Biodiversity Series

Problems and Benefits Associated with the Development of Offshore Wind-Farms

OSPAR Commission
2004

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. It has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain.

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. La Convention a été ratifiée par l'Allemagne, la Belgique, le Danemark, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède et la Suisse et approuvée par la Communauté européenne et l'Espagne.

ISBN 1-904426-48-4

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Executive Summary

The use of offshore wind energy is a relatively new and a rapidly increasing activity in the marine environment. This report identifies gaps on an international scale in scientific knowledge and future research needs with regard to potential impacts from the establishment of offshore wind-farms (OWFs).

An overview of the key issues and source of potential impacts to be considered when scoping OWF proposals, as well as examples of potential impacts, are given in Table 1. A more detailed description of potential impacts during the construction, operation and removal phases is given in section 6. Further work is needed to determine the significance and/or acceptability of these impacts.

The report recognises a number of potential benefits associated with the development of offshore wind energy in section 4.

Section 5 describes some aspects to be taken into consideration in developing guidance for the location, construction, operation and removal/disposal of OWFs with the view to facilitating their development and to protecting the marine environment.

Récapitulatif

L'exploitation de l'énergie éolienne en mer est une activité relativement nouvelle dans le milieu marin, activité en expansion rapide. Dans le présent rapport, l'on détermine les lacunes, au niveau international, des connaissances scientifiques ainsi que les besoins futurs en matière de recherche des impacts que la création de parcs d'éoliennes en mer peut avoir.

On trouvera au tableau 1 une vue d'ensemble des questions clefs et des sources d'impacts potentiels à prendre en considération dans l'étude des projets de création de parcs d'éoliennes en mer, de même que des exemples d'impacts potentiels. Une description plus détaillée des impacts potentiels pendant la construction, l'exploitation et l'enlèvement figure en Section 6. Il y a lieu de poursuivre les études pour déterminer l'ampleur et/ou l'acceptabilité de ces impacts.

Le fait que le développement de l'énergie éolienne présente plusieurs avantages potentiels est reconnu à la Section 4 du rapport.

La Section 5 décrit certains des aspects à prendre en considération dans l'élaboration des orientations à donner en ce qui concerne les points d'implantation, la construction, l'exploitation et l'enlèvement/élimination des parcs d'éoliennes en mer, ceci afin de faciliter leur création et de protéger l'environnement.

1. Introduction

The use of offshore wind energy is a relatively new activity in the marine environment and there are, therefore, a lot of knowledge gaps with regard to both potential impacts and the scale of such impacts on the marine environment in relation to local areas and particularly in relation to cumulative impacts from the establishment of offshore wind-farms (OWFs) on an international scale. To date rather few ecological studies concerning OWFs have been carried out. Only a small number of OWFs have already been erected. With the exception of one (Horns Rev) all current OWFs are located rather close to shore (e.g. Tuno Knob in Denmark, Utgrunden in Sweden, Blyth in the UK). The development of a number of OWFs - at a greater distance from the coast and in deeper water - is underway. The research and monitoring that will accompany the construction and operational phases of these new projects should provide valuable information on the potential scale of impacts and for the assessment and the avoidance or minimisation of negative environmental impacts for future projects. In particular, impacts on birds, benthos, fish and mammals may occur during the construction, operational and removal phase. Due to its physical presence, a wind-farm may provide a hazard to shipping. Accidental collision between vessels and the wind turbines may result in the release of oil and chemicals and subsequently in an environmental contamination. In addition, the lighting of wind-farms may have impacts on the landscape. An overview of the key issues and source of potential impacts as well as examples of potential impacts are given in Table 1 and a more detailed description of potential impacts is given in section 6. Further work is needed to determine the significance and/or acceptability of these impacts.

2. Knowledge Gaps and Future Research Needs

Gaps in scientific knowledge and future research needs include:

