PROCEEDINGS OF THE ASCOBANS/ECS WORKSHOP

OFFSHORE WIND FARMS AND MARINE MAMMALS: IMPACTS & METHODOLOGIES FOR ASSESSING IMPACTS

Held at the
European Cetacean Society's 21st Annual Conference,
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Peter G. H. Evans

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Editor:

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INTRODUCTION

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Over the last ten years, the construction of offshore wind farms has taken place in shallow coastal areas throughout Europe. Many individuals and groups have been contracted to investigate possible impacts on marine mammals (notably harbour porpoise, harbour seal, and grey seal). This has involved a variety of methodologies - visual surveys by boat and plane, deployment of passive acoustic listening devices such as T-PODs, land-based observations, and radio telemetry (see, for example, Koschinski *et al*., 2003; Tougaard *et al*., 2003a, b, 2005), and has resulted in some useful reviews (Lucke *et al*., 2006; Madsen *et al*., 2006; Thomson *et al*., 2006).

Parties to the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) at their 5th Meeting (2006) called for further research to be conducted on the effects of wind farms on small cetaceans (Resolution 4). Accordingly, the aims of this workshop, jointly convened by ECS and ASCOBANS, were: 1) to examine the findings so far with respect to marine mammal impacts and assess possible effects at the construction and production phase; and 2) to recommend best practice for monitoring species in the vicinity, together with impacts. Some consideration was also given to other forms of renewable energy currently being considered by European governments, such as tidal power.

The workshop, held at the start of the 21st Annual ECS Conference in April 2007, was attended by c. 60 persons from 16 countries. There follows summaries of the information presented at the meeting, along with some general conclusions and specific recommendations arising from the discussions. In order to make this volume more complete, I have also invited Klaus Lucke to contribute a paper on auditory studies of harbour porpoises in relation to offshore wind turbines.

Sponsorship for the Proceedings comes from UNEP/ASCOBANS to whom we are very grateful, and I would like to thank Heidrun Frisch, Ana Berta García, and Marco Barbieri for their invaluable logistical support.

REFERENCES

Koschinski, S., Culik, B.M., Henriksen, O.D., Tregenza, N., Ellis, G.M., Jansen, C., and Kathe, G. 2003. Behavioural reactions of free-ranging harbour porpoises and seals to the noise of a simulated 2 MW windpower generator. *Mar. Ecol. Progr. Ser.*, **265**: 263-273.

Lucke, K., Storch, S., Cooke, J. and Siebert, U. 2006. Literature Review of offshore wind farms with regard to marine mammals. Pp. 199-284. In: *Ecological Research on Offshore Wind Farms: International Exchange of Experiences. Part B: Literature Review of Ecological impacts* (Eds. C. Zucco, W. Wende, T. Merck, I. Köchling, and J. Köppel). BfN – Skripten 186. 284 pp.

Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K., and Tyack, P. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. *Mar. Ecol. Progr. Ser.*, **309**: 279-295.

Thomson, F., Lûdemann, K., Kafemann, R. and Piper, W. 2006. *Effects of offshore wind farm noise on marine mammals and fish*. Biola, Hamburg, Germany on behalf of Cowrie Ltd. 62 pp.

Tougaard, J., Carstensen, J., Henriksen, O.H., Skov, H., and Teilmann, J., 2003a. *Short-term effects of the construction of wind turbines on harbour porpoises at Horns Reef.* Technical Report to Techwise A/S. Hedeselskabet.

Tougaard, J., Ebbesen, I., Tougaard, S., Jensen, T., and Teilmann, J. 2003b. *Satellite tracking of Harbour Seals on Horns Reef. Use of the Horns Reef wind farm area and the North Sea.* Report request. Commissioned by Tech-wise A/S., Fisheries and Maritime Museum, Esbjerg. 42 pp.

Tougaard, J., Carstensen, J., Teilmann, J., Bech, N.I., Skov, H., and Henriksen, O.D. 2005. *Effects of the Nysted Offshore wind farm on harbour porpoises*. Technical Report to Energi E2 A/S. NERI.

ALL AT SEA: RENEWABLE ENERGY PRODUCTION IN THE CONTEXT OF MARINE NATURE CONSERVATION

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INTRODUCTION Here we seek to provide a short introduction to the marine nature conservation concerns relating to the development of new 'renewable' sources of energy in the sea, and particularly as they relate to cetaceans. Renewable energy sources will undoubtedly have an increasing role to play in future energy generation across Europe and elsewhere in the world. Their development is being encouraged by declining fossil fuel reserves, and growing concerns about climate change. The International Panel on Climate Change recently stated that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level"(IPCC, 2007). The significance of climate change for marine species has also recently been highlighted (e.g. Simmonds and Isaac, 2007).

Many countries have made public commitments to reduce their carbon emissions and linked this to expansion of their renewable energy sectors. In the UK, in 2007, for example, the government announced an enormous increase in wind farm development that could allow companies to develop up to 25 gigawatts of offshore wind by 2020, in addition to the 8 gigawatts already planned (BERR, 2007). This is intended to be enough to power the equivalent of all of the UK's homes. The UK government also reported that it will be conducting a Strategic Environmental Assessment (SEA) of this planned expansion covering the UK's territorial waters and adjacent areas where the water depth is around 60 m or less (but excluding Scottish and Northern Irish territorial waters). An idea of the distribution of European wind farm developments is given in Figure 1 (Dolman *et al*., 2003), and it is now apparent that several large marine wind farms are under construction in nearshore areas overlapping with high densities of marine mammals (Carstensen *et al.*, 2007). This 'fast-tracking' of marine renewable energy developments (MREDS) offers significant marine conservation challenges (Dolman *et al*., 2003, 2007).

The most significant concerns relating to wind farms appear to relate to noise production. Marine noise pollution has the potential to displace animals and populations, interfere with normal behaviour (for example by masking effects) and, at very high intensities, may be physically damaging. Such threats should also be seen in the context that many marine animals have evolved to use the acoustic properties of water for their basic needs. For cetaceans in particular, hearing can be described as their primary sense.

POTENTIAL IMPACTS OF MARINE WIND FARMS Knowledge of the effects on marine mammals of constructing and operating offshore wind farms is limited (Madsen *et al*., 2006). The existing literature is relatively slim (Dolman *et al*., 2003, provided an anthology), and there still remain significant data gaps. In particular, cetacean distributions and habitat use are rarely well characterised around the UK coastline, or elsewhere, and as far as we can tell, to date, no studies look directly at impacts on any cetacean species other than the harbour porpoise (*Phocoena phocoena*).

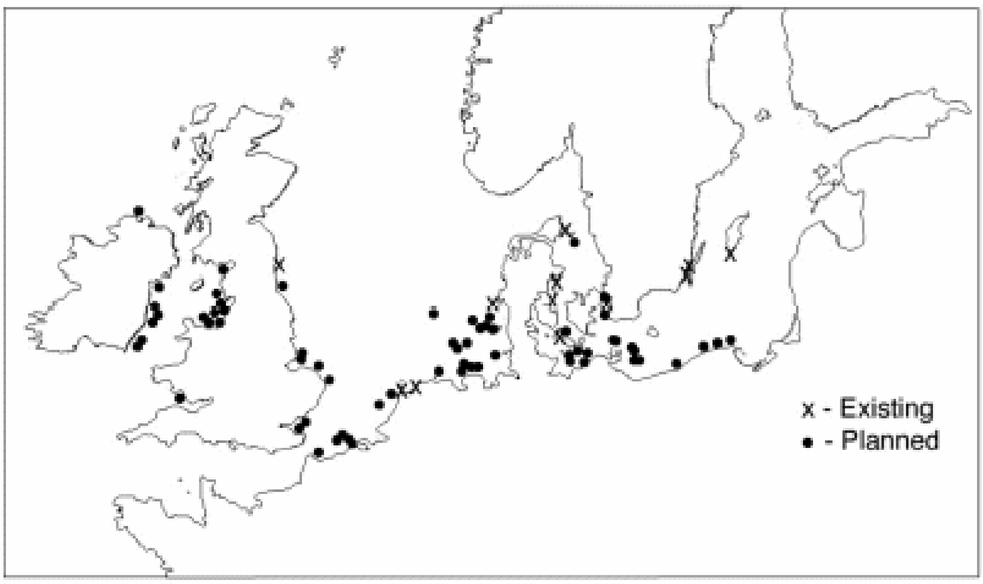

Figure 1
Map of distribution of current and planned near-shore and offshore marine wind farms in northern Europe

Furthermore, the available reports tend to vary in their interpretation of the significance of the potential environmental impacts of marine wind farms, probably related to how precautionary the authors are being in their considerations.

Noise is produced throughout the life of the development, including during construction, operational and decommissioning phases, and from associated vessel traffic. (It is not clear to the authors at this time how many boat trips for inspection and maintenance purposes a marine turbine might require during its operational life.). Pile-driving is a particularly intense noise source and may disrupt the behaviour of marine mammals at distances of many kilometres, with hearing potentially impaired at closer range (Madsen *et al*., 2006). Carstensen *et al*. (2007) reported on the reaction of porpoises to the construction of the Nysted offshore wind farm in the western Baltic by monitoring their echolocation clicks. On the basis that clicks relate to density, they found substantial changes in habitat use, with the porpoises leaving the construction area. They also noted that only future monitoring will determine if the porpoise population will recover, and that their methods could be modified to look at other cetacean species.

Operational farms produce broadband low frequency noise at the lower end of the threshold frequency spectra of selected representative odontocetes (Richardson *et al*., 1995). However, the zones of audibility and potential exclusion around operational marine wind farms have not been clearly defined. Notwithstanding, a small masking effect has been reported for a porpoise in an experimental study (Lucke *et al*., 2007), although this was based on the noise produced by a small turbine. The authors describe the likely masking zone as extending several tens of metres.

Some trends in the present and future development of marine wind farms are evident. To date, marine wind farms have mainly been in near-shore waters, within approximately 5 km of the coast. However, plans are now being made for deeper-sea developments and wind farms with hundreds of turbines. Turbine size has also been increasing; for example, Germany and the Netherlands are developing a turbine more than 100 m long which will produce in the region of 5 MW (Hörter, 2002). The size of the turbines, the size of the wind farm, and, where they are positioned, all have implications for environmental impact.

The nature of the foundations of wind farms will also affect the transmission of noise from the operating turbines (Ødegaard & Danneskiold – Samsøe, 2000). Typically turbines are seated on either steel monopiles driven into the seabed with large pile drivers or on concrete gravitational foundations placed on pebble cushion layers (Carstensen *et al*., 2007). Madsen *et al*. (2006) comment that "if the very large offshore wind farms are realised… this could involve construction activities at several locations in the area [of the German Bight] simultaneously every summer for the next decade."

Those aspects of wind farm development and operation that we believe to be of particular concern to marine mammals are outlined in Table 1. In addition, cable-laying from wind farms to take the electricity generated to suitable nodes to connect with national grids may require considerable cable laying, with associated noise pollution and physical habitat disturbance due to upheaval of the seabed.

Table 1. Some wind farm related concerns for marine mammals

- Intense noise during piling-driving, drilling and dredging operations;
- Increased vessel activities during exploration and construction;
- Increased turbidity and re-suspension of polluted sediments due to construction;
- Physical decommissioning of wind farms which might involve the use of explosives;
- The presence of structures (including artificial reef effects causing habitat alterations) and, potentially, changes to prey and food webs;
- The 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);
- Increased vessel traffic from maintenance operations; and
- Effects on prey, such as changes to fish behaviour.

With respect to impacts on other marine species, changes in seal haul-out behaviour have been predicted and reported (Madsen *et al*., 2006), and changes to habitat and changes in prey species can be expected to affect cetaceans and seals (Hiscock *et al*., 2002). The effects that marine wind farms have on fish have been the focus of a number of reports, and Wahlberg and Westerberg (2005) concluded that fish behaviour could be affected at ranges of several kilometres.

OTHER MREDs The launch of a new generation of MREDs that extract wave or tidal energy, and which range from underwater turbines to floating structures, is imminent (Wilson *et al*., 2007). A recent modelling exercise has suggested that in the context of a commercial underwater turbine development off the coast of western Scotland, 10.7% of the harbour porpoise population (some 1300 individuals) would encounter a rotating blade in the space of one year (Wilson *et al*., 2007). The authors conclude that "the introduction of these new energy generation technologies may pose a significant new threat to European cetacean populations", and emphasise the urgent need to better understand this matter.

CONCLUSIONS Much remains unknown about the potential for wind farms and other MREDS to impact marine species and marine ecosystems, and these increasingly widespread and large scale projects should not be seen in isolation. We now see many other new energy-related developments in the marine environment, including, for example, plans for carbon sequestration under the seabed; ongoing exploitation of fossil fuels; and a new generation of coastal nuclear power stations that will draw on seawater and potentially dispose of spent fuel rods at sea. In addition, there are expansions of other human activities in the marine environment. For example, in many coastal areas, leisure activities have greatly increased.

Plate 1. Offshore Wind Turbine Construction

If we consider just one sea area, the Moray Firth, recognised as important for its bottlenose dolphin population (for which a Special Area of Conservation has been designated), the following new activities can be identified: proposed plans for new fossil fuel exploitation (in addition to ongoing activities in the outer Firth); potentially a large scale wind farm containing up to 200 turbines (see Plate 1); the development of a large marina; and, related to all these things, leisure activities that locally include commercial boat-based dolphin watching, increasing movements of vessels. Carstensen *et al.* (2007) commented that 'given the extensive plans for expanding the offshore wind energy sector, it is important to know the effect of single wind farms and well as the cumulative affects of several wind farms within the range of each marine mammal species". Indeed, it would make good sense to consider the cumulative impact of all new developments on populations and yet, in our experience, this rarely seems to happen.

Like other environmentalists, we welcome the development of renewable energy sources and we believe that marine renewable energy, if developed with consideration in Europe, could demonstrate best practice to the rest of the world. However, we still have a responsibility to protect our natural marine heritage and a profound lack of knowledge that needs to be urgently addressed.

More positively, there are signs that there is some high level recognition of the need to address the impacts of MREDs, for example, in Resolution 7.5 'Wind Turbines and Migratory Species', adopted by the seventh meeting of the Conference of the Parties to the Convention on the Conservation of Migratory Species of Wild Animals (CMS),
a number of actions were identified for Parties. These included identifying areas where migratory species are vulnerable to wind turbines. However, such initiatives remain rare, whilst the MREDs continue to progress extremely rapidly in many areas, including the North East Atlantic area.

REFERENCES

BERR 2007. Plans for a major expansion of offshore wind – Hutton Monday 10 December 2007 13:33 UK Department for Business, Enterprise and Regulatory Reform (National). Press Release: http://www.gnn.gov.uk/environment/fullDetail.asp?ReleaseID=337237&NewsAreaID=2&NavigatedFromDepartment=True

Carstensen, J., Henriksen, O.D. and Teilmann, J. 2007. Impacts on harbour porpoises from offshore wind farm construction: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). *Marine Ecology Progress Series* **321**: 295–308.

Dolman, S.J., Green M. and Simmonds M.P. 2007. Marine Renewables and Cetaceans. Paper presented to the Scientific Committee of the International Whaling Commission. IWC/SC/59/E4

Dolman, S.J., Simmonds M.P. and Keith S. 2003 Marine wind farms and cetaceans Paper presented to the Scientific Committee of the International Whaling Commission IWC/SC/55/E4

Gill, A.B. and Taylor, H. 2001. *The potential effects of electromagnetic fields generated by cabling between offshore wind turbines upon elasmobranch fishes*. CCW Science Report No. 488.

Hiscock, K., Tyler-Walters, H. and Jones, H. 2002. *High Level Environmental Screening Study for Offshore Wind Farm Developments - Marine Habitats and Species Project*. Report from the Marine Biological Association to the Department of Trade and Industry New & Renewable Energy Programme. (AEA Technology, Environment Contract: W/35/00632/00/00.)

Hörter, A. 2002. *German Offshore Wind Projects Planning and Status Quo*. Report from the Conference 'Offshore Wind Energy', Cuxhaven, 7-8th March, 2002. http://www.offshore-conference.de.

IPCC. 2007. *Climate Change 2007. Impacts, Adaptation and Vulnerability*. Summary for Policymakers, Intergovernmental Panel on Climate Change.

Lucke, K.,.Lepper, P.A., Hoeve, B., Everaarts, E.,. van Elk, N., and Siebert, U. 2007. Perception of Low Frequency Acoustic Signals by a Harbour Porpoise (*Phocoena phocoena*) in the Presence of Simulated Offshore Wind Turbine Noise. *Aquatic Mammals*, **33**: 55-68.

Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K. and Tyack, P. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. *Mar Ecol Prog Ser*., **309**: 279-295.

Ødegaard & Danneskiold – Samsøe A/S 2000. *Underwater noise measurements, analysis and predictions.* Rødsand Offshore Wind farm EIA Technical Background Report: Underwater Noise, Dec 2000. Report no. 00.792 rev.1.

Richardson, W.J., Greene, C.R., Malme, C.I. and Thompson, H.H. 1995. *Marine Mammals and Noise*. Academic Press, San Diego.

Simmonds M.P. and Isaac, S.J. 2007. The impacts of climate change on marine mammals: early signs of significant problems. *Oryx*, **41**: 19-26.

Wilson, B., Batty, R. and Carter, C. 2007. A cost of green energy: are wind and tidal energy devises a threat to European cetaceans? Poster Abstract presented at the 2007 meeting of the European Cetacean Society, San Sebastian, Spain.

Wahlberg, M. and Westerberg, H. 2005. Hearing in fish and their reactions to sounds from offshore wind farms. *Mar Ecol Prog Ser*., **288**: 295-309.

MARINE MAMMALS AND NOISE FROM OFFSHORE RENEWABLE ENERGY PROJECTS – UK DEVELOPMENTS[1]

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Potential noise impacts of offshore renewable energy in the United Kingdom

Offshore renewable energy installations are likely to be the most intensive engineering interventions in the UK's coastal waters in the next decade. Offshore renewables have the potential to significantly contribute to the reduction of greenhouse gas emissions and consequently mitigate the impacts of climate change, an issue that could affect marine mammal distribution and abundance (Evans *et al*., 2007). However, noise arising from the construction and, to a lesser extent, operation, of marine renewables may also have adverse effects on marine mammals such as, in UK waters, harbour porpoise (*Phocoena phocoena*), bottlenose dolphin (*Tursiops truncatus*) and common and grey seals (*Phoca vitulina* and *Halichoerus grypus*).

The environmental impacts of such developments will vary according to location and design. However, four main categories of potential noise impacts may arise:

– *Noise from construction*

Noise from construction and, in particular the use of driven piles, may give rise to extremely loud noise levels. Development proposals for offshore wind farms in UK waters have generally considered large mono-pile designs with diameters of between 4 and 6 metres. This size of driven pile has the potential to give rise to peak-to-peak source levels in excess of 250 dB re. 1 µPa @ 1 m (Nedwell *et al*, 2008);

– *Noise from operation of wind farms*

Operational noise transmitted from turbines through structures into the sea may give rise to barrier effects or avoidance behaviours, although initial noise measurements suggest that the risk of this is low (Nedwell *et al*, 2008);

– *Noise from decommissioning*

Decommissioning of OREI at the end of their commercial life may involve noise creating activities such as cutting, drilling and, in extreme cases, the use of explosives to ensure compliance with government regulations requiring re-instatement of the seabed;

[1] The authors of this paper are employed by two of the United Kingdom's statutory nature conservation agencies. The agencies are responsible for nature conservation advice to government both in territorial waters and, through the UK's Joint Nature Conservation Committee (JNCC), outside of territorial waters (12nm – 200nm).

– *Noise from operation of wave and tidal devices*

While generally at a demonstrator or pre-commercial stage, and therefore largely unstudied, these technologies could introduce turbine noise directly into the marine environment (Scottish Executive, 2007) although any effects are likely to be localised. Although pile sizes are likely to be smaller than those utilised in the offshore wind industry (South West of England Development Agency, 2006) construction noise may also be a significant issue, particularly in areas of high marine mammal abundance.

Development programme for offshore renewable energy in UK waters

Development of offshore wind farms in UK waters has taken place in licensing "rounds". Round 1 represented an initial limited demonstrator phase, Round 2 incorporated larger projects, while the recently announced proposals for Round 1[2] could amount to around 25 GW of capacity with hundreds, if not thousands, of turbines.

– *Round 1 projects*

At the time of writing eleven Round 1 projects have been consented with five projects generating electricity. These projects are relatively small in scale with no more than 30 turbines. Largely (but not exclusively) they are located in areas of low cetacean activity.

The short construction periods associated with these projects, where in some instances pile driving has taken less than a month to complete, means that impacts are usually likely to be short term. Studies from the Horns Rev and Nysted sites in Denmark suggest that harbour porpoise return to wind farm sites following construction[3], although further studies in this respect are required.

Monitoring of noise levels arising from piling has taken place at many of the UK Round 1 wind farms, including Barrow, Burbo Bank, Kentish Flats and Lynn and Inner Dowsing (Nedwell *et al*, 2008). These measurements have confirmed the potential for high noise levels, although details vary between sites depending on substrate type, bathymetry and installation methods.

– *Round 2 projects*

The wind farms proposed as part of the second licensing round are larger developments, up to 1 GW in size, often incorporating hundreds of turbines (the largest, London Array, could have as many as 340 turbines). Fifteen projects have been proposed within three strategic areas; the Thames, the Wash (Southern North Sea) and North-West / North Wales (Irish Sea). To date, four of these projects have been consented.

Piles up to 6 metres in diameter have been considered in Environmental Statements for Round 2 projects, in order to support the potential for larger turbines in the marine environment. Installation of these piles has the potential for disproportionately increased

[2] http://www.offshore-sea.org.uk/downloads/Offshore_Energy_SEA_Scoping.pdf

[3] http://www.hornsrev.dk/Engelsk/Miljoeforhold/uk-rapporter.htm#Porpoises

levels of noise compared to the smaller piles used on Round 2 projects (Nedwell *et al*, 2005). These higher noise levels have the potential to give rise to disturbance effects over tens of kilometres from the piling activity (Nedwell *et al*, 2005, 2008).

