The Scottish Government
Riaghaltas na h-Alba

MS Offshore Renewables Research: Work Package A3:

Request for advice about the displacement of marine mammals around operational offshore windfarms

marinescotland

1. Summary

- In comparison to the loud impulsive sounds of pile driving, the underwater noise from operating turbines is generally low intensity.
- Although turbine noise may be perceived as a loud sound it is unlikely that it would cause TTS in realistic field conditions and is therefore unlikely to cause permanent hearing damage in phocid seals.
- Sound levels recorded at existing operational wind farms would not cause hearing damage to porpoises or bottlenose dolphins even at very short ranges. It is also unlikely that the low frequency tonal noise would mask the high frequency signals in porpoise vocalisations.
- The limited data available suggest that where porpoise activity was reduced during windfarm construction it returned to normal levels during the operational phase.
- Although seals have been shown to move short distance away from simulated turbine noise, telemetry studies suggest that operational wind farms do not affect harbour seals' movement patterns.
- The limited data available suggest that where counts of seals on nearby haulout sites were reduced during construction they returned to normal during the first two years of wind farm operation.

2. Introduction

There is widespread concern about the potential impacts of marine renewable energy developments on marine mammals. Although the effects of loud impulsive sounds such as pile driving have been widely reported and are relatively well understood we have little information on the likelihood of impacts due to long term wind farm operations. This report aims to provide an authoritative review of what is known about the behaviour of marine mammals (seals and cetaceans) around operational offshore wind farms and, particularly, any degree of displacement that persists, after completion of the most disruptive construction phase and to provide an initial assessment of the significance of any displacement risk, and proposals for practical research activity, if necessary.

3. Noise characteristics

The noise characteristics of operational offshore wind farms have been reviewed by Madsen *et al* (2006). In comparison to the loud impulsive sounds of pile driving, the underwater noise from the operating turbines is generally low intensity (Madsen *et al.* 2006, Tougaard *et al*. 2008, 2009a,b). Low frequency sounds generated in the turbine are transmitted through the tower to the foundations and radiated into the water column and the substrate. Sound levels from a range of turbines measured approximately 100 m from the foundations lay in the range of 100-120 dB re 1 µPa (1/3 Octave band levels) (Tougaard *et al.* 2009a).

Wahlberg & Westerberg (2005) reviewed underwater noise measurements from operating wind turbines. They reported considerable variation in the reported noise levels from wind turbines related to different wind speeds and recording conditions but also noted major device specific differences in noise output and sound radiation patterns, but there are nevertheless strong indications that some wind turbines make more underwater noise than others. For example, intensities reported from the

Utgrunden wind farm in the Baltic Sea were approximately 10 dB or more higher than other estimates (Wahlberg & Westerberg 2005).

The underwater noise produced by wind turbines appears to be dominated by low frequency pure tone signals below 1 kHz and mostly below 750 Hz. The strongest tonal component in Ingemansson Technology's (2003) recordings was around 180 Hz at a wind speed of $13m.s^{-1}$. The frequency content of the signals does not seem to vary with wind speed. Early studies seem to indicate that sound intensity is not closely related to the size of the turbine, but this contention may not be valid for large turbines of several megawatts.

Ingemansson Technology (2003) reported that sound level increased with increases in the number of active wind turbines in a wind farm. The measured sound intensity at any point will therefore be a composite of noise from several devices and the resulting interference patterns will create a complex sound field.

The received level at any distance from a turbine or wind farm will depend on the transmission characteristics as well as the source levels. Transmission in deep open water can be approximated by a spherical spreading model where received sound intensity will decrease by approximately 20log(r), where r is the distance in metres, (at the low generated by turbines absorption is trivial). However, sound may be channelled through reflection at the surface and bottom in shallow, or through refraction in stratified, water. The degree of channelling will depend on the surface conditions (wave structure) and the topography and sediment type of the sea bed. The site specific modelling of transmission loss can produce accurate estimates of received levels, but extrapolation of such models to greater ranges or to other apparently similar sites and areas may be problematic.

Tougaard *et al.* (2008) suggested that although these noises levels are relatively low, the fact that they will be produced almost continuously for long periods means that they could significantly increase the ambient noise level in the vicinity of a device or a windfarm. If background noise levels are low the turbine noise may be audible to seals and odontocetes, at distances of several kilometres from the turbines.