- more data on distribution and abundance of species, to establish densities and locations at which populations occur throughout the year, for example data on the location of reproduction and foraging sites of marine mammals and on bird-habitat relationships to predict sensitive areas;
- more data on bird migration, such as site-specific information of migratory routes and scale of passage, species-specific flight altitudes, also in relation to weather conditions, including local movement;
- investigation of generic sensitivities of different species based on life history traits, population dynamics, ecology and abundance;
- generic studies on behavioural responses of different species with regard to construction, operational and removal phases of OWFs to establish species-specific sensitivities, including influence of turbine lighting on behavioural responses, e.g. birds;
- more data on hearing sensitivities (such as audiograms) of marine mammals and fish to predict possible effects of underwater sound emission;
- further development of cost-effective monitoring and assessment (survey design and methods) to ensure that the methods are ‘fit for purpose’ and can be widely applied, e.g. improve the methodology for radar tracking of birds;
- more data on possible impacts of OWFs and associated power cables on marine species and habitats, such as effects of introducing artificial substrate, noise (including *in situ* measurements of underwater sound emissions), electromagnetic emissions, increases in sediment temperature and possible changes in the marine community structure, as well as shadow effects resulting from the movement of rotor blades;
- use of impact scales for temporal and spatial aspects in order to prioritise the potential effects, assess the significance of these on spatial and temporal scales and the likely effects leading to generic guidance;
- determine the resilience of areas, habitats and species to change induced by the developments, i.e. the half-life of each effect;
- hydrodynamic models to predict local and large-scale changes in current and sediment dynamics, as well as verification of these models by adequate *in situ* assessment of these changes;
- further development and testing of existing methods, as well as novel techniques for measuring impacts of OWFs, for example how to monitor bird collision rates or long-term

effects such as possible reduction of biological fitness of animals due to stress from maintenance traffic or habitat loss;

- development of biological predictive modelling and biological risk assessment techniques for aiding decision-making and develop links between physical modelling and biological modelling;
- detailed approach to determining the physical and ecological footprint at several scales: of a single windmill installation, a wind-farm, several wind-farms close together and on a north-west European scale;
- determination of quantitative indicators of change, thresholds for change and levels of acceptable change for biological components;
- methodology to assess cumulative impacts of OWFs on migratory species, particularly birds and on the biodiversity of original marine flora and fauna;
- development of the ecosystem approach especially in determining potential effects (studies of the physical changes leading to the biological ones);
- development and testing measures to minimise and mitigate the environmental impact of OWFs on the marine environment and nature, such as bird collisions (for example through layout design, lighting and appearance of OWFs) or sound emissions during the building phase, e.g. by employing bubble curtains and by developing new installation techniques for wind turbine foundations with reduced sound emissions;
- development of windmill installation designs that minimise the damage to ships in case of collisions.

3. Overview of Potential Impacts of Offshore Wind-farms on the Marine Biota and Environment

Table 1:

This table lists the key issues and source of potential impacts to be considered when scoping OWF proposals. The third column provides examples of potential impacts that might arise – it is not exhaustive. Impacts (when they occur) will vary in significance from location to location. Further work is needed to determine the generic significance and/or acceptability of these impacts.

ISSUE	SOURCE OF POTENTIAL IMPACTS	EXAMPLES OF POTENTIAL IMPACTS
Birds	- turbines, mainly rotor blades and wakes - light emission	- bird collision - attraction of birds due to illumination by navigational lights and subsequent increase in the risk of collision
	- wind-farm as a whole	- temporary or permanent habitat loss or change, including exclusion of habitat, e.g. sandbanks - fragmentation of feeding, breeding and roosting areas, as well as migratory routes due to barrier effect - change of food species availability
	- boat traffic during construction and maintenance	- stress and reduction of biological fitness - temporary or permanent exclusion from habitat
	- electric cable to shore - increase of temperature in sediments during operation	- increased risk for botulism in coastal areas (eulittoral) resulting in an increased death rate for wading birds and water birds
Bats	- turbines, mainly rotor blades and wakes	- collision and barrier effects
Marine Mammals	- shadow from rotor blades - emission of sound and vibration into the water body	- habitat loss due to avoidance - fragmentation of migratory routes and of sites for foraging and reproduction
	- boat traffic during construction and maintenance	- changed behaviour, stress
	- electric cables (see below)	- disturbance of small- and large-scale orientation
Fish	- electric cable within the wind-farm and to shore – artificial electromagnetic fields emitted during operation, in particular from monopolar direct current cables	- disturbance of small- and large-scale orientation (especially migratory species) - impediment of foraging activity
	- emission of sound and vibration into the water body	- habitat loss as fish may leave area disturbance of behaviour and stress
	- clouding and sedimentation during construction	- damage to fish eggs
	- introduction of hard substrate	- alteration of food species availability and abundance, which in turn may alter community composition and abundance of fish

