ICES WKEOMB REPORT 2012

SCICOM STEERING GROUP ON ECOSYSTEM FUNCTIONS

ICES CM 2012/SSGEF:13

REF. BEWG, SCICOM

Report of the Workshop on Effects of Offshore Windfarms on Marine Benthos - Facilitating a closer international collaboration throughout the North Atlantic Region (WKEOMB)

27–30 March 2012

Bremerhaven, Germany

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Recommended format for purposes of citation:

ICES. 2012. Report of the Workshop on Effects of Offshore Windfarms on Marine Benthos - Facilitating a closer international collaboration throughout the North Atlantic Region (WKEOMB), 27–30 March 2012, Bremerhaven, Germany. ICES CM 2012/SSGEF:13. 57 pp.

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Executive summary

The workshop 'Effects of offshore wind farms on marine benthos – facilitating a closer international collaboration' was held at the Alfred Wegener Institute for Polar and Marine Research (AWI) in Bremerhaven, Germany. The workshop was attended by 19 experts, representing seven countries (Belgium, Germany, Estonia, France, Poland, United Kingdom, Netherlands). Valuable remote contributions to the workshop were received from Denmark, Sweden and Norway. The workshop was chaired by Jennifer Dannheim (AWI), Steven Degraer (Royal Belgium Institute of Natural Science, MUMM, Belgium) and Lars Gutow (AWI).

Offshore wind farms will most likely become one of the largest-scale anthropogenic activities in our coastal systems. Thus understanding the effects of offshore wind farms on the benthic system is of high priority. Over the last decade, benthic ecologists have improved their knowledge on understanding how wind turbines affect the ecological functioning of benthos. This workshop aims at bringing together, for the first time, scientists from various countries that work on or are interested in this topic in order to exchange knowledge of the state of the art between experts, to condense knowledge on wind farm effects, to identify possible redundancies in monitoring programs, and to evaluate where to go in wind farm-benthos science, i.e. to identify potential knowledge gaps.

During the first workshop day the national experts reported in a poster presentation on ongoing national research activities on effects of wind farm on marine benthos and demersal fish. An oral introduction to each poster was given by the respective author (17 posters, see Annex 7), followed by a poster session which aimed at intense communication and knowledge exchange among the experts. Based on the scientific exchange of the first workshop day, the aim of the second day was to identify potential knowledge gaps, i.e. what cause-effect relationships arising from the construction and operation of offshore wind farms have not or insufficiently been studied. Finally, as the way forward, the perspectives and opportunities for collaboration with regard to identified knowledge gaps have been discussed. The report structure follows the foci of the workshop days: (1) state of the art knowledge, (2) identification of knowledge gaps, (3) perspectives and collaborations.

The summary of a questionnaire which had been handed out to the participants before the workshop and the poster presentations revealed substantial effects of offshore wind farms on the benthos already in an early stage of the studies in different countries. The main outcomes of the workshop by expert knowledge and experience are:

a) a schematic summary of the manifold cause-effect relationships initiated by offshore wind farm installations;
b) a prioritisation scheme for defined research themes which are highly important for ecosystem goods and services;
c) the agreement that the effects of offshore wind farm installations on the benthic ecosystem and their relevance to goods and services are underestimated (compared to other ecosystem components) and need further investigation;
d) the need for hypothesis-based target monitoring to understand cause-effect relationships in the benthic system; and

e) the need for international collaboration with guidelines for practical implementation and the recommendation to initiate an expert group on the effects on the marine benthal and renewable energy developments.

The outcome and recommendations will enable in the future for focussing on specific processes in the benthal that deserves urgent investigation but which, at the same time, are important for marine ecosystem goods and services in the context of marine spatial planning strategies in future ecosystem-based management approaches.

1 Opening of the meeting

The chairs, J. Dannheim, S. Degraer and L. Gutow, opened the meeting at the Alfred Wegener Institute in Bremerhaven, Germany. Karen Wilshire, alternate director welcomed the group on behalf of the Alfred Wegener Institute highlighting the necessity of the topic offshore wind farms and the workshop. J. Dannheim welcomed the participants with an introduction to the initiation and the aims and terms of references of the workshop. An ICES SharePoint site was made available before and during the meeting. This has as before proved to be a valuable tool to speed up the work and make exchange of information more efficient. The participants then introduced themselves, gave a short review of their scientific activities and a statement on the expectations they have on the workshop. 19 participants from eight countries attended the meeting (Belgium, Germany, Estonia, France, Poland, United Kingdom and the Netherlands).

2 Adoption of the agenda

The group unanimously adopted the agenda without changes.

3 Introduction

Offshore wind farms are expected to develop into one of the largest-scale anthropogenic activities in our marine shelf systems. How wind farms will affect the marine environment, locally, regionally and on larger spatial scales, is to be investigated by ecologists who are currently improving their understanding of these effects. Marine mammals and seabirds still receive much more attention, albeit major effects have also been detected at the level of benthic ecosystem structure and functioning. Introducing artificial hard substrate into an environment, which is naturally dominated by soft-bottoms, might alter hydrodynamic and sedimentary conditions, increase local production of hard substrate epifauna, lead to an organic enrichment of soft sediments (i.e. input of biomass/faeces), and facilitate the spread of (non-native) hard substrate species. Regardless of the region, similar processes will lead to similar impacts. Nevertheless, these effects are (intended to be) investigated in numerous wind farms throughout the North Atlantic region. Hence, a major scope is to increase scientific efficiency of our offshore wind farm benthos research and monitoring. The aim of this ICES-workshop was to increase scientific efficiency of our offshore wind farm benthos research, to discuss the most actual results and to facilitate a closer international collaboration throughout the North Atlantic region. The workshop particularly aims at:

- initiating a closer international collaboration in the field of offshore wind farm effects on benthos;
- exchanging and consolidating state of the art knowledge among experts and discussing the efficiency of ongoing monitoring programs;
- evaluating future scientific perspectives by identifying potential gaps in knowledge; and
- grasping the scope for international collaboration, i.e. to reduce redundancy in ongoing research.

The outcomes of the workshop will enable us to identify potential knowledge gaps and/or research redundancy in ongoing monitoring programs and marine spatial planning strategies within future ecosystem-based management approaches.

4 State of the art knowledge and ongoing activities

One major task of the workshop was to identify the current state of knowledge and the ongoing research activities on the effects of offshore wind farms on the marine benthos. Specifically, the terms of reference were to:

a) review the science of offshore wind farm effects on the benthic system in the North Atlantic and

b) exchange and consolidate state of the art knowledge among experts.

To achieve these goals, questionnaires (see Annex 5) were sent out to all poster authors prior to the workshop. These questionnaires should help to summarise ongoing research activities and first results. The analysis of the questionnaires provided information on geographic and environmental issues at the investigated wind farms sites, the habitats and ecosystem components under study, the scientific framework around the studies, and a first (crude) evaluation of the seriousness of the observed effects.

Offshore wind farms in European waters are situated at various distances from the coasts (Figure 1). While few wind farms are in direct vicinity to the coast most of them are further off the coast. The majority of the wind farms have been built in some tens of kilometres offshore while in Germany, Norway and UK wind farms exist in some hundreds of kilometres from the coast.

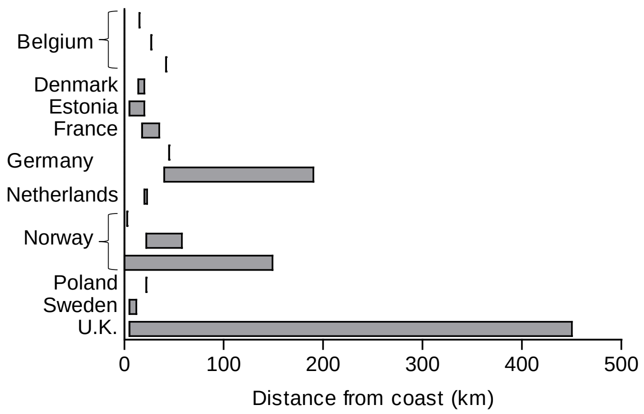

Figure 1. The distance at which wind farms have been built in European waters as reported by the poster authors.

Water depth in the areas of the studied offshore wind farms mostly vary from ~10 m to ~50 m (Figure 2). In Norway only, offshore wind farms are built in water depth of up to ~350 m. Wind turbines in these exceptional depth are not anchored in the sediment but floating at the sea surface.

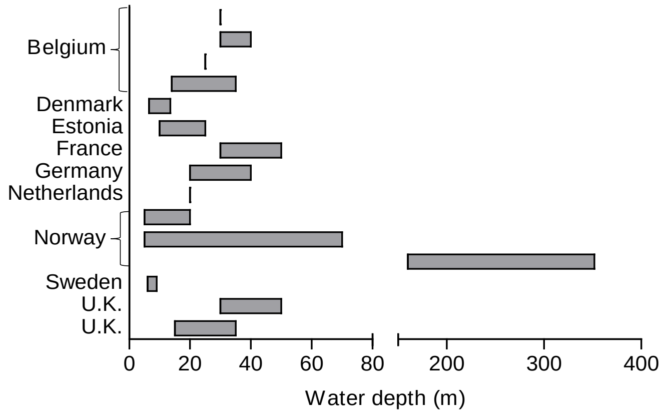

Figure 2. Water depth at the studied wind farms as reported by the poster authors.

Most wind farms have been built on sandy sediments while only a single wind farm rests on muddy sediment (Figure 3). In some wind farms, the seafloor is characterized by gravel or boulders and rocks.

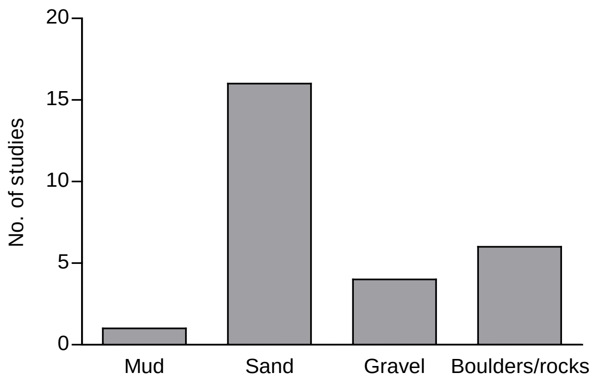

Figure 3. Seafloor characteristics in the studied wind farms as reported by the poster authors.

Most studies focus on more than one group of organisms. Hard bottom benthos on the underwater constructions of the wind turbines, soft bottom benthos in the surrounding sediments, and demersal fish are equally considered in 11 impact assessment studies each (Figure 4). Since most offshore wind farms are constructed in considerable water depth (see above), only few studies address photoautotrophic organisms. Accordingly, seaweeds are considered in 5 studies only.

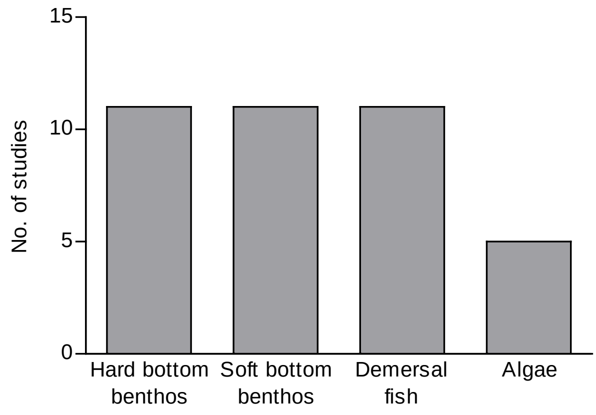

Figure 4. Ecosystem components which are considered in the studies as reported by the poster authors. The total number of studies reported in this figure exceeds the number of posters presented during the workshop because some studies addressed several ecosystem components.

When the poster authors were asked for a preliminary evaluation of the seriousness of the observed effects only a single author responded that no effect was observed on the studied ecosystem component (Figure 5). The majority of the authors evaluated the seriousness of the effects as "intermediate" and "major". Four authors did not evaluate the seriousness.

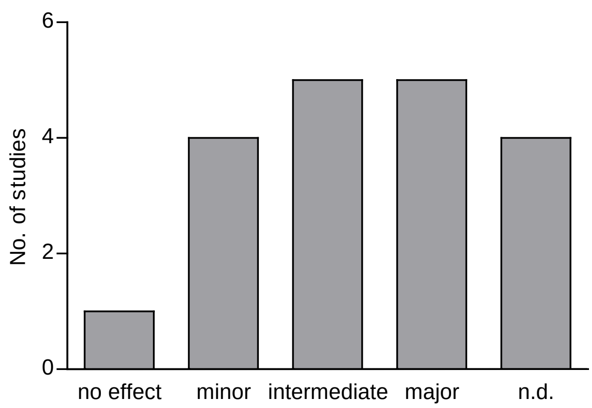

Figure 5. Preliminary evaluation of the seriousness of the observed effects as given by the poster authors.

Most studies do not address the effects of offshore wind farms on the marine benthos exclusively but also consider cumulative effects with other anthropogenic stressors. Most studies on cumulative effects included investigations on fisheries, sediment extraction and dumping, and shipping/neobiota (Figure 6). Other anthropogenic activities considered were eutrophication, artificial hard substrata, climate change, oil exploration and oxygen depletion.

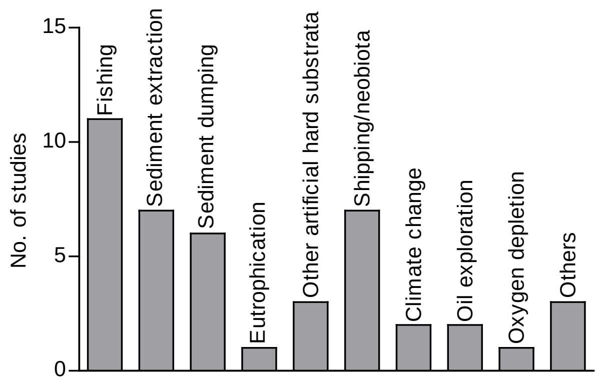

Figure 6. Other anthropogenic stressors considered in the studies which are expected to produce cumulative effects together with offshore wind farms.

The analysis of the questionnaires indicates far reaching implications of offshore wind farming for the marine benthos. Simultaneously, the questionnaires reveal that a well coordinated research on this topic is able to answer a great number of relevant questions with regard not only to offshore wind farming but also to other anthropogenic stressors acting cumulatively on the benthic environment. This research may benefit from the different spatial scales on which the current research is conducted including various distances from the coasts and a wide range of water depths. Studies on different types of sediment and different organismal groups provide a broad overview over the vulnerability of the benthic system. Already in an early stage of the studies substantial effects of offshore wind farms become evident. This brief summary reveals that the questionnaires together with the presentations given during the meeting and the abstracts are a powerful tool for the generation of first results of the workshop.

4.1 Abstracts of poster presentations

In addition to the questionnaires and the abstracts, the contents of each poster was shortly (5 min each) presented orally by the authors. Overall, 17 posters (eight countries) have been presented to summarise the ongoing research on the effects of offshore wind farms on the benthic system. Subsequently specific issues were discussed intensively at the posters in an extensive poster session.

4.1.1 An overview of offshore wind farm (OWF) in England

Author: Silvana Bichenough

Centre of Environment, Fisheries and Aquaculture Science (CEFAS), United Kingdom

Silvana Birchenough (Cefas, UK) presented an overview poster of the current OWF developments in England. A complementary poster with some of the current research being undertaken was also presented by Andrew Gill (Cranfield University). S. Birchenough's poster highlighted the maim drivers in English waters to develop renewable energy, which will contribute to the UK 15 % of energy from renewable sources by 2020. Much of this energy is expected to come from offshore wind. Key issues and lessons learnt from round 1 and 2 were highlighted. These messages will assist with the planning for the new developments to be considered in round 3. The UK is set a target of 8 (GW) of capacity installed by 2016. There are a total of 586 turbines in 15 operational offshore wind farms in the UK. It is recognised that Offshore Wind Farms (OWF) development has to be achieved in a sustainable manner, meeting the requirements of other European and UK legislation, in particular the Marine Strategy Framework Directive. The Marine & Coastal Access Act 2009 introduced a new system of marine planning in the UK which also aims to ensure a sustainable future for our coastal and offshore waters.

4.1.2 Windfarm effects on benthos - Who cares

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Why don't we care?

Currently, in the Netherlands there is no serious research and monitoring into the effects of Offshore Windfarms (OWFs) on the benthic environment. The main reason for this is the prioritization framework: the Bird and Habitat Directives. As a result, all monitoring is focused on the effects of OWFs on coastal and seabirds and marine mammals.

Why should we care?

The Marine Framework Strategy Directive (MSFD) aims at a wider environmental protection than just birds, habitats and associated species. Benthos is referred to in four of the eleven so-called descriptors: Biodiversity, Food web, Seafloor integrity and Invasive species. However, at the moment the implementation of the MSFD is ongoing, and no concrete indicators and targets for the possible effects of OWFs on the benthic environments have been put in practice.

This is likely to change in the foreseeable future, when the MSFD will be further developed and implemented, including the necessary measures for attaining the Good Environmental Status in 2020. Furthermore, the need for a better understanding of the possible effects of OWFs on the benthic environment will also become more acute regarding the goal of installing tens of Gigawatts of OWF capacity in the southern North Sea alone, having likely strong cumulative ecological impacts.

How should we care?

Integrating policy making, management and science is of high importance in ecosystem-based management of the marine environment (for which the MSFD strives explicitly). This integration, which has a cyclical character, asks for being aware of, and coordinating the policy/management process and the scientific process of research and monitoring. This cycle is currently implemented in the Netherlands for the research and monitoring for the larger ecological effects of OWFs in the Netherlands. Understanding the management questions, and using these to prioritize the research needed to fill the knowledge gaps on possible impacts of OWFs, and using the results to evaluate the managements questions and advancing the research cycle to a next step are the most important elements of this cycle.

4.1.3 Soft-sediment macrobenthos around offshore windfarms in the Belgian Part of the North Sea

Authors: Coates Delphine, Vanaverbeke Jan, Vincx Magda

Ghent University Belgium, Biology department, Marine Biology section, Belgium

Two offshore wind farms became functional in the Belgian part of the North Sea during 2009 and 2010 on respectively the Thorntonbank (C-Power) and the Bligh Bank (Belwind). During the past five years, a monitoring programme has been carried out to determine the baseline situation on the soft-sediment endobenthos at a large-scale in these areas. During the first years after implementation of the turbines no large-scale impacts were immediately detected.

A second phase of the monitoring consists of a small-scale sampling strategy around one gravity based foundation on the Thorntonbank, which started in 2010. As soft-sediments around turbines can be altered due to (1) previous created pits due to dredging activities (2) organic enrichment (3) changing hydrodynamics and (4) prohibition of beamtrawl fisheries it enhances the importance to focus on smaller scale effects on the soft-sediment endobenthos. Sediment samples were taken at 1, 7, 15, 25, 50, 100 and 200 meters from the scour protection system (boulders) and along four gradients. Samples at one and seven meters from the scour protection systems were taken by divers. Samples further away from the boulders were taken using a Van Veen grab from a small research vessel. Higher mean total densities and biomass were detected closer to the turbine with a shift from *Nephtys cirrosa* communities to a dominance in Mono*corophium acherusicum, Lanice conchilega* and *Spiophanes bombyx.* Furthermore, *Lanice conchilega* and *Spiophanes bombyx* showed a similar dominance on the northeast and southwest gradients, while Mono*corophium acherusicum* dominated on the northwest and southeast gradients. The above results show the importance of upgrading the monitoring strategy of offshore wind farms to a smaller-scale and short-term in the future and will therefore be followed up during the coming years.

4.1.4 Wind farm effects on benthos in the German Bight (North Sea) - from single structures to cumulative effects and beyond

Authors: Jennifer Dannheim, Katharina Reichert, Roland Krone, Manuela Gusky, Lars Gutow

Alfred Wegener Institute for Polar and Marine Research in the Helmholtz Association, Bremerhaven, Germany

Offshore wind farm industry is continuously increasing in the German exclusive economic zone, particularly in the North Sea. Understanding the effects of offshore wind farms on the benthic ecosystem is therefore inevitable. However, charismatic (marine mammals, seabirds) and economically important marine species receive much more intension than the inconspicuous ones, albeit they contribute a large part to crucial ecological processes. First research on the effects of wind farms on benthos started in 2001 with a monitoring programme around the *alpha ventus* area. In 2003, the research platform FINO 1 was built to assess the local small-scale effects of a single foundation. Results can be summarised as 'reef effects', i.e. accumulation on and export of biomass from the structure into the surrounding sediment, as well as shifts in the benthic community structure. The installation of *alpha ventus* in 2009 allowed for meso-scale investigations in the wind farm area (see chapter 4.1.10, 4.1.14). Concurrently, the number of environmental impact assessments (EIA) and the approval of wind farm projects increased (29 approved, 2001–2010). The collection of EIA-data combined with data from other research and monitoring studies allow for the first time to assess the large-scale cumulative effects of offshore wind farms in the entire German exclusive economic zone (EEZ), to evaluate the standard investigation concept (StUK), to identify benthic spatial patterns and main drivers for species distribution which finally can provide evaluation criteria for identifying sensitive areas in the context of permit procedures of offshore wind farms and marine spatial management.

4.1.5 Monitoring the impact of offshore windfarms on the marine environment: An obligate multidisciplinary and integrated programme

In 2004 the Belgian government assigned a zone for wind energy in the Belgian part of the North Sea. Since then two companies, C-Power, Belwind ad Northwind, were granted a permit to build and exploit a wind farm on the Thorntonbank, the Bligh Bank and the Lodewijkbank, respectively. The first wind turbines are up and running since 2009. A fourth company, Norther, finalised the environmental permit procedure in 2012. The permit includes the obligation to assess the impact of the project on the marine environment. As such, the monitoring programme covers physical, biological and socio-economical aspects of the marine environment.

