provided by the turbines, less competition for early colonisers and a faster growth rate. However, there would likely be patchiness in food availability for the mussels and predators are known to take advantage of the mussel growth on turbines. There is also the potential influence of invasive species on the turbines which may have an impact.

In terms of timescale of meaningful change, if a May/June settlement time with reproduction occurring with several weeks is assumed, there should be within 2-3 years enough mussels of harvestable size.

In terms of spatial scale the sub-group suggested that within a windfarm the changes in mussel abundance and biomass would be sufficient to have an impact in terms of local fisheries benefit. It was recognised that it was important to know the baseline population that would feed the colonisation of the turbines, knowledge on the connectivity between a source site and the turbine foundation and the length of time for the life stages to colonise. Furthermore, it would be necessary to understand the existing fishery.

At the end of the discussion the sub-group was satisfied that this approach of choosing a real example was useful in addressing the question about at what scale meaningful change can occur.

5.4 ToR B: Knowledge improvement

ToR B – Review progress on filling knowledge gaps relating to the benthic ecosystem including differentiation among MRE technologies using e.g. reports of national activities

Jennifer Dannheim gave an introduction to the knowledge ToR by summarising the work that was done by WGMBRED over the last years. This ToR is ongoing whereby, information and research relating to offshore renewable devices is continually reviewed with a view to identifying knowledge gaps relating to the benthic ecosystem including differentiation among MRE technologies using e.g. reports of national activities.

The goal of the work during 2017 is to expand the matrices of effects to encompass those devices not considered in the knowledge publication (Dannheim, Degraer, Jackson *et al.* unpubl.) which considered fixed wind devices only. An overview was provided of the progress on the ToR to date whereby the focus on the knowledge publication was summarised. Approximately 150 papers were reviewed for content. The publication has highlighted a number of knowledge gaps in relation to benthos habitats and marine renewable devices. Examples of knowledge gaps relate to:

- Three dimensional artificial structures modify the hydrodynamic conditions which potentially increase the food availability to filter-feeders and the settlement success and species occurrence in the surrounding soft-sediment;
- Artificial structures might influence the colonization by non-indigenous species through new shipping activities related to offshore wind farms;
- The reduction of the phytoplankton' primary production generated by an increase in turbidity;
- The introduction of noise and vibration potentially extending over large spatial and temporal scales.

Furthermore, a number of recommendations were made in relation to benthos research (and monitoring) in and around marine renewable devices:

- Using hypothesis driven approaches for an improved understanding of ecological patterns and processes on local scales (field studies or experiments);
- Defining scales that are of ecological relevance and particularly look at large scale effects, supported by the hypothesis- driven research at smaller scales (i.e. local effects) in combination with modelling approaches in order to upscale potential ecological changes;
- Combining benthic research into integrated holistic management approaches to assure a sustainable use of benthic services and goods which are of societal and particularly ecological relevance (i.e. food webs, biogeochemical changes, biodiversity).

In order to progress this ToR, it was proposed to update the knowledge base in relation to specific marine renewable devices which will be informed by ongoing research and national reports. Questionnaires were sent to the national experts in order to get an overview which marine renewable energy devices (fixed and floating wind devices, tidal devices and wave devices) are already installed in the different countries. All information was summarised in two tables (Table 1, Table 2).

Table 1. Number of devices, areal extent (km²) and capacity of fixed and floating wind farm devices, tidal and wave devices (in use, under construction and planned) for Belgium, the Netherlands, Germany, United Kingdom and France.

		fixed wind devices			floating wind devices			tidal devices			wave devices		
	Parameter	**in use**	**under construction**	**planned**	**in use**	**under construction**	**planned**	**in use**	**under construction**	**planned**	**in use**	**under construction**	**planned**
Belgium	no. of devices	232	42	137-215									NA[3]
	areal extent (km²)	total: 238											16.72
	capacity (MW)	average: 3-8/turbine											NA
Nether lands	no. of devices	139	150	291				8	18				
	areal extent (km²)	49	70	236				2.05	1.8				
	capacity (MW)	357	600	2448									
Germa-ny	no. of devices	702	1376	6689									
	areal extent (km²)	366	770	4868									
	capacity (MW)	3013	7355	37834									
United King-dom	no. of devices	1578	362	1944			1	5	1233	398	4	NA[4]	28
	areal extent (km²)	4-35/OWF; newer: up to 845					15	NA	NA	NA	NA	NA	NA
	capacity (MW)	average: 5-10/turbine					6	0.03-30/device, average: 2.58			0.02-1.95/device		
France	no. of devices			424									
	areal extent (km²)			445									
	capacity (MW)			2916									

[3] Unknown number of devices

[4] Two projects with unknown number of devices

Table 2. General environmental settings, i.e. water depth (m), distance to coast (km), water current speed (m/s) and predominant bottom type, fixed and floating wind farm devices, tidal and wave devices are deployed in Belgium, the Netherlands, Germany, United Kingdom and France.

Device type	**Parameter**	**Belgium**	**Netherlands**	**Germany**	**United Kingdom**	**France**
fixed wind devices	water depth (m)	20-40	15-38	25-50	up to 60	up to 30
	distance to coast (km)	20-60	10-80	11-237	1-245	10-25
	predominant bottom type	sand-coarse sand	sand	fine-muddy sand		fine sand-hard bottom, mainly coarse
	water current speed (m/s)	0-2	~0.5	0.2-0.4	NA	strong currents
floating wind devices	water depth (m)				95-120	
	distance to coast (km)				25-30	
	predominant bottom type				sand-gravel	
	water current speed (m/s)				NA	
tidal devices	water depth (m)		10-30		>5	
	distance to coast (km)		0-100		1-6.5	
	predominant bottom type		sand		NA	
	water current speed (m/s)		0.5-1		>1.5	
wave devices	water depth (m)	25-40			up to >50	
	distance to coast (km)	0.5-50			2-16	
	predominant bottom type	sand-coarse sand			NA	
	water current speed (m/s)	0-2			NA	

In addition, it was proposed that the likely interactions between specific devices (i.e., floating wind, wave and tidal) be elucidated using the template (specific hypotheses) and scoring system (following Bergström *et al.* 2014) presented in the ICES (2015)[5]. A number of guiding principles were discussed and adopted in order to complete this exercise:

1) In order to progress, it was advised that a clear methodology be defined and that all of the characteristics of the particular devices be taken into account when considering interactions (e.g., likely different anchor systems etc.).

2) Furthermore, in order to ensure consistency of approach, the methodology applied and scoring systems used for each device should be similar to that used for fixed wind devices and presented in the ICES (2015). The confidence scoring system similarly applied.

3) It is important, given the types of devices that the ranges of habitats over which devices might be located, that effects will be broader than those generally considered for fixed wind devices (i.e. sedimentary habitats). For example, hard substrate might not be a deterrent to locating anchored devices in a waterbody. In addition, the nature of the device might also result in location of devices in more confined areas (e.g. estuarine areas) where interactions/risks might be greater.

4) It was considered important that full consensus should be sought within the group as to the extent and 'significance' of the effect. The significance, i.e. the sensitivity scoring, was carried out in relation to the sensitivity of fixed wind farm devices if the sensitivity of the effect was less (-), equal (=) or higher (+) compared to fixed wind farm devices (Table 3)

5) While engaging in the exercise it was considered important to identify pathways of interactions similar to those identified in the fixed wind assessment. It was considered important that differences be also identified and that the justification for these be clearly communicated for these hypotheses. These will be important in identifying knowledge gaps pertaining to the specific devices. These differences would apply to the existing hypotheses but would also lead to the creation of device-specific hypotheses. Clear justification must be provided for the proposal of new hypotheses.

[5] ICES. 2015. Report of the Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED), 21–25 April 2015, Oban, Scotland, United Kingdom. ICES CM 2015/SSGEPI:17. 49 pp.

