Marine wind farms and cetaceans

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ABSTRACT

The development of wind farms in the marine environment is set to expand rapidly in the future as governments strive to meet greenhouse gas emission targets and renewable energy commitments. Marine wind farms constitute a new development and one for which the associated environmental impacts remain largely unexplored. Areas of particular concern, including those related to development within important cetacean habitat, are discussed. It is our contention that marine wind farms should not be developed without due consideration being given to possible environmental consequences and that this should be done via appropriate environmental impact assessments.

KEYWORDS: HABITAT; NOISE; CLIMATE CHANGE

INTRODUCTION

The rapid development of wind farms

Wind farms offer many benefits over traditional energy sources and are expected to contribute significantly to a reduction in climate change in coming years. Many countries have made commitments to reduce their carbon emissions and are therefore planning to expand their current renewable energy sectors. For instance, the UK has recently produced a long-term strategic plan for its energy policy and has committed to a 60% reduction in carbon emissions by 2050 (DTI, 2003). This policy is intended to ensure that energy, the environment and economic growth are properly and sustainably integrated. This means that each country must explore renewable energy sources that have a minimal long-term environmental impact.

Wind energy is the fastest growing renewable energy source. New renewable energies (including wind, solar, geothermal and tide) have experienced an annual growth worldwide of 9% between 1971 and 2000, and wind energy has made up over 50% of this (International Energy Agency, 2002). The terrestrial wind industry accounts for much of this growth. In Germany and the US, for instance, total wind energy amounted to 8750MW and 4261MW, respectively, by the end of 2001 (*see Table 1*). However, as yet, there are no operating marine wind farms in these countries. Whilst the marine wind industry is in its infancy, there is a strong impetus to develop it further and particularly in offshore waters in the near future.

Table 1

Amount of energy produced from existing and planned terrestrial and marine wind farms in selected countries. Planned here includes all the projects which the authors are aware of, including those under construction, with consent granted or with an EIA/proposal under consideration by the relevant authority (*see also the Appendix*).

Country	Terrestrial (MW) [date of figure]	Marine (MW)	
		Existing	Planned
Germany	8750 [end 2001]	0	8200-13000
Denmark	2016 [2000]	234	473
UK	550 [2002]	4	¯1800
Spain	2099 [2000]	0	200
United States	4261 [end 2001]	0	>10500

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Growth in the terrestrial industry has meant that the cost of wind energy has fallen by 90% in the last 20 years, and it will fall further as the industry grows and matures (AWEA, 2002). Reduced costs will encourage further investment in both marine and terrestrial wind energy.

To fulfil their renewable energy commitments, countries have set targets for total wind energy production, for both marine and terrestrial sectors. The US target includes providing at least 5 % of national electricity by wind by 2020 with goals of 500MW by 2005 and 10,000MW by 2010 (Flowers and Dougherty, 2002). Some specific targets for marine wind energy have also been announced. Germany has perhaps the most ambitious target, aiming for 25,000MW of power from marine wind farms by 2020. Denmark is striving for 4,000MW by 2030 and the UK expects 2,000MW from marine wind farms by 2010 (BWEA, 2001). The European Wind Energy Association has also set targets of 5,000MW by 2010 and 50,000MW by 2020 for marine wind energy production (EWEA, 2001).

The massive growth in the terrestrial sector along with the renewable energy targets set by various countries and increased cost efficiency, provide an impetus for extensive wind farm developments in the marine environment. As such, more and more marine sites are being proposed for development. Furthermore, there is some significant public and political pressure to place the wind turbines offshore so that they are out of sight . Certainly land based wind farms have proved controversial, predominantly because of their impact on the landscape. However, being situated out of sight does not, of course, necessarily mean there will be no environmental consequences (Downie in Perry, 2003).

POTENTIAL NEGATIVE IMPACTS OF MARINE WIND FARMS

The potential significance of wind turbines to wildlife has recently been recognised, at least to some extent. For example, Resolution 7.5 *Wind Turbines and Migratory Species* was adopted by the seventh meeting of the Conference of the Parties to the Convention on the Conservation of Migratory Species of Wild Animals (CMS). The Resolution invites intergovernmental organisations to co-operate with CMS in efforts to minimise possible negative impacts of marine wind turbines on migratory species. It also calls upon the Parties to:

- identify areas where migratory species are vulnerable to wind turbines;
- apply and strengthen comprehensive strategic environmental impact assessment to identify appropriate sites;
- evaluate possible negative ecological impacts prior to decision making;
- assess cumulative environmental impacts;
- take full account of the precautionary principle in development; and
- take account of impact and monitoring data as they emerge.

Furthermore, the scientific council of CMS has been instructed to assess existing and potential threats, including those to habitat and food sources, from marine wind farms to migratory mammals and birds for the next Meeting of the Parties.

The impacts on non-migratory species can also be expected to be significant. This may be particularly true for resident or semi-resident populations residing in the vicinity of a marine wind farm.

Summary of related literature

Despite the rapid expansion that is planned for wind farms, to date there is only a relatively small number of reports and papers that relate to their potential environmental impact. This literature is outlined in *Table 2*.

