ICES WGMBRED REPORT 2018

HUMAN ACTIVITIES, PRESSURES AND IMPACTS STEERING GROUP

ICES CM 2018/HAPISG:02

REF. SCICOM

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

6-9 March 2018

Galway, Ireland

ICES CIEM
International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
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

Recommended format for purposes of citation:

ICES. 2018. Report of the Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED), 6–9 March 2018, Galway, Ireland. ICES CM 2018/HAPISG:02. 66 pp.

Contents

Executive summary

In the most recent multi-annual cycle of the Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED), three meetings were held: 14–18 March 2016, Delft, the Netherlands (22 experts); 6–10 March 2017, Gdynia, Poland (19 experts); and 6–9 March 2018, Galway, Ireland (15 experts).

Our focus throughout has been on addressing the 'So what?' question in relation to the interaction between marine renewable energy developments and the benthic ecosystem. The main themes which WGMBRED captured under the Terms of References during the annual meetings and intersessionally focused on understanding the importance of the benthic ecosystem interacting with marine renewable energy developments and ensuring effective communication of scientific findings from the group. The main topics covered were:

i) spatial and temporal scale (e.g. the interaction between a device and the benthic species, how these changes could occur at the scale of an array or over larger scales of defined regions/over time);
ii) the extent of knowledge available (leading to an understanding of the cause-effect pathways between benthos and marine renewable energy devices and developments) in order to identify gaps in knowledge;
iii) development of indicators to measure the effects arising;
iv) understanding how effective the benthic ecologists working on the interactions between the benthal and marine renewables were able to cascade these scientific messages.

The WGMBRED has made significant progress towards meeting the group's Terms of Reference and also our own professional and personal aspirations in communicating that the benthos is a vital part of our marine ecosystems and must be considered in the context of the industrial expansion of marine renewable energy developments. During the three years' work the group has adapted the focus of our activities to more effectively address our objectives in light of our analysis and new knowledge. Some of the topics proved highly complex and require further research. To convey this message several written reviews have helped to summarise the existing knowledge base (across different marine energy device types), and group members have also attended and presented at numerous international conferences and workshops. The specific outputs coming from meeting the Terms of Reference will be useful to inform the advisory process (and licencing) as they are directly linked to the marine renewable energy sector and the ecosystem based management that is being promoted across the ICES region.

The activities of the WG will assist ICES towards a structural and functional understanding of how the marine benthic system associated with marine renewable energy devices contributes to the functioning of the marine ecosystem, and how they can act as areas where benthic biodiversity can potentially be promoted. There is evidently a future need for the WG and a further multi-annual cycle with new co-chairs has been proposed to ICES secretariat. The new objectives to be addressed by this group are considered of high relevance in the context of ecosystem-based management of coastal areas where an increasing number or marine renewable energy devices are planned. There will be direct knowledge gained to support marine spatial planning initiatives. Hence, the activities of

WGMBRED can be considered to be of direct benefit and very high priority for several EGs.

The WGMBRED has worked well with a constant and active membership of experts and representatives of various countries. During 2016–2018, we have produced some significant outputs (with plans to meet all our outstanding deliverables by the end of 2018).

When considering the future, the offshore renewable industry continues to evolve at a rapid pace with expansion across the world. In addition there are upcoming ideas of multiple use of energy device arrays (e.g. for energy generation and food supply via aquaculture), as well as developments of new technologies in countries where no marine renewable energy devices have been installed before. There are several topics which have not been explored yet in this context which cause uncertainty of the potential effects of these evolving new topics and technologies and inconsistent legislation frameworks between countries. Thus, the WGMBRED expertise contributes to the determination of these effects strategies that are as important now as well as in the near future.

A new set of Terms of Reference supported unanimously by all the members to continue with new co-chairs, gives us confidence to propose to ICES that WGMBRED will successfully continue for three more years. With the growing interest in marine renewable energy developments we believe that the activity of the WG will be of key importance for ICES in the event that they need to advise on marine renewable energy developments in relation to the benthic ecosystem.

1 Administrative details

Working Group name

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

Year of Appointment within current cycle

2016

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

3

Chair(s)

Jennifer Dannheim, Germany

Andrew B. Gill, United Kingdom

Meeting venues and dates

14–18 March 2016, Delft, the Netherlands (22 experts)

6–10 March 2017, Gdynia, Poland (19 experts)

6–9 March 2018, Galway, Ireland (15 experts)

2 Terms of Reference

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 Summary of Achievements of the WG during 3-year term

The main outcomes and achievements of the WG during 2016–2018 are:

- Review paper published on monitoring (ToR A), i.e. addressing scale aspects and the relevance to monitoring, defining suitable objectives and approaches to determine relevant changes to the benthic ecosystem;
  - Thomas A. Wilding, Andrew B. Gill, Arjen Boon, Emma Sheehan, Jean–Claude Dauvin, Jean-Philippe Pezy, Francis O'Beirn, Urszula Janas, Liis Rostin, Ilse De Mesel (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.
- Review paper (*in prep.*) based on three different geographical case studies to demonstrate conceptually the consequences of meaningful ecological changes acting on different scales in relation to the effects of marine renewable energy devices on the benthic ecosystem (ToR A).
- Draft review paper for managers, policy makers, developers and academics highlighting the knowledge gaps (ToR B, to be submitted in 2018) in relation to offshore renewable energy devices on the benthal including a Matrix/literature review matrix with specific Cause-Effect hypothesis; an assessment of sensitivity, certainty and consistency of the matrix; and an analysis of knowledge gaps.
- Tables summarising the sensitivity, certainty and consistency of cause-effect relationships (ToR B, published in this report) in relation to different offshore renewable energy devices including Floating wind farm devices, Tidal and Wave devices
- Network analysis of WGMBRED and other relevant groups; the network map highlights the impact of the WGMBRED science (ToR C, publication to be submitted).
- Publication (*in prep.*) Assessing ecosystem functioning in relation to OWFs across several scales, considering the use of indicators to underpin ecological functions and ecosystem services; this publication (to be submitted in January/February of 2019) combines outcomes from the WGMBRED science (ToR D) and a EuroMarine Foresight Workshop.
- Contributions and theme session lead at the Fort Lauderdale ICES ASC 2017, i.e. theme session K: Introducing man-made structures in marine systems: assessing ecological effects, knowledge gaps and management implications.
- Fort Lauderdale ICES ASC 2017, Open Session: Functional links between pressure and state indicators, WGMBRED members convening and presenting.
- ICES ASC 2016 in Riga, Latvia, presentation.
- ICES JMS special issue – ecologically sound decommissioning for offshore man-made structures. WGMBRED Experts Steven Degraer and Silvana Birchenough are editors. A number of contributions have been proposed from the WGMBRED group. Expected publication January 2019.

5 Final report on ToRs, workplan and Science Implementation Plan

The offshore renewable energy industry is rapidly increasing and growing worldwide. Thus, this new industry sector is expected to develop into one of the largest-scale anthropogenic activities in our marine shelf systems. How the different energy devices might affect the marine environment, locally, regionally and on larger spatial scales, is currently investigated by ecologists who are continuously improving their scientific understanding on the underlying ecological processes affected by energy devices. WGMBRED contributes to international knowledge exchange between scientists and is reviewing the state of the art knowledge available by its terms of references, which lead to scientific publications and advisory products. Themes such as scale dependency of energy device effects, the identification of knowledge gaps, the impact of WGMBRED science and the development of indicators to assess potential ecological changes of energy device effects on the benthos at meaningful scales are essential baselines for common legislative frameworks, marine spatial planning and understanding cumulative impacts across national borders. Thus, WGMBRED delivers scientific publications, advisory products and knowledge with consequences for policy makers, managers, developers and academics. The progress and outcomes of WGMBRED science, i.e. of ongoing national activities and the four terms of reference, are highlighted in the following sections.

5.1 Group evolution and achieved work status of WGMBRED

The Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED) was established in 2013 following an ICES workshop "Effects of offshore wind farms on marine benthos" (WKEOMB, see ICES 2012) in 2012. The aim of the workshop was to increase scientific exchange of offshore wind farm benthos research, to discuss the most up to date results and to facilitate a closer international collaboration throughout the North Atlantic region. The workshop highlighted the importance of a regular knowledge exchange, which led to the establishment of WGMBRED. Since then, the working group has a regular attendance by nine countries and 15–23 experts at each meeting (Figure 1). This highlights the need and interest to facilitate an international collaboration on discussing the effects of offshore renewable devices on the benthic ecosystem.

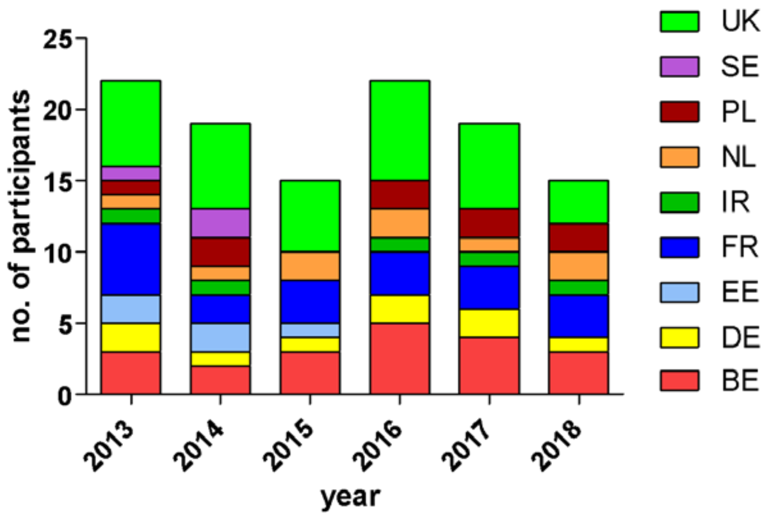

Figure 1. Number of participants from countries since establishment of WGMBRED (2013–2018). BE = Belgium, DE = Germany, EE = Estonia, FR = France, IR = Ireland, NL = the Netherlands, PL = Poland, SE = Sweden, UK = United Kingdom.

WGMBRED has a high consistency in the participation of experts (34 active experts in total), i.e. more than 50% of the experts attended three times or more (Figure 2). 26% of the experts attended all meetings, i.e. one Belgian, one German, two French, one Dutch and two British experts. This continuity enables WGMBRED to work consistently on the ToRs and to ensure regular exchange on a long-term basis.

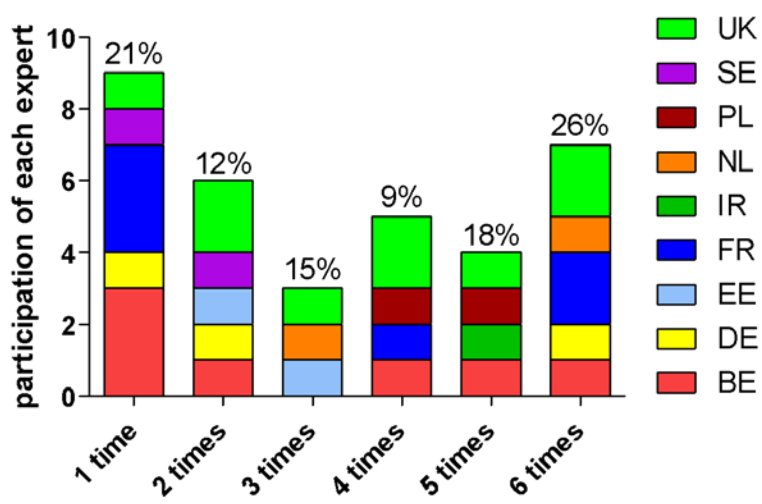

Figure 2. Participation of each expert at WGMBRED meetings since establishment (2013–2018) divided by countries. Percentages = share of expert participation of total active experts. BE = Belgium, DE = Germany, EE = Estonia, FR = France, IR = Ireland, NL = the Netherlands, PL = Poland, SE = Sweden, UK = United Kingdom.

Four multi-annual ToRs (2016–2018) have been tackled through the last three years cycle, namely: the scale issues, the knowledge scheme, the network analysis and the identification of indicators:

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.

Over the last six years work, the group produced valuable outputs, such as publications and oral presentation, organised workshops and theme sessions. Thus, the group is a very productive long-term network. It was noticed that critical scientific gaps might be missed by the interlinked ICES expert group and therefore must be considered in this group. Those gaps were related to new technologies and developments and a greater expansion of marine renewable energy developments worldwide where no devices have been installed to date. Further, multiple use of renewable energy developments is an upcoming topic which will be considered by this group.

Besides the ICES core work on the ToRs within WGMBRED, several intersessional activities have been carried out and organized by members of WGMBRED during the past three years:

- ICES ASC 2016 in Riga, Andrew Gill 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.*
- EcApRHA WP3, workshop on Ecological Network Analysis indices, 14–15 Septembre 2016, Londres, UK. Raoux, A., Dauvin, J.C., Niquil, N. An ecosystem approach of Marine Renewables Energies: what tells us the Ecological Network Analysis on the potential effects of Offshore Wind Farms on the ecosystem resilience?
- 25ème édition de la Réunion des Sciences de la Terre 2016, 24–28 octobre 2016, Caen, France. Pezy, J.P., Raoux, A., Niquil, N., Dauvin, J.C. Can the transition from a taxonomic approach to an integrated food web approach allows the assessment of environmental impacts: Dieppe-Le Tréport and Couseulles-sur-mer case studies?
- MSEAS 2016, Understanding marine socio-ecological systems: including the human dimension in Integrated Ecosystem Assessments, 30 Mai- 3 Juin 2016, Brest, France. Raoux A, Tecchio, S., Dauvin, J.C., Pezy, J.P., Degraer, S., Cachera, M., Grangeré, K., Dambacher, J.F. Modelling impacts of offshore wind

farms on trophic web: the Courseulles-sur-Mer case study, an example of cumulated impacts

- 28ème young oceanographers' forum, 18–20 Mai 2016, Cherbourg, France. Raoux, A., Tecchio, S., Pezy, J.P., Degraer, S., Wilhelmsson, D., Dauvin, J.C., Niquil, N. Benthic and fish aggregation inside an offshore wind farm: Which effects on the trophic web functioning?
- EGU General Assembly 2016, "OS2.7 Environmental Impacts of Marine Renewables", 17–22 Avril 2016, Vienne, Autriche. Raoux, A., Pezy, J.P., Dauvin, J.C., Tecchio, S., Degraer, S., Wilhelmsson, D., Niquil, N. Modelling impacts of offshore wind farms on trophic web: the Courseulles-sur-Mer case study.
- 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.
- Contributions and theme session lead at the Fort Lauderdale ICES ASC 2017, Theme session K: Introducing man-made structures in marine systems: assessing ecological effects, knowledge gaps and management implications which was chaired by two WGMBRED experts (Silvana Birchenough, Jennifer Dannheim), 15 presentations, thereof 14 presentations out of 21 were from or with contribution of WGMBRED experts.
- Fort Lauderdale ICES ASC 2017, Open Session: Functional links between pressure and state indicators. Conveners: Henn Ojaveer, Steering Group on Ecosystem Pressures and Impacts (SSGEPI), and Silvana Birchenough, Steering Group on Ecosystem Processes and Dynamics (SSGEPD). Andrew Gill presented on 'Bringing benthic functional importance into the discussion on human impacts on marine ecosystems'. Steven Degraer gave a presentation titled 'Overview of benthic indicators and their role for ICES science and advice'.
- Post-ICES ASC Workshop at CEI, Bahamas. Andrew Gill hosted BESpE – Benthic Ecosystems Spatial Ecology Workshop Sept 2017, which was attended by Steven Degraer, Silvana Birchenough, Joop Coolen, Jennifer Dannheim, and Tom Wilding from WGMBRED.
- As a member of a US National Academy of Science Steering Committee, Andrew Gill assisted in organising, chairing and presenting at the Atlantic Offshore Energy Development and Fisheries workshop, New Bedford, Massachusetts, USA, Nov 2017.
- EuroMarine Foresight Workshop: "Ecosystem changes associated with offshore wind farms: bridging the gap between biogeochemical effects and its repercussions for ecosystem functioning and services" in Bremerhaven, Germany, February 2018, chaired by two WGMBRED experts (Jan Vanaverbeke, Jennifer Dannheim) and attended by eight WGMBRED experts (of 21 participants): Silvana Birchenough, Paul Causon, Joop Coolen, Steven Degraer, Andrew Gill, Urszula Janas, Roland Krone, Francis O'Beirn.
- 4th International Marine Protected Areas Congress (IMPAC September 2017), Chile. Emma Sheehan attended gave a presentation on co-location of renewables and MPAs.