Additionally, the installation of piles on Round 2 projects is likely to take place over a number of seasons, rather than the relatively short periods associated with Round 1. It can therefore be expected that disturbance effects may therefore be prolonged and could give rise to different impacts from the temporary effects associated with the Danish and UK Round 1 projects. Environmental impact assessment of consented wind farms in the Thames Strategic Area (London Array, Greater Gabbard and Thanet) predicted that population level effects were unlikely to occur (Shepherd, 2006); however it should be noted that the Thames estuary is generally seen as an area of low porpoise abundance (Reid *et al*, 2003).

Round 2 consents under the Food and Environment Protection Act (FEPA) require developers to agree marine mammal mitigation programmes prior to commencement of construction, and to monitor potential impacts on marine mammals. The Countryside Council for Wales, Natural England and JNCC have drafted guidelines for mitigating potential impacts on marine mammal during the construction of Round 2 wind farms, and public consultation on this document will take place in 2008.

– *Round 3 proposals*

The UK government's proposals for Round 3 are currently undergoing Strategic Environmental Assessment; however, the proposed capacity of development may be as much as four times the eventual level built out under Rounds 1 and 2 combined[4]. Concern over cumulative impacts may be prominent during the consenting process, particularly if construction operations on adjacent sites takes place concurrently, giving rise to the potential for longer term and geographically widespread increases in underwater noise.

As discussed above, wave and tidal generation is at a relatively early stage of development although the potential for these technologies is large. For example, Strategic Environmental Assessment of 1300MW of capacity in Scottish Waters, which includes areas of high cetacean abundance, has recently been completed.

Generally, the installation of these technologies is likely to involve construction techniques which give rise to significantly lower levels of noise than those associated with pile driving at offshore wind farms. This is because driven piling, if it occurs at all, is likely to utilise much smaller diameter piles (South West of England Development Agency, 2006). The Scottish SEA environmental report (Scottish Executive, 2007) considered that operational noise from tidal turbines may be a significant risk, giving rise to the potential for barrier and other disturbance effects. This may be a concern in narrows and other constrained areas utilised by migrating or foraging species. *In situ* monitoring of the operational noise of different devices is required. However, initial

[4] http://www.offshore-sea.org.uk/downloads/Offshore_Energy_SEA_Scoping.pdf

studies (Richards *et al*, 2007) suggest that noise may be only localised and of low volume (reflecting device traits aimed at limiting friction and increasing efficiencies).

The research agenda in the United Kingdom To date, much of the study of interactions between marine renewable devices and marine mammals has taken place as part of the environmental impact assessment process. However, in recent years, more collaborative approaches such as COWRIE (see www.offshorewind.co.uk) and the Department for Business, Enterprise and Regulatory Reform's (DBERR) Research Advisory Group (RAG)[5] have also commissioned research.

One of the core areas of COWRIE's work relates to underwater noise. A literature review was initially conducted (Nedwell *et al*, 2003), and measurements of construction and operational noise have also taken place.

Details of further work may be found on the COWRIE website, although two research reports are of particular relevance to this paper.

The first (Nehls *et al*, 2007) considered the availability of techniques to reduce construction noise levels at source. This is a potentially efficient approach because relatively small reductions in the decibel level arising from piling activities can significantly reduce the zone of potential influence around construction sites. The report concluded that deploying insulating sleeves around piles may be both a practical and economical method of effectively reducing noise levels. Other solutions to reducing noise could include alternative pile designs such as gravity bases or "jacket" approaches (these are structures based on offshore oil platforms which use smaller piles to attach to the seafloor), although in some cases, these approaches may not be technically or commercially viable.

The second paper (SMRU, 2007) considers the use of acoustic deterrents as a means of mitigating potential impacts on marine mammals from piling noise. The report concludes that although deployment of such devices may have the potential to minimize risk of injury or death, there are a number of uncertainties and legal barriers to using acoustic deterrents, and further research in this area is required. COWRIE is likely to commission such research during 2008.

COWRIE has also recently commissioned work to consider the statistical and scientific robustness of various techniques for surveying marine mammal distributions and abundances in wind farm areas, and the ability of various monitoring methodologies to detect changes in those distributions and abundances, which might be attributable to wind farm development. This work is due to be published early in 2008.

Future research needs Looking forward, the authors recognise that offshore wind and wave and tidal projects can deliver environmental benefits, but believe that further information on a number of issues is required if projects are to be appropriately located without causing harm to sensitive receptors including marine mammals.

[5] http://www.berr.gov.uk/energy/sources/renewables/policy/offshore/research-advisory/page22590.html

Further research is required on issues such as propagation and attenuation of underwater noise, the responses of marine mammals to that noise, and the significance of those responses in terms of the conservation status of the main species. A key issue is likely to be cumulative impact where robust techniques for assessment are yet to be developed.

We recognise that a pragmatic approach is required in an industry which is relatively young and that many of the gaps in knowledge also need to be addressed by other industries, most notably in the hydrocarbon exploration and extraction sectors. It is also important to acknowledge that some of these gaps may never be fully answered.

Finally, we need to acknowledge that while improvements in our understanding are only likely to arise from the monitoring of constructed wind farms, such monitoring needs to take place with a specific aim or hypothesis in mind, and that further consideration is required as to how best to assess population level impacts given a fluctuating baseline, and a background of environmental change and limited resources available for survey.

REFERENCES

Evans, P.G.H., Boyd, I.L. and MacLeod, C.D. 2007. *Marine Mammals and Climate Change*. In Marine Climate Change Impacts Annual Report Card 2007 (Eds. Buckley, P.J, Dye, S.R. and Baxter, J.M), Online Summary Reports, MCCIP, Lowestoft.

Nedwell, J.R, Langworthy, J. and Howell, D. 2003. *Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore windfarms, and comparison with background noise*. Subacoustech Report No. 544R0424 commissioned by COWRIE.

Nedwell, J.R., Workman, R. and Parvin, S.J. 2005. *The assessment of likely levels of pile driving noise at Greater Gabbard and its comparison with background noise, including pile driving noise measurements made at Kentish Flats.* Subacoustech report No. 633R0115.

Nedwell, J.R., Parvin, S.J., Edwards, B., Workman, R., Brooker, A.G. and Kynoch, J.E. 2008. *Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters*. Subacoustech Report No. 544R0736 to COWRIE Ltd. ISBN: 978-0-9554279-5-4.

Nehls, G., Betke, K., Eckelmann, S. and Ros, M. 2007. *Assessment and costs of potential engineering solutions for the mitigation of the impacts of underwater noise arising from the construction of offshore windfarm*s. BioConsult SH report, Husum, Germany. On behalf of COWRIE Ltd.

Reid, J.B., Evans, P.G.H., and Northridge, S.P. 2003. *Atlas of Cetacean distribution in north-west European waters* Joint Nature Conservation Committee, Peterborough. 76 pp, colour photos, maps. Paperback, ISBN 1 86107 550 2.

Richards, S.D., Harland, E.J. and Jones, S.A.S. 2007. *Underwater Noise Study Supporting Scottish Executive Strategic Environmental Assessment for Marine Renewables* QINETIQ/06/02215/2

Scottish Executive 2007. *Scottish Marine Renewables: Strategic Environmental Assessment, Environmental Report* http://www.seaenergyscotland.net/SEA_Public_Environmental_Report.htm

Shepherd, B. 2006. *Underwater Noise Impact Assessment on Marine mammals and Fish during Pile Driving of proposed Round 2 Offshore Wind Farms in the Thames Estuary*. RPS Energy, Report No. EOR0523

SMRU Ltd 2007. *Assessment of the potential for acoustic deterrents to mitigate the impact on marine mammals of underwater noise arising from the construction of offshore windfarms.* Commissioned by COWRIE Ltd (project reference DETER-01-07).

South West of England Development Agency 2006. *Wave Hub Environmental Statement.* http://download.southwestrda.org.uk/file.asp?File=/projects/general/Environmental Statement.pdf

AUDITORY STUDIES ON HARBOUR PORPOISES IN RELATION TO OFFSHORE WIND TURBINES

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The effects of offshore wind turbines on harbour porpoises can be studied from different perspectives. Line-transect surveys and static or towed acoustic monitoring are valuable tools to describe the status or trends in distribution and abundance of these animals within certain areas and telemetry studies provide insight into the behaviour and habitat use of individual animals. These methods are indispensable in many respects but they are descriptive by nature and cannot explain or predict why any observed effects occur. In this sense they are complementary to studies on the cause-effect-relationship of the presence of or emissions from offshore wind turbines (OWT's) and their direct effect on individual animals. Electromagnetic and visual inputs from OWT's are likely to be negligible in this context, either because of their low strength of emissions or comparatively low sensitivity of harbour porpoises to such stimuli. By contrast, OWT-related acoustic emissions can repeatedly reach extreme intensities. There is a direct link between acoustic emissions and porpoises as these animals have a very acute hearing and rely vitally on this sense. The understanding of noise-induced effects and data on the tolerance of the animals hearing system to such sounds are critical for the assessment of the overall effect of OWT's on harbour porpoises.

A principal key for assessing the impact of these noise emissions on the harbour porpoises are data on the auditory sensitivity and perception capabilities of this species. In harbour porpoises, as in several other cetacean species, the auditory sense evolved to be the primary sensory modality. This is not only represented by its sophisticated sound production mechanism, but also by the auditory capabilities of these animals. Harbour porpoises actively use underwater sound by means of echolocation (Busnel *et al*., 1965; Møhl & Andersen, 1973; Akamatsu *et al*., 1994) to locate their prey as well as for spatial orientation and navigation. Their functional hearing range stretches at least from 250 Hz to 160 kHz with their most sensitive hearing being 32 dB re 1 µPa at 100-140 kHz) (Kastelein *et al*., 2002), overlapping with the frequency content of their echolocation clicks (i.e., between 125 kHz and 148 kHz) (Møhl & Andersen, 1973; Hatakeyama & Soeda, 1990; Goodson *et al*., 1995). So far, it has only been scientifically proven that porpoises actively use the high frequency portion of their acoustic signals ("clicks") for echolocation. Since communicative signals, comparable for example to the whistles emitted by dolphins, so far have not been clearly documented for harbour porpoises, and their echolocation signals contain a considerable amount of sound also at low frequencies (1.4–2.5 kHz at a source level of 100 dB re 1µPa at 1m), it has been repeatedly hypothesized that these animals use their clicks also for communication (Schevill *et al.*, 1969, Verboom & Kastelein, 1995). Those low frequency portions of the clicks are almost omni-directional and provide a higher range. Both aspects make these signals suitable for communicative purposes.

Using auditory evoked potential (AEP) methods, a study was conducted on a harbour porpoise (*Phocoena phocoena*) at the Dolfinarium Harderwijk in The Netherlands. The aim of the study was to assess the potential masking effect of operational sounds of offshore wind turbines on the perception of important signals by harbour porpoises in general, and those probably used for communication purposes in particular. Operational sound is continuously emitted from OWT's at varying source levels (depending on the wind conditions) with its main acoustic energy below 1 kHz. There are tonal components within these sounds which can reach intensities at least up to 125 dB re 1µPa^2/Hz. The measurement of AEP's was chosen as the best method for obtaining the hearing data from the animal. A male harbour porpoise was trained to actively participate in the study. AEP's were evoked with two types of acoustic stimuli: click type signals and amplitude-modulated signals. The masking noise resembling the underwater sound emissions of an operational wind turbine was simulated. At first, the animal's hearing threshold was measured at frequencies between 0.7 and 16 kHz. Subsequently these measurements were repeated at frequencies between 0.7 and 2.8 kHz in the presence of two different levels of masking noise (115 and 128 dB re 1µPa). The resulting data show a masking effect of the simulated wind turbine sound at a level of 128 dB re 1µPa at 0.7, 1 and 2 kHz. This masking effect varied between 4.8 and 7.3 dB at those frequencies. No significant masking was measured at a masking level of 115 dB re 1µPa.
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If the received level of the operational sounds on average drop below 120 dB within a range of 100 m from a wind turbine (Madsen *et al.*, 2006), the higher level of masking sound used in this study would have been received only at a short distance from an average type of offshore wind turbine (several tens of m). The difference between the effective masking intensity at the high masking level and the non-effective moderate masking level was approximately 13 dB. Thus the effective range of the observed masking would be comparatively small as the operational sound of an offshore wind turbine would be attenuated by 13 dB in shallow water within 20 m from the sound source (assuming spreading with a loss of 10 log r [r = distance in m]), and at less than 10 m distance from the sound source in deep waters (assuming spherical spreading with a loss of 20 log r). Due to oceanographic or geological features, the spreading loss can reach even higher levels thus decreasing the effective masking range of the wind turbine sounds. However, actual sound measurements have been carried out at comparatively small wind turbines. Several offshore wind farms are currently planned with turbines of up to 5 MW. It is unclear to what extent sound emissions of these turbines will rise in level with increasing size. So far, these emissions have only been modelled (DEWI, 2004), but should be measured upon construction of the turbines. The available data indicate that a potential masking effect would be limited to short ranges in the open sea. However, all estimates are based on existing turbine types, and do not take into account future developments for larger and potentially noisier turbine types.

The tolerance of the hearing system of harbour porpoises to sound was studied in another male harbour porpoise, held at the Fjord & Bælt Centre in Kerteminde, Denmark. It is known from studies on other toothed whale species (e.g. Finneran *et al.*, 2002) that the exposure to impulsive sounds such as the ramming impulses emitted during pile driving, can at high intensities lead to temporary or even permanent reduction of hearing sensitivity, impairing the hearing of the animals (temporary threshold shift, TTS *vs*. permanent threshold shift, PTS). Based on these data, it can be assumed that the ramming impulses measured during the installation of OWTs (which on average exceed peak pressures of 225 dB re 1µPa at 1 m), will create a risk of at least TTS in the auditory system of harbour porpoises. As mentioned above, these animals are vitally dependent on their hearing system. Any impairment or damage to their hearing capabilities could have severe consequences for the affected animal.

Again, all hearing data were collected by using the AEP-method. After obtaining baseline hearing data across the animal's functional hearing range, it was subsequently exposed to single fatiguing sound impulses (produced by an airgun; with acoustic characteristics comparable to a ramming impulse) at increasing received levels in a controlled exposure experiment. Immediately after each exposure, the animal's hearing threshold was tested again for any significant changes, at three selected frequencies. The received levels of the airgun impulses were increased until TTS was reached at one of the frequencies.

The animal's hearing thresholds were elevated by comparison to published data from other studies. A systematic electrophysiological masking due to the active positioning of the animal at its underwater station, and an acoustic masking due to the high background noise level in the enclosure, are likely reasons for these elevated hearing thresholds. The acoustic characteristics of the auditory stimuli may also account for a systematic difference in hearing sensitivity. The harbour porpoise's hearing sensitivity obtained here therefore does not represent absolute but masked hearing threshold levels (MTTS). This, however, has no implication on the tolerance of the animal's hearing system for intense impulsive sounds.

At 4 kHz, the TTS-criterion was exceeded when the animal was exposed to a single impulse at a received sound pressure of 200 $dB_{peak\text{-}peak}$ re 1µPa and a sound exposure level of 164 dB re $1µPa^2$. The documented MTTS level of the harbour porpoise is considerably lower than levels found in other toothed whale species tested so far, thus supporting the hypothesis for mass-dependant differences in the tolerance of the auditory system by toothed whales. Also, recovery from TTS, i.e. the return of the hearing sensitivity to pre-exposure levels, took much longer in the harbour porpoise compared with other species. Modelling the impact range of multiple exposures reveals a risk for auditory effects in harbour porpoises over larger distances as compared to single exposures. The results provide a baseline to define the noise exposure limit for this species for single impulses, comparable to those proposed by Southall *et al.* (2008). Thus they are likely to have implications for regulatory procedures for the construction of offshore wind turbines as well as for the use of other impulsive sound sources.

REFERENCES

Akamatsu, T., Hatakeyama, T. and Soeda, H. 1994. Echolocation rates of two harbor porpoises (*Phocoena phocoena*). *Mar. Mamm. Sci*., **10**(4) : 401-411.

Busnel, R.G., Dziedzic, A. and Andersen, S. 1965. Rôle de l'impédance d'une cible dans le seuil de sa détection par le système sonar du marsouin *P. phocaena*. *C.R. Séances Soc. Biol*., **159**: 69-74.

DEWI (Deutsches Windenergie-Institut) 2004. Standardverfahren zur Ermittlung und Bewertung der Belastung der Meeresumwelt durch die Schallimmission von Offshore-Windenergieanlagen. Forschungsvorhaben 0327528A. Deutsches Windenergie-Institut, Wilhelmshaven. (In German).

Kastelein, R.A., Bunskoek, P. Hagedoorn, M. and Au, W.W.L. 2002. Audiogram of a harbour porpoise (*Phocoena phocoena*) measured with narrow-band frequency-modulated signals. *J. Acoust. Soc. Am*., **112**(1): 334-344.

Finneran, J.J., Schlundt, C.E., Dear, R., Carder, D.A. and Ridgway, S.H. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. *J. Acoust. Soc. Am*., **111**(6): 2929-2940.

Goodson, A.D., Kastelein, R.A. and Sturtivant, C.R. 1995. Source Levels and echolocation signal characteristics of juvenile Harbour porpoises (*Phocoena phocoena*) in a pool. Pp. 41-53. In: (P.E. Nachtigall, J. Lien, W.W.L. Au and A.J. Read, Eds.). *Harbour porpoises – laboratory studies to reduce bycatch*. De Spil Publishers, Woerden, The Netherlands.

Hatakeyama, Y. and Soeda, H. 1990. Studies of echolocation of porpoises taken in salmon gillnet fisheries. Pp. 262-282. In: (J.A: Thomas and R.A. Kastelein, Eds.). *Sensory Abilities of Cetaceans: Laboratory and Field Evidence*. Plenum Press, New York.

Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K. and Tyack P. 2006. Wind turbine underwater noise and marine mammals: Implications of current knowledge and data needs - review. *Mar. Ecol. Prog. Ser*., **309**: 279-295.

Møhl, B. and Andersen, S. 1973. Echolocation: High-frequency component in the click of the harbour porpoise (*Phocoena phocoena*. L.). *J. Acoust. Soc. Am*., **54**(5):.1368-1372.

Schevill, W.E., Watkins, W.A. and Ray, C. 1969. Click structure in the porpoise, *Phocoena phocoena*. *J. Mammalogy*, **50**: 721-728.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R. Jr., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A. and Tyack, P.L. 2008. Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammals*, **33** (4).

Verboom, W.C. and Kastelein, R.A. 1995. Structure of harbour porpoise (*Phocoena phocoena*) click train signals. Pp. 343-362. In: (A.J. Read, P.R. Wiepkema and P.E. Nachtigall, Eds). *The Biology of the Harbour Porpoise*. De Spil Publishers, Woerden, The Netherlands.

LINKING WIND FARMS AND HARBOUR PORPOISES: A REVIEW OF METHODS

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Several methods have been used in different projects to study the possible effects that the construction and running of offshore wind farms have on harbour porpoises (*Phocoena phocoena*). Some methods stem from before the time of offshore wind farms, while others are comparatively new methods, which have been developed for other studies of harbour porpoise behaviour or abundance. No method has been developed directly with wind farms and harbour porpoises in mind, but they have all been adapted to fit the problem within their different limitations. This compilation briefly reviews different methods that have or could be used in a study of impacts, and summarises the advantages and disadvantages of each of them.

The methods are compared directly, where it has been possible, largely based on the results of the MINOS and MINOS^{+} projects conducted in German waters in the years 2002-07.

Questions asked

There are often two questions asked when it comes to the effects of offshore wind farms on harbour porpoises.

1. Is there a change in distribution/abundance in the wind farm area?
2. Is there a change in behaviour in the wind farm area?

And the questions are both usually asked for two time periods, the construction phase and the production phase.

Possible methods

A total of eight methods have been used in monitoring projects on harbour porpoises, but they can generally be classified in three basic groups:

1) Line-transect surveys
    a) Visual aerial based
    b) Visual ship based
    c) Acoustic ship based
2) Static acoustic monitoring
    a) T-PODs (Timing Porpoise Detector)
    b) PCL (Porpoise Click Logger)
3) Attachment devices
    a) Satellite tags
    b) VHF-radio tags
    c) Data logger

These could also be grouped through more technical aspects such as visual, acoustic and attachment methods, but the grouping above is based on the underlying concepts of the methods and is more logical in this discussion.

Description of methodologies

Attachment devices Those methods using devices that are attached to harbour porpoises are based on the idea of getting precise information on geographic position, behaviour (e.g. swimming or acoustic), etc., of individual animals. The obvious advantage is that the results are hard to refute. If a tagged harbour porpoise spent 10% of its time inside a wind farm area both before and after the construction of the wind turbines, we would conclude that the construction of the wind farm did not affect the behaviour of those individual animals. But there will usually be a problem of getting enough animals with devices attached first of all, getting one in the area of the wind farm, and finally having sufficient tagged animals to extrapolate the results to the entire population.