The Management Unit of the North Sea Mathematical Model (MUMM) coordinates the monitoring and cooperates with different institutions that have expertise in a specific domain: Research Institute for Nature and Forest (INBO; birds), Institute for Agricultural and Fisheries Research (ILVO; soft sediment epibenthos and fish), Ghent University's Marine Biology Section (soft sediment macrobenthos), Ghent University's Renard Centre of Marine Geology (underwater noise) and MUMM (sea mammals, hard substrate biofouling and fish, radar detection of seabirds, underwater noise, hydrodynamics and seascape).

In general, two parallel and complementary aspects can be distinguished within the monitoring programme. The baseline monitoring, generally following a Before/After-Control/Impact or BACI design, aims at the detection and quantification of the combined effect. The targeted monitoring aims at unraveling and hence understanding the underlying causes of a selected set of priority effects, such as bird collisions and altered (commercial) fish (re)productivity.

The multidisciplinary and integrative approach will lead to scientifically sound advices for possible mitigating measures for existing, but also future offshore wind mill farms in both Belgian waters and abroad.

4.1.6 Monitoring the effects of the Belgian windmill parks on the epibenthic and demersal fish fauna of soft bottom sediments

Authors: Derweduwen J., Vandendriessche S. & Hostens K.

Institute for Agricultural and Fisheries Research (ILVO), Animal Sciences, Fisheries, Biological Environmental Research, Belgium

The monitoring strategy conducted by the Institute for Agricultural and Fisheries Research (ILVO) consists of a baseline monitoring and a targeted monitoring. For the baseline monitoring, a BACI strategy is applied to monitor the parameters density, biomass, diversity and length-frequency. For the targeted monitoring, several cause-effect relationships are investigated to answer following questions; are there changes in fishing activities in the vicinity of the windmill parks (VMS data), are there changes in feeding guild structure (stomach analyses of several fish species), are windmills used as spawning and nursery area (fish larvae) and is there an effect of underwater noise on juvenile fish and fish larvae?

The results of 2010 indicate a lower number and slightly larger individuals of swimming crab (*Liocarcinus holsatus*) and brown shrimp (*Crangon crangon*) and higher autumn densities of whiting *(Merlangius merlangus*) inside the Thornton windmill park compared to the reference area. VMS data show an increase in fishing intensity between the Thorntonbank and the Bank Zonder Naam (Lodewijkbank) since the construction of the windmills. The absence of the smallest size classes of sole (*Solea solea*) in this area might be an indication of an increased indirect fishing mortality (such as discards) or changes in local benthic community.

The preliminary results of 2011 show larger individuals of plaice (*Pleuronectes platessa*) inside the Bligh Bank windmill park. No such large individuals were found outside the park. Several individuals of turbot (*Psetta maxima*) and brill (*Scophthalmus rhombus*) were present in the windmill park and were not found outside the park. There were also higher densities of green sea urchin (*Psammechinus miliaris*) in the gullies of the Bligh Bank windmill park compared to gullies in the reference area. The absence of fishing activities in the windmill park and the presence of a heterogeneous habitat around the windmills can explain these results and indicate that windmill parks could function as a refugium for epibenthos and demersal fish.

Challenges for future research are the further testing of the refugium hypothesis, the experimental tests concerning underwater noise, the acquisition of VMS data on foreign vessels and vessels smaller than 15m and the communication and collaboration with the sector.

4.1.7 Determing the effects of Offshore Wind Farms on marine benthic organisms throughfield scale experiments

Author: Andrew B. Gill

Cranfield University, Natural Resources Department, Cranfield MK43 0AL, United Kingdom

Collaborators: Cefas, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK; CIMS Centre for Intelligent Monitoring Systems, The University of Liverpool; Department of Electrical Engineering and Electronics,Liverpool,L69 3GJ;CMACS ltd, 80 Eastham Village Road Eastham Wirral CH62 0AW; Cornwall College Newquay, Wildflower Lane, Trenance Gardens, Newquay, Cornwall, TR7 2LZ, UK; Stockholm University, Dept. of Zoology, S-106 91 Stockholm, Sweden; Swedish Defence Research Institute, Dept. of Underwater Research, S-164 90 Stockholm, Sweden; Marine Biological Association, Citadel Hill, Plymouth, PL1 2PB, Devon, UK

There are different phases in the life of an Offshore Wind Farm (OWF) that need to be considered in terms of how they interact with the coastal ecosystem. Furthermore there are different time and spatial scales that OWF impacts will occur over. To move towards determining the impacts we set up a framework of associated stressors and their effect on coastal organisms which is an important step before going on to determine whether actual impacts may occur. In light of this framework, we have developed studies focussing first on assessing the effects on species individuals at an appropriate scale and, subsequently looking at the effect across multiple individuals which could then be used to assess effects at the level of the population, thereby providing evidence for an impact (either positive or negative). To obtain ecologically relevant results at a scale appropriate for OWFs, we have taken the experimental approach, incorporating a treatment and control, into the coastal environment using large underwater netted structures (mesocosms) to provide a more realistic setting. To date, our studies have used the mesocosm approach to increase understanding of two relatively unknown effectors on fish: underwater pile-driving noise (Construction Phase) and Electromagnetic Fields (EMF), associated with the production of the electricity by OWFs (Operational Phase). The approach presented here clearly demonstrates that specific effects of OWFs on fish (and potentially other marine benthic organisms) can be determined at a scale that is relevant both ecologically and to the industry. Furthermore, it provides an important step in assessing what effectors need to be considered in terms of their possible impacts, thereby moving the research agenda forward whilst also meeting the needs of the stakeholders involved with OWF.

4.1.8 Planned offshore wind farms in the Polish Marine Areas and benthic communities

Author: Janas U.[1], Zarzycki T.[1], Dziubińska A.[1], Warzocha J.[2]

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There are no offshore wind farms in the Polish Marine Areas but four regions are chosen for these investments in future (regions of Oder Bank, Middle Bank, Słupsk Bank and Żarnowiec). In total, 109 sites were chosen with total area 2503.45 km^2. According to the Polish regulations, offshore wind farms have to be located at least 22.2 km from the seashore. Maximum technical potential was firstly estimated as 35 GW but it was limited to 20 GW because of distance from the seashore. It can be corrected with the exclusion zones (like protected areas within Natura2000 network) that reduces the potential down to 7.5 GW.

Areas proposed for offshore wind farms are situated on sandy or mixed sediment bottoms inhabited by benthic communities which may be affected by future investments. Soft sediment benthic communities at the areas designed for offshore wind farms are mainly composed of infauna like *Pygospio elegans*, *Macoma balthica* and *Monoporeia affinis* which play an important role in sediment by influencing the biogeochemical processes. These processes may be of high importance for the whole Baltic Sea ecosystem (e.g. buffer zone).

New artificial constructions of wind farms will create convenient substrate for hard bottom communities and may support appearance or development of non-indigenous species.

4.1.9 Fouling communities on offshore windmill parks

Authors: Francis Kerckhof, S. Degraer, A. Norro & B. Rumes

There is a world-wide concern of the expansion of non-indigenous species because they alter local biodiversity and sometimes compete with native species, some of which of commercial interest. This is especially the case in shallow coastal waters, subject to a multitude of human activities, including the construction of artificial hard substrata. We took the opportunity of the construction of numerous windmills off the Belgian coast to study the colonisation of non-indigenous species on these new artificial structures. Therefore we monitored the fouling communities of the wind farms on a regular basis from the beginning of their installation. We demonstrated that the new artificial hard substrata of the windmills offer new opportunities for non-indigenous species (introduced and southern Northeast Atlantic range-expanding species) to enter the Southern North Sea. Or, if already present, to expand their population size and hence strengthen their strategic position in the Southern North Sea. This is particularly important for the obligate intertidal hard substrata species, for which other offshore habitat is rare to non-existing.

During the considered period – late 2008/ mid-2011 – we identified 26 species in the intertidal samples at the windmills. Of these species we considered 17 species as intertidal. The non-indigenous species form an important part of the intertidal fouling community. We found eight non-indigenous species. These include six introduced species: the oyster *Crassostrea gigas*, the barnacles *Elminius modestus* and *Megabalanus* *coccopoma*, the amphipod *Jassa marmorata*, the crab *Hemigrapsus sanguineus* and the midge *Telmatogeton japonicus*, and two range expanding species: the barnacle *Balanus perforatus* and the limpet *Patella vulgata*. The ratio for non-indigenous to introduced species is high 1/3. Their relative abundance, as estimated from the SACFOR scale, is in most cases high almost from the beginning.

This study demonstrated that the newly introduced hard substrata within offshore wind farms play an important role in the establishment and the expansion of the population size of non-indigenous species, thus strengthening their strategic position in the Southern North Sea. This is particularly important for the obligate intertidal hard substrata species, for which offshore habitat is rare to non-existing.

4.1.10 Biofouling, fish and crabs at offshore wind power foundations

Authors: Roland Krone, Alexander Schröder*, Thomas Brey, Lars Gutow

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The ecological consequences of the large-scale introduction of wind turbine foundations are still little understood. On the one hand, offshore research is costly in terms of time and finances. On the other hand, only a few of the planned wind park projects hitherto have been realised. In 2003, before the construction of the first German wind park *alpha ventus* in the North Sea, the research platform FINO1was constructed. FINO 1 provided the first possibility to conduct investigations on the local effects of a single foundation on macro- and megafauna and to improve the assessment on the impact for the first time. Epibenthos was sampled by scientific diving within three seasons of the 3rd and 5th year after construction. Biomass accumulation ~6000 kgwas attached to the entire underwater construction. Blue mussels (*Mytilus edulis)* contributed the largest part to the biomass (75%) but only in the upper 5mof the construction while deeper areas were dominated by the amphipod *Jassa* spp. (> 200 000 N m^{-2}). The fish and crab fauna of FINO 1 was compared to five shipwrecks and the natural soft-bottom fauna in the surrounding of the artificial hard substrates (2008/ 2009). In general, the reef fauna of wrecks and the FINO 1 foundation was similar, but abundances at wrecks were up to 5 times higher. Further, the fish and crab coenosis on the two steel-foundation types (jacket, tripod) of *alpha ventus* was studied (2008) in comparison to the soft bottom in the foundation surrounding. No differences between the foundation types were found. However, some species such as the bull rout, *Taurulus bubalis,* occurred only at the foot-print area of the structures. Some species such as hermit (*Pagurus bernhardus)* and edible crabs (*Cancer pagurus)*were 90 respectively 600 times more abundant at the foundations than on the flattened soft bottom.

4.1.11 Effects of wind farm constructions on benthic and fish communities in Danish waters - experiences from the Horns Rev (North Sea) wind park

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Effects on the pelagic, semipelagic and demersal fish communities and infauna benthic communities and the development of epibenthic fouling communities from the establishment of one of the largest offshore wind farm – Horns Rev 1 - were studied during anPSO (Public Service Obligation) financed environmental monitoring programme from 2001 to 2010. Sampling of fish communities and benthos infauna were performed before and after the construction of the offshore farm, which was established in late 2002. Sampling of epibenthic communities were performed on monopiles and scour protections from 2003 to 2005. The presence of introduced hard substrate impacted the sandy seabed communities by increasing habitat heterogeneity and food availability for fish and seabirds. Epifouling communities were dominated by a few species including *Jassa marmorata* and *Caprella mutica* were not previously recorded from Danish waters. The edible crab (*Cancer pagurus*) colonized the foundations as larvae and juveniles and showed a significant increase in biomass from 2003 to 2005. Significant seasonal variation was found in the fish community showing low species diversity in spring compared to autumn. The introduction of hard bottom substrate resulted in higher species diversity close to each turbine with a distinct spatial distribution. However, no distinct spatial distribution patterns were found in the acoustic surveys. Reef habitat fish such as goldsinny wrasse (*Ctenolabrus rupestris*), viviparous eelpout (*Zoarces viviparous*) and lumpsucker (*Cyclopterus lumpus*) not recorded prior to the establishment of the wind farm, were observed on the newly introduced reef areas. No significant impact was observed in the native infauna community or in the sand dwelling sandeel communities as a result of the establishment of the offshore wind farm. Self-reproducing near shore communities of greater sandeel might benefit from the exclusion of trawling activities inside areas with wind turbines.

4.1.12 Implementation of French offshore wind farm in the Channel: toward an assessment strategy of benthic habitat changes

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No offshore wind farms have yet been constructed on French coasts. Five areas are however under call of tender and the laureate company will be released in April 2012*. After that, environmental impact assessment should be started. Four out of five sites are actually in the Channel and three concerns more particularly the Normandy region and the eastern part of the English Channel. In this part of the Channel, we benefited of historical and recent information on the sediment composition, macrobenthos and fish community structure and functioning. These databases should be a precious source for the estimation of reference conditions and the assessment of real impacts of wind farms in such megatidal environments where coarse sand, gravels and pebbles dominated. By anticipation, the PRES Université Normandie has established a multidisciplinary approach from zero state to the environmental monitoring and for the duration of the wind farm exploitation: the WIN-MIE Project (*Wind Innovation in Normandy – Milieux et Impact Environnementaux*). Six main types of research operations are planned to assess the impact of wind turbine implementation according to the main problems induced in terms of impact: (i) on the hydrodynamism created around the conjunction foundation/tower, (ii) on the sediment changes, (iii) on the artificial reef effects on benthic and demersal fishes population, (iv) of the airflow change consequences, (v) on the cumulated impacts with other economic activities at sea and (vi) on the social reception and the biogeography of the wind energy. Finally, for a global understanding, they will be considered at three different scales (local/meso-scale/regional).

* Four out of five areas have been accepted. Le Tréport site, which is the PRES Université Normandy study area, hasn't been retained.

4.1.13 Development of offshore windparks in Estonian marine areas and related research on their environmental impacts

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Estonia has jurisdiction over 36 500 km^2 of sea area in the NE Baltic Sea. From this area 11 300 km^2 belongs to EEZ. Development of infrastructure for utilisation of renewable energy resources is in high priority on the governmental level and so several projects are currently developed including establishment of offshore wind parks in Estonian territorial sea and EEZ. Currently in total three projects are issued a permit for performing official EIA procedures. Two of them are almost finalised their EIA process. At the moment no official building permits are issued but in very nearest future the decision on the official endorsement is coming.

EIA procedures for two almost finalised projects included detailed inventories and research covering all possible aspects of environmental impact. Detailed inventories of benthic habitats and biota, benthic and pelagic fish communities, bird migration as well as occurrence of marine mammals in the planned project areas were conducted. Studies on possible effects of the construction on benthic communities have been carried out in two project sites (Neugrund bank and Hiiumaa offshore windfarm area).

Effects of construction and exploitation of offshore windparks on benthic communities are very often difficult to predict. Lack of experience in construction of largescale windfarm projects in the Baltic Sea is one of the reasons. The large variability in the nearbottom environmental conditions (substrate character, salinity, oxygen regime, effect of ice scouring) in the NE Baltic Sea causes large variability in benthic communities making predictions even more difficult.

In our case studies on the possible effect of construction of offshore wind farms on benthic communities included artificial substrate colonisation experiments and substrate recolonisation experiments after mechanical destruction of sessile communities. Results show that in certain depth intervals the effect from construction activities could have significant effect on the condition of benthic community and the effect could be followed through several vegetation periods in highly dynamic conditions of NE Baltic Sea.

We will present results of substrate recolonistaion experiments carried out in Neugrund bank area where planned windpark project consists of 25–27 turbines situated in the shallowest part of the Neugrund bank. The capacity of offshore windpark is planned to be ca. 180 MW. In original application it was planned to use gravitation foundations.

Material for current study was collected during the investigations carried out in the process of EIA of Neugrund offshore windpark project. During one field season (April until October 2008), benthic disturbance experiments were carried out in three different depth intervals in the area of planned construction. Benthic communities of limestone rock were disturbed in three treatments during the vegetation season and then recolonisation of disturbed sites was followed monthly. Possible effect of construction activity was then calculated based on the data from quantitative mapping of the project area.

4.1.14 Offshore wind farms and benthos in the German Bight (North Sea) - Environmental impact assessment and approaches beyond

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In the near future the areal extent of the planned offshore wind farms (OWF) will be approximately 25 % of the German exclusive economic zone (Status: January 2012). The potential areas of OWF are mostly characterised by considerable water depths (30–40 m) and distances from the coast (40–190 km). Each OWF project is accompanied by an environmental impact assessment (EIA) based on a BACI sampling design (before-after-control-impact). The soft bottom benthos as well as the benthic communities on the artificial hard structures has to be surveyed by various sampling techniques. In addition to the EIA a research project, studying the effects of the OWF *alpha ventus* (German Bight, North Sea) on the benthic infauna, is applied. First results showed that the differences in the infauna between the impact and control areas increased significantly from 2008 (i.e. before *alpha ventus* was built) until the 1st year of operation in 2010. After the construction phase, the abundance patterns of some species changed in the *alpha ventus* area relative to the control areas. Based on analyses of variance, it could be shown that from before to after the construction the mean species richness varied significantly in the *alpha ventus*area, but not in the control areas. Whether the observed changes were related to the wind turbines or were due to the exclusion of trawling, should be decided from the results of specific further studies.

4.1.15 The secret life of Atlantic cod (*Gadus Morhua*) at a wind farm in the Belgian part of the North sea: where Ecology meets Economy

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A substantial expansion of offshore wind farms in the North Sea (BPNS) has been planned, inducing a growing interest in the possible effects of these artificial habitats on the marine environment. Demersal fishes are likely to be affected by these changes in the environment. The offshore wind turbines may provide a suitable habitat for hard substrate dwelling fish since hard substrates, e.g. shipwrecks and windmill artificial reefs (further referred to as WAR), have been reported to attract and concentrate fishes and/or to enhance local fish stocks. Since 2009 the trophic ecology and community structure of Atlantic cod has been investigated at the wind turbines on the Thorntonbank. In this study, the state of the art of ecological knowledge of Atlantic cod inhabiting WAR in the BPNS after three years of environmental monitoring is given. Reubens *et al.* (2010) revealed that high densities of Atlantic cod were present in the vicinity of the WAR in summer and autumn. Research on length-frequency distribution in combination with a migration study based on acoustic telemetry disclosed that Atlantic cod between 2 and 3 years old arrive at the WAR in spring, stay throughout summer and autumn and leave the area in winter time. Furthermore, the (ongoing) migration study (Reubens *et al.* 2011) revealed high site fidelity and residency near the WAR. Investigation of the feeding ecology revealed the high dependency of hard substrate associated epifaunal prey items in the diet of Atlantic cod caught near WAR. It can be concluded that the WAR play an important role in part of the life history of Atlantic cod in the BPNS. Every year, large aggregations of Atlantic cod dwell in the WAR and feed there throughout summer and autumn. Atlantic cod has considerable economical importance; hence several fishing industries lobby to allow small-scale fisheries within this 'de facto' marine reserve. However, as fish aggregation may easily lead to overfishing it is important that thorough management restrictions are implemented and careful monitoring continues in the long term.

4.1.16 Wind farm developments in Scottish near and offshore waters

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Currently Scotland has two operational wind farms (Robins Rigg and the Beatrice Demonstrator) however several large developments are planned and have received permission for development. Over the next ten years it is expected that up to 3000 turbines will be constructed, providing an estimated 10GW of electrical power. It should also be noted that Scotland is investing heavily in the development of wave and tidal power which will generate electrical power at similar levels. All consented applications have been subject to strict control administered under not only under EU legislation such as the Habitats Directive 2000 but also under more local legislation, namely the UK Marine and Coastal Access Act 2009 and the Marine (Scotland) Act 2010. These Acts require developers to carry out Environmental Impact Assessments which include seabed/benthic surveys at all their selected wind farm sites. The surveys generally comprise acoustic seabed mapping, TV/video survey, epifaunal and infaunal sampling. So, although no formal benthic research projects are underway in Scottish waters large volumes of benthic data are being gathered as part of the consenting process.

4.1.17 Modelling of local and far field effects of turbine foundations in Danish waters

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Offshore wind farm turbine foundations can have significant influence on the benthic and pelagic environment at local and regional spatial scales. Two aspects of potential ecological feedbacks are introduced in more detail. The first study compared the growth and feed-backs of blue mussels in natural beds and on turbine foundations in a Danish off-shore wind farm by coupling a dynamic energy budget model to a small-scale 3D hydrodynamic-biogeochemical model. The results showed that blue mussels located higher up in the water column on turbine pillars achieved a 7–18 times higher biomass than those located on the scour protection. High biomasses of blue mussels on foundations also created local 'hot spots' of biological activity and changed ecosystem dynamics due to their feed-backs e.g. ingestion of microplankton and copepods, excretion of ammonium and egestion of faecal pellets. A second aspect is centred on the question of turbine foundations as potential stepping stones for migratory species. Blue corridors are shaped either by biological mechanisms (route of choice) or by physical factors (currents, hydrography) in the case of passive particle dispersal (eggs, larvae, plankton). Particle tracking techniques in combination with 3D hydrodynamic models provide useful tools to identify the role of natural boulder reefs in the Kattegat and Belt Sea for non-random particle dispersal and to carry out sensitivity studies on the impact of offshore constructions on particle pathways.

4.2 Overarching issues and concerns

Based on the scientific activities and results presented during the poster session, the workshop participants identified and compiled important issues and concerns which were assigned to one of three categories: (1) knowledge gaps, (2) sampling design and analytical issues, and (3) policy framework. This compilation will form the base for the identification of specific cause-effect-relationships resulting from the anthropogenic activities associated with the construction and operation of offshore wind farms and the resultant pressures on the marine benthic environment.