- Conference on wind and wildlife (CWW), Berlin, Germany - September 2015 and Estoril, Portugal - September 2017. Andrew Gill is a founder member of the Scientific Committee attending each conference where he focuses on offshore wind and the environment being represented. CWW focuses on onshore and offshore wind farms and impacts on wildlife.
- 4th Conference on Wind Energy and Wildlife Impacts, 6–8 September 2017, Estoril, Portugal. Pezy, J.P., Raoux, A., Niquil, N., Dauvin, J.C. Trophic webs comparison of two different habitats in the English Channel : the Courseulles-sur-mer and the Dieppe-Le Tréport OWF case study.
- Colloque national sur la cartographie des habitats marins benthiques CARHAMB'AR, 14–16 mars 2017, Brest, France. Pezy, J.P., Raoux, A., Niquil, N., Dauvin, J.C. Les sables grossiers de la baie de Seine et de la Manche orientale ont-ils des réseaux trophiques différents ? Le cas des parcs éoliens offshores de Courseulles-sur-mer et de Dieppe - Le Tréport.
- ASLO 2017 conference (Jan Vanaverbeke) mostly tidal & wave rather than wind. Emphasis on production of electricity for local use e.g. desalination rather than for production for commercial or domestic use on land. It may not be a representative view of the entire situation in US.
- Coastal Future conference 2017: Co-location studies of offshore aquaculture and renewables, participation by Emma Sheehan.
- INSITE North Sea (www.insitenorthsea.org): Influence of man-made structures in the Ecosystem, included ten projects with the aim to investigate the magnitude of the effects of man-made structures compared to the natural spatial and temporal variability of the North Sea ecosystem and whether man-made structures in the North Sea represent a large inter-connected hard substrate system. Two projects were run by WGMBRED experts (Jennifer Dannheim, Joop Coolen, Silvana Birchenough, Steven Degraer, Jan Vanaverbeke): UNDINE (www.insitenorthsea.org/projects/undine/). The projects were mainly about oil & gas platforms, but with clear relevance for marine renewables.
- ICES JMS special issue – ecologically sound decommissioning for offshore man-made structures. WGMBRED Experts Steven Degraer and Silvana Birchenough are editors. A number of contributions have been proposed from the WGMBRED group.

5.2 National summaries

[*Note*: national ongoing activities and up to date research related to marine renewable energy and benthic ecosystems are given in Annex 2]

Belgium

As of 2016, an installed capacity of 870 Megawatt (MW), consisting of 232 offshore wind turbines, is operational in the Belgian part of the North Sea. In 2017 and 2018, an additional capacity of respectively 275 and 320 MW will be added, with three other projects scheduled for the next few years after that. The area reserved for offshore renewables in Belgian waters now cover 238 km² reserved.

Possible future developments

The marine spatial plan for the Belgian waters is currently under review. New sites for offshore renewables are being searched for. A proposal for an extra offshore renewable energy zone ~180 km² is on the table. Some 40 km² will be situated into a Special Area for Conservation (Habitats Directive). Possible implications of having offshore renewables inside Natura 2000 areas are being discussed in relation to possible conflicts with the conservation objectives. RBINS is tasked to facilitate the discussions.

Contact: Steven Degraer, Jan Vanaverbeke, Royal Belgian Institute of Natural Sciences (RBINS), Operational Directorate Natural Environment (OD Nature), Marine Ecology and Management (MARECO), Brussels, Belgium.

France

Offshore renewable energy development in France with an emphasis on the eastern part of the English Channel: state at the end of 2017:

Since 2000, the French government has had the ambition that offshore wind production will form 40% of the renewable electricity in 2030, and three calls for tenders of offshore wind farms construction have been released since 2011. However, no marine wind farm had been constructed by the end of 2017 due to long administrative procedures and numerous appeals in justice, at French and European levels. Nevertheless, several studies have been undertaken to identify the environmental conditions and ecosystem functioning at selected sites before offshore wind farm installation. However, these studies are generally focused on the conservation of some species or groups of species and there is no holistic study on the effects of the construction and operation of offshore wind farms on an ecosystem taken as a whole. In 2017, a complete and integrated view of the ecosystem of two future OWF sites of the eastern English Channel (Courseulles-sur-Mer and Dieppe-Le Tréport) were developed to describe the marine ecosystems before offshore wind farm development and to simulate reef effects due to new spatial occupation of maritime territory. Results contribute to a better knowledge of the impacts of the offshore wind farms on marine ecosystems. They also allow recommendations to be made for environmental managers and industry in terms of monitoring the effects of Marine Renewable Energy, not only locally, but also on other sites, at national and European levels. They also highlight the urgent need to simplify the French administration procedure to adopt a National strategy.

Contact: Jean-Claude Dauvin, Jean-Philippe Pezy, Aurore Raoux, UNICAEN, Université de Caen Basse-Normandie, Caen, France.

Germany

Currently, 17 wind farms are operational, with a further seven now under construction. By 2019 a total of 24 wind farms will be operational in the German Exclusive Economic Zone (EEZ). In the framework of EIA's and monitoring for the 24 wind farms a large number of benthic surveys have been carried out. While the offshore wind farm industry is continuously increasing, other marine devices such as floating wind farms, tidal and wave energy devices are not planned for the German EEZ yet.

Contact: Jennifer Dannheim, Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany; Roland Krone, Krone-Projekte, Bremerhaven

Ireland

Marine renewable energy activities in Ireland are primarily focused upon the development of devices within engineering (academic) research facilities and the testing of prototype (or smaller scaled devices up to 1/4-scale) at a designated marine test site in Galway Bay, which is operated by the SMARTBAY Ireland programme. A second location, the Atlantic Marine Energy Test Site (AMETS) is being developed by the Sustainable Energy Authority of Ireland (SEAI) to facilitate testing of full-scale wave energy converters in an open ocean environment. AMETS is located off County Mayo and will be connected to the national grid. Currently, there are no specific research projects focusing on the impacts or interactions of marine renewable devices on benthal habitats and species.

Contact: Francis O' Beirn, Marine Institute, Galway, Ireland.

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 2020 and may reach 6 GW by 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 has 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.

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

The Netherlands

The fourth Dutch OWF GEMINI (ca. 80 km north of Groningen province) was officially opened in 2017.

The third Dutch ecological effects monitoring programme started in 2016 and in 2017, the T10 for the long-term monitoring of the soft-sediment benthos, roughly following the set up in 2007 and 2011 in Egmond aan Zee and Prinses Amalia, was carried out. The next campaign is expected in 2021. In 2018–2019 the T10 benthic survey of hard substrate in these wind farms is planned.

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

United Kingdom

A large amount of continued OWF planning, licensing (particularly further offshore) and installation has occurred, with most being in the Southern North Sea.

In Scotland a diversity of marine energy options are being pursued - including floating OWF, tidal turbine array (x 5 devices) in Pentland Firth, other tidal turbines being tested and wave devices also under test. European Marine Energy Centre (EMEC) in Orkney is hosting a number of wave and tidal devices tests.

Focus in Welsh waters is on harnessing tidal regime through tidal barrages.

Contact: Andrew Gill. PANGALIA Environmental, U.K.

International meeting for joint research and monitoring programmes

Rijkswaterstaat (NL), BSH (DE) and Marine Scotland organised a meeting in Hamburg with a focus on scoping for possibilities for joint research /monitoring programmes w.r.t. the environmental effects of offshore wind farms. The meeting was attended by Steven Degraer, who reported to WGMBRED. During the meeting it was identified and discussed that there is a lot of environmental monitoring being required and conducted across Europe and in particular the North Sea. It was considered useful to know how much and where to highlight opportunities for collaboration to understand large scale patterns and processes. There was a main focus on three groups: marine mammals, birds and, benthos and fish (combined). There was also an emphasis on ecosystem function. Some topics covered are very relevant to the discussion on the definition of WGMBRED ToRs for next three years. Nominated individuals for each topic are being identified.

5.3 Scale issues, summary 2016–2018

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

Throughout the six years that WGMBRED has existed the topic of scale(s) has been a recurring theme in our discussions. The continued expansion of marine renewable energy installations (primarily offshore wind) across national seas and up to transnational boundaries means that the question of how the spatial extent (spatial scale) and the length of time that marine renewable energy structures are in the water (temporal scale) are central to understanding and interpreting the effects on the marine environment and specifically the benthic ecosystem.

In WGMBRED's first three years we had a ToR dealing with monitoring. When discussing monitoring, scale became an important consideration to integrate into our expert opinion on determining changes that will/may occur and recommendations for how appropriate environmental monitoring should be conducted. We identified that the environmental monitoring that is required to meet permitting and licencing conditions for offshore wind farms and which occurs routinely at offshore wind farm sites is actually questionable in being able to quantify changes in the benthic system. Hence, scale became fundamental to answering one of WGMBRED's primary questions that of 'At what scale are changes to the benthos biologically or ecologically meaningful?' These considerations led to an already well-cited publication by WGMBRED:

Wilding, T.A., Gill, A.B., 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 benthic-related assessments around marine renewable energy developments. *Renewable & Sustainable Energy Reviews*, 74, 848–859.

Taking account of scale is fundamental to contextualising the changes to species occurrence, distribution and biodiversity that have been recorded and also those predicted to occur. The spatio-temporal aspect has risen to the top of WGMBRED's priority list for determining the interaction between the benthic ecosystem and MREDs. Hence, one of our main ToRs for WGMBRED in the past three years has been scale, specifically the ToR has been focussed on critically assessing relevant scales in relation to the effects of MREDs on the benthic ecosystem and evaluate the consequences in relation to environmental policy and decision-making.

In the period, the main task that the WG set out to address was the scaling up from small-scale effects (in space and time) with differences in information needs and associated scales to determine when changes to the benthos become relevant for policy and management. The agreed approach we took was to use expert judgement (supported by literature) within suitable examples, where we worked towards ecosystem services to tackle spatial issues (with links to indicators of change) for the three societally relevant groups that WGMBRED specified during the initial group forming stages, namely: Biodiversity, Biogeochemical reactor and Food resources.

The WG split into three sub-groups to tackle three regionally distinct areas subject to marine renewable energy development. The three areas were: the Baltic Sea, the Southern North Sea and Irish Sea. These case examples were built on during the three workshops and intersessionally to provide the basis for our consideration of scale.

At first it appeared that progress on ToR A had been slow, hampered by the simple fact that scale cross-cuts through almost all the other discussions within MBRED and hence the other ToRs. Importantly, it was recognised that the 3 years of looking at the scale had in fact been an important catalyst for a number of the intersessional activities (see above). It also became evident that Indicator (ToR D) is difficult to separate from the scale ToR A. Therefore, the WG decided that the Indicator ToR deliverable would be best incorporated into the Spatial Scale ToR and EuroMarine workshop outputs (which both have the deliverable of an article to be submitted for peer-review publication).

More specifically there was much synergy between the key elements of the Spatial scale ToR and the output of the BESpE – Benthic Ecosystems Spatial Ecology workshop, Bahamas, which focussed on applying a landscape ecology approach to the question of determining at what point scale of change in the benthic ecosystem is significant in the context of the 'So what ?' question.

The WG agreed that the best way to address the spatial scale ToR was to acknowledge that the benthic ecosystem was important for delivery of specific food resources (in terms of societally important issues) and use worked case examples to identify and assess the interactions arising between OWFs and the benthos. Hence, we aimed to clearly define and/or demonstrate interactions and potential benefits of the MRED to the delivery of the ecosystem service of food production.

Three sub-groups discussed one of the three different case study areas (Baltic, Irish, Southern North seas). During the discussions we considered: (i) How offshore wind farms play a role in the production of the particular species (of food resource interest), also whether an OWF does have a role in terms of the scale of potential changes; (ii) In situations where other factors play a major role in distribution and/or overall survival of a given species is it possible to partition the effects with a view to assigning the importance of OWF to these species as examples. Ultimately we determined that these can be linked to the indicators and the correct scale such that we should be able to find a way to measure these effects.

General Approach

A structured process was undertaken to ensure the approach could be applied consistently across case examples and for future use if other researchers were interested in applying it. Within the approach we highlighted the need for the spatial scale at which the processes occur (e.g., food webs) to be considered and then further consider how it could be measured (such as through indicators).

For each case study and the WG determined the most relevant and achievable general approach was:

(A) Define Boundaries:
- Hydrographic/Bathymetric
- Geographic
- Geopolitical
- Wind farm footprint

(B) Define Food production
- Ecosystem service provided
- Species parameters (refs) that will plausibly change ecosystem service

(C) Use cause-effect pathways to identify changes relevant to:
- Species w.r.t a turbine/device
- Species w.r.t. an array
- Species w.r.t. national/Geopolitical/hydrographic boundaries defined in A

It was important that the approach taken worked for different case studies, for example we looked at a single species, mussels, found within the system (Irish Sea); sub units considered to reflect genetic distinctions of cod (Baltic); food web considerations as they relate to flatfish production (Southern North Sea). There the scale consideration would be different for each case study - this was seen as good in order to show how the generic approach could be used for different MBRED sites.

We applied a Socio-Ecological System (SES) framework to provide the appropriate basis for biological-geographical-physical context that defines species spatial and functional boundaries and constraints, labelled the endosystem (with embedded micro-endosystems; Figure 3). Furthermore, the SES enables the societal and governance actors, and institutions and policy to be associated with and define exogenous boundaries/constraints on the bio-geo-physical aspects. As ecosystems are dynamic and complex systems they are well suited to applying the SES which also is adaptive to take into account changes in the exo- and endo- systems, which are often a result of research advances and knowledge gain. Hence, the SES allowed us to set the spatial context within our case studies and means we can set the cases within the exo- and endo-system used to defined boundaries to the processes and functions which ultimately determine the ecosystem service output.

