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Edited by Dan Wilhelmsson *et al.*

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About the Organisations

IUCN

IUCN, International Union for Conservation of Nature, helps the world find pragmatic solutions to our most pressing environment and development challenges.

IUCN works on biodiversity, climate change, energy, human livelihoods and greening the world economy by supporting scientific research, managing field projects all over the world, and bringing governments, NGOs, the UN and companies together to develop policy, laws and best practice.

IUCN is the world's oldest and largest global environmental organization, with more than 1,000 government and NGO members and almost 11,000 volunteer experts in some 160 countries. IUCN's work is supported by over 1,000 staff in 60 offices and hundreds of partners in public, NGO and private sectors around the world.

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E.ON Climate and Renewables

With €82 billion in sales and roughly 88,000 employees, E.ON is one of the world's largest investor-owned energy companies. E.ON Climate & Renewables is the division responsible for E.ON Groups renewable energy portfolio and carbon sourcing business worldwide and E.ON is investing €8 Billion for 2007 -2011 in renewable energy generation and carbon abatement project to significantly grow its business. For more information: http://www.eon.com/renewables

Swedish International Development Cooperation Agency

Swedish International Development Cooperation Agency (Sida) is the Swedish agency for development cooperation. The overall goal of Swedish development cooperation is to contribute to making it possible for poor people to improve their living conditions, and Sida includes environmentally sustainable development as one of the key goals in its activities in the developing world.

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Executive summary

In the relatively rapid development of offshore renewable energy, the issue of marine biodiversity is often not fully considered. IUCN has undertaken a joint project with the multinational energy corporation E.ON and the Swedish International Development Cooperation Agency (SIDA) to improve the environmental performance of offshore renewable energy projects by developing guidance to support best practice and fully integrate biodiversity considerations.

The Greening Blue Energy project aims to facilitate well-balanced and science-based discussions on the impacts on the marine environment from offshore renewable energy developments.

The guidance provides a synthesis of current knowledge on the potential biodiversity impacts of offshore wind energy on the marine environment. It is based on scientific evidence and experiences from offshore renewable energy development and other relevant sectors. The foundation of the document is a review of more than 1000 reports and documents, at least 400 of which are peer-reviewed articles published in scientific journals, and results are presented in a jargon-free and balanced way. It aims to be user-friendly as well as structured in a way to provide more detail for those that need it and ultimately to encourage improvements in the sustainability of the offshore renewable energy industry. Overall, the guidance promotes the consideration of science-based impact research, suitable for conducting, scoping and evaluating Strategic Environmental Assessments (SEAs) and Environmental Impact Assessments (EIAs), based on international and national standards.

Potential impacts of offshore wind power development on the marine environment include disturbance effects from noise, electromagnetic fields, changed hydrodynamic conditions and water quality, and altered habitat structure on benthic communities, fish, mammals and birds. To date, evidence for negative impacts on the subsurface marine environment are strongest for the construction phase. However, long-term disturbance of local marine ecosystems during the operational phase cannot be excluded, and some bird species may largely avoid the wind farm areas. Various mitigation measures can be applied to reduce the risk to local biodiversity, including difference in timing, location, design of system, and the use of measures to temporarily disperse affected species.

Nevertheless, if offshore wind power development is well planned and co-ordinated, the local subsurface marine environment could even benefit from wind farms in several ways. Trawling, for both fish and invertebrates, is one of the most severe threats to the marine environment, and is prohibited or limited inside wind farms. Furthermore, the foundations of wind turbines, including the boulders that are often placed around them for scour protection, will function as so-called artificial reefs, locally enhancing biomass for a number of species. It has, moreover, been suggested that surface-oriented offshore energy devices may function as Fish Aggregation Devices (FAD).

All this shows that environmental impacts from offshore renewable energy projects need to be assessed with a comprehensive approach. As the global offshore wind energy industry further expands and continues to mature, companies and governments will benefit from increased knowledge and experience.

Ongoing monitoring will be crucial in identifying how successful previous mitigation strategies have been in avoiding or reducing impacts on the marine environment. Future decisions can integrate new findings and mitigate new threats. By undertaking rigorous impact assessment and systematic environmental management, the industry will continue to learn through the plan, do, check, act approach, and apply continuous improvement to their practices and procedures. Through marine spatial planning, cumulative and synergistic impacts can be better managed, and impacts and opportunities for all sea users taken into consideration.

Planning and development decisions made at this stage of the development of offshore wind energy will be setting a precedent for future developments, both in Europe and beyond, so it is imperative that shortcomings in research and knowledge are addressed as a matter of urgency.

1 Introduction

1.1 Background

Increasing energy demands, and recognition of the effects of a changing climate resulting from fossil fuel use, require a shift in the balance of energy sources.

Offshore wind-power generation capacity is anticipated to grow significantly as the world makes unprecedented attempts to transition to a lower carbon economy. The potential for renewable energy to be sourced from the offshore wind environment is only now being fully realised. Engineering solutions now allow terrestrial concepts to be reconsidered in a marine environment, an energy territory previously considered the domain of offshore oil and gas. However, any type of energy production will exert some impact on the local and global environment. In reducing the atmospheric impacts from our energy sources, we must avoid replacing one set of significant impacts with another.

Whilst acknowledging that research into the impacts of the offshore renewable industry is still in its infancy, it is widely regarded that the risk for impacts on the marine environment may not be negligible and must be taken seriously.

Wind farms may also be beneficial for the marine environment in several aspects, including trawling exclusion and the creation of hard bottom habitats, which could benefit both local fisheries and species conservation. The renewable energy industry is evolving rapidly and the understanding of potential environmental consequences of such developments lags behind, and as a consequence the debate about impacts can run ahead of the available evidence. Science-based evidence should be used to help guide marine impact avoidance and mitigation, and where possible even enhance habitats to ensure that this renewable energy source is also tapped sustainably. As knowledge and experience builds with further development, the understanding of potential negative as well as positive impacts will improve; in the interim, there is the urgent need to draw on current knowledge. This document assists in addressing this situation.

Robin Rigg offshore wind farm, UK.
Photo: E.ON Climate & Renewables

1.2 Aim of the guidance document

IUCN has undertaken a joint project with the multinational energy corporation E.ON and the Swedish International Development Cooperation Agency (SIDA) to improve the environmental performance of offshore renewable energy projects by developing guidance to support best practice biodiversity considerations. It is envisaged that the guidance will also serve to inform the policy and practice of the conservation community and governments. This is especially relevant for developing countries where capacity is lower but renewable energy infrastructure is increasingly promoted.

The Greening Blue Energy project aims to facilitate well-balanced and science-based discussions on impacts on the marine environment from offshore renewable energy developments.

The guidance provides a synthesis of the current knowledge status on the potential impacts of offshore wind energy on the marine environment for project developers and offshore wind farm operators, using a model familiar to those considering impact assessment tools. The foundation for this overview is a review of more than 1000 reports and documents, at least 400 of which are peer-reviewed articles published in scientific journals. It encourages the consideration of the latest scientific-based impact research in conducting, scoping and evaluating Strategic Environmental Assessments (SEAs) and Environmental Impact Assessments (EIAs), based on relevant national and international standards.

The user-friendly summaries of environmental risks, as well as opportunities, enable well-balanced science-based discussions and considerations on the impacts of offshore renewable energy installations on the marine environment. The document is focused on offshore wind, where most information and experience exists, but lessons can also be adapted to other offshore renewable energy sectors such as wave and tidal, which are considered in Annexe 3.

Lillgrund wind farm in Sweden. Photo: Jerker Lokrantz

1.3 Target audience

This document is primarily aimed at offshore wind farm **developers** and operators for improvement of the industry as a whole. However it is recognized that other stakeholders may also be interested in the findings of the document, primarily **authorities** involved in environmental assessment and permitting processes.

It is also hoped that this guidance document will be of use to countries that have not yet considered policies on offshore renewable energy, so they may be aware of and anticipate potential environmental issues.

Other groups that may find the guidance in this document useful include concerned **non-governmental organizations** and **advocacy** groups, as well as other users of seascapes.

1.4 How to use this document

The main body of this guidance document is written in an easily accessible and understandable format. Section 2 provides an overview of the offshore wind energy sector, while section 3 guides the reader through the current status of offshore wind development, the current regulatory framework and existing guidance, and considerations of other marine users. General aspects of development, spatial planning and current research status are summarised. Potential impacts on the marine environment typically associated with the construction, operation and decommissioning of offshore wind farms are presented in section 4. Mitigation measures are suggested, and a way forward in addressing areas of uncertainty and governance issues is presented in section 5.

For those interested in more detail, a synthesis of the most current research on impacts on the marine environment is presented in Annexe 1. The present understanding of potential impacts on receptors and the receiving environment is highlighted, in relation to the extent of impacts. Further legislative context is provided in Annexe 2, with links provided for further information. Moreover, a brief overview of technology development and potential marine environmental impacts of wave, tidal and current power is provided in Annexe 3.

The document reviews existing knowledge and expertise on the marine environment as of December 2009. This document is printed in limited numbers, and the publication is meant to be used on-line, which allows the document to remain 'live' when significant information becomes available in this fast moving industry.

It is intended to present a generic framework for key issues to consider, and is illustrated by specific examples where relevant.

This document aims at providing generic guidance on environmental impacts of offshore wind farms. Also, such issues cannot be addressed without considering associated economic, technical, political, legal and social values. **In this regard, this document can only provide initial guidance and therefore cannot replace comprehensive site specific impact assessments as well as effective stakeholder engagement.**

1.5 Glossary of key terms and acronyms

Assemblage	A sub-set of a species population residing within a certain area.
Biodiversity	Biological diversity, the variability among living organisms from all sources and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems.
Benthos	Organisms that live on the seabed, from the highest water mark to the deepest trenches.
Decommissioning	A general term for a formal process to remove something from active status.
Environmental aspect	Element of an organization's activities or products or services that can interact with the environment.
EIA	Environmental Impact Assessment.
Environmental impact	Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's environmental aspects.
Mitigation	Alleviation/lessening of impacts.
Onshore wind farms	Wind farms located on land, whether on the beach or inland.
Offshore wind farms	Wind farms located in the sea, which could be in shallow coastal waters or on a bank far out at sea.
Life-cycle assessment	Analysis of the overall environmental impact of a particular economic activity.
SEA	Strategic environmental assessment.
Spatial planning	Refers to the methods used to influence the distribution of people and activities in space of various scales, including e.g. urban planning, regional planning, environmental planning.

2 Overview of offshore wind energy

The following chapter gives a short overview on the offshore wind energy sector and the current research status related to the marine environmental impacts of offshore wind facilities.

2.1 Trends

According to the Global Wind Energy Council, the total installed wind power capacity in 2009 represented 120,798 megawatts (MW) worldwide. More than 80 countries around the world have installed wind power. The United States recently overtook Germany with the highest total installed capacity. China is also rapidly expanding its wind capacity, overtaking India. (*see* Table 1)

Country	USA	Germany	Spain	China	India
Capacity	25,170 MW	23,903 MW	16,754 MW	12,210 MW	9,045 MW

Table 1: Top 5 countries wind capacity (International Energy Agency, 2009).

Offshore wind farms are increasingly being promoted as offshore winds are stronger and more sustained than winds over land. Placing turbines in the sea allows larger devices to be constructed, although the offshore environment is demanding in terms of transport, logistics and construction technologies. Moreover, studies indicate that there is generally less public opposition to offshore wind power compared with wind power development on land, although this will depend on the specific location.

So far, offshore wind farms only represent 1.5 per cent of the total installed wind capacity in 2009, primarily in Europe (*see* Table 2).

Offshore wind farms supply only 0.3 per cent of the European Union's total electricity demand today. However, according to the European Wind Energy Association's (EWEA) '*Oceans of Opportunity*' report, offshore wind could potentially supply between 12 and 16 per cent of the total EU electricity demand by 2030. This equates to more than 25,000 wind turbines, in wind farms covering up to 20,000 square kilometres of the European continental shelf. Such large-scale wind generation would eliminate more than 200 million tonnes of CO_2 emissions every year. While North America has no offshore wind farms currently in operation, large projects are planned for the east coast of the United States and Lake Ontario in Canada. China and India are also preparing for large offshore wind power projects. Efforts to combine economic development with environmental sustainability are also causing countries in East Africa to show growing interest in offshore renewables, with a current focus on wave energy.

Existing wind farms typically contain between 2 and 80 turbines, but future farms may consist of hundreds of turbines e.g. the London Array project is planned to contain 341 turbines. The distance between turbines commonly ranges between 500 and 1000 metres, and wind farms can thus cover many square kilometres. Presently, all commercial wind farms use turbines that are directly installed into the seabed, but floating alternatives are under development (*see* Box 1 (p. 17) for further information). At present most wind farms are installed in shallow water within the '20-20 frontier': at maximum of 20 kilometres off the coast and in a maximum water depth of 20 metres. Beyond this

Nation	Total capacity (MW)	No. of offshore wind farms	Number of turbines
UK	883	12	287
Denmark	639	9	305
Netherlands	247	4	130
Sweden	164	5	75
Germany	42	4	9
Belgium	30	1	6
Ireland	25	1	7
Finland	24	1	8
Norway	2	1	1
Japan	1	1	2
TOTAL	**2057**	**38**	**830**

Table 2: Offshore wind farms in operation around the world (adapted from EWEA (2009))

frontier, the challenges around technology, material and human factors increase substantially due to the rough offshore environment. However, these are increasingly being overcome. For example the offshore park alpha ventus is installed 45 kilometres off the shore at 33 metres depth. In Italy, Japan and Norway, countries that all lack broad continental shelves, floating wind power plants are being developed for placement at depth of 50-400 metres.

2.2 Policy drivers

Renewable energy options are increasingly being promoted in response to the global challenges of climate change, depleting indigenous energy resources, increasing fuel costs and the threat of energy-supply disruptions. More than 75 countries around the world have policies in place for renewable energy. For example, the European Union has a policy in place to reduce greenhouse gas emissions by 20 per cent, increase renewable energy provision to 20 per cent of primary demand, and increase energy efficiency by 20 per cent by 2020.

A critical factor in the successful development of wind energy is appropriate government support, often involving feed-in tariffs, subsidies or tax breaks to promote cleaner forms of energy.

In response to these policy trends and the need to diversify portfolios, a large number of energy companies are looking to expand the supply of renewable energy.

Nevertheless, the European Commission (EC) has identified challenges that must be overcome for the further development of the offshore wind sector. The challenges include:

- Weaknesses in the overall framework;
- Industrial and technological challenges;

- Lack of integrated strategic planning;
- Lack of cross-border coordination.

In their reports, the EC note a lack of knowledge and information sharing by authorities hampering the smooth application of EU environmental legislation, and the technical challenges of bottlenecks and power balancing in the onshore electricity grid.

2.3 Research status

Although still in a nascent phase, offshore wind energy is currently the most developed offshore renewable energy technology compared to, for example, wave and tidal power, and as such the associated environmental issues are better documented.

Academic research on environmental and ecological issues related to offshore wind development is being carried out primarily in Denmark, Germany, the UK and Sweden, partly in brackish environments. Although the Danish Monitoring Programme and other similar programmes have advanced the overall research status substantially, most research programmes have only recently been initiated, and many contributions are limited to the development of survey methods. Additionally, the majority of studies and experiments have focussed on single-species systems, and there is limited information about the effects on whole ecosystems.

Scroby Sands offshore wind park, UK. Photo: E.ON Climate & Renewables

The opportunity to extrapolate from onshore wind farm research to the offshore environment is limited. The marine environment differs fundamentally from terrestrial settings, not only in terms of the types of organisms likely to be affected, but also in relation to physical (e.g. sound distribution) and biological factors (e.g. regulation of food and energy flow and dispersal of offspring). Furthermore, offshore wind farms differ from all other marine-based engineering ventures in their scale of development, area of coverage, and their particular combination of disturbance factors (such as construction methods, shape, material, and noise). Nevertheless, information on the nature of environmental disturbance and recovery processes, as well as mitigation lessons, can be drawn from, for example, the oil and gas sector.

3 Impact assessment

This section provides an overview of relevant impact assessment concepts, tools and policies.

3.1 Assessing impacts in a global context

When exploring the impacts of offshore wind energy production, it is important to consider local impacts in the context of broader, global impacts. Climate change is an increasing threat to biodiversity. Energy generated from wind can achieve substantial avoidance of greenhouse gas emissions and thus combating climate change. In addition, toxic pollutants associated with for example the burning of fossil fuels, or the local environmental impacts of large hydropower developments, could be avoided by developing wind power.

These global and local advantages must however be balanced against the specific adverse effects offshore wind power may have on marine life. Minimising detrimental impacts of offshore wind power on marine habitats and ecosystems is central in the permitting process, and, according to surveys in several countries, is also a key topic for local acceptance of wind farms.

It is essential to seek to identify and minimise overall negative impacts on the marine environment. Mitigation of impacts can be done in many stages, based on a so-called 'mitigation hierarchy' (*see* Figure 1), for example, through avoiding sensitive sites, mitigating impacts through clever design and compensating for residual impacts, or through offsets (*see* section 4.3).

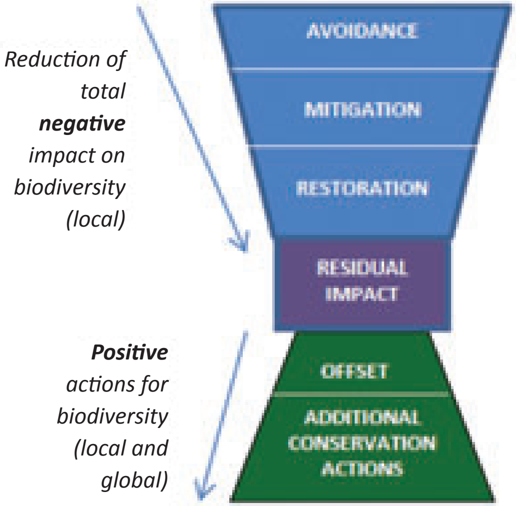


Figure 1: Mitigation hierarchy

3.2 Environmental assessment tools

The main tools that are used to assess the environmental impacts of projects and programmes are:

- **Strategic Environmental Assessments (SEAs) –** a tool that assesses associated environmental impacts of plans and programmes (including multiple projects) mainly undertaken by government authorities. They are accompanied by an Environmental Management Plan and require continual monitoring.
- **Environmental Impact Assessments (EIAs)** – used for individual projects by (a) a developer to take decisions on the project development based on the associated environmental

impacts, including mitigation plans and on-going monitoring and (b) the authorities to verify that the given project respects relevant environmental legislation.

Figure 2 presents a summary of the main differences and complementarities between SEA and EIA. For further information on specific requirements, *see* Annexe 2.

3.3 Legal context

To address the management of the environmental impacts of offshore wind power development, a number of international directives, conventions, treaties and standards, as well as national regulations and industry guidance have been developed. At any location a suite of international, additional regional and national regulations may be applicable, and each developer needs to seek advice pertinent to the country or countries within which their development will be located.

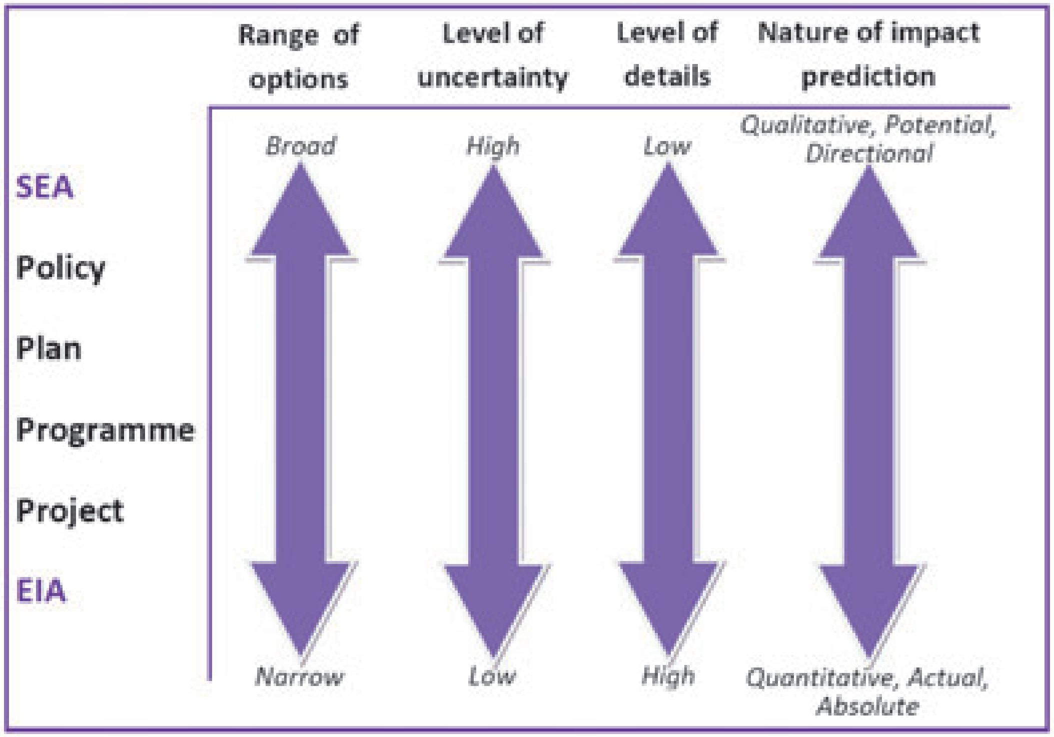


Figure 2: Main differences between SEA and EIA (adapted from Eales, et al., 2003)

3.3.1 European legislation

The European Union (EU) EIA legislation provides the minimum requirements that a Member State should demand from a developer during the life cycle of a project. The complete information required is also determined by the national law and conventions to which the country has signed.

The EU has several relevant legislations that relate to nature conservation and the protection of specific species and habitats (e.g. EU Habitats and Species Directive (92/43/EEC)) as well as EIA [Directive 85/337/EEC] and SEA [Directive 2001/42/EC]. Additionally, the implementation of the Marine Strategy Framework Directive [Directive 2008/56/EC] is expected to facilitate the EIA process for offshore wind energy projects and other offshore renewable energy developments.

Further information is available in Annexe 2.

3.3.2 World Bank requirements

The World Bank Group (WBG) and the International Finance Corporation (IFC) provide a set of guidelines to be followed to access financial resources for large-scale projects. According to the WBG/IFC guidelines, an EIA for an offshore wind farm project is required to list and describe all significant environmental impacts, including those that are:

- Unavoidable and irreversible;
- Positive and negative;
- Direct and indirect;
- Long-term and short-term and;
- Cumulative.

WBG/IFC also requires an analysis of possible alternative investment or policy options. This should include strategies in terms of environmental costs and benefits, coupled with a mitigation plan. Recommendations and guidance on the necessary stages that should be followed to meet the requirements for both assessments are provided by WBG/IFC.

WBG/IFC further specifies that offshore renewable energy projects should include a plan for Environmental Management and Training, Environmental Monitoring and Public Consultation actions.