Knowledge gaps, research questions

- The workshop participants agreed that a comprehensive evaluation of the effects of offshore wind farms on the marine benthos requires the understanding of cumulative effects with other anthropogenic stressors.
- Effect studies must go beyond the mere description of structural changes of benthic communities. Relevant processes can only be understood comprehensively when the functional response of the ecosystem is considered. Alterations of trophic pathways have been considered particularly important in this context.
- Impact assessment studies must be able to distinguish between responses of the benthos and real impact. The important question here is whether the observed changes are ecologically really significant. Therefore, we have to separate transient responses from long-term persistent changes. To clearly identify persistent changes the data from incidental impact assessment studies have to be analyzed in context with data from long-term ecological time series in order to evaluate how far the effects of offshore wind farms push the benthic reaction out of the long-term average.
- The effects of offshore wind farms occur on different temporal and spatial scales. Accordingly, results of impact assessment studies and the seriousness of the effects have to be evaluated carefully. Especially, when it comes to cumulative effects with other anthropogenic stressors we have to acknowledge that effects do not stop at national frontiers but require internationally collaborative research activities.
- Research on the effects of offshore wind farms should be open minded, i.e. we should not only watch out for negative effects of wind farms but also look for the positive potential of this development (e.g. local increase in biodiversity and productivity, opportunities for secondary use of wind farms).
- Research on the effects of offshore wind farms should include modelling approaches to enhance the predictive power of the results for scientifically based advice.
- So far, the cables received relatively little attention.

Sampling design & analytical issues

- The workshop participants agreed that a "best practice" should be developed providing standardized methods for research on the effects of offshore wind farms on the marine benthos.
- Data should be made available within and between countries.

- Standards for the monitoring of hard bottom communities are still missing (e.g. guidelines for scientific diving, application of optical methods, taxonomy).
- National monitoring strategies should be continuous lyre-evaluated in order to make data internationally comparable.
- Experimental approaches should become an integral part of research on the effects of offshore wind farms.

Policy framework

- Research on the effects of offshore wind farms must involve the industry and stakeholders and that these parties clearly document their activities which might affect the interpretability of the scientific results.
- Policy makers have to be convinced that impact assessment must move from a common baseline monitoring to a target monitoring based on scientific hypotheses. Scientist must contribute actively to the development of important research questions and support decision making processes driven by the need for a functioning ecosystem.
- The spatial requirements of research must be considered in marine spatial planning to avoid conflicts of interest with other activities.
- The public must be made aware of the benthos as an important component of the marine ecosystem.

The concerns and issues raised in this session demonstrates again that this new research topic of the effects of offshore wind farms on the marine benthos is embedded in a broad and well established research field of general marine benthic ecology. Accordingly, it has been proven extremely important to bring together experts from this field in an early stage of the wind farm research in order to consider all relevant aspects from the very beginning. By doing so we will be able to finally achieve an international well coordinated research which is directed towards the really important and burning issues of marine environmental research and which considers all relevant aspects with regard to science, methodology and legislation.

5 Identification of knowledge gaps

After the summary of important issues and concerns (chapter 4.2), the participants agreed upon that the first step to evaluate future scientific perspectives, i.e. to identify potential gaps in knowledge (ToR c) is to identify and summarise the pressures that result from offshore wind farm construction and operation activities and which, finally, initiate numerous cause-effect relationships in the benthic system. In a plenary discussion, the participants compiled a list of cause-effect relationships in the benthos initiated by offshore wind farm constructions, summarised them in a schematic presentation in order to give an overview and prioritised them following important research questions which were termed as crucial by the participants.

5.1 Potential cause-effect-relationships in the benthal resulting from construction and operation of offshore wind farms

As a base for the detection of knowledge gaps, concerning the effects of offshore wind farm on marine benthos, and future research, a summarising plenary discussion with all participants was initiated. Presentations from Elliot 2002 and the Deltares report (Boon *et al.* 2010) were used as a base for possible cause-effect-relationships. However, the participants agreed upon that the effects are by far manifold as described in Elliot and Deltares and that a more detailed listing that disentangle the specific cause-effect relationships, following the schematic presentation of the BEWG climate change chart (ICES 2008), is needed. A scientific base of all activities resulting from offshore wind farm construction and operation, the consecutive pressures, as well as the consequential cause-effect-relationships that are affected were listed (Table 1, Table 2).

Table 1. Construction phase of an offshore wind farm: activities during construction, the resulting pressures and the concerned cause-effect-relationships in the benthal by the pressures.

ACTIVITY	PRESSURE	CAUSE-EFFECT-RELATIONSHIPS
Pre-installation activity Construction vessels Anchoring Jackup vessels Foundation construction: Pile driving GBF-installation Scour protection Spoil disposal Cable laying: Scour protection Directional drilling Trenching, jetting and digging fishery cessation, displacement and adaption	Contamination & other issues Vibration (→ sed. characteristics) Noise Light turbidity: photic conditions Physical seabed integrity: Resuspension, contamination, resuspension of pollutants/toxic substances, morphological/bathymetrical changes, loss of sediment/habitat, smothering and clogging Accidental pollution	Mortality of species Bioaccumulation transfer →fitness of species Distribution changes as a consequence of energy (mobile/ non-mobile species) Larval-propagule settlement and survival Food availability (deposition, suspension, remobilization), bentho-pelagic-coupling Changes in soft community structure and function (population demography) Changes in hard community structure and function (population demography), non-indigenous species Benthic primary production changes (through changes in turbidity, sed. changes and introduction of new substrate) Nutrient fluxes alteration Altered biogeochemical cycle Changes in habitat complexity, "habitat banalisation" Changes in population size/production Bioenergetics

Table 2. Operation phase of an offshore wind farm: activities during operation, the resulting pressures and the concerned cause-effect-relationships in the benthal by the pressures.

Activity	Pressure	Cause-Effect-Relationships
Servicing activities Turbine towers Artificial habitat/ construction:Accomodation platforms, Transformer platforms, Turbine foundations Cables Collision fishery cessation, displacement and adaption	Contamination (paints) & other issues Vibration (→ sed. characteristics) Noise Light Hydrodynamic conditions: turbulence, changes in laminarity, vertical mixing, decrease in wave energy) Sediment dynamics (→scour): Contamination, resuspension of pollutants, granulometric changes, changes of habitat heterogeneity and complexity (3D aspects), morphological/bathymetrical changes, loss of sediment/habitat habitat creation (epifouling → nature habitat) temperature EMF (electromagnetic fields) Accidental pollution	(Introduced) species dispersal Bioaccumulation transfer → fitness of species Distribution changes as a consequence of energy (mobile/ non-mobile species) Larval-propagule settlement and survival Food availability (deposition, suspension, remobilization), bentho-pelagic-coupling Changes in soft community structure and function (population demography) Changes in hard community structure and function (population demography), non-indigenous species Benthic primary production changes (through changes in turbidity, sed. changes and introduction of new substrate) Nutrient fluxes alteration Altered biogeochemical cycle Changes in habitat complexity, "habitat banalisation" Changes in population size/production Hard-substrate epifouling impact: -Local organic enrichment through filter feeders and other consumers -Meta-population connectivity and dynamics -Invasiveness -Oxygen depletion Bioenergetics

After the summary of potential cause-effect relationships, the group split into two subgroups: one was working on a schematic presentation to cover visually the dependencies and interactions between all cause-effect-relationships (see chapter 5.2), the other one dealt with the prioritisation of the effects (direct and indirect) ones and their relevance to different research questions (see chapter 5.3). The outcomes of the sub-groups were presented to the audience in a plenary.

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5.2 Identifying and mapping cause-effect relationships

The workshop identified all potentially significant cause-effect relationships between offshore wind farm related activities, their environmental pressures and consequent environmental impacts during a brain storm session. These cause-effect relationships are presented in a flow diagram (Figure 7). On the left hand side the wind farm related activities are listed, distinguishing between the two main phases being the construction and the operational phase. The central part of the diagram comprises the anticipated changes within the abiotic part of the ecosystem, while the biotic impacts are presented at the right hand side.

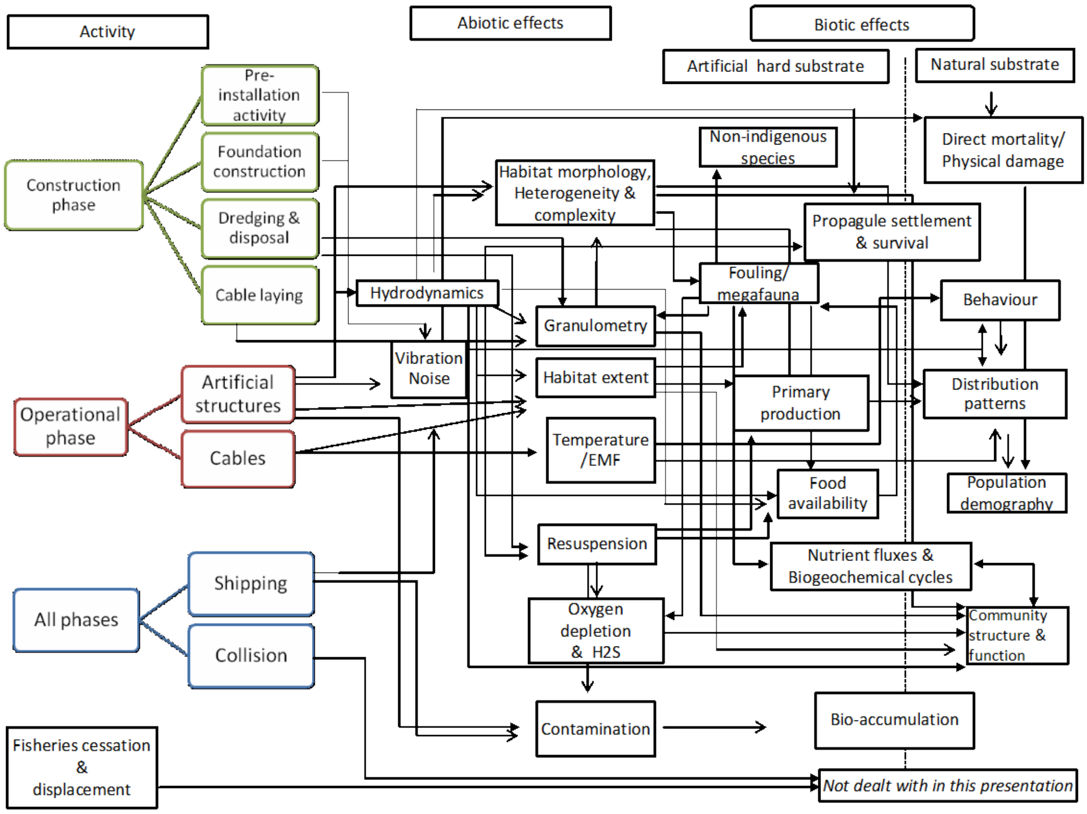

Figure 7. Schematic presentation of the activities, resulting activity pressures and the consecutive abiotic and biotic effects on the benthos during the construction and operational phase of an offshore wind farm.

The diagram should be considered a first attempt for a structured, though comprehensive overview of the cause-effect relationships behind possible impacts of offshore wind farms onto the benthos. The following disclaimer should however be kept in mind while interpreting the flow chart:

- The dismantling phase is not included in this diagram as at this moment the most prominent impacts are to be searched for at the level of both before mentioned phases.

- The impact flows of fisheries cessation and displacement, as well as the impacts of collision are not developed in the diagram as the workshop decided that these impact flows are appropriately dealt with already in literature.
- While ideally all cause-effect relationships should be underpinned by references to literature, on which the hypothesized cause-effect relationships are based, the limited time of the brain storm activity did not allow for a proper literature search. While the flow chart hence remains at the level of expert judgment, it does represent a consensus view of all workshop participants. Ideally, the next step should be to scientifically underpin the cause-effect relationships identified.

The complexity of the diagram is directly related to the multitude of the ecological cause-effect relationships and hence depicts the complex nature of impact evaluation of offshore wind farms. To illustrate on how the flow chart should be read, two examples of cause-effect relation chains are given:

- During the construction phase, the installation of the foundation is often accompanied by the production of excessively high sound pressure levels. This noise might cause behavioural changes that might lead to (short-term) changes in the spatial distribution patterns of local populations of e.g. fish. The noise levels might however be that high that direct physical damage or even mortality occurs in e.g. fish larvae, which will eventually lead to altered population demography.
- Once operational, the artificial structures by definition alter the habitat morphology, heterogeneity and complexity of the original habitat, which on its turn provides habitat for fouling organisms (cf. artificial reef), such as hydro- and bryozoans, hard substrate amphipods and barnacles. The fouling organisms of such structures are known to be prone to contain various non-indigenous species by possibly altering these species' distribution patterns, but also to act as an extra food resource for megafauna such as fish attracted to the structures. Next to this link the so called artificial reef effect is also known to include impacts to the original (often) soft sedimented environment both by changes of the granulometry and the local organic enrichment, which on their turn will spark a whole series of changes in the soft sediment benthic communities.

5.3 Prioritisation of cause-effect-relationships

The aim of this section was to determine the prioritisation of research into cause and effect knowledge gaps. The sub-group discussed the potential criteria for prioritisation. The general opinion was that any research priority had to be able to demonstrate necessity for the research, how effective it will be, cost efficiency, ecological relevance, legal obligations and practicalities. At this stage it was suggested that whilst these are important criteria there was a need to first identify the main ecological research questions that we could then apply these criteria to. Three main questions that all agreed on was how offshore wind farms impact on the production, the processes and cycling and the structure. The main topics relating to these with the link to the importance of benthos were identified as:

(1) Production – Biological Resources: benthic importance →fisheries and food web

(2) Processes/cycling – the Biogeochemical Reactor: benthic importance → bioturbation, ventilation, carbon pathways and long term storage, nutrient dynamics

(3) Structure – Biodiversity: benthic importance →the benthos itself as a major vector in seabed processes, e.g. trophic chain upwards.

The discussion then lead to considering how cause and effect relationships identified on Day1 fit with these questions. A table was drawn up relating the cause and effect relationships to each of the three questions by considering which was most relevant (Table 3). A three point scale with 1 representing the most relevant to 3 the least relevant was assigned to each question. Whilst some of the cause-effect relationships were well defined and easy to determine their relevance (e.g. invasive species effects), others were too general (e.g. soft community changes). The opinion was that the more general relationships needed to be considered further to clearly identify the cause-effect relationships. So a further iteration of the table would probably be required (see Table 3, n/a).

Furthermore some of the cause-effects needed qualified owing to different potential effects as a result of scale (both time and spatial). The next stage was to look at how criteria could be used to potentially prioritise the cause effect relationships. This was done for ecological relevance and resulted in an expanded table with the criteria considered for each of the three questions. A three point categorisation with '+' meaning lower priority to '+++' highest priority was applied (Table 3). It was evident that prioritisation may change by location, time and scale. Other criteria (socially desirable, feasibility, legal requirements) were highlighted but were not dealt with as the focus should first be on the ecological relevance. These criteria will however become important when considering priorities in relation to economics, legislation and getting the message of benthal ecology and offshore wind farms out.

Table 3. Prioritisation of cause-effect-relationships in the benthal affected by construction/operation of offshore wind farms in relation to major research topics (biological resources, biogeochemical reactor, biodiversity). CTR = cross-topic relevance (1 most to 3 least relevant), ER = ecological relevance within each topic ('+++'highest to '+'lowest priority).

Cause-Effect-Relationships	Biological Ressources		Biogeochemical Reactor		Biodiversity	
	CTR	ER	CTR	ER	CTR	ER
(Introduced) species dispersal	2	+	2	+	1	+++
Bioaccumulation transfer → fitness of species	1	+	1	+	2	++
Distribution changes as a consequence of energy (mobile/ non-mobile species)	1	++ (L), + (R)	2	+	2	++ (L), + (R)
Larval-propagule settlement and survival	1	+++	1	++	1	+++
Food availability (deposition, suspension, remobilization), bentho-pelagic-coupling	1	+++	1	+++	2	++
Changes in soft community structure and function (population demography)	n/a	++	n/a	++	1	+++
Changes in hard community structure and function (population demography), non-indigenous species	2	++	2	+	1	+++
Benthic primary production changes (through changes in turbidity, sed. changes and introduction of new substrate)	1	+++ (L&LT)	1	+++ (L&LT)	2	+++ (L&LT)
Nutrient fluxes alteration	2	+	1	+++	2	+
Altered biogeochemical cycle	2	+	1	+++	2	+
Changes in habitat complexity, "habitat banalisation"	2	++	2	+++	1	+++
Changes in population size/production	1	+++	2	+	2	++
Hard-substrate epifouling impact						
- local organic enrichment through filter feeders and other consumers	2	++	1	+++	3	+
- connectivity and dynamics	2	+	2	+	1	+++ (R)
- invasiveness	2	+	2	+	1	+++
- oxygen depletion	1	+	1	+	1	+
Bioenergetics	1	++	2	+	2	++
Mortality of species	1	++	2	++	2	+++

L = local scale R = large scale LT = long term

The prioritization of the specific cause-effect relationships revealed that some processes which are expected to occur in offshore wind farms are of outstanding ecological relevance and are closely linked to great variety of other processes indicating strong cumulative effects. Highest relevance was given to processes which are related to trophic issues (food web effects) and productivity and turnover of matter and energy in the benthic system. Other cause-effect relationships are of high ecological relevance as well but appear to have only weak implications on other processes.

These were mainly specific processes (e.g. larval settlement, oxygen depletion) which, however, have the potential to become relevant on the system level when populations and thus the structure of entire communities are being affected from an impairment of these processes.

5.4 Output of the workshop: viewpoint publication initiative

The workshop participants agreed upon to summarise the outcomes concerning the knowledge gaps in a viewpoint publication. The publication will address the certain need to understand ecological mechanisms behind the effects of offshore wind farms. Baseline monitoring of a BACI-design over time, as undertaken in most countries today, does not allow for the quantification of the mechanisms behind the wind farm induced changes. However, understanding of these mechanisms is inevitable for future predictions of ecological implications in the benthic system. Such predictions have the potential to serve as an important baseline for science-based mitigation actions. The outcome of the workshop on the benthos will serve as an example for the principle need of targeted monitoring on understanding cause-effect relationships of offshore wind farms. The publication will address the science community, but particularly policy makers and authorities on different organisational levels. All participants will contribute to the manuscript under the lead of J. Dannheim and S. Degraer.

It was agreed upon that the viewpoint paper will be presented as a poster presentation on the ICES Annual Science Conference in Bergen (2012). Further, a talk with the main outcomes of the workshop will be presented at the ICES ASC this year.

6 Collaboration and perspectives: the way forward

During the workshop it became clear that the topic of offshore wind farm effects on marine benthos is extensive and that a lot of knowledge is shared by the experts/participants. The participants agreed that there is an urgent need for future scientific collaborations, particularly in the scientific research field of cumulative impact assessments when expert knowledge, scientific results from projects and potentially data are shared among scientists across frontiers (see chapter 6.2). Thereby, a meta database will improve information exchange and guidelines for sampling techniques on renewable energy construction monitoring techniques will simplify collaboration abilities (see chapter 6.1). It was further agreed upon that particularly target monitoring investigating specific cause-effect relationships is of high priority, i.e. to understand the mechanisms behind the changes initiated by offshore wind farm constructions (see chapter 5.4), particularly as many interactions affect higher trophic level parts of the ecosystem as well (see chapter 5.3), directly linked to marine spatial planning strategies and future ecosystem-based management approaches.

The compiled outcomes of the workshop are a scientific base for evaluating the efficiency of ongoing monitoring programs and for future perspectives and potential collaborations (ToRs d-f). The ToRs d – f were not dealt with in detail, but an action plan was developed how future collaborations could be established and how scientific collaborations can be made more efficient. One first initiative on the efficiency of ongoing monitoring programmes, i.e. the need for target monitoring to understand cause-effect relationships (ToR d) has been already started during the workshop (chapter 5.4). The following two subchapters summarises the practical implement future international collaboration and suggest a way forward towards an international research on the offshore wind farm – marine benthos topic (ToR e, f).

6.1 Methodological issues/practicalities

During previous plenary sessions issues arose on knowledge gaps and standardisation of methodologies in monitoring programmes. A best practice guide for OWF monitoring will bring together differences in methodologies and enhance international collaboration between scientists. Certain existing guidelines (e.g. fouling) could be adapted to create a guide which focuses on the methods specific for OWF research: Hard-substrates, soft-substrates, scientific diving, treatment of samples, taxonomic references, sampling frequency, replication and scales (temporal and spatial). Countries with previous OWF monitoring experience (Belgium, Germany, UK etc.) could work together to tackle differences in strategies and methodologies, for example: hard substrate scrape sampling is collected in plastic bags in Belgium while mesh bags are utilised in Germany.

On a national scale a difference could be made between methods which are applicable to all offshore wind farms (i.e. large-scale monitoring) and methods focussing on processes, functioning and specific effects (targeted monitoring).

At an international scale, modelling could enhance the knowledge of large scale cumulative effects by introducing trophic relationships, research on indigenous species and larval distribution. The knowledge of changes in trophic relationships can be enhanced from field work/monitoring and specific experiments and used to model cumulative effects.

Furthermore, scientific diving causes an issue in certain countries where only professional divers can sample. This should be tackled at a national level but could be helped by other countries with experience on scientific diving with a European standard.

Collaboration can be enhanced if funding is found through the ERA network and by coming up with practical research questions.