4. Potential for damage

With an appropriate transmission model and sufficient information on the output of individual turbines, the geometry of the array and the ambient/background noise levels it may be possible to estimate the range at which marine mammals can detect the sounds produced by a windfarm. It is also possible to estimate the ranges at which these estimated received levels are likely to damage their hearing systems. Risk of hearing damage is a clear concern for pile driving operations, but due to the relatively low underwater source levels of wind turbines this is not generally seen as a likely problem.

<u>Small cetaceans</u>

Harbour porpoises and bottlenose dolphins have relatively poor hearing at the low frequencies that have been documented at wind farms. For example, the estimated received levels at 83m from a single device at Utgrunden were around 125 dB re 1µPa at around 180 Hz. and between 100 and 110 dB at frequencies up to 1kHz.

Hearing thresholds for both species are around 100dB at 500Hz and increase rapidly for lower frequencies. The sound levels recorded at Utgrunden would not cause hearing damage to porpoises or bottlenose dolphins even at very short ranges. It is also unlikely that the low frequency tonal noise would mask the high frequency signals in porpoise vocalisations at any range (Tougaard *et al.* 2008) although there is potential masking of low frequency hearing (Lucke *et al* 2007).

Phocid seals

Phocid seals have better low frequency hearing than either porpoises or bottlenose dolphins, e.g. harbour seal hearing thresholds at around 180kHz have been reported to be around 80 to 85 dB although Kastelein *et al.* (2008) suggest that in un-masked conditions harbour seals may be 5 to 10 dB more sensitive at these low frequencies. The recorded source levels at Utgrunden would be approximately 70dB above threshold at a range of 10m from the source. Kastak and Southall (2005) reported temporary threshold shifts (TTS) of between 2.9 and 12.2 dB resulting from 20 to 50 minutes of exposure to 2.5kHz noise at received levels 80 to 95dB above hearing threshold in a harbour seal. All animals recovered from the exposure within 24hr and usually much earlier. Degree of TTS appeared to be related to received level and duration. They obtained similar results from a northern elephant seal and a California sea lion, suggesting that the results may be applied across pinnipeds and therefore apply to both harbour and grey seals.

If TTS is related to sound intensity in the same way at lower frequencies, harbour seals may be susceptible to TTS only at very short ranges, less than 5m from a turbine and only if they remained this close for several seconds. This suggests that although the turbine noise may be perceived as a loud sound it is unlikely that it would cause TTS in any realistic field conditions and is therefore unlikely to cause permanent hearing damage in phocid seals.

5. Audibility

Tougaard *et al.* (2009a) used recorded noise from three different operating turbines to assess the zone of influence on both harbour seals and harbour porpoises. Signals were only detectable above background levels at frequencies below 500Hz. They estimated that harbour porpoises would only be able to hear the sound at ranges of 20–70 m from the foundations. The better low frequency hearing of harbour seals meant that they would be able to detect the signals at ranges of between 60 m and 6.4 km depending on the specific measurement conditions and the choice of cylindrical or spherical spreading loss models.

There is little information on the hearing capabilities of large cetaceans although their predominantly low frequency vocalisations would suggest that they have good low frequency hearing. It is likely that large cetaceans will be able to hear the noise from wind turbines at least as well as seals. Future developments of wind farms in the central and northern North Sea and other waters around Scotland mean that larger numbers of large cetaceans such as minke whales are likely to come into contact with wind farms.

6. Effects on porpoise distribution and behaviour

Koschinski *et al.* (2003) modified recordings of a smaller turbine to simulate a 2MW turbine and played the noise to harbour porpoises. They documented a clear reaction, with closest approach distance increasing from 120 to 182m and acoustic activity increasing significantly. This implies that harbour porpoises can detect the sounds produced by wind turbines. However the playbacks may have contained higher frequency artefacts due to the signal enhancement method used. It is not clear whether the porpoises were responding to the turbine noise or these higher frequency components.

As this is a new and rapidly developing field of study there are few offshore wind farms old enough to have produced useable data on marine mammal responses. Consequently there are few published reports on empirical studies. Three published reports describing the effects of wind farm operations on distribution and local abundance of harbour porpoise are available for wind farm developments in the North Sea:

Horns Reef Offshore Wind Farm in the Danish North Sea: This study entailed seven years of surveys and five years of acoustic recordings of harbour porpoises between 1999 and 2006 covering the pre-construction, construction and operation phases (Tougaard *et al.* 2009b). Acoustic activity monitoring and visual surveys were carried out at the wind farm site and a reference site.