Table 3. Fixed wind farm devices: Hypothesized cause-effect relationships related to fixed wind farm devices and different pressure groups (topic = introduction of energy effects (IEE), artificial reef effects (ARE), mechanical sea-floor disturbance (MSD)). Scoring for the effect size of sensitivity (SN, i.e. magnitude of the effect) (scores: 1 = low, 2 = moderate, 3 = high) is listed as a reference for other renewable energy devices, i.e. sensitivity of other devices was scored as the effect being less (-), equal (=) or higher (+) compared to fixed offshore wind farms devices.

Hypothesis	topic	SN
Vibration and noise might induce avoidance behaviour and reduce fitness of sensitive organisms, thereby potentially changing population structure and distribution patterns (FR H)	IEE	3
Altered food availability to filter-feeders (BD m)	ARE	3
Colonisation by non-indigenous species through transport on shipping, ballast water, translocated equipment	ARE	3
Modified currents/ hydrodynamic conditions will determine settlement success and species occurrences in the surrounding natural substrates (FR G, BD i, BCR M)	ARE	3
Three-dimensional artificial structures which extend through the entire water column will affect local hydrodynamic conditions such as tidal and wind induced currents (FR O, BCR N, BD f)	ARE	2.5
Turbidity caused by suspended matter reduces light penetration into the water column thereby reducing the primary production of photosynthetically active phytoplankton (BCR D)	MSD	2.5
Suspension-feeding fouling organisms extract plankton and suspended matter from the water column and thereby decreasing turbidity (BCR E, BD o, BCR F)	ARE	3
Shipping noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K3, BD a3)	IEE	2
The addition of artificial hard structures will change the morphology and the complexity of benthic habitats. Alters types and amount of habitat (FR A, BCR A, BD e)	ARE	3
Organisms from higher trophic levels (e.g. fish) are attracted/aggregate to the physical artificial structures for shelter (FR B)	ARE	3
Organisms from higher trophic levels forage on the assemblages on the artificial structures and in the surrounding natural habitats (FR D)	ARE	3
Hard-substrate fauna will profit from opportunities in natural habitats and vice versa (BD t)	ARE	3
A specific hard bottom assemblage (fouling and mobile megafauna) consisting of primary and secondary producers will colonise the new and complex artificial habitat (FR C, BD p, BCR B)	ARE	3
Export of organic matter released by the fouling and megafauna community on the artificial structure provides food for benthic communities in the nearby natural substrate (FR E, BCR C)	ARE	3
Fouling organisms themselves, such as mussels, increase structural complexity of the artificial habitat, thereby providing settlement space for other benthic organisms (FR F, BD w)	ARE	3
Altered rates of sedimentation (influences benthic anoxia, anaerobiosis and presence of H2S). Released organic material from the accumulated fouling community on the artificial structure becomes deposited in the nearby sediments.	ARE	3

Hypothesis	topic	SN
Bacteria decomposition is accompanied by oxygen depletion and release of toxic H2S in the structures surrounding (BD k, BCR O)		
Construction noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K1, BD a1)	IEE	2
Change in sediments cause changes in diversity (BD #)	MSD	3
Deposition of particles from fouling assemblages such as shell debris alters granulometry of nearby sediments (BCR J, BD %)	ARE	3
Changes in the current conditions/altered hydrodynamics resuspend fine inorganic and organic sediment fractions in the water column and cause scour effects (BCR K, BD n)	ARE	1
Anaerobic and/or toxic (H2S) conditions in the surrounding sediment of the structure cause organisms mortality in adjacent natural habitats (BCR P)	ARE	3
Changes in benthic anoxia affects mortality/colonisation of natural habitats (BD S)	ARE	3
Operational noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K2, BD a2)	IEE	2
Direct mortality, reduction in fitness or altered function through removal, abrasion, smothering, or increased sedimentation (BD b)	MSD	2
Benthic species are sensitive to sediment conditions and thus community structure and function will change in response to the altered habitat (BCR H)	MSD	3
Changes in water flow can lead to turbulences that cause resuspension of fine sediment fractions. The export of fine sediments will cause scour and select for coarse sediment in the surrounding of the artificial structures (BCR I, BD v)	ARE	2
Electromagnetic fields might affect the migratory behaviour of sensitive species thereby potentially changing population structure and distribution patterns (FR J)	IEE	1
Conduction of electricity through high-voltage cables induce electromagnetic fields (FR L)	IEE	1
Sediment disturbance such as dredging and cable laying during the construction phase will resuspend formerly deposited organic matter from the sediment (BCR L)	MSD	1
Direct mortality or reduction in fitness through damage caused by sound waves of the natural substrates. Changes in distribution: introduced noise will cause distribution changes in natural and artificial hard-substrate fauna (BD c, d)	IEE	1.5
Disturbance of the sea floor by dredging, disposal of extracted sediment and cable laying will change the granulometry of local sediments and thus benthic habitats (BCR G, BD u)	MSD	2

Three sub- groups were created to consider the three device types and a chair/rapporteur was appointed (Tidal – Arjen Boon, Wave – Stephen Degraer, Floating – Paul Causon). The sub-groups reported back to the broader group. (Reports included below).

5.4.1 Tidal devices

The group considered each of the 31 hypotheses and the applicability to the tidal energy devices at the scale of the device (Table 4). Using the fixed wind turbines as a benchmark, tidal devices were considered if they would have a greater or lesser effect for each hypothesis and scored accordingly using the scoring template detailed in the Knowledge paper. Importantly, tidal devices were divided into three subgroups, anchored devices, piled or drilled devices and gravity based devices. Anchored devices considered those that were suspended within the water column but also those that would float at the surface. Overall, piled and drilled devices were largely considered to have similar effects as fixed wind turbines since these are also typically piled. Anchored tidal devices were typically considered to have a lesser effect than fixed wind turbines, whereas gravity devices were typically considered to have a larger effect based on the surface area available for hard substrate species. However, for many hypotheses the spatial and temporal scales were less likely to differ than the magnitude of the effects (sensitivity) identified.

The most obvious differences were those hypotheses that needed to take into consideration the change in hydrodynamics which are greater in spatial scale for tidal devices than for fixed wind devices given the extraction of energy from the system. The second most obvious difference was the influence of the submerged moving parts of tidal devices at the device itself in terms of space available for colonisation. Moving parts were acknowledged to influence biofouling on the devices differently to fixed wind farms (i.e. the rotors), but these effects were considered at the base of the devices where appropriate. One hypothesis was added to the list which related to potential collision with benthic species, this is an important difference to offshore wind effects. The second hypothesis added to the list was in relation to the possibility of barotrauma to larva from the pressure of moving parts of tidal devices. Additionally, not all devices stretch all the way through the water column so the spatial influences in 3D may be less in the vertical dimension. The most important outcome was that there are many different variations of devices even within each category identified and the effects will likely vary with the specific device type (e.g. http://www.emec.org.uk/marine-energy/tidal-devices/).

Table 4. Tidal devices: Hypothesized cause-effect relationships related to tidal devices (anchored, piled/drilled, gravity based) and different pressure groups (topic = introduction of energy effects (IEE), artificial reef effects (ARE), mechanical sea-floor disturbance (MSD). Scoring for the effect size in spatial extent (SE), temporal extent (TE) and sensitivity (SN, i.e. magnitude of the effect) (scores: 1 = low, 2 = moderate, 3 = high). Sensitivity was scored in relation to fixed offshore wind farm devices, i.e. if the sensitivity of the effect was less (-), equal (=) or higher (+) as those by offshore wind farms.