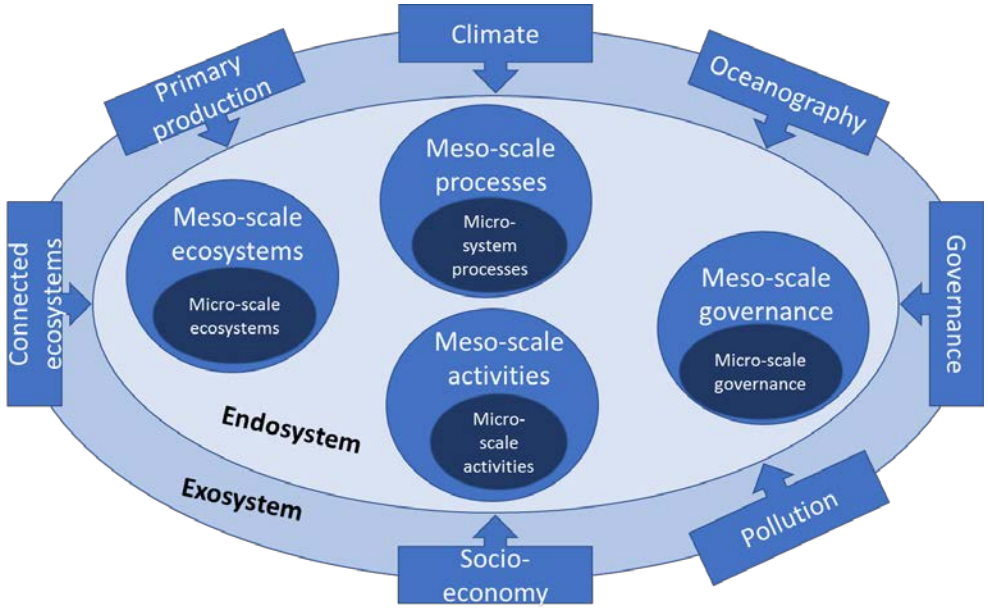

Figure 3. General systems approach overview of the exo- and endo-system used to define boundaries to the processes.

A final element to the general approach was relating indicators to at sea marine management units and how MRED sites fit into these measurements. To address this link between spatial scale and appropriate indicators it is important that endosystem constraints are identified within a case study.

For the purpose of illustration the case study example used here is the ecosystem service of Food Provisioning with cod (*Gadus morhua*) in the Baltic Sea. The SES approach was also considered for the two other food provisioning case studies of flatfish in South North Sea and mussel production in the eastern Irish Sea. Furthermore the SES approach is also applicable to the two other societally important issues BGR or Biodiversity that WGMBRED have defined and used throughout to keep a focus on the 'So what?' question.

The case of cod in the Baltic Sea

The group followed the general approach outlined above to:

(A) Define Boundaries (to endosystem components)

- Baltic Sea – species population & trophic links
- Western Baltic and eastern Baltic populations of cod
- Life history stages using different locations within the Baltic region (micro-endosystem)
    - Spawning: deep waters. Spawning can be inhibited by anoxia
    - Juveniles: migrate to nursery areas, coastal (natural situation in eastern Baltic: No/Very limited hard substrate)
    - 10% of the 2 year old spawn, %increases with age
- Attraction-production hypothesis for cod at OWF and trophic links

- o OWF can interact with the cod life cycle at the juvenile stage (based on Reubens *et al.* 2014)
- o Adult cod stay 2 to 3 years in wind farms before leaving
- o Cod has high site fidelity (97% of their time within 50 m of the same turbine during those 2 years)

(B) Define Food production

Exosystem factors:

- Status of the "cod" water (anoxia prevents spawning)
- Fisheries activities
- Primary production
- Zooplankton production
- Availability of prey items for adult cod
- Top predator (e.g. seal attracted to OWF) predation on juvenile cod

Endosystem factors:

- Soft sediment benthos
- Artificial hard substrates (AHS), fouling fauna
- Associated mobile megafauna (crabs, lobster, goby-like fish)

(C) Use cause-effect pathways to identify changes relevant to the cod.

A range of factors and C-E-Rs and the endo- and exo- system they were associated with were defined and mapped at the scale considered most importance in relation to the potential interactions with OWF (Table 1, see also section 5.6: Figure 5).

Table 1. C-E-R for the Cod endosystem, 1- Biotic and 2- Abiotic factors. Both biotic and abiotic factors define the population structure of small cod. The scale at which the effect is most dominant and a potential indicator are shown.

C-E-R FROM WGMBRED KNOWLEDGE TOR (HYPOTHESIS)	SCALE OF EFFECT	POTENTIAL INDICATOR
1- Biotic		
AHS fouling fauna=>soft benthos (e)	Local	Organic matter in sediment
Soft benthos => small cod (d)	Array	Biomass of prey items AHS
AHS fouling fauna =>small cod (d)	Local	Biomass of prey items soft sediment
Small cod =>adult cod: (I)	Regional	Cohort analysis cod
2- Abiotic		
Habitat morphology=>small cod: (b; shelter)	Turbine	Area of shelter habitat
Habitat morphology=> AHS fouling fauna (c)	Turbine	Biomass AHS fauna
Hydrodynamics =>small cod (g)	Turbine	t.b.d.
Vibration, noise => small cod (h)	Turbine	Noise measurements

A flow diagram specific to the case study was drawn up identifying where the cause effect relationship could be measured/identified (Figure 4). The previous WGMBRED work on our Knowledge ToR and the flow diagram of the C-E-R hypotheses was used to identify the relevant specific hypotheses.

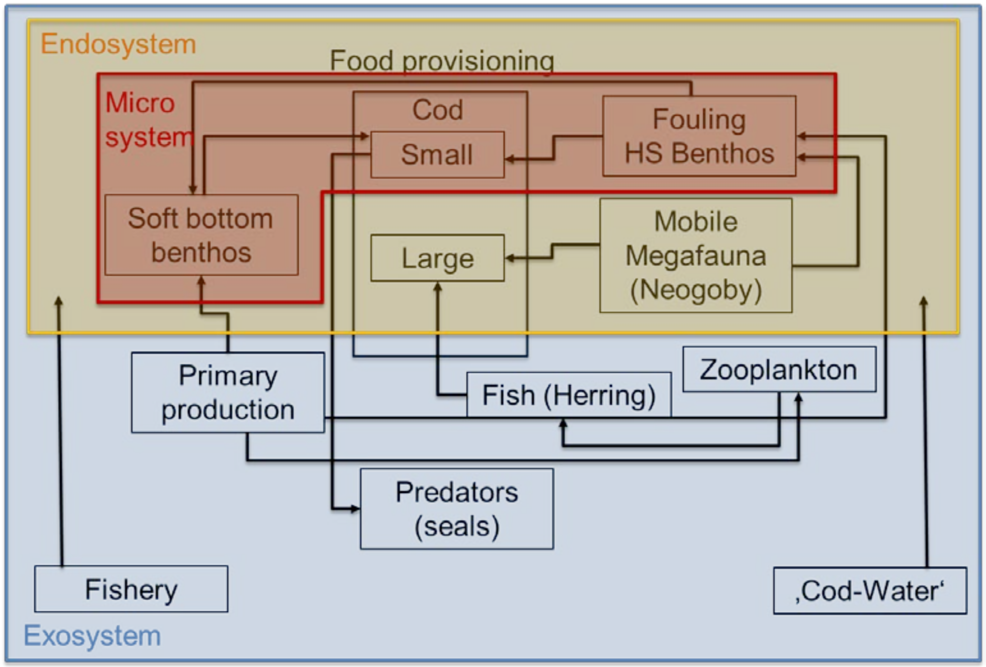

Figure 4. Representation of interactions between OWF and cod in terms of food provisioning at scales of societal importance. The SES approach identified the microsystem components defining the Food Provision embedded within a defined endosystem (i.e. biological production of cod), which in turn would be influenced by external factors within the exosystem.

The expected output coming from the three years WGMBRED work is a paper focussing on scale, which builds on the 'Turning off the DRIP paper' (Wilding *et al.* 2018) that the group published from the first three years activity. It will identify the mismatch between science, monitoring and case-specific appropriate spatial scales and highlight that its purpose is to indicate that scale matters not that we solve the puzzle, as there is a long way to go in this topic area.

Specifically, the paper will take a landscape ecology approach (i.e. ecological understanding of spatial heterogeneity) to present the case for why we need to focus on the factors influencing the ecological patterns and processes of benthic species and communities to address the scale aspect, which in turn addresses the 'So what?' question that has been a constant theme in our WG. We will, in essence, combine the discussions from the intersessional workshop BESpE – Benthic Ecosystems Spatial Ecology Workshop, Bahamas with the discussions from the past three years. The paper will use the three case studies to illustrate how MRE will likely influence the patterns and processes associated with benthic species in relation to the ecosystem service of food provision. The paper will also consider how scale is related to the spatial ecology of the relevant species, the upscaling of the MRE devices, and spatial management.

Literature

Reubens J, Degraer S, Vinc M (2014). The ecology of benthopelagic fishes at offshore wind farms: a synthesis of 4 years of research. Hydrobiologia 727(1): 121–136

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.

5.4 Knowledge theme, summary 2016–2018

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

During the last multi-annual cycle (2013–2015), WGMBRED worked on the identification of knowledge gaps for understanding the various effects of MREDs on the marine benthos as well as on the whole ecosystem. WGMBRED developed a set of hypothesis-driven pathways based on the schematic presentations of cause–effect-relationships to subsequently provide a list of prioritized hypotheses and evaluated what and how much knowledge on related topics (e.g. artificial reefs) contribute to the issue of effects of renewable energy constructions (WGMBRED, ICES 2015). In the current period, WGMBRED screened the literature base relevant to further our understanding of the effects of offshore renewables on the marine benthic environment. Knowledge gaps were identified and prioritised, informing future research and monitoring needs with a focus on the impacts of fixed offshore wind turbines. The knowledge base has been updated and the information has been structured for publishing in scientific literature. The manuscript is intended to be submitted by the end of 2018.

The effects of marine energy developments on the benthos were mainly related to offshore wind farms in the past. However, offshore renewables have significantly evolved since the start of WGMBRED's activities. New devices are continuously being developed, tested and applied throughout the ICES area. For example, while the emphasis was on fixed offshore wind energy installations in the early stages, nowadays floating windmills and, wave and tidal energy converters are becoming viable offshore renewable energy developments. This has boosted both the richness and the breadth of the knowledge base on the effects of offshore renewables on the marine benthic system.

Thus, WGMBRED carried out a review of knowledge gaps relating to the benthic ecosystem including differentiation among other energy devices such as tidal and wave energy devices, as well as floating wind farm devices using e.g. reports of national activities and published literature. Through the knowledge of the experts within WGMBRED on the number, scale and effects of these devices, the group scored the cause-effect-relationships based on the hypotheses developed during the last three years (WGMBRED, ICES 2015).

National experts of WGMBRED collected all data on different renewable energy devices in order to get an overview of which marine renewable energy devices (fixed and floating wind devices, tidal devices and wave devices) are already installed in the different countries (Table 2, Table 3)

Table 2. 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[1]
	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									
Germany	no. of devices	702	1376	6689									
	areal extent (km²)	366	770	4868									
	capacity (MW)	3013	7355	37834									
United Kingdom	no. of devices	1578	362	1944			1	5	1233	398	4	NA[2]	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									

[1] **Unknown number of devices**

[2] **Two projects with unknown number of devices**

Table 3. 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, WGMBRED used the template (specific hypotheses) and scoring system (following Bergström *et al.* 2014) from the updated information in the planned Knowledge theme publication, see also ICES (2015). A number of guiding principles needed to be taken into account in order to complete scoring of energy devices:

1) A clear methodology should be defined ensuring that all of the characteristics of the particular devices are taken into account when considering interactions (e.g. likely different anchor systems etc.).

2) In order to ensure consistency of the 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). A confidence scoring system was 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 was 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) To identify pathways of interactions similar to those identified in the fixed wind assessment, differences also need to be identified and that the justification for these is clearly communicated for these hypotheses. This 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. Thus, a clear justification must be provided for the proposal of new hypotheses.

Furthermore, different types of marine renewable energy devices can have different characteristics. For example, tidal and wave devices can be anchored, piled/drilled or gravity based. This has consequences for the effect of the device on the benthal. Thus in order to score the different types of MREDs, examples were used as benchmarks from currently producing MREDs, i.e. commercial devices in order to have a realistic assessment of what devices might be installed in the future in European waters. These were piled wind turbines (as a reference energy device), gravity based tidal turbines, floating wave convertors and floating wind turbines (Table 4).

Table 4. Benchmarks for the different types of marine renewable energy devices (MRED) assessed.

MRED Type	Foundation	Example	Depth	Footprint [km²]
Wind turbine	Piled	Belwind, Belgium	<50 m	0.0007
Tidal	Gravity	MeyGen / Pentland Firth	<50 m	0.0006
Wave	Anchored + concrete block	Penguin/Orkney		
Sweden			<50 m	0.5
Floating wind	Anchored	Hywind Scotland	>50m	1.7

The baseline MRED to compare more recent developments against was taken to be a wind turbine constructed using a monopile foundation, as present in the Belwind wind farm in Belgium. Belwind is 46 km offshore and placed in water depths of 18–33 meters. It was constructed in 2009 using 5 m diameter steel monopiles, with scour protection of approximately 30 m in diameter.

The tidal turbines taken as reference were from the MeyGen tidal energy project located in Pentland Firth, 2 km offshore in Scotland. The 18 m diameter turbines were constructed in 2016 and are placed on a steel gravity based foundation (estimated to be 25 m in diameter based on figures), held in place by ballast blocks. Local water depth is 39 m while the height of each turbine is 22 m from the seabed.

The wave energy convertor used as reference was the Wello Penguin wave energy converter. This 30x16 m floating system was installed near Orkney, Scotland in 2012. It extends 7 m below the water line and is attached to chains using concrete blocks as anchors.

The Hywind wind farm was taken as reference, installed in 2009 in Buchan Deep, 25 km off Peterhead, Scotland. This floating turbine is placed on a single floating cylindrical buoy moored by three 900 m chains, fixed to the sea bed using suction anchors which are 5 m diameter. The 9–15 m diameter buoy penetrates the water up to 78 meters.

Using a Delphic judgement approach, the WG further compared the knowledge base (focused on fixed offshore wind farms, Table 5) with the other offshore renewable energy devices (Table 6). The sensitivity of the (likely) impacts on the benthal were assessed relative to fixed offshore windmills (Table 5).

Table 5. Fixed wind farm devices (Benchmark example: Belwind, Belgium): 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 (see Table 6), 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. Bacteria decomposition is accompanied by oxygen depletion and release of toxic	ARE	3

Hypothesis	**topic**	**SN**
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

Table 6. Hypothesised cause-effect relationships related to different energy devices (wind farm floating, tidal-gravity based and wave anchored devices, see Table 4 for benchmarks) 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 the spatial extend (SE), temporal extend (TE) sensitivity (SN, i.e. magnitude of the effect) are all 1 – 3 (scores: 1 = low, 2 = moderate, 3 = high), as well as the confidence (CO). The certainty was scored 1 – 4 (scores: 1 = very low, 2 = low, 3 = moderate, 4 = high). Scores are listed as a reference for other renewable energy devices, i.e. sensitivity (SN) of other devices was scored as the effect being less (-), equal (=) or higher (+) compared to fixed offshore wind farms devices (see Table 5).