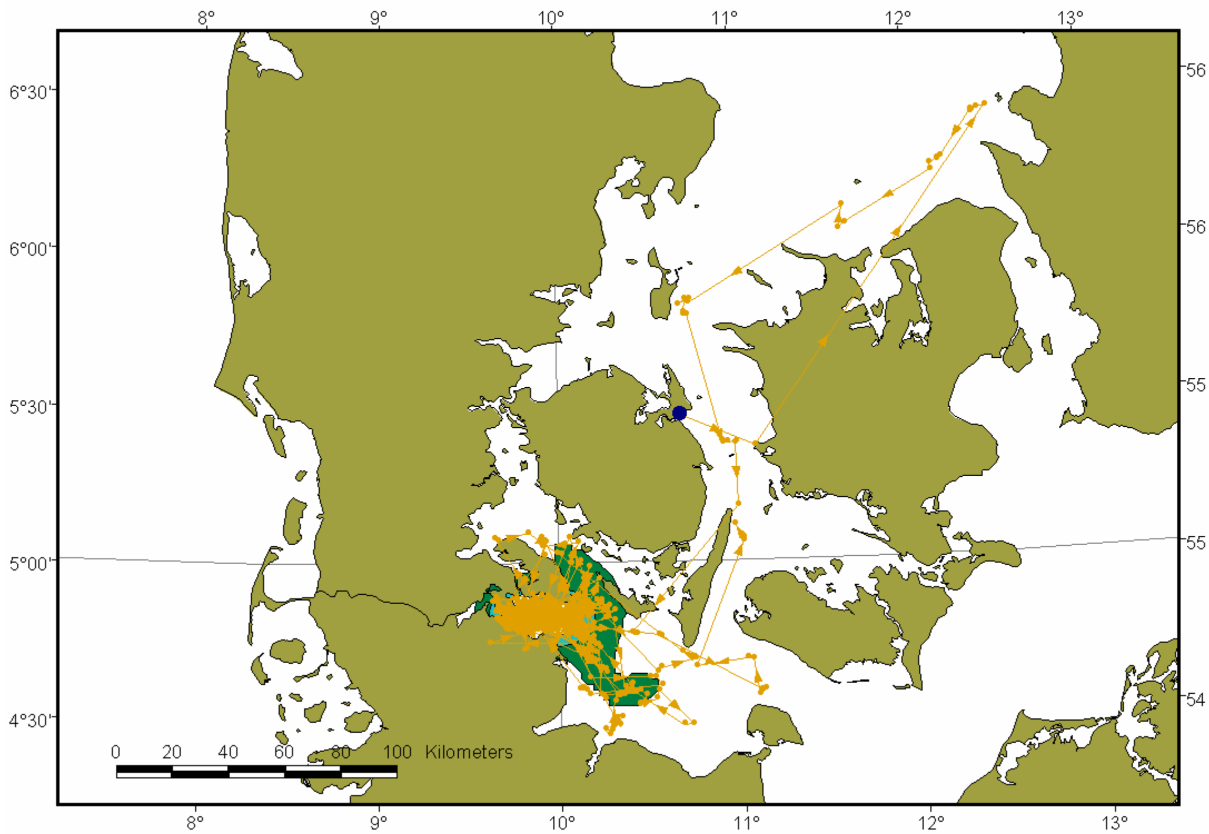

Fig. 1. Example of a track of a satellite tagged harbour porpoise from Danish waters. The blue dot indicates the position of the tagging procedure, the pale brown dots are the satellite positions and the brown line the direct track between subsequent positions (From Teilmann *et al*., 2004)

The above track spanning several months would probably give very interesting results for a wind farm area in the Western Baltic (Flensburger Förde) region, but it is unlikely that the investigators for such an area would choose to tag a harbour porpoise in the Great

Belt region, hoping that it would swim more than a hundred kilometres to their wind farm area. On the other hand, would investigators for a wind farm site in the Great Belt be delighted to tag an animal so close, but end up with very little data from their area?

To summarise, the information potential here is very high, but there are (in most areas) serious difficulties in getting sufficient animals tagged from which to draw conclusions for the overall population, besides the lack of control of where the animals will settle.

Visual monitoring by ship or plane Surveying harbour porpoises from ship or plane represent methods with a basis in Distance sampling theory. This theory is well described in the book *Introduction to Distance Sampling: Estimating Abundance of Biological Populations* by S. Buckland *et al*. (2001, Oxford University Press).

One method in distance sampling is the line-transect survey, which is the foundation for both aerial and ship based monitoring for harbour porpoises. The ultimate goal of the method is generally to achieve an estimate of the absolute abundance of animals in a predetermined study area at a given time. For wind farm studies, the abundance in the wind farm has little biological sense, as this area is very small compared to the daily, weekly and monthly movements of harbour porpoises. More often, however, the density per area (relative abundance) is more telling when it comes to wind farms and should therefore be used, but as this is part of the abundance estimation, the methods can be used with very little adaptation.

Although not designed to study any wind farm sites, the above example shows that it can take several years to compile statements on distribution patterns, even on a quarterly basis, if the harbour porpoise abundance is low. A certain amount of effort is needed before conclusions can be drawn, and this results in one of the limitations of line-transect surveys, that of platform availability. A platform, ship or plane, must be on constant standby, because both methods suffer from a fairly high degree of weather dependence, and every good weather day has to be used. This does not readily fit favoured wind farm areas, which are chosen partly by the presence of constant strong winds. The advantage of line-transect survey methods is the statistics. Since the methodology is some decades old, it is well tested, and the achieved results can be supported by good statistical evidence.

Static acoustic monitoring As PCLs are very new devices, there are no reports available on their performance, but they should be mentioned as a possible alternative to the T-POD, on which this section is written.

PODs were developed in the 1990s as a mean to investigate the timing of harbour porpoise bycatch, mainly in set net fisheries. One of the goals was to see if harbour porpoises were caught during the deployment, soaking or retrieval of the nets, and also to determine whether harbour porpoises approached the net but did not get caught. Although there have been many versions of the POD (now referred to as the T-POD), this first reason for development should not be forgotten, since an acoustic device designed directly for wind farm studies could look and work completely differently.

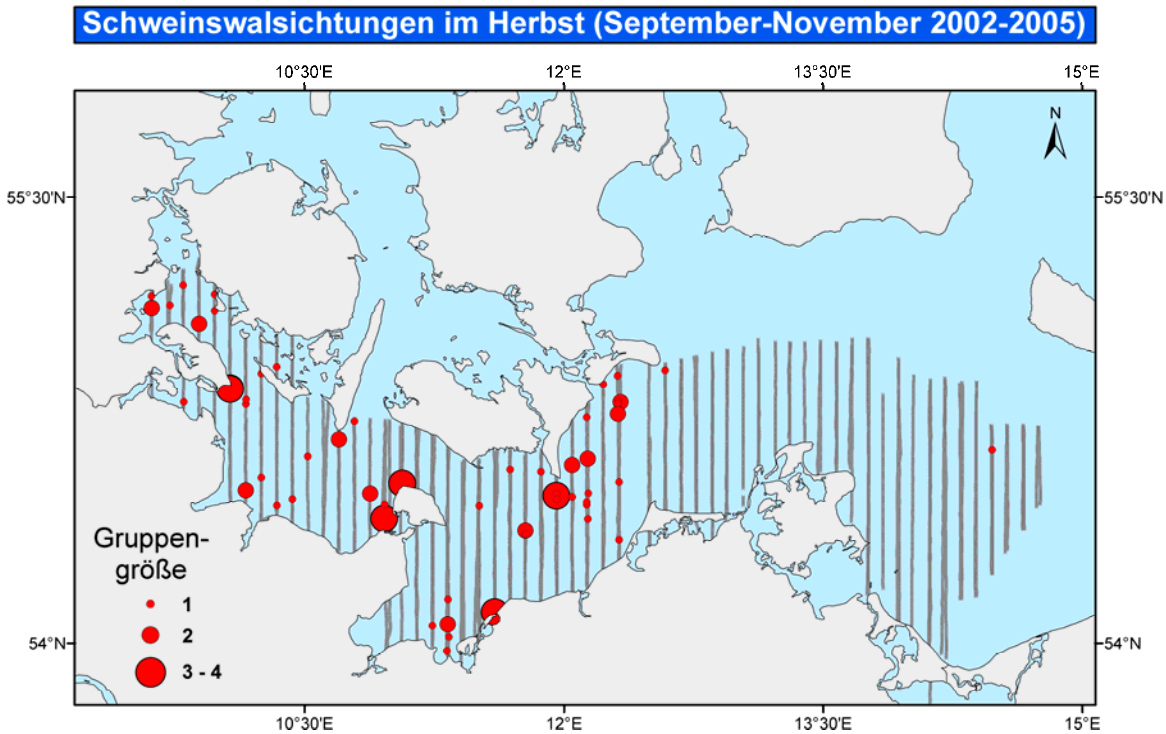

Fig. 2. Harbour Porpoise sightings in the Baltic Sea from the MINOS+ project. The German title reads: “Harbour porpoise sightings in Autumn (Sep-Nov 2002-2005) and the legend title reads: “Group size”. From the MINOS+ report, 2005

T-POD studies, to monitor effects, usually follow the concept of the BACI design. The abbreviation stands for “Before-After-Control-Impact”, and a theoretical result of such a set-up is shown in Fig. 3.

For more on BACI design, the book *Statistics for Environmental Science and Management* by Bryan F.J. Manly (2001, CRC Press) is recommended. With this well formulated statistically based design, one would think that the use of T-PODs should bring very solid results, but as with line- transect survey methods, the main problem is getting sufficient data to run the statistics.

Most T-POD studies on wind farms have suffered from loss of equipment, and in some cases in proportions so high that projects have been terminated as a result of the data income failure. This is not completely surprising, since the seas generally are a rough place, and leaving equipment for longer time periods out there will inherently lead to loss due to breakage, collision etc, at some point.

Although there is no doubt that T-PODs detect harbour porpoises, the developmental work has focused primarily on study design, data analysis and mooring systems. The latter of these may vary considerably from site to site, mainly in size, because different types of vessels are used to service the T-POD stations. But there should be (and have been) efforts to standardise the other two issues, since the questions asked in relation to wind farms usually are the same.

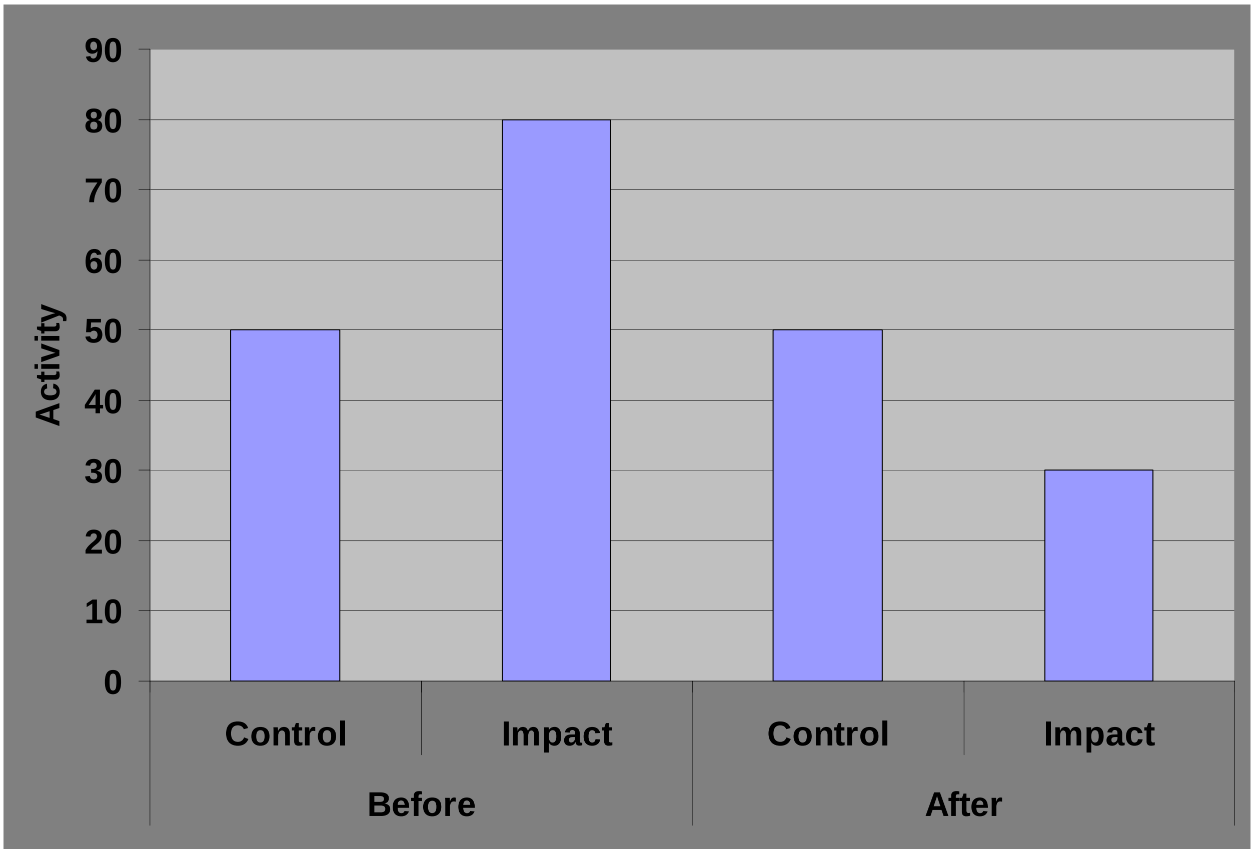

Fig. 3. Theoretical BACI result. This result of a BACI experiment could be interpreted as an action having a negative effect in the Impact area, whereas the Control area is undisturbed. The label "activity" on the Y-axis could really be anything.

Serious concern has been raised about the ability of T-PODs to indicate the abundance (or density) of animals, since it cannot distinguish if two detections come from the same or from different animals. The MINOS$^+$ project has shown a strong correlation between harbour porpoise densities calculated from aerial surveys and recorded harbour porpoise acoustic activities from a grid of T-POD stations. The measure of porpoise positive days per month was a good indicator of harbour porpoise density, at least for low-density areas (less than 0.4 animals per km^2) (see MINOS$^+$ final report, 2008).

In summary, static acoustic monitoring is a completely passive method that has no effect on the animals, except maybe by creating "land marks" for the animals to home in on. The recording of data is weather independent, but some problems can arise because of weather when servicing the T-POD stations. Each individual T-POD can monitor only a very small area, so more than one device is needed for an impact study.

Recommendations Because the issue of wind farms and harbour porpoises poses several questions, the methods described above can be ranked in different ways, and for the most complete picture of the situation, they should all be used because they complement one another. However, recognizing that there are, seldom, sufficient funds and manpower available to run all of them at once in a given project, some recommendations for one method to answer a particular question should be given.

For effects of the construction phase This effect actually has two elements: increased ship traffic, and the actual construction of the pylon foundations. And it is very difficult to separate the effects of each of them.

The construction noise is a periodic occurrence, but it probably results in a strong adverse, but relatively short-lived reaction, especially when the pylons are rammed into the seabed using a pile driver. This scenario with a strong temporal component makes static acoustic monitoring a suitable candidate as a method, but a network or array of devices are required to obtain the necessary geographic extent of the effect. Static acoustic monitoring can answer both behavioural and distributional questions, bearing in mind, of course, that silent animals which are present will not be detected by these devices.

For effects during the production phase Some increased ship traffic compared to the time before the construction of the wind farm must still be expected, but the major effects are likely to come from the turbines themselves. Adverse effects could also come from the noise of blades and/or gearing, the flickering shadows from the turning blades on the water surface and others. Positive effects may also be expected, however, because of the creation of an artificial reef around the foundation structures attracting more (or other) fish species. But, generally, the effects are believed to be more subtle, both in terms of magnitude and duration and for the distribution and behaviour of the animals. The best method currently available to measure small distributional differences is probably aerial visual surveys, and although not designed to study behaviour, it is possible to achieve some information on that in those few seconds when a harbour porpoise is visible from the plane.

Concluding remarks The real strength of the methods described above is their complementary abilities. It is not often that an investigator has a selection of methods so diverse to choose from, and a lot of effort should be given to the newer emerging methods in order to determine if their believed potential can hold up. But the older, more proven, methods must also be continued, because they have formed our basic knowledge to which we compare our findings from new approaches.

APPLICATIONS AND ANALYTICAL METHODS FOR T-POD DEPLOYMENT IN ENVIRONMENTAL IMPACT STUDIES FOR WIND FARMS: COMPARABILITY AND DEVELOPMENT OF STANDARD METHODS

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INTRODUCTION This presentation introduces the AMPOD[6]-project and presents its first results of tank and field calibrations of harbour porpoise (*Phocoena phocoena*) detectors (T-PODs), obtained in cooperation with two collaborating research and development projects[7,8]. Aims of the AMPOD-project are to investigate data comparability from static acoustic monitoring (SAM) with T-PODs, acoustic data loggers that register sounds likely to be dolphin and porpoise echolocation clicks. Therefore, data from different studies and study areas, different T-POD-versions, and –settings, as well as different analytical methods, will be compared. The results will be used to develop guidelines and standard methods for SAM.

Table 1. Standard settings of T-POD version 2 to version 5 in the test tank calibration of the German Oceanographic Museum, Stralsund

Setting	V2	V3	Setting	V4	V5
A-Filter-Frequency	130	130	A-Filter-Frequency	130	130
B-Filter-Frequency	90	90	B-Filter-Frequency	92	92
Ratio A/B	6	6	Click bandwidth	5	5
A-Filter sharpness	10	Short	Noise adaptation	+	+
A-Filter sharpness	18	Long			
Minimum intensity	6	6	Sensitivity	12	12
Limit on clicks logged	none	none	Limit on clicks logged	none	none

MATERIALS AND METHODS Tank calibration A total of 121 T-PODs were calibrated in a 1.0 x 0.7 x 0.7 m tank with play backs of a series of porpoise echolocation clicks for determining the characteristics and sensitivity of different T-POD versions (8 of version 2; 52 of version 3; 47 of version 4; and 14 of version 5 T-PODs). Packages of ten clicks with decreasing amplitude were used to find the minimum receiving level of the T-PODs at eight positions in 45-degree steps to determine their horizontal directivity patterns. Fixed standard settings were used as shown in Table 1. A sensitivity curve was

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[6] AMPOD Applications and analytical methods for T-POD deployment in environmental impact studies for wind farms: Comparability and development of standard methods. FKZ 0327587.
[7] Investigations of the bird collision risk and the responses of harbour porpoises in the offshore wind farms Horns Reef, North Sea, and Nysted, Baltic Sea, in Denmark. FKZ 0329963.
[8] MINOS^{Plus} Further investigations on seabirds and marine mammals for the evaluation of offshore wind farms – P3. FKZ 0329946C.

determined for each unit by altering the "minimum intensity" setting in version 2 and 3 T-PODs, and the "sensitivity" setting in version 4 and 5 T-PODs.

Field calibration Data have been analysed from 17 field trials, with a total of 40 observation days conducted in the framework of the cooperating R+D project[7]. For each experiment, six T-PODs of version 4 and 5 with different sensitivities, set to log clicks in the harbour porpoise echolocation frequency range, were deployed in an array in the Danish wind farm areas of Nysted and Horns Reef for up to five days per experiment. A total of 25 calibrated T-PODs were involved in these trials, with one of the devices being present in each session as standard T-POD**.**

Raw data were processed with the algorithm 3.0 of the T-POD.exe programme. This software detects trains of clicks with specific click patterns. Those classified as likely to be porpoise echolocation sounds ("cetacean high" and "cetacean low"), as well as trains with cetacean characteristics, but likely to be from sources other than cetaceans ("doubtful" and "very doubtful" classifications), were included for further investigation. Detection positive minutes per hour (DPM/h) were analysed as the number of minutes with at least one click train in a particular class per observation hour.

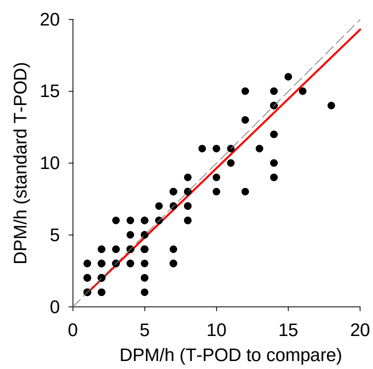

Fig. 1. Regression plot of detection positive minutes per hour (DPM/h) of a test T-POD compared with a standardised unit. In this example, the analysis reveals a regression line x=0.965y (in red) with confidence interval (+/- 0.035). The grey dashed line is the regression with a slope of 1.

This resulted in a set of DPM/h values for each T-POD. These values were matched to the corresponding DPM/h of the standard T-POD resulting in x/y-data pairs for each T-POD/standard T-POD pair (Fig. 1). A regression analysis was performed on each x/y-data set to determine the slope and 95% confidence interval (CI). In a second step, the resulting regression slopes were correlated with the sensitivity value of the corresponding T-POD in a second regression analysis. The mean click count for all clicks (both classified and unclassified), registered per hour and per T-POD, was also calculated.

RESULTS **Tank calibration** With more recent T-POD versions, the differences in sensitivity between the devices have decreased. Whereas a difference in the minimum receiving level of 29 dB was found between the least and most sensitive version 2 T-POD, the difference decreased to 19 dB for version 3, and 5 dB for versions 4 and 5 (Fig.

2). The ability to adjust the receiving threshold with the parameter “minimum intensity” and “sensitivity”, respectively, became more efficient with increasing T-POD version. While only a small range of less than 10 dB adjustability was offered in version 2 T-PODs, the range increased to greater than 10 dB for version 3, and to 25 dB for versions 4 and 5 T-PODs (Fig. 2).

Field calibration The data from all T-PODs show significant correlations with the data of the standard T-POD, as all determined slopes +/- CI are well above zero (Fig. 3). The slopes of regression show a significant correlation with the corresponding minimum receiving level ($p = 0.009$, $R^2 = 0.273$, $n = 24$) (Fig. 4). Excluding one obvious outlying data point (circled in grey - Fig. 3), there is a highly significant correlation ($p = <0.0001$, $R^2 = 0.559$, $n = 23$). The T-POD from which the outlying data resulted, recorded a mean of about 10,000 clicks per hour, while all other T-PODs recorded from <100 to around 6,000 clicks per hour on average (Fig. 5), indicating an unusually high sensitivity.