3.3.3 Guidance from government and industry

While this guidance document presents information on the latest scientific information related to impacts on the marine environment of offshore wind energy development, other guidance materials that have been developed by government or industry bodies should also be considered when seeking broader information on wind farms and their environmental impacts. Specific information on environmental impact assessment processes and monitoring methods are provided in a number of other documents. Examples include:

- Nature Conservation Guidelines on Offshore Wind Farm Development – DEFRA 2005
- OSPAR Guidance on Environmental Consideration for Offshore Wind Farm Development – OSPAR 2008
- Best Practice Guidelines for the Irish Wind Energy Industry – IWEA 2008
- EU Draft Guidelines on Wind Energy Development and EU Nature Conservation Requirements – EU Commission (in prep.)

4 Impacts of offshore wind farms on the marine environment

This section provides a summary of marine environmental issues that are currently discussed by stakeholders in relation to offshore wind developments.

A brief account of potential impacts from offshore wind energy projects on the marine environment that require special attention is provided in section 4.2, along with suggested management options. For more details, Annexe 1 offers a review of trends and status in current research; these will evolve as research and experience develops further.

4.1 Impact summary table

A scientific review of the potential impacts of offshore wind farms on the marine environment was conducted during 2009 as part of this project. Table 3 summarises the results of this review, presenting the potential risks and benefits identified for key environmental issues related to offshore wind power development.

- **Limitations and species and system considerations**

The analysis treats animal groups as representing a cross section of species. Large data gaps exist, however, and effects are species- and season-specific. Systems and ecological responses may also differ significantly between regions and localities, as well as depend on technology and foundation type used. Estimations are notably limited to effects of single wind farms (*see* Annexe 1, sections 11 and 12, for further elaboration on ecosystem responses and variability among species and localities). Also, acceptable levels of disturbances will depend on the local/regional conservation status of species or habitats in question. Statements and conclusions are not necessarily based on consensus, but rather aim to reflect the median views of the authors.

KEY

The following criteria were set by the authors to assess the impacts:

Temporal

Short term: Through construction phase.
Long term: Through operational phase.
Permanent: Impacts persist beyond the operational and decommissioning phases.

Spatial

Very local: Within 10 metres from wind turbine
Local: 10-100 metres from wind turbine
Broad: 100-1,000 metres from wind turbine
Very broad: > 1,000 metres from wind turbine

Estimated degree of severity (-) or benefit (+) of impacts for species assemblages within the wind farm area are categorised as:

Small: Should not influence or have only small impacts on size or structure of assemblage.
Moderate: Impacts could moderately influence species assemblages, generally or for particular species.
Large: Impacts could significantly influence size or structure of species assemblages, generally or for particular species.

Certainty

1 = Literature consists of scientifically founded speculations.

2 = Research is in its infancy and inconclusive.

3 = Available literature provides a fair basis for assessments.

4 = Available literature provides a good basis for assessments.

5 = Evidence base is relatively solid.

Table 3: Key environmental issues of offshore wind energy

Key environmental issues		Level of certainty for predictions/ estimates (1 low to 5 high)	Estimated scale of impact n.a. = Not assessed			Discussed in section in Annexe 1
			Spatial	Temporal	Estimated degree of severity (-) or benefit (+) of impacts for species assemblages within the wind farm area	
FISH	Injuries from sound pulses (construction)	3	Local	n.a.	Small (-)	7.1
	Displacement/habitat loss (construction)	3	Very broad	Short term	(-) *see* 4.2.2	7.3
	Sediment dispersion (construction)	4	Broad	Short term	Small (-)	4
	Disturbance from operational noise	4	Very local	Long term	Small (-)	7.6
	Trawling exclusion	5	Broad	Long term	Large (+) *see* 4.2.3	3.3
	Artificial reef effects	3	Local	Long term	Moderate (+) *see* 4.2.3	3.3
	Electromagnetic fields	2	Local (but *see* migrating fish)	Long term	Small (-) (but *note* level of certainty and *see* migrating fish)	8.1
	Collisions with turbines	2	n.a.	n.a.	Small (-)	3.4
	Noise masking bioacoustics	2	Local	Long term	Small (-) (but *note* level of certainty)	7.9
MARINE MAMMALS	Injuries from sound pulses (construction)	3	Local	n.a.	Small (-) but *see* 4.2.2	7.1
	Displacement/habitat loss (construction)	3	Very broad	Short term	(-) *see* 4.2.2	7.2
	Displacement, disturbance (operation)	3	Very local	Long term	Small (-)	7.7
	Habitat enhancement	1	Broad	Long term	Small (+) (but *note* level of certainty)	3.3
	Migration barriers	2	n.a.	Long term	Small (-) (but *note* level of certainty and extra caution for whales), and *see* 4.2.3	7.9
	Collisions with turbines	2	n.a.	n.a.	Small (-)	3.4
	Noise masking bioacoustics	2	Local	Long term	Small (-) (but *note* level of certainty)	7.9

Key environmental issues		Level of certainty for predictions/ estimates (1 low to 5 high)	Estimated scale of impact n.a. = Not assessed			Discussed in section in Annexe 1
			Spatial	Temporal	Estimated degree of severity (-) or benefit (+) of impacts for species assemblages within the wind farm area	
BIRDS	Displacement/habitat loss (construction)	5	Very broad	Short term	(-) *see* 4.2.2	9.3
	Displacement/habitat loss for seabirds (i.e. sea ducks and divers) (operation)	4	Very broad	Long term	(-) *see* 4.2.3	9.3
	Migration barriers (operation) 1. long distance migrators 2. daily commuters	3	n.a.	Long term	1. Small (-) 2. Moderate (-) *see* 4.2.3	9.2
	Collisions with turbines	3	n.a.	Long term	Small (-) but *see* 4.2.3	9.1
BENTHOS	Sediment dispersion (construction)	3	Broad	Short term	Small (-)	4
	Acoustic disturbance (construction)	2	Local	Short term	Small (-) (but *note* level of certainty)	7.4
	Changes in community structure directly due to turbines	4	Local	Long term	Small to Moderate (-) *see* 4.2.3	3.1 & 5
	Electromagnetic fields	2	Very local	Long term	Small (-) (but *note* level of certainty)	8.2
	Anoxia created	4	Very local	Long term	Small (-)	5
	Habitat enhancement (not considering trawling exclusion)	4	Very local	Long term	n.a.	3.1
	Entry point for invasive species	2	Very broad	Long term	n.a.	3.2
	Effects of trawling exclusion	5	Broad	Long term	Large (+) *see* 4.2.3	3.1
HYDROLOGY	Depletion of phytoplankton	4	Local	Long term	Small (-)	5
	Upwelling or downwelling at the perimeter of wind farm	1	Local	Long term	Small (+/-) (but *note* level of certainty)	5
	Toxic substances	4	Local	n.a.	Small (-)	6
	Oil spills (e.g. ship accidents)	-	n.a.	n.a.	(-) *see* 4.2.3	
SEA TURTLES	Displacement/habitat loss (construction)	2	Very broad	Short term	(-) *see* 4.2.2	7.1 & 7.8
	Displacement/habitat loss (operation)	2	Very local	Long term	Small (-) (but *note* level of certainty) *see* 4.2.3	7.8

4.2 Managing impacts across the project life cycle

This section outlines the environmental issues that, based on the review presented in Annexe 1, call for special attention. Pointers are provided where further information can be found within Annexe 1.

The impacts and potential entry points for reducing the impacts will vary depending on what stage of the project lifecycle the development is operating within (*see* Figure 3). For the purpose of simplification, this guidance is broken down into 4 sections, oriented on the project development phases.

Figure 3: Project life cycle

4.2.1 Planning

Main activities, e.g.

- Site selection/prospecting;
- Planning;
- Design, e.g. turbine type and installation method (*see* Box 1: Foundation types) and consideration of removal options (*see* section 4.2.4 on Decommissioning);
- Licensing/permitting (including EIA). The consideration of alternatives is fundamental, and a comparative assessment undertaken of those options deemed feasible;
- Design of appropriate mitigation measures.

In the prospecting, planning and permitting processes, turbine type, installation methodology (e.g. piling, seabed preparations) and appropriate mitigation measures, need to be taken into careful consideration. Decisions made at the planning stage have implications for the remainder of the life cycle stages. Significant impacts can be avoided at the planning stage, minimising the need for potentially costly mitigation measures later in the project cycle. Most issues that cannot be mitigated through the design can be addressed at the early stage of spatial planning and by including conservation priorities into seascape management plans. Further, potential impacts of seismic shooting during the prospecting phase need to be taken into consideration.

4.2.2 Construction

Main activities:

- Site preparation, dredging and levelling;
- Piling/installation of foundation;
- Cabling;
- Transport (shipping) and
- Transport (air).

Main disturbance factors:

- Noise;
- Seabed disruption and
- Increased activity (e.g. boat traffic).

Box 1: Foundation types

There are different foundation technologies available. Currently commercially viable are gravity foundations, tripod/jacket and monopiles. Other approaches like bucket or floating foundations are under development, or are being researched (*see* Figure 4).

Figure 4: Offshore foundation options – the figure demonstrates the four main types of offshore wind power foundations. From left to right: Gravity, Monopile, Tripod, Floating. © C. Wilhelmsson.

Gravity foundations

Design - Secured to the seabed by their own weight. The structures are normally built in dry docks and transported to the site.

Use - Gravity foundations are in use today (e.g. Lillgrund in Sweden, Rødsand in Denmark), and are the second most common type after monopiles.

Depth - Generally restricted to shallow waters (<5 metres), but construction has started in depths of 20 metres in Thornton Bank, Belgium. Usage in up to 30 metres depths is possible; but costs increase with depth.

Preparation - Gravity foundations require a fair amount of seafloor preparation and care must be taken to prevent erosion around the base.

Monopile foundations

Design - A steel pile, extension of the tower, is driven 10-20 metres beneath the seabed. Compared to gravity foundations, monopiles are much lighter, more resilient and can be placed in deeper waters.

Use - Monopiles are the most common form of foundation used. They are expected to dominate developments for the next few years.

Depth - Can be used in water depths of up to 30 metres, approximately.

Preparation - Monopiles can only be used under specific seabed conditions (e.g. seabed not dominated by large boulders) but then do not require seafloor preparation and are less susceptible to erosion.

Tripod and Jacket foundations

Design - For tripods, the foundations are stabilised by three steel piles connected to the submerged section of the turbine tower. Jacket foundations are normally four-legged and of a stable lattice construction connected to the seafloor. Compared to monopiles, tripod and jacket foundations are more complex and thus more expensive.

Use - Tripod and jacket are used in the alpha ventus project. Also, the Beatrice oil platform off the East coast of Scotland is currently testing two 5 MW turbines in depths of 45 metres using a jacketed structure.

Depth - Tripod and jacket are suitable for greater water depths (30-60 metres).

Preparation - Erosion is usually not a problem, but, as with monopiles, usage in areas with large boulders is not possible due to piling requirements.

Floating and Platforms

Design - Floating turbines and platforms are anchored to the seabed to keep position. Engineering is complicated due the random nature of forces (wind and waves) that act on the turbines. But, as floating systems could be assembled onshore (reduced construction costs), this technology has certain advantages.

Use - Designs are being adapted from the oil and gas sector, but currently no commercial projects using floating platforms are in operation. Floating turbine technologies may be commercially available by 2020.

Depth - As offshore wind farms transit to depths of 50 metres or more, floating turbines or turbines placed on platforms will likely replace conventional foundations. In depths of 70 metres or more, they are predicted to be the sole option available.

(continues overleaf)

Foundation Types (continued)

Floating and Platforms

Preparation – Assembled onshore, and are fixed to the seabed with large anchors (e.g. 'embedded anchors').

Suction Bucket foundations

Design - The suction or bucket foundation is a concept used in the oil and gas industry where a bucket foundation is pressed to the seabed and suction is generated to keep it in place.

Use - Information on this technology is currently limited.

Depth – Not assessed

Preparation – No need for pile driving, and is less complex than jacket/tripod. This type seems most suitable in clay and sandy seabeds, as firmer substrates require larger pressure differences.

ISSUES THAT REQUIRE SPECIAL ATTENTION

Threat: Piling noise/construction activities

The construction phase of wind farms will inevitably generate noise from seabed preparation (e.g. levelling, which could include the use of explosives), installation of foundations and boat traffic. In particular, pile driving for monopiles, tripod and jacket foundations causes acute noise disturbance. Subsequent effects depend on a number of factors, such as seabed topography and composition, diameter of the piles, ambient sound and the marine species under consideration.

Generally, noise impacts should be temporary. However, noise generated during piling may kill or injure fish, mammals and sea turtles, or cause them to abandon an area tens of kilometres from the construction site. Species relocation could severely affect spawning and nursery habitats if appropriate seasonal prohibitions are not used. Sea turtles may be particularly sensitive to even temporary habitat losses, as they seem highly inflexible in their spatial distribution patterns.

Annexe 1 – *see* sections 7.1-7.4 for more details

Mitigation options

- Habitat use and migration patterns of sensitive species need to be considered in terms of timing of construction of wind farms. Seasons when sensitive species of vulnerable populations congregate during key life stages should be avoided during construction (and decommissioning e.g. spring and early summer is the main reproductive season for many species in temperate regions).

- To avoid injuries from acute sound pulses, the use of 'pingers' to scare away porpoises and dolphins before construction activities start has been suggested and has also been used during offshore wind farm construction.

- A standard approach is to gradually increase the strength of the pile-driving hammer to give mammals, larger fish and sea turtles a chance to move from the area before maximum sound generation levels are reached. It should be noted, however, that this method is not uncontroversial as it may lead to gradual habituation and even attraction to the initially weak sounds.

- Another method is to surround the pile driving area with a curtain of bubbles or wrap the piles in sound dampening material. Bubble protection can reduce the sound volume by 3-5 dB, i.e. half of the sound intensity, but the method is dependent on weak currents.

Construction of Utgrunden Wind Farm in Sweden. Photo: Gunnar Britse

4.2.3 Operation and maintenance

Main activities:

- Operation of wind turbines.

e.g. maintenance, such as repairs, change of oil in transformer stations, re-painting and sand-blasting.

Main disturbance factors:

- Physical presence of the turbines;
- Noise and
- Maintenance activities.

ISSUES THAT REQUIRE SPECIAL ATTENTION

Opportunity: Trawling exclusion

Trawling, which is probably one of the most severe threats to the benthic environment, is prohibited or restricted inside offshore wind farms, and areas that encompass several square kilometres will resemble 'no take zones'. Hence, for areas that were previously trawled, there will be less physical disturbance on benthic communities and a more favourable environment for long-lived rather than opportunistic species will be generated. This will benefit biodiversity of benthic species, with potential spill-over effects to adjacent areas. 'No take zones' could positively affect fish stocks, provided the fish spend a sufficient time within the area and, do not avoid the area for example due to noise or other forms of disturbance within the wind farm. Another prerequisite for positive effects on fish stocks is that the reproductive behaviour or feeding efficiency of fish inside the wind farm is not significantly disturbed.

Enhancement options

- In addition to the safety zones around wind farms, the 'no take zone' could be expanded to further enhance the benefits for marine organisms and their habitats.

- Wind farms could also be strategically located to protect certain marine resources, provided disturbance effects of construction and operation of the wind farms do not outweigh or neutralise the advantages of trawling exclusion.

Annexe 1 – *see* sections 3.1 and 3.3 for more details

Fishing vessel leaving Lillgrund Wind Farm in Sweden. Photo: Mattias Rust

Opportunity: Habitat enhancement

Wind turbines and scour protection structures can serve as habitat for fish and invertebrate assemblages. Habitat enhancement could compensate for loss of biologically important areas elsewhere, in line with indications in the EU Marine Strategy Framework Directive (MSFD, 2008/56/EC). The significance of habitat enhancement through offshore energy development will depend on the scale and area under consideration, but for most species it will probably be negligible at regional scales. Likely exceptions to this may occur when heavily-fished, habitat-limited and/or vulnerable species are protected from exploitation or favourable habitat is provided for them.

Annexe 1 – *see* sections 3.1-3.3 for more details

Enhancement options

- To mitigate seabed erosion around turbine foundations due to water movement, boulders or gravel are placed on the seabed. The scour protection extends from the base of turbine to a distance of about 5-10 metres from each turbine. Alternatively, synthetic fronds (scour mats), facilitating sedimentation, are laid around the foundations. These elements, as well as the turbines as such, can be specially designed to enhance the habitat for selected species.
- To enhance, where desired, the extent of artificial reef patches, and the connectivity between them, additional reef patches could be created in a larger area within the offshore wind farm.

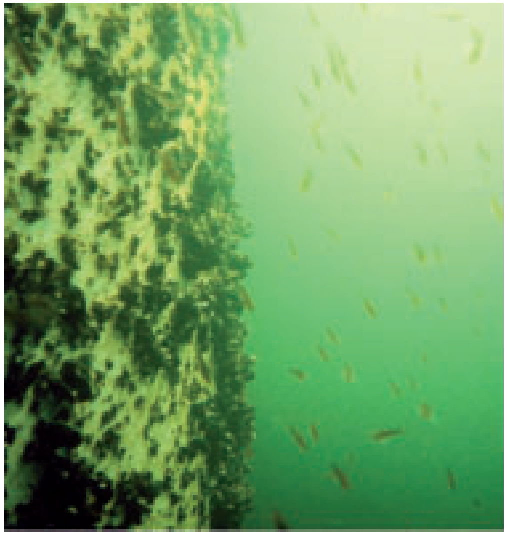
Threat: Habitat loss for sea ducks and divers

It has been shown that some seabird species (e.g. divers and sea ducks) avoid wind farm areas not only during construction but also during operation. The severity of effects on local bird assemblages largely depend on whether the birds find alternative habitats or not.

Annexe 1 – *see* section 9.3 for more details

Mitigation options

- Important habitats for feeding and breeding should be avoided. However, in many cases, these habitats are not yet sufficiently identified.
- By building in waters deeper than 20 metres or avoiding areas with high biomass, benthic feeding grounds for seabirds could be spared.
- For example, an area can be considered



Wind turbine in the Kalmar Strait, providing habitat for blue mussels (*Mytilus trossulus*) and two spotted gobies (*Gobiusculus flavescens).* Photo: Dan Wilhelmsson.

important for a species if more than 1 per cent of a population resides within it or uses it, according to commonly applied criteria from the Ramsar Convention. Detailed species sensitivity indexes for impacts of offshore wind farms on seabirds are available.

Threat: Migration barriers for birds, sea turtles and whales

Several bird species avoid wind farm areas during migration. Studies have shown numbers of eiders and geese flying through offshore wind farm areas to decrease 4-5 times after construction. However, the energetic losses during migration due to barrier effects and through avoidance of single wind farms seem trivial. Energetic costs have only been proposed to be measurable for species commuting daily within a region, for instance between foraging grounds and roosting or nest sites. In these cases wind farms could cause fragmentation of coherent ecological units for the birds. Impacts of sound disturbance from wind farms on long-distance communication and navigation among mammals, such as whales during migration, is largely unknown. Sea turtles are threatened worldwide and may be disturbed by the low frequency sound from turbines. They show strong fidelity to migration routes, which may make them more susceptible to disturbance.

Annexe 1 – *see* sections 9.2 (birds) and 7.7, 7.8 and 7.9 (other species) for more details

Cultivation of blue mussels. (*see* Box 2, p. 26) Photo: Tony Holm, Azote

Mitigation options

- Diurnal migration pathways between resting and feeding areas for vulnerable bird species should be avoided.
- If there are risks of overlap, several kilometres wide alternative migration corridors should be kept open between wind farms.
- Corridors could also be provided inside wind farms, as birds have been shown to use the corridors when flying through such areas.
- Migration patterns of sea turtles need to be thoroughly considered.

Threat: Bird collisions

It has been broadly suggested that collision risks at offshore wind turbines would cause minimal mortality within populations. There are still considerable research gaps, however, and a recent offshore wind farm study, for example, indicated that the majority of collisions occur a few days per year, when bird navigation is hampered by bad weather, which weakens predictions.

Annexe 1 – *see* section 9.1 for more details

Mitigation options

- To minimise collision risk, placement of wind farms in important migration corridors should be avoided.
- The alignment of turbines could be reconsidered, and turbines could be made more visible for birds.
- Illumination could also be adjusted to a level that maintains vessel navigation safety, but reduces the potential attraction of birds.

Threat: Seabed changes

Deployment of wind turbines and scour protection will result in approximately 1-3 per cent direct loss of seabed within the farm area, with each installation claiming up to 450 square metres. The abundance of fish and crabs is likely to increase as a result of the physical structures added, and as a consequence densities of benthic prey can decrease in proximity to wind turbines. The suggested radius of influence on biomass of prey and macroalgae around an artificial reef ranges between 15 and 100 metres. The entrapment and deposition of organic matter, including material that originates from fish and invertebrates on and around an artificial reef, can influence benthic communities up to 40 metres away and cause localised changes in composition of macro-invertebrate assemblages as well as changes in physicochemical and other parameters adjacent to the structure. Filtration by the large numbers of blue mussels on the turbines could, according to one study, deplete phytoplankton and, as a result, cause lower biomass of filter feeding animals on the seabed up to 20 metres from a turbine. These impacts should only be of significance in protected habitats where vulnerable species are present or where the scale of the development is substantial. Wind farms also provide hard substrata (including shallow sections) to areas otherwise often dominated by sedimentary seabed and thus change the dispersal patterns and distribution of reef dwelling species.

Annexe 1 – *see* sections 4 and 5 for more details

Threat: Navigational hazards/oil spills

The increase in number of industrial facilities in coastal and offshore waters as a result of offshore renewable energy development may amplify navigational hazards for ships, particularly where wind farms claim areas of deeper water greater than 20 metres in depth. This increases the risks of oil spills and other types of marine pollution. A wind turbine for example could rip the side of a vessel and cause an oil spill. It is also possible that the wind turbine

Utgrunden Wind Farm, Sweden. Photo: Gunnar Britse

rotor and generator, weighing up to 400 tonnes, could fall on a ship, though this can be prevented through the technical design of a turbine such as at the alpha ventus site. Environmental risk evaluations taking the impacts of different types of foundations on ship hulls into consideration have ranked collisions with jacket and tripod constructions as the most severe, while a collision with a monopile may cause less damage to the environment. The collision risk for each individual case is a product of a number of factors, such as ship traffic, distance to navigational routes, wind, current and weather conditions.

Mitigation options

- The collision risk could be decreased through appropriate security measures.
- The latest generation of ships are constructed with double-hulls, which decrease risks of environmental impacts substantially in the case of a collision, but single hulled ships are still used extensively.
- Follow relevant guidelines. For example, the Maritime and Coastguard Agency in the UK provides guidelines for addressing navigational impacts of all types of wind power installations, including safety measures.

Seals at Utgrunden Wind Farm. Photo: Gunnar Britse

4.2.4 Decommissioning

Given that the life span of an average offshore wind farm is estimated to be 25 years, little evidence has been collated on the issue of decommissioning. However, experiences from the oil and gas sector can be adapted for offshore wind farms. In a manner similar to oil rigs, decommissioned wind turbines could be disassembled and recycled or, discarded to landfill, or be reconditioned and reused. Turbines could also be partially removed or toppled.

Option 1: Complete removal

If a wind farm is completely removed, so are the associated disturbance effects. However, some problems of sediment re-suspension may occur, especially if the cables have been buried, consequently disturbing any sensitive habitats. In addition, habitats that may have been created and developed over a number of years, in many cases constituting islands of comparably undisturbed hard substrata in regions otherwise dominated by deeper soft bottoms, would be disturbed. Further, if a wind farm has effectively protected an area from the destructive effects of fishing this protection is likely to disappear with the farm.