ISSUE	SOURCE OF POTENTIAL IMPACTS	EXAMPLES OF POTENTIAL IMPACTS
Zoobenthos	- cable laying	- disturbance of intertidal habitats
	- local destruction and sediment plumes during the construction/removal of foundations - permanent covering of the seafloor	- temporary and permanent habitat loss
	- introduction of artificial hard substrate - changes in hydrodynamics	- alteration in the benthic community composition - indirect habitat loss through small-scale changes in sediment structure around the turbine and changes of large-scale sediment dynamics
	- electric cable within the wind-farm and to shore - increase of temperature in sediments during operation	- alteration in the endobenthic community including colonisation by alien species - increased degradation of the organic content resulting in a release of heavy metals (depending on the total organic matter content and metal content of the sediment)
Macrophytes	- local destruction and sediment plumes during the construction of foundations - permanent covering of the seafloor	- temporary and permanent habitat loss
	- change of current dynamics and sediment conditions - introduction of artificial hard substrate	- habitat loss - alteration in the plant community composition
Hydrodynamics & Morphodynamics	- construction & presence of foundations and cables	- change of sediment dynamics, for example slowing down of natural erosion and sedimentation processes (at the site and adjacent coastlines) - reduction in wave energy (shadow effects) from different sized arrays and how/if this influences sediment inputs and exchanges - beach faces and flood defences
Landscape	- tall structures, visible from afar - lighting	- intrusion on the typically flat and featureless sea and "industrialisation" of this natural landscape - alteration of the scenic landscape - especially at night
Navigation	- danger of collisions between vessels and wind turbines (including restriction/constriction of shipping routes)	- pollution through oil spills or chemical spills - impact on socio-economic operations
Emergency Operations	- obstacles due to the presence of static structures	- impact on emergency operations
Other Users	- exclusion of other users from the area - disturbance of the natural landscape	- socio-economic losses, e.g. for fisheries and tourism

4. Potential Benefits

Potential benefits associated with the development of offshore wind energy include:

- Reduction of greenhouse gas carbon dioxide;

  The concentrations of man-made greenhouse gases such as carbon dioxide (CO_2) have increased in the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC), the emissions of greenhouse gases due to human activities continue to alter the atmosphere in ways that are expected to affect the climate. The global average surface temperature has increased over the 20th century by 0,6°C and is projected to increase by 1,4 to 5,8°C over the period 1990 to 2100. According to the IPCC, expected effects of climate change for Europe *inter alia* in coastal areas are as follows: the risk of flooding, erosion, and wetland loss will increase substantially with implications for human settlement, industry, tourism, agriculture, and coastal natural habitats. Furthermore increasing run-off of fresh water to the coastal areas will cause changes in salinity and nutrient state with consequences for the marine biodiversity.

  One important cause for this increase of greenhouse gases is the incineration of fossil fuels (oil, gas, coal) whereby CO_2 will inevitably be released. In order to reduce the emission of greenhouse gases, primarily CO_2, international measures (The United Nations Conference on Environment and Development 1992 in Rio; 1997 Kyoto Protocol of the United Nations Framework Convention on Climate Change) were agreed. According to Directive 2001/77/EC of 27 September 2001, the increased use of electricity produced from renewable energy sources (i.e. non-fossil energy sources like wind, solar, hydrothermal, hydropower) constitutes an important part of the packages of measures needed for compliance with the Kyoto Protocol.

  According to the 2002 Delhi Declaration actions are required at all levels, with a sense of urgency, to substantially increase the global share of renewable energy sources with the objective of increasing their contribution to the total energy supply. Offshore wind power is expected to contribute a significant proportion of this renewable energy. According to a study published by the European Wind Energy Association/Greenpeace, in Northern Europe alone more than 20 000 MW of capacity is planned off the coast of European countries.

- Use of a sustainable, pollution-free energy source;
- Use of wind as a free and inexhaustible energy source (wind speeds are considerably higher at sea compared to land; most of the marine sites are expected to deliver 40% more energy than good shoreline sites[2]);
- Economic benefits:
  - creation and safeguarding of jobs, e.g. manufacturing of wind turbines, construction, operation, maintenance and removal of turbines, research and monitoring;
  - potential to develop tourism (boat trips to the wind-farm);
  - potential for EU companies for a world wide export market (technical transfer).
- Potential basis for future hydrogen production by electrolysis of water;
- Potential to act as refuges for fish (if no fisheries are allowed within the wind-farm area).