Hypothesis	Topic	Floating wind turbine					Tidal-device, gravity based					Wave device, anchored				
		SE	TE	SN	CE	CO	SE	TE	SN	CE	CO	SE	TE	SN	CE	CO
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	2	-	2	3	1	2	-	1	3	1	2	-	2	3
Altered food availability to filter-feeders (BD m)	ARE	1	2	=	2	3	1	2	=	2	3	1	2	-	2	2
Colonisation by non-indigenous species through transport on shipping, ballast water, translocated equipment	ARE	3	3	+	2	3	3	3	=	3	3	3	3	=	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	-	2	2	3	2	+	2	2	3	2	-	2	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	1	2	=	2	3	3	2	+	3	3	2	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	-	2	2	2	2	+	2	2	1	2	+	2	1
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	2	+	2	2	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,	IEE	3	2	-	2	3	3	2	=	2	3	3	2	=	2	3

Hypothesis	**Topic**	**Floating wind turbine**					**Tidal-device, gravity based**					**Wave device, anchored**				
		SE	TE	SN	CE	CO	SE	TE	SN	CE	CO	SE	TE	SN	CE	CO
BD a3)																
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	=	2	2	1	2	+	3	2	1	2	=	4	3
Organisms from higher trophic levels (e.g. fish) are attracted/aggregated to/at the physical artificial structures for shelter (FR B)	ARE	3	2	=	2	3	3	2	-	4	3	3	2	=	3	3
Organisms from higher trophic levels forage on the assemblages on the artificial structures and in the surrounding natural habitats (FR D)	ARE	2	2	-	2	2	1	2	?	3	3	1	2	-	2	3
Hard-substrate fauna will profit from opportunities in natural habitats and vice versa (BD t)	ARE	1	2	-	2	1	1	2	=	2	2	1	2	-	2	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	2	2	+	2	3	1	2	=	2	3	1	2	-	4	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	2	2	-	2	3	1	2	=	2	2	1	2	-	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	=	2	3	1	2	=	2	2	1	2	-	4	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	+	2	3	1	2	=	2	1	1	2	-	3	1
Construction noise: Construction activities, operation of devices and shipping (e.g. for maintenance purposes) cause vibration and	IEE	1	1	-	2	3	1	1	-	2	3	1	1	-	2	3

Hypothesis	Topic	Floating wind turbine					Tidal-device, gravity based					Wave device, anchored				
		SE	TE	SN	CE	CO	SE	TE	SN	CE	CO	SE	TE	SN	CE	CO
noise of various frequencies and intensities that might affect performance and behaviour of sound-sensitive organisms (FR K1, BD a1)																
Change in sediments cause changes in diversity (BD #)	MSD	2	3	-	2	1	3	3	+	2	1	2	3	=	2	1
Deposition of particles from fouling assemblages such as shell debris alters granulometry of nearby sediments (BCR J, BD %)	ARE	2	3	=	2	2	1	3	=	2	2	1	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	2	3	-	2	1	3	3	+	2	1	2	3	+	2	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	-	2	1	1	2	-	2	1	1	2	-	2	1
Changes in benthic anoxia affects mortality/colonisation of natural habitats (BD S)	ARE	1	2	-	2	3	1	2	-	2	1	1	2	-	2	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	1	2	-	3	1	1	2	-	2	3	1	2	-	3	1
Direct mortality, reduction in fitness or altered function through removal, abrasion, smothering, or increased sedimentation (BD b)	MSD	1	2	+	2	1	2	2	=	2	2	1	2	=	2	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	2	-	2	1	2	2	-	3	2	1	2	+	2	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	2	-	2	1	3	2	=	2	2	1	2	-	2	1
Electromagnetic fields might affect the migratory behaviour of sensitive species thereby potentially changing population	IEE	2	2	+	2	1	1	2	=	2	1	1	2	=	2	1

Hypothesis	Topic	Floating wind turbine					Tidal-device, gravity based					Wave device, anchored				
		SE	TE	SN	CE	CO	SE	TE	SN	CE	CO	SE	TE	SN	CE	CO
structure and distribution patterns (FR J)																
Conduction of electricity through high-voltage cables induce electromagnetic fields (FR L)	IEE	2	2	+	2	1	1	2	=	3	2	1	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	1	1	-	2	1	3	1	=	3	1	1	1	-	2	1
Changes in distribution: introduced noise will cause distribution changes in natural and artificial hard-substrate fauna (BD c, d)	IEE	1	2	-	2	1	2	2	=	2	2	1	2	-	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	1	-	2	1	2	1	=	3	1	1	1	-	1	1

Floating wind turbines devices

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 5). 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 potentially affect the benthic environment during the operation of the turbine. As noise 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 (Table 5), although it will depend on currents, as it is likely to be dispersed widely 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 devices to be relocated (Table 5). Turbines may be recovered and towed to shore for maintenance or 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.

In total, Table 5 highlights that the spatial extend of floating wind turbines were scored similar to fixed turbines in 10 hypotheses, higher in 13 and lower in eight hypotheses. The sensitivity was scored lower in 19 cause-effect-relationships and only higher for six hypotheses. The confidence was scored low for nearly all hypotheses (one exception) due to the lack of existing knowledge on effects of floating wind turbine on the benthal.

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 and also the exposure to electromagnetic fields;
3) Potential for large deposition following cleaning of cables and moorings;
4) Exclusion of tow fishing due to moorings and, if ‘daisy-chained’, cables.

Tidal devices

There are different types of tidal devices: anchored devices piled or drilled devices and gravity based devices. Anchored devices were 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. Scoring was done for a gravity-based tidal device only (Table 6). However, for many hypotheses the spatial and temporal scales were less likely to differ than the magnitude of the effects (sensitivity) identified. Overall, the spatial extend of the effect of tidal devices was comparable to those of fixed wind farms as 20 out of 31 hypothesis were scored similar to wind farms (Tables 4 and 5). Only seven hypotheses were scored with a larger spatial extent than fixed wind turbines. The sensitivity scored equal for 17 hypotheses, with seven having a larger or smaller magnitude of the effect, respectively, compared to fixed turbines.

The most obvious differences were those hypotheses that needed to take into consideration the change in hydrodynamics and associated influences 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. Two new cause-effect relationships were added to the list:

1) Collision risk of benthic species with tidal device;
2) Possibility of barotrauma to benthic larvae from the pressure of moving parts of tidal devices.

For tidal devices, the confidence was scored low for 22 hypotheses (Table 5), due to the lack of knowledge on the effects of these devices compared to fixed wind turbines. 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/).

Wave devices

Wave energy converters can be distinguished into fixed and anchored structures. 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 fixed wind turbines with regards to the spatial and temporal extent of environmental impacts, its consistency and confidence. Substantial deviations from fixed wind turbines were identified only for anchored wave energy converters which was used as the benchmark commercial example in the scoring exercise (see Table 6). These differences mainly concern two criteria: sensitivity and confidence.

For anchored wave energy converters, sensitivity was assessed lower for 19 out of 31 cause-effect relationships (Table 5). 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 (thereby having less impact on e.g. food webs and organic enrichment). However, the sensitivity of wave energy converters was assessed higher for three cause-effect relationships (Table 4 and 5). All three 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 to be low for 22 cause-effect relationships (Table 5) This discrepancy refers to the lack of knowledge on environmental effects of this fairly novel and hence largely unstudied renewable energy technology. This is much in contrast with a fixed device, because here we can rely on the vast amount of data referring to monopile impacts on the environment.

Literature

Bergström, L., L. Kautsky, T. Malm, R. Rosenberg, M. Wahlberg, N. A. Capetillo and D. Wilhelmsson. 2014. Effects of offshore wind farms on marine wildlife-a generalized impact assessment. Environmental Research Letters 9(3). 12 pp.

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.

5.5 Network analysis, summary 2016–2018

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

During the series of WGMBRED meetings it became evident that only a coordinated effort to harness the wide international interest and requirement to understand MREDs and the benthic ecosystem is needed to then provide the evidence for policy and decision makers. Therefore, a specific ToR was as follows: 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.

Tom Wilding and Raeanne Miller (a colleague at SAMS) have been working on the network analysis as part of a wider initiative. Using data gathered from WGMBRED and associated contacts intersessionally 304 responses were gratefully received. The data are undergoing analysis which is collating the diversity and location of organisations involved in MREDs. The study, currently in draft form, has highlighted where connectivity between different sectors within the general marine renewables field exist.

Initial data interpretation demonstrated interesting patterns of optimism and centrality (Annex IV Tethys is central), whilst WGMBRED was on a bit on a limb in the network of people and organisations dealing with offshore renewables throughout the ICES area. This finding has stimulated the group to reconsider its collaboration and communication strategies. The final wrapping up and conclusions from the analysis remain to be completed in the form of a paper to be submitted to a journal.

In its next term, WGMBRED anticipates strengthening its scoping for international collaboration within the science community (focus: science priorities identified by WGMBRED 2013–2015 and WGMBRED 2016–2018), but also with the science-policy interface community. Especially the latter ambition required some rethinking in relation to the group's communication strategies. The new plan with regards to both international collaboration and communication is reflected in the proposed new Terms of Reference for a third term of WGMBRED.

5.6 Indicator theme, summary 2016–2018

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

Indicators, as a tool for guidance in decision making, are widely used in the framework of international obligations (e.g. European Directives). They 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 traits) are often used in the framework of several international drivers (i.e. Marine Strategy Framework Directive (MSFD), Water Framework Directive (WFD)).

The benthos can be an excellent indicator to assess Ecological Quality Status of soft bottoms, e.g. when referring to MSFD or WFD, and is therefore already taken up as an indicator in these legislative frameworks. 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". In 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.

WGMBRED acknowledged that ICES 2010 had already provided a thorough review of indicators and their application and OSPAR also provided recommendations. Thus, WGMBRED screened indicators in this literature to avoid duplication of work. Further, the group decided that ecological indicators could be used to help define the ecological and societally important issues (SII) that were identified by the knowledge group (WGMBRED, see ICES 2015). During the three years cycle of the group, WGMBRED tackled the identification of indicators at ecologically relevant scales from different directions, i.e. linking indicators (a) to scales (related to ToR A), (b) to cause-effect relationships and ecological functions related to the SII and finally (c) to ecosystem functions and ecosystem services.

Phase 1: Linking indicators to scales within certain case studies

Initially, the group considered three different geographical regions of interest to marine renewable energy developments to identify appropriate indicators, namely the Baltic Sea, the eastern Irish Sea and the Southern North Sea. The regions provided case studies (also used in the Scale ToR A discussions) for the application of indicators relating to the Societally Important Issues (SII's, the biogeochemical reactor, food resources and biodiversity; ICES 2015) whilst incorporating consideration of cumulative effects, connectivity and scale.

Each group worked to the following outline procedure:

Proof of Concept Scale and Indicator development

1) Choose relevant site

2) Start with pressure classifications (Bergström *et al.* 2014): Artificial reef effect, fisheries exclusion, introduction of energy and sound, mechanical sea floor disturbance

3) Link those to each of the three SIIs

4) Critical path analysis looking at:

- cause-effect pathways and the parameters best describing the cause-effect relations in space and time;
- relevant processes in the pathway to be discussed (including connectivity and scale)

5) Leading to proof of concept for indicator selection and scale issues

Each group developed a concept of scale and indicator developments for the three case studies and the outcomes were discussed between experts of WGMBRED. Below the Baltic Sea case study is given as an example (Table 7).

Baltic Sea case study

Background: The Baltic Sea has an impoverished brackish fauna which is sensitive to invasive species. Invasive species are represented already in the soft and hard substrate. Little diversity exists so stability is maintained with only a few species. Spreading of species is restricted as a salinity gradient/reduction inhibits reproduction in certain regions and currents are only wind driven, i.e. there are no larger currents which connect the Baltic Sea areas over large distances.

Table 7. Proof of concept for the indicator development at ecological relevant scale for the Baltic Sea case study.

Proof of concept	Baltic Sea
Choose relevant site	Focus area: south-eastern Baltic Most likely OWF projects: Middle Baltic II, Baltica 3 and Middle Baltic III.
Pressure classification acc. to Bergström *et al.* 2014	Reef effect: potential local enrichment of sediment with organic matter may lead to changes in benthic fauna and anoxic sediments. Changes in local hydrodynamics. Fishery exclusion: cod present in area but fishing activities prevented by stony environment so fishery exclusion would be a less important pressure Energy in the form of sound emitted by: turbine foundations most likely monopole. Effects of piling on benthos largely unknown.
Choose relevant aspects to be discussed and link those to each of the three SII	Hard substrate is rare in this region. Some isolated stony reefs, in shallow (approx. 8–15 m) and relatively pristine areas far from shore. Impoverished fauna is sensitive to invasive species. Invasive species are present on soft and hard substrate. Hard substrate could lead to increases in invasive species Baltic fauna is an impoverished brackish fauna. Little diversity to maintain stability with few species (8 dominant species in area), any effects on species assemblages by introduction of invasive species might severely affect the benthic communities Restrictions on spreading of species (such as common shore crab): salinity gradient/reduction inhibits reproduction in certain regions; mostly wind driven spread means possible lack of connectivity due to reduced ability for fauna to drift long distances between wind farms Biomass increase due to artificial reef effect. This may lead to oxygen depletion. As the system is lacking of strong currents, biomass might not be transported far from wind farms. Link to each of the three Socially Important Issues (SII) Biogeochemical reef effect: local enrichment of sediment with organic matter. May lead to changes in benthic fauna. Changes in local hydrodynamics Biodiversity: introduction of invasive species and potential anoxic sediment conditions will affect biodiversity
Choose relevant process in the pathway to be discussed (include connectivity, scale)	Pathway for biogeochemical change: B-O-P-Q1 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." O: "Released organic material from the accumulated fouling community on the artificial structure become 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." Effects may lead to eutrophication/ cyanobacteria blooms Organic matter may be transported from shallow to deep, anoxic areas. As carbon flux to anoxic zone is faster than from anoxic zone deep areas may act as carbon sink. Hypothesis O would be the critical part of the above pathway. This could lead to a cascading effect through the system, either through space and time or through the food web
Leading to proof of concept for indicator selection and scale issues	Possible indicator measure might be organic matter concentration in sediment. Increased organic matter may increase the redox layer in the sediment. Local scale. Increase in organic matter could lead to increase in deposit feeders and reduction of suspension feeder, causing a 'wormification', increase in fine sediment and change in porosity of seabed. Index of Dauvin *et al.* (2016) on polychaete/amphipod ratio might be used.

This exercise demonstrated the importance of interactions between OWF and cod in terms of biogeochemical interactions and food provisioning at scales of societal importance. Indicators should be based on relevant process-driven changes by OWF which can be identified by the corresponding cause-effect relationships (see Figure 5). However, indicators for process-driven changes affecting biogeochemical changes (see Table 7) and food provisioning (see Table 1) have to be applied at ecological relevant scales as demonstrated in chapter 5.3. This exercise demonstrated well the use of the SII's as a structure in order to stay focused within the aims of the framework which requires a sound collection of information available to ensure a proper understanding of the ecosystem and the identification of indicators at the ecologically relevant scales (chapter 5.3).