6.2 Requirements and capabilities of connected research in the future

The aim of this discussion was to consider the way forward in terms of collaboration and strategic initiatives. Overarching topics to set the frame for sorely needed collaborative and strategic initiatives were defined. Within policy framework (e.g. MSFD) collaboration on research is certainly needed to increase the science based knowledge on a European basis. In order to increase the profile of the benthal (rather than just the benthos), the group seeks an ecosystem approach, i.e. ecosystem based studies involving the whole group of participants. The group agreed upon that there is a certain need to increase of desirability of the benthal in society. Lessons can be learnt from studies relating to charismatic species that currently dominates OWF research which primarily is driven by NGO's, specific legislation and public interest. The issue of data availability and data sharing was identified as an important issue to address. It was suggested to create a metadata list from each country to ensure a good basis for addressing the research questions/gaps previously drawn up. The use of participant's skills and expertise, including data sharing between experts potentially increase the cost effectiveness in research and enhance funding possibilities. Research funding could follow the approach at a country level of the aggregate extraction industry (UK at the moment – e.g. Aggregates Sustainability Levy Fund). Widening the scope of research, the strategy is to look for EU level funding opportunities such as INTERREG and EU Framework Programmes. There was also the possibility of lobbying ICES with an action list. The group suggested a formal move to develop a proposal for INTEREG (MARTEC ERA-NET end of April 2012) using knowledge gaps identified through the workshop and using the skills of the participants in the first instance and then identify potential other specific partners for the research.

According to the identified overarching topics, a number of strategic initiatives to facilitate future international collaboration were identified:

- Links to other meetings – ICES ASC Bergen, September 2012 (see chapter 5.4 and Annex 4);
- Creating metadata information base on ecological data of offshore wind farm research;
- Creating skills directory of workshop participants (e.g. contact list in case of scientific questions);
- Research opportunities:
  - Latitudinal and longitudinal gradient analysis;
  - Time series proxy – i.e. use of OWF at different stages instead of long-term monitoring of a single OWF;
- Expanding research participation (socio economic; risk/uncertainty; industry partners);
- Learning from charismatic-species research/NGOs: enhance the "benthic" outreach (photography, media experts) to increase the desirability of the benthal in society.

7 Closure of the meeting

The main results from the expert group discussions showed the urgent need to increase scientific exchange and collaboration as the marine and offshore renewable energy (principally wind at the moment) industry is rapidly growing. The scale of the planned developments will, most likely, become the major impact in coastal areas across the North Atlantic region. The effects of marine renewable energy constructions on the benthic system are manifold. During the workshop, participants concurred that by far the benthos receives too little attention compared to other ecosystem components (e.g. seabirds and marine mammals – the 'charismatic megafauna'). It was agreed that the benthic organisms and community could be charismatic but it needs to have its profile raised significantly. The poor attention on the benthic community is greatly contrasted by the extensive contribution to marine ecosystem structure and function and the associated services and goods, e.g. biodiversity, long-term carbon storage and trophic connection and energy supply for higher trophic-level species. The expert group also determined that species that inhabit the benthic zone (known as 'the benthal') are important to include.

The main future focus was identified as simplifying and enabling scientific collaborations for the assessment of environmental effects of marine renewable energy developments on the benthal community and the potential for cumulative impact. This would be achieved by developing research and guidance on sampling techniques to effectively and appropriately monitor the effects of renewable energy construction and operation on the benthal organisms. Also by developing a meta-data information base on expert knowledge and potential existing data to specific cause-effect relationships; to evaluate if the lessons learned on offshore wind-farm effects are comparable to other renewable energy installations; as well as to discuss how existing knowledge from related topics (e.g. artificial reefs) are applicable to cause-effect relationships in the benthos as a result of renewable energy constructions. This will enable to focus on specific processes in the benthal that needs urgently investigated but which, at the same time, are important for marine ecosystem services and goods in the context of marine spatial planning strategies within future ecosystem-based management approaches.

The participants decided that these issues will be best tackled by initiating an ICES Expert Group on the effects of renewable energy constructions on the marine benthos which will be co-chaired by Jennifer Dannheim, Germany and Andrew B. Gill, United Kingdom. A recommendation for this initiation will be forwarded to the BEWG.

The co-chairs thanked the participants for their input and closed the meeting on Thursday, 13:00 hours.

Annex 1: List of participants

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Gwenola de Roton	Cellule de Suivi du Littoral Normand	Phone: +33 2 35 21 71 70 Fax: +33 2 35 22 47 50	gwenola.de-roton@csln.fr
Jozefien Derweduwen			
Andrew Gill			
Lars Gutow (Chair)	Alfred Wegener Institute for Polar and Marine Research P.O. Box 120161 27570 Bremerhaven Germany	Phone: +49 471 4831 1708 Fax: +49 471 4831 1425	Lars.Gutow@awi.de
Urszula Janas			
Francis Kerckhof			

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Mike Robertson	Marine Scotland Science Marine Laboratory P. O. Box 101 375 Victoria Road Aberdeen Ab11 9DB	Phone +44 (0) 1224 876544	mike.robertson@scotland.gsi.gov.uk
Liis Rostin			

Contributions were received from Jan Reubens, Christian Mohn, Henning Steen, Bjorn Tunberg and Dan Wilhelmsson.

Annex 2: Agenda

Effects of offshore wind farms on marine benthos - Facilitating a closer international collaboration throughout the North Atlantic region

Bremerhaven, 27–29 March 2012

Tuesday, 27 March 2012

09:00 – 09:30 Arrival and set-up

09:30 – 11:00

- Opening and introduction of all participants
- Introductions to and expectations of the workshop
- Adoption of agenda
- Appointment of rapporteur

11:00 Coffee break

11:00 – 13:00

- Review the current scientific work on offshore wind farm effects on the benthic system in the North Atlantic, oral introduction to posters (5 min each) ToR (a), (b)

13:00 – 14:00 Lunch

14:00 – 15:30

- Review the science of offshore wind farm effects on the benthic system in the North Atlantic, poster session ToR (a), (b)

15:30 Coffee break

16:00 – 18:00

- Plenary discussion on the state of the art knowledge and burning issues of wind farm effects on the benthic system, identify main impacts and changes ToR (b)
- Plenary wrap up of day 1 and brief introduction to day 2

19:30 Dinner, details provided at the workshop (reservation is done by the organisers)

Wednesday, 28 March 2012

9:00 – 09:30

- Appointment of rapporteur
- Plenary introduction to the evaluation of future scientific perspectives, i.e. to identify potential knowledge gaps (ToR c) based on the lessons learned from day 1

9:30 – 11:30 (incl. coffee break)

- Sub-group discussions on future scientific perspectives

11:30 – 13:00

- Plenary feedback of sub-group findings, discussion on and prioritisation of the future scientific perspectives, i.e. identifying potential gaps in knowledge ToR (c)

13:00 – 14:00 Lunch

14:00 -14:30

- Plenary introduction to the efficiency of onging monitoring programs (ToR d) in relation to present day monitoring focus and prioritised future scientific perspectives

14:30 – 16:30 (incl. coffee break)

- Sub-group work on monitoring programme efficiency (ToR d); topic allocation to be based on ToR (b) & (c) findings, e.g. commons, duplication of work and different strategies in ongoing research and monitoring programs (e.g. effects) between countries

16:30 -18:00

- Plenary feedback and discussion of sub-group findings, with the aim of identifying how ongoing monitoring programs could be made more efficient (ToR d), with side excursions to the scope for international collaboration (ToR e)
- Plenary wrap up of day 2 and brief introduction to day 3

19:30 Dinner, details provided at the workshop (reservation is done by the organisers)

Thursday, 29 March 2012

9:00 – 11:00

- Review of and discussion on the scope of international collaboration, to e.g. to reduce redundancy in ongoing research ToR (e), (f); session topics and format to be decided based on the output from days 1 and 2. Topics should include e.g.:
- Practical steps forward and final discussion of an integrated strategy to strengthen international collaboration
- Funding possibilities

11:00 Coffee break

11:30 – 13:00

- Final workshop discussion and wrap up: Where to move on from here?

13:00 – 14:00 Lunch

14:00 End of meeting

Annex 3: Action points

- D. Coates to collect existing guidelines of sampling techniques on the SharePoint and to provide an overview for facilitation of future cooperation and future guidelines on OWF monitoring techniques. Contact D. Coates (delphine.coates@ugent.be) for national contributions.
- J. Dannheim and S. Degraer to take the lead on the initiative of a viewpoint publication on the certain need to understand ecological mechanisms behind the effects of offshore wind farms. Contact J. Dannheim (Jennifer.Dannheim@awi.de) or S. Degraer (steven.degraer@mumm.ac.be).
- S. Degraer, J. Dannheim and L. Gutow to take the lead on the presentation of the viewpoint paper (poster presentation) and the main outcomes of the workshop (oral presentation) at the ICES ASC 2012 in Bergen.
- A. Gill will check regularly (every 2-3 months) for funding opportunities in order to finance potential research focusing on the identified knowledge gaps. Funding opportunities will be posted on the share point side by A. Gill.

Annex 4: Recommendations

Recommendation	Adressed to
1. To establish an expert group on Marine Benthal and Renewable Energy Developments (WGMBRED) (see Annex 5)	SCICOM (BEWG)

Annex 5: Draft resolution for WGMBRED

The **Working group on Marine Benthal and Renewable Energy Developments** (WGMBRED), chaired by Jennifer Dannheim*, Germany, and Andrew B. Gill*, UK, will be established and will meet in VENUE, DATE 2013 to:

a) Critically evaluate current knowledge on the effects of offshore wind farms and other renewable energy constructions on benthal organisms (i.e. marine invertebrates, demersal fish and macroalgae);

b) Review and develop guidelines of sampling techniques on renewable energy construction monitoring techniques by providing an overview of existing guidelines, in order to standardise and simplify future research and monitoring;

c) Develop a meta-data information base for cross fostering research to target monitoring and future potential modelling approaches;

d) Discuss how existing knowledge from related topics (e.g. artificial reefs) are applicable to cause-effect relationships in the benthal associated with renewable energy constructions.

WGMBRED will report by DATE 2013 (via SSGEF) for the attention of BEWG and SCICOM.

Supporting Information

Priority	The working group was initiatied by the workshop "Effects of offshore wind farms on marine benthos – Facilitating a closer international collaboration throughout the North Atlantic Region" (WKEOMB) via BEWG and will lead ICES into issues related to upcoming large-scale ecosystem effects of renewable energy constructions on the marine benthal community (macroalgae, invertebrates and demersal fish. The objectives addressed here will be highly relevant in the context of future ecosystem-based management approaches, marine spatial planning and required monitoring schemes.
Scientific justification	The offshore renewable energy industry is growing fast and will most likely become one of the most important and large-scale anthropogenic pressures within coastal and offshore ecosystems over the next decades. Collision risks for migrating birds and noise impact on marine mammals and fish are issues of major public concern reflected in current monitoring practice and licence guidance. Less charismatic organisms, however, such as benthic invertebrates, algae and demersal fish, receive far less attention. Benthic organisms deserve much greater attention owing to their fundamental place in marine ecosystems and the numerous ecosystem goods and services, such as marine biodiversity and long-term carbon storage and natural resources), that are intimately linked to the benthic system. The installation and operation of extensive renewable energy developments will initiate processes which are expected to affect benthic communities over various spatial and temporal scales.The identification of these processes is the prerequisite for an efficient, hypothesis driven approach towards the disentanglement of the various effects of marine energy developments on the marine benthos as well as on the whole ecosystem. The workshop "Effects of offshore wind farms on marine benthos" (27.-29.03.2012 held at the Alfred Wegener Institute in Bremerhaven, Germany) identified the need to broaden the scope of existing scientific research on benthic systems and take account of cumulative impacts, as well as to disentagle the various effects relating to offshore wind farms. During the ICES Workshop WKEOMB, a first inititative on a schematic summary of benthic cause-effect-relationships triggered by offshore wind farms was started, but the relationships have to be tackled in more detail. The aim of the meeting will be to increase

	scientific efficiency of benthal renewable energy related research, to specify the various cause-effect-relationships resulting from the construction and operation of offshore renewable energy installations, and to develop guidelines and an overview of existing data for cumulative impact research by future international collaboration. The outcomes of the meeting will provide a focus on how the benthal science community should proceed in terms of researching the processes and cause-effect relationships that are important for marine ecosystem services and goods such as biodiversity, the biogeochemical systems (e.g. long-term carbon storage) and the biological resources/food supply for higher trophic levels. The outputs will also be set within the context of marine spatial planning strategies and future ecosystem-based management approaches.
Resource requirements	No specific resource requirements beyond the need for invited members to prepare for and resource their participation in the meeting.
Participants	These would include scientists working with the effects of marine renewable energy developments on the marine benthal community, including algae, infaunal invertebrates to benthic /demersal fish. Participation is sought from ICES countries and by scientists both from disciplines and scientific circles not normally represented at ICES.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	There are no direct linkages with the ICES advisory services, although the workshop results will have potential here.
Linkages to other committees or groups	A close link with Benthos Ecology Working Group (BEWG).
Linkages to other organizations	

Annex 6: Questionnaire

Workshop: Effects of Offshore wind farms on Marine Benthos (WKEOMB)

Poster questionnaire – Author

1. General information

nationality/country	
marine region	
site criteria	water depth (m): distance to coast (km): tidal/non tidal: predominating bottom type:

2. Wind farms

no. of wind farms in your country	in use: under construction: planned:
areal extent of the wind farms investigated or number of turbines	
foundation types	

3. Study design

areal extent of study focus (m^2 to km^2)	
spatial replication	

spatial resolution	
initiation of study	
duration of study	
temporal resolution	
temporal replication	
sampling techniques	

4. Purpose/benthic focus: What has been investigated?

Benthic focus: Interdisciplinary classification

hard bottom		ecology	
soft bottom		behaviour	
benthic invertebrates		physiology	
demersal fish		genetics	
algae/plants		other:	
community analysis			
autecological analysis			
other:			

Observed effects evaluated as ☐ Minor ☐ Intermediate ☐ Ma-jor

Does your monitoring programme also target the qualification of selected cause-effect relationships?

☐ Yes ☐ No

If yes, please specify (research question, methodology, strategy):

5. Monitoring – Environmental impact assessments (EIA)

Does your country have a national monitoring program or design for EIA by legislation?

☐ Yes ☐ No

If yes, please indicate what is investigated:

Benthic focus: sampling techniques:

hard bottom effects		grab, specify here:	
soft bottom effects		trawl, specify here:	
benthic invertebrates		divers	
demersal fish		scrape samples	
algae/plants		other:	
sediment changes			
hydrodynamic changes			

Are EIA related to other directives or legislation guidelines?

Marine strategy framework directive		OSPAR	
National water framework directive		BEQUALM	
others:			

6. Cumulative impacts

Are there studies/monitoring programs that investigate the cumulative impact of several wind farms?

☐ Yes ☐ No

Are other impacts investigated that might potentially interact with the effects of offshore wind farm?

☐ Yes ☐ No

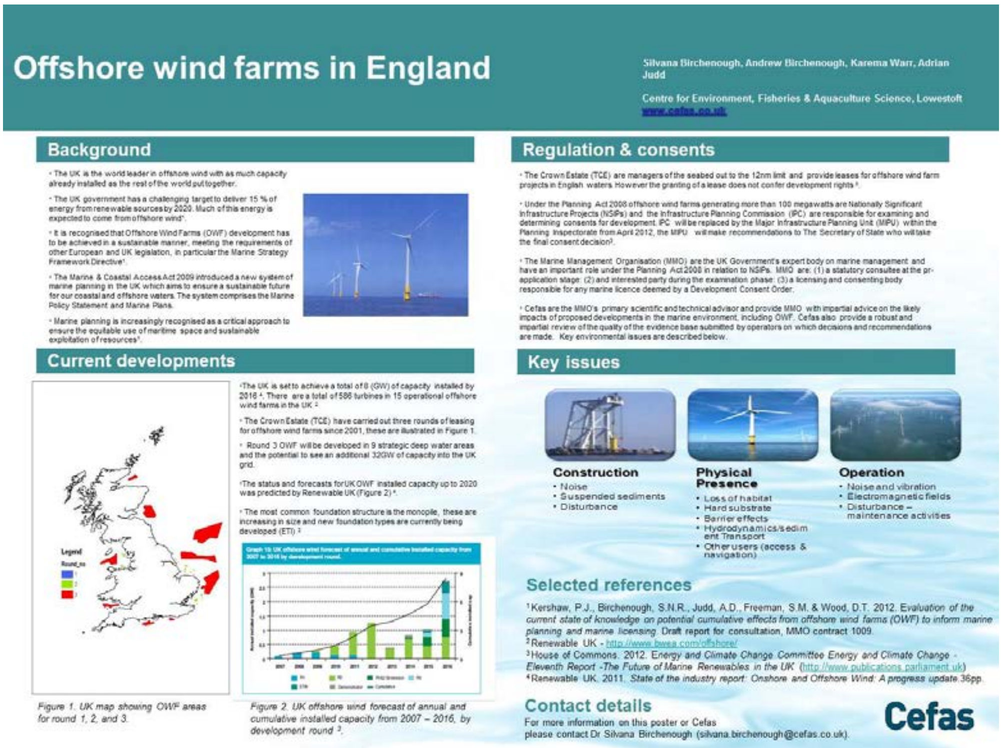
If yes, please indicate what effects are investigated:

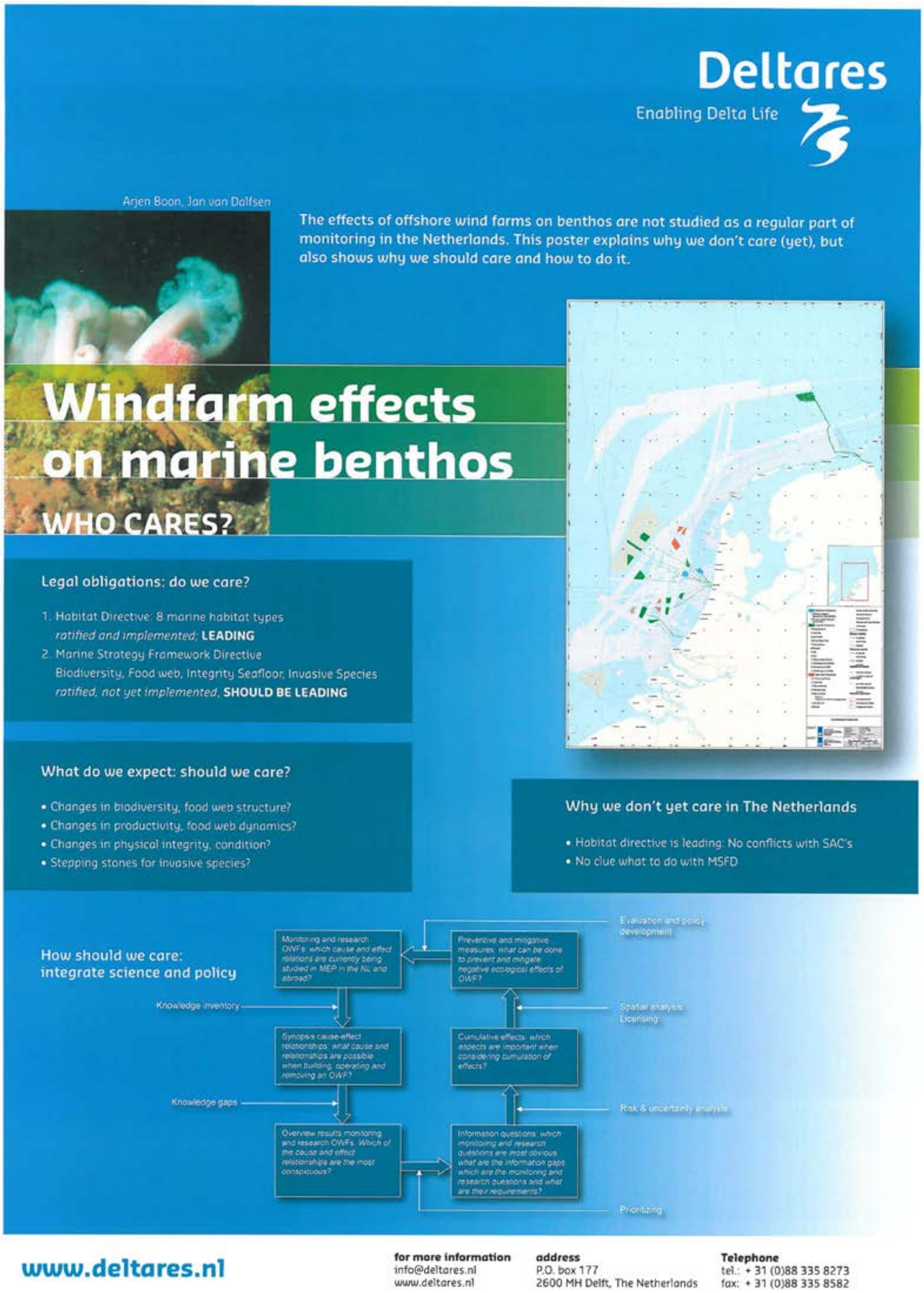
fishing		transport/shipping (e.g. neobiota)	
sand extraction		climate change	
dumping		oil exploration	
eutrophication		oxygen depletion	
other artificial substrates			
others:			