5. Aspects to be Taken Into Consideration in Developing Guidance for the Location, Construction, Operation and Removal/Disposal of OWFs with the View to Facilitating their Development and to Protecting the Marine Environment

In developing guidance, measures which minimise potential impacts on the marine environment should also be incorporated. For guidance, the following aspects, *inter alia*, should be taken into consideration:

Location

- potential conflicts with other past, existing or planned uses/non-uses in the area e.g.:
  - nature conservation areas including OSPAR Marine Protected Areas, Special Protection Areas or candidate Special Areas of Conservation;

  - marine archaeology;
  - marine traffic (shipping routes) including safety zones;
  - leisure-time activities (e.g. sailing);
  - air traffic;
  - fisheries;
  - military uses;
  - gas and oil pipelines;
  - power and communication cables;
  - sediment extraction;
  - oil and gas activities;
  - dumping sites for dredged material;
  - past dumping sites for munitions;
  - other renewable energy installations;
  - tourism.
- wind speeds;
- characteristics of the seabed foundations, internal cabling; scour protection measures; assessment/minimisation of the turbidity;
  - geological (e.g. sonar, seismic) and geo-technical (e.g. drilling, cone penetration tests) ground investigations: the scope of the ground investigations performed should be such that all ground property data relevant to planning are available well before the beginning of turbine installation;
- water depth (foundation type);
- wave heights (foundation type);
- natural ice conditions (foundation type);
- distance from shore (impact on landscape; costs for cabling to shore).

Construction

- seabed type/sediments;
- foundation type (e.g. gravity-based foundation, monopiles, tripods);
- installation methods (e.g. use of bubble curtains to reduce noise; laying of cables);
- scour protection;
- waste management;
- cable type (e.g. flat type bipolar direct current cable, shielding etc);
  - in order to prevent adverse impacts on marine species sensitive to electromagnetic fields, wind-farm power cables with the least damaging electromagnetic field emissions should be employed;
- appropriate seasons (time windows) to avoid sensitive life stages of marine species, such as reproductive or moulting periods / to minimise potential environmental impacts (taking into account human safety aspects).

Operation

- minimisation of disturbances on nature and environment, e.g. minimisation of noise;
- safety zones around OWFs;
- safety distances to shipping routes;
- lighting of OWFs (shipping and aviation);
- development of emergency response plans, e.g. to handle oil spills resulting from a collision between a vessel and a windmill installation;
- inspection of scouring e.g. with side scan sonar, multibeam;
- waste concept;
- mitigation - if possible - in case of unavoidable impact on nature and the environment.

Removal and disposal

- in general, the removal phase of wind turbines (including foundations) may have similar impacts to the construction phase;
- techniques which minimise impacts on the environment (e.g. benthos, fish) including re-suspension of the sediment should be applied for the removal. In general, foundations of wind energy installations are designed to have a life span of up to 50 years and could be used for two generations of wind turbines. As a lot of oil/gas installations will be removed and disposed of on land over the coming decades, it is expected that the removal techniques will evolve and much technical expertise will be gained;
- when decommissioning wind energy installations (end of operational life-time use or premature termination of the project), the wind energy installations (including foundation) and cables should be removed completely and disposed of (recycling) on land. In order to avoid hindrances for e. g. fisheries, the piles should at least be cut off far enough beneath the seabed to ensure that the remaining parts will not be exposed by natural sediment dynamics.

6. Possible Impacts of Offshore Wind-farms on the Marine Environment during Construction, Operation and Removal

Potential impacts during construction, operation and removal

1. Destruction or disturbance of the local seabed area
2. Sediment re-suspension and increased turbidity
3. Noise and vibrations from the turbines
4. Electromagnetic fields
5. Temperature increase in sediments
6. Physical presence of the wind turbines
7. Disturbance due to construction/removal activities and to maintenance operations
8. Introduction of hard substrate habitats

The different types of impact listed above are described below. Some of the impacts may occur during more than one or even all three phases, that is, during construction, operation and removal phase.

1. Destruction or disturbance of the local seabed area

The construction of the wind turbine and transformer platform foundations may require seabed preparation (e.g. levelling). Sea floor preparation may cause destruction or disturbance of the local seabed.

The sea-cables interconnecting the wind turbines and connecting the wind-farm to land will generally be laid beneath the surface of the sea bottom or, in case of rock, the cables may need to be laid on the surface of the seabed. For the installation of sea cables small trenches may be cut into the sediment by a water jet/plough or may be dug. Cables laid on the sediment surface need to be covered, e.g. by rocks so that they are protected from physical damage or do not create an obstacle (e.g. to fishing gear). Trenching and digging floor will cause destruction or disturbance of local sea bottom within the wind-farms or along the cable routes to shore.

It is expected that the removal of cables will result in a similar disturbance of local seabed areas.