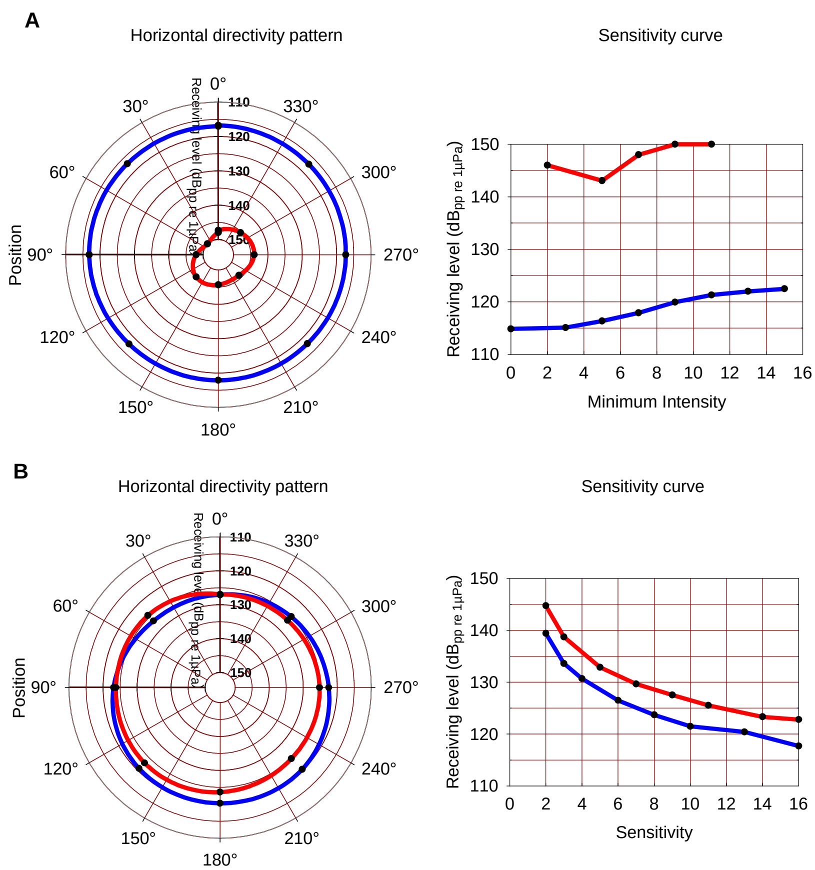

Fig. 2. Horizontal directivity pattern and sensitivity curve of the most sensitive (blue lines) and least (red lines) sensitive T-POD of (A) version 2 and (B) version 5 T-PODs

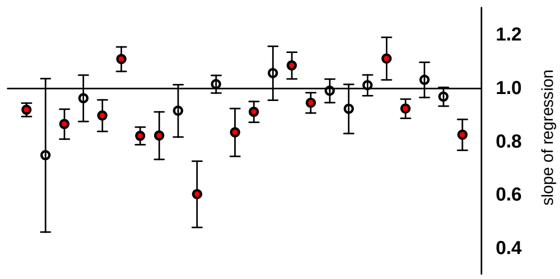

Fig. 3. Plot showing the slope of the regression (dots) and confidence intervals (error bars) of 24 T-PODs compared with a standardised T-POD. Red dots indicate a significant difference between data from the standardised T-POD and the tested T-POD, as the confidence interval is below or above a slope of 1

CONCLUSIONS The results presented here show that the tank calibration of T-PODs combined with a subsequent field calibration provide a powerful tool for researchers to directly compare data obtained with T-PODs of different sensitivities. The tank calibration demonstrated that later versions of T-PODs are more comparable in sensitivity, and the receiving directionality and sensitivity of these units is more manipulable The slope of regression of a data set from any given T-POD compared to a standardised T-POD unit can be used for correcting data sets obtained with different T-PODs of varying sensitivities. It is necessary to take into consideration background noise, since too much noise influences comparability of the data.

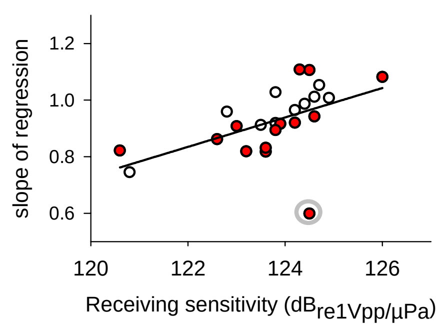

Fig. 4. Slopes of regression (as in Fig. 3) correlated with the receiving sensitivities of the corresponding T-POD obtained by the tank calibration. The black line indicates the regression line. Red dots indicate a significant difference between data from the standardised T-POD and the test unit, as the confidence interval is below or above a slope of 1. The grey encircled data point is regarded as an outlier (see text).

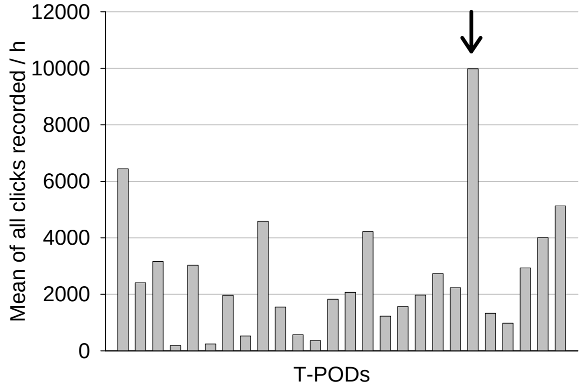

Fig. 5. Mean number of all clicks registered by the different T-PODs. The outlier data (as mentioned in the text) is marked with an arrow

Future tasks will include a repeat of the above analyses excluding the train classes "doubtful" and "very doubtful", as well as performing a detailed analysis on the effect of registered background noise on the data comparability. Furthermore, T-POD versions 2 and 3 as well as a larger range of T-POD sensitivities, should be included in the field calibration, if such units are to continue to be used in the field, as well as a larger range of T-POD sensitivities.

ACKNOWLEDGEMENTS We are grateful for the help of Thomas Grünkorn, Christopher Honnef, Anja Meding, Peter Leopold, Martin Jabbusch, as well as the crews of the MS Christopher and MS Søløven. This work was funded by the Federal Ministry for the Environment (BMU). We thank the Research and Technology Centre Westküste, the Sea Watch Foundation, the Federal Agency for Nature Conservation, and NPA-Tönning for providing their T-POD calibration data for analysis. We are also grateful for all the help and discussions provided by Nick Tregenza of Chelonia Ltd.

SEASONAL & SPATIAL PATTERNS OF HARBOUR PORPOISE AND GREY SEAL AT A UK OFFSHORE WIND FARM SITE

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INTRODUCTION Some of the environmental issues for offshore renewable energy developments are similar to those of the oil & gas sector. One of the issues of greatest concern is the effect of underwater noise on marine mammals. In the case of oil and gas, this is typically seismic exploration and noise from mechanical action of drilling. In the case of offshore wind, the construction phase can often consist of pile driving heavy steel jackets for the towers into the seabed – a high energy activity that produces powerful underwater shock waves. The operational phase of offshore wind farms is also a concern due to the mechanical noise transmission from moving parts and blade beat frequencies. There is clearly potential for negative effects during both construction and operational phases, and there is some preliminary evidence that underwater noise from piling and turbine operation can affect marine mammals (Koschinski *et al*., 2003).

Seldom, when construction activities occur, is there any detailed baseline data on marine mammal distribution and occurrence to compare with the post construction scenario. This paper seeks to address that point by reporting on an annual cycle of dedicated pre-construction marine mammal surveys across a large, UK Offshore Windfarm site. The Offshore Windfarm Site is named Gwynt y Mor (Wind of the Sea) and is located in the waters of the Northern Irish Sea and Liverpool Bay.

METHODS Ship Based Visual Survey Line-transect surveys took place from December 2003 to November 2004 inclusive, and were conducted from a 30 m research vessel. Line-transect surveys were undertaken across the site on pre-determined survey lines, approximately 15 nm (nautical miles) long, and spaced at 1 nm intervals. A total of 12 surveys were undertaken, one per month from December 2003 to November 2004, with each survey covering a period of approximately two days. Standard distance sampling methodology was adopted, with two observers standing forward of the wheel house on a raised platform, approx 9 m eye-line above sea level, and observing the forward 0-90^{o} sector ahead of the vessel on either side.

Although standard distance sampling data, with angle and range measurements, were collected, abundance estimation was not the focus of the project, and, in any case, the number of sightings proved insufficient for accurate determination of g(0). Angles and distance measurements to marine mammals were used to calculate the geographic position in latitude and longitude for each animal, or group of animals sighted, using the reference GPS position of the ship at each sighting. The computed sighting positions were then overlaid on GIS charts to provide visual representations of the distribution of marine mammals. Charts were plotted for harbour porpoises and grey seals separately. Sighting counts of both species were collated by month.

Static Acoustic Monitoring To complement the line-transect surveys, three T-PODs were deployed as static acoustic data loggers to detect and archive the clicks of harbour porpoises. The T-PODs were positioned at three widely spaced positions within the survey area, partially dictated by operational constraints, but also located to give readings from widely separated geographic locations within the survey area. The T-PODs were serviced and their data downloaded on a monthly basis.

T-POD data was processed as detection positive minutes per day (DPM), also known as train positive minutes (TPM). This is simply the number of minutes per day in which cetacean click trains were detected. Graphs of DPM against calendar dates were produced to show the trend in cetacean click activity at each site. The absolute values of DPM are not comparable from site to site, as the individual T-PODs were not individually calibrated and the variable background noise fields at each site were not quantifiable. Therefore, each T-POD data stream is only useful as an illustrator of click detection trends at its respective site.

RESULTS **Visual Line-transect Data** The vessel based visual surveys covered a total transect line mileage of 1681 nautical miles (3114 km). The only species of cetacean sighted from the transect surveys was the harbour porpoise, *Phocoena phocoena*. There were a total of 60 harbour porpoise sighting events through the 12-month period of transect surveying, comprising 84 animals. The majority of animals sighted were single adults, although small groups of 2-5 animals were seen on occasion. The only species of seal positively identified in the survey area was the grey seal. Positive ID was made in most cases and it is assumed that all seal sightings were in fact grey seals, *Halichoerus grypus*. This assumption is consistent with our knowledge of the area. The frequency of seal sightings mirrored, to a large extent, that of porpoise sightings. Figure 1 illustrates the basic sightings data.

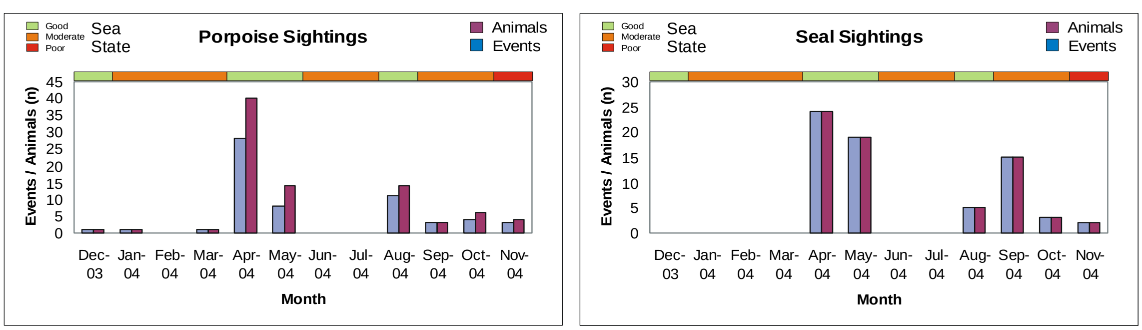

Fig. 1. Histograms of porpoise & seal sightings data by month from line-transects

The position of each porpoise and seal sighting, computed via range and bearing from the survey vessel, is illustrated in Figure 2.

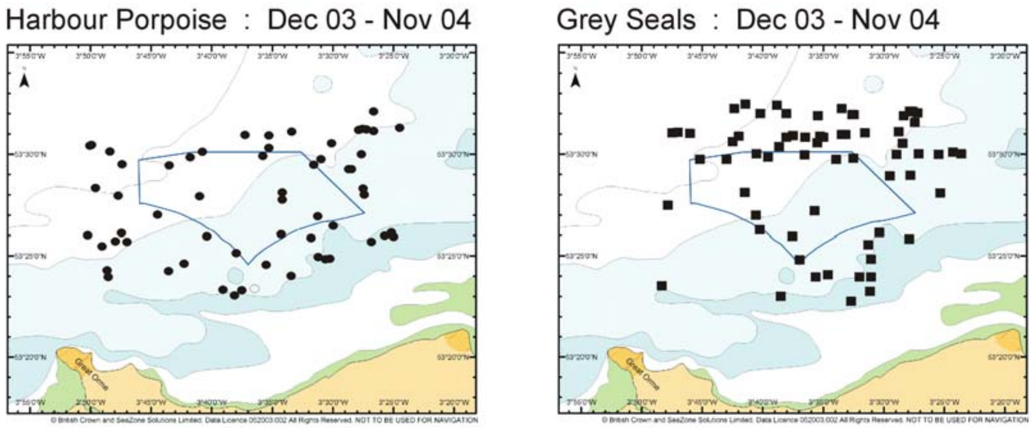

Fig. 2. Charts showing distribution of porpoises and seals across survey area

Static T-POD data The static T-POD data from the three deployment sites indicate year-round use of the survey area by harbour porpoise. A seasonal pattern of detection was evident from the three deployments, with the highest activities occurring at the western and northern deployments – close to the extremities of the construction area.

The western mooring, designated as Constable Bank, displayed the clearest indication of seasonality in TPM throughout the year (Fig. 3). There is a clear peak in porpoise click activity in April, reaching a level of nearly 250 TPM from a base level of around 20 TPM. This trend is particularly encouraging as it matches well with the peak visual sightings obtained during the April transect survey. It is well known that acoustic detection of cetaceans is far less affected by weather conditions than visual sightings and hence this gives some confidence in the robustness of the visual sightings. A similar peak occurred in the data from the northern mooring.

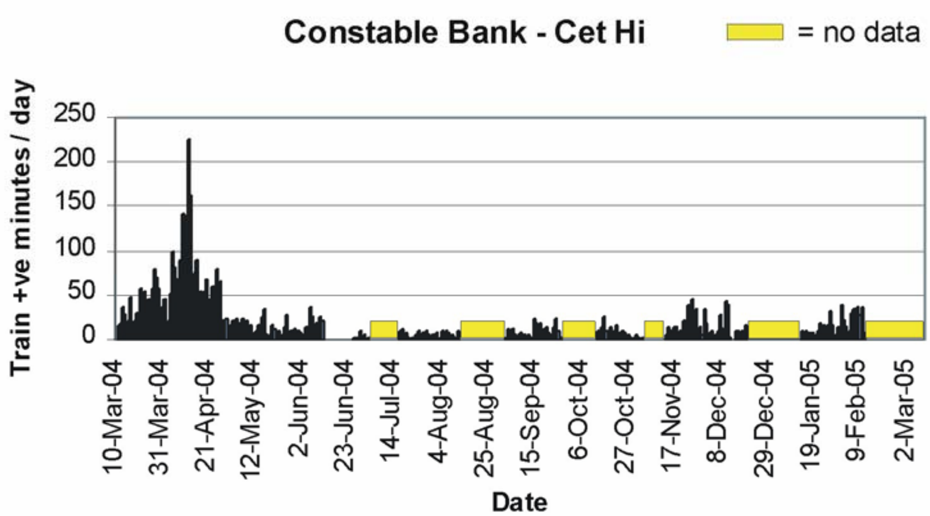

Fig. 3. DPM data from the northern TPOD mooring showing the April peak in porpoise click activity

There were several high probability detections of bottlenose dolphins at the NH Cardinal TPOD on the 7th, 10th, 11th, 12th, 13th, 15th and 16th of May 2004, indicating that the animals were in the vicinity during those dates. These were the only static T-POD detections of bottlenose dolphins throughout the duration of the survey work.

DISCUSSION Overall, the data suggest that both the project area and the wider marine mammal survey area are used year-round by harbour porpoises. Grey seals were sighted for at least six months of the year, and in all probability use the area year-round given the proximity of haul-out sites at Hilbre Island and the east coast of Anglesey. Data from the SEA6 (Strategic Environmental Assessment: Area 6 – Irish Sea) study on seal tagging show fairly heavy use of the southern part of Liverpool Bay by a sample of grey seals (Hammond *et al*, 2005). Seal tracks plotted in the SEA6 study report cross the Gwynt y Môr study area repeatedly. Other species of marine mammal appear to be only transient or occasional visitors to the Gwynt y Môr study area.

For the most part, the visual sighting and acoustic data support one another. In nearly all cases, there appears to be relatively low levels of marine mammal activity in the winter (December – March). Peaks occurred in both vessel-based acoustic and visual data in April and May, suggesting an influx of animals into the area. Although sea state was improved in April and May over much of the winter (except December), such a notable increase in marine mammal activity is not thought to be an artefact of this, especially given that the acoustic data shows the same trend as the visual data.

The interpretation of this is that animals move offshore into continental shelf waters in the winter, and return inshore during the spring/summer to breed and calve. There is evidence that Welsh coastal waters act as something of a nursery ground for harbour porpoises, with a much higher proportion of calves present in the stranding record than around some other parts of the UK coast (Penrose & Pierpoint, 1999). Peak calving time for harbour porpoise around the UK coast appears to be June-July time, and peak numbers of animals appear to be found in inshore Welsh coastal waters at this time of the year, with many calves (Calderan, 2003; Weare, 2003). It is possible that our observations have caught a snapshot of an inshore migration of animals.

The relatively high count of porpoises in April and May might have been due, in part, to the availability of food at that time. Porpoises were seen engaging in both travelling and feeding activity, and anecdotal reports and local knowledge from fishermen suggest a run of herring through the survey area during April (Jones, *pers comm*). It is possible that the porpoises sighted in April were simply following a food resource. However, the two factors need not be mutually exclusive, as small marine mammals like harbour porpoises must feed regularly to sustain themselves. Indeed, the presence of prey species is likely to partially dictate the selection of small cetacean migratory pathways and suitable calving habitat.

The area is very likely to be a foraging ground for grey seals, given that they have been observed feeding in the area, that the area is known locally as something of a flatfish nursery area, and that the Gwynt y Môr project area is located in an area that encompasses grey seal haulout sites to the east at Hilbre Island and to the west along the east coast of Anglesey. Indeed, the seal tracking data from the SEA6 project (Hammond *et al*., 2005) show heavy usage of the southern part of Liverpool Bay by tagged seals, which encompasses the Gwynt y Môr project area. There was an apparent inshore movement of seals between initial sightings in April-May, and later sightings in September. This shift in distribution is consistent with inshore movement of prey species such as flatfish from April through the summer months, as these fish move from offshore wintering areas to inshore spawning grounds.

CONCLUSIONS Pre-construction baseline marine mammal monitoring was conducted across a large offshore wind farm site in southern Liverpool Bay over a complete annual cycle, from December 2003 to November 2004. Both visual line-transect, and passive acoustic (T-POD) monitoring were conducted to examine occurrence and distribution of marine mammals. The primary species encountered were harbour porpoise and grey seals. Porpoises and seals occurred across the survey area, but there was a clear seasonal pattern in numbers and passive acoustic detections. Peak counts and acoustic detections of porpoises occurred in April and May. Seal numbers also peaked at the same time. The porpoise data suggests an inshore movement of animals in the spring, as pregnant females come inshore to calve and breed. Porpoises may also be following migratory fish inshore. Seal distribution was concentrated towards the north of the survey area in the spring, which shifted to a more southerly location in autumn. The data suggest that the seals follow an inshore movement of prey species such as flatfish.

ACKNOWLEDGEMENTS The author would like to acknowledge the support of nPower Renewables, who funded the survey work.

REFERENCES

Calderan, S.V. 2003. *Fine-scale temporal distribution by harbour porpoise (Phocoena phocoena) in North Wales: acoustic and visual survey techniques*. MSc Thesis, University of Wales, Bangor.

Hammond, P.S., Northridge, S.P., Thompson, D., Gordon J.C.D., Hall, A.J., Aarts, G., and Matthiopoulos, J. 2005. Background information on marine mammals for Strategic Environmental Assessment 6. *Report to the Department of Trade & Industry.*

Koschinski, S., Culik, B.M., Damsgaard Hendriksen, O., Tregenza, N., Ellis, G., Jansen, C., and Kathe, G. 2003. Behavioural reactions of free-ranging porpoises and seals to noise of a simulated 2 MW windpower generator. *Marine Ecology Progress Series*, **265**, 263-273.

Penrose, R. and Pierpoint, C. 1999. *The use of Welsh coastal habitats as calving and nursery grounds for the harbour porpoise (Phocoena phocoena).* Marine Environmental Monitoring Report No. 22.

HARBOUR SEALS, WIND FARMS, AND DEAD RECKONING: EXPERIENCES FROM THE GERMAN WADDEN SEA

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INTRODUCTION The German Bight is a part of the North Sea that is extensively used by humans for various purposes such as oil and gas production, commercial and recreational ship traffic, fisheries, and gravel extraction (Umweltatlas Wattenmeer, 1998). In recent years, the construction of offshore wind farms for the production of renewable energy has taken place in various regions of the world. In the German Exclusive Economic Zone (EEZ) of the North Sea, several applications for wind farms have been submitted, of which 15 have already been approved. One of the world´s largest offshore wind farms, operational since 2002, is Horns Rev, located in the German Bight off the west coast of Denmark. With the growing desire of increasing the proportion of renewable energy, the number of offshore wind farms will likely increase further in the near future.

Harbour seals (*Phoca vitulina*) are a common sight in the Wadden Sea, but have also been shown to use offshore areas (Orthmann, 2000; Dietz *et al*., 2003; Tougaard *et al*., 2003; Adelung *et al*., 2004; Liebsch, 2006; Tougaard *et al*., 2006) and will therefore potentially be affected by offshore wind farms. The MINOS *plus* TP6 project aimed at determining the spatial utilization of the Wadden Sea and adjacent offshore areas by harbour seals in relation to the planned offshore wind farms in the German EEZ. Information on habitat use of seals was compared to the locations of planned and/or approved wind farms to determine the overlap and, thus, possible impact of wind farms on these animals. A satellite-supported dead-reckoning system was used to collect information on seal location, movement, and behaviour. This paper describes the dead-reckoning method used in this project and the type of data that can be obtained, and discusses the suitability of the method in achieving the aims of the project.