Author (Date)	Title	Topic/Summary	Type of Report	Size
Gill & Taylor (2001).	The Potential effect of electromagnetic fields generated by cabling between offshore wind turbines upon elasmobranch fishes.	Review of literature on elasmobranch electroreception, offshore wind farm development, British elasmobranchs and a study demonstrating a certain level of avoidance by the dogfish (*Scyliorhinus canicula*) of the maximum predicted electric field (1000 Vcm^{-1}) generated from 3-core undersea 150kV, 600A cables.	Report for a government agency (CCW, in the UK).	47 pages (excluding references).
Engell-S¿rensen (2002).	Possible effects of the offshore wind farm at Vindeby on the outcome of fishing: The possible effects of electromagnetic fields and noise.	Noise recordings from the literature[1,2] and predicted electromagnetic fields are evaluated in terms of their potential impacts on fish species at Vindeby marine wind farm, Denmark. A study of the effect that this wind farm has on a local flatfish fishery is also outlined and discussed.	Consultant report.	18 pages (excluding references).
Engell-S¿rensen & Skyt (2000).	Evaluation of the Effect of Noise from Offshore Pile-Driving on Marine Fish.	The hearing ability and avoidance of sound by fish are considered in evaluating the effects of pile-driving activity on the behaviour and physiology of different fish species using noise recordings from the literature[3].	Consultant report.	18 pages (excluding references).
ETSU (2000).	An assessment of the environmental effects of offshore wind farms.	Identifies environmental concerns in terms of environmental assessment and highlights where future research should focus. Discusses effects of wind farms on birds, marine mammals, fish and the benthos.	Consultant report.	15 pages.
Henriksen *et al.* (2001).	Does underwater noise from offshore wind farms potentially affect seals and harbour porpoises?	Noise level recordings from different wind turbines are compared with cetacean audiograms to calculate the maximum detection distance from an operational marine turbine for a harbour porpoise. 50m is proposed as the detection limit.	Poster presentation to marine conference.	Poster presentation
Hiscock *et al*. (2002).	High Level Environmental Screening Study for Offshore Wind Farm Developments — Marine Habitats and Species Project.	Focuses on marine habitats and species: identifying biotopes that are likely to be developed by marine wind farms in the UK. Biotope sensitivity to this form of development is also addressed. Key issues that should be considered in EIA of marine wind farms are highlighted.	Report to government (DTI, UK)	34 pages (excluding references).
Hoffman *et al*. (2000).	Effects of marine windfarms on the distribution of fish, shellfish and marine mammals in the Horns Rev area.	The impacts of proposed windmills in the Horns Rev area, on marine wildlife were addressed in terms of their physical presence, artificial reef effects, noise and magnetic fields.	Consultant report.	39 pages (excluding references).
Laidre *et al*. (2001).	Satellite tracking as a tool to study potential effects of an offshore wind farm on seals at R¿sand.	A study that evaluates the use of satellite tags as a tool to assess the extent to which the planned marine wind farm at R dsand effects the local seal populations. The resolution of the satellite telemetry data was not fine enough to determine the use of the proposed wind farm area by seals.	Report for government (Denmark).	41 pages (excluding references).

Table 2
Summary of recent literature related to marine wind farms, cetaceans and other wildlife.

Author (Date)	Title	Topic/Summary	Type of Report	Size
Laidre *et al*. (2002)	Monitoring effects of offshore windfarms on harbour porpoises using PODs (porpoise detectors).	Collates data from PODs from four areas: R¿dsand, Horns Reef, Mecklenburg Bay and Vindeby offshore wind farm, in Denmark. The authors evaluate the sensitivity of PODs and validity of POD data. A monitoring design and statistical method are developed for detecting the effects of marine wind farms on harbour porpoises.	Report for government (Denmark).	95 pages (including references and appendices).
Vella *et al*. (2001).	Assessment of the effects of noise and vibration from offshore wind farms on marine wildlife.	A review of studies and information on the effects of noise and vibration from offshore wind farms on marine invertebrates, fish and marine mammals. It identifies uncertainties and makes recommendations for further work.	Report to government (DTI, UK)	80 pages (excluding references).
[1]Westerberg (1994)	Fiskeriunders kninger vid havbaseret vindkraftverk 1990-1993.	Details some of the first recordings of sound produced from a 220kW operational wind turbine at two different wind speeds ($6ms^{-1}$ & $12ms^{-1}$), across the frequency range 1Hz to 20 kHz.	Consultant report.	
[2]fldegaard & Danneskiold — Sams¿e (2000a).	Underwater noise measurements, analysis and predictions. R¿dsand Offshore Wind farm EIA Technical Background Report: Underwater Noise	Noise levels from operational wind turbines are compared with ambient levels across a wide frequency range (1Hz to 100kHz) and for different foundation types and power classes.	Consultant report.	29 pages.
[3]fldegaard & Danneskiold - Sams¿e (2000b).	Offshore pile driving underwater and above water noise measurements and analysis.	Measurements of sound levels from pile-driving a monopile foundation during construction, at different distances from the source and across different frequencies. The results are given with no discussion.	Consultant report.	31 pages.

Table 2
Continued.

PRESENT AND FUTURE EXTENT OF MARINE WIND FARMS

Marine wind farm development

The sources of information available on marine wind farms are not consistent in their formatting. Thus, in order to evaluate properly the extent of marine wind farm development, there is a need to collate information in a comprehensive and consistent format. A first attempt to do this has been made here (*see Appendix*). The need to gather available information on environmental aspects of offshore wind energy has also been recognised (for example, Bruns *et al*., 2002; Vella *et al.*, 2001).