2. Sediment re-suspension and increased turbidity

Both sea bottom preparation and cable laying activities during the construction phase will result in temporary sediment re-suspension and thus in increased turbidity of the water, which may change sediment characteristics. The extent of sediment re-suspension will depend on the methods used, the steps taken to avoid sediment re-suspension and the sediment type and the hydrographic conditions in the area at the time of such activities.

The increase of the turbidity will depend on the amount of sediment re-suspended, the sediment grain size and the local hydrographic conditions at the time of the sediment re-suspension. Sedimentation is slower for sediment with a small grain size and thus, there is a higher and longer lasting turbidity when the grain size of the sediment is small.

As in the construction phase, there will be a temporary sediment re-suspension and thus an increased turbidity in the removal phase of foundations and cables.

With regard to re-suspension and turbidity it should be taken into account that depending on the local natural conditions in the marine environment, a natural re-suspension and (re)-sedimentation takes place.

3. Noise and vibrations

Noise comes from different sources during the construction, the operation and the removal phase. During construction, noise will be emitted e.g. from shipping operations, pile driving, sea floor preparation for foundations, laying of cables. The noise generated by these sources, except mono-pile driving, will primarily be of low frequencies. If mono-piles are used as foundations for the turbines, pile driving will be used to construct them and this is likely to cause high noise levels.

When operating the wind turbines and the transformer, noise will be emitted to air and through the tower and foundation to water. Measurements of noise from a wind turbine show that the airborne noise makes a negligible contribution to the underwater noise level. So, the noise measured underwater from the wind turbines is transmitted through the tower and the foundation of the wind turbine.

During operation, the underwater noise from the offshore wind turbines is not higher than the ambient noise level in the frequency range above approximately 1 kHz. In the frequency range below approximately 1 kHz, the underwater noise emitted from the offshore wind turbines is higher than the ambient noise level (Ødegaard & Danneskiold-Samsøe, 2000).

When operating, the turbines will transmit vibrations to the surroundings and this might have an impact on the benthic fauna, fish and marine mammals in the vicinity of the foundations. So far, this type of impact has not been investigated thoroughly and knowledge on the subject is very limited.

The removal phase will also result in the emission of noise, e.g. removal of foundations, boat traffic.

Research on OWF locations, monitoring and geotechnical surveys have to be carried out by using seismic equipment. In order to minimise potential impacts on marine mammals and fish, precautionary measures should be taken and investigations should be performed with care.

4. Electromagnetic fields

Generally, electromagnetic fields are created within cables when an electric current is running through the cable. The magnitude of the magnetic field around a cable depends, *inter alia*, on the type of cable employed. Different power cable types with different properties exist, e.g. monopolar and bipolar direct current cables or alternating current cables.

Monopolar and bipolar direct current cables

A direct current cable will contain a constant unidirectional current and induce a magnetic field with fixed poles. Monopolar direct current cables can emit an electromagnetic field strength many times above that of the natural geomagnetic field strength, e.g. for the “Baltic Cable” the electromagnetic field strength in 1 m distance to the cable has been calculated to be more than six times higher than the natural geomagnetic field strength. Unlike monopolar direct current cables, bipolar direct current cables have two parallel conductors with opposite current direction. The less distance there is between these two conductor cables the less the expected electromagnetic field emission, as the opposing field emissions will cancel each other. This compensatory effect is particularly strong in a so-called flat type bipolar direct current cable. For this cable type the electromagnetic field emission in 1 m distance from the buried cable has been calculated to be much lower than the natural geomagnetic field strength in the North Sea. A recently developed new type of coaxial cable – which is still being tested – is expected to have electromagnetic emissions close to zero.

Alternating current cables (three phases in one cable or as three single cables)

Alternating current cables do not generate the same constant electromagnetic field as direct current cables because of the alternating and pulsating current. If the three phases are bundled in one cable, there is a strong compensatory effect which will minimise the electromagnetic field. The electromagnetic field surrounding such cables at a distance of about 1 m is calculated to be much lower than the natural geomagnetic field strength in the North Sea. Therefore such alternating current cables are not expected to influence the marine fauna to the same degree (if at all) as a conventional direct current cable.

The knowledge of the impact of electromagnetic fields on marine animals is limited.