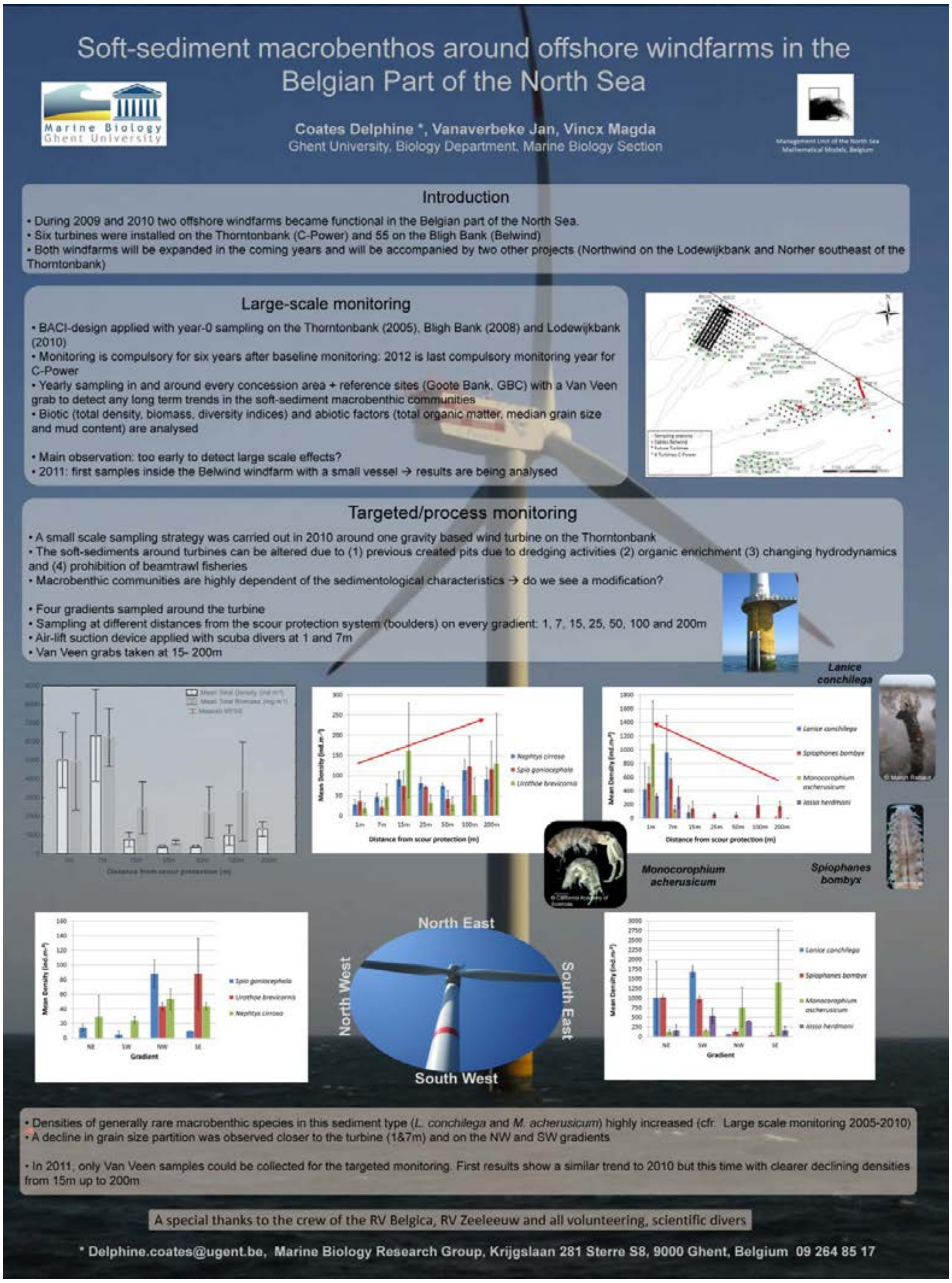
7. Further thoughts

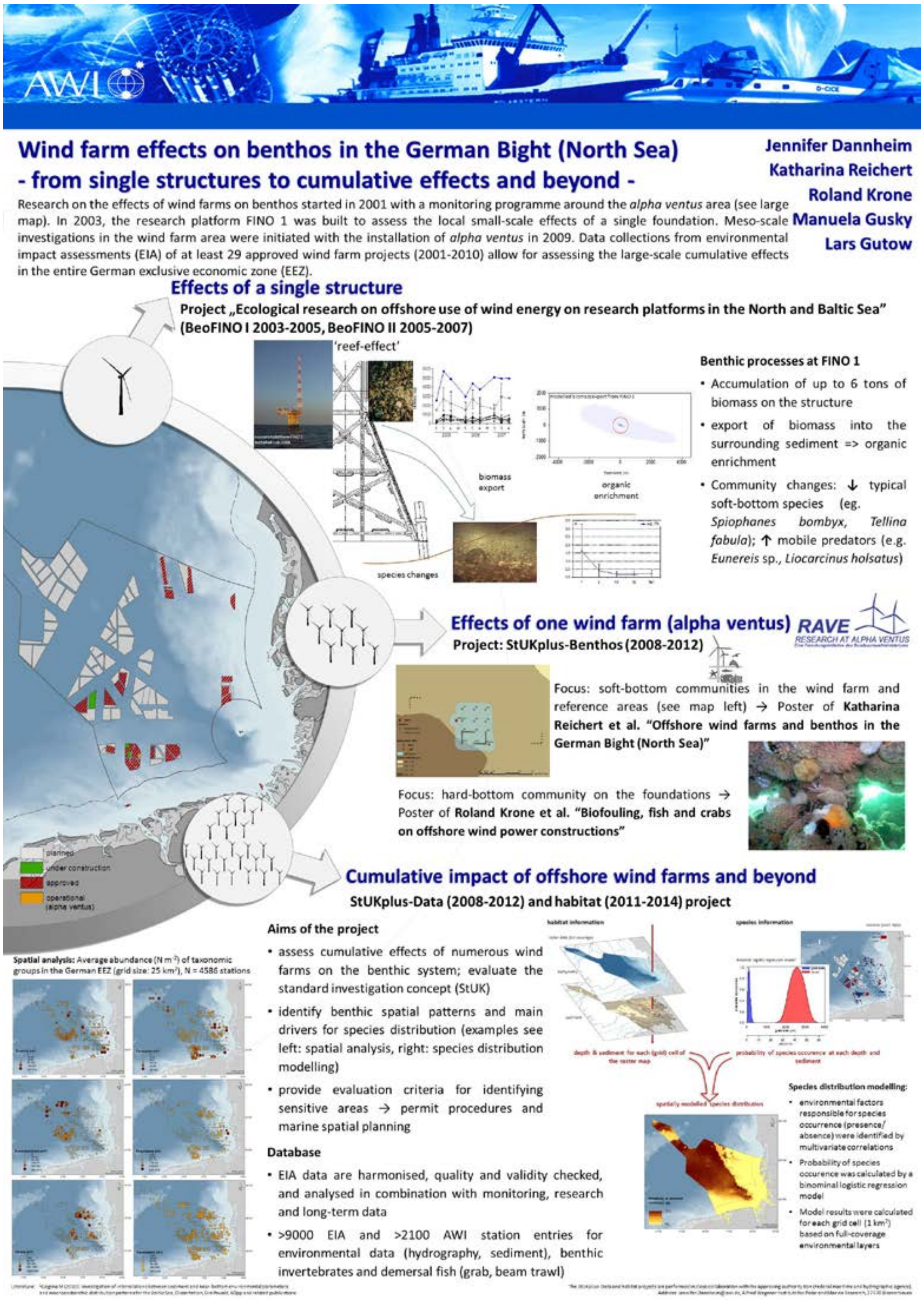
Please add here, whatever you missed in point 1-6, but you feel necessary to be included in this questionnaire:

Annex 7: Poster presentations

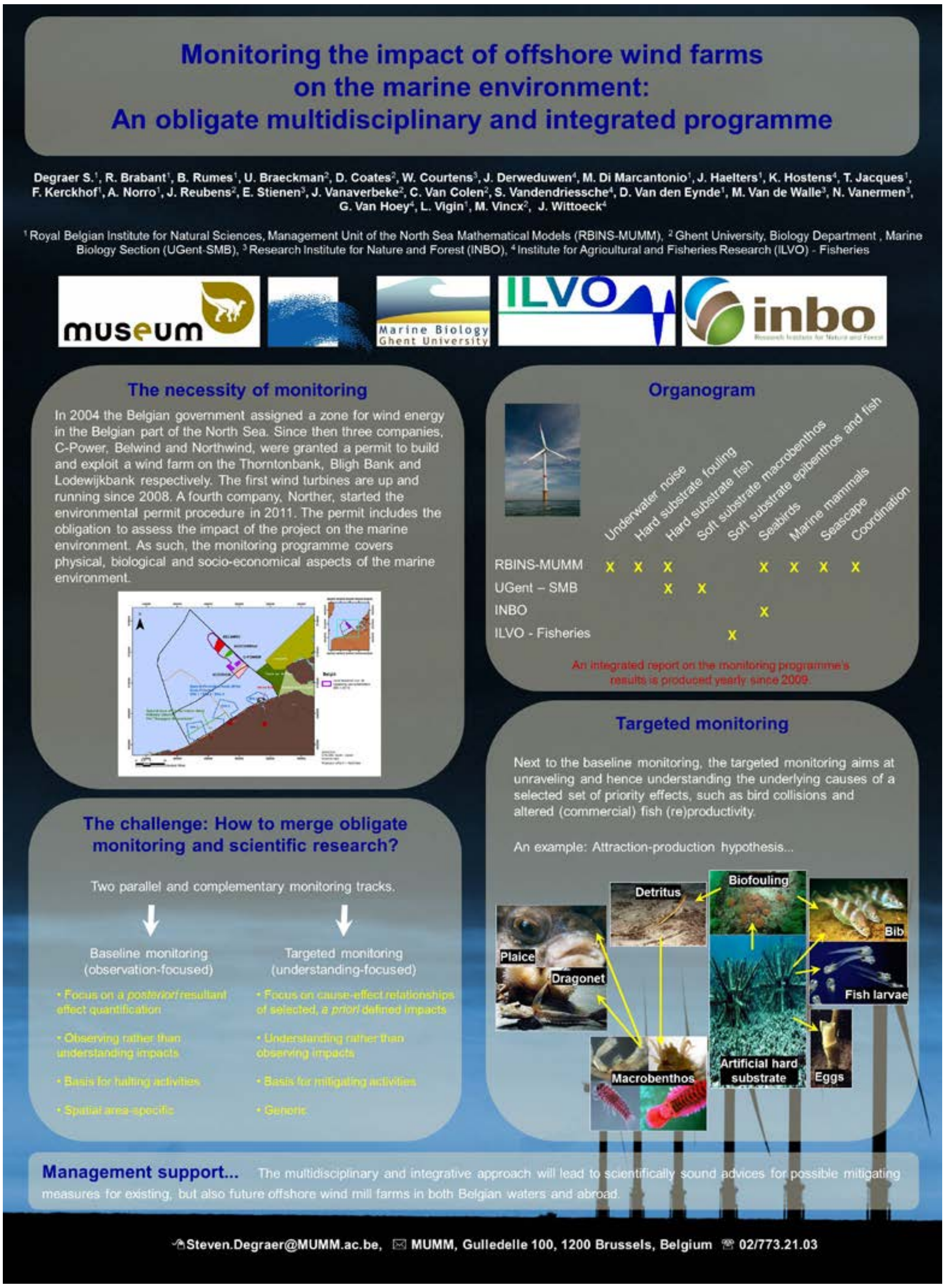



Deltares
Enabling Delta Life
Arjen Boon, Jan van Dalfsen
The effects of offshore wind farms on benthos are not studied as a regular part of monitoring in the Netherlands. This poster explains why we don't care (yet), but also shows why we should care and how to do it.
Windfarm effects on marine benthos
WHO CARES?
Legal obligations: do we care?
1. Habitat Directive: 8 marine habitat types ratified and implemented; LEADING
2. Marine Strategy Framework Directive Biodiversity, Food web, Integrity Seafloor, Invasive Species ratified, not yet implemented, SHOULD BE LEADING
What do we expect: should we care?
• Changes in biodiversity, food web structure?
• Changes in productivity, food web dynamics?
• Changes in physical integrity, condition?
• Stepping stones for invasive species?
Why we don't yet care in The Netherlands
• Habitat directive is leading: No conflicts with SAC's
• No clue what to do with MSFD
How should we care: integrate science and policy
Monitoring and research OWFs: which cause and effect relations are currently being studied in MEP in the NL and abroad?
Preventive and mitigative measures: what can be done to prevent and mitigate negative ecological effects of OWF?
Evaluation and policy development
Knowledge inventory
Synopsis cause-effect relationships: what cause and relationships are possible when building, operating and removing an OWF?
Cumulative effects: which aspects are important when considering cumulation of effects?
Spatial analysis
Licensing
Knowledge gaps
Risk & uncertainty analysis
Overview results monitoring and research OWFs. Which of the cause and effect relationships are the most conspicuous?
Information questions: which monitoring and research questions are most obvious what are the information gaps which are the monitoring and research questions and what are their requirements?
Prioritizing
www.deltares.nl
for more information
info@deltares.nl
www.deltares.nl
address
P.O. box 177
2600 MH Delft, The Netherlands
Telephone
tel.: + 31 (0)88 335 8273
fax: + 31 (0)88 335 8582


Soft-sediment macrobenthos around offshore windfarms in the Belgian Part of the North Sea
Marine Biology Ghent University
Coates Delphine *, Vanaverbeke Jan, Vincx Magda
Ghent University, Biology Department, Marine Biology Section
Introduction
• During 2009 and 2010 two offshore windfarms became functional in the Belgian part of the North Sea.
• Six turbines were installed on the Thorntonbank (C-Power) and 55 on the Bligh Bank (Belwind)
• Both windfarms will be expanded in the coming years and will be accompanied by two other projects (Northwind on the Lodewijkbank and Norher southeast of the Thorntonbank)
Large-scale monitoring
• BACI-design applied with year-0 sampling on the Thorntonbank (2005), Bligh Bank (2008) and Lodewijkbank (2010)
• Monitoring is compulsory for six years after baseline monitoring: 2012 is last compulsory monitoring year for C-Power
• Yearly sampling in and around every concession area + reference sites (Goote Bank, GBC) with a Van Veen grab to detect any long term trends in the soft-sediment macrobenthic communities
• Biotic (total density, biomass, diversity indices) and abiotic factors (total organic matter, median grain size and mud content) are analysed
• Main observation: too early to detect large scale effects?
• 2011: first samples inside the Belwind windfarm with a small vessel → results are being analysed
Targeted/process monitoring
• A small scale sampling strategy was carried out in 2010 around one gravity based wind turbine on the Thorntonbank
• The soft-sediments around turbines can be altered due to (1) previous created pits due to dredging activities (2) organic enrichment (3) changing hydrodynamics and (4) prohibition of beamtrawl fisheries
• Macrobenthic communities are highly dependent of the sedimentological characteristics → do we see a modification?
• Four gradients sampled around the turbine
• Sampling at different distances from the scour protection system (boulders) on every gradient: 1, 7, 15, 25, 50, 100 and 200m
• Air-lift suction device applied with scuba divers at 1 and 7m
• Van Veen grabs taken at 15- 200m
Lanice conchilega
Monocorophium acherusicum
Spiophanes bombyx
Distance from scour protection (m)
Mean Density (ind.m⁻²)
Nephtys cirrosa
Spio goniocephala
Urothoe brevicornis
Lanice conchilega
Spiophanes bombyx
Monocorophium acherusicum
Jassa herdmani
North East
South East
South West
North West
Gradient
• Densities of generally rare macrobenthic species in this sediment type (L. conchilega and M. acherusicum) highly increased (cfr. Large scale monitoring 2005-2010)
• A decline in grain size partition was observed closer to the turbine (1&7m) and on the NW and SW gradients
• In 2011, only Van Veen samples could be collected for the targeted monitoring. First results show a similar trend to 2010 but this time with clearer declining densities from 15m up to 200m
A special thanks to the crew of the RV Belgica, RV Zeeleeuw and all volunteering, scientific divers
* Delphine.coates@ugent.be, Marine Biology Research Group, Krijgslaan 281 Sterre S8, 9000 Ghent, Belgium 09 264 85 17

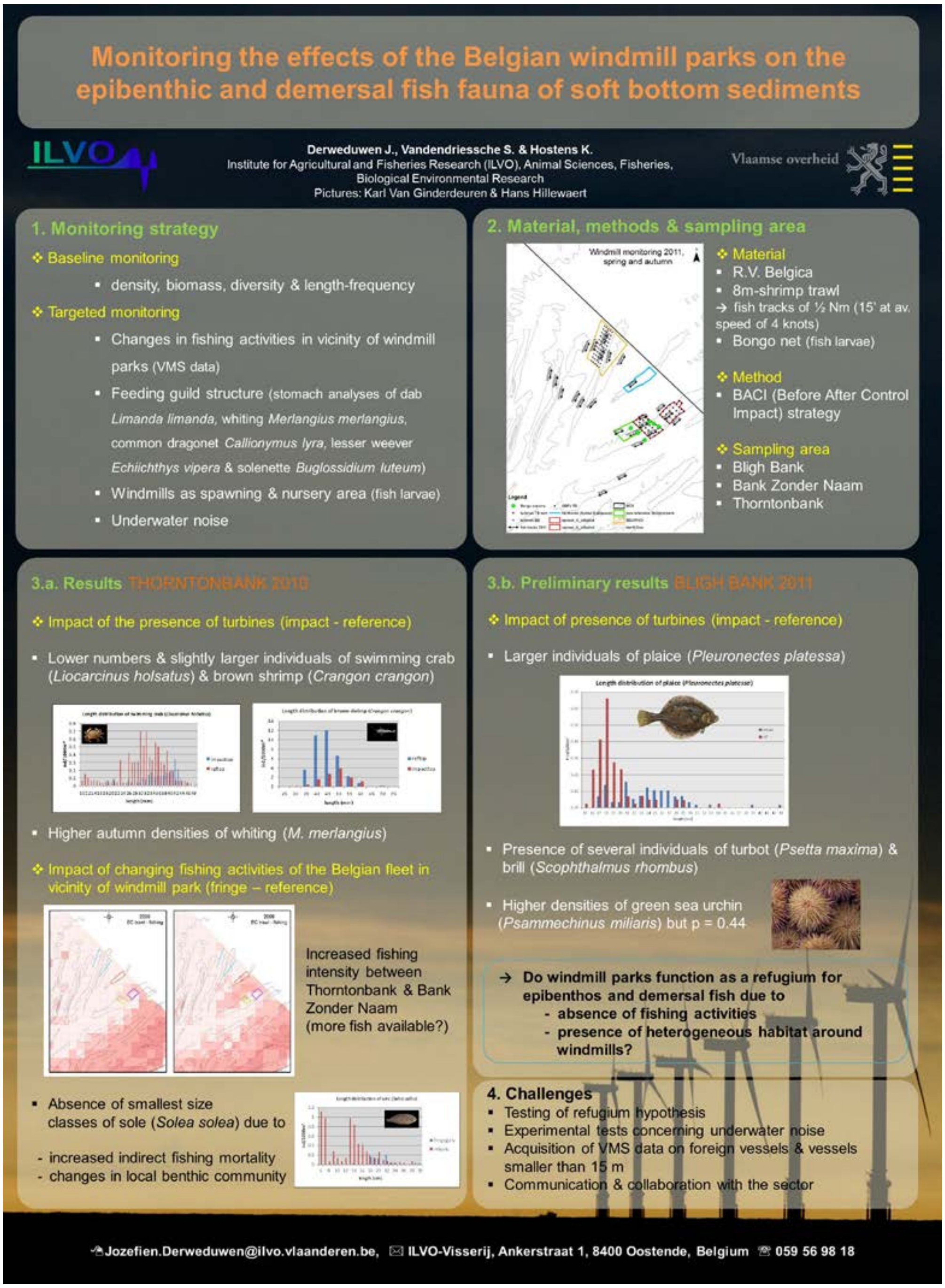


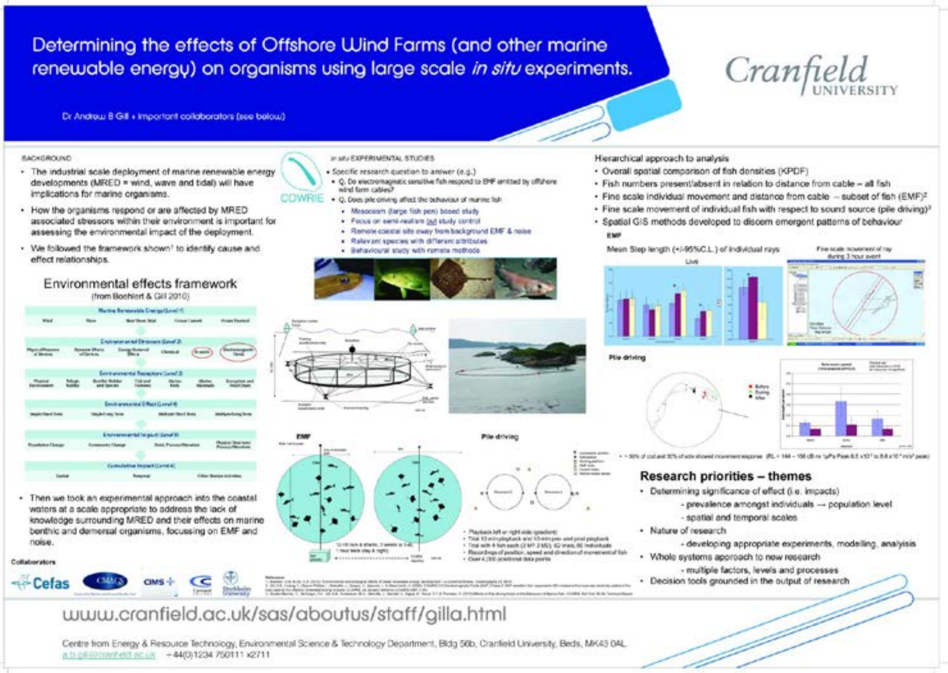
AWI
Wind farm effects on benthos in the German Bight (North Sea)
- from single structures to cumulative effects and beyond -
Jennifer Dannheim
Katharina Reichert
Roland Krone
Manuela Gusky
Lars Gutow
Research on the effects of wind farms on benthos started in 2001 with a monitoring programme around the alpha ventus area (see large map). In 2003, the research platform FINO 1 was built to assess the local small-scale effects of a single foundation. Meso-scale investigations in the wind farm area were initiated with the installation of alpha ventus in 2009. Data collections from environmental impact assessments (EIA) of at least 29 approved wind farm projects (2001-2010) allow for assessing the large-scale cumulative effects in the entire German exclusive economic zone (EEZ).
Effects of a single structure
Project „Ecological research on offshore use of wind energy on research platforms in the North and Baltic Sea" (BeoFINO I 2003-2005, BeoFINO II 2005-2007)
'reef-effect'
biomass export
organic enrichment
species changes
Benthic processes at FINO 1
• Accumulation of up to 6 tons of biomass on the structure
• export of biomass into the surrounding sediment => organic enrichment
• Community changes: ↓ typical soft-bottom species (eg. Spiophanes bombyx, Tellina fabula); ↑ mobile predators (e.g. Eunereis sp., Liocarcinus holsatus)
Effects of one wind farm (alpha ventus)
RAVE RESEARCH AT ALPHA VENTUS
Project: StUKplus-Benthos (2008-2012)
Focus: soft-bottom communities in the wind farm and reference areas (see map left) → Poster of Katharina Reichert et al. "Offshore wind farms and benthos in the German Bight (North Sea)"
Focus: hard-bottom community on the foundations → Poster of Roland Krone et al. "Biofouling, fish and crabs on offshore wind power constructions"
planned
under construction
approved
operational (alpha ventus)
Cumulative impact of offshore wind farms and beyond
StUKplus-Data (2008-2012) and habitat (2011-2014) project
Spatial analysis: Average abundance (N m⁻²) of taxonomic groups in the German EEZ (grid size: 25 km²), N = 4586 stations
Aims of the project
• assess cumulative effects of numerous wind farms on the benthic system; evaluate the standard investigation concept (StUK)
• identify benthic spatial patterns and main drivers for species distribution (examples see left: spatial analysis, right: species distribution modelling)
• provide evaluation criteria for identifying sensitive areas → permit procedures and marine spatial planning
Database
• EIA data are harmonised, quality and validity checked, and analysed in combination with monitoring, research and long-term data
• >9000 EIA and >2100 AWI station entries for environmental data (hydrography, sediment), benthic invertebrates and demersal fish (grab, beam trawl)
habitat information
species information
depth & sediment for each (grid) cell of the raster map
probability of species occurence at each depth and sediment
spatially modelled species distribution
Species distribution modelling:
• environmental factors responsible for species occurrence (presence/absence) were identified by multivariate correlations
• Probability of species occurence was calculated by a binominal logistic regression model
• Model results were calculated for each grid cell (1 km²) based on full-coverage environmental layers