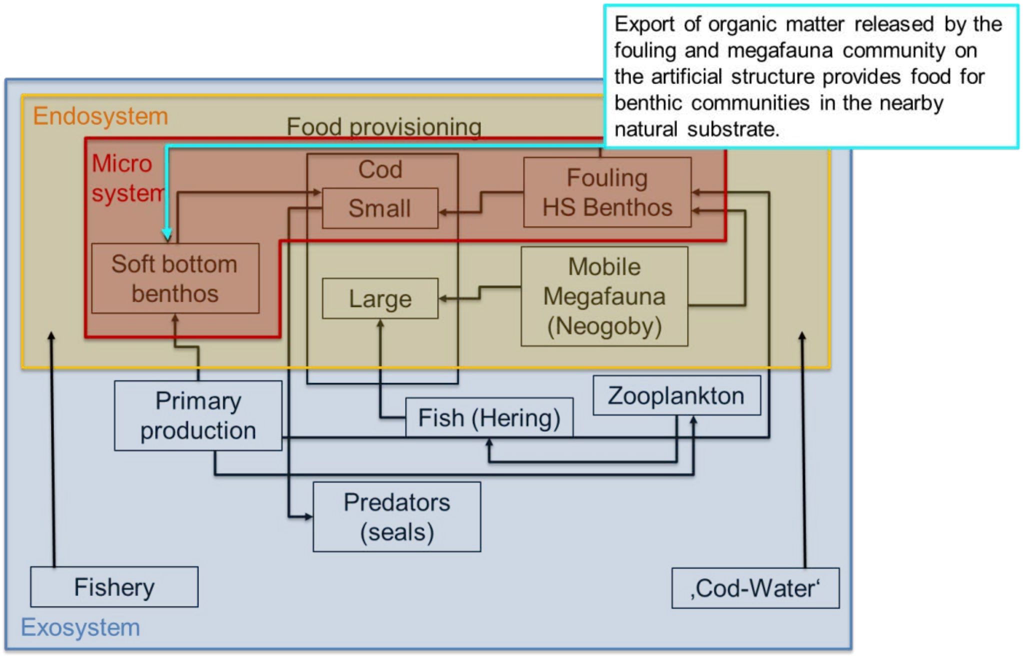

Figure 5. Representation of interactions between OWF and cod in terms of food provisioning at scales of societal importance (see also section 5.3 of this report). The SES approach identified the microsystem components defining the Food Provision embedded within a defined endosystem (i.e. biological production of cod), which in turn would be influenced by external factors within the exosystem. The box shows one cause-effect relationships within the critical path analysis as an example.

Phase 2: Linking indicators to ecological functions

As a second step the group linked indicators to ecological functions via the cause-effect relationships underlying the three SII's. The SII's span multiple ecosystem services and the identified cause-effect relationships can thus be linked to ecosystem functions supporting the delivery of the ecosystem services. WGMBRED followed the publication of Hattam *et al.* (2015) as a guidance document to translate the cause-effect relationships associated with the SII's into an ecosystem functioning – ecosystem service concept.

Thus, the SII's were redefined into Ecosystem Services (ES), following Hattam *et al.* (2015, which basically follows CICES) but by critically looking at them again, since there may be disagreement with e.g. i.e. 'Nursery habitat' being a final ES. The group also considered the Paul Montagna paper (BEWG initiative, unpublished) and University of Liverpool report (under embargo at ETC/ICM, Culhane *et al.* unpublished). WGMBRED linked the different SIIs to ecological functions and ecosystem services in order to evaluate changes by the introduction of offshore renewable devices through relevant pathways to define indicators detecting functional changes following the conceptual scheme in Figure 6.

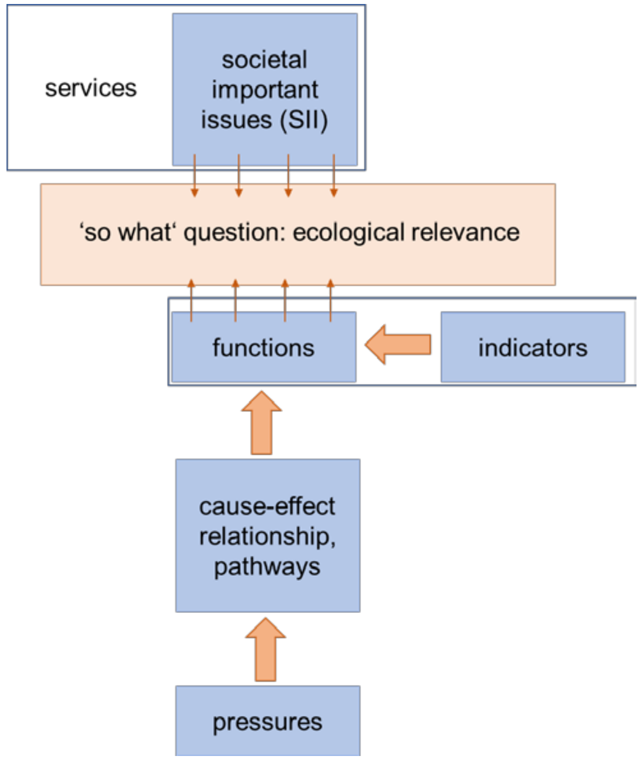

Figure 6. Conceptual scheme linking pressures to cause-effect pathways to functions and ecosystem services in order to identify adequate indicators.

As an example for this conceptual linking, the SII 'food resource' is used in the following:

WGMBRED identified possible effects on food resources from MREDs by identifying hypotheses that relate to food resources from the sensitivity analysis. Artificial reef effects and the introduction of energy were identified as major pressures (see definition of Bergström *et al.* 2014). The following hypotheses were also identified for these two pressures (Table 8) and the 'so what' question, i.e. the ecological relevance, was self-evident: commercially important species may be affected, threatening food security.

Table 8. Example on linking ecosystem services and ecosystem functions related to food resources with cause-effect hypotheses related to artificial reef effect and the introduction of energy.

Ecosystem service	Ecosystem function	Cause-effect hypotheses: Artificial reef effect
Food provisioning	- create space for other species (native or non-native), as well as feeding or spawning grounds - species may be displaced - changes in primary and secondary production by introducing new species and modifying trophic interactions - introduction of nutrients	- 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:

	which would further influence trophic interactions - filter feeding species may be enhanced, displacing nutrients in the water column	Exclusion of fishing - Hanging cables and moorings for floating devices - Provision of shelter for fish
Ecosystem service	Ecosystem function	Cause-effect hypotheses: Introduction of energy
Food provisioning	- species displacement and potential interruption of migrations - species fitness and fecundity trophic interactions could be modified as species are displaced - changing transfer of energy between trophic levels affecting trophic interactions which may ensure stability of the ecosystem	- Noise/vibration: shipping, construction and operation of renewable energy devices - electromagnetic fields: transmission of electricity through cables and from substations - compression of sediment (may be relevant but this has not been investigated): piling or placement of gravity base and anchors

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

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

WGMBRED found that linking indicators to ecological functions and services at different scales is a very broad and involved topic and that the group needed to discuss in detail. The group would not be able to cover the work required to meet this ToR within the period of annual meetings of the WGMBRED. However, the process of developing an indicator was also a key element that led to the intersessional application for a EuroMarine Foresight Workshop. The WG decided that the best way to meet the deliverables of the ToR, was to link the development of the indicators with the EuroMarine outputs.

Phase 3: Linking indicators to functions and services

WGMBRED members successfully applied for EuroMarine funding to organise a workshop 'Ecosystem changes associated with offshore wind farms: bridging the gap between biogeochemical effects, ecosystem functioning and ecosystem services'. The workshop aimed at linking ecological changes induced by the exploitation of offshore wind farms (OWFs) to the provisioning of ecosystem services to society. The workshop was attended by a number of WGMBRED members, complemented by social scientists and ecological and oceanographic modellers to allow for (1) the implementation of a methodology leading to a numerical analysis of the effect of OWFs on the provisioning of relevant ecosystem services to society and (2) to pave the way towards the development of indicators for the relevant ecosystem services.

Relevant ecosystem services were defined according to the CICES classification (https://cices.eu/) and related to well-defined pressures, biological components and ecosystem functions associated with OWFs (Figure 7).

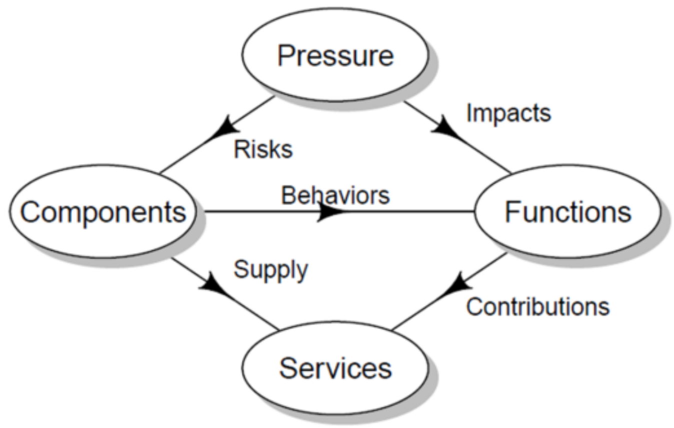

Figure 7. Diagram showing relations between pressures, components, functions and ecosystem services associated with the exploitation phase of offshore wind farms.

Based on this concept, it was decided that indicators for the provisioning of ecosystem services need to be as closely as possible associated to the ecosystem service of interest, according to Figure 8. In addition, indicators needed to be (1) measurable, (2) sensitive, (3) specific, (4) scalable and (5) transferable, following the recommendations of Hattam *et al.* (2015).

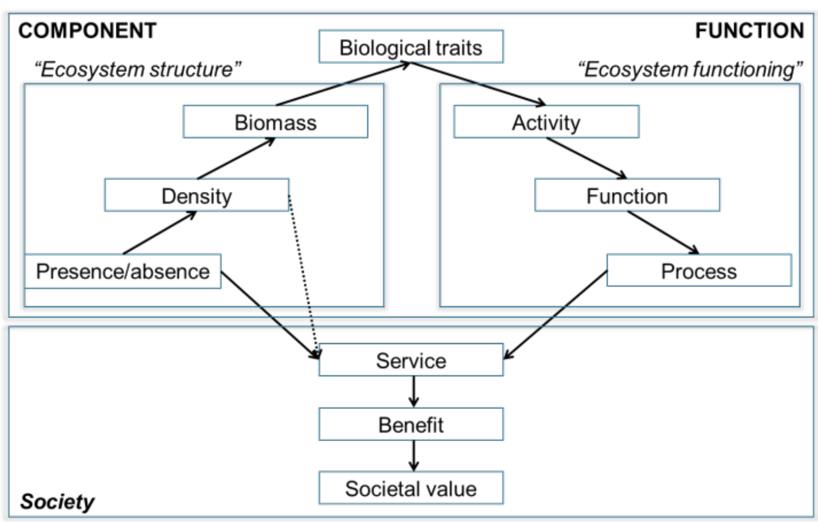

Figure 8. Diagram on the relations between the structural part of the ecosystem (left upper box), the functioning part (left right box) and the societal relevance (lower box).

The concept was tested during the workshop, and it was found that many of the suggested indicators, compliant with the five mentioned conditions, were actually in the "ecosystem function" or "ecosystem process" part of the diagram (Figure 8). An example is provided in Table 9.

Table 9. Example of defining indicators for ecosystem service. The links between ecosystem services, ecosystem processes and ecosystem functions were defined through the implementation of Figure 7. The ecosystem service considered here is "bioremediation", the closest ecosystem process (Figure 8) is "nutrient cycling", the associated ecosystem function is nitrogen removal. For this ecosystem function, the indicator "nitrogen flux" was considered compliant with the criteria suggested by Hattam *et al.* (2015).

	CATEGORY	INDICATOR	METHOD
Ecosystem Service	Bioremediation	Not available	Not relevant
Ecosystem Process	Nutrient Cycling	Not available	Not relevant
Ecosystem Function	Nitrogen removal	Nitrogen flux (in µmol day^{-1} m^{-2})	Closed lab incubations

The outcomes of the workshop are still under progress and will be published in peer-reviewed scientific journal as joint publication of the WGMBRED and the EuroMarine workshop group.

Literature

Bergström, L., L. Kautsky, T. Malm, R. Rosenberg, M. Wahlberg, N. A. Capetillo and D. Wilhelmsson. 2014. Effects of offshore wind farms on marine wildlife-a generalized impact assessment. Environmental Research Letters 9(3). 12 pp.

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.

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.

ICES. 2016. Interim Report of the Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED), 14–18 March 2016, Delft, the Netherlands. ICES CM 2016/SSGEPI:03. 42 pp.

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

6 Cooperation

WGMBRED has close links to several other ICES WGs, particularly to WGMRE, chaired by Finlay Bennett, and the BEWG, chaired by Steven Degraer and Silvana Birchenough respectively. While WGMBRED is focused on the scientific challenges of MRE monitoring for the benthic ecosystem, WGMRE has a wider remit and is focused on the policy aspects of MRE siting, consenting, licensing and monitoring.

WGBEWG deals with the benthic ecosystem component in general and does not specifically tackle the effects of MRED on the benthos.

As a member of BEWG, co-chair of WGMBRED Jennifer Dannheim gave annual updates of WGMBRED activities at the BEWG meetings. WGMBRED's current position is that it is focused on offshore renewable energy devices (e.g. wind farms, tidal and wave energy installations) but acknowledges that there are other MRE devices. WGMBRED does not currently have the full spectrum of in-house expertise to deal with these newer devices. If future scientific questions require it, WGMBRED will aim at finding the appropriate expertise to contribute to the WG.

In the past three years, WGMBRED has had no cooperation with the advisory structures. The only engagement for giving advice has been a recent request from OSPAR's Environmental Impacts of Human Activities (EIHA) Committee for advice on 'the current state and knowledge of studies into the deployment and environmental impacts of wet renewable technologies and marine energy storage systems.' The advice will inform the future discussion on any action within the EIHA Committee on guidance or measures relating to these types of devises. WGMBRED and WGMRE together responded favourably to the request stating that we both had valuable expertise and have already considered some of the likely aspects relating to this request. We also informed the requester that we are holding our annual meetings in Belgium around the same time in March 2019 and that this could be an ideal opportunity to move forward with providing further advice relating to the request. We are awaiting further communication regarding any cooperation.

In the future, WGMBRED is open for any requests giving advice on the knowledge developed within the group. Besides the group as a whole entity, single experts of the group are involved in national committees giving scientific advice to authorities, decision-makers and policy makers. The same holds true for cooperation with IGOs and national experts of WGMBRED.