5. Temperature increase in sediments

The thermal loss of a buried power cable in operation will result in a warming of the surrounding sediments. The increase in temperature in the sediments depends, *inter alia*, on the electric current, the resistance of the cable, the thermal resistance of the surrounding sediments and the cable type. In general, the highest temperature release from a cable will occur when the wind-farm is operated under full-load (high wind speeds). The warming of the sediment decreases from the cable surface to the surface of the seabed. Therefore, the laying depth of the cable also plays an important role. Alternating current cables have in general higher thermal losses than direct current cables and thus will therefore cause a higher warming of the surrounding sediments. Although the temperature increase will decrease with vertical and horizontal distance from the cable it may still be high enough to cause abiotic and biotic impacts in the sediments near the sea bottom. Potential impacts may be:

- alteration in the endobenthic community including colonisation by alien species;
- increased degradation of the organic content of the sediments resulting in a release of heavy metals (depending on the total organic matter content and metal content of the sediment, i.e. not relevant for sandy sediments);
- increased risk of botulism in eulittorial areas resulting in an increased death rate for wading birds and water birds.

Since there will be fluctuations within the load of the wind-farm, the amount of thermal energy released from the cable will also vary, which makes predictions about the intensity and time-scale of the temperature changes in the sediment difficult.

6. Physical presence of the wind turbines

The wind turbines are large structures that may change the physical characteristics of the area markedly. This may have an impact on some species, causing them to minimise their use of the area or completely abandon the area.

The physical structure of the foundations might also attract certain species, which may use them as resting-place or protection against predation.

7. Disturbances

Disturbances as a result of the wind-farm may occur during the construction, the operation and the removal phase. During the construction phase, boats, machinery and people operating in the wind-farm area might disturb the marine fauna living in the area. Similar impacts may occur during the removal phase.

During the operational phase, boats and people entering the wind-farm area to carry out maintenance work, might disturb the marine fauna occurring in the area.

8. Introduction of hard substrate habitats

As a secondary element of establishing offshore wind-farms, the foundations and the rocks placed to prevent scouring at their bases will introduce new hard substrate surfaces. The foundations and the scour protection may form a new type of sub-littoral habitat, which may be colonised by a variety of marine species. Likewise the covering of power cables which need to be laid on the sea floor may introduce unnatural or additional hard substrate.

The hard substrate may increase the opportunities for epifauna to settle and it may provide a substrate, which is more attractive to hard substrate communities than the pre-wind-farm seabed. In turn, the naturally occurring species, i.e. the soft substrate community, which may have been present previously in the area will be out-competed and displaced. The establishment of epifauna and flora on the hard substrates may increase the food available to fish, which in turn could lead to an increase in the food available to marine mammals and birds.

The possible effects of introducing hard substrate cannot be established until the foundations have been in place for some time.

Potential impacts on affected parts of the environment

The potential impacts of OWFs described above are of various importance to the different parts of the environment in and around the offshore wind-farms. In the following the possible impacts of an offshore wind-farm on the different parts of the environment are described in general.

1. Hydrography / geomorphology

The construction and operation of an offshore wind-farm can potentially have an impact on the hydrography and the geomorphology in the wind-farm area and in the areas surrounding the wind-farm. An offshore wind-farm may change the water flow and thereby the transport of material and the sediment properties in the area.

The resistance from the foundations may influence the current and wave conditions in the wind-farm area and this may influence the rate of erosion and deposition of sediment in the area.

The potential impacts on local hydrography may also affect the coastal morphology in the area, due to changes in current conditions and erosion and deposition of material.

2. Benthic fauna and flora

The introduction of hard substrate into the marine environment will allow the settlement of sedentary epibiota and a fouling community will develop that will evolve over time. In temperate areas of Europe communities developing on new hard substrata are considered to take about 5 years to reach a state similar to mature communities on natural rock.

The precise nature of the community depends on, amongst other things, availability of larvae to settle, the physical complexity of the habitat and the time of year the substrata are deployed. In addition, mobile fauna will enter the community both from the plankton and through migration, their inclusion will depend on the suitability of the habitat available. The overall complexity/diversity of the final community will depend on the habitat complexity available assuming that other parameters such as food availability, predation and physical disturbance are not the dominant force influencing the community development.

The sea bottom preparation for foundations and cable laying activities during the construction phase will cause destruction and disturbance of the local benthic fauna and flora. Seabed preparation will cause both increased sediment re-suspension in an area around the activity and increased turbidity of the water. Increased turbidity can cause clogging and destruction of the feeding organs of the benthic organisms. Furthermore, increased sedimentation of suspended material can cause shading of the benthic vegetation. As the suspended material settles on the seabed the increased sedimentation may cause smothering of the benthic flora and fauna. Similar potential impacts are expected during the removal phase.