Hypothesis	**topic**	**anchored**			**piled/drilled**			**gravity based**		
		SE	**TE**	**SN**	**SE**	**TE**	**SN**	**SE**	**TE**	**SN**
Vibration and noise might induce avoidance behaviour and reduce fitness of sensitive organisms, thereby potentially changing population structure and distribution patterns (FR H)	IEE	1	1	-	3	3	=	1	1	-
Altered food availability to filter-feeders (BD m)	ARE	1	2	-	3	2	=	3	2	-
Colonisation by non-indigenous species through transport on shipping, ballast water, translocated equipment	ARE	3	2	=	3	2	=	3	2	=
Modified currents/ hydrodynamic conditions will determine settlement success and species occurences in the surrounding natural substrates (FR G, BD i, BCR M)	ARE	3	2.5	+	3	2.5	+	3	2.5	+
Three-dimensional artificial structures which extend through the entire water column will affect local hydrodynamic conditions such as tidal and wind induced currents (FR O, BCR N, BD f)	ARE	2	2	-	3	2	-	2	2	-
Turbidity caused by suspended matter reduces light penetration into the water column thereby reducing the primary production of photosynthetically active phytoplankton (BCR D)	MSD	1	2	-	3	2	=	2	2	+
Suspension-feeding fouling organisms extract plankton and suspended matter from the water column and thereby decreasing turbidity (BCR E, BD o, BCR F)	ARE	1	2	-	2	2	=	2.5	2	+
Shipping noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K3, BD a3)	IEE	2.5	3	=	2.5	3	=	2.5	3	=
The addition of artificial hard structures will change the morphology and the complexity of benthic habitats. Alters types and amount of habitat (FR A, BCR A, BD e)	ARE	1	2.5	-	1	2.5	=	1	2.5	+
Organisms from higher trophic levels (e.g. fish) are attracted/aggregated to/at the physical	ARE	1	2.5	-	1	2.5	-	1	2.5	-

Hypothesis	topic	anchored			piled/drilled			gravity based		
		SE	TE	SN	SE	TE	SN	SE	TE	SN
artificial structures for shelter (FR B)										
Organisms from higher trophic levels forage on the assemblages on the artificial structures and in the surrounding natural habitats (FR D)	ARE	1	2.5	?	1	2.5	?	1	2.5	?
Hard-substrate fauna will profit from opportunities in natural habitats and vice versa (BD t)	ARE	1	2.5	=	1	2.5	=	1	2.5	=
A specific hard bottom assemblage (fouling and mobile megafauna) consisting of primary and secondary producers will colonise the new and complex artificial habitat (FR C, BD p, BCR B)	ARE	1	2.5	-	1	2.5	=	1	2.5	=
Export of organic matter released by the fouling and megafauna community on the artificial structure provides food for benthic communities in the nearby natural substrate (FR E, BCR C)	ARE	1	2.5	-	1	2.5	=	1	2.5	=
Fouling organisms themselves, such as mussels, increase structural complexity of the artificial habitat, thereby providing settlement space for other benthic organisms (FR F, BD w)	ARE	1	2.5	-	1	2.5	=	1	2.5	=
Altered rates of sedimentation (influences benthic anoxia, anaerobiosis and presence of H2S). Released organic material from the accumulated fouling community on the artificial structure becomes deposited in the nearby sediments. Bacteria decomposition is accompanied by oxygen depletion and release of toxic H2S in the structures surrounding (BD k, BCR O)	ARE	1	2.5	-	1	2.5	=	1	2.5	=
Construction noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K1, BD a1)	IEE	1	1	-	3	1	=	1	1	-
Change in sediments cause changes in diversity (BD #)[6]	MSD	3	3	-	3	3	+	3	3	+
Deposition of particles from fouling assemblages such as shell debris alters granulometry of nearby sediments (BCR J, BD %)	ARE	1	2/ 3	-	1	2/ 3	=	1	2/3	=
Changes in the current conditions/altered hydrodynamics resuspend fine inorganic and organic sediment fractions in the water column and cause scour effects (BCR K, BD n)	ARE	3	2	-	3	2	+	3	2	+

[6] potentially different for floating devices which are away from the seabed

Hypothesis	**topic**	**anchored**			**piled/drilled**			**gravity based**		
		SE	**TE**	**SN**	**SE**	**TE**	**SN**	**SE**	**TE**	**SN**
Anaerobic and/or toxic (H2S) conditions in the surrounding sediment of the structure cause organisms mortality in adjacent natural habitats (BCR P)	ARE	1	2	-	1	2	-	1	2	-
Changes in benthic anoxia affects mortality/colonisation of natural habitats (BD S)	ARE	1	2	-	1	2	-	1	2	-
Operational noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K2, BD a2)	IEE	no knowledge what noise is caused by the rotors in water								
Direct mortality, reduction in fitness or altered function through removal, abrasion, smothering, or increased sedimentation (BD b)[7]	MSD	2.5	2	=	2.5	2	=	2.5	2	=
Benthic species are sensitive to sediment conditions and thus community structure and function will change in response to the altered habitat (BCR H)	MSD	2	2	+	2	2	+	2	2	+
Changes in water flow can lead to turbulences that cause resuspension of fine sediment fractions. The export of fine sediments will cause scour and select for coarse sediment in the surrounding of the artificial structures (BCR I, BD v)	ARE	3	2	=	3	2	=	3	2	=
Electromagnetic fields might affect the migratory behaviour of sensitive species thereby potentially changing population structure and distribution patterns (FR J)	IEE	1	2	=/+	1	2	=/+	1	2	=/+
Conduction of electricity through high-voltage cables induce electromagnetic fields (FR L)	IEE	1	2	=/+	1	2	=/+	1	2	=/+
Sediment disturbance such as dredging and cable laying during the construction phase will resuspend formerly deposited organic matter from the sediment (BCR L)	MSD	3	1	=	3	1	=	3	1	=
Direct mortality or reduction in fitness through damage caused by sound waves of the natural substrates. Changes in distribution: introduced noise will cause distribution changes in natural and artificial hard-substrate fauna (BD c, d)	IEE	1	1	-	2	1	=	1	1	-
Disturbance of the sea floor by dredging, disposal of extracted sediment and cable laying will	MSD	2	1	=	2	1	=	2	1	=

[7] perhaps also applicable to the operational phase but not from dredging/disposal

Hypothesis	topic	anchored			piled/drilled			gravity based		
		SE	TE	SN	SE	TE	SN	SE	TE	SN
change the granulometry of local sediments and thus benthic habitats (BCR G, BD u)										
NEW cause-effect relationship for tidal devices: Collision risk fish with device	ARE	2	2	3	2	2	3	2	3	3
NEW cause-effect relationship for tidal devices: Barotrauma benthic larvae	IEE	2	2	2	2	2	2	2	2	2

5.4.2 Wave devices

The subgroup on wave energy converters distinguished between fixed and anchored structures (Table 5). Fixed wave energy converters are devices attached to monopiles, while anchored converters are floating devices chained up to the bottom using a series of anchors.

Being mounted on monopiles, fixed wave energy converters were assessed nearly identical to offshore wind farms with regards to the spatial and temporal extent of environmental impacts, its consistency and confidence. Substantial deviations from offshore wind farms were hence identified only for anchored wave energy converters. These differences mainly concern two criteria: sensitivity and confidence.

For anchored wave energy converters, sensitivity was assessed lower for 16 out of 31 cause-effect relationships. These lower values are to be found mainly in the artificial reef effect category. These are derived predominantly from the fact that the anchored devices were considered offering less artificial habitat than offshore windfarms (having less impact on e.g. hydrodynamics) and – consequently – hosting a lower amount of epifouling organisms (having less impact on e.g. food webs and organic enrichment). However, the sensitivity of wave energy converters was assessed higher for seven cause-effect relationships. All seven relationships refer to the supposedly high dynamics of the anchors and the chain, permanently disturbing the seabed, which is reflected mainly in altered cause-effect relationships in relation to mechanical seafloor disturbance.

For anchored wave energy converters, confidence was assessed lower for 18 cause-effect relationships. This discrepancy refers to the lack of knowledge on environmental effects of this fairly novel and hence largely unstudied renewable energy development. This is much in contrast with fixed device, because here we can rely on the vast amount of data referring to monopile impacts on the environment.

Table 5. Wave devices: Hypothesized cause-effect relationships related to wave devices (anchored, piled/drilled) and different pressure groups (topic = introduction of energy effects (IEE), artificial reef effects (ARE), mechanical sea-floor disturbance (MSD). Scoring for the effect size in spatial extent (SE), temporal extent (TE) and sensitivity (SN, i.e. magnitude of the effect) as well as consistency (CS) between biotopes (scores: 1 = low, 2 = moderate, 3 = high). The amount of knowledge available (confidence, CF) was scored from 1-4, i.e. 1 = very low, 2 = low, 3 = moderate, 4 = high. Sensitivity was scored in relation to fixed offshore wind farm devices, i.e. if the sensitivity of the effect was less (-), equal (=) or higher (+) as those by offshore wind farms.