Some trends in the present and future development of marine wind farms are evident. At present, all marine wind farms are limited to shallow, less than 10m deep, near-shore waters, within approximately 5km of the coast. However, plans are now being made for large-scale development further offshore out to EEZ boundaries (*see Appendix*). Current marine wind farms have been on a small scale, generally less than 20 turbines, but future plans are considering farms with hundreds of turbines. The largest marine wind farm to date is sited at Horns Reef, Denmark. It came into operation in December 2002 and has 80 turbines.

The actual size of the turbines has also been increasing; for example, Germany and the Netherlands are developing a wind turbine in excess of 100m high that produces in the region of 5MW (H rter, 2002). Larger scale development, larger turbines and plans to develop further offshore have wider implications for environmental impact.

Europe

As far as the authors are presently aware, there are currently 12 existing operational marine wind farms in the world and all of these are in Europe. World wide, a number of marine wind farms are in various stages of development. There are projects under construction, projects with approval, planned projects that are still under consideration and a number of other project proposals. An indication of the scale and distribution of current and planned development is given in *Figure 1*, which shows marine wind farm developments in northern Europe (*also see Appendix*).

Coastal regions of the North and Baltic Seas are set to become hot spots for development because many European countries have extensive plans for future projects near-shore and beyond their respective territorial waters, Germany, Denmark and the UK in particular. Germany has plans to build very large turbines and situate them more than 30km offshore in depths of 20-35m. Potential development of marine wind farms is not limited to northern Europe. In Italy, for instance, there is a lot of interest offshore (Rosenbeck, 2001).

United States

Currently, there are no operational marine wind farms in the US. However, two are set for construction and a number of others have been planned for the eastern seaboard (Parenteau, 2002) (*also see Appendix*). The US has a great potential for offshore wind energy because of its extensive coastline and these projects will constitute an extensive and large scale development of the Outer Continental Shelf.

Asia and the rest of the world

There are no operational marine wind farms in Asia, of which the authors are aware, but the terrestrial wind industry is developing rapidly in some countries. The main limitations for future developments will be financial and infrastructural (*see below*). China had a total installed capacity of 400MW by the end of 2001 (Zhipeng & Zhigang, 2002) but the majority of turbines have been imported, so development of near-shore and offshore wind resources is not imminent. Similarly, India has a relatively large operational terrestrial wind capacity; 1094MW of power was installed in 2000 (Whitman, 2001).

Factors influencing development and environmental impact assessment

The status of the wind energy industry varies in different countries. The expense, expertise and infrastructure required for a viable marine wind farm development means that the terrestrial sector is generally explored first. So the state of the terrestrial sector, to a certain extent, reflects potential for development of marine wind farms. In addition, the marketplace, subsidies and other investment encouragement are important factors that influence the extent of future marine wind farm development (H rter, 2002). For example, although Sweden has three operational marine wind farms and full permission for two further projects, further viable development is uncertain (Wizelius, 2002). Sweden also has an extensive terrestrial wind resource that has not been explored.

The levels of environmental investigation into possible effects and precise methods of environmental impact assessment (EIA) also differ between countries (Bruns *et al.*, 2002). The soundness of the framework for planning and consent for proposed marine wind farms on the Outer Continental Shelf in the US has also recently been questioned (Parenteau, 2002).