MATERIALS AND METHODS The dead-reckoning system consists of a dead-reckoner, a satellite tag, and a housing that provided buoyancy and protection. In the following, a short summary will be given on the devices and procedures; for a full description, see Adelung *et al.,* 2004; Adelung & Müller, 2007. The dead-reckoner (Fa. Driesen & Kern GmbH, Bad Bramsted, D) is a multi-channel logger that collects information on depth, speed, compass heading (three channels), pitch, roll, body orientation, temperature, and light at predefined intervals. In our case, the sampling interval was 5 seconds, allowing the device to continuously collect information for up to 94 days. Information on depth, speed, compass heading, pitch, and roll were used to reconstruct the three-dimensional routes of the animals (see below). The satellite transmitter (SPOT 2, 3, or 4 from Wildlife Computers, Redmond, USA) provided information on seal haul-out location. The housing was made of a mixture of resin and microscopic glass beads. The system was attached to the lower back of the seal via a neoprene base using a two-component epoxy glue.

The three-dimensional trajectories of the seals were determined by standard dead reckoning procedures (Davis *et al*., 2001; Mitani *et al*., 2003; Adelung *et al*., 2004), using MT Route (Jensen Software Systems, Laboe, D). The three-axis magnetic sensors provided information on the X, Y, and Z magnetic components which were used to calculate compass heading, corrected for changes in pitch and roll due to animal movements in all three dimensions (Caruso, 2000). Depth, speed, and compass heading were then used to calculate a position for each sampling interval throughout the foraging trip. The satellite locations were used as start and end points, allowing a correction for drift. The programme produced two ASCII output files: one with the uncorrected route, and one with the route corrected for drift. The latter was used to show and compare the two-dimensional movements of the seals. Adding the depth information allowed the plotting of three-dimensional trajectories of individual dives or complete foraging trips.

Seals were captured at two locations in the Wadden Sea: on the sand bank Lorenzenplate in the German Wadden Sea, and on Rømø in the Danish Wadden Sea, and, additionally, on the offshore island Helgoland.

RESULTS In this paper, an individual foraging trip will be used to exemplify what type of information can be obtained from a dead-reckoning system. The four-day foraging trip was made by an adult male seal, equipped on Rømø during spring 2005. The two-dimensional route shows that the seal moved westward out of the Wadden Sea area (Fig. 1A). The seal moved in a rather directed manner about 60 km offshore, where it started meandering in a comparatively small area. After spending about 65 hours in this area, the seal swam back towards the coast, again in a directed manner. When combining latitude and longitude with depth, the three-dimensional trajectory of the animal can be reconstructed (Fig. 1B). It becomes apparent, that the seal followed the seabed, with depth increasing as the animal moved away from the coast. In addition, the almost continuous diving activity becomes visible. Most of the dives made by harbour seals from the German Bight are U-shaped dives. However, when selecting series of dives from the more linear and from the convoluted part of the route (marked in Fig. 1B and shown in detail in Fig. 1C and 1D), the movements differ significantly. Fig. 1C shows the movements when the seal is meandering furthest from the coast. The movements are highly variable and the heading is changing markedly from dive to dive. By comparison, the dives made during the directional movement (Fig. 1D) show a rather constant heading during all phases of the dive.

DISCUSSION One of the most important advantages of the dead reckoning system is the wealth of information that it provides. The available information on latitude and longitude is essential in the determination of space use, movements, and home ranges. Positional data, particularly when it is continuous, is also suitable for the determination of movement patterns and changes herein that may reflect switches in behavioural states (Adelung *et al*., 2004; Wilson *et al*., 2007). Routes of harbour seals show a high variability in the degree of meandering throughout their foraging trips, showing that periods of rather straight travel alternate with periods of intense meandering, which is interpreted as foraging activity (Adelung *et al*., 2004; Adelung &

Müller, 2007; Müller *et al.*, in press). The results have also shown that harbour seals extensively use offshore areas adjacent to the Wadden Sea for foraging, including areas where German offshore wind farms have been planned and/or approved (Adelung & Müller, 2007).

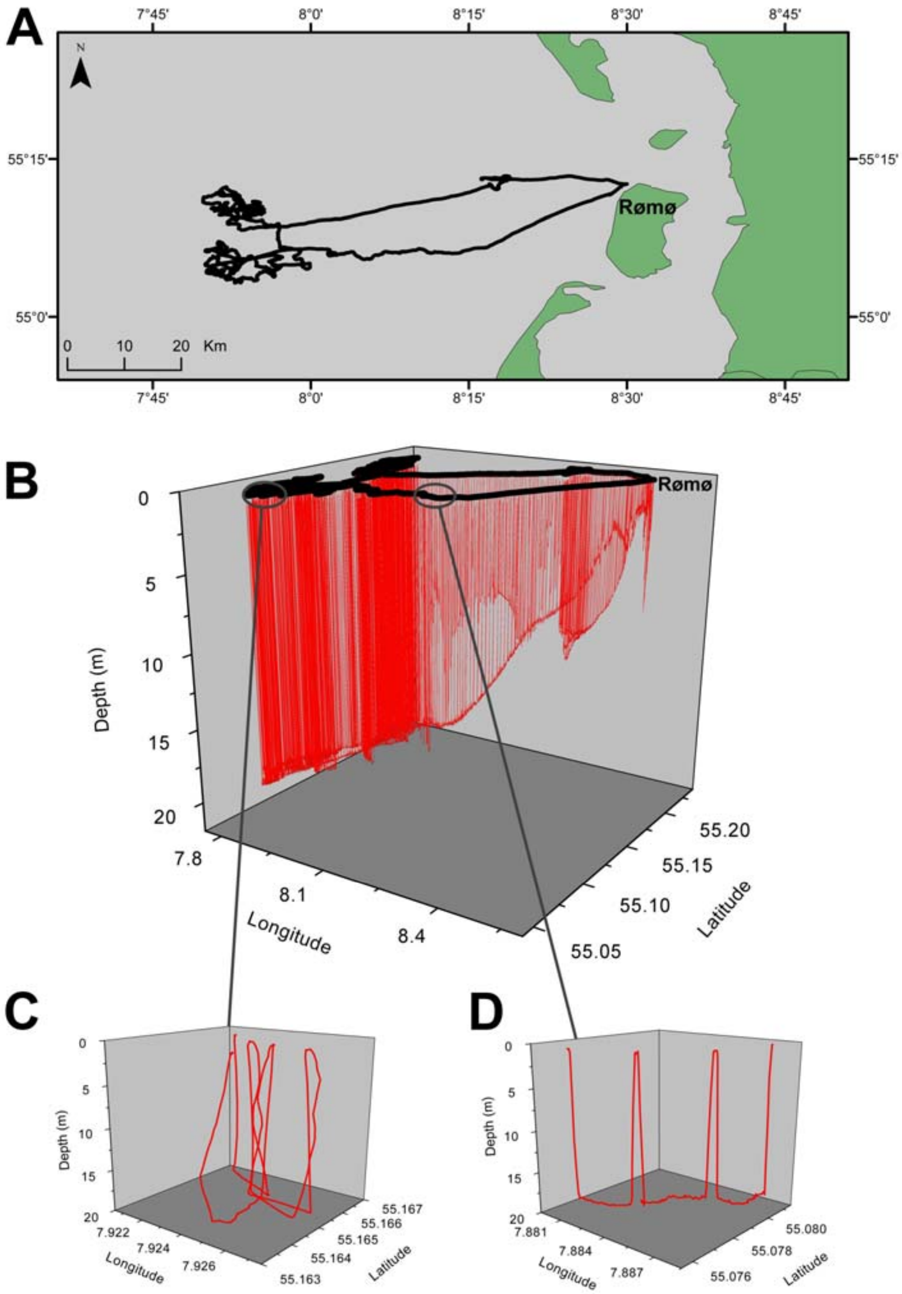

Fig. 1. Two- and three-dimensional movements of a harbour seal equipped at Rømø, Denmark. A: two-dimensional route based on latitude and longitude information. B: three-dimensional route (in red) with two-dimensional route shown as black line. C and D: three-dimensional plot of several dives from locations marked in B

Beyond providing information on latitude and longitude, three-dimensional movements of individual dives, and complete foraging trips can be reconstructed from the dead-reckoning data. This allows the visualization of how the animal uses its three-dimensional habitat, and may also aid in the determination of animal activity.

The comparatively high number of parameters needed for the dead-reckoning calculations can also be used for an analysis of diving behaviour. Depending on the sampling interval, the information on depth, speed, pitch, and roll can provide a very detailed picture of the behaviour at depth, and even on hunting strategies and events (Adelung *et al.*, 2004; Adelung & Müller, 2007). Mean and standard deviations of all parameters can be obtained for each dive and for individual dive phases, using the MT Dive software (Jensen Software Systems, Laboe, D). This can then be used to assign specific functions to individual dives, which subsequently can be combined with the information on location in order to determine habitat use on a smaller scale (Adelung *et al*., 2004).

The amount of data that are collected by the dead-reckoning system is too large for attempting a transmission via e.g. satellite, and thus a recovery of the devices is necessary in order to access the data. The efficiency of a timed release mechanism as used in our case is highly dependent upon local geographic conditions, but a recovery rate of over 75% was achieved in this project.

The accuracy of the locations calculated via dead-reckoning procedures depends on various factors such as the length of the sampling interval, the duration over which a route is reconstructed (i.e. in our case, the duration of individual foraging trips), and drift experienced by the animal. The effect of sampling interval on the accuracy may be related to animal activity, as compass heading is much more constant during travel phases than during foraging (compare Fig. 1C and D). The length of time over which a route is reconstructed is probably of more importance in our study - short trips generally gave a higher accurarcy than longer trips. This is likely related to the accumulation of small errors due to sampling rate and the offset due to drift. The latter is particularly relevant in areas with strong tidal currents, such as the German Bight. As the aim of our study was to determine the spatial utilization of the Wadden Sea and adjacent offshore areas (at a time with no offshore wind farms), the available accuracy of the dead-reckoning system was adequate. However, when aiming at determining seal movements around existing wind farms, the dead-reckoning system could be used in conjunction with a GPS. The GPS would provide exact positions at regular intervals, which can be used to correct the dead-reckoning route, and thus minimize the errors mentioned above.

To conclude, the dead-reckoning system is well suited for the determination of habitat use in seals, despite the necessity of recovering the devices for data access, and the lowered accuracy over longer time frames. It allows the calculation of position for each sampling interval, as well as the reconstruction of three-dimensional trajectories over shorter or longer intervals. In addition, the available information permits a detailed analysis of seal diving behaviour.

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REFERENCES

Adelung, D., Liebsch. N. and Wilson, R.P. 2004. *MINOS Endbericht Teilprojekt 6. Telemetrische Untersuchungen zur räumlichen und zeitlichen Nutzung des Schleswig-Holsteinischen Wattenmeeres und des angrenzenden Seegebietes durch Seehunde* (*Phoca vitulina vitulina*) *in Hinblick auf die Errichtung von Offshore-Windparks*. 114 pp.

Adelung, D. and Müller, G. 2007. *MINOSplus Endbericht Teilprojekt 6. Telemetrische Untersuchungen zur räumlichen und zeitlichen Nutzung des Schleswig-Holsteinischen Wattenmeeres und des angrenzenden Seegebietes durch Seehunde* (*Phoca vitulina vitulina*) *in Hinblick auf die Errichtung von Offshore-Windparks*. 150 pp.

Caruso, M.J. 2000. *Application of Magnetic Sensors for Low Cost Compass Systems*. Honeywell, *SSEC*. 8 pp.

Davis, R.W., Fuiman, L.A., Williams, T.M. and Le Boeuf, B.J. 2001. Three-dimensional movements and swimming activity of a northern elephant seal. *Comp. Biochem. Physiol.* A, **129**:759-770.

Dietz, R., Teilmann, J., Hendriksen, O.D. and Laidre, K. 2003. Movements of seals from Rødsand seal sanctuary monitored by satellite telemetry. Relative importance of the Nysted Offshore Wind Farm area to the seals. National Environmental Research Institute, Denmark - *NERI Technical Report* No. 429, 44 pp. http://faglige rapporter.dmu.dk

Mitani, Y., Sato, K., Ito, S., Cameron, M.F., Siniff, D.B. and Naito, Y. 2003. A method for reconstructing three-dimensional dive profiles of marine mammals using geomagnetic intensity data: results from two lactating Weddell seals. *Pol. Biol.*, **26**: 311-317.

Liebsch, N. 2006. *Hankering back to ancestral pasts: constraints on two pinnipeds,* Phoca vitulina & Leptonychotes weddelli *foraging from central place*. PhD-Thesis Univ. Kiel. 161 pp.

Müller, G., Adelung, D. and Liebsch, N. In Press. Determination of space and depth utilization of the Wadden Sea and adjacent offshore areas by Harbour seals (*Phoca vitulina*). In: *Marine mammals and seabirds in front of offshore wind energy. MINOS – Marine warm-blooded animals in North and Baltic Seas*. (Eds. K. Wollny-Goerke and K. Eskildsen). Teubner, Wiesbaden.

Orthmann, T. 2000. *Telemetrische Untersuchungen zur Verbreitung, zum Tauchverhalten und zur Tauchphysiologie von Seehunden* (*Phoca vitulina vitulina*) *des Schleswig-Holsteinischen Wattenmeeres*. PhD-Thesis Univ. Kiel. 229 pp.

Tougaard, J., Ebbesen, I., Tougaard, S., Jensen, T. and Teilmann, J. 2003. Satellite tracking of Harbour seals on Horns Reef. Use of Horns Reef wind farm area and the North Sea. Report to Techwise A/S, *Biological Papers from the Fisheries and Maritime Museum*, No. 3, Esbjerg, Denmark. 43 pp.

Tougaard, J., Tougaard, S., Cording Jensen, R., Jensen, T., Teilmann, J., Adelung, D., Liebsch, N. and Müller, G. 2006. Harbour seals at Horns Reef before, during and after construction of Horns Rev Offshore Wind Farm. Final Report to Vattenfall A/S. *Biological Papers from the Fisheries and Maritime Museum,* No. 5, Esbjerg, Denmark. 57 pp.

Wilson, R.P., Liebsch, N., Davies, I.M., Quintana, F., Weimerskirch, H., Storch, S., Lucke, K., Siebert, U., Zankl, S., Müller, G., Zimmer, I., Scolaro, A., Campagna, C., Plötz, J., Bornemann, H., Teilmann, J. and McMahon, C.R. 2007. All at sea with animals: tracks; methodological and analytical solutions for the resolution of movement. *Deep Sea Res.* II, **54**: 193-210.

Umweltatlas Wattenmeer (Eds.) 1998. *Nationalparkamt Schleswig-Holsteinisches Wattenmeer und Umweltbundesamt, Eugen Ulmer.* Verlag Stuttgart, Bd.2.

**OFFSHORE WIND FARMS –
DISTURBANCE OR ATTRACTION FOR HARBOUR PORPOISES?
FIRST RESULTS OF T-POD INVESTIGATIONS IN HORNS REV AND NYSTED**

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INTRODUCTION The expansion of offshore wind farms in German waters is planned with the background goal of reducing CO_2 output. Fifteen licences for wind farms in the North Sea, and three licences for wind farms in the Baltic Sea, have been made available since 2002 (BSH, 2007).

Harbour porpoises (*Phocoena phocoena*) regularly occur in both German Seas. The influence of wind farms on these animals is part of a controversial discussion. Basically, three negative effects of offshore wind farms on harbour porpoises are suspected:

1. Direct habitat loss;
2. Displacement by noise emissions;
3. Displacement by additional service operations and traffic.

On the other hand, it is possible that a wind farm may attract porpoises due to a higher density of prey, since fishing is prohibited inside the wind farm area, and the turbine foundations may function as artificial reefs. Theoretical considerations about noise emissions, sound intensity and auditory sensitivity of harbour porpoises conclude that the audibility of offshore wind energy turbines reaches up to several hundred metres (Madsen *et al*., 2006). A reaction (threshold) is therefore only expected in the direct surroundings of the turbines. Results of operating wind farms in Denmark show occurrences of harbour porpoises even after the construction of wind farms within the area of the wind farm (no complete avoidance - Tougaard *et al.*, 2006a, b). Whereas significantly fewer harbour porpoises have been registered to occur in the area of the offshore wind farm Nysted (Baltic Sea) during its operation than before the plant's development, no clear effects on the porpoise population could be determined in a "before" and "after" comparison for the offshore wind farm Horns Rev in the North Sea. Because the central question is how offshore wind energy turbines may influence harbour porpoises during the expansion and development of this technology in German waters, the Federal Ministry for the Environment commissioned the study presented here.

The main objective of this study, which was carried out by the University of Hamburg in co-operation with BioConsult SH, is the review of potential effects of offshore wind farms in the areas surrounding wind farms and/or single turbines. The following questions are addressed:

- Do small-scale differences exist between the presence / absence of harbour porpoises between areas inside and outside wind farms?

- Do small-scale differences exist in the behaviour of harbour porpoises inside and outside wind farms?
- Can wind farms cause potential differences?
- Which role do different factors, such as water depth, topography of the seabed, noise from ships, etc, play?

To answer these questions, we used a passive acoustic monitoring method, consisting of so called "T-PODs" (Timing Porpoise Detectors). These devices continually record and save the high frequency echolocation sounds of harbour porpoises with a hydrophone and filters. The data investigation lasted from June 2005 until November 2006.

METHODS

Areas of Investigation The investigations were cnducted in both Danish offshore wind farms Horns Rev (North Sea) and Nysted (Baltic Sea, Fig. 1). The wind farm Horns Rev began operation in 2002, Nysted in 2003.

The T-POD Harbour porpoises orientate themselves under water with short high frequency echolocation clicks (echolocation). The T-POD takes advantage of this behaviour. The clicks can be recorded with help of a hydrophone and after presetting different filters, the clicks can be transformed into digital data and saved. The T-POD is housed in a 70 cm long PVC pipe, with an external hydrophone at one end and a lid screwed on the other. The sensitivity of the filter and its bandwidth can be individually set for each device. All devices were equally set within this investigation. An important precondition for the comparison of data from different devices is the same sensitivity of the devices. Therefore all used PODs were calibrated in a test tank as well as outdoors. Gathered data were saved and analysed in an Access database. The main parameter for analysis is the so-called porpoise positive time per time unit (mostly the number of porpoise-positive 10-minute blocks per day). This parameter is used to measure the presence of harbour porpoises within the measurement range of each T-POD.

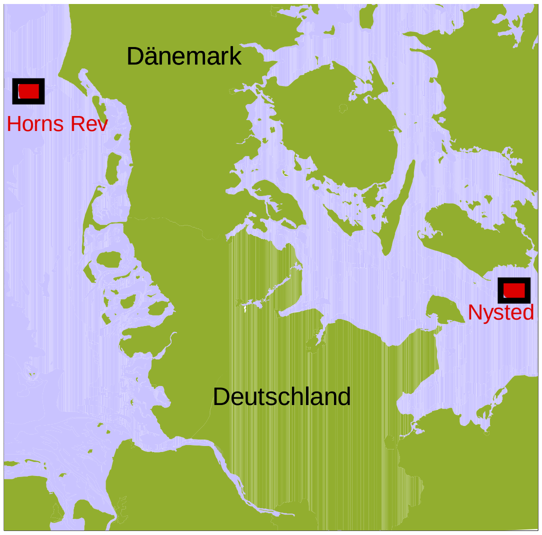

Fig. 1. Position of the investigation areas Horns Rev (North Sea) and Nysted (Baltic Sea)

The T-PODs were installed with an easily retrievable two-anchor system, in which they were placed two metres above the seabed with the upward opening angle of the hydrophone pointing towards the open water column.

Study design The study design was chosen so that in each case 10 T-PODS were installed in each wind farm at the same time. Respectively, five devices were fastened in a row with a distance of approximately 600 m to each other. Two devices of one row were placed outside the wind farm up to a maximum distance of around 1,400 m to the next wind turbine. Two of the three devices within the wind farm were placed next to a wind turbine (below 200 m).

In the first analysis, we compared the mean "porpoise positive time" in one row with the results of a second row that was installed at the same time but at some kilometres distance. It was tested in this way to determine whether small-scale differences in the presence of harbour porpoises within the wind farm area of 16 to 20 km^2 could be assessed.

As a second step, the results of the two devices of a row located outside of the wind farm were averaged and compared to the ones of the devices of the row that was located mostly inside (comparison between inside and outside of the wind farm).

To minimize the influence of small-scale differences of the habitat and of the topography, each row was seen as a single experiment, and, around every 8 weeks, the rows were changed. The results presented here refer mainly to the offshore wind farm Nysted.

RESULTS AND DISCUSSION We changed the rows four times in both wind farm areas. So, a total of 10 different row experiments were carried out in both areas. The survey started in the middle of June 2005 and stopped in November 2006. In the Nysted area the T-PODs recorded a sum of 3,591 days.

Data gathered from the offshore wind farm Horns Rev was approximately 40% less because of background noise – possibly caused by sand movements during extremely windy weather conditions.

Comparison of North Sea vs Baltic Sea The first analysis of "porpoise positive time" as the parameter for the presence of harbour porpoises shows that the T-PODs recorded harbour porpoises almost daily in both areas of the wind farms (Fig. 2). If the temporal solution of days is elevated to the smallest analysed unit of minutes, it can be seen that the devices recorded harbour porpoises almost daily but that the presence of the animals within the investigation area of the PODs was on average very short. In the offshore wind farm of Nysted, harbour porpoise signals were recorded on average at 36 minutes of a day, distributed over 7.4 hours. By comparison, harbour porpoises were registered in the North Sea on average at 88 minutes of a day distributed over 13.4 hours.