Hypothesis	Topic	piled/drilled					anchored				
		SE	TE	SN	CS	CF	SE	TE	SN	CS	CF
Vibration and noise might induce avoidance behaviour and reduce fitness of sensitive organisms, thereby potentially changing population structure and distribution patterns (FR H)	IEE	3	2	-	3	1	3	2	-	3	1
Altered food availability to filter-feeders (BD m)	ARE	3	2	=	2	3	2	2	-	2	1
Colonisation by non-indigenous species through transport on shipping, ballast water, translocated equipment	ARE	3	2	=	2	3	3	2	=	2	3
Modified currents/ hydrodynamic conditions will determine settlement success and species occurrences in the surrounding natural substrates (FR G, BD i, BCR M)	ARE	2	2.5	=	3	3	1	2.5	-	3	1
Three-dimensional artificial structures which extend through the entire water column will affect local hydrodynamic conditions such as tidal and wind induced currents (FR O, BCR N, BD f)	ARE	3	2	=	2	2	2	2	-	2	1
Turbidity caused by suspended matter reduces light penetration into the water column thereby reducing the primary production of photosynthetically active phytoplankton (BCR D)	MSD	3	2	=	1	2	4	2	+	1	2
Suspension-feeding fouling organisms extract plankton and suspended matter from the water column and thereby decreasing turbidity (BCR E, BD o, BCR F)	ARE	2	2	=	2	3	1	2	-	2	1
Shipping noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K3, BD a3)	IEE	2.5	3	=	3	2	2.5	3	=	3	2
The addition of artificial hard structures will change the morphology and the complexity of benthic habitats. Alters types and amount of habitat (FR A, BCR A, BD e)	ARE	1	2.5	=	3	4	1	2.5	=	3	4
Organisms from higher trophic levels (e.g. fish) are attracted/aggregated to/at the physical artificial structures for shelter (FR B)	ARE	1	2.5	=	3	3	1	2.5	=	3	3

Hypothesis	Topic	piled/drilled					anchored				
		SE	TE	SN	CS	CF	SE	TE	SN	CS	CF
Organisms from higher trophic levels forage on the assemblages on the artificial structures and in the surrounding natural habitats (FR D)	ARE	1	2.5	=	3	4	1	2.5	-	3	1
Hard-substrate fauna will profit from opportunities in natural habitats and vice versa (BD t)	ARE	1	2.5	=	3	4	1	2.5	-	3	1
A specific hard bottom assemblage (fouling and mobile megafauna) consisting of primary and secondary producers will colonise the new and complex artificial habitat (FR C, BD p, BCR B)	ARE	1	2.5	=	3	4	1	2.5	-	3	4
Export of organic matter released by the fouling and megafauna community on the artificial structure provides food for benthic communities in the nearby natural substrate (FR E, BCR C)	ARE	1	2.5	=	3	3	1	2.5	-	3	3
Fouling organisms themselves, such as mussels, increase structural complexity of the artificial habitat, thereby providing settlement space for other benthic organisms (FR F, BD w)	ARE	1	2.5	=	3	4	1	2.5	-	3	4
Altered rates of sedimentation (influences benthic anoxia, anaerobiosis and presence of H2S). Released organic material from the accumulated fouling community on the artificial structure becomes deposited in the nearby sediments. Bacteria decomposition is accompanied by oxygen depletion and release of toxic H2S in the structures surrounding (BD k, BCR O)	ARE	1	2.5	=	1	3	1	2.5	-	1	3
Construction noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K1, BD a1)	IEE	3	1	=	3	3	2	1	-	3	1
Change in sediments cause changes in diversity (BD #)	MSD	1.5	2	=	1	3	1.5	2	=	1	1
Deposition of particles from fouling assemblages such as shell debris alters granulometry of nearby sediments (BCR J, BD %)	ARE	1	2	=	2	3	1	2	- or =	2	1
Changes in the current conditions/altered hydrodynamics resuspend fine inorganic and organic sediment fractions in the water column and cause scour effects (BCR K, BD n)	ARE	3	2	=	1	4	3	2	+	1	1
Anaerobic and/or toxic (H2S) conditions in the surrounding sediment of the structure cause organisms mortality in adjacent natural habitats (BCR P)	ARE	1	2	=	1	3	1	2	-	1	3
Changes in benthic anoxia affects mortality/colonisation of natural habitats (BD S)	ARE	1	2	=	1	3	1	2	-	1	3
Operational noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect perfor-	IEE	3	2	-	3	1	3	2	-	3	1

Hypothesis	Topic	piled/drilled					anchored				
		SE	TE	SN	CS	CF	SE	TE	SN	CS	CF
mance and behaviour of sound-sensitive organisms (FR K2, BD a2)											
Direct mortality, reduction in fitness or altered function through removal, abrasion, smothering, or increased sedimentation (BD b)	MSD	1	2	=	1	3	1	2	+	1	1
Benthic species are sensitive to sediment conditions and thus community structure and function will change in response to the altered habitat (BCR H)	MSD	1.5	1	=	3	4	1.5	1	+	3	1
Changes in water flow can lead to turbulences that cause resuspension of fine sediment fractions. The export of fine sediments will cause scour and select for coarse sediment in the surrounding of the artificial structures (BCR I, BD v)	ARE	1	2	=	1	3	1	2	+	1	1
Electromagnetic fields might affect the migratory behaviour of sensitive species thereby potentially changing population structure and distribution patterns (FR J)	IEE	2	2	=	1	2	2	2	?	1	1
Conduction of electricity through high-voltage cables induce electromagnetic fields (FR L)	IEE	2	2	=	3	4	2	2	=	3	1
Sediment disturbance such as dredging and cable laying during the construction phase will resuspend formerly deposited organic matter from the sediment (BCR L)	MSD	3	1	=	1	4	3	1	=	1	1
Direct mortality or reduction in fitness through damage caused by sound waves of the natural substrates. Changes in distribution: introduced noise will cause distribution changes in natural and artificial hard-substrate fauna (BD c, d)	IEE	2	1	=	2	3	2	1	=	2	1
Disturbance of the sea floor by dredging, disposal of extracted sediment and cable laying will change the granulometry of local sediments and thus benthic habitats (BCR G, BD u)	MSD	1.5	1	=	1	4	1.5	1	+	1	1

5.4.3 Floating wind turbines devices

In the discussion for scoring for floating wind turbines it was considered that the spatial extent of noise and the sensitivity would be low in comparison with fixed wind turbines (Table 6). As connectivity to the benthos would be via the moorings (e.g. chains and anchors) rather than a fixed foundation the transference of mechanical noise would be reduced. Additionally, in deep water gravity or suction anchors are expected to be utilised. Therefore, the high impact noise of pile driving would not be introduced. Temporal noise will only effect the benthic environment during the operation of the turbine. As it is indiscriminate, noise would affect multiple biotopes.

Transfer of organic matter, deposition of particles, and sedimentation due to epibenthic growth on the structure was also given a medium to high score for spatial scale, although it is dependent on currents, as it is likely to be dispersed widely by currents as it sinks through the water column. Due to wide dispersal, the sensitivity was considered to be less than for fixed wind turbines. Once on the seabed organic and inorganic matter would not be greatly influenced by wave and wind action. The temporal extent was thought to be medium to high as moorings and anchors would most likely remain in place after turbines are decommissioned.

Colonisation of non-indigenous species was scored highly for spatial scale, due to the ability of the floating to be relocated. Turbines may be recovered and towed to shore for maintenance to be decommissioned. Temporal extent was also scored high as non-native species may persist long after the turbines are decommissioned. For these reasons, sensitivity was considered to be greater for floating wind turbines than for fixed wind turbines.

Four additional effects were identified that are specific to floating wind turbines.

1) Potential for chain abrasion of the seabed due to the mooring system;

2) Cable designs whether floating or on seabed may present different outcomes in terms of benthic fouling community;

3) Potential for large deposition following cleaning of cables and moorings;

4) Exclusion of tow fishing due to moorings and, if 'daisy-chained', cables.