In the operational phase, changes in the pattern of erosion and deposition of sediment around the individual foundations might affect the benthic fauna. Changes in the sedimentary environment can make it less attractive to some species and perhaps more attractive to other species, and thereby change the species composition of the benthic fauna and flora.

3. Fish

The wind-farms might affect the fish fauna in an area permanently by introducing new or additional hard substrate on which epibenthos can settle, by changing sediment characteristics, by introducing electric cables that might possibly interfere with fish migration and by the noise and vibrations generated by the wind-farms during their operation. However, it is also possible that the fish become habituated to the noise from the wind turbines. Additional impacts may be generated during the construction phase.

Changes in the water quality and the food resources caused by the construction and/or operation of the wind-farm may affect the fish population in the area.

Changes in the sedimentary environment may also affect the fish. Sandeels and sprats are very dependent on the availability of suitable sediment, and are particular sensitive to changes in the content of silt and fine sand.

The physical structure of the foundations and the scour protection may attract some fish species, e.g. because the physical structure provides protection against predation or because it provides protection against the prevalent current and thus saves the fish energy.

4. Marine mammals

The construction and operation of the offshore wind-farm can potentially affect the marine mammals in the area in a number of ways. The marine mammals can be affected by the noise and disturbances caused by the construction work. The construction work might affect the food sources and thus, make the area less attractive to the marine mammals during the construction. Also during the removal phase marine mammals may be disturbed due to the working activities.

As a result of establishing an offshore wind-farm, the habitat might change, making it less attractive to marine mammals which might abandon the area e.g. because it is no longer suitable as a foraging or breeding area.

The electromagnetic fields generated around the cables interconnecting the wind turbines and connecting the wind-farm to land, may affect and disturb the marine mammals and cause them to avoid the area.

4.1 Seals

The common seal (*Phoca vitulina*) and the harbour seal (*Halichoerus grypus*) are both included in Annex II of the EC-Habitat Directive, which aims to maintain a favourable conservation status of natural habitat and species of wild fauna and flora of community interest.

The most significant impacts on seals are expected to come from the physical presence of the wind turbines, the noise from ships and construction and removal work, as well as the temporary or permanent loss of habitats near offshore wind-farms. Seals use sound to communicate and perhaps for hunting both on the surface and under water. The seals' ability to communicate can be affected by the noise generated by the construction work and the operation of the wind turbines, and cause them to leave the wind-farm area.

4.2 Harbour porpoises

The harbour porpoise (*Phocoena phocoena*) is also included in Annex II of the EC-Habitats Directives and listed as “vulnerable” in the “Red List of Globally Threatened Animals and Plants” by the International Union for the Conservation of Nature (IUCN).

The breeding period of harbour porpoises begins by late June and ends by late August. Ovulation and conception typically take place by late July and early August. The calves begin suckling immediately after birth and are fed by their mother until March the following year and possibly longer (Sørensen & Kinze, 1994).

Harbour porpoises feed on schooling fishes such as herring and sprat. Porpoises are expected to follow the migrations of these species. The construction, removal and/or operation of the wind-farm might affect the distribution of food resources for the harbour porpoises.

Where pile driving is used for establishing the foundations there is a high risk of hearing damage to the harbour porpoises in the vicinity of pile driving. The emitted energy within such a series of short signals is most certainly high enough to seriously impair the hearing of harbour porpoises and seals in the surrounding area. The signals will have the potential to physically damage the animals’ tissues in the close vicinity (depending on the received peak pressure) or to impair the animals’ auditory sensitivity (i.e. hearing) over a medium range around the ramming site. The repetitive nature of this sound production is thereby increasing the potential negative effects as the threshold for impairing the auditory sensitivity is lowered accordingly.

Since the harbour porpoise is not by nature a stationary animal, but is believed to move around within a large sea area, it must be expected that harbour porpoises will leave areas in which construction activities are taking place. The noise emitted during the removal phase may also disturb the harbour porpoise.

The noise generated by the operation of the turbines may also affect the harbour porpoises and this may cause the animals to abandon the wind-farm area completely. Depending on the importance of the wind-farm area as a feeding or breeding area for the harbour porpoises, this may have an impact on the harbour porpoise population in the area.

5. Birds

Wind-farms might affect birds by increasing mortality rates through collisions, by disturbance of birds in their resting and feeding habitat, or by altering the amount of resting and feeding habitat. Large wind-farms may also produce a barrier effect, deflecting bird movements away from their intended tracks.

In particular, migrating birds on the East Atlantic flyway and waterfowl staging, moulting and wintering in waters for shorter or longer periods during migration are vulnerable to impacts from wind-farms.