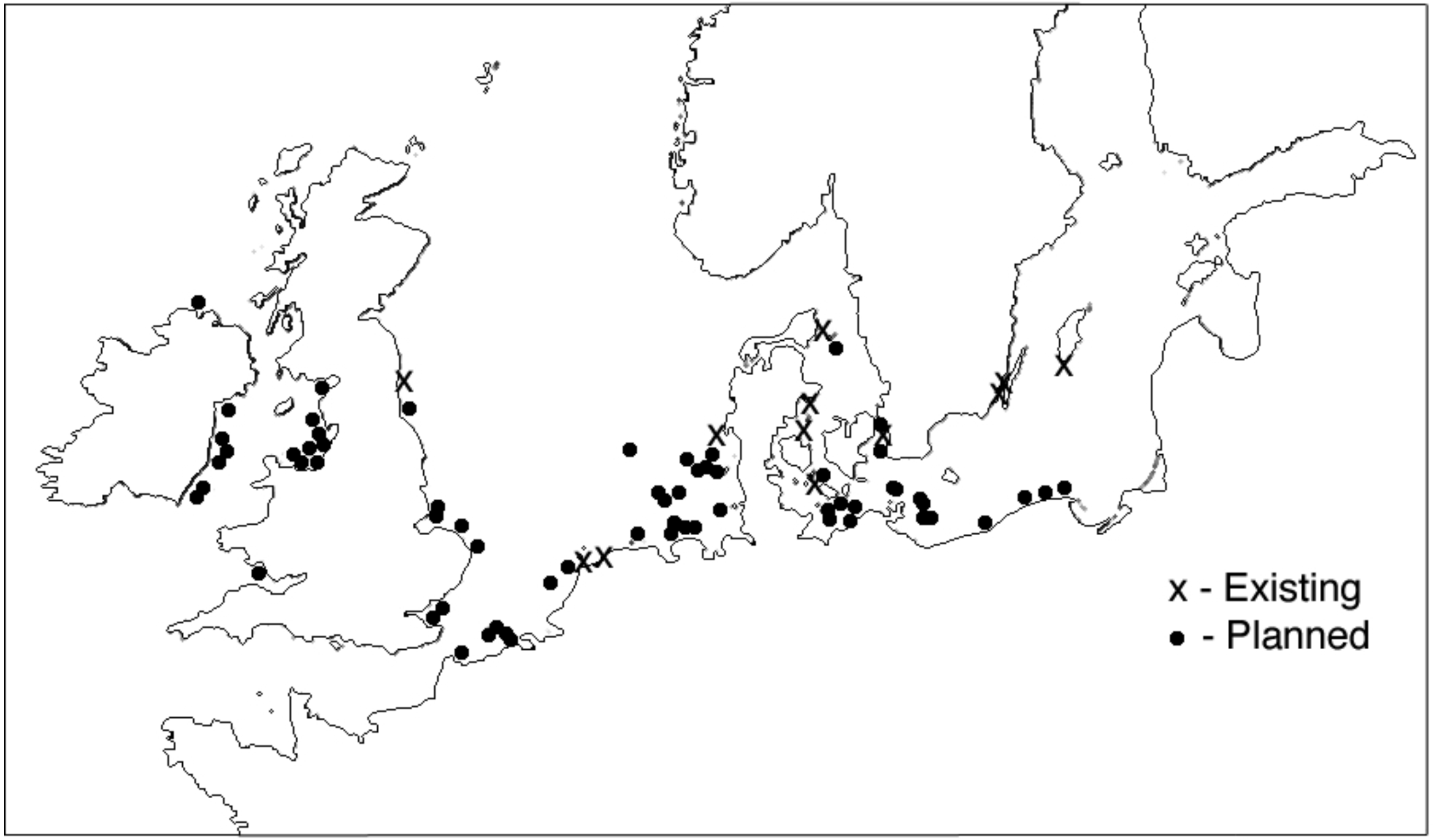

Figure 1
Map of distribution of current and planned near-shore and offshore marine wind farms in northern Europe.

LATEST INFORMATION ON IMPACTS OF MARINE WIND FARMS

General Considerations
The environmental impacts of marine wind farms can be viewed as long or short-term and each stage of a marine wind farm development has associated impacts. The construction and decommissioning phases have many short-term associated impacts while the operational phase is likely to be a major source of long-term impact. Generally, greatest concern has been raised about the operational phase because of its potential for long term impact (WWF & TWT, 2001).

Activities that are of particular importance to cetaceans are listed below:

Activities likely to cause short term impacts:
- seismic exploration;
- intense noise due to ramming/piling, drilling and dredging operations;
- increased vessel activities during exploration and construction;
- increased turbidity due to construction and cable laying; and, later,
- decommissioning of wind farms. (This may involve the use of explosives.)

Activities likely to cause long term impacts:
- the presence of structures (physical presence of the towers and artificial reef effects);
- continual operational noise and vibrations emanating from the wind turbines;
- electromagnetic impacts due to cabling that may impact navigation (this may be of particular concern for elasmobranchs (Gill & Taylor, 2001)); and,
- increased vessel traffic, from maintenance operations, for instance.

Cumulative impacts, on a local and regional scale, may result from a number of these activities in combination and, potentially, they may also act to cause negative environmental consequences in combination with other marine activities.

The number and arrangement of turbines and the site location vary considerably depending on the specific project. There may be one to several hundreds of turbines arranged in rows or clusters and a variety of different foundation types are used depending on local circumstances (Engell-S¿rensen & Skyt, 2001b). The number and size of turbines, the arrangement and the foundation type all have different implications for environmental impact. Different foundation types require different construction operations. The construction phase is commonly very intensive (Laidre *et al*., 2001). For driven monopile foundations, pile-driving activity will consist of repetitive percussive impacts lasting for hours. The pile-driving of one monopile at the proposed R¿dsand marine wind farm will last for four hours and there are 72 turbines to build (Engell-S¿rensen & Skyt, 2000a). Furthermore, the foundation type of each turbine will affect the transmission of noise to the water during the operational phase (ﬂdegaard & Danneskiold — Sams¿e 2000a).

Areas of Research
Much of the consideration given to the impacts of marine wind farms on cetaceans has focused on harbour porpoises and some dolphin species. Little attention has been paid to other odontocete species and the authors not aware of any studies to assess the possible impacts of offshore wind farms on baleen species. Most other literature on the environmental impacts of marine wind farms deals with impacts on other wildlife (*see Table 2, above*).

Due to a lack of data and conclusive evidence, the available reports tend to vary in their interpretation of the significance of the potential environmental impacts of marine wind farms. (This may also be affected by how precautionary the authors are in their evaluation.). For example, one report comments that odontocetes are likely to show initial avoidance, followed by habituation and possibly attraction to wind farms as feeding grounds (Vella *et al*., 2001). Whereas in another report, it is suggested that cetaceans will be temporarily displaced over a wide area during construction and decommissioning phases. Then, the report goes on to suggest they will be displaced more permanently over a smaller area during the operational phase, and, unless this area is a critical habitat, the overall effect is expected to be insignificant (Hoffman *et al*., 2000). Similarly, the extent to which artificial reef effects are considered to be significant also varies in the literature (ETSU, 2000; Hoffman *et al*., 2000; Vella *et al*., 2001).