Table 6. Floating wind farm devices: Hypothesized cause-effect relationships related to floating wind farm devices and different pressure groups (topic = introduction of energy effects (IEE), artificial reef effects (ARE), mechanical sea-floor disturbance (MSD). Scoring for the effect size in spatial extent (SE), temporal extent (TE) and sensitivity (SN, i.e. magnitude of the effect) as well as consistency (CS) between biotopes (scores: 1 = low, 2 = moderate, 3 = high). The amount of knowledge available (confidence, CF) was scored from 1-4, i.e. 1 = very low, 2 = low, 3 = moderate, 4 = high. Sensitivity was scored in relation to fixed offshore wind farm devices, i.e. if the sensitivity of the effect was less (-), equal (=) or higher (+) as those by offshore wind farms.

Hypothesis	**Topic**	**SE**	**TE**	**SN**	**CF**	**CS**
Vibration and noise might induce avoidance behaviour and reduce fitness of sensitive organisms, thereby potentially changing population structure and distribution patterns (FR H)[8]	IEE	1	2	-	1	3
Altered food availability to filter-feeders (BD m)	ARE	3	2	-	1	3
Colonisation by non-indigenous species through transport on shipping, ballast water, translocated equipment	ARE	3	3	+	2	3
Modified currents/ hydrodynamic conditions will determine settlement success and species occurrences in the surrounding natural substrates (FR G, BD i, BCR M)[9]	ARE	1/2	2	-	2	2
Three-dimensional artificial structures which extend through the entire water column will affect local hydrodynamic conditions such as tidal and wind induced currents (FR O, BCR N, BD f)	ARE	1	2	-	2	3
Turbidity caused by suspended matter reduces light penetration into the water column thereby reducing the primary production of photosynthetically active phytoplankton (BCR D)[10]	MSD	1	2	-	2	2
Suspension-feeding fouling organisms extract plankton and suspended matter from the water column and thereby decreasing turbidity (BCR E, BD o, BCR F)	ARE	1	2	-	2	2
Shipping noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K3, BD a3)	IEE	2	2	-	2	3
The addition of artificial hard structures will change the morphology and the complexity of benthic habitats. Alters types and amount of habitat (FR A, BCR A, BD e)	ARE	2	3	=	2	2

[8] Potential strumming of mooring but less than a fixed device
[9] Depends on anchoring/mooring
[10] May depend on predominant substrate and mooring system

Hypothesis	**Topic**	**SE**	**TE**	**SN**	**CF**	**CS**
Organisms from higher trophic levels (e.g. fish) are attracted/aggregated to/at the physical artificial structures for shelter (FR B)	ARE	2	3	=	2	3
Organisms from higher trophic levels forage on the assemblages on the artificial structures and in the surrounding natural habitats (FR D)	ARE	2	3	-	1	2
Hard-substrate fauna will profit from opportunities in natural habitats and vice versa (BD t)[11]	ARE	1	3	-	1	1
A specific hard bottom assemblage (fouling and mobile megafauna) consisting of primary and secondary producers will colonise the new and complex artificial habitat (FR C, BD p, BCR B)[12]	ARE	2	3	+	1	3
Export of organic matter released by the fouling and megafauna community on the artificial structure provides food for benthic communities in the nearby natural substrate (FR E, BCR C)[13]	ARE	2/3	2	-	1	3
Fouling organisms themselves, such as mussels, increase structural complexity of the artificial habitat, thereby providing settlement space for other benthic organisms (FR F, BD w)	ARE	1	2/3	=[14]	2	3
Altered rates of sedimentation (influences benthic anoxia, anaerobiosis and presence of H2S). Released organic material from the accumulated fouling community on the artificial structure becomes deposited in the nearby sediments. Bacteria decomposition is accompanied by oxygen depletion and release of toxic H2S in the structures surrounding (BD k, BCR O)	ARE	2	2	+	1	3
Construction noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K1, BD a1)	IEE	2	1/2	-	1	3
Change in sediments cause changes in diversity (BD #)	MSD	1	3	-	1	1
Deposition of particles from fouling assemblages such as shell debris alters granulometry of nearby sediments (BCR J, BD %)[15]	ARE	2	3	=	2	2
Changes in the current conditions/altered hydrodynamics resuspend fine inorganic and organic sediment fractions in the water column and cause scour effects (BCR K, BD n)	ARE	1	3	-	1	1

[11] Depends on habitat/substrate
[12] Assuming mooring etc are permanent
[13] Potential for lots of organic matter/detritus but diluted over larger area
[14] Scale dependent
[15] Depends on scale of moorings and turbines

Hypothesis	Topic	SE	TE	SN	CF	CS
Anaerobic and/or toxic (H2S) conditions in the surrounding sediment of the structure cause organisms mortality in adjacent natural habitats (BCR P)[16]	ARE	1	2	-	1	1
Changes in benthic anoxia affects mortality/colonisation of natural habitats (BD S)	ARE	1	2	-	1	1
Operational noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K2, BD a2)	IEE	2	2	-	1	2
Direct mortality, reduction in fitness or altered function through removal, abrasion, smothering, or increased sedimentation (BD b)[17]	MSD	2	2	+	1	2
Benthic species are sensitive to sediment conditions and thus community structure and function will change in response to the altered habitat (BCR H)	MSD	1	2	-	1	1
Changes in water flow can lead to turbulences that cause resuspension of fine sediment fractions. The export of fine sediments will cause scour and select for coarse sediment in the surrounding of the artificial structures (BCR I, BD v)	ARE	2	3	-	1	1
Electromagnetic fields might affect the migratory behaviour of sensitive species thereby potentially changing population structure and distribution patterns (FR J)[18]	IEE	2	2	+	1	2
Conduction of electricity through high-voltage cables induce electromagnetic fields (FR L)	IEE	2	2	+	1	2
Sediment disturbance such as dredging and cable laying during the construction phase will resuspend formerly deposited organic matter from the sediment (BCR L)	MSD	2	1	-	2	2
Direct mortality or reduction in fitness through damage caused by sound waves of the natural substrates. Changes in distribution: introduced noise will cause distribution changes in natural and artificial hard-substrate fauna (BD c, d)	IEE	2	2	-	1	2
Disturbance of the sea floor by dredging, disposal of extracted sediment and cable laying will change the granulometry of local sediments and thus benthic habitats (BCR G, BD u) [19]	MSD	1	1	-	2	1

[16] Depends on depth and substrate and currents/tides
[17] Depends on mooring (i.e. catenary mooring on specific habitats)
[18] Depends on whether cable is mid-water or on seabed. We assume seabed contact
[19] Export cable to shore most likely

5.5 ToR C: Network Analysis

ToR C – Analysis of network and interactions amongst WGMBRED and other relevant groups including regulators, stakeholders, policy makers and scientists, in order to evaluate the impact of MBRED science

Network analysis is a systematic method of assessing the connectivity between individuals. This interconnectivity, when combined with information about individuals' membership of groups, generates new information on the way that groups interact, exchange knowledge and influence each other. These groups can include broad sectors such as researchers, regulators and policy makers. In this way, network analysis can reveal lines of communication between different sectors and indicate which groups/sectors are isolated, which are 'gatekeepers' (knowledge brokers) and which are highly integrated within other groups. The objective of the network analysis ToR, which is being led by Tom Wilding (WGMBRED) and Raeanne Miller (WGMRE) is to complete the data gathering phase by the end of June, the analysis by the end of October and to submit for publication by the end of the 2017.

The ICES WGs on 'Marine Benthal and Renewable Energy Developments' and 'Marine Renewable Energy' have combined efforts to assess communication between individuals working in the following sectors: Academic, consultancy, funders, Industry test centres, non-governmental organisations, unaffiliated, regulators and advisors (all within the marine renewable energy field). A 'SurveyMonkey' questionnaire was designed and iteratively checked by volunteers and then promoted during the 2017 meetings of both groups.