Future technologies may provide better alternatives, but current experience from oil rig decommissioning favours explosives and cutting. Explosives would kill most animals in the zone nearest to each turbine, and fish with swim bladders would be most severely impacted. Considering the large numbers of turbines and the area they cover, impacts could be substantial if this technique is used.

Although the presumption at the outset is for complete removal of all turbines, the decommissioning of the subsurface parts of wind turbines may in many cases become questioned.

Option 2: Leave structures in place, including toppling

Another option for decommissioning is to leave the subsurface structures in place. Toppled turbines would not emit noise or have any moving parts. If not removed, the installations would effectively be permanent due to very slow degradation rates for carbon steel. Any habitats that have been created and any habitat disturbances from the physical presence of the turbines would then be maintained.

Option 3: Continual upgrades

Dissimilar to oil and gas, wind resources are renewable, and so it may be decided that the wind farm

Service vessel at Nysted wind farm in Denmark. Photo: Gunnar Britse

should remain in operation, with continuous maintenance and upgrading where necessary. Both positive and negative impacts on the marine environment of the operation of the turbines would then be maintained.

In conclusion, decisions on the fate of the wind turbines should inevitably be made on a case-by-case basis.

4.3 Residual impacts

Although the offshore wind-farm developer may work through the mitigation hierarchy (*see* Figure 1) and identify, avoid and minimise impacts from a particular development, residual impacts will still remain. These may or may not be significant, depending on the sensitivity of the area and species. Residual impacts may include (but not be restricted to):

- The loss of habitat within physical footprint of turbine/foundation/scour protection and in nearby areas.
- Enforced changes to species assemblages through the physical presence of the turbine and resulting impacts on predator/prey balance.
- Noise and electromagnetic fields may still effect some species behavioural changes, despite any mitigation actions taken to lessen these impacts.
- Although restricting fishing activity within an area may be beneficial to the marine environment in the wind farm, there could still be residual biological and social impacts as fishing may be displaced to other areas.

Project developers are now increasingly considering ways to try and address, or compensate, for their residual impacts. Biodiversity offsets are one way to ensure that a net loss to biodiversity from the project development is avoided and that a net gain may result overall.

Offsets need to be quantifiable and anticipated biodiversity losses predicted and balanced against predicted gains with respect to species composition, habitat structure, ecosystem function and people's use of biodiversity. The Business and Biodiversity Offset Programme (BBOP) is currently considering many of these aspects in relation to real world case studies, and is working with key developers to design and implement biodiversity offset projects for their operational sites (http://bbop.forest-trends.org/index.php).

4.4 Cumulative impacts and synergies

Cumulative impacts can be assessed on two levels:

- The combined impacts of a single wind power project against the background of existing anthropogenic pressures, such as pollution, ship traffic, sand and gravel extraction.
- The consequences of several wind farms in an area or region, in terms of e.g. migration barriers and habitat loss and fragmentation.

Offshore wind farms affect habitats over a broad seascape where the combined effects may be more pronounced than the sum of the impacts of individual turbines and farms. Though often required in EIA legislation, EIAs rarely address the cumulative effects of existing activities or other planned developments, including strategic aims for offshore wind power. To improve this, criteria and methods for assessing cumulative effects need to be designed and standardised at appropriate temporal and spatial scales. SEAs should also address cumulative effects and synergies should be addressed at a scale appropriate to the plan/policy/programme.

Figure 5 *below* illustrates the process for assessing impacts of wind power developments on marine species, which should incorporate ecological links between species and cumulative effects of several wind farms in an area/region.

Figure 5: A summary of stages within an SEA (based on EC Directive 2001/42/EC)

To estimate regional impacts, for example, seafloor maps and models of population connectivity need to be developed. The ecological consequences (e.g. growth, survivorship, reproduction) for organisms positively or negatively affected by wind farms, as well as any potential cascading effects need to be investigated and monitored throughout the operational duration, in order to gain a more comprehensive picture of disturbance effects.

4.5 Interactions with other marine users

The impacts of offshore wind farms should not be considered in isolation of other concerned users of a marine environment. Through an effective consultation as part of an impact assessment process, potential threats can be identified, and opportunities could be better managed. The below indicates examples of threats and opportunities presented by offshore wind farms. Sectors to consider include (but are not limited to):

- Fisheries;
- Aquaculture (*see* Box 2);
- Shipping;
- Leisure and tourism and
- Other offshore renewable energy sectors (*see* Box 3).

Box 2: Aquaculture

Aquaculture of fish, mussels for human consumption is predicted to increase considerably in the next few decades. Cultivation of mussels has also been tested for production of animal protein and fertilisers, and for recycling of nutrients in eutrophicated water bodies. Wind farm developments may offer unique opportunities to exploit areas further offshore. Solid wind turbine foundations could provide anchoring for aquaculture installations in areas that are not suitable for conventional techniques. It has, also, been shown that blue mussels from open ocean sites may have significantly less parasite infestations than at inshore sites, which in theory could enhance survival and growth.

Aquaculture installations offshore may also benefit from lower levels of pollution from urban and agricultural runoff. Blue mussels, growing on the turbines themselves, providing beneficial conditions for settlement and growth of filter feeding organisms (*see* Annexe 1, section 3.1.), could also be harvested if cost-effective techniques are developed. Mussels from oil platforms have been harvested for human consumption in Southern California Bight. Provided that this reduces the density of aquaculture ventures nearshore, and that related environmental problems are not simply transferred to sensitive pristine habitats offshore, this option could offer environmental mitigation for the aquaculture sector.

Box 3: Synergies with wind and wave power parks

The viability of a combined wave and wind energy park is currently being tested in Denmark. Wind and wave power installations could share foundations, electricity transmission routes and maintenance costs, with associated reduction in overall disturbance of the marine environment. Wind and wave power may have complementary periods of optimal performance and so combining the output from both could provide a more continuous electricity supply, with less need for back up energy sources.

5 Conclusions and recommendations

5.1 Strategic and Governance issues

Ocean resources are limited; therefore comprehensive integrated approaches are essential to manage human activities. Large-scale offshore renewable energy developments constitute a relatively new challenge for integrated coastal management strategies and marine spatial planning. Wind farm development within territorial waters should therefore be incorporated within Integrated Coastal Zone Management (ICZM) and spatial planning instruments, where applicable.

Coordination of conservation measures (e.g. Natura 2000 designation) and wind power development should be facilitated through enhanced information exchange among authorities. The relatively rapid rate of development for wind power could otherwise forestall the often complex processes of research, evaluation and designation of marine protected areas. As wind farms exclude trawling, both spatial planning and nature protection may, on the other hand and under certain circumstances, benefit from combining conservation measures with offshore wind farm development.

Impacts on mammals and fish during construction activities (e.g. piling) largely depend on the availability of suitable alternative habitats. Thus, to minimise cumulative effects of concurrent development activities, both the timing and areas for construction by different developers need to be coordinated at central level.

Spatial planning should be fully utilised. As impacts from offshore wind farm construction may extend several kilometres from the development area, for example, appropriate safety/buffer zones should be applied in the spatial planning process, avoiding biodiversity hotspots and vulnerable habitats.

5.2 Areas of uncertainty and points to address

Substantial knowledge gaps and uncertainties still exist in this area, and these hamper the effective assessment of impacts and the issuing of some construction and operational permits. For example, there is a considerable paucity of ecological baseline data, which limits EIAs and monitoring programmes. If a precautionary approach is not applied, this could also jeopardise habitats, species and ecosystems, including those of high conservation interest. The number of targeted biological and environmental surveys in relation to offshore energy development is, nevertheless, increasing. Continued and enhanced monitoring of carefully selected environmental (both biotic and abiotic) parameters during construction and operation of offshore renewable energy farms will in time generate more reliable data on both the adverse and potentially positive effects of offshore wind power development. The opportunity for identifying and achieving consensus among stakeholders on areas to be considered for exploitation could thus be facilitated, and the development of mitigating construction methods and other measures to protect the marine environment could also be enhanced.

It will, however, take several years for new monitoring programmes to provide a comprehensive overview of environmental risks and opportunities. Caution is further advised when, for example, applying research or data generated in temperate regions to other regions such as the tropics, as there are major differences in regulating factors, species and habitats at different latitudes. Uncertainty about predicting consequences also increases with the scale of wind farm development, in terms of both the size and number of installations.

5.3 Improving use of impact assessments

Some EIA standards request up to two complete successive years of data before construction of wind farms can be approved. These timeframes must, however, be seen as a result of a pragmatic approach, as they are generally not sufficient to fully understand the ecological effects for each site in question, including seasonal and inter-annual variability at both ecosystem and species levels. Furthermore, the Before-After-Control-Impact (BACI) impact studies, a standard approach in EIAs, would benefit from including sampling of appropriate distance related effects to a larger degree.

The existing baseline data available for a marine area strongly influences the quality of the EIA, which should be taken into account during the site selection and permitting processes.

EIAs for offshore wind farms are performed at varying scales, and at different scopes and depths of studies. This has resulted from a lack of comparable national standards, as well as differing interpretations of EIA requirements by consenting authorities. To avoid arbitrary or non-precautionary approaches, solid scientifically based standards and threshold values for assessments of impacts should be developed at national, and if possible also at regional levels. Additionally, international guidelines and information exchange networks (such as EMODNET) should be established to minimise local and national obstacles to conduct and scope EIAs.

The relevant criteria upon which impact prognoses are to be based should be clarified. Population and particularly subpopulation effects on species are central in impact assessments and consenting processes. There are, however, generally no regional or national agreements on acceptable levels (i.e. impact intensity) or scales (e.g. reference populations to consider and biogeographic distribution affected) of disturbance for species in question. These weaknesses need to be addressed at national as well as transnational levels.

Appropriate assessments of cumulative effects should be supported by data provided at SEA level. Information on environmental requirements for completion of SEAs for construction at sea is, however, still too minimal.

Appropriate baseline data on the state of the marine environment, distribution of important and sensitive species and habitats, and migration routes of birds, fish and mammals are generally very scarce in relation to the requirements for impact assessments. Research on species distribution and abundance over annual cycles, population structures and status, as well as the development of analytical tools for assessing ecosystem and cascading effects are therefore required.

Strategic research to develop species-specific sensitivity indices in relation to offshore wind energy development (currently only available for birds) in different life stages and in different regions is also required.

More research on the effects of noise on different species, as well as the mechanism and cues underlying avoidance behaviour by birds, is required for the development of appropriate mitigation strategies where necessary. This is also the case in regard to the impacts of electromagnetic fields as barriers for migrating fish. In addition, the potential benefits of fishery closures and the provision of artificial habitats as a by-product of wind farm development should be further explored.

5.4 Final conclusions

As the global offshore wind energy industry further expands and continues to mature, companies and governments will benefit from increased knowledge and experience.

Ongoing monitoring will be crucial to identify how successful previous mitigation strategies have been in avoiding or reducing impacts on the marine environment. Future decisions can integrate new findings and mitigate new threats. Learning from other processes, other types of installation (e.g. multi-use sites in Japan) should not be overlooked. By undertaking rigorous impact assessment and systematic environmental management, the industry will continue to learn through the plan, do, check, act approach and apply continuous improvement to their practices and procedures. Through marine spatial planning, cumulative and synergistic impacts can be better managed and impacts and opportunities for all sea users taken into consideration.

Planning and development decisions made at this stage of the development of offshore wind energy will be setting a precedent for future developments, both in Europe and beyond, so it is imperative that shortcomings in research and knowledge are addressed as a matter of urgency.

6 Additional resources

While the Annexe 1 provides significant scientific guidance, the below section is intended to provide references to the main resources referred to in the text above.

E.ON

Offshore fact book: http://www.eon.com/de/unternehmen/23700.jsp

World Bank

In 2007, the World Bank Group (WBG) and the International Finance Corporation (IFC) released a revised version of their Environmental, Health and Safety Guidelines. These offer general and sector-specific examples of 'Good International Industry Practice'. The industry guidance for the Electric Power Transmission and Distribution sector includes good practice on wind energy. These documents complement the Environmental Assessment Sourcebook released 10 years earlier by WBG.

Environmental, Health and Safety Guidelines: http://www.ifc.org/ifcext/sustainability.nsf/Content/EHSGuidelines - *see* General EHS Guidelines (full document) and Industry Sector Guidelines subheadings Power/Wind Energy and Power/Electric Power Transmission and Distribution

Environmental Assessment Sourcebook: http://go.worldbank.org/LLF3CMS1I0

European Commission

EU environmental legislation to offshore wind farm development such as Directives on:

- The conservation of wild birds: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1979:103:0001:005:EN:HTML
- Natural habitats and of wild fauna and flora: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31992L0043:EN:HTML
- EIA (the assessment of the effects of certain public and private projects on the environment) [Directive 85/337/EEC];
- SEA (the assessment of the effects of certain plans and programmes on the environment) [Directive 2001/42/EC].

European Wind Energy Association(EWEA): http://www.ewea.org

EWEA (2009) Oceans of opportunity: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Offshore_Report_2009.pdf

Annexe 1 Research on impacts

Review of the impacts of offshore wind energy on the marine environment

1 Introduction

A review of potential negative and positive impacts of Offshore Wind Farms (OWF) on the marine environment was conducted in 2009, and the results are presented below. Statements and conclusions are not necessarily based on consensus, but rather aim to reflect the median views of the authors.

The analysis treats animal groups as representing a cross section of species. Large data gaps exist, however, and impacts may also be species- and season-specific. Systems and ecological responses may also differ significantly between regions and localities. Also, acceptable levels of disturbances will depend on the local/regional conservation status of species or habitats in question. Most impacts treated in this review are assessed on spatial, temporal scales, as well as in terms of the estimated degree of severity or benefit for organisms within a wind farm area, according to the legend below.

Key: Temporal and spatial dimensions, as well as the severity/benefit of effects on species assemblages are noted in the text according to categories as defined below (in bold italic text). Where appropriate, conclusions provide 'certainty' scores, indicating the level of certainty of understanding provided by current research:

Temporal

- ***Short term***: Through construction phase.
- ***Long term***: Through operational phase.
- ***Permanent***: Impacts persist beyond the operational and decommissioning phases.

Spatial

- ***Very local***: Within 10 m from wind turbines.
- ***Local***: 10-100 m from wind turbine.
- ***Broad***: 100-1,000 m from wind turbine.
- ***Very broad***: > 1,000 m from wind turbine.

Estimated degree of severity (-) or benefit (+) of impacts for species assemblages within the wind farm area are categorised as:

- ***Small***: Should not influence or have small impacts on size or structure of assemblage.
- ***Moderate***: Impacts could moderately influence species assemblages, generally or for particular species.
- ***Large***: Impacts could significantly influence size or structure of species assemblages, generally or for particular species.

Certainty

1 = Literature consists of scientifically founded speculations.

2 = Research is in its infancy and inconclusive.

3 = Available literature provides a fair basis for assessments.

4 = Available literature provides a good basis for assessments.

5 = Evidence base is relatively solid.

2 Main types of sea areas likely to be used for offshore wind power

Current technologies, including monopiles, tripods and gravity foundations (*see* Box 1 in Chapter 4 of the main document) limit offshore, non-floating, wind turbines to coastal areas not deeper than 30 metres, with some exceptions (e.g. Zhixin, et al., 2009). Seabeds consisting of muddy sand, sand or gravel beds with only scattered boulders are preferred for technical and economic reasons. Exploited areas are obviously exposed to strong wind forces. Thus, the substrate is frequently turned over during storms and communities may be dominated by opportunistic algae and animal.

However, offshore banks that are technically suitable for wind power development can provide a refuge for species that have been excluded by pollution, eutrophication and anthropogenic development further inshore. Infaunal assemblages that are important sources of food for birds and fish usually dominate the seabed in these habitats, in both temperate and tropical regions. Such areas provide habitats for feeding, resting, and may be especially important as nursery habitats for mammals and seabirds.

Adjacent areas to wind farms may include a range of habitats, such as rocky or coral reefs, sandy shores, kelp forests, etc. Thus, the disturbance caused by construction and operations of the turbines may not be limited to the wind farm area itself, and risk assessments for a variety of habitats are necessary.

3 Impacts of the addition of hard bottom habitats

3.1 Sessile organisms

Whenever a new material is submerged in the sea it will become colonised by marine organisms. Microbial colonisation occurs within hours and will be followed over weeks to months by settlement of macrobiota (e.g. Svane & Petersen, 2001). The initial phases of colonisation are predominantly influenced by physical conditions and are relatively predictable (Wahl, 1989). The macrobiotic assemblage that develops on a structure can be difficult to predict and is strongly influenced by availability of settling stages and subsequent biological interactions (Keough, 1983; Rodriguez, et al., 1993; Santelices, 1990). However, in the longer term, the season of submersion tends to have no significant influence on the sessile community (e.g. Qvarfordt, et al., 2006; Langhamer, et al., 2009). Further, the position of the structure in the water column may be more important than age or type of the substrate (Connell, 2000; Knott, et al., 2004; Perkol-Finkel, et al., 2006).

Typical ‘pier piling assemblages’ (Davis, et al., 1982), dominated by filter feeding invertebrate generally develop on wind turbines. In post construction surveys of wind turbines in Denmark Sweden, and UK two principal assemblages have been observed; either dominance by barnacles and blue mussels (*Mytilus edulis*), in true marine areas together with predatory starfish, or dominance by anemones, hydroids and solitary sea squirts (Dong Energy, et al., 2006; Linley, et al., 2007; Wilhelmsson & Malm, 2008; Maar, et al., 2009). Wind turbines may offer a particularly favourable substrate for blue mussels (Wilhelmsson, et al., 2006; Maar, et al., 2009). Turbines can facilitate 10 times higher biomass of blue mussels than on bridge pilings (Maar, et al., 2009). Each turbine may support 1-2 metric tonnes of mussels, and double the biomass of filter feeders in a wind farm area as a whole compared to before construction (Maar, et al., 2009). The mussel matrices on the turbines provide habitat and food for small crustaceans, which in turn constitute prey for fish and other predators (e.g. Zander, 1988; Norling & Kautsky, 2008).

The structural complexity provided by mussel beds promotes biodiversity of macro-invertebrates and the waste material they produce can enhance the abundance of other species (e.g. Ragnarsson & Raffaelli, 1999; Norling & Kautsky, 2007; Norling & Kautsky, 2008). Mussels can also cause a shift from a primary producer and grazer dominated food chain towards a detritus feeding community (Norling & Kautsky, 2007; Norling & Kautsky, 2008).

From an operational perspective fouling of the wind turbine tower is detrimental, adding to the weight and drag from water movement and it may also facilitate corrosion. Antifouling paints are generally not used on wind turbines. However, cleaning of the turbines creates a periodic (every 2 years, approximately) disturbance/removal of assemblages. Studies on wind power turbines, bridge pilings and buoys, however, suggest that the biomass of dominating organisms on these vertically oriented structures does not increase notably with time after 1-2 years of submergence (Qvarfordt, 2006; Wilhelmsson & Malm, 2008; Langhamer, et al., 2009). This is a result of counteraction of colonisation/growth by dislodgment of mussels due to gravity and wave action, as well as to food and space limitations. Similar effects could be expected in tropical water (e.g. Wilhelmsson, et al., 1998; Svane & Petersen, 2001). Unless repainting is necessary, cleaning of turbines may therefore not be sufficiently beneficial to justify the costs and habitat disturbance involved.

Trawling, which is one of the most severe threats to the marine environment (e.g. Thrush & Dayton, 2002), including both fish and benthic assemblages, will be prohibited or limited inside wind farms. This would cause less physical disturbance of benthic communities and more favourable environments for long-lived species (Dayton, et al., 1995; Jennings & Kaiser, 1998; Kaiser, et al., 2006; Tillin, et al., 2006).

Conclusions

Particularly on soft bottom habitats, but to some extent also on hard bottom dominated areas, the addition of hard substrata increases habitat heterogeneity and the biodiversity of sessile organisms. These ***long-term*** changes should be ***very local***, and limited to the turbines and the adjacent seabed. The magnitude of these effects is not assessed here, due to the fact that although the habitat alterations will be localised to the turbines, total biomass of species and diversity may increase notably for the area as a whole. Research on fouling communities on artificial and natural hard substrata is relatively well advanced, and the bases for general predictions are good, although variability among localities and environmental conditions limits predictability. **Certainty: 4**

In the ***long term***, trawling exclusion enhances abundance of several species within the whole wind farm area (***broad***) and effects can be considered large. **Certainty: 5**

3.2 Dispersal patterns of hard bottom species

Wind turbines provide hard substrata in regions and at depths often dominated by soft bottom habitats. Wind farms could thus fill in gaps between natural areas of hard substrata, and so change the biogeographic distribution of species within a region (Bulleri & Airoldi, 2005; Nielsen, 2009). Not only may the distribution of native reef species be affected by this. Based on studies on pier pilings and oil platforms, it has been suggested that large scale urbanisation of coastal areas could provide entry points and stepping-stones for alien rocky shore species brought in as larvae by ballast water (Glasby & Connell, 1999; Connell, 2001; Airoldi, et al., 2005; Bulleri & Airoldi, 2005; Page, et al., 2006; Glasby, et al., 2007; Villareal, 2007). Artificial structures have also been shown to better cater for non-native species than natural reefs by changing the competitive interactions (Fenner & Banks, 2004; Sammarco, et al., 2004; Bulleri & Airoldi, 2005; Glasby, et al., 2007). Three non-indigenous species have been recorded on wind turbines in Denmark and Sweden (Dong Energy, et al., 2006; Brodin & Andersson, 2009). Two of these species dominated their respective sub-habitat. One of the species was also recorded as an exotic species in large densities on offshore oil platforms off California and concerns were raised on how it may influence native amphipod species (Page, et al., 2006).

Conclusions

The significance of these effects would vary greatly among regions, depending on geography, hydrology, existing artificial structures (e.g. buoys, pier pilings and coastal defence structures), seabed type and species compositions. As development of wind farms progresses, effects on dispersal patterns of certain species within a region may be significant. The ***long-term*** effects on sessile species could be ***very broad***, but although there may be impacts, too little information is available on overall impacts on benthic assemblages to make firm predictions. The influence of the structures on connectivity and dispersal patterns of marine organisms has not been established. Unproportionally large assemblages of non-indigenous species on artificial structures are, nevertheless, relatively well documented.
Certainty: 2

3.3 Fish, crustaceans and mammals

Construction and deployment of artificial reefs in coastal waters is practiced worldwide with the intent to manage fisheries, to protect and facilitate the rehabilitation of certain habitats or water bodies, or to increase the recreational value of an area (Ambrose, 1994; Brock, 1994; Guillén, et al., 1994; Hueckel, et al., 1989; Milon, 1989; Pickering, et al., 1998; Wilhelmsson, et al., 1998; Jensen, 2002; Claudet & Pelletier, 2004; Seaman, 2007). The materials used range from specially designed concrete- or steel units to scrap materials such as car tires, shipwrecks and train carriages (Baine, 2001). Although some studies have revealed no significant effects of artificial reefs on fish assemblages, accumulated evidence suggests that artificial reefs generally hold higher fish densities, biomass, and provide higher catch rates compared to surrounding soft bottom areas, and in some cases also in relation to adjacent natural reefs (e.g. Ambrose & Swarbrick, 1989; Beets, 1989; Bohnsack, et al., 1991; Bohnsack & Sutherland, 1985; De Martini, et al., 1989; Brock & Norris, 1989; Bohnsack, et al., 1994; Kim, et al., 1994; Pickering & Whitmarsh, 1996; Wilhelmsson, et al., 1998; Arena, et al., 2007). Reasons suggested for higher abundance and diversity of fish on and around artificial reefs include enhanced protection and food availability, and the use of the structures by fish as reference points for spatial orientation (Bohnsack & Sutherland, 1985; Jessee, et al., 1985; Ambrose & Swarbrick, 1989; Bohnsack, 1989; Grove, et al., 1991).