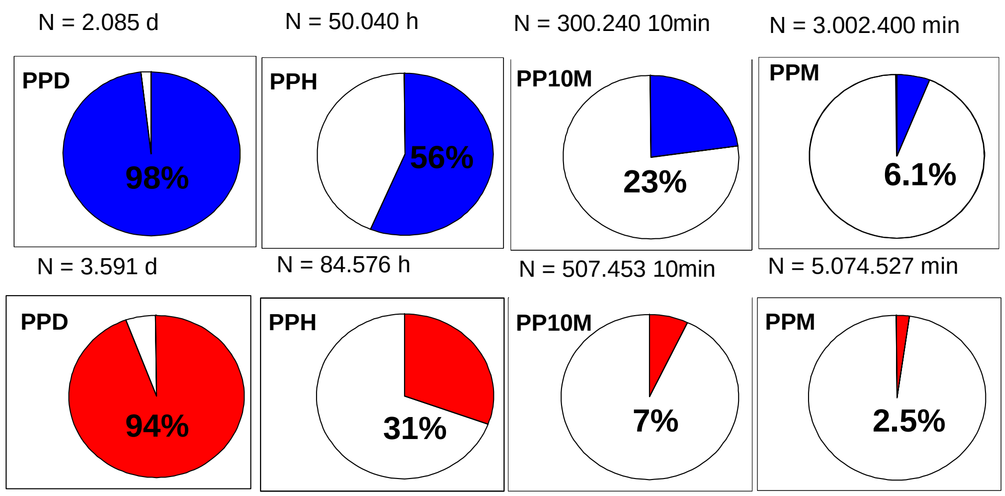

Fig. 2. Sum of "porpoise positive time" of all devices for different time units in the offshore wind farm Horns Rev (above) and Nysted (below)

The parameter "porpoise positive 10 minutes per day" is used in the following analyses. It is a good compromise between a temporally high-scaled resolution and an adequate scale to avoid blur caused by small differences of sensitivity of the different devices.

Seasonality The temporal distribution of the recorded patterns of presence of harbour porpoises shows clear seasonal effects within the wind farms. Not only seasonal differences with a maximum in summer and a minimum in autumn/winter, but also differences between years of observation can be seen. In 2005, in July as well as in October, the highest number of harbour porpoise contacts was obtained in the area of the offshore wind farm Nysted. But, in the following year, only one population peak was measured, in July.

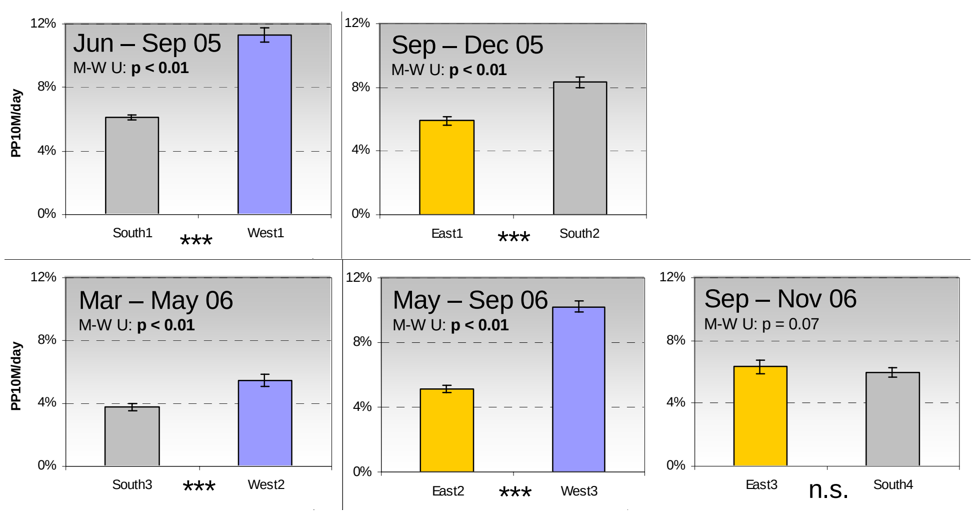

Fig. 3. Presence of harbour porpoises in different rows that were installed in the offshore wind farm Nysted at the same time (mean values of porpoise positive 10 minutes/day per measuring time; ± SE)

Spatial Differences The five comparisons of the two simultaneously installed rows showed significant differences in the average periods of presence in four experiments (Fig. 3). The two rows varied most in factor 2 (May-Sep. 2006).

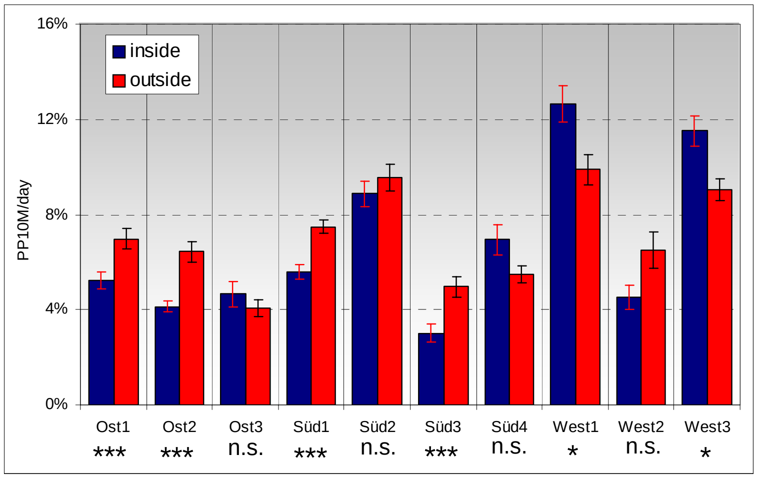

Fig.4. Presence of harbour porpoises inside and outside of the wind farm for 10 different rows within the offshore wind farm, Nysted (mean values of porpoise positive 10 minutes/day per measuring time; ± SE)

This difference between the areas, which were over three to eight kilometres apart, was significantly stronger than the variation between inside and outside areas of the wind farm within one row (Fig. 4).

Latter comparison indicates no explicit trend: Within four of ten rows, significantly more time intervals with sounds by harbour porpoises were measured outside of the wind farm. In the two rows that registered the most porpoise clicks, a (small) significant effect with a higher activity within the wind farm was determined. No difference between inside and outside areas of the wind farm was found within four rows.

Effects of Temporary Turbine Standstill Between 25 June and 2 July 2006, all turbines in the offshore wind farm, Nysted, were temporarily shut down due to maintenance. This special case was assessed for possible changes of presence of harbour porpoises within the wind farm area. In the week of the shut down, the mean presence of harbour porpoises was determined and the results were compared to the weeks before and after (Fig. 5). The result shows that the weeks of standstill had no apparent influence on the presence of harbour porpoises. An assumed negative effect in row west (Fig. 5, below left) inside of the wind farm cannot be found in row east. Four weeks before, as well as five weeks after, a similar low presence of harbour porpoises was measured. Furthermore, because the traffic of service ships did not differ from the ordinary service traffic (two installation ships per day), an effect of turbine standstill can be excluded up to now. Investigations of further days of turbine standstill are needed here.

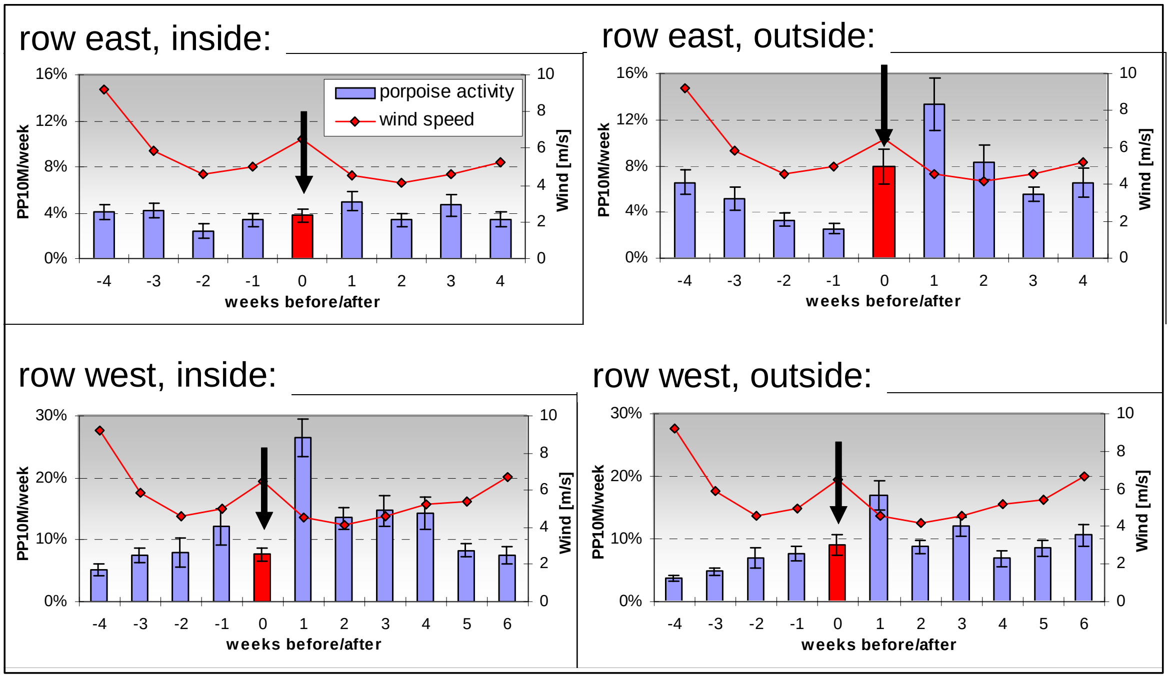

Fig. 5. Presence of harbour porpoises inside and outside of the offshore wind farm, Nysted, in the rows east (above) and west (below) in different weeks before and after the shut down of turbines (arrow). The red line additionally shows the mean wind speed for the relevant week

Diurnal Differences For each row, a 24-hour-rhythm in the presence of harbour porpoises was assessed on the basis of "porpoise positive minutes per hour in the 24-hour day" (Fig. 6). In summer 2005, a clear day-night-rhythm with high activity during the night and low activity during the day turned out in the offshore wind farm Nysted. This pattern was noticeable inside of the wind farm, but was not noticeable outside the wind farm (Fig. 6).

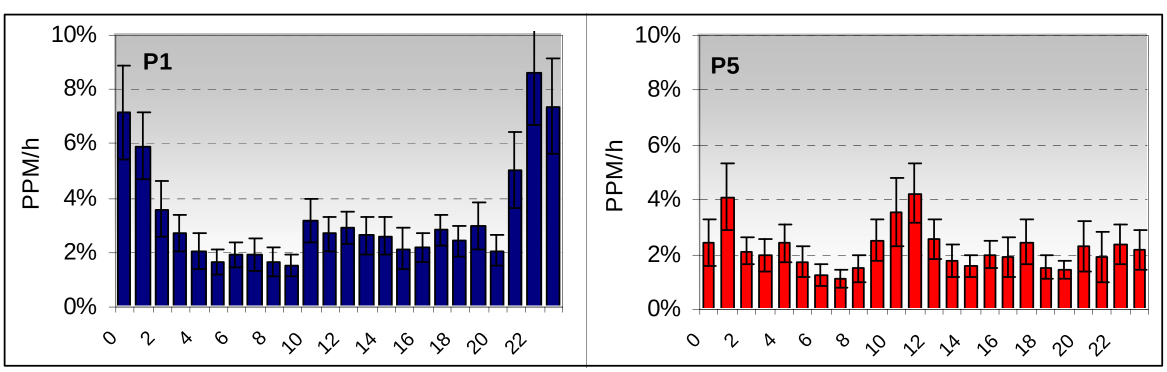

Fig. 6. Mean presence of harbour porpoises in the course of a 24-hour day between June and September 2005 inside (left) of offshore wind farm Nysted and outside (right)

Such a pattern was clearly observable in summer 2006, but it was spatially recognizable with significant high activity at night outside the wind farm but with no pattern inside. The pattern identified in 2005 is consistent with the results of Danish researchers. They observed in 2005 a higher density of fish in the water column inside the wind farm at night (Leonhard *et al.*, 2006). No parallel observations of fish were available for 2006, so that an interpretation of the result without another analysis of data remains inconclusive.

Behaviour The analysis of data with high temporal resolution makes it possible to identify special click patterns additional to the patterns of presence. These possibly allow conclusions relating to certain behaviours. According to Busnel & Dziedzic (1967), the click sequences during foraging are shaped by a medium interval of noise between clicks of about 40 ms, with an abrupt and rapid decrease to 10 ms (up to 2 ms) (“feeding buzz”). This typical pattern of noise can be recognized by the T-POD data.

In a first approach, we defined that part of the click series via an enquiry of the database. These had an inter-click interval that was shorter than 10 ms, and that could be part of a “feeding buzz”. The results of this analysis showed a significant difference between the areas of Horns Rev and Nysted. In Nysted, the part of such a click series occurred on average 12% of the time, and over a 24-hour day, showed no pattern. In Horns Rev, by contrast, the part of the click series with a short click interval was higher than 30% at night, and decreased during the day to 10%. This pattern indicates different foraging behaviour within a day, and merits further analysis.

CONCLUSIONS The study presented here emphasizes the suitability of passive acoustic monitoring as an informative method to analyse questions about the influence of wind energy turbines on harbour porpoises. The results show that harbour porpoises occur in the two areas of Horns Rev (North Sea) and Nysted (Baltic Sea) almost daily, and that they were recorded by T-PODs. A significant difference between the marine areas with respect to the presence of harbour porpoises was detected, with a high rate of harbour porpoise contacts in the North Sea. This result corresponds with aerial surveys that observed the density of harbour porpoises in both seas (Siebert *et al.*, 2006).
In both areas, a clear seasonal pattern was observed, with a maximum in summer and minimum in winter. The differences in presence of harbour porpoises inside the whole area of the wind farm were higher between two areas that were spatially separated by some kilometres than the difference in a T-POD row between inside and outside areas of the wind farm. No consistent trend was thus observed, so that no significant influence of the wind farm on the occurrence of harbour porpoises could be seen.

The shut down of all turbines in the offshore wind farm, Nysted, had no effect on the presence of harbour porpoises.

Clear differences of activity of harbour porpoises were detected between day and night. These were different depending on the position of the T-PODs to the wind farm, and, in 2005, they were consistent with surveys relating to the occurrence of fish within the area of the wind farm.

A preliminary analysis of "clicktrain structures" showed a different behaviour of harbour porpoises in Nysted and Horns Rev.

REFERENCES

Busnel, R.G. and Dziedzic, A. 1966. Acoustic signals of the pilot whale *Globicephala melaena* and of the porpoises *Delphinus delphis* and *Phocoena phocoena*. Pp 607-646. In: *Whales, Dolphins and Porpoises*. (Ed. K.S. Norris). University of California Press, Berkeley, California, USA..

BSH 2007. Genehmigte Windparkprojekte in der Nordsee. http://www.bsh.de/de/Meeresnutzung/Wirtschaft/Windparks/index.jsp

BSH 2007. *Standard. Untersuchung der Auswirkungen von Offshore-Windenergieanlagen auf die Meeresumwelt (StUK 3)*. Hamburg and Rostock 2007, 30-33.

Leonhard, S.B., Hvidt, C.B., Klaustrup, M. and Pedersen; J. 2006. Hydroacoustic monitoring of fish communities at offshore wind turbine foundations; Nysted Offshore Wind Farm at Rødsand. Annual Report 2005. *Technical report to Energi E2 A/S, Denmark*, June 2006. 65 pp.

Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K. and Tyack, P.L. 2006. Wind turbine underwater noise and marine mammals: Implications of current knowledge and data needs. *Mar. Ecol. Prog. Ser.*, **309**: 279-295.

Siebert, U., Gilles, A., Lucke, K., Ludwig, M., Benke, H., Kock, K.-H. and Scheidat, M. 2006. A decade of harbour porpoise occurrence in German waters – analyses of aerial surveys, incidental sightings and strandings. *Journal of Sea Research*, **56** : 65-80.

Tougaard, J.; Carstensen, J.; Bech, N. I. and Teilmann, J. 2006a. Final report on the effect of Nysted Offshore Wind Farm on harbour porpoises. *Technical report to Energi E2 A/S*, Ministry of the Environment; Roskilde, Denmark, July 2006. 65 pp.

Tougaard, J., Carstensen, J., Wisz; M.S., Jespersen, M., Teilmann, J., Bech, N.I. and Skov, H. 2006b. Harbour Porpoises in Horns Reef. Effects of the Horns Reef Wind Farm. *Final Report to Vattenfall AS*. NERI Commissioned Report. Roskilde, Denmark, November 2006. 110 pp.

EFFECTS FROM OFFSHORE WIND FARMS ON HARBOUR PORPOISES IN DENMARK

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BACKGROUND In 1996, in the wake of the Kyoto summit, the Danish government passed an action plan for energy: Energy 21, in which it was decided to establish 5,500 MW of wind power in Denmark before 2030, 4,000 MW of which was planned to be large-scale offshore wind farms. This decision was followed by action in 1998 where the Minister for Environment and Energy commissioned the Danish power companies to establish 750 MW of offshore wind power in Danish waters as a demonstration project. The aim of the project was both to test the feasibility and economy of large-scale offshore wind power, and address potential negative effects on the marine environment by establishment of an ambitious environmental monitoring program. The demonstration project was later reduced to include two wind farms (a total power of 326 MW), one at Horns Reef in the North Sea (Horns Rev Offshore Wind Farm, 80 turbines of 2 MW), and one in the south-western Baltic (Nysted Offshore Wind Farm, 72 turbines of 2.3 MW).

Horns Rev Offshore Wind Farm came into operation by the end of 2002, while Nysted Offshore Wind Farm was operational from 1 December 2003. Initial problems with the turbines at Horns Rev resulted in heavy vessel activity during most of 2003 and 2004. In the following, the period 2003-2004 is thus referred to as “semi-operation” due to the much higher level of disturbance of the animals than under normal operation from 2005 and onwards.

The Environmental Impact Assessments on harbour porpoises for the two wind farms were carried out in 2000, following the guidelines jointly drafted by the Danish Energy Agency and the National Forest and Nature Agency. Since 1999, studies on the distribution and behaviour of the local harbour porpoise stocks have been studied to evaluate the effect of the wind farms. This contribution summarises and compares the main results from the demonstration programs and the significance of these results for other wind farms.

Harbour porpoises in the areas around the two wind farms, and potential effects At the time of the environmental impact assessments, little information was available on the presence of harbour porpoises in the areas around Horns Reef and Nysted. From surveys prior to the onset of the monitoring program, it was known that harbour porpoises were present in both areas and that the abundance was higher in the south-eastern North Sea than in the south-western Baltic (Heide-Jørgensen *et al.*, 1993, Hammond *et al.*, 2002). Because of the relatively low abundance in the western Baltic, it was decided to focus the monitoring programs on the harbour porpoises around Horns Reef. Therefore, regular ship surveys as well as acoustic monitoring were carried out at Horns Reef while only acoustic monitoring was conducted at Nysted.

Satellite-tagged porpoises in the south-western Baltic show that they often move over large distances, and only occasionally stay within the same area for longer periods (Teilmann *et al.*, 2004). No porpoises were tagged in the south-eastern North Sea, and none of the porpoises tagged elsewhere entered the southern North Sea. Together with genetic evidence, this suggests that the porpoises living around the two wind farms belong to two distinct populations. From the surveys, it was clear that the eastern North Sea and thus also Horns Reef was home to a large number of porpoises, whereas densities in the Western Baltic and thus the area around Nysted, was lower.

Offshore wind farms can potentially affect marine mammals in several ways. The physical presence of the turbines and especially the construction activities could cause animals to avoid the area, partly or completely. The most important factor in this respect is likely to be underwater noise. Construction activities are generally noisy and especially pile driving generates very high sound pressures. Wind turbines in operation also generate noise, but at considerably lower levels than pile driving and potential effects are expected to be small and local (Madsen *et al.*, 2006). Construction of an offshore wind farm also creates permanent alterations to the local environment, especially on soft bottoms, where the turbine, foundations and scour protection will be colonised by algae and animals new to the area and thereby creating an artificial reef. This is likely to cause subsequent changes in the fish fauna and possibly increase the productivity of the local area. Such changes to the fish fauna and productivity are likely to be neutral or even positive to opportunistic feeders like porpoises and seals.

Monitoring programs on harbour porpoises In order to study the potential effects from the construction and operation of the wind farms on the local harbour porpoise stocks, three separate monitoring programs were carried out:

At Horns Reef

1) Continuous automatic acoustic monitoring using passive acoustic data loggers (T-PODs).

2) Regular ship surveys to determine the presence of animals in and around the wind farm.

At Nysted

3) Continuous automatic acoustic monitoring using T-PODs.

These methods do not allow for studies of small-scale behaviour of individuals and therefore only general effects of the wind farm as a whole were investigated. In future studies, advanced technology may be able to determine how harbour porpoises behave around individual wind turbines, thereby also monitoring the reactions to specific disturbances.

In the following, the main results from the three monitoring studies will be given. The final results of the monitoring programs at the two wind farms can be found in Carstensen *et al.* (2006) and Tougaard *et al.* (2006a, b).

RESULTS **Acoustic monitoring** Investigations were conducted using autonomous acoustic data loggers, T-PODs, that record and store the time and duration of echolocation sounds from harbour porpoises. The first T-PODs were deployed in November 2001 at Nysted, and July 2001 at Horns Reef in the wind farm areas before construction started. At both sites, several reference or control stations with T-PODs were used to determine the relative effect of the wind farm in a so-called statistical BACI design (Before-After-Control-Impact). Relative differences between the wind farm and a reference area were thus tested when comparing the baseline, construction and operation periods with each other. Additional factors, such as seasonal variation and difference between measuring stations and individual data loggers, were also included in the statistical model.