To date (May 2017), there have been >260 surveys completed from over 18 nations. Over 140 separate groups/organisations involved in marine renewables have been identified. Preliminary analysis indicates that the Ocean Energy Systems, Annex IV group was most 'central' and clustered with both European and North American groups. Within ICES, the Marine Renewable Energy group clustered with the European Wind Energy Association and the Scottish 'SpORRAn' group whilst the Marine Benthal and Renewable Energy Development group appears relatively isolated. Optimism in relation to the offshore wind sector is high whilst it is lower from both tidal-stream and wave power. The degree of optimism was relatively consistent across the various sectors (e.g. academic/regulators). Patterns of communication between sectors were complex but academics were the mostly highly connected sector (i.e. consultancies, regulators etc.) communicated with academics more than with any other sector.

5.6 ToR D: Indicators

ToR D – Identifying and operationalising relevant indicators in relation to assessing ecosystem functioning and change in relation to MBRED at scales related to ToR A.

In order to proceed with ToR D and to have a view on indicators from different angles, the WGMBRED experts Silvana Birchenough, Jean-Claude Dauvin and Arjen Boon gave introductory presentations to the WGMBRED:

Silvana Birchenough introduced the use of indicators, as a tool for guidance in decision making, widely used in the framework of international obligations (i.e. Water Framework Directive, Marine Strategy Framework Directive). Indicators can be structural or functional, univariate or multivariate, and should be used in an ecosystem framework. Indicators need to be (1) easy to understand; (2) sensitive and relevant for human activities; (3) tightly linked to specific human activities; (4) easy and accurately measurable; (5) affordable and feasible and (6) capable of proving early warning. Various aspects of the benthos (structural characteristics, functional characteristics based on functional traits) are often used in the framework of several international drivers (i.e. Marine Strategy Framework Directive, Water Framework Directive).

Jean-Claude Dauvin presented how benthos can be used as an indicator to assess Ecological Quality Status of soft bottoms. On the one hand, the benthic communities are easy to sample and they are considered as global indicators of disturbance, integrating information over time. On the other hand, there is a high cost associated to the full elaboration of benthic samples. Therefore, targeting specific aspects of benthic communities, reflecting specific pressures, is considered a promising way forward to cost-effective monitoring. A suitable ecological framework can be found in the Pearson-Rosenberg model, reflecting changes in community composition along a gradient of organic enrichment. This framework has been used to develop a suite of benthic indicators based on the relative composition of the macrobenthos where species are allocated to classes ranging from tolerant to sensitive species (i.e. AMBI). Further index development resulted in – amongst others – the m-AMBI (taking into account diversity), the BENTIX index (a simplified index, applied in Greece) and trait-based indices (i.e. the Infaunal Trophic Index [ITI]). To increase cost-efficiency, indices have been developed based on specific taxonomic groups (in contrast to the entire community), in combination with identification of the organisms to higher taxonomical level and/or classifying all organisms within a higher taxon as "sensitive". A recent study, BO2A index and the BPOFA index (Dauvin *et al.* 2016) showed that the loss of information was very low when polychaetes were identified only at family level and all amphipods were considered as a single sensitive group. As such, the more cost-effective BPOFA can be preferred as a surrogate of the BO2A index representing a simple effective benthic indicator for assessing the ecological status of coastal water masses.

Arjen Boon then introduced Critical Ecosystem Network Analysis (CENA) as a tool to map, prioritise and simplify complex causal ecological networks. A CENA approach was applied to the cause-effect relationships underlying the three Societally Important Issues (biogeochemical reactor, food resources and biodiversity) (ICES 2015). The approach was generic and not tailored to the specific case studies (Baltic Sea, western British and Irish Coast, North Sea) identified during WGMBRED 2016 (ICES 2016). Based on this presentation, the group realized that (1) the identified Societally Important Issues (SII) were actually spanning multiple ecosystem services, and (2) that the identified cause-effect relationships could be linked to ecosystem processes supporting the delivery of the ecosystem services. The group decided to follow the paper of Hattam *et al.* (2015) as a guidance document to translate the cause-effect relationships associated with the SSI's into an ecosystem functioning – ecosystem service concept for the three Societally Important Issues.

To address ToR D it was decided to go back to the original schematic presentation of all cause-effect relationships (instead of the three separate ones) to redefine the causal linkages between the SII and the possible indicators. Also it was decided that the group would redefine the SII into Ecosystem Services (ES), following Hattam *et al.* (2015, which basically is following CICES) but by critically looking at them again, since there may be disagreement with e.g. i.a. 'Nursery habitat' being a final ES. The group also considered the Montana paper (BEWG initiative, unpublished) and University of Liverpool report (under embargo at ETC/ICM, Culhane *et al.* unpublished). The WG split into three sub-groups to cover the SII, i.e. BCR – Biogeochemical reactor; FR – Food resources; BD – Biodiversity, in order to link functions possibly changed by the introduction of offshore renewable devices through pathways to the societal relevant issues and services and to define indicators to quantify functional changes following the conceptual scheme in Figure 1.

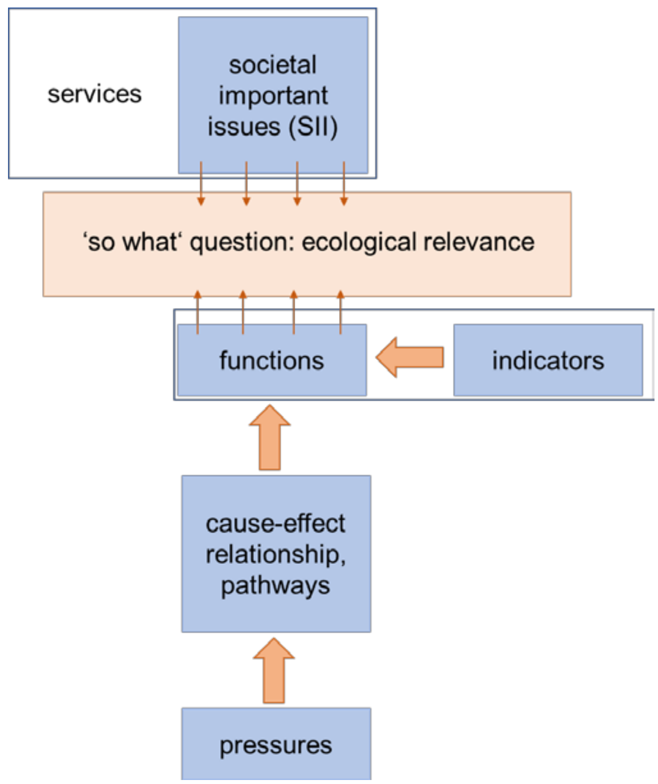

Figure 1. Conceptual scheme linking pressures to cause-effect pathways to functions and ecosystem services in order to identify adequate indicators.

Literature

Dauvin JC, Andrade H, de-la-Ossa-Carretero JA, Del-Pilar-Ruso Y, Riera R. 2016. Polychaete/amphipod ratios: An approach to validating simple, Ecological Indicators 63. 89-99.

Hattam C, Atkins JP, Beaumont N, Börger T, Böhnke-Henrichs A, Burdon D, Groot R de, Hoefnagel E, Nunes PALD, Piwowarczyk J, Sastre S, Austen MC (2015) Marine ecosystem services: Linking indicators to their classification. Ecological Indicators 49:61–75

ICES. 2015. Report of the Working Group on Marine Benthal and Renewable Energy Develop-ments (WGMBRED), 21–25 April 2015, Oban, Scotland, United Kingdom. ICES CM 2015/SSGEPI:17. 49 pp.

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5.6.1 Biogeochemical reactor

The breakout group first identified the pressures related to the installation of offshore renewable energy installations on the benthic environment. Pressure identification was based on the conceptual presentation of the biotic and abiotic processes linked to the biogeochemical reactor (Fig. 4, ICES 2016). Based on this scheme, "Mechanical sea floor disturbance" and "artificial reef effect" were considered to be the pressures resulting in possible important consequences for the benthic environment. In a next step, these pressures were linked with possibly disturbed ecosystem processes through the series of working hypotheses resulting from the WGMBRED activities in 2016 (ICES 2016). It was then possible to deduce a set of possibly affected ecosystem services. These ecosystem services were slightly modified from Hattam *et al.* (2015) to reflect the situation where offshore renewable energy installations are introduced in the marine environment. Tables 7 and 8 show the relationship between ecosystem services, ecosystem processes, pressures and cause-effect related hypotheses for both "Mechanical sea floor disturbance" and "artificial reef effect". The relevant cause-effect relationships are presented in Table 9.