Different types of urban structures in the sea, constructed primarily for other purposes, such as oil platforms (Helvey, 2002; Love, et al., 1999; Rooker, et al., 1997; Seaman, et al., 1989; Ponti, et al., 2002), breakwaters (Stephens, et al., 1994), pier pilings and pontoons (Connell & Glasby, 1999; Rilov & Benayahu, 1998) also serve as habitats for dense fish and invertebrate assemblages. These are often defined as 'secondary artificial reefs' (e.g. Pickering, et al., 1998). Surveys of oil rigs, for example, have revealed higher growth rates, densities, and larger individuals of fish around these artificial structures compared to surrounding natural seabeds (e.g. Nelson, 1985; Love, et al., 1999). Notably, oilrigs off Louisiana and in the Gulf of Mexico provide 90 per cent and 15-28 per cent of the hard-bottom substrate in the respective coastal areas, adding significant amounts of habitat for rockfishes and other species (Bohnsack, et al., 1991; Scarborough Bull & Kendall, 1994).

Figure A1-1: Wind turbines, even without scour protection (e.g. boulders), can aggregate fish. Photo: Dan Wilhelmsson

Studies in Denmark and Sweden have shown that wind turbines and the associated scour protection can significantly enhance local abundance of bottom-dwelling fish and crabs (Figure A1-1; Figure A1-2; e.g. Wilhelmsson, et al., 2006; Maar, et al., 2009). Westerberg (1994), investigated fish distribution patterns around a single small wind turbine, and reported higher abundance of cod and some pelagic species 50 metres from the turbine compared to 200-800 metres away. However this pattern was only noted while the turbine was not running. Settlement rates and abundance of lobster, a species that often is habitat limited, could also increase around scour protection boulders (Pickering & Whitmarsh, 1996; Jensen, et al., 2000; Wihelmsson, et al., 2009).

Depth-related distribution patterns of fish and sessile biota are typical in shallow water habitats (Gibson, 1969; Pedersén & Snoeijs, 2001; Ponti, et al., 2002). Vertically oriented structures, such as wind turbines, provide a selection of depths, which may cater for different life stages and species of fish (Molles, 1978; Aabel, et al., 1997; Rooker, et al., 1997; Rilov & Benayahu, 2002; Rauch, 2003). If not buried, the physical presence of power cables could also provide shelter for benthic fish, especially juveniles, according to both observations in wind farms (D.W, personal observations) and structured surveys of pipelines (Nøttestad, 1998). Evidence from studies around oil rigs (Todd, et al., 2009) indicate that wind turbines may also attract feeding porpoises, and this was also mentioned as a possibility for both seals and porpoises by Avelung, et al. (2006) and Frank (2006), provided that the operational noise does not deter these mammals (*see* section *below*).

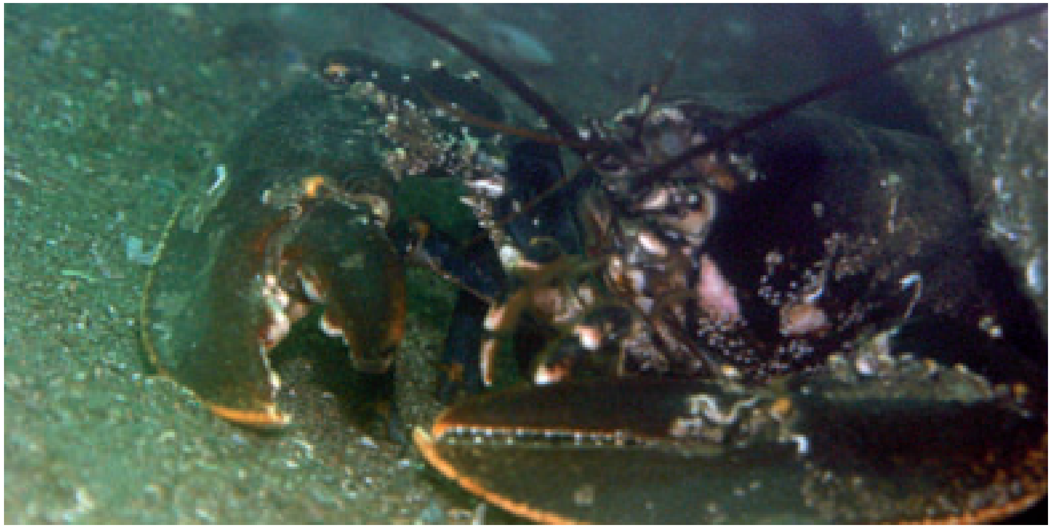
Unless operational noise deters fish, turbines (particularly the floating deep water turbines) are also likely to function as artificial reefs and/or Fish Aggregation Devices for pelagic fish with increasing effects with depth, (Chou, 1997; Rey-Valette, et al., 1999; Schröder, et al., 2006; Fayram & de Risi, 2007). Many commercial fish species, such as cod and flatfish, are known to congregate around projecting structures on seabed (Gregory & Andersson, 1997; Light & Jones, 1997; Stanley, et al., 2002; Tupper & Rudd, 2002; Johnsson, et al., 2003; Cote, et al., 2004). Even simple surface buoys are commonly used to aggregate fish and the radius of influence can be several hundred metres (Seaman & Sprague, 1991; Relini, et al., 1994). In ecological studies in conjunction with winds farms, it is often presumed that the sessile community is important for aggregation of fish (e.g. Dong Energy, et al., 2006). Some species are, however, likely to be attracted by the refuge provided by structure itself.

Results from preliminary studies in Denmark, Holland, Japan and Sweden on fish abundance in a wind farm area as a whole (i.e. not only considering aggregations around turbines) indicate either increased species abundances (e.g. sand eels, cod, whiting, sole), or no effects (Hvidt, et al., 2005; Dong Energy, et al., 2006; Naruse, et al., 2006; Nielsen, 2009; Musalears, 2009 and *see* Müller 2007 for references), although a decrease in lesser weever (*Echiichthys vipera*) was indicated (Musalears, 2009). Most studies to date have aimed at method development and/or are statistically weak (some can only be considered as observations), or are conducted at limited spatial and temporal scales that cannot be generalised to effects of the artificial structures on fish abundance in the whole area (*see also* Ehrich, et al., 2006). Improved and additional monitoring efforts are currently under way.

Acknowledging the potential scale of offshore renewable energy development, there is an increasing interest in articulating the potential positive effects of the creation of artificial hard bottom habitats, as well of the limitations of fishing in the wind power parks, for the benefit of fisheries management and conservation. Habitat enhancement could compensate for losses of biologically important areas elsewhere, in line with indications by the EU Marine Strategy Framework Directive (MSFD, 2008/56/EC). Research has already shown that modification of engineered structures can influence diversity and increase the abundance of commercially exploited species (Langhamer & Wilhelmsson, 2009; Martins, et al., 2010). Research is under way to identify species-specific habitat preferences in the design of offshore energy foundations to optimise biomass of desired species. The configuration of scour protections is also likely to be important, in terms of density of boulders and void space (Grove, et al., 1991; Kim, et al., 1994; Lan & Hsui, 2006). Frond mats may also function as artificial algae or sea grass beds, providing nursery areas for juvenile fish, and habitats for fish of high conservation importance, such as pipefishes and seahorses (Linley, et al., 2007; Wilson & Elliot, 2009).

For fish and crustacean species limited by the amount of reef habitat for refuge, territory, food and behavioural requirements, artificial reefs may augment total stock size (e.g. Bohnsack, 1989). For example, abundance of many coral reef fishes are limited by availability of shelter sites (Risk, 1972; Luckhurst & Luckhurst, 1978; Shulman, 1984), and many decapod stocks may be habitat limited (Jensen, et al., 1994; Pickering & Whitmarsh, 1996; Sheehan, et al., 2008). Further, the amount of suitable habitat could be limiting during certain life stages, such the early benthic phase, molting, or spawning, and these demographic bottlenecks could be widened through provision of artificial habitats (Werner & Gilliam, 1984; Wahle & Steneck, 1991; Chojnacki, 2000; Jensen, 2002; Hunter & Sayer, 2009). However, for other species, or for the same species in other regions, artificial reefs may only redistribute fish biomass and production (Bohnsack, 1989). This is believed to be the case particularly for species acting below the carrying capacity of the environment in terms of space or food due to recruitment limitation, through high fishing or predation mortality (e.g. Rong-Quen, et al., 2003), or an extreme physical environment (e.g. low salinity and temperature; Thorman & Wiederholm, 1986).

The importance of habitat enhancement through offshore energy development will depend on scale and area in consideration. Often, cost-benefit analyses of artificial reef deployments are restricted to the site level, however, and the eventual beneficial influence of artificial reef projects on conservation or fishery management through enhanced biomass production may be minimal at regional scales (Bohnsack, 1989; Polovina & Sakai 1989; Grossman, et al., 1997; *see* also Ehrich, et al., 2006 for discussion on effects of wind farms). Likely exceptions may occur when heavily-fished and vulnerable species are protected from exploitation on artificial reefs, or when artificial reefs are used for trawling prevention in an area to protect a segment of a fish stock or areas of significance for spawning or nursing, and thereby secure certain levels or stability of reproduction ('buffering') (e.g. Campos & Gamboa, 1989; Beets & Hixon, 1994; Jensen, 2002). The size of the wind farms, and the cumulative effects of several wind farms in the same area (depending on connectivity between them (*see* section 11)), will have an influence to this regard. The ecological performance (e.g. growth, survivorship, reproduction) of fish around wind turbines is, however, relatively unknown to date.



A European lobster residing under an offshore energy foundation. Photo: Olivia Langhamer

Nevertheless, trawling, which is one of the most severe threats to the marine environment (e.g. Thrush & Dayton, 2002), including both fish and benthic assemblages, will be prohibited or limited inside wind farms. Areas that could encompass several square kilometres will in practice resemble 'no take zones' (Pitcher, et al., 1999; Wilson, et al.,1999). These areas will, in addition, contain hundreds of artificial reefs. Management strategies combining Marine Protected Areas and artificial reef deployment are increasingly recognised (e.g. Pitcher, et al., 1999; Claudet & Pelletier, 2004). It has, further, been suggested that, as surface-oriented offshore energy devices (i.e. buoys, supporting structures) may function as Fish Aggregation Devices (FAD) for large predatory fish (for floating turbines e.g. tuna, dolphin fish), wind farms could provide management opportunities for this fishing sector (Fayram & de Risi, 2007).

Conclusions

According both to studies on wind turbines in operation and an extensive literature on artificial reefs it is certain that the wind turbines and scour protections will function as artificial reefs for several species of fish. In most cases these ***local*** and ***long-term*** effects on fish assemblages or stocks overall may be negligible, but under some circumstances (*see above*) artificial reefs deployed over large areas could have significant effects. Estimated magnitude of these beneficial effects is, thus, on average ***moderate***. The large variability in the response to differently designed artificial reefs among fish species and regions/latitudes weakens our ability to make predictions. **Certainty: 3**

Effects of eventual habitat enhancement on marine mammals could be ***broad***, considering the mobility of mammals, but should overall be ***small***. Little research on this is, however, available. **Certainty: 1**

Long-term, trawling exclusion enhances abundance of several species fish within the whole wind farm area (***broad***), and effects can be considered ***large***. **Certainty: 5**

3.4 Collision risks for marine mammals and fish

Concerns have been raised that mammals and fish could collide with the wind turbines. Fixed, large, submerged structures, such as wind turbine foundations, pose little collision risk (e.g. Pelc & Fujita, 2002; Wilson, et al., 2007; Inger, et al., 2009). Little structured research on this has been conducted, but the collected practical experience is large. These risks are likely to be negligible at a population level.

Conclusions

If collisions occur, they are likely to be very rare and have ***small*** impacts on an assemblage of fish or mammals as a whole. **Certainty: 2**

4 Sedimentation and seabed disruption during construction

Deployment of wind turbines and scour protection will result in a 0.14-3 per cent direct loss of the seabed within the wind farm area, with each turbine claiming up to 450 square metres (Bioconsult A/S, 2000a; Hvidt, et al., 2005; Wilson & Elliot, 2009). Wind farm construction and decommissioning may have acute pulse effects since they will disturb and re-suspend particulate material from the seabed. Concentration of suspended particles and radius of impact depend on a variety of factors,

Various species of corals. Photo: SDRMI

such as the seabed substrate (e.g. grain size), hydrodynamics and type of foundations being installed. Excavation activities needed for gravity foundations are likely to cause greater suspension of sediment than other types of foundations. This may result in localised smothering of the seabed (Wilding, 2006; Gill, 2005). The effects of smothering are likely to be more severe for organisms such as barnacles, grazing and filter feeding molluscs, that live on hard surfaces, as well as for reef building tube worms (i.e. *Sabellaria* spp.) (Menge, et al., 1994; Airoldi, 1998; Balata, et al., 2007; Vaselli, et al., 2008), and also for corals, which have limited ability to tolerate sediment (McClanahan & Obura, 1997; Gilmour, 1999). Seaweed communities on hard bottoms in the temperate regions may respond to increased sedimentation with a shift in species composition from dominance of large foliose algae to filamentous turf algae (Balata, et al., 2007; Vaselli, et al., 2008). This change in vegetation may negatively affect the recruitment other organisms, such as fish (Kaaria, et al., 1997; Stratoudakis, et al., 1998). Soft bottom species are also affected by increased sedimentation, but for example seagrass (Vermaat, et al., 1997) and mangrove systems (Ellison, 1998) have greater tolerance and relatively large amounts of material are required to cause adverse effects. Generally, the disturbed areas will undergo a succession starting with opportunistic species gradually replaced by secondary species towards a recovery of the seabed assemblages (Grassle & Sanders, 1973).

When particles are suspended, they may also affect respiration for example by clogging gills, as well as inhibiting feeding, and this may particularly be the case for small species or vulnerable life stages such as fish larvae (e.g. Auld & Schubel, 1978). Turbidity may also cause temporary avoidance by fish (Westerberg, et al., 1996; Knudsen, et al., 2006). Recent studies related to the dredging for wind turbine gravity foundations identified no negative effects on either juvenile or adult fish at a distance of 150 metres from the activities (Hammar, et al., 2008). Within the Danish Monitoring Program, only localised and short-term sedimentation impacts were reported on benthos during the installation of gravity foundations (Dong Energy, et al., 2006). Further, case-specific modelling of sediment distribution and concentrations in conjunction with wind turbine installation, including worst case scenarios (calcareous sediment), has suggested only local and short-term effects (e.g. Didrikas & Wijkmark, 2009). The requirements for a certain degree of seabed stability for proper fixation of turbine foundations mean that construction mainly takes place in course sediments, which in turn results in short periods of sediment dispersion and turbidity.

Cables are either laid directly on the seabed (Kogan, et al., 2006) or, particularly in areas with intensive fishing and other human activities, they are buried (by dredging or ploughing) about 1 metre deep into the seabed (e.g. Vize, et al., 2008). Depending on seabed structure, cables may naturally become completely buried within a few years; experiences from the oil and gas sector show that pipelines are buried in 5-15 years (OE, 1999; Knudsen, et al., 2006), although sections could also be undermined by currents and subsequently hang freely above the seabed (OE, 1999). On hard bottoms, the cables are anchored with stones or concrete. Similar to deployment of gravity foundations, the installation of cables implies a certain risk of re-suspension and sedimentation and direct elimination of fauna and flora (Di Carlo & Kenworthy, 2008). When burying pipelines for example, 10-20 metres broad belts of seabed are directly affected by sedimentation (Knudsen, et al., 2006), but a zone of 50 metres wide on each side can be affected by construction activities, such as cable laying and associated boat activities (Hiscock, et al., 2002). These results are, however, not directly applicable to laying of cables of smaller dimensions. Changes in species diversity may occur particularly where large slow-growing species such as reef building corals are replaced by small short-lived opportunistic species.

Wind power cables may relatively soon resemble natural hard substrata with no or very localized measurable impacts on the adjacent seabed (e.g. Hiscock, et al., 2002; Malm, 2005; Dong Energy, 2006; Vize, et al., 2008). A number of studies of animal-dominated soft bottoms have shown no significant long-term (> 2 years) impacts of cable ploughing or other dredging activities (OE, 1999; Andrulewicz, et al., 2001; Lewis, et al., 2003). In some cases it may, however, take several decades before the biomass and species composition on the surrounding seabed returns to pre-construction conditions (Mateo, et al., 1997; Di Carlo & Kenworthy, 2008). Deep cold seabeds may take up to 10 years to recover (Knudsen, et al., 2006). In extreme cases where water movement is large, re-colonization of the larger species could be prevented completely, and erosion may even cause gaps in for example seagrass meadows (Whitfield, et al., 2002).

When seabeds are disturbed, damages of a serious nature may, however, only arise in cases where cables are drawn across habitats that include threatened or habitat forming (e.g. coral, seagrass) species (e.g. Duarte, et al., 1997; Marba, et al., 1996). Cables could increase the temperature of the surrounding water and seabed. The only study that to the authors´ knowledge dealt in depth with this issue, estimated the increase in temperature of the sediment above a buried cable to be insignificant; approximately 0.2 ^{o}C, and the increase in seawater temperature would only be 0.000006 ^{o}C (BERR, 2008). However, cumulative effects of substantial numbers of turbines, and localised effects of much greater elevation of temperature in sediments surrounding cables need to be evaluated.

Conclusions

Although re-suspension of particulate material can be ***broad*** and increase mortality of fish, larvae and eggs, effects are ***short-term***, and should in most cases cause ***small*** impacts on whole fish assemblages. Research on sensitivity of fish, including larvae and eggs, to sediment loads and sediment dispersal is relatively advanced. **Certainty: 4**.

Impacts on invertebrates are less studied. **Certainty: 3**. Careless siting of turbines could affect threatened species with narrow distribution ranges, but generally impacts on benthic species assemblages in the area as a whole would be ***short-term*** and ***small***.

5 Impacts on hydrodynamics and changed nutrient transports

Wind power structures will affect water flow, and this will be critical to marine organisms since it influences larval recruitment, sedimentation, the availability of food and oxygen and the removal of waste (Breitburg, et al., 1995; Snelgrove & Butman, 1994; Zettler & Pollehne, 2006). Recent results from analytical modelling suggested that wind wakes created by large wind farms could generate significant up-welling or down-welling velocities in the vicinity of farms even at quite moderate wind speeds (Broström, 2008). This could affect nutrient transport and the local ecosystem as a whole. However, no field observations confirming the model have yet been reported.

The operational phase is likely to have chronic effects on the nature of subtidal sediments. Most wind-turbine developments are in shallow water with predominantly mobile seabeds. There may be localised erosion of unconsolidated material due to scour around the toe of the structure; in some locations this can be extensive resulting in depressions several metres deep around the base and influencing sediments up to 25 metres from the structure itself (Wallingford, 2005). These changes in sediment characteristics influence the associated infaunal and benthic communities (Martin, et al., 2005; Schröder, et al., 2006) and nutrient regeneration (Danovaro, et al., 1999; Maar, et al., 2009) around the structures. The extent of erosion by scour can be reduced by the introduction of rock armour or anchored polypropylene fronds (1–1.5 metres in length) to stabilise sediment, although these additions will also have effects on the marine life (*see* section 3.3).

The influence of sheer stress on the transport of sediment and the subsequent effects on sediment characteristics and the associated benthic community, especially organisms living within the sediment, are well described (Ong & Krishnan, 1995; Joschko, et al., 2004; Schröder, et al., 2006). Also, where water movement is slowed there will be increased deposition of suspended material. The entrapment and deposition of organic matter, including material that originates from fish and sessile organisms on and around an artificial reef, can provide a source of food for the benthic community up to 40 metres away and cause localised changes in composition and production of macro-invertebrate assemblages as well as chemico-physical parameters adjacent (up to ~ 1 metre) to the structure (e.g. Bray, et al., 1981; Kellison & Sedberry, 1998; Schröder, et al., 2006; Wilding, 2006; Maar, et al., 2009). Around a research platform aiming to mimic conditions around wind turbines, effects on the benthic species assemblages were noted 15 metres from the structure (Schröder, et al., 2006). However, in the monitoring program at Horns Rev in Denmark no distance related effects on sediment dwelling animals (infauna) were discerned within the wind farm area as a whole (Dong Energy, et al., 2006). Modelling in the same program suggested that the changes in current velocity within 5 metres from the foundation would be less than 15 per cent, and 1.5-2 per cent between foundations.

Concerns have been raised regarding the effects that the entrapment and deposition of organic matter may have in strongly stratified water bodies, where anoxic conditions already prevail. Field observations have confirmed that localized anerobic conditions may occur around the feet of the turbines (M.H. Andersson, personal communication 2009). Other potential impacts include ammonium excretion by the mussels, which could increase growth rates of phytoplankton and filamentous algae (Kautsky & Wallentinus, 1980; Norling & Kautsky, 2008; Maar, et al., 2009). This has also has been indicated in field observations (Malm, 2005; Maar, et al., 2009). Moreover, filtration by the large numbers of mussels on the turbines could deplete phytoplankton and, as a result, cause lower biomass of filtrating animals on the seabed, including mussels, up to 20 metres from a turbine (Maar, et al., 2009).

The biomass of filter feeding animals, such as blue mussels and barnacles, is higher on the seabed around turbines compared with reference areas, while the biomass of macroalgae, particularly species of red algae, is lower (Wilhelmsson & Malm, 2008; Maar, et al., 2009). As shown around oil-rigs, at larger scales (e.g. Love, et al., 1999), new mussel beds can form around wind turbines, as a consequence of dislodgement of mussels from the structures. These beds create hot spots of biological activity, and can fundamentally alter the natural soft bottom assemblage (Norling & Kautsky, 2008; Maar, et al., 2009). So far these changes in macrofauna and flora composition have only been observed within a few metres from each turbine (Wilhelmsson, et al., 2006).


Boat traffic around offshore wind farm. Photo: E.ON Climate & Renewables

Many species of fish and crustaceans use artificial reefs primarily as a refuge from predators and water movements, and forage mainly in the neighbouring habitats (Ambrose & Anderson, 1990; Kurz, 1995; Einbinder, et al., 2006). Densities of benthic prey items have, in some of studies, been shown to decrease with proximity to these artificial reefs due to increased predation (Davis, et al., 1982; Kurz, 1995; Jordan, et al., 2005). The suggested radii of influence on biomass of prey and macroalgae around an artificial reef range between 15 and 100 metres. This probably depends on visibility and the levels of risk for the fish as they move away from the shelter of the artificial reef (Davis, et al., 1982; Kurz, 1995; Einbinder, et al., 2006). Low biomass of common prey species has been recorded on the seabed around wind turbines, which could be a result of increased predation pressure from fish and crustaceans associated with the turbines (Maar, et al., 2009). In many areas, enhanced biomass production of prey species on and around the turbines, may be cancelled out by this increase in predation pressure. For example, it has been estimated that, unless blue mussels and other prey were produced on and around the turbines, shore crabs, shrimps and fish associated with turbines in the Nystedt wind farm would have needed food resources equivalent to what is provided in a larger area than the whole wind farm area itself (Maar, et al., 2009).