The results showed a clear effect of pile driving. The T-POD acoustic data indicate that porpoises left the entire Horns Reef area in response to the loud impulse sound generated by the pile driving operation. After a period of 6-8 hours, activity returned to levels normal for the construction period as a whole. Overall the level of porpoise acoustic activity was not significantly lower during construction, but was lower during a period described as “semi-operation” when large amounts of boat and other maintenance activity seems to have reduced porpoise activity within the wind farm. Ship survey data indicated a reduction in porpoise activity within the farm during construction. Overall the authors considered there to have been a weak negative and local effect of the wind farm during construction.
Porpoise acoustic activity and ship based sightings surveys indicated an increase in porpoises in the area as a whole during the operational period compared to the baseline. This is consistent with the general increase in porpoise numbers in the Southern North Sea. Overall the study found no significant changes in the distribution of porpoises between wind farm and reference areas in the operational phase compared to the baseline period.

Egmond aan Zee wind farm in the Dutch North Sea: This study entailed two periods of monitoring acoustic activity at the wind farm site and at two reference sites (Scheidat *et al.* 2011). The study covered the preconstruction/baseline period (2003-2004) and an operational period 2007-2009. Porpoise acoustic activity increased during the operational period when compared to the pre-construction baseline. However, there has been a recorded increase in porpoise abundance in Dutch waters over the last decade. Porpoise activity was significantly higher inside the wind farm than in the reference areas. The authors suggest that this apparent increase in porpoise activity within the operating wind farm may indicate an attraction effect due to increased food availability inside the wind farm (reef effect) and/or a sheltering effect with reduced levels of disturbance from vessels within the wind farm compared to the heavy ship traffic in adjacent areas of the southern North Sea.

Nysted wind farm in the Danish Baltic Sea. Porpoise acoustic activity was monitored before, during and for two years after construction of the wind farm by deploying 3 T-Pods within the wind farm site and 3 at remote reference sites 10km away. Porpoise activity declined significantly in the wind farm during and for two years after construction. A smaller but significant decrease in activity was recorded in the reference area. This may indicate a more widespread disturbance effect due to construction activities. The levels in the reference sites had returned to pre-construction levels by the second year of operation.

7. Effects of wind turbines on seal distribution and behaviour

Koschinski *et al.* (2003) modified recordings of a smaller turbine to simulate a 2MW turbine and played the noise to harbour seals. They documented reduced surface activity of harbour seals within 200m of the playback system implying that the seals could clearly hear the sounds and moved away from the source. However, the playbacks may have contained higher frequency artefacts due to the signal enhancement method used. It is not clear whether the seals were responding to the turbine noise or these higher frequency components.

Again, as with porpoises there are few completed studies of seal movements and distribution around operational wind farms.

Nysted and Rødsand II : McConnell *et al.* (2012) used high resolution GPS telemetry tags to study movements of harbour and grey seals in southern Denmark. Seals were tagged at haul out sites within 10 km of two wind farms: Nysted and Rødsand II. The results were compared with similar data collected in 2009. Both species frequently transited from the haulout sites through the two nearby wind farms. Visually, there was no obvious interruption of travel at the wind farms' boundaries. Interactions with wind farms were assessed using residence times within wind farm zones, comparison of path speed and tortuosity inside and outside the wind farms and the proximity of individual locations to individual turbines. No significant effect of the wind farms on seal behaviour was detected. This is in accord with another local study of haulout counts that concluded that the wind farms had no long term effect on the local seal population trends.

Egmond aan Zee: Brasseur *et al.* (2010) used similar GPS tags and older ARGOS satellite tags to track 12 harbour seals before and 24 seals after the construction of the Egmond aan Zee wind farm in the Netherlands. The satellite telemetry data indicate that seals tended to avoid shipping activity in the major shipping routes. The large distance between the wind farm and the haul-out areas meant that there was limited data to assess interactions. Their results indicated that seals avoided the area during construction, but were observed to use the wind farm areas after construction activities ceased and seals from another study were also recorded inside the operational wind farm (Lindeboom *et al.* 2011). The authors concluded that although seals have been observed in the wind farm, minor effects on behaviour cannot be ruled out.

Horns Reef: Tougaard *et al.* (2006, 2009a) again used similar telemetry devices to study the movements of seals from haulout sites adjacent to Horns Reef wind farm site. They deployed 21 simple location only satellite transmitters. The results showed that seal foraged over a wide area that incorporated the Horns Reef wind farm area. The results did not indicate a major effect of either construction or operation but the study animals spent little time inside the windfarm site either before or after construction and the study therefore had limited power to detect effects. Tagged Seals were recorded in or close to the wind farm during operational periods and concurrent visual surveys indicated reduced seal activity in the area during construction but showed that seals were present within the wind farm during normal operations.