Sightings of harbour porpoises (*Phocoena phocoena*) entering the marine wind farm area at Vindeby (Skov *et al*., 2002) illustrate that porpoises still traverse this area, despite the presence of the marine wind farm. However, this does not tell us whether they are being impacted in any way by the farm or allow us to say how significant any such impact might be. A porpoise might still enter an area that is of key biological importance to it, despite negative consequences, and exposure to certain sound levels for a prolonged period might adversely affect it (perhaps causing hearing deterioration). Anecdotal observations of harbour porpoises within the proposed marine wind farm area at R¿dsand (Carstensen *et al*., 2001) mean there is a potential for the proposed development to interfere with porpoise movements.

Noise

Noise has the potential to cause short and long term impacts (*see above*). It is a potential source of disturbance to cetaceans and could lead to displacement from an area and therefore loss of access to potentially important habitat. The widespread development of marine wind farms (for example, *see Figure 1*) means this could be significant.

Noise is produced during the construction, operational and decommissioning phases and by associated vessels. At present, very little research has focused specifically on the impact that noise produced from individual wind turbines or entire marine wind farms might have on cetaceans. Furthermore, relevant data from existing operational wind farms is only very slowly becoming available. It will be of importance to establish sound emission levels from all of the phases of wind farm development and give consideration to their consequences and their mitigation.

Recordings of noise during pile-driving activity at land, Sweden, showed that sound levels had not reduced significantly at a distance of 760m, compared to the level at 30m (fldegaard & Danneskiold — Sams¿e 2000b). Sound levels from pile-driving impacts exceeded ambient levels in the frequency range 4Hz to 20kHz and peaks varied with distance from source and were in the 250Hz to 400Hz range. Cetaceans have not been specifically addressed in relation to this form of noise and no evaluation of these results, of which the authors are aware, has been carried out for cetaceans. However, on the basis of these measurements, Henriksen *et al.* (2001a; *in* Laidre *et al*., 2001) noted concern about the potential effects on marine mammals. They indicated that there is a high risk of hearing damage in the vicinity of pile-driving and that the animals will be able to hear the noise over a large area . Other reports have indicated that sound levels for pile-driving are in the range of 50-100Hz and 150dBre.1 Pa at 1m (Richardson *et al* ., 1995).

Operational farms have been reported to produce broadband low frequency noise above ambient levels (fldegaard & Danneskiold — Sams¿e 2000a) and at the lower end of the threshold frequency spectra of selected representative odontocetes (Richardson *et al*., 1995). fldegaard & Danneskiold - Sams¿e 2000a) showed that marine wind turbines with different foundation types emit sound with different characteristics. Turbines with concrete foundations emit higher noise levels below 50Hz and lower levels between 50Hz and 500Hz, than those with monopile foundations. Westerberg (1994) Details some of the first recordings of sound produced from a 220kW operational wind turbine at two different wind speeds ($6ms^{-1}$ & $12ms^{-1}$), across the frequency range 1Hz to 20 kHz. It was found that, although higher wind speeds meant that higher noise levels were emitted from marine wind turbines, the relative level of noise above ambient did not change because ambient noise levels increased in line with wind speed.

The zone of audibility and potential zone of exclusion around operational marine wind turbines and marine wind farms has not been clearly defined. Different studies reach different conclusions, perhaps affected by local conditions. By comparing the auditory sensitivities of odontocete species for different frequencies with the characteristics of the sound emitted from wind turbines, Henriksen *et al* (2001b) predicted that the maximum detection distance for harbour porpoises is likely to be in the region of 50m from an operational wind turbine. Whereas from sound recordings made at the marine wind farms at Vindeby in Denmark and Gotland (Bockstigen) in Sweden it was predicted that noise from a wind turbine will be audible to marine mammals only up to 20m from its foundations (Bach *et al*., 2000).

Furthermore, there is a potential for different sound emission characteristics from the larger turbines likely to be employed in deeper waters. Noise levels from 2MW turbines are predicted to be higher than turbines of the 500kW class at frequencies below 100Hz and lower at frequencies above 100Hz (fldegaard & Danneskiold — Sams¿e 2000a).

Habitat Use / BACI / Distribution and Relative Abundance
One study has specifically looked at the presence and movements of cetaceans within a proposed marine wind farm area. The motivation for this study has been the implementation of a BACI (Before/After Controlled Impact) design to EIA (Skov *et al*., 2002). This research has looked at harbour porpoises, using PODs (Porpoise Detectors). PODs promise to be a useful and reliable tool for monitoring distribution and relative abundance of animals in an area, giving an idea of habitat use. Skov *et al.* (2002) tested the reliability and validity of POD data for this purpose and developed statistical tests for their data. They recommend a robust monitoring design.

Previously, in studies at R¿dsand and Vindeby offshore wind farms, it had not been possible to draw conclusions from the data collected due to practical difficulties (Carstensen *et al*., 2001). However, continued deployment of PODs should aid future comparisons aiming to detect and assess any changes in harbour porpoise activity due to marine wind farms. Some PODs remain in place and Skov *et al.* (2002) recommend that monitoring be continued at all positions.

Other Wildlife
The impacts of marine wind farms on seals have been investigated. Using the same method as for harbour porpoises, Henriksen *et al*. (2001a) predict that seals may hear the noise emitted from marine wind farms at a distance of up to 1km. Tracking studies at the proposed R¿dsand marine wind farm have not been able to address fine scale movement of seals within the study area (Laidre *et al*., 2001). However, Laidre *et al.* were able to make inferences about seal home ranges and how seals use the general area. They note that because grey seals (*Halichoerus grypus*) have large home ranges they do not use the wind farm area very often and that harbour seals (*Phoca vitulina*), which have a more localised habitat, do not use the wind farm area.