Monitoring the impact of offshore wind farms
on the marine environment:
An obligate multidisciplinary and integrated programme
Degraer S.[1], R. Brabant[1], B. Rumes[1], U. Braeckman[2], D. Coates[2], W. Courtens[3], J. Derweduwen[4], M. Di Marcantonio[1], J. Haelters[1], K. Hostens[4], T. Jacques[1], F. Kerckhof[1], A. Norro[1], J. Reubens[2], E. Stienen[3], J. Vanaverbeke[2], C. Van Colen[2], S. Vandendriessche[4], D. Van den Eynde[1], M. Van de Walle[3], N. Vanermen[3], G. Van Hoey[4], L. Vigin[1], M. Vincx[2], J. Wittoeck[4]
[1] Royal Belgian Institute for Natural Sciences, Management Unit of the North Sea Mathematical Models (RBINS-MUMM), [2] Ghent University, Biology Department , Marine Biology Section (UGent-SMB), [3] Research Institute for Nature and Forest (INBO), [4] Institute for Agricultural and Fisheries Research (ILVO) - Fisheries
museum
Marine Biology Ghent University
ILVO
inbo
The necessity of monitoring
In 2004 the Belgian government assigned a zone for wind energy in the Belgian part of the North Sea. Since then three companies, C-Power, Belwind and Northwind, were granted a permit to build and exploit a wind farm on the Thorntonbank, Bligh Bank and Lodewijkbank respectively. The first wind turbines are up and running since 2008. A fourth company, Norther, started the environmental permit procedure in 2011. The permit includes the obligation to assess the impact of the project on the marine environment. As such, the monitoring programme covers physical, biological and socio-economical aspects of the marine environment.
Organogram

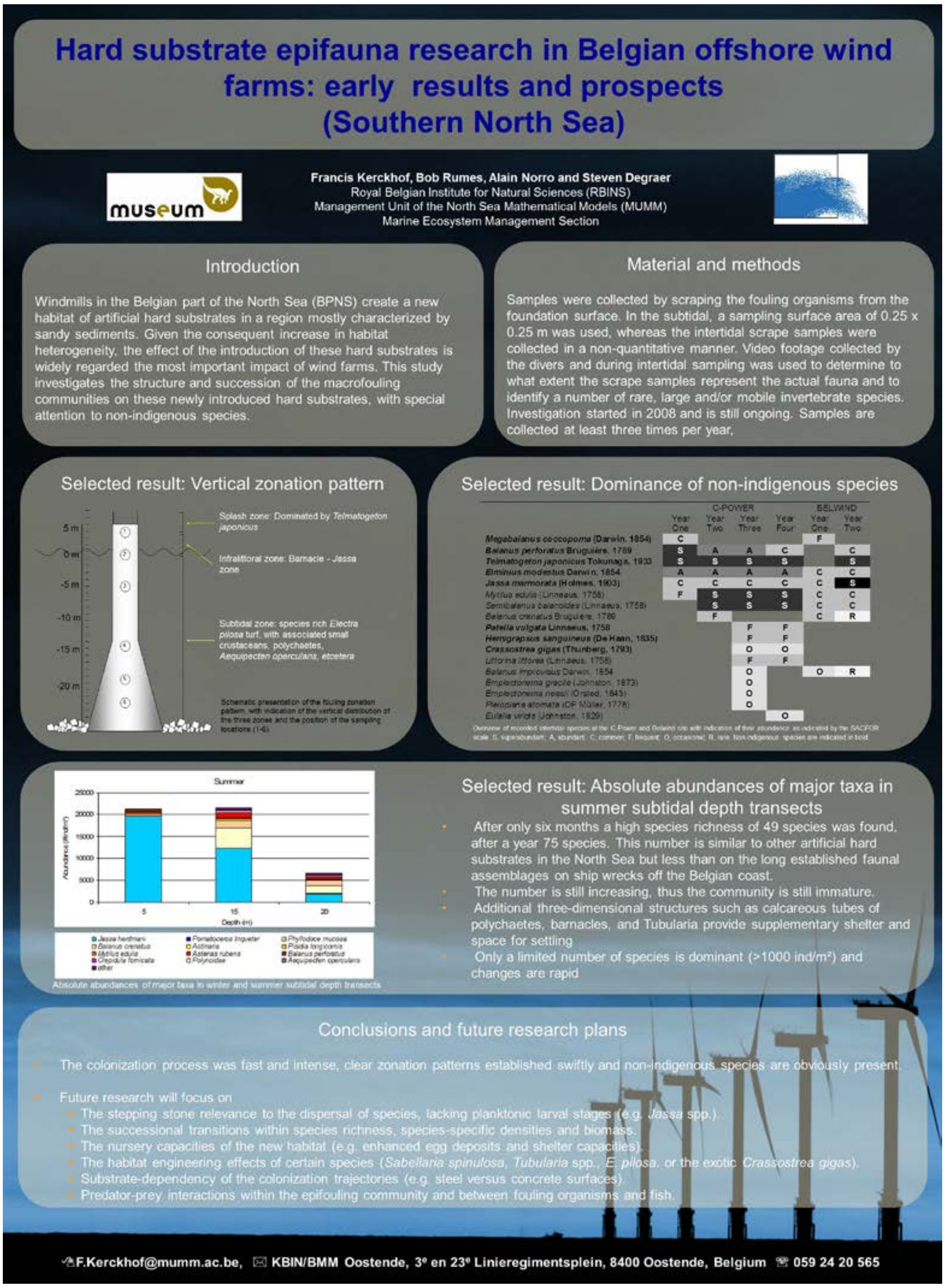
	Underwater noise	Hard substrate fouling	Hard substrate fish	Soft substrate macrobenthos	Soft substrate epibenthos and fish	Seabirds	Marine mammals	Seascape	Coordination
RBINS-MUMM	X	X	X			X	X	X	X
UGent – SMB			X	X					
INBO						X			
ILVO - Fisheries					X				

An integrated report on the monitoring programme's results is produced yearly since 2009.
The challenge: How to merge obligate monitoring and scientific research?
Two parallel and complementary monitoring tracks.
Baseline monitoring (observation-focused)
• Focus on a *posteriori* resultant effect quantification
• Observing rather than understanding impacts
• Basis for halting activities
• Spatial area-specific
Targeted monitoring (understanding-focused)
• Focus on cause-effect relationships of selected, *a priori* defined impacts
• Understanding rather than observing impacts
• Basis for mitigating activities
• Generic
Targeted monitoring
Next to the baseline monitoring, the targeted monitoring aims at unraveling and hence understanding the underlying causes of a selected set of priority effects, such as bird collisions and altered (commercial) fish (re)productivity.
An example: Attraction-production hypothesis...
Detritus
Biofouling
Bib
Plaice
Dragonet
Fish larvae
Artificial hard substrate
Macrobenthos
Eggs
Management support... The multidisciplinary and integrative approach will lead to scientifically sound advices for possible mitigating measures for existing, but also future offshore wind mill farms in both Belgian waters and abroad.
Steven.Degraer@MUMM.ac.be, MUMM, Gulledelle 100, 1200 Brussels, Belgium 02/773.21.03


Monitoring the effects of the Belgian windmill parks on the epibenthic and demersal fish fauna of soft bottom sediments
ILVO
Derweduwen J., Vandendriessche S. & Hostens K.
Institute for Agricultural and Fisheries Research (ILVO), Animal Sciences, Fisheries, Biological Environmental Research
Pictures: Karl Van Ginderdeuren & Hans Hillewaert
Vlaamse overheid
1. Monitoring strategy
Baseline monitoring
density, biomass, diversity & length-frequency
Targeted monitoring
Changes in fishing activities in vicinity of windmill parks (VMS data)
Feeding guild structure (stomach analyses of dab Limanda limanda, whiting Merlangius merlangius, common dragonet Callionymus lyra, lesser weever Echiichthys vipera & solenette Buglossidium luteum)
Windmills as spawning & nursery area (fish larvae)
Underwater noise
2. Material, methods & sampling area
Windmill monitoring 2011, spring and autumn
Material
R.V. Belgica
8m-shrimp trawl
→ fish tracks of ½ Nm (15' at av. speed of 4 knots)
Bongo net (fish larvae)
Method
BACI (Before After Control Impact) strategy
Sampling area
Bligh Bank
Bank Zonder Naam
Thorntonbank
3.a. Results THORNTONBANK 2010
Impact of the presence of turbines (impact - reference)
Lower numbers & slightly larger individuals of swimming crab (Liocarcinus holsatus) & brown shrimp (Crangon crangon)
Higher autumn densities of whiting (M. merlangius)
Impact of changing fishing activities of the Belgian fleet in vicinity of windmill park (fringe – reference)
Increased fishing intensity between Thorntonbank & Bank Zonder Naam (more fish available?)
Absence of smallest size classes of sole (Solea solea) due to
- increased indirect fishing mortality
- changes in local benthic community
3.b. Preliminary results BLIGH BANK 2011
Impact of presence of turbines (impact - reference)
Larger individuals of plaice (Pleuronectes platessa)
Length distribution of plaice (Pleuronectes platessa)
Presence of several individuals of turbot (Psetta maxima) & brill (Scophthalmus rhombus)
Higher densities of green sea urchin (Psammechinus miliaris) but p = 0.44
→ Do windmill parks function as a refugium for epibenthos and demersal fish due to
- absence of fishing activities
- presence of heterogeneous habitat around windmills?
4. Challenges
Testing of refugium hypothesis
Experimental tests concerning underwater noise
Acquisition of VMS data on foreign vessels & vessels smaller than 15 m
Communication & collaboration with the sector
Jozefien.Derweduwen@ilvo.vlaanderen.be, ILVO-Visserij, Ankerstraat 1, 8400 Oostende, Belgium 059 56 98 18



Determining the effects of Offshore Wind Farms (and other marine renewable energy) on organisms using large scale in situ experiments.
Cranfield UNIVERSITY
Dr Andrew B Gill + important collaborators (see below)
BACKGROUND
• The industrial scale deployment of marine renewable energy developments (MRED = wind, wave and tidal) will have implications for marine organisms.
• How the organisms respond or are affected by MRED associated stressors within their environment is important for assessing the environmental impact of the deployment.
• We followed the framework shown1 to identify cause and effect relationships.
Environmental effects framework
(from Boehlert & Gill 2010)
• Then we took an experimental approach into the coastal waters at a scale appropriate to address the lack of knowledge surrounding MRED and their effects on marine benthic and demersal organisms, focussing on EMF and noise.
Collaborators
Cefas
CMACS
CIMS
Stockholm University
COWRIE
in situ EXPERIMENTAL STUDIES
• Specific research question to answer (e.g.)
• Q. Do electromagnetic sensitive fish respond to EMF emitted by offshore wind farm cables?
• Q. Does pile driving affect the behaviour of marine fish
• Mesocosm (large fish pen) based study
• Focus on semi-realism but study control
• Remote coastal site away from background EMF & noise
• Relevant species with different attributes
• Behavioural study with remote methods
EMF
Pile driving
• Playback left or right side (gradient)
• Total 10 min playback and 10 min pre and post playback
• Trial with 4 fish each (2 M? 2 M2) 42 trials, 66 individuals
• Recordings of position, speed and direction of movement of fish
• Over 4,000 positional data points
Hierarchical approach to analysis
• Overall spatial comparison of fish densities (KPDF)
• Fish numbers present/absent in relation to distance from cable – all fish
• Fine scale individual movement and distance from cable – subset of fish (EMF)2
• Fine scale movement of individual fish with respect to sound source (pile driving)3
• Spatial GIS methods developed to discern emergent patterns of behaviour
EMF
Mean Step length (+/-95%C.L.) of individual rays
Live
Fine scale movement of ray during 3 hour event
Pile driving
Before
During
After
Research priorities – themes
• Determining significance of effect (i.e. impacts)
- prevalence amongst individuals → population level
- spatial and temporal scales
• Nature of research
- developing appropriate experiments, modelling, analyisis
• Whole systems approach to new research
- multiple factors, levels and processes
• Decision tools grounded in the output of research
www.cranfield.ac.uk/sas/aboutus/staff/gilla.html
Centre from Energy & Resource Technology, Environmental Science & Technology Department, Bldg 56b, Cranfield University, Beds, MK43 0AL
a.b.gill@cranfield.ac.uk +44(0)1234 750111 x2711


Hard substrate epifauna research in Belgian offshore wind farms: early results and prospects (Southern North Sea)
Francis Kerckhof, Bob Rumes, Alain Norro and Steven Degraer
Royal Belgian Institute for Natural Sciences (RBINS)
Management Unit of the North Sea Mathematical Models (MUMM)
Marine Ecosystem Management Section
museum
Introduction
Windmills in the Belgian part of the North Sea (BPNS) create a new habitat of artificial hard substrates in a region mostly characterized by sandy sediments. Given the consequent increase in habitat heterogeneity, the effect of the introduction of these hard substrates is widely regarded the most important impact of wind farms. This study investigates the structure and succession of the macrofouling communities on these newly introduced hard substrates, with special attention to non-indigenous species.
Material and methods
Samples were collected by scraping the fouling organisms from the foundation surface. In the subtidal, a sampling surface area of 0.25 x 0.25 m was used, whereas the intertidal scrape samples were collected in a non-quantitative manner. Video footage collected by the divers and during intertidal sampling was used to determine to what extent the scrape samples represent the actual fauna and to identify a number of rare, large and/or mobile invertebrate species. Investigation started in 2008 and is still ongoing. Samples are collected at least three times per year.
Selected result: Vertical zonation pattern
5 m
0 m
-5 m
-10 m
-15 m
-20 m
Splash zone: Dominated by Telmatogeton japonicus
Infralittoral zone: Barnacle - Jassa zone
Subtidal zone: species rich Electra pilosa turf, with associated small crustaceans, polychaetes, Aequipecten opercularis, etcetera
Schematic presentation of the fouling zonation pattern, with indication of the vertical distribution of the three zones and the position of the sampling locations (1-6)
Selected result: Dominance of non-indigenous species
C-POWER
BELWIND
Year One
Year Two
Year Three
Year Four
Megabalanus coccopoma (Darwin, 1854)
Balanus perforatus Bruguière, 1789
Telmatogeton japonicus Tokunaga, 1933
Elminius modestus Darwin, 1854
Jassa marmorata (Holmes, 1903)
Mytilus edulis (Linneaus, 1758)
Semibalanus balanoides (Linnaeus, 1758)
Balanus crenatus Bruguière, 1789
Patella vulgata Linnaeus, 1758
Hemigrapsus sanguineus (De Haan, 1835)
Crassostrea gigas (Thunberg, 1793)
Littorina littorea (Linnaeus, 1758)
Balanus improvisus Darwin, 1854
Emplectonema gracile (Johnston, 1873)
Emplectonema neesii (Ørsted, 1843)
Pleioplana atomata (OF Müller, 1776)
Eulalia viridis (Johnston, 1829)
Summer
Abundance (ind/m²)
Depth (m)
Jassa herdmani
Balanus crenatus
Mytilus edulis
Crepidula fornicata
other
Pomatoceros triqueter
Actinaria
Asterias rubens
Polynoidae
Phyllodoce mucosa
Polydora longicornis
Balanus perforatus
Aequipecten opercularis
Absolute abundances of major taxa in winter and summer subtidal depth transects
Selected result: Absolute abundances of major taxa in summer subtidal depth transects
After only six months a high species richness of 49 species was found, after a year 75 species. This number is similar to other artificial hard substrates in the North Sea but less than on the long established faunal assemblages on ship wrecks off the Belgian coast.
The number is still increasing, thus the community is still immature.
Additional three-dimensional structures such as calcareous tubes of polychaetes, barnacles, and Tubularia provide supplementary shelter and space for settling
Only a limited number of species is dominant (>1000 ind/m²) and changes are rapid
Conclusions and future research plans
The colonization process was fast and intense, clear zonation patterns established swiftly and non-indigenous species are obviously present.
Future research will focus on
The stepping stone relevance to the dispersal of species, lacking planktonic larval stages (e.g. Jassa spp.).
The successional transitions within species richness, species-specific densities and biomass.
The nursery capacities of the new habitat (e.g. enhanced egg deposits and shelter capacities).
The habitat engineering effects of certain species (Sabellaria spinulosa, Tubularia spp., E. pilosa, or the exotic Crassostrea gigas).
Substrate-dependency of the colonization trajectories (e.g. steel versus concrete surfaces).
Predator-prey interactions within the epifouling community and between fouling organisms and fish.
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Planned Offshore Wind Farms in the Polish Marine Areas and Benthic Communities

Urszula Janas, Tomasz Zarzycki, Anna Dziubińska, Institute of Oceanography, University of Gdańsk
Jan Warzocha, National Marine Fisheries Research Institute, Poland

Introduction

There are no offshore wind farms in the Polish Marine Areas but three potential locations were proposed. These areas are situated on sandy or mixed sediment bottoms inhabited by benthic communities which may be affected by the future investments. Moreover, new artificial constructions in the Baltic Sea will create convenient substrate for hard bottom communities.

The aim of the work was to find out:

- what types of soft bottom benthic communities inhabit areas designed for the offshore wind farms,
- what species and benthic communities will occupy the surface of the underwater constructions,
- what is the potential effect of the offshore wind farms on the benthic fauna,
- if there is any ongoing monitoring programs nearby the areas of planned offshore wind farms.

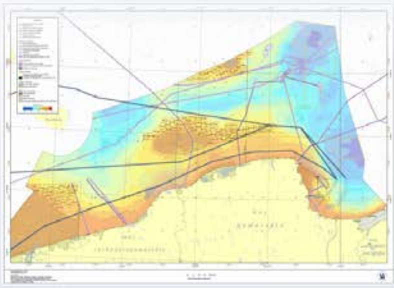


Fig. 1. Potential areas for the location of the offshore wind farms in the Polish Marine Areas (red edge sub-areas)
(source: Maritime Institute in Gdańsk)

Where offshore wind farms are planned?

- They have to be located at least 12 nautical miles (22,2 km) from the seashore. Max. area 3590 km^2.
- Technical potential around 35 GW (was limited to 20 GW because of distance from the seashore, stil could be corrected with the exclusion zones (protected areas within Natura2000 network) that reduces the potential down to 7.5 GW).
- Till now 109 sub-areas were choosen with total area 2503.45 km^2.

Soft bottom benthic communities

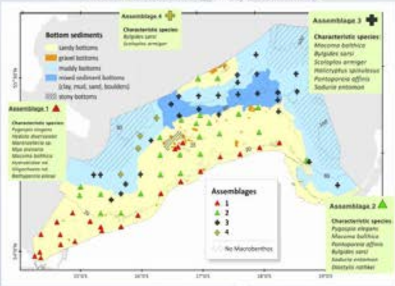


Fig. 2. Type of sediment and distribution of the benthic communities
(source: National Marine Fisheries Research Institute)

Soft sediment benthic communities at the areas designed for offshore wind farms are mainly composed of a few species (usually below 10). The most frequent and most abundant are: *Pygospio elegans*, *Macoma balthica* and *Pontoporeia affinis*.

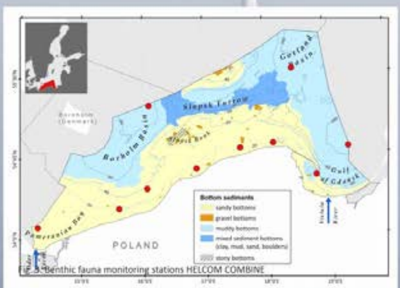


Fig. 3. Benthic fauna monitoring stations HELCOM COMBINE

Hard bottom benthic communities

Artificial substrate was fouled by benthic community consisted of 34 taxa (26 animals and 8 algae) during the experiments in the Gulf of Gdańsk (Dziubińska 2011). *Balanus improvisus*, *Mytilus trossulus* and *Gonothyrea loveni* were the first invertebrates which appeared on the substrate. These species were present at all study sites (3) and during the whole studied period (max. 484 days).