7 Summary of Working Group self-evaluation and conclusions

The full Working Group evaluation can be found in Annex 5, below is the summary and main conclusions:

- The WG made a significant contribution to the Science plan research priorities: 5, 6, 8, 9, 11, 14, 15, 25, 26, 27 and 31
- The main outcomes and achievements of the WG are:
  - Review paper on monitoring (ToR A), i.e. addressing scale aspects and the relevance to monitoring, defining suitable objectives and approaches to determine relevant changes to the benthic ecosystem;
    - Thomas A. Wilding, Andrew B. Gill, Arjen Boon, Emma Sheehan, Jean–Claude Dauvin, Jean-Philippe Pezy, Francis O'Beirn, Urszula Janas, Liis Rostin, Ilse De Mesel (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.
  - Review paper being written based on three different geographical case studies to demonstrate conceptually the consequences of meaningful ecological

changes acting on different scales in relation to the effects of marine renewable energy devices on the benthic ecosystem (ToR A).
    - Review paper for managers, policy makers, developers and academics highlighting the knowledge gaps (ToR B, to be submitted in 2018) in relation to offshore renewable energy devices on the benthal including a Matrix/literature review matrix with specific Cause-Effect hypothesis; an assessment of sensitivity, certainty and consistency of the matrix; and an analysis of knowledge gaps.
    - Tables summarising the sensitivity, certainty and consistency of cause-effect relationships (ToR B, published in this report) in relation to different offshore renewable energy devices including Floating wind farm devices, Tidal and Wave devices
    - Network analysis of WGMBRED and other relevant groups; the network map highlights the impact of the WGMBRED science (ToR C, publication to be submitted).
    - Publication being written assessing ecosystem functioning and change in relation to OWFs at different spatial scales and applying indicators to assess changes in ecological functioning and ecosystem services; this publication (to be submitted in the beginning of 2019) combines outcomes from the WGMBRED science (ToR D) and a EuroMarine Forsight Workshop.
    - Contributions and theme session lead at the Fort Lauderdale ICES ASC 2017.
    - Fort Lauderdale ICES ASC 2017, Open Session WGMBRED members convening and presenting.
    - ICES ASC 2016 in Riga, presentation.
    - ICES JMS special issue – ecologically sound decommissioning for offshore man-made structures. WGMBRED Experts Steven Degraer and Silvana Birchenough are editors. A number of contributions have been proposed from the WGMBRED group
- WGMBRED did not get any requests from ACOM.
- Within the last three years, experts of WGMBRED contributed to a number of conferences and meetings acting as members of scientific advisory committees, keynote presenter, main conference oral presentation and posters and workshop leading and participation. Intersessionally there have successful funding awarded for workshops involving WGMBRED members, with the output now closely tied to WGMBRED for added value in our activity.
- During the last three years' work of the WGMBRED a slight adaptation of the focus of the ToRs has been conducted. While the ToRs B and C were straightforward and fully completed within the three years' cycle, the group underestimated the work of the ToRs A and D. These topics were very complex and the focus was too wide. This was assisted by activities outside of the WGMBRED annual work during the post ICES ASC Workshop at CEI, Bahamas ('BESpE – Benthic Ecosystems Spatial Ecology Workshop') and during the EuroMarine Forsight Workshop at AWI, Germany ('Ecosystem changes associated with offshore wind farms: bridging the gap between biogeochemical effects and its repercussions for ecosystem functioning and services'). Both workshops were initiated and attend-

ed by WGMBRED experts and thus the outputs are a result of the WGMBRED work. However, for the next draft resolution for multi-annual terms of reference, the group formulated more specific objectives leading into more specific scientific publications and advice.

Future plans

- The experts agreed that a continuation of the WG is definitely required. The reasons are the still rapidly evolving industry with a worldwide expansion, the upcoming ideas of multiple use of energy device arrays (e.g. for aquaculture), as well as the developments of new technologies in the offshore renewable energy sector in countries where no marine renewable energy devices have been installed before. There are several topics which have not been explored yet in this context. Thus, the ongoing uncertainty of the potential effects of these evolving new topics and technologies and inconsistent legislation frameworks between countries call for an implementation of a common legislative framework and projects with wider geographic scopes to look at cumulative impacts across borders for a thorough ecological understanding. This calls for a strong international collaboration and knowledge exchange and WGMBRED provides this scientific platform for exchange.
- Based on the current knowledge, WGMBRED realises that biodiversity of the benthos may be positively affected in areas with marine renewable energy devices by the provision of habitat, food and shelter for a number of marine organisms. As such, marine renewable energy device arrays could act as *de facto* conservation areas for benthos, adding to the existing network of designated Marine Protected Areas. WGMBRED is of the opinion that this is of high importance and should be taken into consideration in the marine spatial planning and decision-making process for locating and potential decommissioning, as well as multiple activities within concession zones of marine energy devices sites.
- Further, WGMBRED recognises that the development of a knowledge base to support the implementation of the Ecosystem Approach to Management with respect to marine renewable energy devices is of high importance. This calls for moving towards a process-driven understanding of how the changes to the structural and functional composition of the benthos associated with marine renewable energy devices contributes to ecosystem functioning and the provisioning of ecosystem services. In this context, WGMBRED will develop standardised data collection and methodologies to enable integration of benthos data of marine renewable energy devices from various sources into wider international frameworks to overcome differences in national standards in data collections. This will demonstrate how an integrated dataset of benthos data stored in a database can serve as thorough scientific base to enable analysis for different scientific purposes by the international scientific community on large geographical scales.

Annex 1: List of participants

Name	Institute/ Country	Email
Arjen Boon	Deltares Research Institute Unit of Coastal and Marine Science P.O. Box 177 2600 MH Delft The Netherlands	arjen.boon@deltares.nl skype: arjenrboon
Radosław Brzana	Instytut Oceanografii Uniwersytet Gdański al. Marszałka Piłsudskiego 46 81 - 378 Gdynia	radek.barbus@gmail.com
Joop W.P. Coolen	Wageningen Marine Research Ankerpark 27, 1781 AG Den Helder, NL Aquatic Ecology and Water Quality Management group Wageningen UR	Joop.coolen@wur.nl skype: joop.coolen
Jennifer Dannheim (co-chair)	Alfred Wegener Institute for Polar and Marine Research P.O. Box 120161 27570 Bremerhaven Germany	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	jean-claude.dauvin@unicaen.fr
Steven Degraer	RBINS-OD Nature Gulledelle 100 B-1200 Brussels Belgium	steven.degraer@naturalsciences.be
Angus Jackson	Cornwall College Newquay, Wildflower Lane Trenance Gardens Newquay Cornwall TR7 2LZ UK	angus.jackson@cornwall.ac.uk
Urszula Janas	Instytut Oceanografii Uniwersytet Gdański al. Marszałka Piłsudskiego 46 81 – 378 Gdynia	oceuj@univ.gda.pl
Ilse de Mesel	RBINS-OD Nature 3e en 23e linieregimentsplein B-8400 Oostende Belgium	Idemesel@naturalsciences.be
Andrew B. Gill (co-chair)	PANGALIA Environmental, Ampthill, UK	andrewbgill0510@gmail.com Skype: andrewbgill
Francis O' Beirn	Marine Institute, Rinville, Oranmore, Galway, IRELAND	fobeirn@marine.ie
Jean-Philippe Pezy	UNICAEN, Université de Caen Normandie.	jean-philippe.pezy@unicaen.fr

Name	Institute/ Country	Email
	UMR CNRS 6143 Morphodynamique continentale et côtière 24 rue des Tilleuls F-14000 Caen	
Aurore Raoux	UNICAEN, Université de Caen Normandie. UMR CNRS 6143 Morphodynamique continentale et côtière 24 rue des Tilleuls F-14000 Caen	raoux.aurore@unicaen.fr
Emma Sheehan	Plymouth University Marine Institute Marine Building Drake Circus Plymouth, PL4 8AA UK	emma.sheehan@plymouth.ac.uk
Jan Vanaverbeke	RBINS-OD Nature Gulledelle 100 B-1200 Brussels Belgium	jvanaverbeke@naturalsciences.be

Annex 2: National ongoing activities and up to date research

Belgium

Within the WinMon.BE monitoring programme, the Royal Belgian Institute of Natural Sciences (RBINS) and its partners assess the extent of the anticipated impacts on the marine ecosystem and aim at revealing the processes behind these impacts. The first objective is basically tackled through the baseline monitoring, focusing on the a posteriori, resultant impact quantification, while the second monitoring objective is covered by targeted or process monitoring, focusing on cause-effect relationships of a priori selected impacts. As such, baseline monitoring deals with observing rather than understanding impacts and hence leads to area-specific results, which might form a basis for halting activities.

The results of the monitoring programme are published in a yearly report. These reports target marine scientists, marine managers, policy makers and offshore wind farm developers, and present an overview of the scientific findings of the Belgian offshore wind farm monitoring programme. The 2017 report, based on data collected unto 2016, can be found at:

http://odnature.naturalsciences.be/downloads/mumm/windfarms/winmon_report_2017_final.pdf.

Contact: Steven Degraer, Jan Vanaverbeke, Royal Belgian Institute of Natural Sciences (RBINS), Operational Directorate Natural Environment (OD Nature), Marine Ecology and Management (MARECO), Brussels, Belgium.

France

The PhD thesis of Jean Philippe PEZY entitled "Ecosystem Approach of a future offshore wind farm in the Eastern English Channel: the Dieppe-Le-Treport case study" and the PhD of Aurore RAOUX entitled "Ecosystem approach of marine renewable energy: Study of the impact on the trophic web of the construction of the Courseulles-Sur-Mer Offshore Wind Farm and cumulative impacts" which were based on food web modelling tools through the collection of new data on biological compartments (zooplankton, suprabenthos, benthos with isotopic analysis, and demersal fishes) and data from the Environmental Impact Assessment have been successfully defended in November 2017.

Relevant publications

Raoux, A., Lassalle, G., Pezy, J.P., Tecchio, S., Safi, G., Ernande, B., Mazé, C., Le loch, F., Lequesne, J., Girardin, V., Dauvin, J.C. and Niquil, N, in press. Measuring sensitivity of two Ospar indicators for a coastal food web model under Offshore Wind Farm construction. In press in *Ecological Indicators*

Pezy J.P., Raoux A., Niquil N., Dauvin J.C. In press. Offshore renewable energy development in France with an emphasis on the eastern part of the English Channel: state at the end of 2017. Proceedings of the Conference on Wind Energy and Wildlife Impacts, Estoril, September 2017

Raoux, A., Dambacher, J.M., Pezy, J.P., Mazé, C., Dauvin, J.C., Niquil, N. 2017. Assessing cumulative socio-ecological impacts of offshore wind farm development in the Bay of Seine (English Channel). Marine Policy. 89, 11–20.

Raoux, A., Tecchio, S., Pezy, J.P., Degraer, S., Wilhelmsson, D., Cachera, M., Ernande, B., Lassalle, G., Leguen, C., Grangeré, K., Le loch, F., Dauvin, J.C., Niquil, N. 2017. Benthic and fish aggregation inside an offshore wind farm: Which effects on the trophic web functioning? Ecological Indicators. 72, 33–46.

Contact: Jean-Claude Dauvin, Jean-Philippe Pezy, Aurore Raoux, UNICAEN, Université de Caen Basse-Normandie, Caen, France.

Germany

Over the decade, the Alfred Wegener Institute (AWI) in collaboration with the Federal Maritime and Hydrographic Agency (BSH), the approval authority for offshore wind farms in Germany, has built up an information system on benthic invertebrates from environmental impact assessments (EIA) of offshore wind farms and research projects. The system has served as an important tool for high-resolution and large-scale analysis of occurrence and spatial distribution on endangered (red-list) species and biodiversity, biological traits and benthic communities. Thus, the information system has served to estimate species or group specific "natural corridors of variation" to discriminate anthropogenic effects from natural background variability. As an example, the spatial distribution of red-list species and their most important traits, which might make them more sensitive to anthropogenic impacts, were analysed and species rareness and species categorisation into red-list categories were evaluated.

This information system is core in the current project ANKER, a joint collaboration between BSH, AWI and the Research and Technology Centre, West coast (FTZ). ANKER has the aim, by using this information system now named MARLIN (Marine Life Investigator), to reduce costs and increase the efficiency of monitoring data surveys of offshore projects. MARLIN comprises, amongst others, data on benthic invertebrates, demersal fish and seabirds from environmental impact assessments (EIA) and research projects.

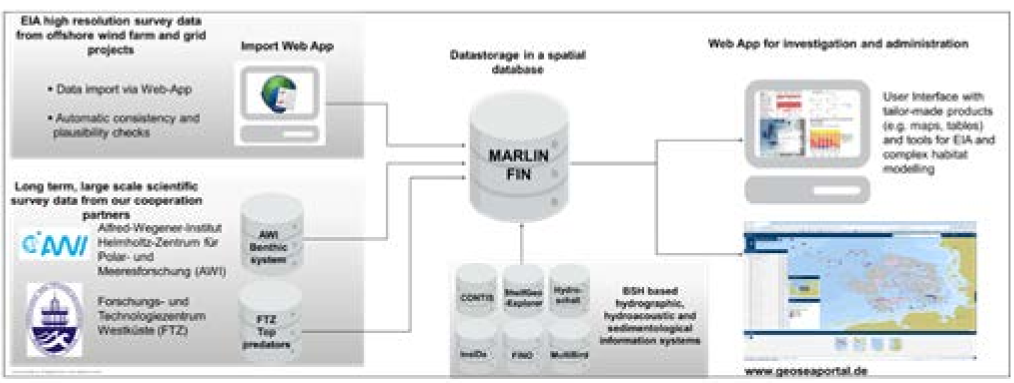

Figure 9. Basic compounds, i.e. structure and databases, of the MARLIN (Marine Life Investigator) information system.

ANKER has established 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. It is planned that MARLIN will be fully accessible online by 2019.

A lobster settlement project was initiated in the offshore wind farm Riffgat by the Alfred Wegener Institute and Roland Krone. The project aim was to evaluate if operating offshore wind farms might serve to establish new stocks of the European lobster (*Homarus gammarus*). A successful settlement could support the species population which is locally endangered. The wind farm is located inside the southern German Bight approximately eight nautical miles north-westerly of the island Borkum. In 2014, a total of 2400 one-year-old lobsters from the hatchery of the Hummerstation Helgoland were released at four scour protections of natural rock surrounding the monopiles of the wind turbines. Each lobster was marked to enable identification after release. One year after the lobster release, a monitoring was performed by scientific diving and pot fishery on the scour protections. Preliminary results show that the lobster abundances at the settlement scour protections were up to 4.5 times higher per square metre than at a typical natural lobster site at Helgoland, German Bight.

A second research project investigated how the presence of wind turbine foundations might alter the mobile demersal megafauna of the North Sea, i.e. the epifaunal communities at common types of offshore wind power foundations jackets and tripods without scour protection and monopiles with scour protections. In the second year after construction, monopiles with scour protections were inhabited by more reef species, such as the edible crab (*Cancer pagurus*, see Krone *et al.* 2017) and goldsinny wrasse (*Ctenolabrus rupestris*) compared to the other structures. However, the typical sand bottom inhabiting gobies (Gobiidae) are nearly excluded by the scour protections.

Relevant publication: Krone, R., G. Dederer, *et al.* (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.

Contact: Jennifer Dannheim, Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany; Roland Krone, Krone-Projekte, Bremerhaven

Ireland

Currently, there are no specific research projects focusing on the impacts or interactions of marine renewable devices on benthal habitats and species.

Contact: Francis O' Beirn, Marine Institute, Galway, Ireland.