Changes to habitat and changes in prey species resulting from wind farm installations can be expected to affect cetaceans and seals (Hiscock *et al*., 2002). The effect that marine wind farms have on fish has been the focus of a number of reports (*see Table 2*). For instance, there is a potential for electromagnetic fields emanating from undersea cables to affect the movements of some fish species (Engell-S¿rensen, 2002; Gill & Taylor, 2001). This issue is also being considered in the proposed R¿dsand marine wind farm EIA (Engell-S¿rensen, 2002). Artificial reef effects have been predicted to influence the numbers of fish in a marine wind farm area (Vella *et al*., 2001). However, the significance of this effect, to form a food chain basis, has been questioned (Hoffman *et al*., 2000).

The effects of different types of construction on fish have been evaluated for factors such as sediment spill (Engell-S¿rensen & Skyt, 2001b) and noise (Engell-S¿rensen, 2002). Noise emitted from pile-driving activity may also effect fish (Engell-S¿rensen & Skyt, 2001b). Engell-S¿rensen & Skyt use results from the baseline study by ﬂdegaard & Danneskiold — Sams¿e (2000b; *outlined above*) to assess the impact of pile-driving. However, in a different report, Engell-S¿rensen & Skyt (2001a) use results from another baseline study by ﬂdegaard & Danneskiold — Sams¿e (2000a) to assess the impact of noise from operational marine wind farms. It is clear that more baseline studies are required to draw conclusions in future assessments, especially considering the variation in sound transmission conditions between sites. There is also a need for this kind of assessment to be carried out for cetacean different species.

LACK OF INFORMATION AND AREAS OF CONCERN

There is a lack of information about the potential impacts that marine wind farms have on cetaceans. It is also evident that the majority of research work to date has been conducted in inshore waters around Europe. This is because this is where the current development is focused (*see Figure 1, above*). Yet the potential for widespread development elsewhere, in the US particularly, should be an incentive to initiate more research.

It is not unreasonable to propose that the parties to ASCOBANS (the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas), as part of their commitment to cetacean conservation, should be responding to marine wind farm developments. They could be initiating research into effects and mitigation of any impacts that may threaten the status of small cetaceans. Furthermore, the harbour porpoise and the bottlenose dolphin are species of primary concern in Europe and are listed on

Annexes 2 and 4 of the Habitats and Species Directive (Council Directive 92/43/EEC). All cetaceans are listed on Annex 4. Therefore, European countries would appear to have a requirement to research and respond to the precise nature and significance of any impacts that may affect these species.

CONCLUSIONS AND RECOMMENDATIONS

It has been shown that although marine wind farms are limited to certain areas at present, the industry is set for massive expansion with the implementation of various planned projects. International renewable energy policy is likely to drive these projects swiftly to completion. It appears that marine wind farm development is continuing without a sound understanding of the long-term impacts that could result.

Baseline data

Knowledge of the abundance and distribution of cetaceans in many parts of the world, as well as of important habitats, remains significantly limited. This is a considerable problem in relation to the assessment of suitable locations for wind farms with respect to cetaceans because it is difficult to identify important habitat areas. Therefore, without prior knowledge of distribution and abundance, no firm conclusions can be made as to the significance of the impact from marine wind farms.

Work is also limited on the potential for marine wind farms to displace cetaceans from habitat. Consideration might also be given to whether cetacean migrations might be affected by electromagnetic fields generated from the under surface cables, noting that cetaceans appear to be sensitive to variations in the Earth s magnetic field (Klinowska, 1990).

Although some studies have addressed measurement of the noise emitted from marine wind farms, this has only occurred on a limited basis. To properly assess the significance of noise from whole marine wind farms, comprehensive measurements of the sound produced from different numbers, arrangements, foundation types and sizes of wind turbines in different areas, coastal morphology, seabed characteristics and conditions (wind speeds and temperature for example) are required.

Environmental Impact Assessment and Monitoring

It is also apparent that the EIA process is not sufficiently developed in many countries to properly address the impacts of marine wind farms on cetaceans. EIA can help mitigate the impacts of any proposed development if applied rigorously. Some recommendations for EIA in relation to marine wind farms and cetaceans are detailed here.

Consideration of impacts should begin at the initial stages of planning and encompass the entire life of the marine wind farm. Therefore, all elements of the exploration, construction, operation, maintenance and decommissioning of wind farms and any proposed extensions to the project in the future should be considered. Importantly, environmental assessment should involve dedicated baseline surveys to assess the use of the area by marine wildlife during all seasons and, in particular, the significance of the area for breeding, feeding or migration.

The current lack of knowledge of impacts should result in the application of a highly precautionary approach, especially where large scale projects are under consideration. It is also important that all potential impacts are assessed on a regional scale in a strategic assessment that takes into account other local activities. The migratory nature of many cetaceans as well as the restricted nature of others needs to be considered.

There should be extensive public consultation at each stage of the process, including before decisions are made about site selection. Care should be taken to mitigate impacts to the fullest extent possible through considered site selection, design and monitoring. Once underway, the project should involve continuous monitoring and evaluation of impacts on all cetaceans, other marine life and the marine environment. Evaluation and monitoring reports need to be submitted to the appropriate bodies, including government agencies and relevant conservation organisations.