The largest percent coverage and biomass was found in summer. The maximum biomass (3980 g dry mass m^{-2}) was observed after 60 days of experiment at HelPeninsula Station (5 m depth).

Phot. 1. Hard bottom community dominated by *Mytilus trossulus* (6 months old) Gdynia 2005 (Phot. Dziubińska).

Phot. 2. Hard bottom community dominated by *Balanus improvisus* (3 months old) Gdynia 2009 (Phot. Dziubińska).

Monitoring

In Poland there are two monitoring programs taking into account benthic fauna:

- HELCOM COMBINE – 10 benthic sites sampled every year.
- National Monitoring Program – several dozen sites in very coastal and transitional waters under WFD.

There are no monitoring stations close to the areas of planned offshore wind farms.

Artificial hard substrate is a good place for non-indigenous species

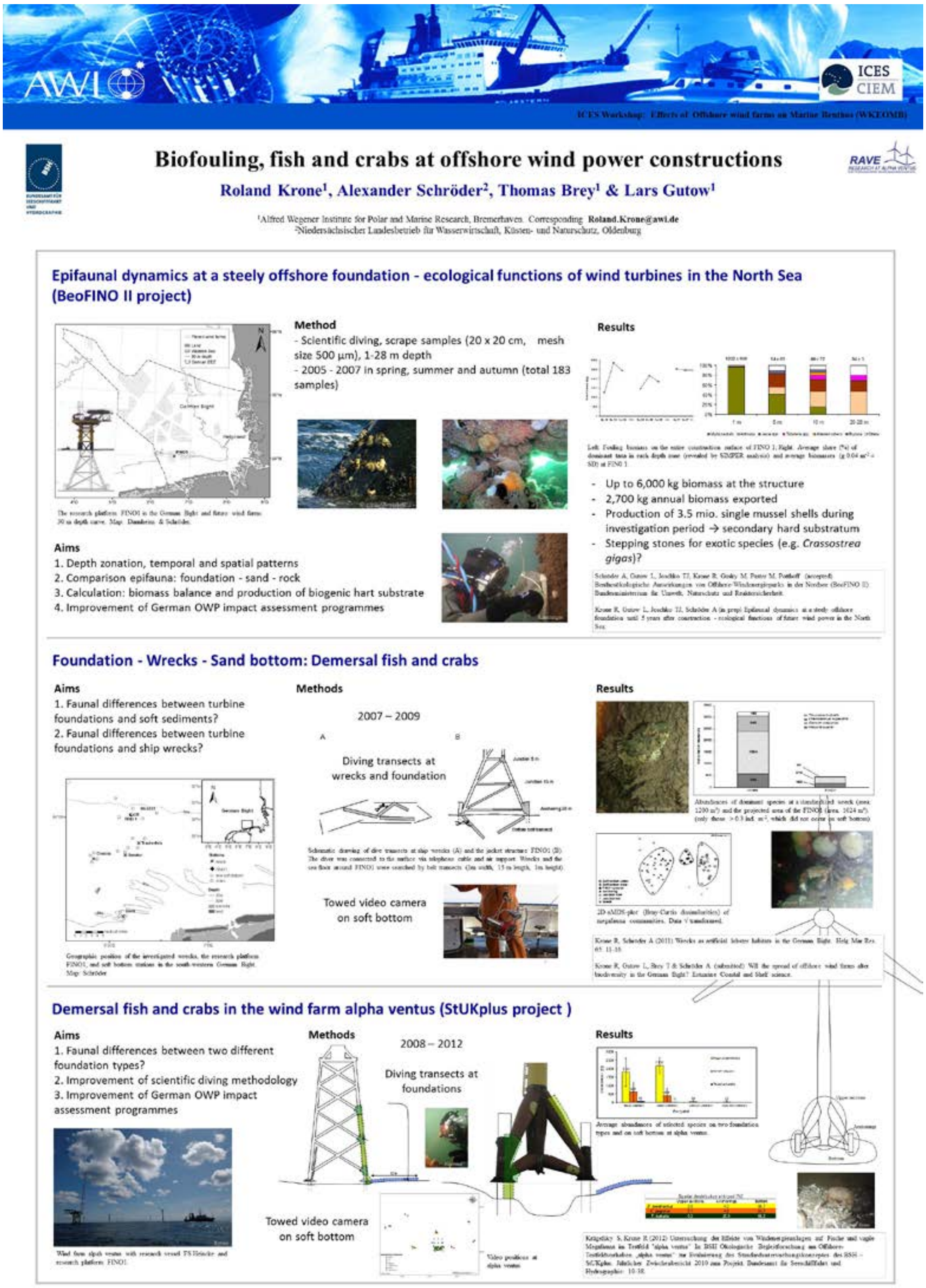
Underwater constructions are very good substrates for non-indigenous species. Four out of the fourteen non-indigenous species observed in the southern Baltic Sea prefer hard bottom: *Cordylophora caspia, Balanus improvisus, Palaemon elegans, Mytilopsis leucophaeata*

Phot. 3,4,5,6. Non indigenous specis: *Cordylophora caspia, Balanus improvisus, Palaemon elegans, Mytilopsis leucophaeata*

Conclusions

Future offshore wind farms will affect the benthic communities by:

- local and permanent destruction of the soft bottom habitat and the present benthic community,
- creating a new substrate convenient for the hard bottom benthic communities. This new hard substrate might support appearance of non-indigenous species.


AWI
ICES CIEM
ICES Workshop: Effects of Offshore wind farms on Marine Benthos (WKEOMB)
Biofouling, fish and crabs at offshore wind power constructions
RAVE
Roland Krone[1], Alexander Schröder[2], Thomas Brey[1] & Lars Gutow[1]
[1]Alfred Wegener Institute for Polar and Marine Research, Bremerhaven. Corresponding: Roland.Krone@awi.de
[2]Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz, Oldenburg
Epifaunal dynamics at a steely offshore foundation - ecological functions of wind turbines in the North Sea (BeoFINO II project)
Method
- Scientific diving, scrape samples (20 x 20 cm, mesh size 500 µm), 1-28 m depth
- 2005 - 2007 in spring, summer and autumn (total 183 samples)
Results
The research platform FINO1 in the German Bight and future wind farms. 30 m depth curve. Map: Dannheim & Schröder
Left: Fouling biomass on the entire construction surface of FINO 1; Right: Average share (%) of dominant taxa in each depth zone (revealed by SIMPER analysis) and average biomasses (g 0.04 m⁻² ± SD) at FINO 1
- Up to 6,000 kg biomass at the structure
- 2,700 kg annual biomass exported
- Production of 3.5 mio. single mussel shells during investigation period → secondary hard substratum
- Stepping stones for exotic species (e.g. Crassostrea gigas)?
Aims
1. Depth zonation, temporal and spatial patterns
2. Comparison epifauna: foundation - sand - rock
3. Calculation: biomass balance and production of biogenic hart substrate
4. Improvement of German OWP impact assessment programmes
Foundation - Wrecks - Sand bottom: Demersal fish and crabs
Aims
1. Faunal differences between turbine foundations and soft sediments?
2. Faunal differences between turbine foundations and ship wrecks?
Methods
2007 – 2009
A
B
Diving transects at wrecks and foundation
Towed video camera on soft bottom
Results
Geographic position of the investigated wrecks, the research platform FINO1, and soft bottom stations in the south-western German Bight. Map: Schröder
Schematic drawing of dive transects at ship wrecks (A) and the jacket structure FINO1 (B). The diver was connected to the surface via telephone cable and air support. Wrecks and the sea floor around FINO1 were searched by belt transects (2m width, 15 m length, 1m height).
Abundances of dominant species at a standardized wreck (area: 1200 m²) and the projected area of the FINO1 (area: 1024 m²). (only those > 0.3 ind. m⁻², which did not occur on soft bottom)
2D nMDS-plot (Bray-Curtis dissimilarities) of megafauna communities. Data √ transformed.
Demersal fish and crabs in the wind farm alpha ventus (StUKplus project)
Aims
1. Faunal differences between two different foundation types?
2. Improvement of scientific diving methodology
3. Improvement of German OWP impact assessment programmes
Methods
2008 – 2012
Diving transects at foundations
Towed video camera on soft bottom
Results
Average abundances of selected species on two foundation types and on soft bottom at alpha ventus.
Wind farm alpha ventus with research vessel FS Heincke and research platform FINO1.
Video positions at alpha ventus

Effects of wind farm constructions on benthic and fish communities in Danish waters– experiences from the Horns Rev wind park

Simon B. Leonhard[1] and Claus Stenberg[2]

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Effect of the Horns Rev 1 Offshore Wind Farm (North Sea) on Fish Communities

This study presents results from a field experiment at the Horns Rev Offshore Wind Farm 1 (Fig. 1), one of the world's largest offshore wind farms established in late 2002. The establishment of wind farms is hypothesized to positively impact sandy seabed benthic communities, fish abundance and fish community structures by increasing habitat heterogeneity and through exclusion of trawling activities. Baseline surveys were carried out in September 2001 and March 2002 (prior to construction). Seven years later surveys using the same design were conducted to analyze changes in fish community structure, spatial distribution and changes in sandeel assemblages. Surveys included multi-mesh gillnets targeting semi-pelagic and demersal (bottom-dwelling) species and acoustic surveys targeting pelagic and demersal fish. This study has been published by Leonhard et al. (2011).

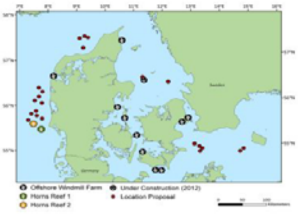

Fig. 1. Location of Denmark's offshore wind farms in operation and proposed locations for new farms.

Increased species richness

The introduction of hard substrate and greater seabed complexity resulted in minor changes in the fish community and species diversity. We observed changes in densities of *whiting* (*Merlangius merlangus*) and *dab* (*Limanda limanda*), but not beyond the general trend of these fish populations in the North Sea (Fig. 2). No significant changes in abundance or distribution of pelagic and demersal fish were found in the acoustic surveys. The introduction of hard bottom substrate resulted in higher species diversity close to each turbine with a distinct spatial distribution, most pronounced in autumn (Fig. 3). New reef habitat fish such as *goldsinny wrasse* (*Ctenolabrus rupestris*), *viviparous eelpout* (*Zoarces viviparous*) and *lumpsucker* (*Cyclopterus lumpus*) were found on the introduced reef area. Species richness and abundance was lower in spring compared to autumn.

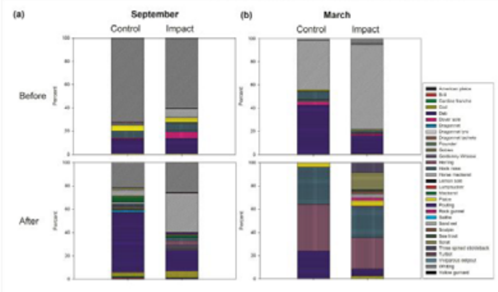

Fig. 2. Species distribution in September (autumn) (a) and March (spring) (b) before and after the wind farm construction in the control and impact areas

Sandeel communities

Horns Rev is a habitat for sandeels. The results revealed no indication that the wind farm had a detrimental long-term effect on the overall occurrence of sandeels. However, a short-term effect was detected in March 2004, mainly due to a temporary increase in juveniles of the *greater sandeel* (*Hyperoplus lanceolatus*), which completely dominated the sandeel community at the Horns Rev area. This study indicates that wind farms represent neither a threat nor a direct benefit to sand dwelling sandeels in near-shore areas, although the recruitment of *greater sandeel*, which are self reproducing in the Horns Reef area, might benefit from the exclusion of fisheries in the wind farm area.

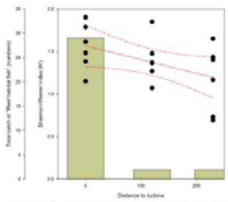

Fig. 3. Total cumulated catch of reef habitat fish species (bar plot) and Shannon-Wiener diversity index (scatter plot) related to distance to turbine foundations in September after the construction of Horns Rev 1.

Effect of the Horns Rev 1 Offshore Wind Farm (North Sea) on Benthic Communities

Results from the environmental monitoring programme on the development of epifouling communities on the introduced sub-surface wind turbine structures at Horns Rev Offshore Wind Farm from 2003 to 2005 showed an increase in biomass of available food items for fish and seabirds of approximately 50 times compared to the biomass of the native infauna community. The epifouling community on monopiles and scour protection differed significantly from the infauna community and was dominated by a few species (Fig. 4). These species including *Jassa marmorata* and *Caprella mutica* not previously recorded in Danish Waters made up more than 89% of the total abundance and biomass recorded. No significant changes in the infauna *Goniadella-Spisula* community was found due to the establishment of the wind farm. This study has been published by Leonhard and Pedersen (2006).

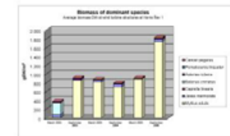

Fig. 4. Increase in biomass of epifouling dominants at the turbine foundations from 2003 to 2005.

Increase in biomass and increased abundance of edible crab (*Cancer pagurus*).

Increase in biomass was mainly due to the settlement and growth of common mussels (*Mytilus edulis*) primarily on the monopile foundations (Fig. 4). Also, an significant increase in the biomass of the commercial important edible crab settled on the wind turbine structures as larvae and juveniles was recorded (Fig 5). Furthermore, in 2009, the number of adult crabs caught in crab pots placed on the sandy seabed has shown to increase towards the turbine foundations.

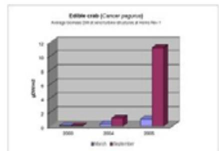

Fig. 5. Increase in biomass of edible crab at the turbine foundations from 2003 to 2005.

References:

Leonhard, S.B. and Pedersen, J. 2006 . Benthic communities at Horns Rev. Before, during and after construction of Horns Rev Offshore Wind Farm. Final report. Commissioned by Vattenfall Vindkraft A/S. pp. 1-187.

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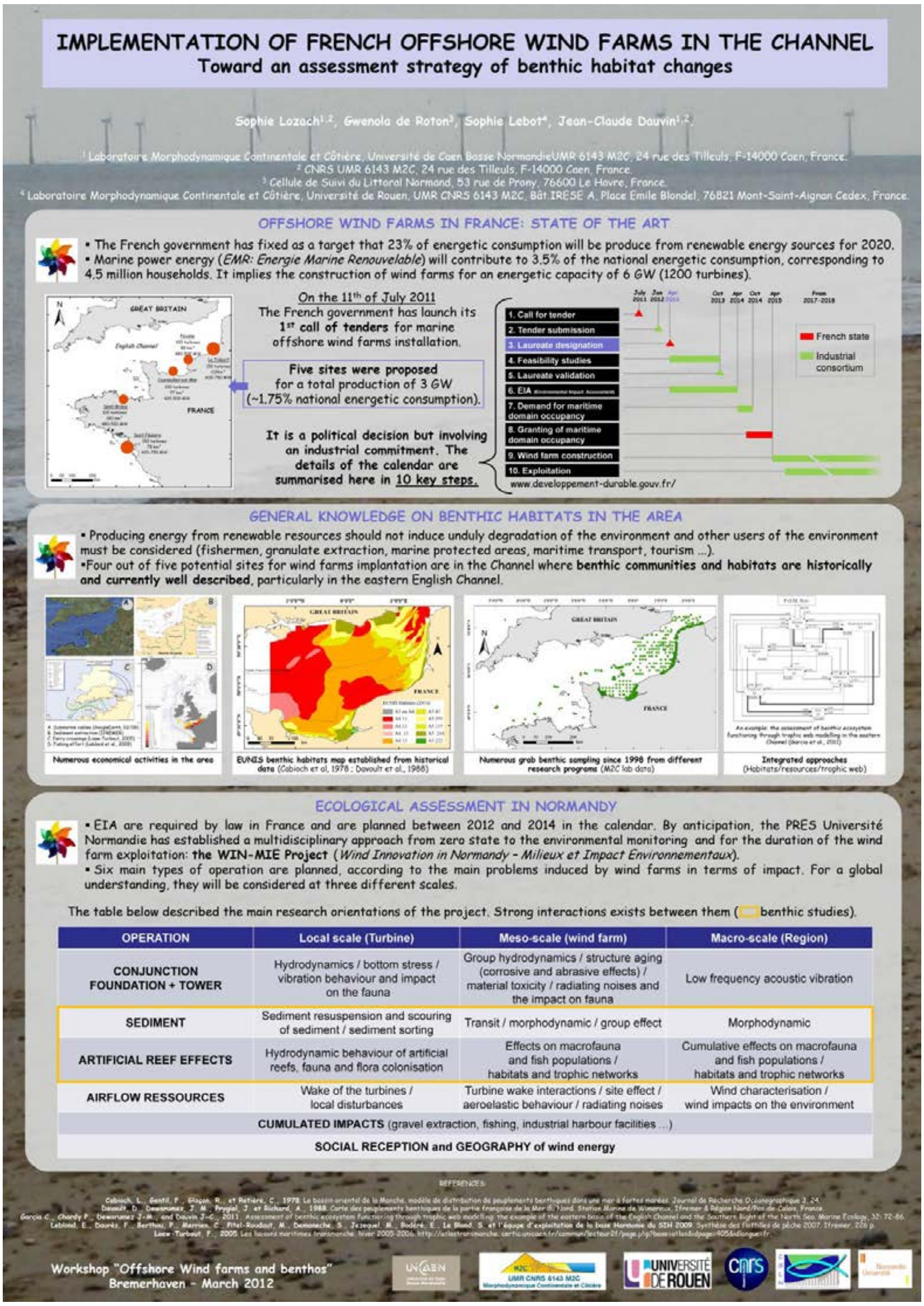
Acknowledgements:

We like to thank the Environmental Group consisting of representatives from the Danish Nature Agency, the Danish Energy Authority, Vattenfall Vindkraft A/S and DONG Energy A/S who has organized the environmental studies financed through the PSO (Public Service Obligation) programme. We thank Christian Mohn (Aarhus University) for supporting the poster editing process.