Conclusions

The ***long-term*** influences of potential up- or downwelling at the perimeter of a wind farm may be measurable in the area as a whole, although effects on species or ecosystem functions should be ***local*** and ***small*****.** No field observations confirming the model have yet been reported, and studies on potential impacts on biota within wind farms are scarce. **Certainty: 1**

Changed hydrodynamics around turbines in operation are likely to have ***long-term*** effects on the nature of subtidal sediments and thus the assemblage structure of benthic organisms, but those will be ***local***, limited to the surroundings of each turbine. Altered water flows by artificial reefs and other structures, and the influences on adjacent seabeds are relatively well studied. Measurable effects of altered transports of organic material and nutrients, as well as increased predation on benthic organisms, are ***long-term*** but should be ***local***, i.e. within a few metres up to 100 metres from a turbine, and ***very local*** for potential anoxic conditions. Careless siting of turbines could, however, affect threatened species with narrow distribution ranges, but overall, the degree of severity of effects may on average range between ***small*** and moderate. Accumulated evidence from related research areas is comparably strong, and a few studies have been conducted in wind farms, but the dynamics of predation effects are unclear. **Certainty: 4**

6 Toxic substances

According to international expertise (e.g. GESAMP), the only constituent chemicals of significant danger in the marine environment are mercury, tin and cadmium, primarily due to their bioavailability, and potential to accumulate in the food chain. These metals are reportedly not released during construction and operation of wind farms. Antifoulants typically release toxic chemicals, but use is largely regulated towards licensed protective coatings that are low- or non-toxic. For example some wind turbines are painted with glass flake reinforced polyester coatings with no biocide activity, and antifoulants are typically not used.

Measurements of trace metals, volatile solids, copper, zinc and hydrocarbons have shown no anomalies in mussels, crabs and fish around oil platforms in the California Bight (Schroeder & Love, 2004). The risks of pollution from wind turbines should be even lower. There is, however, a legacy of our past history of contaminants in many coastal areas adjacent to industrial estuaries and coast. The largest risks of negative environmental impacts from pollution will most probably arise while dredging sediments containing pollutants (Nendza, 2002), and although these effects are likely to be local and/or temporary, caution is needed when constructing many turbines over a longer time. In relation to a specific offshore wind farm project the estimated release of metals and organic substances would lead to increased concentrations of less than 10 per cent of background levels. It has, nevertheless, been pointed out that copper contamination of filter-feeding organisms on the seabed adjacent to the turbines, as well as of plankton, may occur (DHI, 1999; Bio/consult, 2000b). Maintenance sandblasting and painting could release several cubic metres of paint and sand unless this is removed or excluded from the water (Bio/consult, 2000b). Further, when changing oil in transformer stations, release of service-aged oil needs to be avoided.

Conclusions

Serious pollution does not seem likely, and if pollution would occur effects on biotic assemblages should be ***local*** and overall effects thus ***small***, provided that there are no large oil spills when serving transformer stations. The risk of stirring up polluted seabeds and variability in construction methods among developers bring in some uncertainty, but research and information base is otherwise good. **Certainty: 4**

Legend: Green and red concentric rings indicate positive and negative influences respectively on species abundance.

5 metres radius:
Artificial reef effects with enhanced biomass of blue mussels, decapods (e.g. crabs and lobsters) and bottom dwelling fish (Wilhelmsson, et al., 2006; Wilhelmsson & Malm, 2008; Maar, et al., 2009).

20 metres radius:
Depletion of phytoplankton by high densities of filtrating organisms (i.e. mussels) on and around the turbine could adversely affect growth of filtrators on the seabed (e.g. Maar, et al., 2009).

40 metres radius:
Input of organic material from organisms associated with the turbines, as well as entrapment of material by the turbines, could enrich the seabed and enhance the abundances of deposit-feeding organisms, and in turn increase the abundance of predators on these (e.g. Kellison & Sedberry, 1998; Bray, et al., 1981; Maar, et al., 2009).

100 metres radius:
Predation by fish and crabs associated with the turbines could negatively affect the abundances of prey species (Davis, et al., 1982; Kurz, 1995; Jordan, et al., 2005).

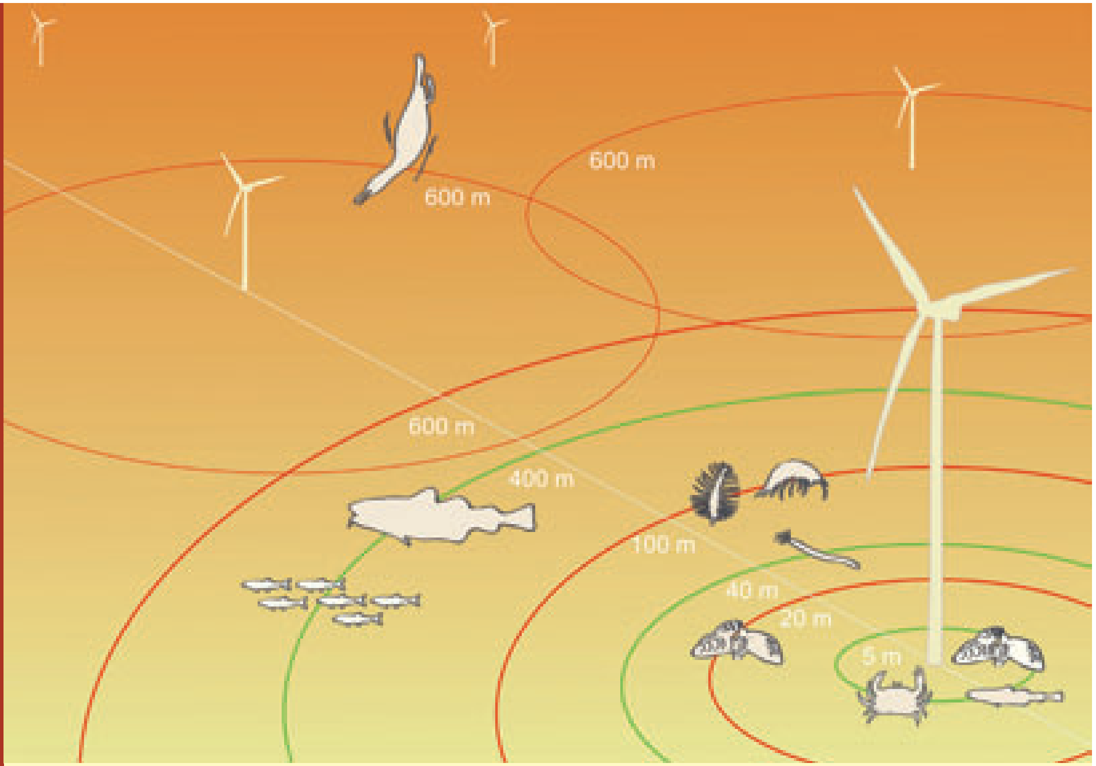


Figure A1-2. Schematic overview of some theoretical factors influencing wildlife, and radii of impact, during operation of offshore wind turbines. © C. Wilhelmsson

400 metres radius:
An artificial reef (here turbine and scour protection) can enhance abundances of pelagic fish species, and attract flatfishes to the reef, within this radius (e.g. Grove, et al., 1991; Fayram & De Risi, 2007).

600 metres radius:
Diving seabirds have been shown to avoid turbines at a larger distance than this (e.g. Stewart, et al., 2007; Larsen & Guillemette, 2007).

7 Acoustic disturbance

7.1 Construction noise and injuries on vertebrates

There has been a dramatic increase in anthropogenic underwater noise in coastal areas during the last few decades (Samuel, et al., 2005; Tougaard, et al., 2009). Hearing and processing of sound differ radically among species (e.g. Thomsen, et al., 2006; Kastelein, et al., 2007), and the nature and detection level of wind turbine construction noise, including e.g. boat traffic, pile driving, seismic surveys, is largely unexplored. Generally, though, construction of foundations and the laying of cables can generate considerable acute noise (Peak 260 dB re: 1 µPa and Peak 178 dB re: 1 µPa respectively) and could damage the acoustic apparatus of organisms within 100 metres (Enger, 1981; McCauley, et al., 2003; Gill, 2005; Madsen, et al., 2006). Piling generates a very loud sound of wide bandwidth (Hardyniec & Skeen, 2005). The highest energies occur in the lower frequencies of 20 Hz to 1 kHz (Greene & Moore, 1995). Close to the piling site this noise could cause serious injury or even death to fish, marine mammals and sea turtles (Hardyniec & Skeen, 2005; Nowacek, et al., 2007; Snyder & Kaiser, 2009). For example piling during construction of a bridge killed fish within a 50 metres radius. Experimental work has, on the other hand, shown several fish species (including trout) to be unaffected 10 metres away from the driving of 0.7 metres diameter piles (*see* Snyder & Kaiser, 2009 for references). Other species of fish are predominantly sensitive for particle motion and not pressure, and their responses to subsea noise and vibration are poorly known (Thomsen, et al., 2006).

Mammals may suffer hearing impairment, such as changes in hearing thresholds (e.g. Frank, 2006; Madsen, et al., 2006) when exposed to piling noise (1.5 MW, 228dB 1 µPa) at close range. Both Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS) represent changes in the ability of an animal to hear, usually at a particular frequency, with the difference that TTS is recoverable after hours or days and PTS is not. Impairment through TTS or PTS of a marine animal's ability to hear can potentially have quite adverse effects on its ability to communicate, to hear predators and to engage in other important activities. Both TTS and PTS are triggered by the level and duration of the received signal. Sound can potentially have a range of non-auditory effects such as damaging non-auditory tissues, including traumatic brain injury/neurotrauma. Recently, Southall, et al. (2007) proposed sound exposure criteria for cetaceans and pinnipeds composed both of peak pressures and sound exposure levels which are an expression for the total energy of a sound wave. These values are currently discussed within the scientific community as they are based on very limited data sets with respect to noise induced injury and behavioural response in marine mammals. Mammals and also most fish, are, however, likely to move away from areas of pile driving (Figure A1-3; Engås, et al., 1996; Popper, et al., 2004).

Conclusions

Although hearing impairments could occur within a larger radius, any mortality due to acute sound pulses is ***local***. Particularly mammals, but also most large/mobile fish, will not reside in close proximity to pile driving, and impacts of any injuries on a species assemblage should be ***small*** (Figure A1-3), provided mitigation measures are taken (*see* 4.5). Temporal scale of impact is not assessed here as, although the construction is temporary, hearing impairment can be permanent. There are a number of focused studies on impacts of sound, and these indicate that effects can vary greatly among species. **Certainty: 3**. However, no studies are available showing the extent of TTS and PTS for different applications of mitigation measures. More studies are clearly needed to optimise the management of the exposure of marine mammals and fish to underwater noise during construction.

7.2 Construction noise and avoidance by marine mammals

Effects on animal behaviour can extend far beyond the farm area, and pile driving may cause behavioural changes in seals, dolphins, and porpoises more than 20 kilometres away (Edren, et al., 2004; Tougaard, et al., 2008; Tougaard, et al., 2009; David 2006; Madsen, et al., 2006; Brandt, et al., 2009; Tougaard, et al., 2009). Hearing thresholds for seals and porpoises have been identified within the MINOS Programme (Frank, 2006). During wind farm construction at Nysted wind farm in Danish part of the Baltic Sea, harbour porpoises (*Phocoena phocoena*) abandoned the area (with effects noted 15 kilometres away), but at Horns Rev wind farm in the Danish part of the North Sea where monopiles were erected, porpoises largely returned within a few hours after pile driving (Henriksen, et al., 2003; Carstensen, et al., 2006; Tougaard, et al., 2009; Dong Energy, et al., 2006). The Danish monitoring Program (Dong Energy, et al., 2006) concluded that the construction phase as a whole only had weak effects on porpoises, while piling had distinct but short lived effects. However, scaring devices (pingers) were used in conjunction with the pile driving. The acoustic activities of porpoises increased within the wind farm between pile driving activities within a construction period (Tougaard, et al., 2004; Tougaard, et al., 2005). It was suggested that this could be linked to exploratory behaviour by the porpoises. Ship traffic during construction seems so far to have only minor effects on abundance and acoustic activity of porpoises (Frank, 2006). For seals, studies around wind farms to date have shown no large-scale displacement during construction, although some influence on seal density at a haul out site was indicated in direct association with pile driving (Tougaard, et al., 2003; Dong Energy, et al., 2006). Seals crossed the wind farm area during construction (Tougard, et al., 2003). It was concluded that the construction phase had no or marginal effects on the seals. Baseline data on habitat use before the construction took place is however relatively weak. It should be noted that any species relocation could severely affect spawning and nursery habitats

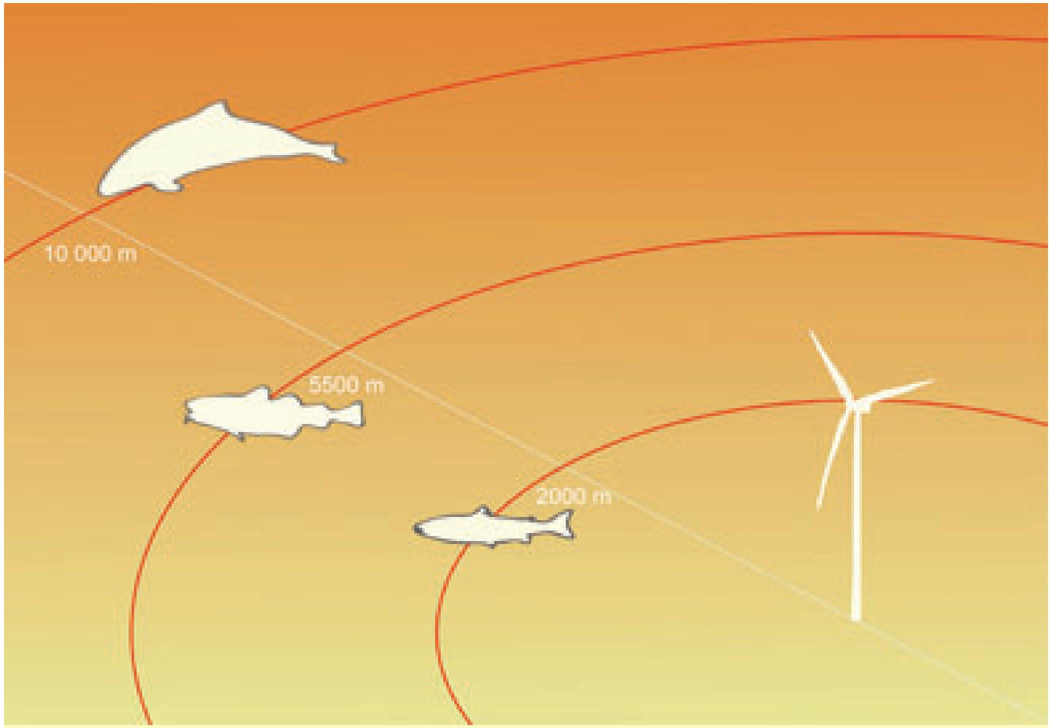


Figure A1-3. Schematic overview of suggested radii within which avoidance could be initiated by different species during construction (monopiles) of offshore wind turbines. © C. Wilhelmsson

Data sources:

Up to 2000 metres radius: Avoidance by salmonoids (Nedwell & Howell, 2003)

Up to 5500 metres radius: Avoidance by cod (Nedwell & Howell, 2003)

Up to 10 000 metres radius: Avoidance by porpoises (Dong Energy, et al., 2006)

if appropriate seasonal prohibitions are not used (e.g. spring and early summer is the main reproductive season for many species in temperate regions).

Conclusions

Displacement and behavioural changes of marine mammals can be ***very broad***, but seem to be ***short -term***, unless the wind farm is very large and require several years for construction. Baseline data for the targeted studies are weak, however, and studies on impacts of other activities on marine mammals need to be used with caution. Note that, as for the other issues treated, this is based on the construction of single wind farm. In case of construction activities at multiple wind farms cumulative impacts could potentially take place affecting subpopulations and movements across large areas. Also during installation of single wind farms, reproductive periods could be disturbed which could have impacts on subpopulations. **Certainty: 3**

7.3 Construction noise and avoidance by fish

Sub-lethal effects on fish caused by pile driving, mainly behavioural changes, are poorly studied (Popper & Hastings, 2009), although experimental and theoretical estimates are available for some species. Nedwell and Howell (2003), for instance, suggested that a certain level of sound pressure above hearing thresholds would cause avoidance by cod and salmon. These estimates have, however, not been satisfactorily validated. The response also depends on the life cycle stage, species (highly variable) and body size (Nedwell & Howell, 2003; Wahlberg & Westerberg, 2005; Thomsen, et al., 2006; Kastelein, et al., 2007). Studies on juvenile fish and larvae exposed to seismic shooting and explosions showed an impact on survival in these groups, although these results cannot be directly translated into possible effects of pile driving due to the difference between the sound sources (Popper & Hastings, 2009). However, juvenile fish and larvae would probably have less opportunity to escape than larger and more mobile or pelagic species (Engås, et al., 1996). Salmon and cod, for example, may hear and avoid the piling area within a radius of 2 and 0.6-5.5 kilometres respectively (Nedwell & Howell, 2003 and *see* Müller, 2007 for references).

Many bottom-dwelling fish lack swim bladders and are thus less sensitive to sound pressure, but they are as susceptible as other fish to the high levels of particle motion generated by pile driving (Sigray, et al., 2009). Although the effects on bottom-dwelling fish species are probably significant during piling, high abundance of small-bodied demersal fish was recorded near wind turbines in the southern Baltic Sea two years after the pile driving was completed (Wilhelmsson, et al., 2006). Fish have also been shown to return to an area within a few days after air gun use ceases (e.g. Slotte, et al., 2004; Engås, et al., 1996). These results and other studies on responses to disturbance show that the re-colonization of fish after pile driving may be rapid. It is, however, reasonable to assume that pile driving in the vicinity of more spatially limited habitats, such as tropical coral reefs, could cause considerable damage to the fish community, due to limited opportunities for some species to relocate (Sale, 1977). It should be noted that any species relocation could severely affect spawning and nursery habitats if appropriate seasonal prohibitions are not used (e.g. spring and early summer is the main reproductive season for many species in temperate regions).

Conclusions

Displacement of fish can be ***very broad***, but should be ***short-term***, and severity of impacts for local fish assemblages should generally be small. This is provided that the wind farm is not very large and requires several years for construction. Note that, as for the other issues treated, this is based on the construction of single wind farm. If the construction of several wind farms succeeds each other in the same region effects will be longer term. Sensitive reproductive periods could be disturbed and in some cases this could have impacts on assemblages and subpopulations. Few field studies have been conducted. Parallels could with caution, however, be drawn from investigations of impacts of other activities on fish, as well as a number attempts to theoretically predict avoidance behaviour of fish in conjunction with wind farm construction. **Certainty: 3**

7.4 Construction noise and invertebrates

The effects of sounds from e.g. seismic shooting, pile driving and operation of wind farms on invertebrates are unknown (Moriyasu, et al., 2004). Invertebrates constitute a diverse array of animal groups, and generalisations about effects need to be done with particular caution. Even within a single class of crustacean such as the Malacostracans (e.g. crabs, lobsters, shrimps, krill) significant differences in tolerance to loud and/or low frequency sounds have been observed, with responses varying from no measurable reaction to increased mortality and reductions in growth and reproduction rates (Lagardère, 1982; Moriyasu, et al., 2004). Some molluscs such as abalones (*Haliotis corrugata* and *H. fulgens*) have also proved to be sensitive to acute noises, while others, such as oysters (*Ostrea edulis*), are very tolerant (Moriyasu, et al., 2004). The diversity of invertebrates is large and thus potential responses may vary greatly, and little is known about the potential effects on differing life cycle stages.

Conclusions

It is reasonable to assume that the impacts of noise on invertebrates during construction will be ***local***. and thus have ***small*** effects on assemblages as a whole. Little research on this is, however, available. **Certainty: 2**

7.5 Mitigation of construction noise effects

For marine species avoiding the area under construction, this inevitably results in loss of habitat, which could include feeding, spawning, nursing and resting (migrating species) grounds. In the prospecting, planning and permitting processes, key species, key life cycle stages and seasonal habitat use, as well as approaches (e.g. mitigation measures) used, need to be taken into careful consideration (Anderson, 1990; David, 2006). To mitigate adverse effects, construction activities can be timed with regard to the seasonal behaviour of key marine organisms using the area. For instance, for temperate species, reproduction generally takes place during spring and summer, and the abundance of juveniles then increases near shore. It has, also, been noted that in many areas the highest ambient noise environment occurs during the winter (temperate areas, US DIMMS, 2007). Construction activities during wintertime may therefore cause less disturbance impacts. This unfortunately concurs with the most unfeasible (technically and logistically) and unsafe period for sea work. Also, by developing floating wind turbines for shallow areas, the size of piles used for anchoring of turbines could be significantly reduced (Henderson, et al., 2004).

Several methods are used to reduce the damage caused by noise from pile driving. A standard approach is to gradually increase the strength of the pile-driving hammer to give mammals and larger fish a chance to escape the most dangerous area (Joint Nature Conservation Committee, 2004; Dong energy, et al., 2006). It should be noted, however, that this method is controversial as it may lead to gradual habituation and even attraction to the initially week sounds (Compton, et al., 2008). Another method is to surround the pile driving area with a curtain of bubbles or wrap the piles in sound damping material, although the implementation of the former is limited, as it is dependent on weak currents. Such bubble protection can reduce the sound volume by 3-5 dB, i.e. half of the sound intensity (Würsig, et al., 2000). A bubble curtain significantly reduced mortality of caged bluegill (*Lepomis macrochirus*) during demolition work on the Mississippi River (Keevin, et al., 1997). Scaring devices (seals) and pingers (porpoises) have been used to clear the vicinity of pile driving activities from marine mammals (Frank, 2006). *See* Nehls, et al. (2007) for details on sound mitigation measures.

7.6 Operational noise and fish

During operation, vibrations in the tower of the wind turbine generated by the gearbox mesh and the generator cause underwater noise with frequencies in the range of 1–400 Hz and of 80–110 dB re: 1µPa, and this is likely to increase as a function of the number of turbines (e.g. Nedwell & Howell, 2003). In the frequency range above 1000 Hz emitted noise is generally not higher than ambient noise. The towers have a large contact surface with the water that transmits sound effectively. The tower will also transmit vibrations to the sea floor but this effect is in most cases highly local and therefore considered of minor importance. Airborne noise from the blade tips is effectively reflected away from the water surface and is unlikely to significantly add to the underwater noise level (Ingemansson, 2003).

Estimates of how far fish can detect a wind turbine vary from a few hundred metres to 50-60 kilometres, depending on environmental conditions and species (Nedwell & Howell, 2003; Wahlberg & Westerberg, 2005; Thomsen, et al., 2006). The spread of noise, including both sound pressure and particle motion, in the water depends largely on the type of wind turbine, local hydrography and geological conditions, depth, the ambient noise level caused by both natural and anthropogenic sources, and weather conditions (Nedwell & Howell, 2003; Wahlberg & Westerberg, 2005; Madsen, et al., 2006; Sigray, et al., 2009). Since it is very complicated to model noise distribution around wind power plants in a particular area, scientists recommend that noise measurements are obtained in each area that is being considered for development (e.g. Wahlberg & Westerberg, 2005).