Poland

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 deemed as a potentially significant interaction in the local marine environment. As there are no offshore wind farms in the 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. However, collecting samples around 70-year old foundations enables studies of fully developed effects of such structures on benthic assemblages. Ongoing research is focused on fouling communities and their ecological functioning in comparison to assemblages associated with natural hard bottom. Also the role of artificial structures in introductions of non-indigenous species has been investigated. Samples for the research have been collected at foundations of two World War II offshore watchtowers as well as at two natural boulder fields in the Gulf of Gdańsk. The most recent observations include records of two new non-indigenous species of crustaceans in the assemblages associated with artificial substrata – an amphipod *Melita nitida* and a tanaid *Sinelobus vanhaareni.* At the same time an impact of artificial structures on nearby natural soft bottom has been investigated. The most recent research was focused on possible dissolved oxygen depletion in bottom water around an artificial structure due to organic debris falling from its walls. Dissolved oxygen concentration, temperature and salinity were measured 1m, 7m and 50m away from a structure using data loggers that were deployed at the bottom for nearly 20 months. Samples of macrobenthos were also collected at same distances from the structure. Results do not clearly indicate that an artificial structure may have a significant impact on oxygen concentration of the surrounding bottom water. Nevertheless significant differences between benthic assemblages from various distances of the structure were observed.

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

The Netherlands

In 2018, a study will make an inventory of possible large-scale systemic impact of wind energy extraction and water turbulence on the physics and ecology of the southern North Sea. This study is a first reconnaissance regarding possible system limits and how large-scale offshore wind farm implementation will approach these limits.

After pilots in coastal locations, in 2018 several European Flat oyster restoration initiatives are planned to start in offshore wind farms in the Netherlands. These will include active introduction of live flat oysters as well as introduction of settlement substrates.

In the summer of 2018, a pilot with the first offshore floating solar panel installations will be launched by the Oceans of Energy company.

Relevant publications

Coolen, J. W. P., Jak, R. G., Weide, B. E. van der, Cuperus, J., Luttikhuizen, P., Schutter, M., Dorenbosch, M., *et al.* (2018). RECON: Reef effect structures in the North Sea, islands or connections? Wageningen Marine Research report C074/17A. 33 pp.

Coolen, J. W. P. 2017. North Sea Reefs. Benthic biodiversity of artificial and rocky reefs in the southern North Sea. PhD-thesis Wageningen University & Research. 203 pp. http://dx.doi.org/10.18174/404837.

Lengkeek, W., Didderen, K., Driessen, F., Coolen, J. W. P., Bos, O. G., Vergouwen, S., and Raaijmakers, T. 2017. Eco-friendly design of scour protection: Potential enhancement of ecological functioning in designs for scour protection in offshore wind farms. Bureau Waardenburg, Wageningen Marine Research, Deltares report. 98 pp.

Smaal, A., Kamermans, P., Kleissen, F., and van Duren, L. 2017. Flat oysters on offshore wind farms. Wageningen Marine Research, Deltares, Bureau Waardenburg report C052/17. 54 pp.

Dias, I. M., Spierings, M., Coolen, J. W. P., Van Der Weide, B., & Cuperus, J. (2017). First record of *Syllis vittata* (Polychaeta: Syllidae) in the Dutch North Sea. Marine Biodiversity Records, 10(1), 16. doi:10.1186/s41200–017–0120–3

Spierings, M., Dias, I. M., Coolen, J. W. P., Van Der Weide, B., & Cuperus, J. (2017). First record of *Harmothoe aspera* (Hansen, 1879;Polychaeta: Polynoidae) in the Dutch North Sea. Marine Biodiversity Records, 10(29), 4. doi:10.1186/s41200–017–0131–0

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

United Kingdom

Specific related research:

***Ecological Interactions with a Marine Renewable Energy Installation in a temperate ecosystem* -** Concerns exist that Marine Renewable Energy Installations (MREI) will negatively impact marine fauna and habitats through a multitude of factors e.g. collision, electromagnetic fields, noise and physical disturbance from cables and moorings. While the effects of MREI may represent short term, local scale disturbance to marine ecosystems, we anticipate positive impacts over wide spatial (many tens of km^2) and longer temporal scales (years) as MREIs will displace fishing activity and introduce structures which may act as artificial reefs. Clean Energy From Ocean Waves (CEFOW) is an EU Horizon 2020 project, which is testing a new wave energy converter, Wello's Penguin, and assessing the interaction of an array of these devices on benthic and demersal assemblages. Using a towed, flying video array, and static baited remote underwater cameras, species and habitat data are being collected annually over the period 2017–2019 at the European Marine Energy Centre (EMEC) Billia Croo test site. Critically, this study incorporates relevant reference sites from which robust analyses of change, or lack thereof, can be determined. Observations from the first year of data collection will be presented, alongside some considerations of appropriate environmental monitoring strategies in MREIs. This work will aid future development of management approaches to minimise negative impacts, and promote biodiversity while ensuring the delivery of energy from renewable sources in the marine environment.

Contact: Emma Sheehan, University of Plymouth, U.K.

Effects of energy emissions (EMF) on receptors - WGMBRED's Zoe Hutchison and Andrew Gill have recently completed a major project researching electromagnetic field (EMF) effects on marine fauna (report can be found at https://www.boem.gov/espis/5/5659.pdf). The international project was led by The University of Rhode Island, USA, with major involvement of Andrew and Zoe through Cranfield University, UK, and the Swedish Defence Agency FOI, Sweden. The project was contracted by the USA Federal Agency, Bureau of Ocean Energy Management (BOEM) with the team funded for a two-year study entitled 'MAGNETlse - Electromagnetic Field (EMF) Impacts on Elasmobranch (sharks, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables.' The main relevant findings of this novel research were:

1) The EMF emitted by HVDC cables was measured in situ highlighting the presence of unexpected AC components extending to 5–10m for DC and AC magnetic fields and AC electric fields extending to 100 m from a cable.

2) The acoustic telemetry tracked movements of marine animals with much higher accuracy (<5 cm for beacon tag) and frequency (<3 second interval) of recorded positions than previous studies (accuracy of <1m and frequency of <3 minutes).

3) A field experiment, using enclosures, provided *in situ*, high frequency 3D positional data on individual animals at both an experimental treatment enclosure on a power cable and an enclosure at a reference site.

4) *Homarus americanus* (American lobster) exhibited a statistically significant but subtle change in behavioural activity when exposed to the EMF of the HVDC cable (330 MW; 1175 Amps). At the treatment enclosure (B), lobsters were on average closer to the seabed and exhibited a higher proportion of changes in the direction of travel (termed large turns), when second in the sequence, compared to the control enclosure (A). They also made more use of the central space of the treatment enclosure (B) compared to the control (A).

5) *Leucoraja erinacea* (Little skate) exhibited a strong behavioural response to the EMF encountered. The cable was powered for 62.4% of the study and most frequently transmitted electrical current at 16 Amps (at 0 MW, 37.5% of time), 345 Amps (100 MW, 28.6%) and 1175 Amps (330 MW, 15.2%). In comparison to the control enclosure (A), the skates at the treatment enclosure (B) travelled further but at a slower speed, closer to the seabed and with an increased proportion of large turns which suggested an increase in exploratory activity and/or area restricted foraging behaviour. The increased distance travelled and increased proportion of large turns was associated with the zone of high EMF (>52.5 μT, i.e. above the Earth's magnetic field) where they were more frequently recorded and spent more time.

6) For both species, the behavioural changes have biological relevance in terms of how the animals will move around and be distributed in a cable EMF zone. The EMF associated with the HVDC cable did not constitute a barrier to movements across the cable for either lobsters or skates. The findings from this research provide clear evidence that receptor animals can and do respond to subsea cable EMF of the type and intensity emitted by offshore/marine renewable energy cables.

Cross-disciplinary research into epibenthic biodiversity colonising marine renewable energy structures - Paul Causon is in his 3rd year of his PhD at Cranfield University, supervised by Andrew Gill. Paul's PhD is funded by the UK Research Council EPSRC/NERC REMS (Renewable Energy and Marine Structures) programme, which specifically allows Paul to work closely with marine structural engineers. His cross-disciplinary research is focussed on offshore wind structures, the colonising biodiversity and the consequences for associated ecosystem services.

Cumulative environmental assessment - Ed Willsteed of Cranfield University is in his final year of his PhD researching Cumulative environmental change. Supervised by Andrew Gill and Silvana Birchenough and funded by the UK Research Council NERC and Cefas through the industrial Case PhD programme. The research is set within the context of marine renewable energy and a well-received paper was recently published which compliments a 2016 review paper by Ed and his co-authors:
- Willsteed, E., Jude, S., Gill, A.B. & Birchenough, S.N.R (2018). Obligations and aspira-

tions: A critical evaluation of offshore wind farm cumulative impact assessments. Renewable and Sustainable Energy Reviews. 82(3), 2332–2345.

- Willsteed, E., Gill, A.B., Birchenough, S.N.R. & Jude, S. (2016). Assessing the cumulative environmental effects of marine renewable energy developments: Establishing common ground. Science of The Total Environment, 577, 19–32.

Other projects - Two main projects were funded in 2017 that highlight the interest in combining marine renewable energy with other marine activities. The European Commission H2020 programme has funded Cranfield and Strathclyde Universities along with European academic and industry partners for a project researching Multi-use platforms – aquaculture + floating offshore wind. A second project funded by the UK Research Councils (EPSRC and NERC) and the National Science Foundation of China through the UK-China initiative on a project is researching Multi-use platforms – aquaculture, offshore wind and wave.

Andrew Gill introduced his new initiative PANGALIA Environmental, which is a sole-trader business that Andrew has set up to offer and promote his marine and offshore energy environmental expertise to the wider community (both academic and industry).

Contact: Andrew Gill. PANGALIA Environmental, U.K.

Annex 3: Recommendations

Recommendation	Addressed to
1. To continue the expert group on Marine Benthal and Renewable Energy Developments (WGMBRED) (see Annex 4)	SCICOM
2. To cascade and integrate the relevant outputs across other ICES EGs (e.g. Working Group on Integrative, Physical-biological and Ecosystem Modelling and Working Group for Marine Planning and Coastal Zone Management).	WGMBRED (self-recommendation)

Annex 4: WGMBRED draft resolution 2019–2021

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

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2019	11–15 March	Brussels, Belgium	Interim report by 31 May	
Year 2020			Interim report by 31 May	
Year 2021			Final report by 31 May	

ToR descriptors

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
a	Develop guidelines on standardised data collection methodologies and criteria for metadata to enable integration of benthos data of marine renewable energy devices into wider international frameworks	WGMBRED recognises the fact that data on the benthos of marine renewable energy devices are collected and stored according to different standards, hampering in integrated analyses of the effect of such devices on the benthos on wider spatio-temporal scales. Standardisation of data collection and storage methodology will overcome this problem, facilitating joint analyses and international collaboration		Year 1–3	Synthesis report to ICES on review of existing standards and methodologies including guidelines for setting criteria of metadata facilitating integration and analysis of marine renewable energy devices benthic data.
b	Provide an integrated example dataset based on benthos data of marine renewable energy devices from various sources	To date, data on the effect of marine renewable energy devices are scattered in national or institutional databases. This lack of integration hampers the understanding of the general effects in space and time of renewable		Year 1–3	Prototype database on the benthos of renewable energy devices, submitted to a database repository.

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
		energy devices on the marine benthos. WGMBRED will therefore provide a prototype of an integrated database (based on publicly available data) that can be used for scientific purposes by the international scientific community			
c	Review the knowledge on changes in the benthos associated with environments where marine renewable energy devices are located and relate them to the presence of these structures and the changes to other human activities (e.g. fisheries)	Earlier WGMBRED work, showed a locally increased habitat diversity in areas where renewable energy arrays are in function. This results in increased diversity of the benthos (including non-indigenous species). At the same time, many fisheries activities are excluded from these areas. As such, marine renewable energy device arrays could act as de facto conservation areas for benthos, adding to the existing network of designated Marine Protected Areas. This is of high importance and should be taken into account during marine spatial planning processes where multiple activities within concession zones for marine renewable energy devices are being planned for.		Year 1–3	Report to ICES on the assessment of the evidence of whether marine renewable energy device arrays can be considered as de facto marine protected areas.
d	Develop the scientific basis for assessing the conservation of benthic habitats beyond the exploitation phase of	Based in the current knowledge, WGMBRED realises that the local and regional biodiversity		Year 1–3	Manuscript to be submitted to peer-reviewed journal

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
	marine renewable energy installations	of the benthos may be positively affected in areas where marine renewable energy devices are exploited. This results from a combination of the provisioning of habitat, food and shelter for a number of marine organisms. These effects need to be taken into consideration in the decision making process for locating and the possible decommissioning of marine renewable energy devices sites.			
e	Review and provide an empirical overview on the role of benthos associated with marine renewable energy devices in the maintenance of important ecosystem processes.	WGMBRED aims to provide the knowledge base to support the implementation of the Ecosystem Approach to Management with respect to marine renewable energy devices. This requires moving towards a process-driven understanding of how the changes to the structural and functional composition of the benthos (including non-indigenous species) associated with marine renewable energy devices) contributes to ecosystem functioning and the provisioning of ecosystem services (such as nutrient cycling and food provision via fisheries species).		Year 1–3	Manuscript submitted to a peer-reviewed scientific journal

Summary of the Work Plan

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

Supporting information

Priority	The activities of the EG will lead ICES into a structural and functional understanding of how the marine benthal community of marine renewable energy devices contributes to the functioning of the marine ecosystem, and how they can act as areas where benthal biodiversity can be promoted. The objectives addressed for this group are therefore considered of high relevance in the context of ecosystem-based management of coastal areas where an increasing number or marine renewable energy devices are planned, and will be of directly use in marine spatial planning initiatives. Hence, the activities can be considered to be of very high priority.
Resource requirements	No specific resource requirements beyond the need for invited members to prepare for and resource their participation in the meeting.
Participants	The Group is normally attended by 15–20 members and guests working with the effects of marine renewable energy developments on the marine benthal communities (i.e. algae, invertebrates, and demersal fish). Participation from current ICES member countries and also from countries where marine renewable energy developments have started recently (Spain, Portugal) to develop knowledge on these activities.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	There are no obvious direct linkages. However, some contributions could be made to under 'pressures' as part of ICES ecosystems overviews
Linkages to other committees or groups	There is a very close working relationship with Benthos Ecology Working Group (BEWG), the Working Group on Marine Renewable Energy (WGMRE), the Working Group for Marine Planning and Coastal Zone Management (WGMPCZM) and the Working Group on Biodiversity Science (WGBIODIV).
Linkages to other organizations	OSPAR ICG-CUM

Annex 5: WGMBRED self-evaluation

1) **Working Group name**: Working Group on Marine Benthos and Renewable Energy Developments (WGMBRED)

2) **Year of appointment**: 2016

3) **Current Chairs**: Jennifer Dannheim (Germany) and Andrew B. Gill (United Kingdom)

4) Venues, dates and number of participants per meeting:

14–18 March 2016, Delft, the Netherlands (22 experts)

06–10 March 2017, Gdynia, Poland (19 experts)

06–09 March 2018, Galway, Ireland (15 experts)

WG Evaluation

5) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution.