Other recommendations

Considering the uncertainties surrounding the potential impacts of marine wind farms, designated protected areas should be granted additional protection mechanisms, such as extended buffer zones.

A comprehensive list that details all existing marine wind farms and all developments in every stage of planning needs to be compiled and this would require the co-operation of governments, researchers and developers. Agreeing on a standard format and using common, advanced, mapping techniques, such as GIS, would promote compatibility with different users in different countries. It would also allow a comparison with other marine activities to facilitate further consideration of the potential for cumulative impacts.

In addition, international co-operation is called for to enable an international strategic environmental assessment that deals with the potential impacts of marine wind farms. A particular need for such an approach has been illustrated for northern European countries (*Figure 1*). The International Whaling Commission, CMS and ASCOBANS could potentially act as mediators for the co-operation required for such an ambitious undertaking. The authors support this concept in principle.

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APPENDIX

The following table is a list of the operational and planned marine wind farms in selected countries.

Location	Stage	Total MW	Distance to Shore	Area	Water depth	Number of Turbines, rating and arrangement	Foundation	Notes
DENMARK								
Operational								
Vindeby (north coast Lolland Island)	1991	4.95	1.5-3.0km		2.5-5m	11 (Bonus 450kW) two rows	Concrete caisson	
Tun¿Knob	1995	5	6km		3-5m	10 (VestasV39 500kW) two rows	Concrete caisson	
Middelgrunden, Copenhagen	2000	40	2-3km		2-6m	20 (Bonus76 2MW) curved line	Concrete caisson	
Horns Rev (west of Bl vands Huk)	Dec. 2002	160	14-20km	27km2	6-14m	80 (VestasV80 2MW) cluster	Drilled Monopile	possible extension area
Frederikshavn	Dec. 2002	3	500m		1m	1 (VestasV90 3MW)	Bucket	Ex. to 12 MW Jun 2003
Samso (Paludans Flak south of)	Feb. 2003	23	3.5km		11-18m	10 (Bonus 2.3MW)	Monopile	
Planned								
Laeso (Kattegat, south of Laeso)	prop. 2003	150						
Omo Stalgrunde	prop. 2005	150						
Gedser Reef (South of Lolland)	prop. 2008	15						
R¿dsand (Nysted, Lolland)	Oct. 2003	158	10km		6-9.5m	72 (2.2MW) a square 8 rows by 9		Construction to start
UK								
Operational								
Blyth Offshore (North Sea)	2000	4	1km		6m (5m tide)	2 (VestasV66 2MW)	Drilled Monopile	
Planned								
Solway Firth (Robin Rigg)		199	9.5-8.5km			60		
Barrow		>90	10km			30		
Shell Flats		270	7km	30km2		90 (3MW)	Monopile	
Southport		>90	10km			30		
Burbo		>90	5.2km			30		
North Hoyle (Wales)	Summer 2003	>90	6km			30		License granted
Rhyl Flats (Wales)	2004	100	8km			30		
Scarweather Sands		>90	9.5km			30		
Kentish Flats (North Sea)		129	8km			30		
Gunfleet Sands (North Sea)		108	7km	10km2 (5x2)		30 (3.6MW)		
Scroby Sands (North Sea)	Aug. 2004	37.5	2.3km			25 (1.5MW)		License granted
Cromer (North Sea)		>90				30		
Lynn (North Sea)		>90	5km	10km2		30		
Inner Dowsing (North Sea)		>90				30		
Teeside (North Sea)		>90	1.5km			30		
Tunes Plateau		>90				30		
Ormonde		>90				30		

Location	Stage	Total MW	Distance to Shore	Area	Water depth	Number of Turbines, rating and arrangement	Foundation	Notes
SWEDEN								
Operational								
Gotland (Bockstigen)	Mar. 1998	2.8	4km		6-7m	5 (WindWorld37 550kW) V pattern		
Utgrunden (Oland)	Dec. 2000	10.5	8-12km		7-10m	7(Enron Wind70 1.5MW) cluster	Driven Monopile	
Yttre Stengrund (Oland)	Jul. 2001	10	5km		8-9m	5 (NEG Micon72 2MW) single line	Drilled Monopile	
Nogersund (single turbine)	1990	0.22	250m		7m	1 (Wind World 220kW)	Three legged	
Planned								
Gotland (Klasarden/Oresund)	2003	44				16 (2.75MW NEG-Micon)		all permissions granted
Lillgrund Bank	2002 (delayed)	86				48 (1.8MW Enercon E-66)		all permissions granted
Barsebank	prop.	750						
Karlskrona (South of Yttre Stengrund)	2005	17.5-?				5 (3.5MW ScanWind)		first phase
GERMANY								
Planned								
Butendiek, West of Isle of Sylt	Jun 2005	240	30km			80 (3MW)		Construction to start
Borkum Riffgrund	prop. 2003	600-1000	34-38km			200 (3-5MW)		
Borkum Riffgrund West	prop. 2004	up to 1800	45km			458 (2.5MW)		
Borkum (III) - North	prop. 2003	60 approx.	45km			12 (4-5MW)		License Nov 2001
Borkum (IV) - North	prop.	400	7km			90-160 (2.5-4MW)		
Borkum Riffgat		130	within EEZ			27 (4.5-5MW)		
Uetze (30km NE of Hanover)	prop. 2002	31.5	30km			21 (S70 turbines 1.5 MW)		
Reinsfeld	prop. 2002	13.5				9 (S70 turbines 1.5 MW)		
Wilhelmshaven	prop. 2002	4.5	within EEZ					
Pommersche Bucht, Baltic Sea	2004-2005	240-1000	40km			200 (5MW)		
Nordsee-Ost	2006	1000-1250						
Nordsee AWZ	prop. 2004	500-1000	17km			100-200 (5MW)		
Dan-Tysk	prop. 2005	15000	60km			300 (5MW)		
Helgoland I-III	prop.	800-1000	outwith EEZ					
Arkona-Becken	prop. 2005	700-850	25-45km			172 (4-5MW)		
Adlergrund	prop. 2005	200-350	40km			69 (3-5MW)		
Nordergrunde		150-600	within EEZ			30-200 (3-5MW)		
Mowensteert		210	within EEZ			140 (1.5MW)		
Helgoland offshore	prop. 2005	200	13km			100 (2MW)		
Langeoog		180	within EEZ			40 (4.5MW)		
Schleswig-Holsteinische Nordsee	prop. 2004	500-1000	17km			100-200 (5MW)		
Emden	prop. 2002	7.5	within EEZ			7 (1.5MW)		
Mecklenburg-Vorpommern	prop. 2002	40	15km			20 (2MW)		
Sky 2000 - Mecklenburg Bay	2003	100	17km		23-25m	50 (2MW)		Construction to start