The potential impacts can be divided into two subjects of expected impact, namely disturbance and collision risk.

5.1 Disturbance / loss of habitat

The noise and disturbances during the construction and removal phase can affect the birds and cause them to abandon the area, resulting in a temporary loss of habitat area.

Birds are likely to be displaced from foraging habitat by the disturbance caused by wind-farms in operation, in effect a loss of feeding habitat. They may become habituated to such disturbance over time, and it is even possible in some cases that once such habituation occurs, some species might benefit from increased amounts, or concentrations, of food in the vicinity of individual turbines or wind-farms. Thus short term and medium term effects of wind-farm development might differ, or effects may differ between species. Particularly sensitive bird species might never habituate to wind-farms and be permanently displaced from the area or continually disturbed from these areas by maintenance activities such as helicopter flights.

It is suggested that birds resting or foraging on or in the water will maintain a minimum distance from the wind-farm, which will affect their ability to exploit the habitat for foraging and/or resting (NERI, 2000). The aspect of habitat loss is mainly relevant for the waterfowl species.

The proposals for large wind-farms in shallow sea areas may conflict with the feeding distributions of seabirds, notably leading to a cumulative impact on sea ducks if these are displaced as a result of disturbance.

The effects attributable to wind-farms are variable and are species-, season- and site-specific. Disturbance can lead to displacement and exclusion from suitable habitats, thus resulting in a loss of bird habitats. The scale of such habitat loss, together with the availability of other suitable habitats that can accommodate displaced birds, will influence the impact. There are several reliable studies indicating negative effects on land up to 600 m from wind turbines, i.e. a reduction in bird use of or absence from the area close to the turbines, for some species (e.g. whooper swan *Cygnus cygnu*s, pink-footed goose *Anser brachyrhynchu*s, European white-fronted goose *A. albifron*s, Eurasian curlew *Numenius arquat*a).

The wind energy industry is in its infancy offshore and, consequently, there has been little research into the impacts on birds. Disturbance potentially may arise from increased human activity in the vicinity of wind-farms, e.g. maintenance visits, or from just the presence/noise of turbines. Few studies are conclusive in their findings, often because of a lack of well-designed studies both before and after construction of the wind-farm or because they are not of sufficient duration to distinguish short- versus long-term effects. There is some indication that wind turbines may be barriers to bird movement. Instead of flying between the turbines, birds may fly around the outside of the cluster. The cumulative effects of large wind-farm installations may be considerable if bird movements are consequently displaced. This may lead to disruption of ecological links between feeding, breeding and roosting areas. Wind-farm design may alleviate any barrier effect, for example allowing wide corridors between clusters of turbines. Research and post-construction monitoring at several pilot sites will be necessary to determine whether and where this is an acceptable solution.

5.2 Collision risk

There is the risk that birds will collide with the wind turbines in operation. This can affect wintering and staging species, which over-fly the wind-farm area every day over longer periods. Furthermore, it can affect a population of migrating birds, where a smaller or larger number of individuals over-fly the wind-farm area once or twice a year. A rather limited knowledge exists on the risk of birds colliding with wind turbines.

Collision rates are extremely difficult to predict since it is not possible to extrapolate with any confidence from experience with terrestrial wind-farms to what will happen at marine wind-farms. The high natural survival rates of seabirds and sea ducks, together with their low recruitment rates, make them vulnerable at a population level to even small increases in mortality rates of fully-grown birds. Therefore, it is not possible to be certain that the wind-farms will have only trivial impacts on seabird populations.

Site selection is crucial to minimising collision mortality and should therefore be carried out carefully. There may also be adverse effects on birds as a result of disruption to or encouragement (collision risk for birds feeding among turbines) of avian food resources such as benthos and fish populations.

6. Visual and socio-economic impact

OWFs can potentially have a major impact on the landscape and the local community. An OWF with several wind turbines will most likely change the landscape considerably, particularly in the dark because of lighting. This will affect both the local communities (if the wind-farm is visible from the coast) in the area and the people visiting the area.

The impact on tourism and on the local community can be either negative or positive. A negative impact will occur if the tourists stay away from the area, the rental of holiday cottages is reduced and the general use of the area for recreational activities such as yachting, angling, diving etc. is reduced because of the presence of the OWF.

A positive impact will occur if the offshore wind-farm becomes an attraction for tourists.

The noise emitted from the wind turbines during operation can potentially be a nuisance to the people on land. According to the modelling of the noise emitted by an OWF, the wind turbines will be heard at a distance of 1 km at the most.

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