Four indicators were calculated on basis of the porpoise click recordings:

1) Porpoise positive minutes (minutes with porpoise clicks recorded), which is an indication of porpoise echolocation activity and thereby relative density;
2) Waiting time (time between groups of echolocation clicks) indicates how often porpoises enters the area;
3) Encounter duration indicates how long the porpoises remain in detectable range of the T-POD;
4) Number of clicks per porpoise positive minute is an indicator of how intensively the porpoise uses its echolocation when within detectable range.

Horns Rev Offshore Wind Farm
At Horns Reef, six T-PODs were used for the acoustic monitoring. Two were placed inside the wind Farm area and four reference stations were placed up to 25 km both east and west of the wind farm (Fig. 1). The reason for placing four reference stations along the entire reef was due to the hydrodynamically complex environment, making it more likely to include the natural variation in porpoise presence on the reef when averaging across stations.

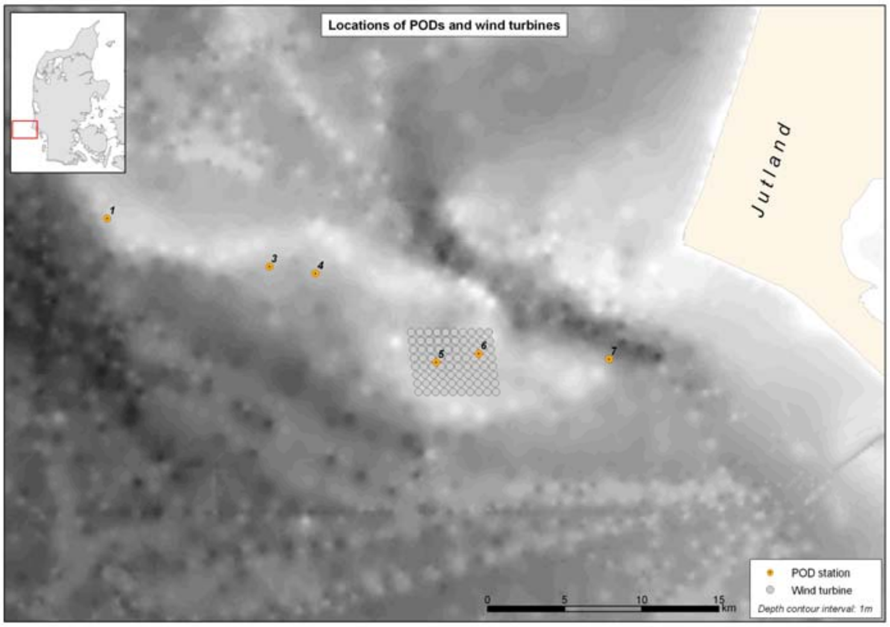

Fig. 1. Study area with individual turbines indicated with open circles and positions of the six T-POD measuring stations (see methods section). Depth indicated by shades of grey; shallow areas in white

At Horns Reef, acoustic recordings did not show any overall significant change in abundance in the wind farm area compared to the reference areas during construction (Fig. 2). However, there was a significant difference between semi-operation (when intensive maintenance work took place) and operation, measured by the indicator, porpoise-positive-minutes (PPM). PPM reached the lowest mean value in the entire monitoring period during semi-operation. During the last year of monitoring when normal operation of the wind farm started, the porpoise acoustic activity was higher in the operation phase than during baseline, but this was the case both in the wind farm and in the reference areas.

Similar to the Nysted area (see below), acoustic activity on Horns Reef was high with shorter waiting times in late spring, summer and autumn (April-October), whereas low echolocation activity was found in winter and early spring (November-March).

Nysted Offshore Wind Farm

At Nysted three T-PODs were placed inside the wind Farm area before, during and after the wind farm was constructed. At the same time three T-PODs were placed 10 km east of the wind farm serving as reference stations (Fig. 3). The reference stations were placed in an area with similar depth and distance to shore to resemble the same natural ecological variation as the wind farm area and at the same time be undisturbed by the activities in the wind farm.

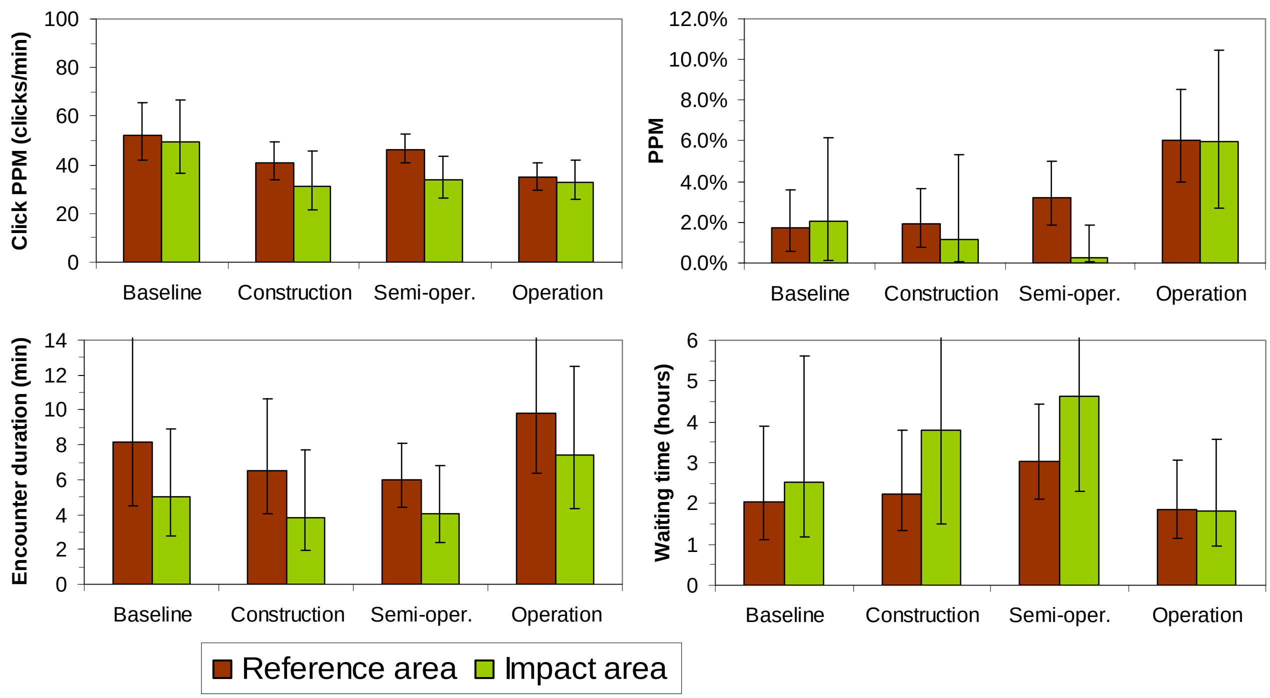

Fig. 2. Acoustic results from Horns Rev Offshore Wind Farm. Mean values for waiting time, porpoise positive minutes (PPM), Clicks/PPM and encounter duration divided by the reference and impact (wind farm) areas. Values are separated into four periods: baseline, construction, semi-operation, and operation. Semi-operation covers a period following construction, where intensive maintenance and service operations occurred and the turbines thus were not operating at full capacity. Error bars indicate 95% confidence limits for the mean values

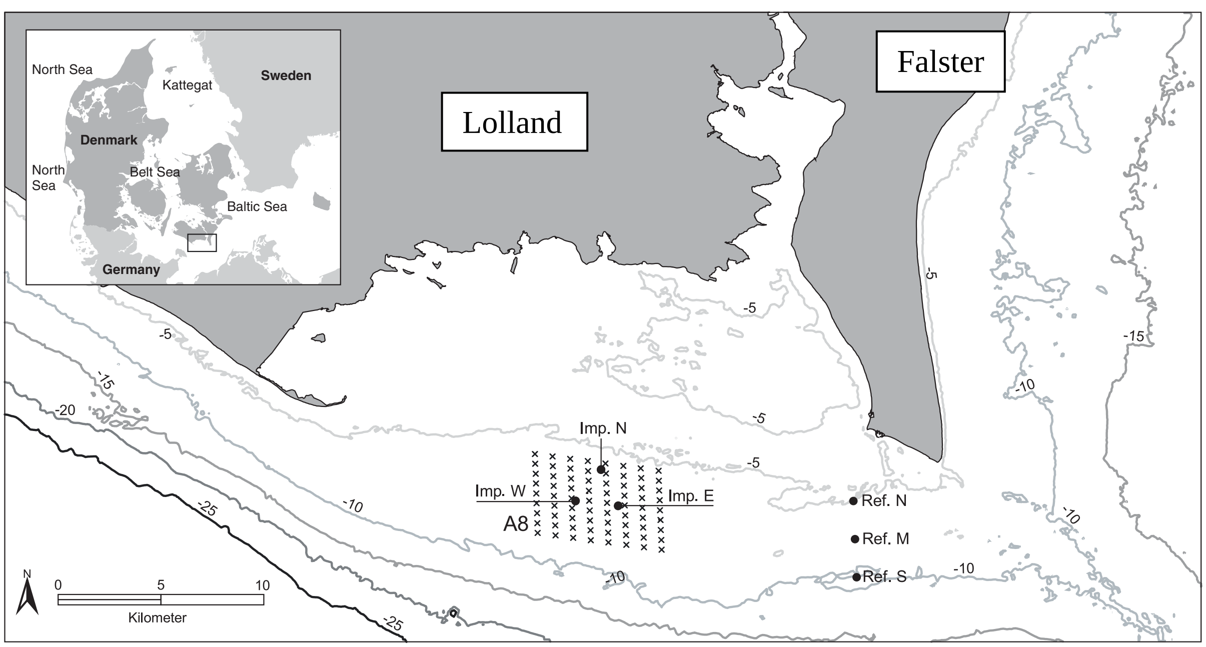

Fig. 3. Study area at Nysted Offshore Wind Farm. Wind turbines are indicated with x and T-POD monitoring stations with solid circles. Three stations (Imp. W, Imp. N and Imp. E) are located inside the wind farm and three stations (Ref. N, Ref. M and Ref. S) are located in a reference area about 10 km east of the wind farm. Foundation A8 where pile driving took place is located in the south-western corner of the wind farm.

During the baseline period at Nysted there was no difference in either waiting time or number of porpoise positive minutes between the reference and impact area (Fig. 4). During construction and the first two years of operation, waiting time increased and porpoise positive minutes decreased considerably in the wind farm area, indicating that fewer porpoises were present in the wind farm area in these periods. A smaller, yet still significant, increase in waiting time and decrease in porpoise positive minutes, was also observed in the reference area, possibly signifying a general effect of the wind farm construction on porpoise at least 10 km away from the Nysted Offshore Wind Farm. However, the decrease in the reference area may also be due to a local effect from a corridor for service ships, which sailed close to the reference area during the construction phase.

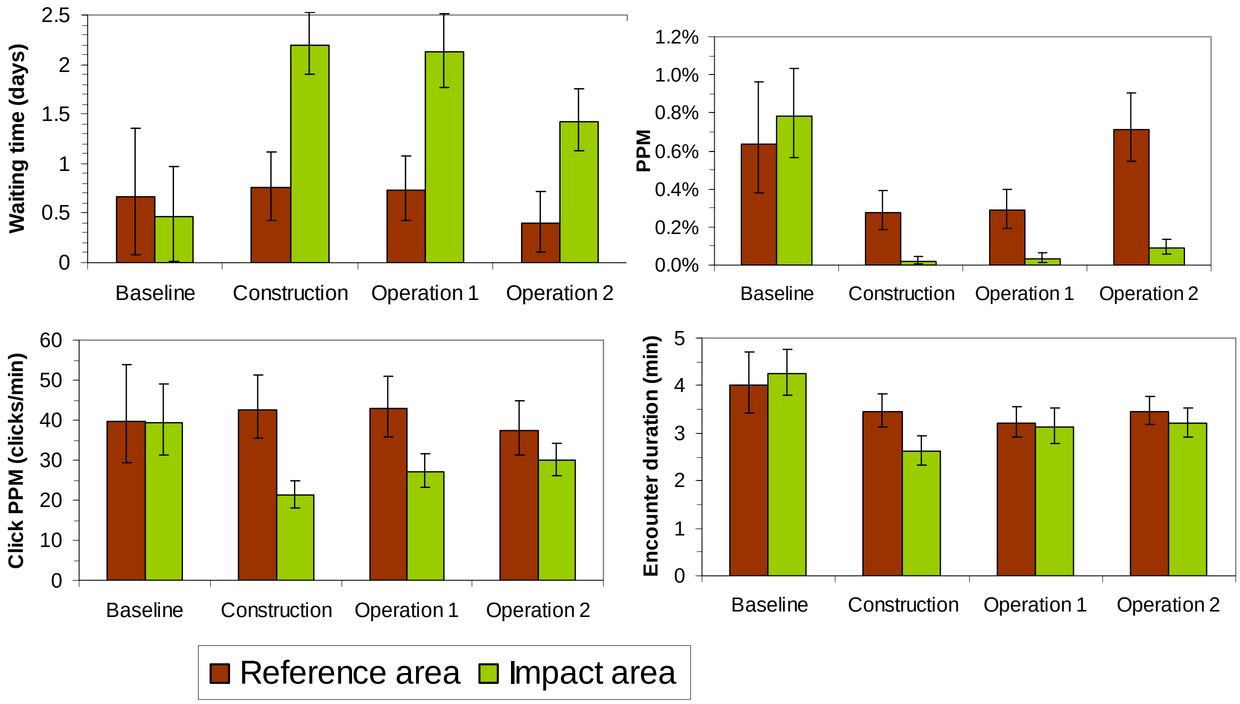

Fig. 4. Acoustic results from Nysted Offshore Wind Farm. Mean values for waiting time, porpoise positive minutes (PPM), Clicks/PPM and encounter duration divided by the reference and impact (wind farm) areas. Error bars indicate 95% confidence limits for the mean values

Although the indicators are still significantly affected two years after completion of the wind farm, there is a tendency towards return to baseline (pre-construction) levels in waiting time and porpoise positive minutes in the wind farm area. Activity in the reference area was back to baseline levels two years after end of construction. This likely indicates that some porpoises have gradually habituated and returned to the wind farm during the first two years of operation.

Encounter duration and number of clicks per porpoise positive minute decreased significantly from baseline to construction period in the wind farm area (Fig. 4), suggesting that not only were there fewer porpoises in the area during construction, their echolocation behaviour may also have been affected. This effect disappeared in the second year of operation, indicating that the acoustic behaviour of porpoises in the wind farm area returned to baseline levels.

The seasonal variation in acoustic activity in the general Nysted area showed the highest activities and shortest waiting times in late spring, and summer & autumn (April-November), whereas the lowest echolocation activity was found in winter and early spring (December-March).

Ship surveys at Horns Reef

Systematic ship surveys covered the wind farm and the rest of Horns Reef. Thirty surveys of 1-3 days duration were conducted between 1999 and 2006. Surveys were only carried out in light winds to make observations of porpoises possible. Porpoise observations, salinity, temperature, depth and tide were recorded and used in development of a spatial model of the distribution of porpoises on individual surveys. This made it possible to construct maps of porpoise density covering the entire survey area. From the density maps, a comparison of the relative density of porpoises inside the wind farm was compared to three zones progressively more distant from the wind farm (Fig. 5).

The ship surveys at Horns Reef showed that porpoises were found throughout the survey area, both before, during, and after construction of the wind farm. The porpoises tended to concentrate on the reef and only few animals were observed in the deeper areas south of the reef. During construction, few observations of porpoises were made in the wind farm. There was a substantial variation in number of animals counted per survey. This variation was consistent with the acoustic monitoring, with generally fewer animals observed in winter and more animals during the summer months.

The results from the ship surveys at Horns Reef point in the same direction as the acoustic data, i.e. a weak negative and local effect of the wind farm during construction but otherwise no significant changes (Fig. 5). Also, ship survey data indicate more porpoises in the area as a whole during the operational period than for any other of the periods, baseline included.

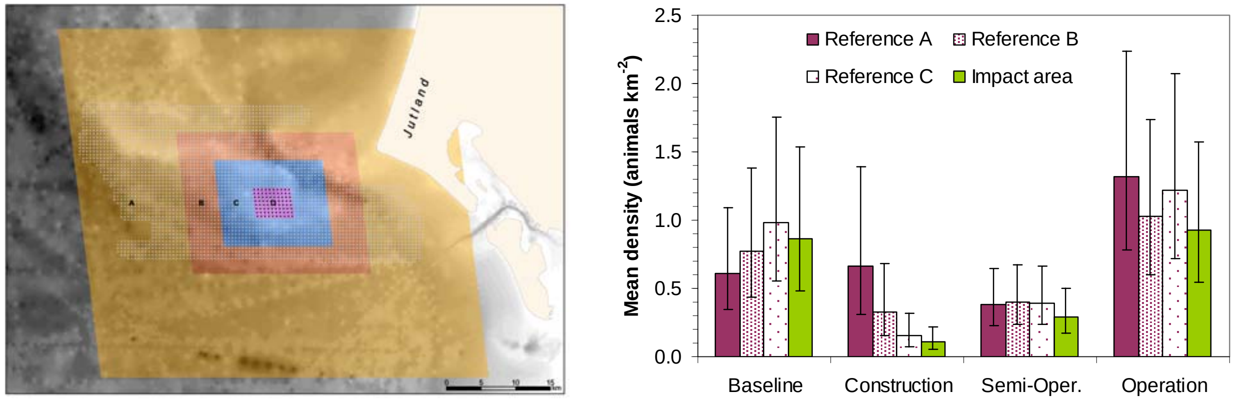

Fig. 5. Left: Zones (A-D) used for statistical test of chance in distribution of harbour porpoises on Horns Reef. Only the parts of the four zones within the surveyed area (indicated by white dots) were included in the analysis. Each white dot represents one grid cell of the spatial model. The purple square indicates the wind farm area. Right: Estimated mean densities based on the spatial model for combinations of the four areas and four periods. Error bars show the 95% confidence intervals for the estimated mean densities

CONCLUSIONS The most comprehensive study assessing the effect of offshore wind farms on harbour porpoises to date was conducted. A large amount of data have been collected, and a wealth of new information about how harbour porpoises respond to wind farms inferred.

Comparison between the two wind farms The effects on porpoises were mainly connected to the construction phase, and only for porpoises at Nysted did the negative effect persist through the first two years of operation. At Horns Reef, which is an important area for porpoises and with generally higher densities of animals, there was a weak negative effect of the construction period as a whole. At Nysted, an area with lower porpoise density, there were strong negative reactions to the construction, where animals left the wind farm area almost completely. Also, the reference site 10 km away appeared affected. After two years of operation, the porpoise activity in the reference area has returned to baseline levels, but activity in the wind farm is still lower than expected. Whereas the disturbance during construction was anticipated in the impact assessment, the slow recovery at Nysted was unexpected.

The population effect of constructing and operating the two wind farms has not been assessed. In general, however, one can say that at Horns Reef a large number of animals were affected, but for a limited period of time (construction period). At Nysted, a comparatively lower number of porpoises were affected at any time due to the lower density of porpoises in the south-western Baltic. However, when evaluating the total impact from the entire study period, a higher proportion of the population at Nysted was probably affected because the response to the wind farm was stronger and because the duration of the disturbance was considerably longer than at Horns Reef.

The monitoring programs were designed to show if the animals avoided the wind farm areas during construction and operation of the wind farms. Therefore, it is not possible to conclude on what specific factors like noise, presence of the turbines, boat traffic or change in prey availability, were responsible for the observed effects. It is likely that the most important negative effect on porpoises, most pronounced at Nysted Offshore Wind Farm, was a combination of disturbance from the different construction activities, involving boat traffic, with associated underwater noise, as well as disturbance to the seabed with re-suspension of sediment, etc. Secondary effects, where prey species of fish were deterred by the construction activities, are also possible. There are no clear explanations to the slow recovery at Nysted, and why this was not observed at Horns Reef.

One possible explanation to the larger response at Nysted may be that the area is a less important habitat to porpoises than Horns Reef, and that the lower porpoise density at Nysted implies less competition for food resources and thereby that the porpoises do not necessarily have a strong incentive to search for food in an area with disturbances. In other words, the porpoises at Horns Reef may be more tolerant to disturbance, because the area is of great importance, whereas the porpoises around Nysted are not particularly interested in the area and will simply avoid it if disturbed, without any larger consequences than the need to swim around the area. Another possible explanation is that the Nysted wind farm is located in a relatively sheltered area, whereas Horns Reef has a high exposure to wind and waves resulting in higher background noise. Thus, the relative noise level from the turbines is higher and audible to the porpoises at greater distances at Nysted than at Horns Reef.

The effects on harbour porpoises were different in magnitude at the two wind farms, and thus it can be concluded that the same species may react differently to similar types of disturbance (wind farms) in different localities. This is an important conclusion for future monitoring programmes of wind farms and other offshore installations. Until more information is available on the true nature of the difference between the reactions to the two wind farms, the results can only to a limited degree (general effect of construction) be generalised to other wind farms.

REFERENCES

Carstensen, J. Henriksen, O.D. and Teilmann, J. 2006. Impacts on harbour porpoises from offshore wind farm construction: Acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). *Mar. Ecol. Prog. Ser.*, **321**:295-308.

Hammond,P.S., Berggren,P., Benke,H., Borchers,D.L., Collet,A., Heide-Jørgensen,M.-P., Heimlich,S., Hiby,A.R., Leopold,M.F., and Øien,N. 2002: Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *J. Appl. Ecol*., **39**:361-376.

Heide-Jørgensen, M.-P., Teilmann, J., Benke, H. and Wulf, J. 1993: Abundance and distribution of harbour porpoises, *Phocoena phocoena*, in selected areas of the western Baltic and the North Sea. *Helgoländer Meeresuntersuchungen*, **47**: 335-346.

Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K. and Tyack, P.L. 2006. Wind turbine underwater noise and marine mammals: Implications of current knowledge and data needs. *Mar.Ecol.Prog.Ser*., **309**:279-295.