Table 7. Linking ecosystem services and ecosystem functions with cause-effect hypotheses related to mechanical sea floor disturbances. Letters refer to the hypotheses expressed in Table 9.

Ecosystem service	Ecosystem function	Cause-effect hypotheses: Mechanical sea floor disturbances
Food provisioning: wild food	Primary production + Nutrient cycling	D / L
Food provisioning: farmed	Primary production + Nutrient cycling	
Climate regulation	Carbon mineralization Carbon sequestration	G / L G / L
"Waste treatment" (i.e. removal of excess nutrients	Nutrient cycling	H / G

Table 8. Linking ecosystem services and ecosystem functions with cause-effect hypotheses related to artificial reef effects. Letters refer to the hypotheses expressed in Table 9.

Ecosystem service	Ecosystem function	Cause-effect hypotheses: Artificial reef effects
Food provisioning: wild food	Primary production Nutrient cycling	C/E/F/K/N/Q3
Food provisioning: farmed	Primary production Nutrient cycling	C/E/F
Climate regulation	Carbon mineralization Carbon sequestration	C/O/Q2/Q3 C/O/Q2
"Waste treatment"	Nutrient cycling	A/B/C/I/J/M/P/Q1/Q3

(i.e. removal of excess nutrients		

Table 9. Codes and associated hypothesis, used in Tables 7 and 8.

Letter	Hypothesis (from ICES 2016)
A	The addition of artificial hard structures will change the morphology and the complexity of benthic habitats.
B	A specific hard bottom assemblage consisting of fouling organisms (fauna and flora) and associated mobile megafauna will colonise the new and complex artificial habitat.
C	Export of organic matter released by the fouling and megafauna community on the artificial structure provides food for benthic communities in the nearby natural substrate.
D	Turbidity caused by suspended matter reduces light penetration into the water column thereby reducing the primary production of photosynthetically active phytoplankton.
E	Suspension-feeding fouling organisms extract plankton and suspended matter from the water column and thereby decreasing turbidity.
F	Suspension-feeding fouling organisms on the artificial hard structure consume planktonic microalgae. This might affect the pelagic primary production at least on a local scale.
G	Disturbance of the sea floor by dredging, disposal of extracted sediment and cable laying will change the granulometry of local sediments and thus benthic habitats.
H	Benthic species are sensitive to sediment conditions and thus community structure and function will change in response to the altered habitat.
I	Changes in water flow can lead to turbulences that cause resuspension of fine sediment fractions. The export of fine sediments will cause scour and select for coarse sediment in the surrounding of the artificial structures.
J	Deposition of particles from fouling assemblages such as shell debris alters granulometry of nearby sediments.
K	Changes in the current conditions resuspend fine inorganic and organic sediment fractions in the water column.
L	Sediment disturbance such as dredging and cable laying during the construction phase will resuspend formerly deposited organic matter from the sediment.
M	Modified currents will determine settlement success of benthic species in the surrounding natural substrates.
O	Released organic material from the accumulated fouling community on the artificial structure becomes deposited in the nearby sediments. Bacteria decomposition is accompanied by oxygen depletion and release of toxic H2S in the structures surrounding.
P	Anaerobic and/or toxic (H2S) conditions in the surrounding sediment of the structure cause organisms mortality in adjacent natural habitats.
Q1	Important functions of the benthos such as bioturbation and decomposition may change due to the altered benthic assemblage structure. This may substantially affect biogeochemical processes crucial to the functioning of the local marine ecosystem.
Q2	Pelagic primary production supports benthic biogeochemical processes. Accordingly, altered rates of primary production may affect biogeochemical turnover rates of benthic species. This may substantially affect biogeochemical processes crucial to the functioning of the local marine ecosystem.

Literature

Dauvin JC, Andrade H, de-la-Ossa-Carretero JA, Del-Pilar-Ruso Y, Riera R. 2016. Polychaete/amphipod ratios: An approach to validating simple, Ecological Indicators 63. 89-99.

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5.6.2 Food resources

The sub-group took a top-down approach to identify possible effects on food resources from renewable energy devices. The group began by identifying hypotheses that related to food resources from the sensitivity analysis. Artificial reef effects or the introduction of energy were identified as major pressures. The following hypotheses were identified for artificial reef effect:

- Structures may function as aggregation devices
  - Promote fish stocks through overspill
  - Increase shellfish stocks
  - Promote catches due to aggregation of animals
  - May promote some species but displace others
- Opportunities for multitrophic aquaculture within wind farms
- Fishing methods and devices may need to be adapted within wind farm
  - Exclusion of fishing
- Hanging cables and moorings for floating devices
- Provision of shelter for fish

Following this the group discussed the functions relevant to the hypotheses. The added substrate could create space for other species (native or non-native), e.g. create feeding or spawning grounds. Littoral fall would also create habitat and niches. In addition to creating habitat and niches, other species may be displaced.

The group identified possible changes in primary and secondary production. By introducing new species, trophic interactions would be modified. Nutrients would also be introduced which would further influence trophic interactions. Filter feeding species may be enhanced, displacing nutrients in the water column.

The following pressures were identified for the introduction of energy:

- Noise/vibration
  - Shipping, construction and operation of renewable energy devices
- EMF

    - Conduction of electricity through cables
- Compression of soil (may be relevant but this has not been investigated)
    - Piling or placement of gravity base and anchors

The group discussed the functions relevant to these hypotheses. Species could be displaced and migrations may be interrupted, which could influence distribution structure of species. As a result, species fitness and fecundity could be affected.

Again, trophic interactions could be modified as species are displaced from the area. This would affect the transfer of energy between trophic levels. By changing trophic interactions, the stability of the ecosystem may also be affected.

Possible indicators that may highlight changes in the ecosystem and food resources are:

- Biodiversity indices
- Secondary production
- Size classes of fish
- Individual fitness
- Biomass balance

The group agreed that the ‘so what’ question, i.e. the ecological relevance, was self-evident: commercially important species may be affected, threatening food security.

5.6.3 Biodiversity

Using Table 1 from Hattam *et al.*, 2015, the ecosystem services were considered in turn to determine their applicability to the societally important issue (SII), biodiversity. The group determined that many of the ecosystem services were applicable, a total of 12 services were identified. It was acknowledged that biodiversity also contributed to other services that were not considered in full as they would be included by the other subgroups looking at food provision and the biogeochemical reactor. For example, climatic regulation (ES No 4, Hattam *et al.*, 2015) is influenced by biodiversity but is better considered by the biogeochemical reactor and was thus not considered by the subgroup. The ecosystem services identified to be applicable to biodiversity are outlined in the table below together with the ‘so what?’ question, i.e. the ecological relevance, that the group considered to explain their applicability to the SII.