Noise from wind turbines in operation is low in frequency and intensity, and direct physical damage to mammals and fish near the plants is highly unlikely (Wahlberg & Westerberg, 2005; Madsen, et al., 2006). A review suggested that potential avoidance behaviour of fish due to sound pressure would only occur within four metres of the turbine (Wahlberg & Westerberg, 2005). According to measurements by Sigray, et al. (2009), the particle acceleration created by wind turbines should not affect fish beyond 1 metre from the turbines, and cod (*Gadus morhua*), perch (*Perca fluviatilis*), flatfish (*Pleuronectidae*) and salmonoids (*Salmonidae*) would not sense the induced particle acceleration at a distance of 10 metres from a turbine (Sigray, et al., 2009). These studies were, however, limited to frequencies below 20 Hz. Only decimetres from a wind turbine, the particle velocity measured was 3.5 times lower than what is suggested to cause escape responses by roach (*Rutilus rutilus*). Experiments (although with considerable limitations) and theoretical estimates have, further, suggested that it is not likely that turbot (*Psetta maxima*), flounder (*Psetta flesus*), roach, perch, and brown trout (*Salmo trutta*) would avoid wind turbines, even at close range (Engell-Sørensen, 2002; Båhmstedt, et al., 2009). On the other hand, the use of sound projectors, producing high levels (0.003-0.01 m/s^{-2}) and low frequent (<20 Hz) particle acceleration, levels that equal what has been measured up to 10 metres from wind turbines in Kalmar Strait in Sweden, has shown to be successful in scaring away cyprinids, eel (*Anguilla anguilla*) and juvenile salmon from water inlets of power plants in lakes and rivers (Knudsen, et al., 1994; Sand, et al., 2000; Sonny, et al., 2006).

Experimental work has shown no behavioural or physiological (e.g. stress hormone levels) responses of fish to operational noise, equal to that recorded 80 metres from turbines (Båmstedt, et al., 2009). Results were, however, limited to frequencies below 30 Hz. Laboratory tests with simulated wind turbine noise, however, showed increased respiration in flatfish (Wikström & Granmo, 2008).

Fish are likely to become acclimatised to the relatively continuous operational noise, as shown in many harbour areas and in association with other human activities (e.g. boat traffic, breathing divers (e.g. Schwartz, 1985; Wahlberg & Westerberg, 2005)). Results from a series of aquarium experiments, suggest that cod and plaice (*Pleuronectes platessa*) may be disturbed by wind turbine noise, but not to the level that they would permanently leave a preferred habitat (Müller, 2007). However, measurements at one wind turbine anchored in bedrock, which provides less damping than soft bottoms, showed considerable noise levels that could cause disturbance to fish (Linley, et al., 2007).

Conclusions

There is no evidence of fish avoiding wind farms in operation (*see also* section 7.3), and based on current knowledge, any impacts should be ***very local***. Although in the long term, the severity of impacts on fish assemblages as a whole is considered ***small***. There are limitations in survey design and scale of the studies. However, several field studies on the subject have been conducted. Parallels can also, with caution, be drawn from well-investigated impacts of other disturbance factors on fish.
Certainty: 4

7.7 Operational noise and marine mammals

Estimates for the distance at which porpoises detect the sound from wind turbines range between 10-100 metres (Koschinski, et al., 2003; Thomsen, et al., 2006; Tougaard, et al., 2009), while seals may detect wind turbines 360-10,000 metres away (Koschinski, et al., 2003; Thomsen, et al., 2006; Tougaard, et al., 2009). Madsen and colleagues (2006) estimated that the known noise levels and spectral properties from turbines in operation are likely to have small or minimal impacts on shallow water marine mammals i.e. the harbour porpoise, the bottlenose dolphin (*Tursiops truncatus*), the northern right whale (*Eubalaena glacialis*), and the harbour seal (*Phoca vitulina*) especially considering the already prevailing man-made sources of underwater noise.

Green turtle. Photo: Jerker Tamelander, IUCN

Porpoises and seals have been shown to react to simulated sound from 2 MW wind turbines, but they did not display fear behaviour (Koschinski, et al., 2003). Acoustic signals increased in intensity, which could be an exploratory behaviour. Tougaard, et al. (2009) expected no behavioural responses of seals and porpoises to occur apart from in the immediate vicinity of turbines, and studies by Tougaard and colleagues (2003) and the Danish Monitoring Program (Dong Energy, et al., 2006) suggested no effects on seals and porpoises of the wind farm in operation at Horns Reef in Denmark. Boat traffic during maintenance seemed to have only small effects on porpoises (Tougaard, et al., 2004). At Horns Rev, porpoise abundance returned to preconstruction levels shortly after the installations were finalised (Dong Energy, et al., 2006). At the Nysted wind farm in the southern Baltic Sea, on the other hand, the abundance of porpoises had not reached pre-construction levels two years after construction (e.g. Dong Energy, et al., 2006). It was speculated that the Nysted area may not be important enough for the porpoises to remain in the area and withstand the disturbance. Baseline data is, however, not sufficient to firmly attribute this distribution change neither to the presence of the wind farm nor to the production noise. Preliminary results from the Dutch monitoring programme at the offshore wind farm Egmond aan Zee suggest a significant increase in porpoise abundance after the construction (Musalears, 2009)

Several whale species (e.g. beluga whale (*Delphinapterus leucas*), killer whale (*Orcinus orca*), humpback whale (*Megaptera novaengliae*)) have notably displayed behavioural and avoidance responses to low frequency sounds from anthropogenic activities, such as oil and gas exploration and boat traffic (*see* Samuel, et al., 2005 for references). While habitat use patterns for whales may not generally overlap with the relatively shallow areas used for wind farms (apart from floating turbines), noise disturbance might still impact behaviour, including the migration patterns, of these species.

Conclusions

From studies of wind farms to date, there is no evidence of marine mammals avoiding wind farms during operation due to noise, and any ***long-term*** avoidance behaviour of porpoises and seals should be ***very local***. Hence, based on current knowledge, impacts on whole assemblages of porpoises, dolphins and seals are considered ***small***. Although there are limitations in survey design, several field studies and reviews on the subject have been conducted. **Certainty: 3**. One should be extra cautious with regard to whales, however, as impacts of sounds on migration are not understood (*see* also conclusions in 7.9).

7.8 Noise and avoidance by sea turtles

The hearing range of sea turtles is confined to low frequent sounds (below 1kW, highest sensitivity between 200 and 700 Hz, Ridgeway, et al., 1969; Bartol, et al., 1999), which coincides with the frequencies at which most noise occurs during operation of wind farms. Experiments have shown that low frequency sounds (25-750 Hz, 1.5-120 dB) can cause startle responses, as well as changes in swimming patterns and orientation, among sea turtles (i.e. loggerhead sea turtle *Caretta caretta*, O´Hara & Wilcox, 1990 and *see* Samuel, et al., 2005 for references). Although, little is known on how these results translate to impacts on the biology and ecology of sea turtles (Samuel, et al., 2005). It is worth noting that sea turtles remain, forage and reproduce in coastal areas with ambient sounds levels similar to those around wind farms (Samuel, et al., 2005). However, sea turtles have strong fidelity to their foraging and nesting areas, and to their migratory routes, and may be inflexible in seeking alternative locations when these are disturbed or blocked (Morreale, et al., 1996; Avens, et al., 2003).

Conclusions

Very broad-scale displacement of sea turtles is likely in the ***short term*** during construction activities, but out of the reproduction seasons overall impacts on subpopulations/assemblages should be relatively small. The displacement could, however, overlap with periods for beaching and egg laying, hatching and nursery periods, which could affect reproduction success. **Certainty: 2**

It is not likely that sea turtles would avoid the wind farms during operation, considering their presence in other urbanised areas. If avoidance would occur, it should be ***very local***, and impacts would thus be ***small***. If they would avoid larger areas, on the other hand, there could be serious consequences if construction takes place in or seaward to areas important for reproduction. No (or very few) studies or estimations regarding impacts on sea turtles of offshore wind power development have been conducted. Although relevant literature is scarce, parallels can be drawn from some solid studies on impacts of other activities. **Certainty: 2**

7.9 Masking of ambient sounds and bioacoustics

A wide range of marine species including mammals, fish and crustaceans use sound to find their prey, to communicate with each other (which is often linked to reproduction), to avoid predators and to navigate (*see* e.g. Richardson, et al., 1995; Wahlberg & Westerberg, 2005). The operational noise from wind turbines is not considered sufficient to mask communication of seals and porpoises (Madsen, et al., 2006; Tougaard, et al., 2009). For fish however, it is not known whether wind farms could mask bioacoustics, and what implications this could have on their ecological fitness and reproduction (Amoser & Ladich, 2005; Wahlberg & Westerberg 2005). Low frequency sounds from the turbines may, for example, overlap with the mating calls of gadoids (i.e. cod and haddock) with potential consequences for community dynamics (Wahlberg & Westerberg, 2005).

Conclusions

Impacts on fish and mammal assemblages as a whole of eventual ***local*** masking of bioacoustics should, although ***long-term***, generally be ***small***. There may be exceptions for isolated spawning populations if a fish species is particularly sensitive to this kind of disturbance. Little research is available, though, and no studies have estimated what long-term consequences any impacts could have. **Certainty: 2**

Impacts of sound disturbance from wind farms on long distance communication and navigation among mammals, such as whales during migration, is largely unknown (**Certainty 2**). If likely at all, impact on assemblages of porpoises, dolphins and seals may generally be ***small***, with special caution for whales migrating long distances.

8 Electromagnetic fields (EMF)

The electricity generated by an offshore wind farm may be transmitted to the onshore network through 50 Hz (EU) and 60 Hz (USA) high voltage alternating current (AC) or direct current (DC) cables. These cables will emit EMF (electromagnetic fields or electric and magnetic fields). The electric field generated by the power transmission through the cable is shielded within the cable (AC cable), while a magnetic field is measurable around cables. The rotational magnetic fields created around industry standard AC cables induce an electric field in the environment. Electric fields are, also, induced by marine organisms and water ('conductors') moving through the magnetic field (VRD, 2009). A number of factors may influence the distribution of the EMF in the water, such as voltage, electric current, cable design, if AC (used for wind farms today; VRD, 2009) or DC is transmitted, and the salinity of the water. It is difficult to model how the fields will be distributed at a particular wind farm. It is, however, estimated that the EMF from an AC cable, of typical capacity for connecting a large wind farm with the grid on land, differs little from background levels only a few tens of metres from the cable and 0.5 metres away for DC cables (Elsam Engineering & Energi-E2, 2005; Gill, et al., 2005; VRD, 2009). At the same time, many electrosensitive species, including fish and migrating whales and sea turtles, may sense the induced variations in the field at much larger distances than that (e.g. Walker, et al., 2002; Walker, et al., 2003; VRD, 2009). The risks for EMF to cause behavioural changes and pose migration barriers should, thus, be considered in research efforts and risk assessments. The following sections are limited to fish and invertebrates.

8.1 EMF and fish

Little is known about the influence of electromagnetic fields around cables on fish behaviour (Gill, et al., 2005; Öhman, et al., 2007). The most sensitive fish species are elasmobranches (sharks and rays), common eels and electric fishes, which use weak electrical currents for orientation (induced electric field in relation to the geomagnetic field) and/or prey location (Kalmijn, 2000; Klimley, 1993; Gill, et al., 2005; Meyer, et al., 2005; Peters, et al., 2007; Gill, et al., 2009). Behavioural thresholds in relation to EMF for a number of electrosensitive species is provided by Peters and colleagues (2007).

A number of studies have suggested that fish behaviour could be affected by relatively weak EMF (*see* review by Öhman, et al., 2007). Modelling by Gill, et al. (2009) suggested that many electrosensitive species should be able to detect EMF from wind power cables at a distance of more than 300 metres. Recent large-scale experiments, attempting to mimic conditions in a wind farm, showed EMF-related behavioural responses among elasmobranches, including attraction to the EMF sources, but with high variability among individuals (Gill & Taylor, 2001; Gill, et al., 2009). Whether impacts are positive or negative for the fish has not yet been sufficiently addressed in research to date, and this is still unclear (Gill, et al., 2009). Earlier experiments showed that lesser spotted dogfish (now called small spotted catshark, *S. canicula*) were repelled by a certain strength of induced electric fields, while attracted to weaker levels (Gill & Taylor, 2001). There are, also, examples of sharks that have attacked power cables as the EMF has triggered their feeding behaviour (Marra, 1989).

EMF may affect migration behaviour in tunas, salmonids and eels (Walker, 1984; Formicki, et al., 2004), although the importance of geomagnetic cues for their navigation is unclear (Walker, et al., 2003; Lohman, et al., 2008). In experiments where magnets, disturbing geomagnetic cues, were attached to migrating salmon, no effects were shown (Westerberg, et al., 2007; Yano, et al., 1997). Salmonids were not affected by a cable between Sweden and Poland, according to a study by Westerberg and colleagues (2007). Tracking studies on European eel (*Anguilla anguilla*), mostly in relation to wind farms, have shown that the eels were delayed by the cables by 30-40 minutes or slightly changed their course, but that the cables did not obstruct migration overall (Westerberg & Lagenfelt, 2006;

Westerberg, et al., 2007; Lagenfelt I. oral presentation at Vindval Seminar, Stockholm, November 22, 2009). In addition, the results were not isolated to EMFs, and it was speculated that the physical presence of the cables could be more important.

Surveys in Denmark indicated some effects of cables on migration through and within the wind farms by European eel, Atlantic cod and flounder, but the survey design was not sufficient to link these effects firmly to EMF (Dong Energy, et al., 2006).

The density of cables on the bottom close to urban areas is currently relatively low, and potential problems are restricted to some migratory species depending on geomagnetic cues for navigation. In an offshore wind farm a comparably dense network of cables is created, which could deter sensitive species such as elasmobranches and cause negative effects on benthic assemblages throughout the farm (Gill & Kimber, 2005). Cables could alternatively attract electrosensitive species into the wind farm areas, where they would gain protection from trawling (Gill, 2005). As for research on many other effects of offshore wind farms, behavioural ecology still dominate this field, however, and the ecological or population effects of submarine power cables and EMF are yet poorly understood.

Conclusions

No significant effects of EMF have been established to date. Although ***long-term***, eventual effects on fish should be ***local***, and overall impacts on resident fish assemblages should be ***small***. There are considerable uncertainties, when it comes to different life stages of fish, barrier effects of EMF for electrosensitive migrating fish, and long-term ecological effects of altered feeding behaviours of elasmobranches in areas with high densities of cables.
Certainty: 2

8.2 EMF and invertebrates

Little has been done to describe electromagnetic reception among invertebrates (Bullock, 1999), although experiments with lobsters and isopods indicate that they may at least in part use geomagnetic cues for navigation (Ugolini & Pezzani, 1994; Boles & Lohman, 2003). The survival and physiology of some species of prawns, crabs, starfish, marine worms, and blue mussels have been examined in relation to EMF levels corresponding to the intensity on the surface of ordinary sub-marine DC cables in the Baltic Sea (Bochert & Zettler, 2004). No significant effects were observed for any of these after three months. Further, a visual survey of benthic communities along and on a wind power cable, revealed no abnormalities in assemblage structure (Malm, 2005).

Black tipped reef shark. Photo: Dan Wilhelmsson

Conclusions

Potential ***long-term*** impacts on sessile organisms are likely to be localised (***very local***) and ***small***. The number of studies addressing invertebrate tolerance to EMF is quite limited, but the scale of impact can be estimated on a relatively solid basis. **Certainty: 2**

8.3 Mitigation of EMF effects

It is commonly recommended that cables should be buried 1 metre into the seabed to minimize effects. Burial, however, only increases the distance between the cable and electrosensitive fish (Gill, et al., 2005). The sediment layer itself does not influence the size of EMF (Gill, et al., 2009; VRD, 2009). The burial of cables would, moreover, need to be weighed against the disturbance caused by the dredging and ploughing activities, including the risk of re-suspending pollutants (*see* section 6). The transmission system can, further, be constructed so that magnetic fields are reduced or to some extent cancel out each other (*see* Gill, et al., 2009; VRD, 2009), although the costs involved makes this unlikely to become a standard approach.

9 Impacts on birds

9.1 Collision risks

The interaction between birds and wind turbines is the most thoroughly investigated environmental concern relating to wind power. Early considerations included the extent of bird collisions with the turbines and subsequent effects on population dynamics and migration (Winkelman, 1985; Ivanov & Sedunova, 1993; Gill, et al., 1996; Richardson, 1998; Langston & Pullan, 2003; Desholm & Kahlert, 2005; Kunz, et al., 2007). Including both on- and offshore facilities, estimated rates of mortality for different bird species range from 0.01 to 23 mortalities per turbine per year (Drewitt & Langston, 2005), with an average across bird species of 1.7 collisions per turbine per year according to an ongoing scientific synthesis (M. Green, personal communication on synthesis in progress 2009). Raptors seem to be more sensitive than other species according to studies of land based wind turbines (e.g. de Lucas, et al., 2008), and the average collision rate for raptors was estimated to 0.3 per turbine per year (M. Green, personal communication on synthesis in progress, 2009). For raptors around onshore wind farms, fatality does not seem to be dependent on the number of birds, but varies with species-specific flight behaviour, weather and topography (Langston & Pullan, 2003). It is important to note that both collision rates and impacts of increased mortality on populations vary greatly with species (e.g. Fox, et al., 2006; Desholm, 2009).

Although monitoring at the established offshore wind farms have only partly involved combined visual and radar-based observations of behavioural responses of migrating birds to the structures, experiences of species-specific responses have been gathered. Least is known about the collision risks exposed on the largest component of long-distance migration: the migration of passerines. Many studies on collisions on land have reported that passerines are being killed in larger numbers than other birds. Hüppop, et al. (2006) reported the same from the Fino offshore research platform in the German Bight with several hundred passerines being killed during isolated events. Still, it’s important to recall that passerines outnumber other terrestrial bird species on migration by at least an order of magnitude, and hence the relative impact may not be highest for passerines. In fact, the experience from land-based wind farms point at larger species as the most sensitive to collision. Frequent collisions, however, have been reported from only a few exposed sites with high migration densities (e.g. at passes, straits and peninsulas) and large numbers of, for example, soaring resident raptors. In such worst-case scenarios like the Altamont Pass and Smöla wind farms (Erickson, et al., 2001; Dahl, 2008), mortality rates of raptors as a direct result of collisions with the rotor blades are relatively high in comparison with the size of the affected populations. There is an almost complete lack of experience regarding the behavioural responses of large birds on long-distance migration, such as raptors and cranes, around offshore wind farms, as wind farms have not yet been erected in migration corridors for these species groups. A worst case scenario offshore would be a situation in which raptors were being attracted to an offshore wind farm along a major migration corridor.

A recent offshore wind farm related study in Germany, indicated that the majority of collisions might take place during a couple of days each year, when migratory birds are hampered by bad weather (Hüppop, et al., 2006). The commonly applied radar surveys that cover only parts of the migration seasons, and for which quality decreases with certain weather conditions, distance and size of birds, may thus have underestimated the collision risks for birds passing through wind farms (Hüppop, et al., 2006). The flight altitude of migrating birds is usually lower offshore than on the coast and inland (Krüger & Garthe, 2001; Hüppop, et al., 2004), limiting the application of data that are collected on land (Hüppop, et al., 2006). For many seabirds, the flight altitude ranges within 0-50 metres (Dierschke & Daniels, 2003) and e.g. most common eiders may fly at altitudes lower than 20 metres (Larsen & Guillemette, 2007), well below the rotors of wind turbines. Nocturnal migrants may, on the other hand, be attracted to illuminated wind turbines (e.g. Montevecchi, 2006 and *see* Hüppop, et al., 2006 for references but *see* Dong Energy, et al., 2006). However, for example common eiders seem to keep a longer distance from turbines at night compared to in daylight (*see* Desholm, 2009 for references). For common eiders passing Nysted wind farm, it was predicted that 0.02 per cent (45 birds) would collide each year and impact of this single wind farm was considered negligible (Dong Energy, et al., 2006). For the 250 bird species migrating across the German Maritime area, it has been estimated that increases up 0.5-5 per cent (depending on species) of the adult mortality would cause no effects at population scale (*see* Hüpopp, et al., 2006 for references). Modelling tools for different scenarios and turbine types are available (Garthe & Hüppop, 2004; *see* Hüppop, et al., 2006 for references, Desholm, 2009).

In relation to local movements of birds considerations should be focused on staging birds. The local movements undertaken by waterbirds and seabirds in staging areas may be attributed to current drift, movements between sites in response to prey aggregation and between sites of different functional role. No field studies have yet investigated the frequency of local movements in their staging and wintering areas, and hence the risk of collision for these birds cannot be assessed.

Conclusions

Most studies indicate ***small*** impacts of bird collisions on assemblages as a whole for most species studied and the few areas considered, although any effects would be ***long-term***. The temporal and methodological limitations in most studies and variability among species call for further clarification though. **Certainty: 3**

9.2 Migration barriers

Several bird species avoid wind farms during migration (e.g. Pettersson, 2005; Masden, et al., 2009; Muselears, 2009). Although monitoring at the established offshore wind farms have only partly involved combined visual and radar-based observations of behavioural responses of migrating birds to the structures experiences of species-specific responses have been gathered. Least is known about the barrier effects exposed on the landbirds, including large species like raptors and cranes, whereas due to the Danish demonstration projects a large amount of information is available on the behavioural responses of migrating waterbirds to offshore wind farms (Dong Energy, et al., 2006). Waterbirds reacted to the wind farms at Horns Rev 1 and Nysted wind farms at distances of 5 kilometres from the turbines, and generally deflected at the wind farm at a distance of 3 kilometres (Petersen, et al., 2006). Within a range of 1-2 kilometres more than 50 per cent of the birds heading for the wind farm avoided passing within it. At the Rønland offshore wind farm 4.5 per cent of all waterbird flocks entered a zone of 100 metres from the wind farm (Durinck & Skov, 2006). At the Utgrunden wind farm in Kalmar Strait low-flying flocks of eiders were rarely seen to pass within 500 metres of the wind turbines during daytime, and avoidance behaviour was observed, with some birds altering direction 3-4 kilometres before reaching the Utgrunden wind farm to fly around it (Petterson, 2005).

For long-distance migrations, the energetic losses due to migration barrier effects through avoidance of single wind farms seem trivial, especially considering the impacts of other factors, such as wind conditions and visibility, although there may be potential cumulative effects of several wind farms in a region (e.g. Petterson, 2005; Masden, et al., 2009). Energetic costs due to single wind farms are only likely to be measurable for species commuting daily within a region, for instance between foraging grounds and roosting or nest sites (e.g. Masden, et al., 2009). In these cases wind farms could cause fragmentation of coherent ecological units for the birds (e.g. Fox, et al., 2006; Hüpopp, et al., 2006; Stewart, et al., 2007).