IMPLEMENTATION OF FRENCH OFFSHORE WIND FARMS IN THE CHANNEL
Toward an assessment strategy of benthic habitat changes
Sophie Lozach[1,2], Gwenola de Roton[3], Sophie Lebot[4], Jean-Claude Dauvin[1,2].
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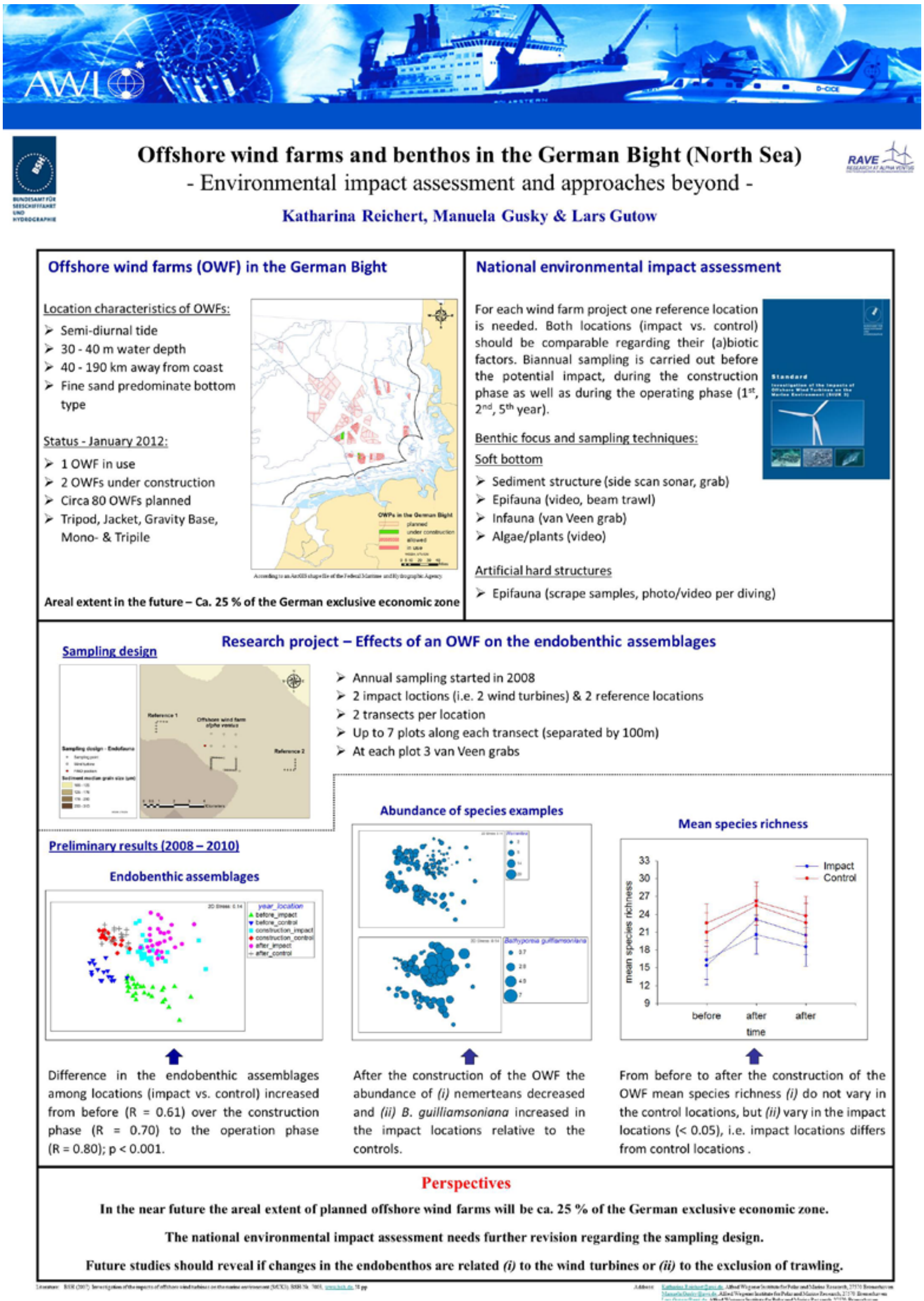
[2] CNRS UMR 6143 M2C, 24 rue des Tilleuls, F-14000 Caen, France.
[3] Cellule de Suivi du Littoral Normand, 53 rue de Prony, 76600 Le Havre, France.
[4] Laboratoire Morphodynamique Continentale et Côtière, Université de Rouen, UMR CNRS 6143 M2C, Bât.IRESE A, Place Emile Blondel, 76821 Mont-Saint-Aignan Cedex, France.
OFFSHORE WIND FARMS IN FRANCE: STATE OF THE ART
• The French government has fixed as a target that 23% of energetic consumption will be produce from renewable energy sources for 2020.
• Marine power energy (EMR: Energie Marine Renouvelable) will contribute to 3.5% of the national energetic consumption, corresponding to 4.5 million households. It implies the construction of wind farms for an energetic capacity of 6 GW (1200 turbines).
GREAT BRITAIN
FRANCE
On the 11th of July 2011
The French government has launch its 1st call of tenders for marine offshore wind farms installation.
Five sites were proposed for a total production of 3 GW (~1.75% national energetic consumption).
It is a political decision but involving an industrial commitment. The details of the calendar are summarised here in 10 key steps.
1. Call for tender
2. Tender submission
3. Laureate designation
4. Feasibility studies
5. Laureate validation
6. EIA
7. Demand for maritime domain occupancy
8. Granting of maritime domain occupancy
9. Wind farm construction
10. Exploitation
www.developpement-durable.gouv.fr/
French state
Industrial consortium
GENERAL KNOWLEDGE ON BENTHIC HABITATS IN THE AREA
• Producing energy from renewable resources should not induce unduly degradation of the environment and other users of the environment must be considered (fishermen, granulate extraction, marine protected areas, maritime transport, tourism ...).
•Four out of five potential sites for wind farms implantation are in the Channel where benthic communities and habitats are historically and currently well described, particularly in the eastern English Channel.
Numerous economical activities in the area
EUNIS benthic habitats map established from historical data (Cabioch et al, 1978 ; Davoult et al., 1988)
Numerous grab benthic sampling since 1998 from different research programs (M2C lab data)
Integrated approaches (Habitats/resources/trophic web)
ECOLOGICAL ASSESSMENT IN NORMANDY
• EIA are required by law in France and are planned between 2012 and 2014 in the calendar. By anticipation, the PRES Université Normandie has established a multidisciplinary approach from zero state to the environmental monitoring and for the duration of the wind farm exploitation: the WIN-MIE Project (Wind Innovation in Normandy - Milieux et Impact Environnementaux).
• Six main types of operation are planned, according to the main problems induced by wind farms in terms of impact. For a global understanding, they will be considered at three different scales.
The table below described the main research orientations of the project. Strong interactions exists between them (benthic studies).
OPERATION | Local scale (Turbine) | Meso-scale (wind farm) | Macro-scale (Region)
CONJUNCTION FOUNDATION + TOWER | Hydrodynamics / bottom stress / vibration behaviour and impact on the fauna | Group hydrodynamics / structure aging (corrosive and abrasive effects) / material toxicity / radiating noises and the impact on fauna | Low frequency acoustic vibration
SEDIMENT | Sediment resuspension and scouring of sediment / sediment sorting | Transit / morphodynamic / group effect | Morphodynamic
ARTIFICIAL REEF EFFECTS | Hydrodynamic behaviour of artificial reefs, fauna and flora colonisation | Effects on macrofauna and fish populations / habitats and trophic networks | Cumulative effects on macrofauna and fish populations / habitats and trophic networks
AIRFLOW RESSOURCES | Wake of the turbines / local disturbances | Turbine wake interactions / site effect / aeroelastic behaviour / radiating noises | Wind characterisation / wind impacts on the environment
CUMULATED IMPACTS (gravel extraction, fishing, industrial harbour facilities ...)
SOCIAL RECEPTION and GEOGRAPHY of wind energy
REFERENCES
Workshop "Offshore Wind farms and benthos"
Bremerhaven - March 2012
UMR CNRS 6143 M2C
UNIVERSITÉ DE ROUEN
CNRS


AWI
Offshore wind farms and benthos in the German Bight (North Sea)
- Environmental impact assessment and approaches beyond -
Katharina Reichert, Manuela Gusky & Lars Gutow
BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE
RAVE
Offshore wind farms (OWF) in the German Bight
Location characteristics of OWFs:
Semi-diurnal tide
30 - 40 m water depth
40 - 190 km away from coast
Fine sand predominate bottom type
Status - January 2012:
1 OWF in use
2 OWFs under construction
Circa 80 OWFs planned
Tripod, Jacket, Gravity Base, Mono- & Tripile
OWFs in the German Bight
planned
under construction
allowed
in use
Areal extent in the future – Ca. 25 % of the German exclusive economic zone
National environmental impact assessment
For each wind farm project one reference location is needed. Both locations (impact vs. control) should be comparable regarding their (a)biotic factors. Biannual sampling is carried out before the potential impact, during the construction phase as well as during the operating phase (1st, 2nd, 5th year).
Standard
Benthic focus and sampling techniques:
Soft bottom
Sediment structure (side scan sonar, grab)
Epifauna (video, beam trawl)
Infauna (van Veen grab)
Algae/plants (video)
Artificial hard structures
Epifauna (scrape samples, photo/video per diving)
Research project – Effects of an OWF on the endobenthic assemblages
Sampling design
Reference 1
Offshore wind farm alpha ventus
Reference 2
Sampling design - Endofauna
Sediment median grain size (µm)
Annual sampling started in 2008
2 impact loctions (i.e. 2 wind turbines) & 2 reference locations
2 transects per location
Up to 7 plots along each transect (separated by 100m)
At each plot 3 van Veen grabs
Preliminary results (2008 – 2010)
Endobenthic assemblages
year_location
before_impact
before_control
construction_impact
construction_control
after_impact
after_control
Abundance of species examples
Bathyporeia guilliamsoniana
Mean species richness
Impact
Control
mean species richness
33
30
27
24
21
18
15
12
9
before
after
after
time
Difference in the endobenthic assemblages among locations (impact vs. control) increased from before (R = 0.61) over the construction phase (R = 0.70) to the operation phase (R = 0.80); p < 0.001.
After the construction of the OWF the abundance of (i) nemerteans decreased and (ii) B. guilliamsoniana increased in the impact locations relative to the controls.
From before to after the construction of the OWF mean species richness (i) do not vary in the control locations, but (ii) vary in the impact locations (< 0.05), i.e. impact locations differs from control locations .
Perspectives
In the near future the areal extent of planned offshore wind farms will be ca. 25 % of the German exclusive economic zone.
The national environmental impact assessment needs further revision regarding the sampling design.
Future studies should reveal if changes in the endobenthos are related (i) to the wind turbines or (ii) to the exclusion of trawling.

THE CIRCLE OF LIFE OF ATLANTIC COD (*GADUS MORHUA*) AT A WIND FARM IN THE BELGIAN PART OF THE NORTH SEA: WHERE ECOLOGY MEETS ECONOMY

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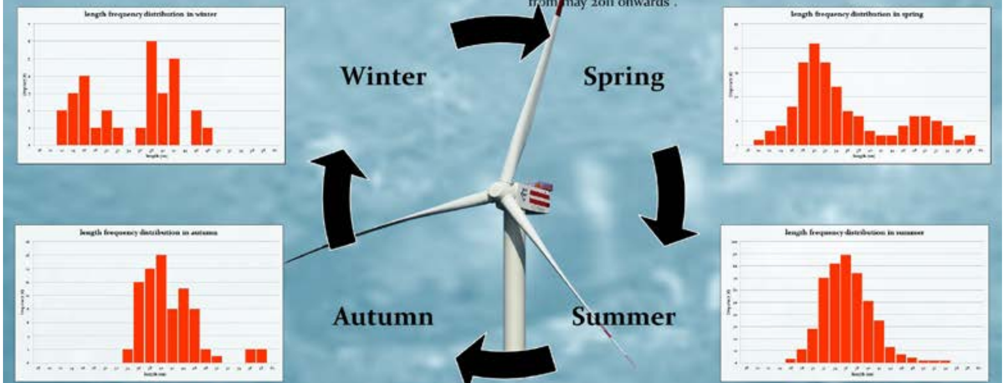
Cod at Windmill artificial reefs

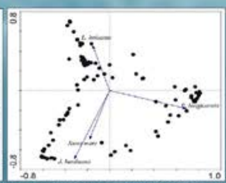
A substantial expansion of offshore wind farms in the North Sea has been planned, inducing a growing interest in the possible effects of these artificial habitats on the marine environment. Demersal fishes are likely to be affected by these changes in the environment. The offshore wind turbines may provide a suitable habitat for hard substrate dwelling fish since hard substrates, e.g. windmill artificial reefs (further referred to as WAR), have been reported to attract and concentrate fish and/or to enhance local fish stocks.

Since 2009 the trophic ecology and community structure of Atlantic cod has been investigated at WAR on the Thorntonbank. In this study, **the state of the art of ecological knowledge of Atlantic cod** (*Gadus morhua* L.) inhabiting WAR in the Belgian part of the North Sea after three years of environmental monitoring is given.

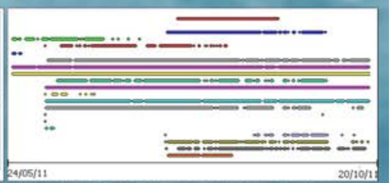
Study area & sampling design

The wind farm under consideration is located at a sandbank 27 km offshore the Belgian coast. The turbines in combination with the buffer (i.e. erosion protection layer) form the WAR, which has a diameter of 50 m. Several techniques were used to investigate the trophic (feeding) ecology and community structure: (1) Standardized line fishing (hooks: size 4; bait: *Arenicola marina*) was performed to **quantify the catch rates** and (2)to investigate the **length frequency distribution** of Atlantic cod. (3) Stomach content analysis was performed to **investigate the feeding ecology**. (4) An acoustic telemetry study was set up to investigate **residency and seasonal migration**. 19 specimens were tracked with Vemco VR2W receivers from may 2011 onwards .





PCA ordination based on AFDW. Only the dominant prey species in the diet of Atlantic cod are visualized



Daily detections of 20 tagged cod (different colors) from May until October 2011

This study disclosed the importance of the WAR in the life history of Atlantic cod in the BPNS.
Every year, large aggregations of Atlantic cod (aged 2 to 3 years) arrive at the WAR in spring, stay throughout summer and autumn (while feeding upon hard substrate associated epifauna) and leave the area in winter time. The acoustic telemetry study (Reubens et al. 2011) revealed high site fidelity and residency near the WAR.
Currently the WARs in the BPNS actually are *de facto* marine protected areas. However, a study has been performed to investigate the possibility of small-scale passive fisheries inside these concession areas (Verhaeghe et al., 2011). Fish aggregations, as e.g. found at the WARs for Atlantic cod, are particularly vulnerable to fishing pressure and overexploitation (Rose and Kulka, 1999). Therefore it is important to carefully monitor the aggregations of Atlantic cod in the long term.

Ref: [illegible]

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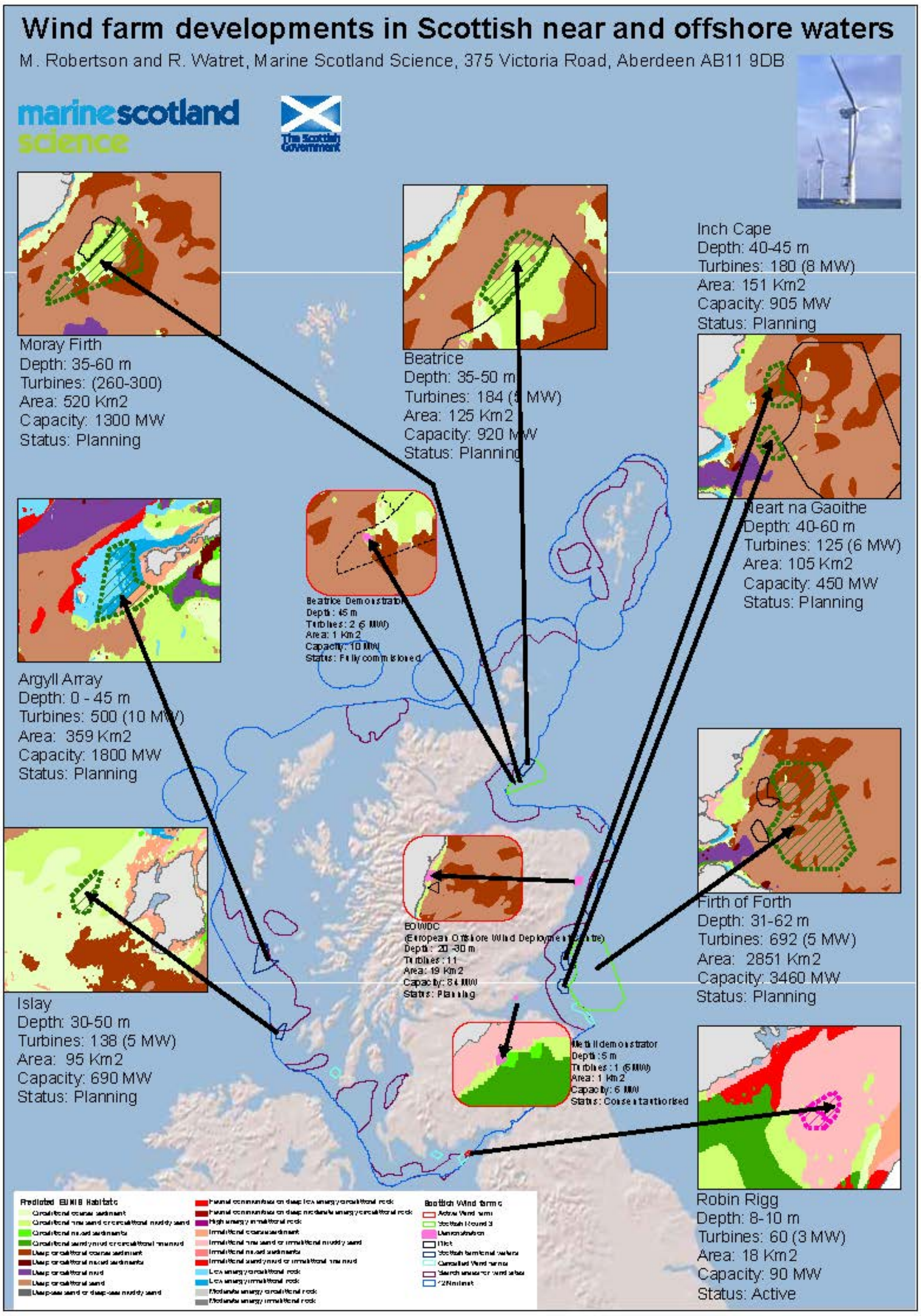
Wind farm developments in Scottish near and offshore waters
M. Robertson and R. Watret, Marine Scotland Science, 375 Victoria Road, Aberdeen AB11 9DB
marine scotland science
The Scottish Government
Moray Firth
Depth: 35-60 m
Turbines: (260-300)
Area: 520 Km2
Capacity: 1300 MW
Status: Planning
Beatrice
Depth: 35-50 m
Turbines: 184 (5 MW)
Area: 125 Km2
Capacity: 920 MW
Status: Planning
Inch Cape
Depth: 40-45 m
Turbines: 180 (8 MW)
Area: 151 Km2
Capacity: 905 MW
Status: Planning
Neart na Gaoithe
Depth: 40-60 m
Turbines: 125 (6 MW)
Area: 105 Km2
Capacity: 450 MW
Status: Planning
Beatrice Demonstrator
Depth: 45 m
Turbines: 2 (5 MW)
Area: 1 Km2
Capacity: 10 MW
Status: Fully commissioned
Argyll Array
Depth: 0 - 45 m
Turbines: 500 (10 MW)
Area: 359 Km2
Capacity: 1800 MW
Status: Planning
Islay
Depth: 30-50 m
Turbines: 138 (5 MW)
Area: 95 Km2
Capacity: 690 MW
Status: Planning
EOWDC
(European Offshore Wind Deployment Centre)
Depth: 20-30 m
Turbines: 11
Area: 19 Km2
Capacity: 84 MW
Status: Planning
Firth of Forth
Depth: 31-62 m
Turbines: 692 (5 MW)
Area: 2851 Km2
Capacity: 3460 MW
Status: Planning
Methil demonstrator
Depth: 5 m
Turbines: 1 (6 MW)
Area: 1 Km2
Capacity: 6 MW
Status: Consent authorised
Robin Rigg
Depth: 8-10 m
Turbines: 60 (3 MW)
Area: 18 Km2
Capacity: 90 MW
Status: Active
Predicted EUNIS Habitats
Scottish Wind farms

AARHUS UNIVERSITY

Modelling of local and far field effects of turbine foundations in Danish waters

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2) Bolding and Burchard Aps., Strandgyden 25, 5466 Asperup, Denmark

Local Effects of Blue Mussels around Turbine Foundations at Nysted Off-Shore Wind Farm, Denmark

The present study compared the growth and feed-backs of blue mussels in natural beds and on turbine foundations in an off-shore wind farm (OWF, fig.1) located in a shallow coastal ecosystem by coupling a dynamic energy budget (DEB, fig. 2) model to a small-scale 3D hydrodynamic-biogeochemical model. The results showed that blue mussels located higher up in the water column on turbine pillars achieved a 7-18 times higher biomass than those located on the scour protection (fig.3) because the former experience an enhanced advective food supply. Secondly, the high biomasses of blue mussels on foundations created local 'hot spots' of biological activity and changed ecosystem dynamics due to their feed-backs e.g. ingestion of microplankton and copepods, excretion of ammonium and egestion of faecal pellets. The model results were supported by field measurements around foundations of Chl *a* concentrations and biomasses of the fauna community. A sensitivity study also showed that mussel beds significantly changed ecosystem dynamics (fig. 4,5). Our study emphasised that OWF's seem to be particularly favourable for blue mussels in the western Baltic Sea and that the functioning of the OWF's as artificial reef ecosystems depends upon how the blue mussels interact with their local pelagic and benthic environment. This study has been published by Maar et al. (2009).

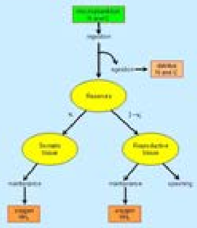

Fig. 1. DEB model. The dynamic energy budget model describes the growth and reproduction of blue mussels (van der Meer 2006).

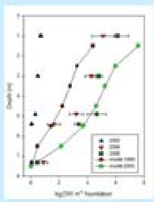

Fig. 2. Biomass on foundations - decreased with depth due to a lower advection of food closer to the bottom.

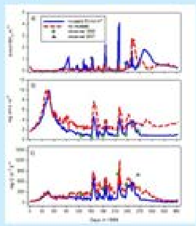

Fig. 3. Sensitivity study. The presence of mussel beds significantly changed nutrient conc., chl *a* conc. and primary production in the ecosystem due to their feed-back mechanisms.

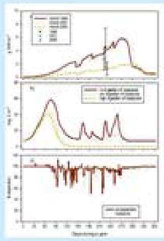

Fig. 4. Depletion. A) The biomass of mussel beds decreased from 1999 to 2005 and affected mussels on foundations. B,C) Mussel filtration caused depletion of phytoplankton and copepods above the bottom.

Offshore wind farms in Danish waters

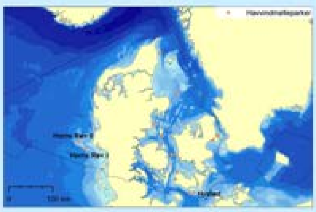

Fig. 1. Location of Denmark's offshore wind farms. Only wind farms in operation are shown (source: Danish Energy Agency)

References:

- Bendtsen, J., Söderkvist, J., Dahl, K., Hansen, J.L.S., Reker, J., 2007. Modelsimulations of blue corridors in the Baltic Sea. EU BALANCE project report. The Danish Forest and Nature Agency. 25 pp.
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- Van der Meer, J., 2006. An introduction to Dynamic Energy Budget (DEB) models with special emphasis on parameter estimation. J. Sea Res., 56, 85-102.

Acknowledgements:
We thank Cordula Göke (Aarhus University, Department of Bioscience) for producing the offshore wind farm overview map.

The potential role of turbine foundations for large-scale transport of particles in the Kattegat and Belt Sea

Offshore wind farm turbine foundations can be considered as artificial reefs, i.e. adding hard substrate in an environment otherwise dominated by soft bottom. These constructions can not only serve as additional stepping stones and habitats for migrating species, but also altering existing non-random pathways (blue corridors). Blue corridors are shaped either by biological mechanisms (route of choice) or by physical factors (currents, hydrography) in the case of passive particle dispersal (eggs, larvae, plankton). Particle tracking techniques in combination with 3D hydrodynamic models provide useful tools to identify the role of natural boulder reefs in the Kattegat and Belt Sea for non-random particle dispersal (Fig. 5) and to carry out sensitivity studies on the impact of offshore constructions on particle pathways.

Fig. 5. Dispersal routes of passive particles at boulder reefs in the Kattegat and Belt Sea - Circles are proportional to bottom tracer concentration (Bendtsen et al., 2007). The results are based on model simulations as part of the EU-BALANCE project and indicate the role of individual boulder reefs as regions of particle sources, sinks or stepping stones. How would a dense network of wind turbine foundation change this pattern?