Ecosystem Service	**So what?/explanation of applicability**
2) Biotic raw materials (non-food)	
Genetic resources	Provision, Genetic resources: ORE may provide an increased stock of endangered species that may be harvested for restocking initiatives
Medicinal resources	Provision, Medicinal resources: ORE may increase the stock of medicinal compounds
Ornamental resources	Provision, Ornamental resources: ORE may increase the stock of ornamental compounds
Other biotic raw materials	Provision, other raw biotic material: ORE creates a locally enhanced stock of biomass (that may be used as e.g. fish food/fertilizers)

Regulating services		
6	Regulation of water flows	ORE offer habitat for epifouling communities that may locally alter hydrodynamics (potentially important at full scale of array for coastal currents).
7	Waste treatment and assimilation	ORE epifouling communities may act as a biofilter altering the carbon distribution of C-stocks; carbon storage capacity
9	Biological control	ORE alter the spatial distribution of species which ultimately may change ecosystem resilience, provides opportunity for population expansion but also for potential for pest control via larval filtering[20]
Habitat Services		
10	Migratory & nursery habitat	ORE and their epifouling communities do provide migratory and nursery habitat to fish and other mobile megafauna[21]
11	Gene pool protection	ORE offers new habitat for hard substrate species as such increasing the population size of those species and hence enhancing their gene pool protection.
Cultural Services		
12	Leisure, recreation & tourism	ORE offers potential MPA effect with increased leisure and recreational activity provision such as diving and fishing
13	Aesthetic experience	ORE offers changes the landscape above and below the water that generates a noticeable emotional response within the individual observer
18	Information for cognitive development	ORE contributes to a marine ecosystem which offers education and research opportunities as well as collective cognitive development

The group reported that the SII, 'Biodiversity' is very complex and many ecosystem services are applicable. It was found to be difficult to work from the SII cause-effect hypotheses and attribute ecosystem services in this way so the reverse route was taken. The group focused on biofiltration which is a functional trait more prevalent due to the increase in biodiversity on the hard substrate provided by the ORE structure and specifically those species which feed in this way. Specifically, we found it to influence hypotheses 'n' and 'o' from the biodiversity conceptual scheme (ICES 2016) which link the changes in hydrodynamics to the level of suspended particles in the water. Biofiltration was identified to be linked to four of the ecosystem services identified in the table above. These were carbon storage (ES7), the provision of raw biotic materials (ES2d) and biological control such as pest control (ES9). Further work is required to identify the functions related to the SII 'Biodiversity' and to understand how each of these functions contribute to

[20] Although ORE can act as stepping stones for invasive species/pests, the ability for the biodiversity growing on the ORE devices to filter the larval population of pests is a potential service.

[21] It was noted within the group that the provision of migratory and nursery habitat is not an end-point ecosystem service but should be considered part of a pathway to an overarching ecosystem service such as the provision of food.

the ecosystem services identified above. In later discussions the full group identified the need to return to the original biodiversity conceptual scheme on cause-effect relationships and link it to the above mentioned ecosystem services.

Liteature

Hattam C, Atkins JP, Beaumont N, Börger T, Böhnke-Henrichs A, Burdon D, Groot R de, Hoefnagel E, Nunes PALD, Piwowarczyk J, Sastre S, Austen MC (2015) Marine ecosystem services: Linking indicators to their classification. Ecological Indicators 49:61–75

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5.7 Opportunities for collaboration and funding

The group decided to set up 'factsheets' per WGMBRED person to facilitate collaboration between the members of the WGMBRED group. Arjen Boon volunteered to set up an outline of what needs to be in such a factsheet (photo, ORE-oriented biopic, shared keywords for knowledge and abilities), based on work that is currently being done for a comparable activity within Deltares.

WGMBRED will apply for the current EuroMarine call on FWS foresight workshop – 'horizon scanning', focusing on the effects of the introduction of OWF on the biogeochemistry of the water column and sediment (related to ToR D).

6 Revisions to the work plan and justification

There is no revision of the work plan necessary.

7 Next meetings

The group agreed that the meeting in 2018 will take place on 5–9 March in Galway, Ireland.

Annex 1: List of participants

Name	Address	Phone/Fax	Email
Silvana Birchenough	Cefas Lowestoft Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK	Tel:+44(0) 1502 527786 Mobile: +44 (0) 7827661379	silvana.birchenough@cefas.co.uk skype:silvana.birchenough
Arjen Boon	Deltares Research Institute Unit of Coastal and Marine Science P.O. Box 177 2600 MH Delft The Netherlands	Fax: + 31 88 3358582 Mobile: + 31 6 51635449	arjen.boon@deltares.nl skype: arjenrboon
Paul Causon	School of Energy, Environment and Agrifood, Offshore Renewable Energy Engineering Centre, Cranfield University Cranfield Bedfordshire MK43 0AL, UK	+44(0)7870194676	p.causon@cranfield.ac.uk
Radosław Brzana	**Instytut Oceanografii** Uniwersytet Gdański al. Marszałka Piłsudskiego 46 81 - 378 Gdynia		radek.barbus@gmail.com
Jennifer Dannheim (co-Chair)	Alfred Wegener Institute for Polar and Marine Research P.O. Box 120161 27570 Bremerhaven Germany	Phone: +49 471 4831 1734 Fax: +49 471 4831 1425	Jennifer.Dannheim@awi.de
Jean-Claude Dauvin	UNICAEN, Université de Caen Normandie. UMR CNRS 6143 Morphodynamique continentale et côtière 24 rue des Tilleuls F-14000 Caen	Phone: +33 2 31 56 57 22 Fax: +33 2 31 56 57 57	jean-claude.dauvin@unicaen.fr
Steven Degraer	RBINS-OD Nature Gulledelle 100 B-1200 Brussels Belgium	Phone: +32 2 773 2103	steven.degraer@naturalsciences.be skype: sdegraer
Ilse de Mesel	RBINS-OD Nature 3e en 23e linieregimentsplein B-8400 Oostende Belgium	Phone: +32 59 24 20 51	Ilse.demesel@naturalsciences.be skype: ilsedemesel

Andrew B. Gill (co-Chair)	Cape Eleuthera Institute (CEI), PO Box EL-26029 Rock Sound, Eleuthera, The Bahamas	+242 334-8552 ext 6001	andygill@ceibahamas.org
Zoe Hutchison	School of Energy, Environment and Agrifood, Offshore Renewable Energy Engineering Centre, Cranfield University Cranfield Bedfordshire MK43 0AL, UK	+44 (0) 1234 750111 ext 4706	zoe.l.hutchison@cranfield.ac.uk
Urszula Janas	**Instytut Oceanografii** Uniwersytet Gdański al. Marszałka Piłsudskiego 46 81 - 378 Gdynia	Phone: +48585236867	oceuj@univ.gda.pl
Roland Krone	**Krone- Projekte, Meereskunde Technik Umweltwissenschaften Germany** **Hummertation Helgoland** Alfred Wegener Institute for Polar and Marine Research **D-27498 Helgoland**	Phone: +4947195481249	r.krone@krone-projekte.de
Francis O'Beirn	Marine Institute, Rinville, Oranmore, Galway, IRELAND	Ph: +353-91-387250	fobeirn@marine.ie
Jean-Philippe Pezy	UNICAEN, Université de Caen Normandie. UMR CNRS 6143 Morphodynamique continentale et côtière 24 rue des Tilleuls F-14000 Caen	+33231565708	jean-philippe.pezy@unicaen.fr
Aurore Raoux	UNICAEN, UMR-CNRS-BOREA, Biologie des OrganismesMarins et Écosystèmes Aquatiques IBFA – Université de Caen Normandie Esplanade de la Paix CS 14032 14032 CAEN Cedex 5	+33649663864	raoux.aurore@unicaen.fr

Emma Sheehan	Plymouth University Marine Institute Marine Building Drake Circus Plymouth, PL4 8AA UK	0044 1752 584699	emma.sheehan@plymouth.ac.uk
Jan Vanaverbeke	RBINS, Operational Directorate Natural Environment Gulledelle 100 B-1200 Brussels Belgium	+32 2 773 21 15	jvanaverbeke@naturalsciences.be
Tom Wilding	SAMS, Scottish Marine Institute Dunbeg Nr Oban Argyll, Scotland,PA37 1QA UK,	+44(0)1631 559214	Tom.wilding@sams.ac.uk

Annex 2: Recommendations

RECOMMENDATION	ADDRESSED TO
1. Ensure scale aspects are central to any advice prvided to ICES from the WGMBRED	Decision makers advised by ICES
2. Network analysis approach could be more widely applied within ICES WGs	SCICOM and WGs
3. Promote the ecosystem service value of the benthos when considering the environmental implications of MREDs	SCICOM and ACOM

Annex 3: Intersessional work and action points

Inter-sessional work and action points

- Arjen Boon and Andrew Gill will setup an outline for the publication on scale issues (ToR A), with help of Tom Wilding, Steven Degraer, Jennifer Dannheim, Silvana Birchenough, Zoe Hutchison and Urszula Janas being the subgroup leaders of ToR A)
- Emails for survey monkey to be send out for the network analysis
- Factsheets Arjen for future collaboration