Conclusions

The potential impacts on long distance migrating birds are considered to be ***small***, but for daily commuting birds, long-term habitat fragmentation and extended routes could have ***moderate*** effects on assemblages. Several published studies and estimations exist. **Certainty: 3**

9.3 Habitat loss for seabirds

Habitat loss for seabirds may take place both as a function of behavioural responses (habitat displacement) and due to impacts from the wind farm construction and operation on the available food supply of the birds. The evidence gathered from existing monitoring programmes at offshore wind farms indicate that specific responses of waterbirds to wind farms are highly variable, both as a function of specific disturbance stimuli and site-specific characteristics. In addition, adaptations to the turbines and rotor blades are observed, which make accurate assessment of the scale of habitat displacement rather difficult, especially over the long term (Petersen, et al., 2006). A further complication is the fact that habitat displacement impacts as documented during the monitoring programmes of existing wind farms may not have taken (natural) changes in food supply into consideration. Despite these uncertainties, habitat displacement is generally regarded as the main source of impact on birds from offshore wind farms.

Aggregation of sea birds off the Azores. Photo: Sarah Gotheil

The intensive boat traffic around farms during construction poses a problem for some species of seabirds such as divers (*Gavia* spp.), common scoter (*Melanitta nigra*) and long tailed duck (*Clangula hyemalis*) (Tucker & Evans, 1997). Studies suggest that the species that are affected by boat traffic will also be affected by the operation of the wind farms (Dierschke, et al., 2006). From the published monitoring reports a pattern emerges in which species with offshore habitats display stronger reactions to wind farms than species with more coastal habitats (Petersen, et al., 2006; PMSS, 2007; Gill, et al., 2008). Among the seaducks the more marine common scoter and long-tailed duck have a higher potential for habitat displacement than the more coastal eider.

Studies performed at existing wind farms, primarily in Denmark and Sweden, show that common scoters avoided the wind farms during resting and wintering periods (Guillemette & Larsen, 2002; Larsen & Guillemette, 2007; Petterson, 2005; Petersen, 2005; Dong Energy, et al., 2006; but *see* Musalears, 2009). At the Nysted wind farm in southern Denmark the abundance of eider duck decreased by more than 80 per cent immediately after the installation of the turbines (Kahlert, et al., 2004; Desholm & Kahlert, 2005).

Avoidance by significant numbers of several species of diving birds has been noted 2 kilometres from a wind farm (Dong Energy, et al., 2006), and numbers of diving birds have been recorded to decrease by 55 per cent even at a distance of 2-4 kilometres from a farm (Petersen, et al., 2004). Available literature indicates that sensitivity and impacts may increase with size of bird flocks (Stewart, et al., 2007). Baseline data on temporal variations is often weak however (Fox, et al., 2006; Stewart, et al., 2007). Despite the documented reductions in densities of some of these species following construction of offshore wind farms it should be pointed out that the reported numbers displaced so far are relatively small in comparison to total population levels, and hence bear no significance to the overall populations. Moreover, it is not clear what characteristics of wind farms caused this avoidance behaviour. For common eiders, it has been shown that neither noise nor movement of the blades were the primary causes (Giullemette & Larsen, 2002; Larsen & Guillemette, 2007). To speculate, as sea ducks generally avoid flying over land, the wind turbines could be interpreted by the birds as patches of land, which could cause avoidance of the area as whole.

Species occurring widespread close to human developments, like gulls, seem generally not disturbed by wind farms. Cormorants, gulls, and terns, have been observed to use wind turbines as resting sites between dives, and local increases of some species within wind farm areas have been shown (e.g. Petersen, et al., 2004; Dong Energy, et al., 2006; Fox, et al., 2006; Musalears, 2009). It has also been suggested that locally enhanced abundance of bivalves and fish around wind turbines could enrich feeding grounds for e.g. cormorants, gulls, and sea ducks, although effects on populations of this are likely to be minimal (Dong Energy, et al., 2006; Fox, et al., 2006).

Offshore wind farms have grown in number and size. It has been suggested that habitat fragmentation for birds and potential ecological effects, such as trophic cascades as a consequence of this may become an important issue (West & Caldow, 2005). For example, several bird species utilise temperate ice-free areas, such as offshore banks, for wintering and migrate to northern boreal or arctic areas for breeding during the spring (McLaren & McLaren, 1982). Furthermore, there is strong evidence that the supply of invertebrates limits the abundance of bird populations and determines the distribution of the flocks (Stott & Olson, 1973; Guillemette, et al., 1992; Smaal, et al., 2001), and populations of ducks can subsequently influence the structure of benthic communities (Hamilton, 2000; Vaitkus & Bubinas, 2001). The most numerous bird species in temperate areas relevant for offshore wind power in north-western Europe and eastern North America, are common Eider (*Somateria mollissima*), long tailed duck (*Clangula hyemalis*), Common Scoter, (*Melanitta nigra*) and Velvet Scoter (*Melanitta fusca*) (Milne & Campbell, 1973; Goudie & Ankney, 1986; Brager, et al., 1995; Reinert & Mello, 1995; Merkel, et al., 2002). In addition, other equally sensitive but less abundant species such as divers may be found in the same areas.

Detailed species sensitivity indexes for impacts of offshore wind farms on seabirds are available (e.g. Garthe & Hüppop, 2004; Bright, et al., 2008).

Conclusions

The risk of ***very broad*** habitat loss for sea birds (at least, or most, for sea ducks and divers) in a wind farm area during both construction (***short term***) and operation (***long term***) calls for special attention in planning and development of offshore wind power. The severity of effects on local bird assemblages largely depends on whether the birds find alternative habitats or not. Evidence base from targeted studies is comparably strong, although understanding of longer term avoidance of areas is not established. During construction: **Certainty: 5**; During operation: **Certainty: 4**

10 Aspects of decommissioning

The life span of an average offshore wind farm has been estimated to be 25 years. Turbines could, similarly to oilrigs, be disassembled and recycled, discarded to landfill, or be reconditioned and reused. Turbines could also be partially removed or toppled. For wind energy the resource harvested is obviously renewable, and so it may be decided that the wind farm should remain in operation, with continuous maintenance and upgrading.

If the farm is completely removed, some problems of sediment re-suspension may occur, especially if the cables have been buried. As a consequence sensitive habitats may again be disturbed. Future technologies may provide better alternatives but current experience from oilrig decommissioning favours explosives and cutting. Explosives would kill most animals in the zone nearest to each turbine, and fish with swim bladders would be most severely impacted. Considering the large numbers of turbines and the areas they cover, impacts could be substantial, and the decommissioning of the subsurface parts of wind turbines may thus in many cases become questioned. *See* for example Gill, et al., 2005 for further reading.

When the wind turbines are removed, so are potential disturbance effects, although toppled turbines would not emit noise or have any moving parts. If not removed, the installations would be permanent; degradation of carbon steel, for example, is 0.1 millimetres per year in oxygen rich waters (Jacobsen, et al., 1999). For buried pipelines it has been estimated that it will take 1200-4400 years for a complete natural breakdown (DNV, 1999). However, habitats that may have been created and developed over a number of years, in many cases constituting islands of comparably undisturbed hard substrata in regions otherwise dominated by deeper soft bottoms, would be disturbed. In addition, if a wind farm has effectively protected an area from the destructive effects of fishing this protection is likely to disappear with the farm. Interestingly, it has been argued that the potential for oilrigs to constitute Essential Fish Habitats should be considered in the environmental review processes before decommissioning (Helvey, 2002). It is reasonable to conclude that decisions on the fate of the wind turbines will inevitably have to be made on a case-by-case basis.

11 Ecosystem and seascape considerations

An area can be considered important for a species if 1 per cent of a population resides within it or uses it, according to commonly applied criteria from the Ramsar Convention (Atkinson-Willes, 1972). However, research and surveys focusing on single species, habitats or ecosystems services do not offer a thorough base for assessment of the effects of wind power development. To better understand species-landscape interactions it is important to consider the ecological dynamic of multiple species and habitats on larger scales (*see* efforts for offshore wind farms by e.g. Nunneri, et al., 2008; Buckhard, et al., 2009 and Punt, et al., 2009 and references therein).

The scientific discipline landscape ecology focuses on how spatial patterns and ecological processes are related in a multitude of landscape scales (Troell, 1939; Turner, et al., 2001; Wu & Hobbs, 2007), and an important aspect to consider is the geographical position of a habitat (or other ecological unit). Coastal seascapes are typically spatially heterogeneous areas, which are affected by anthropogenic activities such as fisheries and agriculture. Offshore wind power development is an example of how human activities are changing the coastal environment and potentially their ecology within landscape mosaics. Species distribution within the landscape, which is commonly determined by the ability of species to move or disperse among habitats, might be affected as well as metapopulation dynamics and source-sink relationships.

For instance, most fish and invertebrates that are associated with wind farms do not reside there for their entire life history. Different life stages (egg, larvae, juvenile and adult) could inhabit other depths and environments, and assemblages within wind farms are usually only sub-sets of populations. Habitat destruction and fragmentation of coherent ecological units (habitat loss and isolation, for example seabirds in section 9.3), or the potential of new hard bottom habitats to connect different areas (*see* section 3.2), could thus have effects on biodiversity as well as on single species (in terms of distribution patterns, behaviour, reproduction, growth and survival). The degree to which such effects occur depends on connectivity (e.g. distance between patches, metapopulation dynamics, source/sink relationships) and landscape configuration (e.g. Hanski, et al., 1995; Eriksson & Ehrlén, 2001; Mouquet & Loreau, 2003). Consequently, a wind farm development should consider future scenarios of how landscape connectivity, i.e. 'the degree to which the landscape facilitates or impedes movement among resource patches' (Taylor, et al., 1993) might change after such disturbance events. For improved assessments of the influences of wind farm developments, greater understanding of the biological and physical connectivity processes within habitats and populations is thus needed.

Cumulative effects of several wind farms in an area need to be thoroughly considered. Assessments of possible impacts of proposed offshore wind farms in coastal regions of Germany indicate that 2-16 per cent of national sea bird populations could be affected, depending on the species (Dierschke, et al., 2006). Another study suggested that in a worst case scenario, where 18 wind farms are constructed simultaneously in the German North Sea, 39 per cent of the harbour poises in the region could show behavioural responses to this (Gilles, et al., 2009).

When baseline studies are conducted (according to e.g. EIA and SEA requirements), ecological integrity and ecological risks should be assessed in order to understand how the provision of ecosystem services is affected by one or several wind farms in a region (Nunneri, et al., 2008). Furthermore, with the focus on large-scale patterns and processes using an ecosystem or a seascape as focal unit, spatial variability, landscape complexity and temporal dynamics need to be integrated and analysed across scales. To achieve such quite complex analyses, the most suitable tools would be Geographical Information Systems (GIS), spatial statistics, remote sensing techniques and Global Positioning Systems (GPS) (Turner, et al., 2001; Farina, 2006).

Using empirical information of temporal (seasonal and interannual) and spatial variability in the distribution and movement of organisms as well as the distribution and fragmentation of coastal habitats a conceptual GIS model could be created.

Examples of parameters could be:

- Relevant daily movement/migration and ontogenetic migration of fish;
- Distance from fish spawning sites;
- Larval dispersal/supply/connectivity;
- Daily and seasonal migration of birds and
- Cetacean behaviour focusing on foraging, nursery and areas used for reproduction.

Such a model would typically be conducted using raster GIS modelling on generalized and continuous spatial data where geographic spaces of interest are divided into regular cells, each with a specific attribute digital value, and subsequently utilized as input to mathematic equation models. For application in the chosen GIS program (e.g. ArcGIS) all ecological parameters are put in a dynamic predictive model where the suitability of a locality is analysed (quantitatively and qualitatively). The proposed GIS model should be useful to simulate future scenario dynamics of biophysical characteristics and ecological patterns. If possible, the model should also take into account unexpected large-scale processes such as potential future environmental changes/events (e.g. elevated temperature, increased runoff and/or alterations in nutrient input).

In order to turn GIS modelling into firm implementation recommendations, information of the aforementioned ecological parameters will be stored as different layers and used in the analyzing process. All components are included in the model as continuous data, put as layers upon each other in maps, and analyzed by automated selection procedures, e.g. stepwise regression and cross-validation techniques. To evaluate suitable locations for wind farms within a certain area a graded scale, based on risk of environmental disturbances, can be used. This approach does not only promote due precautionary approaches, but may also facilitate more cost- and time-effective application, consenting and permitting processes for offshore wind power projects.

12 Variability across latitudes, regions and localities

Variability, not only between groups of organisms but also among related species, makes predictions of impacts of offshore wind farms on marine ecology and the marine environment difficult. Apart from the obvious variation in species composition between regions, general findings from one geographic area may not be applicable to another since regional ecological and environmental factors strongly influence the ecological performance of marine organisms (Bohnsack, et al., 1991; Baine, 2001). Major regulatory factors on fish communities, for example, differ at larger geographic scales (e.g. Bohnsack, et al., 1991). Trophic interactions, mobility and spatial use of marine biota also vary along latitudinal gradients (e.g. Floeter, et al., 2004; Laurel & Bradbury, 2009).

At regional and local levels, bio-geographic and oceanographic factors influence the marine ecological settings. Available habitats and the connectivity between them are of key importance. For instance, the extent and type of colonisation of turbines will depend on the proximity and connectivity (including current patterns) to existing hard habitats that could supply larvae and propagules (Cummins, 1994; Svane & Petersen, 2001). The diversity of shallow water fishes associated with the turbines is also likely to decrease with distance from the shore (e.g. Molles, 1978; Gladfelther, et al., 1980; Cummins, 1994). With increasing exposure to wave action, delivery of rates of plankton to the turbine habitats is likely to increase, benefiting filter feeding animals such as mussels and planktivorous feeding fish (Wilhelmsson, et al., 2006).

Depth is a key structuring factor in the marine environment (e.g. Pedersén & Snoeijs, 2001; Ponti, et al., 2002). Littoral species, particularly on rocky shores, as well as subtidal species are typically confined to specific depths defined by the physical and biological characteristics of the habitat, such as light and wave conditions, temperature, and competition for space and other resources (Gibson, 1969; Bohnsack, et al., 1991). In particular for transient fish species, the depth at which turbines are situated may also be the most important factor for the magnitude of fish aggregation effects (Moffit, et al., 1989). Salinity also affects the assemblages present in the area (e.g. Mann, 1991). Latitudinal, regional, and local factors, thus, influence species, habitats and their sensitivity to wind farm development.

13 Conclusions

To date, wind farm related research and monitoring, along with related research, indicates that the largest potential impacts of offshore wind power development take place during the construction phase. Disturbance from noise and seabed disruption during the construction phase could lead to loss of feeding, spawning and nursery grounds for e.g. fish, marine mammals, and birds for varying periods of time, and could also adversely affect sensitive benthic species and habitats. Although impacts often seem to be short-term or spatially limited, the acceptable levels of disturbance will ultimately depend on the local/regional conservation status and sensitivity of the species or habitat in question.

On the other hand, if offshore wind power development is well planned and co-ordinated the local subsurface marine environment could even benefit from wind farms in several aspects. (e.g. trawling exclusion and habitat enhancement for many species).

Knowledge on the various disturbance effects on the marine environment for offshore wind power is increasingly substantiated due to the realisation of several long-term monitoring programmes along with targeted studies and experiments. However, most programmes were only recently initiated and many research contributions are limited to method development. Additionally, the majority of studies and experiments are limited to single species systems, and there is little elaboration at ecosystem scale. Furthermore, Environmental Impact Assessments do not regularly address additive environmental effects of existing activities or other planned developments, including strategic aims for offshore wind power. To improve this, criteria and methods for assessing cumulative effects need to be designed and standardised at appropriate temporal and spatial scales

Through continued and enhanced monitoring of carefully selected environmental (biotic and abiotic) and species-specific parameters during construction and operation of offshore energy farms, adverse and positive impacts could more reliably be recognised. This would facilitate the process of identifying and achieve concurrence on areas to be considered for offshore wind power, as well as advance the development of methods and mitigating measures for the benefit of the marine environment.

Annexe 2 Legislation

Contents

1 Environmental Impact Assessment (EIA)

Directive 85/337/EEC (EIA, amended by Directives 97/11/EC, 2003/35/EC and 2009/31/EC)

According to Directive 85/337/EEC of the European Commission on the assessment of the effects of certain public and private projects on the environment, wind energy production projects do not require an EIA by default. The Member States determine through:

- A case-by-case examination, or
- Thresholds or criteria set by the Member State;

whether the project shall be made subject to an assessment.

An exception to this may the use of underwater high voltage electricity transmission cables, but this will be the case only if it involves 'Construction of overhead electrical power lines with a voltage of 220 kV or more and a length of more than 15 kilometres' that would therefore require an EIA.

An EIA should describe the project in terms of its:

- physical characteristics
- land-use requirements
- characteristics of the production processes
- expected residues and emissions
- alternatives
- significant perceived threats to the environment and
- a mitigation plan.

Areas that might be affected by the proposed project, are identified by the directive as the minimum threshold. These include:

- population
- fauna
- flora
- soil
- water
- air
- climatic factors
- material assets, including architectural and archaeological heritage,
- landscape and
- the inter-relationship between the above factors

For those project impacts that exert direct or indirect, secondary, cumulative, short, medium or long-term, permanent or temporary, positive or negative effects should be described as well.

2 Strategic Environmental Assessment (SEA) - Part 1

Directive 2001/42/EC (SEA)

According to the Directive 2001/42/EC, the national or international plans and programmes with likely significant environmental impacts e.g. offshore wind energy development shall be subject to an SEA.

An SEA should include the description of the main objectives of the plan or programme, the current state of the environment and the 'business as usual' scenario. It should explain:

- The likely significantly affected environmental aspects
- The current environmental situation (characteristics and problems)
- The likely significant effects
- The mitigation plans
- The alternatives and
- The monitoring plan.

The minimum threshold of the effects that should be considered is the same as that applied in an EU EIA and is obtained by adding the biodiversity and human health impacts. Additionally, the synergistic effect should be reported but not the indirect impacts.

The stages of an SEA include:

Screening (Directive 2001/42/EC, Article 3)

The Member State, in consultation with the environmental authorities, makes a decision on whether SEA is required. The decision should be reasoned and published. Please notice that wind energy production projects are listed in Annexe II and underwater high voltage electricity transmission cable in Annexe I

Environmental Studies (Directive 2001/42/EC, Article 5 and Annexe I)

The Member State carries out studies to collect and prepare the environmental information required by the Directive 2001/42/EC, Annexe I:

1. An outline of the contents, main objectives of the plan or programme and relationship with other relevant plans and programmes;

2. The relevant aspects of the current state of the environment and the likely evolution thereof without implementation of the plan or programme;

3. The environmental characteristics of areas likely to be significantly affected;

4. Any existing environmental problems which are relevant to the plan or programme including, in particular, those relating to any areas

of a particular environmental importance, such as areas designated pursuant to Directives 79/409/EEC and 92/43/EEC;

5. The environmental protection objectives, established at international, Community or Member State level, which are relevant to the plan or programme and the way those objectives and any environmental considerations have been taken into account during its preparation;

6. The likely significant effects on the environment, including on issues such as biodiversity, population, human health, fauna, flora, soil, water, air, climatic factors, material assets, cultural heritage including architectural and archaeological heritage, landscape and the interrelationship between the above factors;

7. The measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the plan or programme;

8. An outline of the reasons for selecting the alternatives dealt with, and a description of how the assessment was undertaken including any difficulties (such as technical deficiencies or lack of know-how) encountered in compiling the required information;

9. A description of the measures envisaged concerning monitoring in accordance with Article 10;

10. A non-technical summary of the information provided under the above headings.

Review
In some Member States there is a formal requirement for independent review of the adequacy of the environmental information before it is considered by the competent authority. In other Member States the competent authority is responsible for determining whether the Information is adequate.

Consultation
(Directive 2001/42/EC, Article 6 and 7)
The environmental information must be made available to authorities with environmental responsibilities and the public affected or likely to be affected as well as to relevant NGOs. They must be given an opportunity to comment on the draft plan or programme and its environmental effects before a decision is made on the adoption of the plan or programme or its submission to the legislative procedure. If transboundary effects are likely to be significant other affected Member States must be consulted.

Decision
(Directive 2001/42/EC, Article 8)
The environmental report and the consultants' opinion must be taken into account before the adoption of the plan or programme or its submission to the legislative procedure.

Submission
The Member State adopts the plan or programme or submit it to the legislative procedure.

Monitoring
(Directive 2001/42/EC, Article 10)
The Member State monitors the significant environmental effects of the implementation of the plan or programme.

3 Marine Strategy Framework Directive

The Marine Strategy Framework Directive covers the '[establishment of] a framework for community action in the field of marine environmental policy' and is addressed to the Member States. This directive requires the submission of an assessment of:

- The initial environmental status of marine regions (Article 8)
- The determination of good environmental status (Article 9 and Annexe I)
- The establishment of targets (Article 10), and of
- Monitoring programmes (Article 11)

The information reported by the Member States, namely characteristics, pressures and impacts (Annexe III), as well as the guidelines for monitoring programmes (Annexe V) and the type of measures (Annexe VI), could facilitate the process and help reduce the cost to Developers of environmental impact assessments for offshore renewable energy development projects.

It should be noted that in the biological features section of Annexe III, the fauna and flora described in seabed and water column habitats include:

- Phytoplankton and zooplankton
- Marine algae and bottom fauna
- Fish, mammals and reptiles
- Seabirds
- Other species as well as non-indigenous and exotic species

It is a requirement that biodiversity impacts on these species should be described in both an EIA or an SEA.

Good environmental status, as described in this directive, is contingent on respecting existing EU legislation, such as:

- The EU directive on the conservation of wild birds (Directive 79/409/EEC)
- The conservation of natural habitats and wild fauna and flora (Directive 92/43/EEC), and
- The regional and international sea and wildlife protection conventions, such as:
  - OSPAR
  - MAP and BSC
  - Bonn, Bern and Helsinki (HELCOM)
  - Ramsar
  - AEWA
  - Eurobats
  - ASCOBANS and ACCOBAMS conventions.

4 Other regional and global regulations

Examples of regional and global regulation that will applicability to offshore wind-farms include:

- London Convention (dredging, including sediment dumping)
- OSPAR Convention (1992/1999)
- Ramsar Convention (1971)
- The Bonn Convention (1979)
- ACOBANS (1992)
- The convention on Environmental Impact Assessment in a Transboundary Context (1971)
- The European Bird Directive 79/409/EEG (Special Protection Areas (SPAs), 1979)
- The European Habitat Directive
- EU Natura 2000
- United Nation’s Law of Seas

Annexe 3 Brief on Wave, Tidal and Current Power

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Introduction

Since the ocean covers 71 per cent of the Earth's surface and thus holds enormous energy potential (e.g Figure A3-1), it is natural to consider possibilities for offshore renewable energy development. Numerous technologies that use offshore locations to generate electricity have been developed or are in the research phase. These technologies include harnessing energy from the ocean such as wind, waves, tides, currents, and thermal and salinity gradients. Marine biomass as well as offshore solar energy are also being considered. A significant expansion of all aforementioned technologies is expected in the future as countries strive to balance economic development with sustainability initiatives.