Location	Stage	Total MW	Distance to Shore	Area	Water depth	Number of Turbines, rating and arrangement	Foundation	Notes
NETHERLANDS								
Operational								
Lely (Ijsselmeer) (Medemblik)	1994	2	800m		4-5m	4 (NedWind40 500kW) single line	Driven Monopile	
Dronten (Ijsselmeer)	1996	14	20-30m		1-2m	28 (Nordtank43 600kW) single line	Driven Monopile	
Planned								
Western Mouth of the River Scheldt	prop.	100						
Ijmuiden	prop.	100						
North Sea Q7-WP	prop.	120	outside EEZ			60 (2MW)		
NSWP, North Sea	2005	99				36 (2.75MW)		
Egmond	2004	100-120	8-23km			(NEG-Micon)		Construction to start
IRELAND								
Planned								
Kish Bank/Bray Bank	1st Rights	250+						
Arklow Bank (off County Wicklow)	2003-2005	200-520						(1st Rights)
Blackwater Bank	2nd Rights							
Blackwater Bank	1st Rights							
Codling & Greater Codling Bank	1st Rights							
Dundalk Bay	1st Rights							
BELGIUM								
Planned								
Vlakte van de Raan (1)	License granted	100	12.5km	5.8km2	5-10m	50 (2MW)	Driven Monopile	20MW: Apr. 2003 & 80 MW: 2004
Wenduinebank	Gov. assessing EIS	115	5.1km	12.5km2	5-10m	50		
Vlake van de Raan (2)	preparing EIS	100	8km	7.3km2	5-10m	33-40		
Vlake van de Raan (3), Thornton Bank	preparing EIS	300	11km		5-10m	130 (50x2MW & 80x2.5MW)		
POLAND								
Planned								
Sarbinowo	Early prop.					11?		
Rowy	Early prop.					11?		
Bialogora	Early prop.					11?		
Karwia	Early prop.					11?		
SPAIN								
Planned								
Cadiz (Strait of Gibraltar)		200		5km2		100 (2MW)		10 turbines in pilot phase

Location	Stage	Total MW	Distance to Shore	Area	Water depth	Number of Turbines, rating and arrangement	Foundation	Notes
UNITED STATES								
Planned								
Cape Cod	Operational 2005	468		8.5km2		130-170 (3.6MW) grid		
Delaware (Indian River)		1101	5.5km	13km2	18m	306		
Maryland (Gulf Bank)		1821	5.5km	10.5km2	18m	506		
Maryland (Island of Wight)		1267	5.5km	13.5km2	18m	352		
Massachusetts (Nantucket 1)		830	11km	13km2	12.5m	230		
Massachusetts (Nantucket 2)		763	11km	10.5km2	6.5m	212		
Massachusetts (Davis Bank)		748	24km	11km2	9m	208		
New Jersey (Asbury Park)		352	5.5km	5km2	14.5m	98		
New Jersey (Five Fathom Bank 1)			9.5km	10.5km2	14.5m	196		
New Jersey (Five Fathom Bank 2)			9.5km	12.5km2	14.5m	268		
New Jersey (Great Egg)		439	10km	9km2	16m	122		
New York (Fire Island)		226	<2km	5.75km2	14.5m	63		
New York (Hampton)		295	<2km	6.5km2	16m	82		
New York (Jones Beach)		241	2km	6.5km2	14.5m	67		
New York (Long Island)		100-140	5-10km	800km2?				
New York (Plum Island)		12	<2km	23km2	9m	6		
New York (Smith Island)		205	<2km	8.5km2	18m	57		
Virginia (Porpoise Banks)		716	8km	10km2	18m	199		
Virginia (Smith Island)		795	5km	11km2	18m	221		
CANADA								
Planned								
Queen Charlotte Islands	Agreed Feb. 2002	700						