5 Quantify the role of structural and functional diversity in marine ecosystems in providing stability and resilience

6 Investigate linear and non-linear ecological responses to change, the impacts of these changes on ecosystem structure and function and their role in causing recruitment and stock variability, depletion and recovery.

8 Define and quantify north Atlantic Ecosystem Goods and Services, model their dependence on ecosystem processes and habitat condition and their social, economic and cultural value

9 Identify indicators of ecosystem state and function for use in the assessment and management of ecosystem goods and services

11 Develop methods to quantify multiple direct and indirect impacts from fisheries as well as from mineral extraction, energy generation, aquaculture and other anthropogenic activities and estimate the vulnerability of ecosystems to such impacts

14 Evaluate ecological, economic and social trade-offs between ecosystem protection and sustainable use to advise on management of human activity in marine ecosystems

15 Develop tactical and strategic models to support short and long term fisheries management and governance advice and increasingly incorporate spatial components in such models to allow for finer scale management of marine habitats and populations

25 Identify monitoring requirements for science and advisory needs in collaboration with data product users, including a description of variable and data products, spatial and temporal resolution needs, and the desired quality of data and estimates

26 Develop a cost benefit framework to evaluate and optimize monitoring strategies in the context of the capabilities of, and requests from ICES Member Countries and clients.

27 Identify knowledge and methodological monitoring gaps and develop strategies to fill these gaps

31 Ensure the development of best practice through establishment of guidelines and quality standards for (a) surveys and other sampling and data collection systems; (b) external peer reviews of data collection programmes and (c) training and capacity building opportunities for monitoring activities

6) In bullet form, list the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc. *

- Review paper on monitoring (ToR A), i.e. addressing scale aspects and the relevance to monitoring, defining suitable objectives and approaches to determine relevant changes to the benthic ecosystem;

  Thomas A. Wilding, Andrew B. Gill, Arjen Boon, Emma Sheehan, Jean–Claude Dauvin, Jean-Philippe Pezy, Francis O'Beirn, Urszula Janas, Liis Rostin, Ilse De Mesel (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.
- Review paper on the assessment of different spatial scales in relation to the effects of marine renewable energy devices on the benthic ecosystem evaluating the consequences for policy makers, managers, developers and academics (ToR A), review paper is based on three different case studies to demonstrate conceptually the consequences of meaningful ecological changes acting on different scales
- Review paper for managers, policy makers, developers and academics highlighting the knowledge gaps (ToR B, to be submitted in 2018) in relation to offshore renewable energy devices on the benthal including a
  - Matrix/literature review on related topics of hypothesis that are part of the specific cause-effect relationships of effects of offshore energy constructions on the benthal
  - Assessment of sensitivity, certainty and consistency of cause-effect-relationships of the matrix
  - Analysis of knowledge gaps via literature review in order to identify and prioritise the known unknowns.
- Matrices on the sensitivity, certainty and consistency of cause-effect relationships for managers, policy makers, developers and academics (ToR B, published in this report) in relation to different offshore renewable energy devices on the benthal including
  - Floating wind farm devices
  - Tidal devices
  - Wave devices

- Publication on a network analysis in order to demonstrate the interactions amongst WGMBRED and other relevant groups such as policy makers, stakeholders, regulators and scientists; the network map is highlighting the impact of the WGMBRED science (ToR C, publication close to submission)
- Publication on assessing ecosystem functioning and change in relation to offshore renewable energy devices at different spatial scales and how to identify meaningful indicators to assess changes in ecological functioning and ecosystem services; this publication (to be submitted in the beginning of 2019) includes outcomes from the WGMBRED science (ToR D) and a EuroMarine Forsight Workshop entitled as "Ecosystem changes associated with offshore wind farms: bridging the gap between biogeochemical effects, ecosystem functioning and ecosystem services"
- Contributions and theme session lead at the Fort Lauderdale ICES ASC 2017, Theme session K: Introducing man-made structures in marine systems: assessing ecological effects, knowledge gaps and management implications which was chaired by two WGMBRED experts (Silvana Birchenough, Jennifer Dannheim), 15 presentations, thereof 14 presentations out of 21 were from or with contribution of WGMBRED experts
- Fort Lauderdale ICES ASC 2017, Open Session: Functional links between pressure and state indicators. Conveners: Henn Ojaveer, Human Activities, Pressures and Impacts Steering Group (HAPISG), and Silvana Birchenough, Ecosystem Processes and Dynamics Steering Group (EPDSG). Andrew Gill presented on 'Bringing benthic functional importance into the discussion on human impacts on marine ecosystems'. Steven Degraer gave a presentation titled 'Overview of benthic indicators and their role for ICES science and advice'.
- 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?'
- ICES JMS special issue – ecologically sound decommissioning for offshore man-made structures. WGMBRED Experts Steven Degraer and Silvana Birchenough are editors. A number of contributions have been proposed from the WGMBRED group

7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.

WGMBRED did not get any requests from ACOM.

8) Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.

- 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
- Marine Renewable Energy session, European Geosciences Union Assembly (EGUA) in Vienna, Austria, 17–22 April 2016, Degraer *et al.*
- EcApRHA WP3, workshop on Ecological Network Analysis indices, 14–15 Septembre 2016, Londres, UK. Raoux, A., Dauvin, J.C., Niquil, N. An ecosystem approach of Marine Renewables Energies: what tells us the Ecological Network Analysis on the potential effects of Offshore Wind Farms on the ecosystem resilience?
- 25ème édition de la Réunion des Sciences de la Terre 2016, 24–28 octobre 2016, Caen, France. Pezy, J.P., Raoux, A., Niquil, N., Dauvin, J.C. Can the transition from a taxonomic approach to an integrated food web approach allows the assessment of environmental impacts: Dieppe-Le Tréport and Couseulles-sur-mer case studies?
- MSEAS 2016, Understanding marine socio-ecological systems: including the human dimension in Integrated Ecosystem Assessments, 30 Mai- 3 Juin 2016, Brest, France. Raoux A, Tecchio, S., Dauvin, J.C., Pezy, J.P., Degraer, S., Cachera, M., Grangeré, K., Dambacher, J.F. Modelling impacts of offshore wind farms on trophic web: the Courseulles-sur-Mer case study, an example of cumulated impacts
- 28ème young oceanographers' forum, 18–20 Mai 2016, Cherbourg, France. Raoux, A., Tecchio, S., Pezy, J.P., Degraer, S., Wilhelmsson, D., Dauvin, J.C., Niquil, N. Benthic and fish aggregation inside an offshore wind farm: Which effects on the trophic web functioning?
- EGU General Assembly 2016, "OS2.7 Environmental Impacts of Marine Renewables", 17–22 Avril 2016, Vienne, Autriche. Raoux, A., Pezy, J.P., Dauvin, J.C., Tecchio, S., Degraer, S., Wilhelmsson, D., Niquil, N. Modelling impacts of offshore wind farms on trophic web: the Courseulles-sur-Mer case study
- post ICES ASC Workshop at CEI, Bahamas. Andrew Gill hosted BESpE – Benthic Ecosystems Spatial Ecology Workshop Sept 2017, which was attended by Steven Degraer, Silvana Birchenough, Joop Coolen, Jennifer Dannheim, and Tom Wilding from WGMBRED.
- As a member of a US National Academy of Science Steering Committee, Andrew Gill assisted in organising, chairing and presenting at the Atlantic Offshore Energy Development and Fisheries workshop, New Bedford, Massachusetts, USA, Nov 2017.
- EuroMarine Foresight Workshop: "Ecosystem changes associated with offshore wind farms: bridging the gap between biogeochemical effects and its repercussions for ecosystem functioning and services" in Bremerhaven, Germany, February 2018, chaired by two WGMBRED experts (Jan Vanaverbeke, Jennifer Dannheim) and attended by seven experts (of 21 partici-

pants): Silvana Birchenough, Paul Causon, Joop Coolen, Steven Degraer, Andrew Gill, Urszula Janas, Francis O'Beirn

- 4th International Marine Protected Areas Congress (IMPAC September 2017), Chile. Emma Sheehan attended and presented. Co-location of renewables and MPAs
- Conference on wind and wildlife (CWW), Berlin, Germany - September 2015 and Estoril, Portugal - September 2017. Andrew Gill is a founder member of the Scientific Committee attending each conference where he focuses on offshore wind and the environment being represented. CWW focuses on onshore and offshore wind farms and impacts on wildlife.
- 4th Conference on Wind Energy and Wildlife Impacts, 6–8 September 2017, Estoril, Portugal. Pezy, J.P., Raoux, A., Niquil, N., Dauvin, J.C. Trophic webs comparison of two different habitats in the English Channel: the Courseulles-sur-mer and the Dieppe-Le Tréport OWF case study.
- Colloque national sur la cartographie des habitats marins benthiques CARHAMB'AR, 14–16 mars 2017, Brest, France. Pezy, J.P., Raoux, A., Niquil, N., Dauvin, J.C. Les sables grossiers de la baie de Seine et de la Manche orientale ont-ils des réseaux trophiques différents ? Le cas des parcs éoliens offshores de Courseulles-sur-mer et de Dieppe - Le Tréport.
- ASLO 2017 conference (Jan Vanaverbeke) mostly tidal & wave rather than wind. Emphasis on production of electricity for local use e.g. desalination rather than for production for commercial or domestic use on land. It may not be a representative view of the entire situation in US.
- Coastal Future conference 2017: Co-location studies of offshore aquaculture and renewables, participation by Emma Sheehan
- INSITE North Sea (www.insitenorthsea.org): Influence of man made structures in the Ecosystem, included ten projects with the aim to investigate the magnitude of the effects of man-made structures compared to the natural spatial and temporal variability of the North Sea ecosystem and whether man-made structures in the North Sea represent a large interconnected hard substrate system. Two projects were run by WGMBRED experts (Jennifer Dannheim, Joop Coolen, Silvana Birchenough, Steven Degraer, Jan Vanaverbeke): UNDINE (www.insitenorthsea.org/projects/undine/). The projects were mainly about oil & gas platforms, but with clear relevance for marine renewables.

9) Please indicate what difficulties, if any, have been encountered in achieving the workplan.

During the three years' work of the MBRED working group a slight adaptation of the focus of the ToRs has been conducted. While the ToRs B and C were straightforward and fully completed within the three years' cycle, the group underestimated the work of the ToRs A and D. These topics were very complex and the focus was too wide. Thus, the two ToRs were even handled outside of the WGMBRED annual work during the post ICES ASC Workshop at CEI, Bahamas ('BESpE – Benthic Ecosystems Spatial Ecology Workshop') and during the EuroMarine Foresight Workshop at AWI, Germany ('Ecosystem changes associated with offshore wind farms: bridging the gap between biogeochemical effects and its repercussions for ecosystem functioning and services'). Both workshops were initiated and attended by WGMBRED experts and thus the outputs are a result of the WGMBRED work. However, for the next draft resolution for multi-annual terms of reference, the group formulated more specific objectives leading to targeted scientific publications. These publications could provide scientific knowledge to support advice.

Future plans

10) Does the group think that a continuation of the WG beyond its current term is required?

Yes. The experts agreed that a continuation of the WG is definitely required. The reasons are the still rapidly evolving industry with a worldwide expansion, the upcoming ideas of multiple use of energy device arrays (e.g. for aquaculture), as well as the developments of new technologies in the offshore renewable energy sector in countries where no marine renewable energy devices have been installed before. There are several topics that have not been explored yet in this context. Thus, the ongoing uncertainty of the potential effects of these evolving new topics and technologies and inconsistent legislation frameworks between countries call for an implementation of a common legislative framework and projects with wider geographic scopes to look at cumulative impacts across borders for a thorough ecological understanding. This calls for a strong international collaboration and knowledge exchange and WGMBRED provides this scientific platform for exchange.

Based on the current knowledge, WGMBRED realises that biodiversity of the benthos may be positively affected in areas with marine renewable energy devices by the provision of habitat, food and shelter for a number of marine organisms. As such, marine renewable energy device arrays could act as de facto conservation areas for benthos, adding to the existing network of designated Marine Protected Areas. WGMBRED is on the opinion that this is of high importance and should be taken into consideration in the marine spatial planning and decision-making process for locating and potential decommissioning, as well as multiple activities within concession zones of marine energy devices sites.

Further, WGMBRED recognises that the development of a knowledge base to support the implementation of the Ecosystem Approach to Management with respect to marine renewable energy devices is of high importance. This calls for moving towards a process-driven understanding of how the changes to the structural and functional composition of the benthos associated with marine renewable energy devices contributes to ecosystem functioning and the provisioning of ecosystem services. In this context, WGMBRED will develop standardised data collection and methodologies to enable integration of benthos data of marine renewable energy devices from various sources into wider international frameworks to overcome differences in national standards in data collections. This will demonstrate how an integrated dataset of benthos data stored in a database can serve as thorough scientific base to enable analysis for different scientific purposes by the international scientific community on large geographical scales.

11) If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.

No, please see the new category 2 draft resolution on multi-annual terms of references for WGMBRED continuation.

12) What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR?

With respect to the new developments and expansion of marine renewable energy devices, WGMBREDs ability to fulfil its ToRs would be to invite actively experts from new countries such as Portugal, Spain, Denmark, Norway, Sweden, USA and Canada. Further WGMBRED recognises the need to link to other ICES WGs concerning the ToRs tackling multiple-use, cumulative effects and conservation spatial planning. WGMBRED also realises that a stronger linkage to ICES communications will help to fulfil the new ToRs in order to distribute products of WGMBRED more widely.

13) Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used?

We believe that the specific outputs of the ToRs should be used to inform the advisory process as they are directly linked to the marine renewable energy sector and the ecosystem based management that is being promoted across the ICES region. The outputs of the ToRs form the main conclusions of the journal papers that have been and will be written within WGMBRED. Some papers have yet to be submitted as they are in the final stages of work with the main authors prior to final submission. However, they are covered in the WGMBRED reports to ICES and centre on making the benthic ecosystem of wider relevance by setting their importance within the ecosystem services context. In particular, the following specific publications should be used in the advisory process:

- Publication: Thomas A. Wilding, Andrew B. Gill, Arjen Boon, Emma Sheehan, Jean–Claude Dauvin, Jean-Philippe Pezy, Francis O'Beirn, Urszula Janas, Liis Rostin, Ilse De Mesel (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.

  Review paper on monitoring addressing scale aspects and the relevance to monitoring, defining suitable objectives and approaches to determine relevant changes to the benthic ecosystem

- Updated publication: Jennifer Dannheim, Steven Degraer, Angus C. Jackson, Lena Bergström, Silvana Birchenough, Radosław Brzana, Arjen Boon, Joop Coolen, Jean-Claude Dauvin, Ilse de Mesel, Jozefien Derweduwen, Zoe Hutchison, Urszula Janas, Georg Martin, Aurore Raoux, Jan Reubens, Liis Rostin, Tom Wilding, Dan Wilhelmsson (to be submitted by the end of 2018). Benthic effects of offshore renewables: prioritizing the known unknowns.

Review paper highlighting the knowledge gaps in relation to offshore renewable energy devices effects on the benthal

- Matrices on the sensitivity, certainty and consistency of cause-effect relationships in relation to different offshore renewable energy devices on the benthal including floating wind farm devices, tidal devices and wave devices (see section 5.4 of this report).