While offshore wind power is treated in the main document and Annexe 1, this report focuses on wave, and marine tidal and current energy, and briefly describes some of the potential environmental effect these systems may have. Wave and tidal projects are already being developed in several countries including Argentina, Australia, Canada, China, Denmark, Germany, India, Ireland, Italy, Japan, the Netherlands, Norway, the Philippines, Portugal, Sri Lanka, Sweden, Taiwan, the UK and the USA. Estimates for potential energy, in particular wave energy, indicate enormous untapped sources that can be used to meet global energy demand (Table A3-1).

Table A3-1: Estimated energy potential for wave and tidal technologies

Technology	Theoretical Estimated Global Energy Potential (TWh) (1)	% of Global Electricity Demand (2)
Tidal	300+	2 %
Wave	8,000-80,000	42-421 %

(1)Energy potential is taken from the IEA-OES, Annual Report 2007.

(2)Estimated global electricity production was taken from the CIA World Factbook for 2007 and was approximately 19,000 TWh.

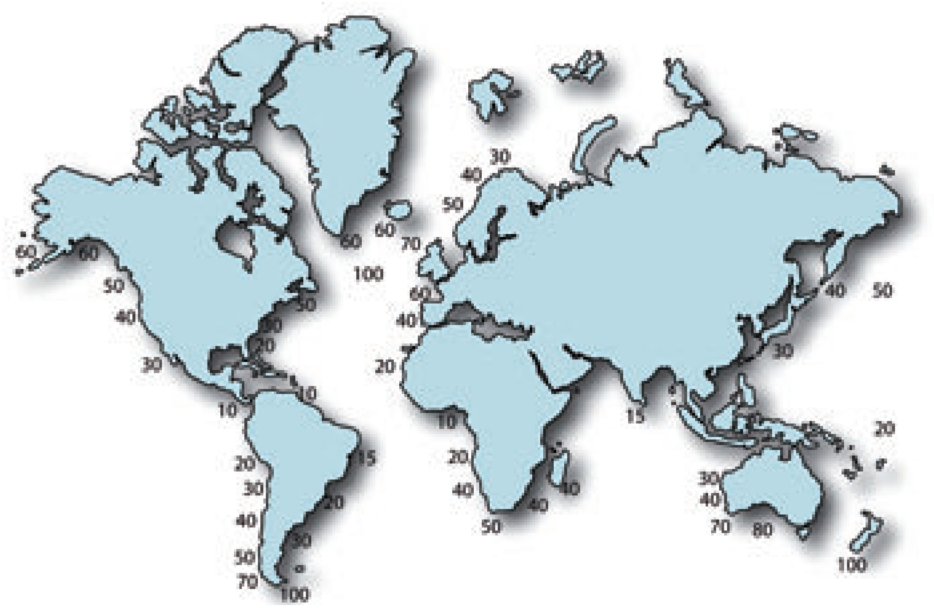

Figure A3-1: Wave power density (kW/m) of wave front in different parts of the world (Adapted from Langhamer, 2009b)

Wave energy

Wave energy directly harnesses the kinetic energy in waves and converts it to electricity (Bhuyan, 2008). Presently, the development of wave energy harvesting systems centre on three main principles; Overtopping systems (OTS), Oscillating Water Column systems (OWC), and wave activated bodies. OTS channel waves towards an elevated ramp. Behind the ramp, a large basin that is above seawater level collects the directed water and leads it back via hydro-turbines. The Wave Dragon is a floating offshore wave energy converter constructed after the OTS principle (Figure A3-2). OWC is based on a low-pressure air turbine that is partly submerged and open below the water surface, so that an oscillating water pillar can pump air through a turbine. The Limpet plant is an example of a full-scale shoreline OWC device (Figure A3-3). Wave activated bodies systems are moored to the seabed and float on top of the ocean's surface. As the device bobs or pitches, it converts mechanical energy from its movement into electricity. The Pelamis Project (Figure A3-4) is an example of a pitching generator that creates electricity through the bending of joints in a long cylindrical device (IEA, 2007). Another example is the point absorber (Figure A3-5; Leijon, et al., 2008) that has a relative small structure in comparison to the wave length. Technologies to harvest energy from waves are still in initial phases, and future technology could be radically different compared to pilot projects in development today. OWC devices would generally be located along the shoreline, while OTS and wave activated body systems will generally be located in waters with depths of 20-200 metres (e.g. Langhamer, et al., 2009a).

Marine and tidal current energy

Tidal energy takes advantage of the displacement of water around the world due primarily to the gravitational pull of the moon. Only certain areas in the world have large tidal displacements because tidal strength is determined by local geography (Bhuyan, 2008). Locations such as the Bay of Fundy can experience tidal ranges of up to 17 metres (NASA, 2009). The easiest method of harvesting tidal energy is through a dam that allows water in during high tides and releases that water through a turbine during low tides (so called tidal barrage systems). There are three tidal barrage systems in operation today. The largest is located in La Rance, France and is rated at 240 MW. The other two systems are in Annapolis Royal, Canada and Kislaya Guba, Russia (IEA, 2007). Other technologies under development to harness tidal energy include tidal

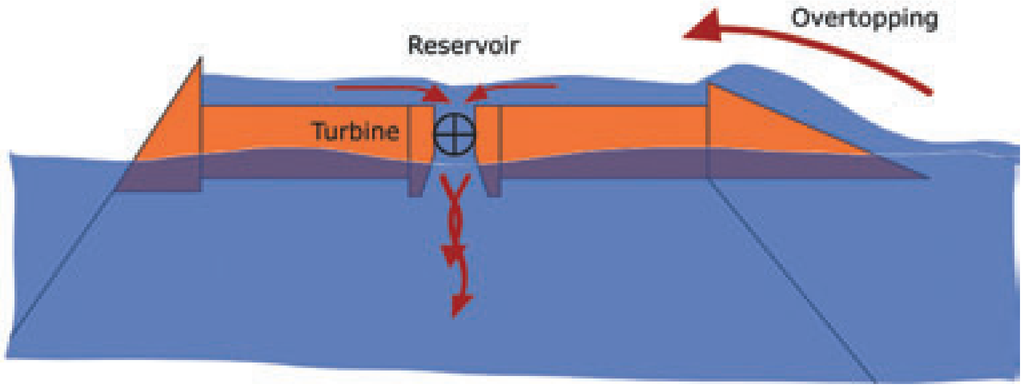

Figure A3-2: Example of wave converter based on the Overtopping System (OTS) principle, the Wave Dragon.

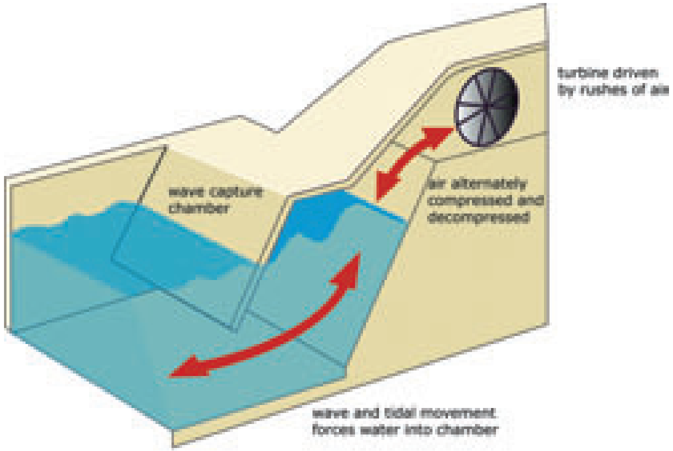

Figure A3-3. Example of wave converter based on the Oscillating Water Column (OWC) principle, the Limpet Plant (Wavegen).

fences that stretch across a channel with tidal currents and have vertical axis turbines, through which the tidal water is forced to pass, and tidal turbines, which are solitary units that resemble underwater wind turbines.

Marine current energy differs from tidal energy in that it takes advantage of the global ocean currents, generated primarily by the thermohaline circulation (one part of the thermohaline circulation is the Gulf Stream). Ocean currents provide steady sources of kinetic energy, which can be harvested by underwater turbine devices, similar to tidal turbines. Current energy is still in the research phase, and the exact dimensions of structures are still unspecified. Likely sites for tidal and marine current turbines are expected to be in depths between 20 to 80 metres (DTI, 2003).

Potential impacts on the marine environment

First, it is worth noting that tidal barrage systems have similar environmental impacts as traditional dams and can lead to significant habitat changes, sedimentation, marine migration problems, and changes in estuarine water flow (Pelc & Fujita, 2002; Clark, 2006; Fraenkel, 2006). In the case of La Range, the aquatic ecosystem was disturbed due to the complete closure of the estuary during construction (Frau, 1993). During operation, biological production was higher in the La Range basin than

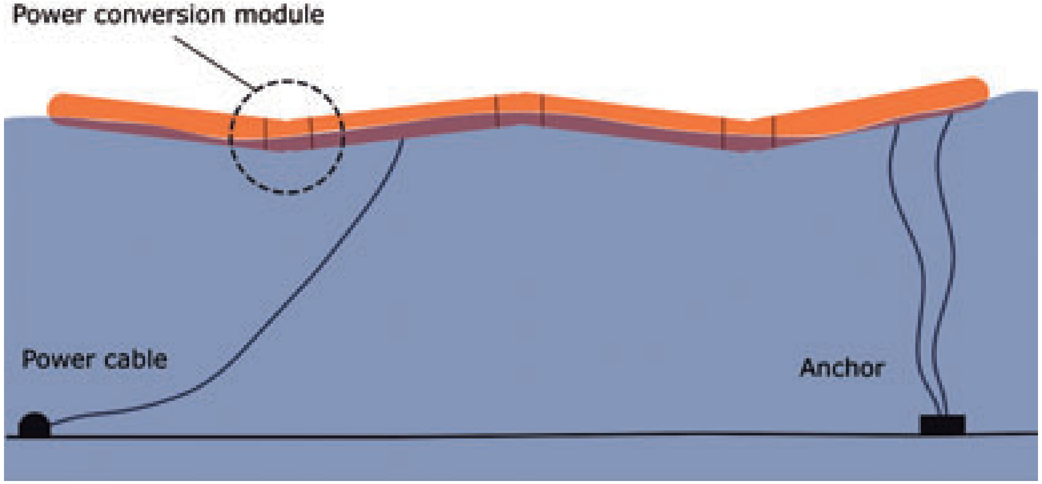

Figure A3-4: Example of a wave activated body, the Pelamis.

in comparable estuaries (Frau, 1993). Worldwide, however, there are only a handful of sites suitable for tidal barrages (Pontes & Falcão, 2001), and this report does not attempt to evaluate the potential effects of these technologies.

Marine tidal fences and tidal and current turbines (hereafter referred to as marine tidal and current energy), as well as wave energy devices, are believed to cause fewer environmental impacts than tidal barrages (e.g. Pelc & Fujita, 2002); however, their potential impact is spread out over larger areas. The nature and magnitude of these impacts are discussed in brief below. In this paper, the collection name WTC will hereafter be used for wave power, and marine and tidal current power.

Estimated environmental impacts from WTC are highly site- and device-specific (Cruz, 2008). The type of WTC that will dominate the market and be developed for large scale commercial use is still uncertain, and no full scale WTC park is yet in place. Environmental concerns related to WTC will become better defined as the systems are designed and implemented.

As for offshore wind power, concerns at the moment centre on habitat disturbance, noise and electromagnetic fields, as well as dangers from spinning blades and other moving parts. These effects could be amplified around vulnerable locations such as estuaries.

Attempts to predict the impacts of WTC on the marine environment are growing in number (EIAs, scientific reviews). However, very few studies have, naturally, collected primary data on potential impacts (but *see* Langhamer, et al., 2009; Langhamer & Wilhelmsson, 2007; Langhamer & Wilhelmsson, 2009; Langhamer, 2009 for wave power). Many of the findings outlined in the review on offshore wind power and the marine environment presented in Annexe 1, will be directly relevant to WTC generation. The readers are thus referred to relevant sections in Annexe 1 for further details on the nature and magnitude of potential impacts.

During installation of WTC devices, drilling and placement, cable laying, as well as boat traffic can cause acute sound pulses and give raise to sediment plumes (*see* Annexe 1, sections 4 and 7). The noise levels associated with WTC devices in operation may be low compared to ambient noise, apart from stochastic mechanical sound pulses (Shields, et al., 2009; The Ångström Laboratory, personal communication, 2009). However, the knowledge base is weak, and research is needed on the potential impact of noise emissions on marine organisms that inhabit or migrate through the area. (*see* Annexe 1, section 7 for more details)

Cables transmitting power between WTC devices and to the mainland may have an effect on marine organisms, such as migratory fish, elasmobranches, crustaceans and marine mammals that use magnetic fields for navigation or finding prey (Kalmijn, 2000; Gill, et al., 2005; Öhman, et al., 2007; Gill, et al., 2009). No significant effects on marine organisms from exposure to electromagnetic fields have been established (Bochert & Zettler, 2004; Gill et al., 2005; Gill, et al., 2009), but further research is needed to investigate how, for example, the relatively dense networks of cables within WTC parks may affect navigation and foraging by electrosensitive species. (*see* Annexe 1, section 8 for more details)

Studies on collision risks between marine organisms, such as mammals and fish, and submerged structures are rare (Gill, 2005). For wave power, it appears unlikely that installations would result in large numbers of collision fatalities of marine organisms. However, fish and mammals may be harmed colliding with or entangling in mooring chains (Wilson, et al., 2007). Some concerns that tidal fences and turbines blocking channels may harm or hamper migration by wild life have, on the other hand, been raised (e.g. Pelc & Fujita, 2002; Inger, et al., 2009). It is not certain that the slow moving turbines cause any impacts, as no effects on either fish or water movement were recorded in conjunction with a prototype built by Nova Energy, in the St. Lawrence Seaway (Blue Energy Canada, 2001).

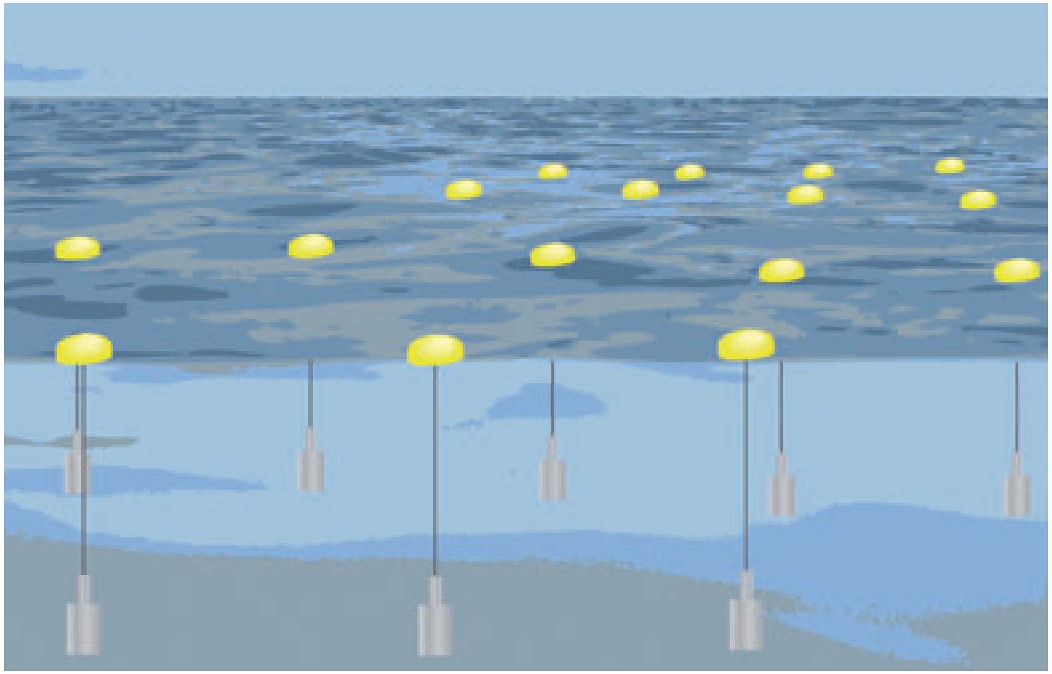

Figure A3-5: Example of a wave activated body, the point absorber (Seabased Ltd). © C. Wilhelmsson.

To decrease collision fatalities and barrier effects on fish, developers could construct systems where the space between the caisson wall and rotor foil is large enough for fish to pass through (e.g. Pelc & Fujita, 2002). Turbines could also be geared for low velocities (25-50 rounds per minute) which would keep the fish fatalities to a minimum (*see* Pelc & Fujita, 2002). It has been suggested that larger animals, such as marine mammals, could be kept away from the rotors through fences (Pelc & Fujita, 2002), but this may, on the other hand, cause barrier effects in narrow channels. The use of sonar sensors to shut the system down when mammals approach the devices has also been mentioned as an option (Pelc & Fujita, 2002).

Above water, WTC devices have few moving parts, and have relatively low profiles, which should decrease the risk of fatal bird collisions (*see* section

9.1 in Annexe 1). Obstruction lights (Montevecchi, 2006, and *see* Cruz, 2008 for references), as well as congregations of fish (*see below*), may, however, attract seabirds and thereby increase the risk of injuries due to collision. Impacts of WTC parks on the behaviour and migration of seabirds cannot be ruled out (*see* Annexe 1. sections 9.2 and 9.3). Further, the physical footprint of OWC devices (Figure A3-3) placed in the littoral zone could in some cases cause direct habitat loss for birds residing on the shores.

As for offshore wind power (*see* Annexe 1, sections 3 and 4), the construction of WTC devices will increase the amount of hard substrate in coastal environments and may thus positively affect abundance of several taxa (Langhamer & Wilhelmsson, 2009; Figure A3-6). Results from studies on foundations of wave energy converters confirmed that the structures are rapidly colonised by epifauna, fish, and crustaceans, with increasing diversity over time (Langhamer & Wilhelmsson, 2007; Langhamer & Wilhelmsson, 2009; Langhamer, et al., 2009b). One current case study is the wave power park that has been under development on the Swedish west coast since 2005 (Langhamer & Wilhelmsson, 2007; Leijon, et al., 2008). Within the environmental research package associated with the project, the potentials for low cost modifications to the design of the foundations in order to encourage the colonisation of fish and shellfish are of particular interest. The current research primarily targets species that are habitat limited, and seeks to augment local stocks where desired (e.g. Langhamer & Wilhelmsson, 2009; Figure A3-7). On the other hand, the research has shown that increased abundance of predators (i.e. edible crab *Cancer pagurus*) may have adverse effects on local numbers of certain species. Further, WTC parks will provide hard substrata in regions and at depths often dominated by soft bottom habitats, and could fill in gaps between natural areas of hard substrata, changing the biogeographic distribution of rocky bottom species within a region (Bulleri & Airoldi, 2005; Nielsen, et al., 2009). *(see* Annexe 1 and sections 3, for more issues related to the addition of artificial hard substrata)

Figure A3-6: An edible/brown crab (*Cancer pagurus*) taking shelter on a wave energy foundation. Photo: O. Langhamer.

WTC devices on the water surface (i.e. for wave power) may act as Fish Aggregation Devices (FAD) and attract both juvenile and adult fish (Kingsford, 1993; Castro, et al., 2002; Fayram & de Risi, 2007). Still, the functions and area of influence from different types of FADs remain unclear and require further investigation (Dempster & Taquet, 2004).

Pelc and Fujita (2002) raised concerns about the potential for floating devices to reduce water mixing causing detrimental effects on food supply for benthic organism. However, WTC devices will usually be subjected to fouling where sessile mussels often dominate (Wilhelmsson & Malm, 2008; Langhamer, 2009a; Langhamer, et al., 2009b). WTC devices may, thus, rather enhance benthic productivity within the areas, through the deposition of organic material, such as faecal matter, and live and dead organisms originating from the WTC device (Wilhelmsson, et al., 2006; Langhamer & Wilhelmsson, 2009; Maar, et al., 2009). WTC parks may also increase inorganic sedimentation rates in the area by altering the hydrodynamics (*see* Annexe 1, section 5). However, even slight currents in the area are likely to minimise these impacts (*see* e.g. Cruz, 2008 for references).

In particular wave power devices, which float on the surface and are only anchored to the seabed (Figure A3-3 and Figure A3-4), or have comparably small foundations (Figure A3-5), will have less impact on the seabed than wind turbines. A study by Langhamer (in press) suggests that the impacts of wave power on the seabed in the area as a whole are minimal. Shoreline devices, such as OWC (Figure A3-3), may have greater short-term impacts than those deployed offshore, as the former may require excavation of the coastline (Cruz, 2008).

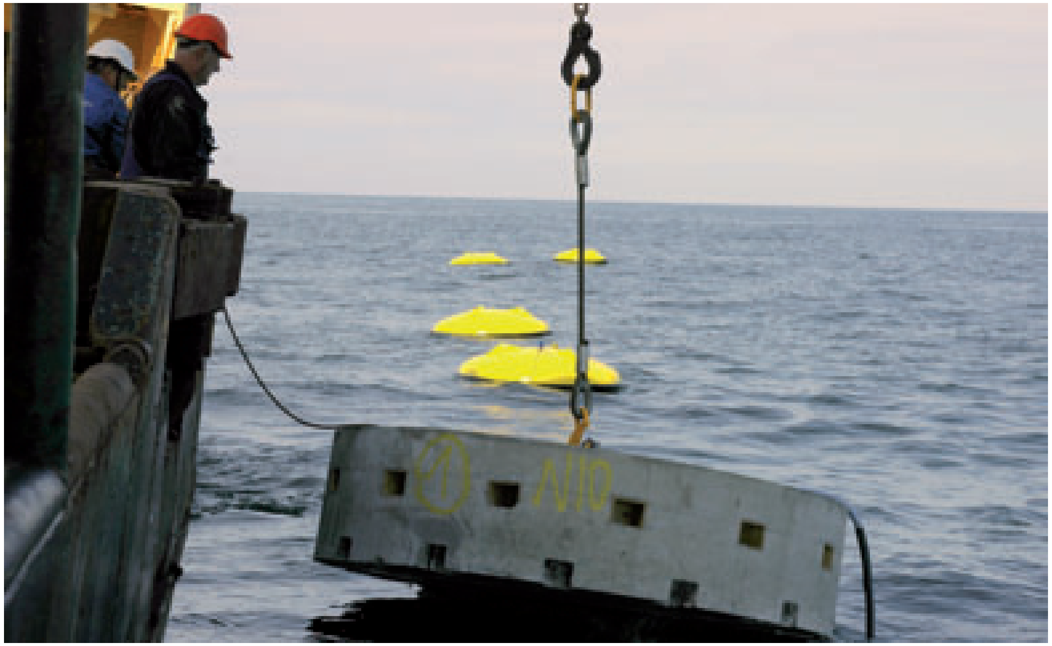

Figure A3-7: Deployment of a wave energy foundation that has been perforated with holes to investigate how it may enhance abundance of fish and crustaceans (Langhamer & Wilhelmsson, 2009). Photo: O. Langhamer.

Damping of waves by large arrays of wave energy converters may reduce erosion on the shoreline. However, most devices will be placed more than 1-2 kilometres from the shoreline, and the sheltering effect of wave energy devices is probably negligible in most cases (Pelc & Fujita, 2002; Cruz, 2008 and Ångström Laboratory, personal communication, 2009).

It should be emphasised again that primary data is to date only available from studies in conjunction with small scale pilot wave energy projects using e.g. point absorbers (Figure A3-5). Future wave parks may claim sizable areas (tens of square kilometres), and cumulative effects of large numbers of wave energy converters need to be thoroughly considered.

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