Teilmann, J., Dietz, R., Larsen, F., Desportes, G., Geertsen, B.M., Andersen, L.W., Aastrup, P.J., Hansen, J.R. and Buholzer, L. 2004: *Satellite tracking of harbour porpoises in Danish and adjacent waters*. Technical report from NERI no. 484: 86pp (in Danish). Available at: http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR484_samlet.PDF

Tougaard, J., Carstensen, J., Bech, N.I. and Teilmann, J. 2006a. *Final report on the effect of Nysted Offshore Wind Farm on harbour porpoises*. Technical report to Energi E2 A/S. Available at: http://www.ens.dk/graphics/Energiforsyning/Vedvarende_energi/Vind/havvindmoeller/vvm%20Horns%20Rev%202/Nysted/Nysted%20marsvin%20final.pdf

Tougaard, J., Carstensen, J., Wisz, M.S., Jespersen, M., Teilmann, J., Bech, N.I. and Skov, H. 2006b. *Harbour Porpoises on Horns Reef Effects of the Horns Reef Wind Farm*. Final Report to Vattenfall A/S. Available at: http://www.ens.dk/graphics/Energiforsyning/Vedvarende_energi/Vind/havvindmoeller/vvm%20Horns%20Rev%202/begge%20parker/Porpoises%20Horns%20Reef%202006%20final.pdf

MARINE RENEWABLE ENERGY DEVICES:
A COLLISION RISK FOR MARINE MAMMALS?

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INTRODUCTION Renewable energy (including wind, photovoltaic, biomass and marine) is an integral part of the UK government's plan to reduce greenhouse gases by 12.5% (compared to 1990 levels) by 2008-12 (SEA, 2006, DTI, 2007). As a result, an ambitious target has been set of 10% energy requirement generated from renewable sources by 2010 (18% in Scotland) (SEA, 2006). Marine renewable energy is potentially an important component of these renewable sources as it is estimated that 15-20% of the UK's electricity demand could be met by wave and tidal energy (Carbon Trust, 2006).

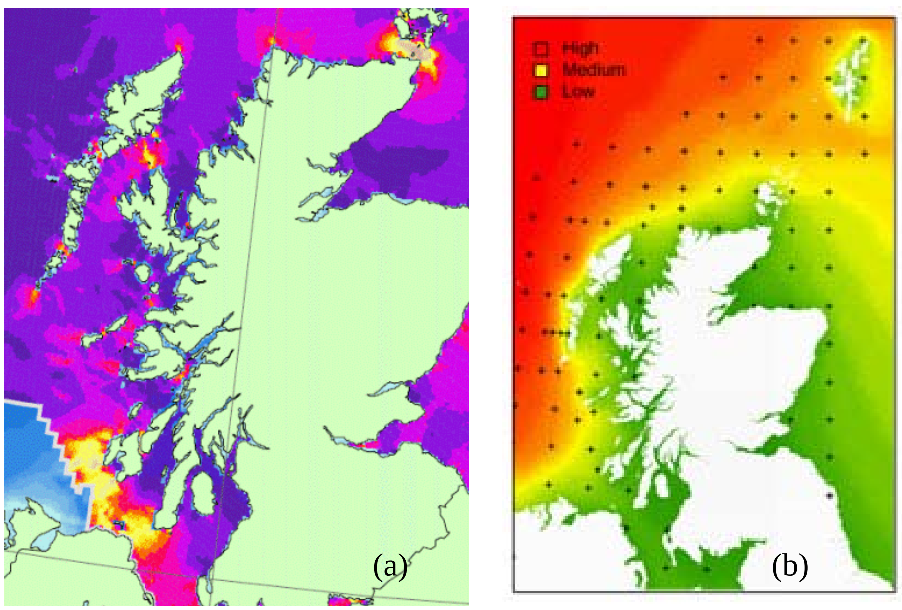

Fig. 1. (a) Tidal and (b) Wave resource for Scotland (DTi, Tidal Atlas, www.scotland.gov.uk)

At present, the marine renewable industry is far behind the wind turbine industry with the majority of devices at the developmental stage, but it is poised to expand rapidly in the near future, resulting in the deployment of wave and tidal devices in coastal waters. Due to the current early stage in development, little is known about the environmental impacts of these devices, especially marine mammal collision risks.

Although the achievement of green, clean energy is desirable, one potential barrier to the development of these devices is the perceived collision risk to pelagic animals. However, it is often stated by developers and consultants that the risk to marine mammals is negligible, based on the belief that because they are highly agile and possess excellent sensory abilities, they will have no problem navigating around these devices.

At this early stage in the industry's development, it is difficult to study the collision risk directly, therefore the aim of this study was to explore the amount of warning time and distance that may be available to marine mammals upstream of a device.

METHODS Existing and developing marine renewable energy devices were reviewed in terms of their size, speed of moving parts and their location in the water column. This study focused on tidal stream devices because the combination of turning turbines and the flow of the tidal stream intuitively present the greatest risk (Fig. 2). Since these devices are novel hazards in the marine environment, existing collision parallels, *i.e.* shipping, fisheries interactions and wind farms were reviewed.

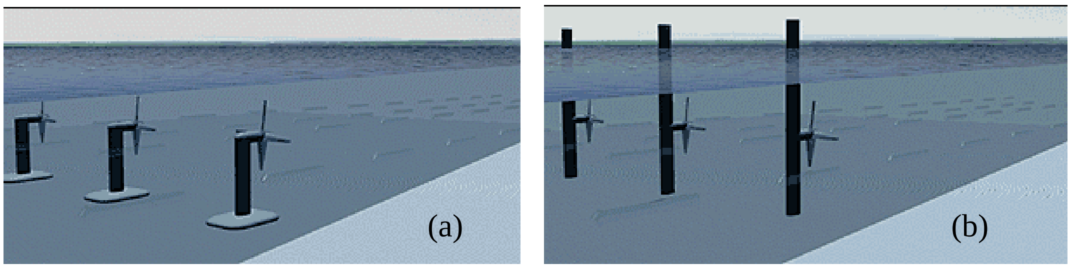

Fig. 2. Examples of horizontal axis tidal turbines (a) bottom or gravity mounted and (b) pile, surface piercing. (Images: www.emec.org.uk). (There are many different designs of tidal device, this image is only one example for illustration purposes)

Four marine mammal species (harbour porpoise, bottlenose dolphin, killer whale, and harbour seal) were selected as examples of animals typically found in areas suitable for tidal stream energy extraction. The characteristics most relevant to marine mammals' ability to detect and avoid tidal stream devices are reviewed, with emphasis on underwater vision and hearing, together with swimming agility.

Marine mammals are well adapted to their underwater environment with good vision and hearing abilities, but the operating range of vision is limited by the transmission of light underwater. Acoustic cues are therefore likely to be the most important sensory component of device detection and avoidance. An acoustic device detection model (based on source, path receiver models) is constructed to explore how much warning and avoidance time might be available.

The model uses a range of potential device source levels to calculate the received level of sound with increasing distance away from the device. Then the received noise levels are compared with the hearing abilities of the marine mammals, and a range of background noise levels to estimate the detection distance.

RESULTS The collision parallels reviewed illustrated the following: ship strikes are a known cause of cetacean mortality; fisheries incidental capture rate threatens many species of marine mammals worldwide; and birds and bats, like marine mammals, are agile with good sensory perception, but collisions with man made structures including wind turbines are well documented.

The device detection model estimated a wide range of detection distances from distances less than 10 m to over 10 km, and acoustic warning times of less than 1 second to approximately 20 minutes, depending upon the scenario of hearing threshold, background noise, and device output.

CONCLUSIONS Collision risk parallels suggest a possible risk to marine mammals from marine energy devices. Especially considering 1) these devices will be big (for example, the turbines of one device have a diameter of approximately 15 to 20 m), and 2) that the developers' aim is for the deployment of a number of devices in appropriate locations as 'energy farms' or arrays. The preferable sites for tidal stream devices will be restricted passages, for example, between islands and the mainland, or around headlands. This is of concern since marine mammals are known to target these tidal stream locations either in transit or to forage (Johnston *et al.*, 2005; Mendes *et al*., 2002).

The device detection model highlighted conditions when the warning time available could be less that one second. Even with warning times in the order of minutes, when decision and reaction time are considered together with the size of the devices, this is probably not enough warning.

There are currently significant data gaps in terms of acoustic warning, the levels of device noise and shallow background noise are not well known, and, crucially, the marine mammal behavioural response to tidal stream devices is poorly understood. If we are to mitigate the impacts of tidal devices on marine mammals, then a better understanding of all these factors is required. Essentially, it cannot be assumed just because marine mammals are highly mobile, with excellent sensory capabilities, that they will always be able to avoid a collision with tidal stream devices.

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REFERENCES

Carbon Trust. 2006. *Future Marine Energy. Results of the Marine Energy Challenge: Cost competitiveness and growth of the wave and tidal stream energy*. Accessed on line (03/09/06) at www.thecarbontrust.co.uk

DTI 2007. *Energy White paper. Meeting the Energy Challenge*. Accessed on line (10/10/06) at www.dti.gov.uk/energy/whitepaper/

Johnston, D.W. Westgate, A.J. and Reid, A. 2005. Effects of fine-scale oceanographic features on distribution and movements of harbor porpoises *Phocoena phocoena* in the Bay of Fundy. *Mar. Ecol. Prog. Ser.*, **295**: 279-293.

Mendes, S. Turrell, W. Lütkebohle, T. and Thompson, P. 2002. Influence of the tidal cycle and a tidal-intrusion front on the spatio-temporal distribution of coastal bottlenose dolphins. *Mar. Ecol. Prog. Ser.*, **239**: 221-229.

SEA. 2006. *Scottish Marine Renewables SEA – Scoping report*. Report to the Scottish Executive. Accessed on line (03/09/06) at www.seaenergyscotland.co.uk.

CONCLUDING REMARKS

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Offshore renewable energy represents perhaps the fastest moving industrial development facing the coastal zone of Europe. So far, the main emphasis has been upon wind power, and offshore wind farms have been constructed in shallow waters across Northern Europe, particularly in a wide band from the Irish Sea eastwards across the southern North Sea to the Baltic. In those regions, for the most part, only three marine mammal species typically occur: harbour porpoise, harbour seal, and grey seal. New proposals are now extending this region of development northwards to eastern Scotland and southwards to France and the Iberian Peninsula, with plans for larger turbines and to operate in deeper waters. Inevitably, this will pose new challenges and potential concerns for other marine mammal species whose ranges fall within those areas of development.

On the whole, the industry has moved faster than proper procedures to survey affected populations, or monitor impacts. The result has been inadequate assessment in many locations, and the application of different techniques in different areas with little calibration between them. For the future, it is recommended that standards for baseline studies and monitoring are established and applied generally. For those locations currently under consideration for future wind farm construction, there should first be adequate baseline studies so that a more informed environmental impact assessment can be made and appropriate mitigation measures put in place BEFORE any environmental damage is caused.

A variety of survey and monitoring methods have been used, adapted to suit the target species and local situation. For optimum spatial coverage of cetaceans such as harbour porpoise, line-transect surveys are advocated using vessels or planes or both. Visual surveys combined with towed PAM (passive acoustic monitoring) surveys provide useful supplementary information since acoustic detections are less influenced by weather and daylight than visual surveys, and they usually generate more data. For monitoring at specific sites over a longer time period, static acoustic devices such as T-PODs are considered the most appropriate. However, all units should be calibrated so that they can be more directly compared with one another. These will yield information not only on the presence of porpoises (and dolphins) in the area but also of their behaviour, notably feeding (through analysis of foraging click trains). In low-density porpoise areas, they may be the only practical means to monitor these animals, but in those situations it may be difficult to assess impacts in a statistically robust manner. Telemetry has proved very useful for examining the movements and behaviour of individuals (porpoises, harbour seals and grey seals), although its applicability to cetaceans in Europe will be limited. Aerial surveys of seal haul-out numbers using thermal imaging and conventional photography, along with video surveillance at these sites yield information on population responses and to some extent also individual behavioural reactions.

To date, there have been few detailed studies of impacts on marine mammals, the most obvious being those conducted around the Danish wind farms of Nysted in the south-west Baltic, and Horns Reef in the Wadden See area of the eastern North Sea. Some other studies have taken place but unfortunately the results from these have not been made widely available. It is recommended that wind farm companies sponsoring such research are as open as possible with the results from those studies, and ensure they are published in a timely manner. It would also be useful to have a European-wide database giving as many relevant details as possible from different wind farm studies. From these a generic set of solutions and tools could be developed that can be selected for addressing site-specific issues.

Most effects demonstrated have been during the construction phase. At this time, noise source levels from impact pile driving are in the order of 218-227 dB_{pp} re 1µPa @1metre, comprising short (100-200 ms) but intense impulses with maximum overall energy <1 kHz, but some components from ramming impulses up to 100 kHz. Each pile may take up to two hours to drive. It is important to note that the maximum sound pressure levels (SPLs), as well as the spectral content, strongly depend on the bottom substrates. Recordings from installation into hard bottom substrate showed SPLs of up to 240 dB re 1µPa @ 1 metre, and possibly higher (Lucke *et al*., 2006). Various thresholds have been proposed for injury and hearing impairment of individuals. The most relevant values at present are those of the US National Research Council, which places these at received peak pressure levels (RLs) of 180 dB re 1µPa for cetaceans and 190 dB re 1µPa for seals. The German government (through the Federal Environment Agency), in the context of pile driving activities, has recently recommended that at a distance of 750 m from the noise source, SPLs should not exceed 160 dB re 1µPa (Künitzer, 2006). They also recommend that maximum values should not exceed 10 dB above the mean sound level. In those circumstances, relevant mitigation measures should be applied to ensure that no marine mammals are within the area exceeding 160 dB re 1µPa. They further instruct that compliance with these conditions should be demonstrated by measurements. Potential negative behavioural responses are widely reported at RLs of 160-180 dB (and Sound Energy levels, SELs, of 145 dB), and temporary threshold shifts (TTS) at SELs of 183 dB for mid-frequency cetaceans such as the bottlenose dolphin or the beluga (see many references in Richardson *et al*., 1995; Evans & Nice, 1996; Würsig & Evans, 2002; National Research Council, 2003; Nowacek *et al*., 2007).

The results of impact studies at Horns Reef and Nysted can be summarised as follows:

a) *Porpoises*

i) A clear behavioural short-term effect was observed at Horns Reef during the construction phase with animals being scared away at distances of at least 15 km

ii) A weak long-term effect was observed at Horns Reef, but a strong impact at Nysted during construction, and a negative effect persisting into the operational phase

iii) Peak activity at night-time at Nysted, but little diurnal pattern at Horns Reef; both sites show a seasonal pattern but this may vary between years

iv) Higher abundance but more irregular usage of Horns Reef than Nysted

v) Porpoises are still present on a daily basis at both sites well into the operational phase; furthermore, stopping the turbines had no effect on their presence/absence
vi) Differences between sites may relate to their differential usage: individuals at Nysted may have been more resident than those at Horns Reef, or less dependent upon the area.

b) *Seals*
i) No large-scale avoidance was observed by harbour seals at Horns Reef; however, there was limited apparent usage of the area anyway, with seals having much larger home ranges than the wind farm area itself
ii) During pile driving at Nysted, significantly fewer harbour seals occurred on land 10 km away at the nearest haul-out site at Rødsand
iii) No re-location of seals from Rødsand took place to other sites during the construction phase
iv) No negative effects observed during operational phase for either wind farm site
v) Harbour seal populations around Nysted are generally increasing so this may obscure effects.

Although relatively little impact upon seals has been found during the construction phase, it must be noted that a fine-scale study of individual behavioural responses by seals has yet to be conducted. The application of dead reckoner instrumentation to telemetry studies would be useful in this context in order to establish changes in individual behaviour.

A BACI (Before-After Control-Impact) experimental design to assess impacts has some merit (see, for example, Carstensen *et al*., 2006), but care must be taken to ensure that a) monitoring covers the entire period, starting some time before any construction activities; b) the area monitored extends beyond likely impacts (at least 20 km from the source of activity); and c) the study is maintained well into the operational phase, preferably at least to five years from the start, to assess possible long-term impacts. It is important to obtain a good understanding of the context in which the area is being used by the target species - for feeding, breeding or as a migration pathway. This highlights the need for an adequate baseline study started in a control situation before any human activity has started.

It is unwise to extrapolate from one wind farm situation to another. The type of pile driving, substrate and local sound propagation properties, the size of the enterprise, and particular use of the area by the marine mammal species all contribute to the kind of impact that may occur. The same applies to drawing conclusions from one species to another since they have different hearing sensitivities and ecologies.

A number of mitigation measures are recommended during the construction phase:

i) Avoid high activity seasons of potential target species when initiating construction activities

ii) Do not start pile driving until visual and acoustic monitoring have shown that no marine mammal is within range of possible harm (SPLs not exceeding 160 dB re 1µPa); this highlights the need to be taking direct sound measurements at the same time as monitoring

iii) Employ bubble curtains (Würsig *et al*., 2000; CALTRANS, 2001) wherever possible, preferably also with deployment of a closed cell foam layer. Other possible sound mitigation measures include isolation piles (in offshore areas) and cofferdams (in shallow waters) (see Illingworth & Rodkin, 2001; Thorson, 2004; Thorson & Reyff, 2004). Clearly more research is needed

iv) Further examine the effectiveness of acoustic harassment devices (AHDs) such as seal scarers, and pingers, both of which were employed during the construction of the Horns Reef wind farm (Tougaard *et al*., 2003, 2004).

Impacts during operational, maintenance and decommissioning phases will need further investigation (see, for example, Lucke *et al*., 2007), as will possible cumulative effects from the installation of multiple wind turbines as well as from other human activities. And, finally, these remarks have focused upon the offshore wind farm industry. The potential impacts of other renewable energy structures such as tidal turbines, barrages, etc, also need serious consideration. By their nature, they will be sited in high-energy coastal areas and these tend to be precisely the same locations as used for feeding by species such as harbour porpoise and minke whale.

REFERENCES

CALTRANS (California Department of Transportation) 2001. *San Francisco-Oakland Bay Bridge East Span Seismic Safety Project.* Pile Installation Demonstration Project. Marine Mammal Impact Assessment. PIDP EA 012018.

Carstensen, J. Henriksen, O.D. and Teilmann, J. 2006. Impacts on harbour porpoises from offshore wind farm construction: Acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). *Mar. Ecol. Prog. Ser.*, **321**:295-308.

Evans, P.G.H. and Nice, H. 1996. *Review of the Effects of Underwater Sound generated by Seismic Surveys on Cetaceans.* Report to UKOOA. Sea Watch Foundation, Sussex. 50pp.

Illingworth, R. and Rodkin, I. 2001. *NMFS Marine Mammal Safety Zone.* Final Data Report. Noise and Vibration Measurements Associated with the Pile Installation Project for the San Francisco-Oakland Bay Bridge East Span. D-1-D-10.

Künitzer, A. 2006. Objectives and Requirements of Marine Environmental Protection Concerning Offshore Wind Energy. Pp. 12-17. In: *Ecological research on Offshore Wind Farms: International Exchange of Experiences. Part A: Assessment of Ecological Impacts.* BfN-Skripten 171. 90pp.

Lucke, K., Storch, S., Siebert, U., Cooke, J. and Garthe, S. 2006. International Exchange of Experience on the Assessment of the Ecological Impacts of Offshore Wind Farms – Marine Mammals. Pp. 38-40. In: *Ecological research on Offshore Wind Farms: International Exchange of Experiences. Part A: Assessment of Ecological Impacts.* BfN-Skripten 171. 90pp.

Lucke, K., Lepper, P.A.,Hoeve, B., Everaarts, E., van Elk, N., and Siebert, U. 2007. Perception of low-frequency acoustic signals by a harbour porpoise (*Phocoena phocoena*) in the presence of simulated offshore wind turbine noise. *Aquatic Mammals*, **33**: 55-68.

National Research Council (NRC) 2003. *Ocean Noise and Marine Mammals.* National Academies Press, Washington, D.C.

Nowacek, D.P., Thorne, L.H., Johnston, D.W. and Tyack, P.L. 2007. Responses of cetaceans to anthropogenic noise. *Mammal Review*, 37: 81-115.

Reyff, J.A. 2003. *Underwater Sound Pressure Associated with Restrike of the Pile Installation Demonstration Project Plans*.State of California, Department of Transportation.

Richardson, W.J., Greene Jr., C.R., Malme, M.I., and Thomson, D.H. 1995. *Marine mammals and noise.* Academic Press, London & New York. 576pp.

Thorson, P. 2004. *San Francisco-Oakland Bay Bridge East Span Seismic Safety Project.* Revised Marine Mammal Monitoring Plan. EA 012024 and 0120E4, 04-SF-80 KP 12.2/KP 14.3.

Thorson, P. and Reyff, J.A. 2004. *San Francisco – Oakland Bay Bridge East Span Seismic Safety Project. Marine Mammal and Acoustic Monitoring for the Eastbound Structure.* EA 012023. 04-SF-80 KP 12.2/KP 14.3.

Tougaard, J., Carstensen, J., Henriksen, O.D., Skov, H., and Teilmann, J. 2003. *Short-term effects of the construction of wind turbines on harbour porpoises at Horns reef.* Technical report to TechWise A/S. HME/362-02662. Hedeselskabet, Roskilde, Denmark.

Tougaard, J. Castensen, J., Henriksen, O.D., Teilmann, J. and Hansen, J.R. 2004. *Harbour Porpoises on Horns Reef - Effects of the Horns Reef Wind Farm. Annual Status Report 2003* to Elsam Engineering A/S. NERI Technical Report, Roskilde, Denmark.

Wursig, B. and Evans, P.G.H. 2002. Cetaceans and Humans: Influences of Noise. Pp. 555-576. In: *Marine Mammals: Biology and Conservation* (Eds. P.G.H. Evans & J.A. Raga). Plenum Press/Kluwer Academic, London. 630pp.

Würsig, B., Greene, C.R. Jr and Jefferson, T.A. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. *Mar. Env. Res.*, **49**, 79-93.

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