Scroby Sands: The effects of windfarm construction activities on seal haulout patterns have been studied at Scroby Sands (Skeate *et al.* 2012). A mixed haulout of harbour and grey seals is situated less than 2 km from the Scroby Sands wind farm. Monthly surveys of the haulout showed a decline in harbour seal numbers during construction and an apparent failure to recover in the 2 subsequent years. During the annual moult monitoring surveys (SCOS 2011) numbers of harbour seals recorded at Scroby has increased continuously since 2003 suggesting that wind farm operation has not depressed haulout numbers. The numbers of grey seals increased year on year throughout the construction and early operational periods.

The temporary decline in harbour seal numbers seen at Scroby may indicate an effect of construction activity with some persistence in that effect. However, the Scroby counts represent approximately 5% of the East Anglian population and the observed changes may simply reflect similar changes in the harbour seal population in East Anglia (SCOS 2011).

A similar temporary reduction in numbers of seals using haulout sites close to Horns Reef and Nysted was recorded during construction phases.

8. Significance of observed changes in distribution

As requested, we are dealing purely with the effects of operating wind farms and ignoring the significant but apparently temporary effects of piling noise and other forms of construction disturbance.

Porpoises

The underwater noise levels from operational wind farms are considered to be too low to pose any realistic risk of physical damage to porpoises.

The frequency range of the underwater noise from wind turbines also makes it unlikely that there are any masking effects.

Controlled exposure experiments indicate that porpoises may be able to detect wind turbine noise at ranges of tens to hundreds of metres. However, based on the results of acoustic and visual monitoring of porpoises at operational wind farms there is no clear evidence of significant displacement of animals from the wind farm sites due to turbine noise. Studies at Nysted and Horns Reef suggest that construction effects may be detectable tens of kilometres from the wind farm sites. At Nysted the observations suggested that the decrease in activity due to construction carried over into the two subsequent years although there were reportedly indications that the effect was decreasing. Activity levels in the reference area were depressed during construction but had returned to normal by the second year. It seems therefore that the underwater noise generated by operational wind farms is unlikely to cause significant disturbance to harbour porpoises within the wind farms. If there are no significant local effects it seems highly unlikely that there are significant wider scale effects.

We are not aware of any reports of studies of other cetaceans around wind farms. Other small cetaceans likely to occur in UK waters will have similar hearing capacities to harbour porpoises at the low frequencies produced by tidal turbines. Some may be several dB more sensitive, but the same arguments about lack of damage risk and lack of masking effects will apply.

As there have been no reported studies of reactions of other species to wind farms it is not possible to predict their responses to wind turbine noise.

Seals

The underwater noise levels from operational wind farms are probably too low to pose any realistic risk of physical damage to seals at ranges of more than 10m. Even within this range seals would need to remain within the sound field for considerable periods before suffering any TTS effects. It therefore seems unlikely that any seals will suffer hearing damage from wind turbine noise.

Seals are more sensitive to low frequency sound than are small cetaceans. If they use this low frequency band for passive prey detection or predator detection it is possible that wind farm noise may cause some masking of biologically significant sounds. If such effects occur and are biologically meaningful they will probably be restricted to the close vicinity of turbines.

The only study of seal movements with sufficient power to detect effects of an operating wind farm was McConnell *et al.* (2012). They found no effect on any of the movement and distribution metrics that they could test. In addition, other studies with lower power are broadly in agreement.

A study of haulout behaviour at Scroby Sands within 2km of the wind farm indicated that counts of both harbour and grey seals have continued to increase during the 6 years of operation after a possible temporary effect of construction activity on harbour seals.

There is at present only a limited amount of information, but these preliminary results do not indicate a major change in distribution of either grey or harbour seals as a result of current wind farm operations. It is also therefore unlikely that there have been larger scale redistributions as a result of wind farm operations.

9. Suggested future research.

Seals: As already stated there is little useful information on the movements of seals in and around operational wind farms. The technology exists to increase the amount of information wherever there are wind farms and accessible seal haulouts in reasonable proximity.

At present there is limite4d scope to to directly study the effects of offshore wind farm operations in Scottish waters as there is onlyone operational farm at Robin Rig in the Solway Firth. However, any attempt to study the effects of operational wind farms and/or construction activities on seal distribution will require baseline information before disturbance for comparison. The carrying out of a set of targeted telemetry studies in areas where wind farms are being planned or developed is a pre-requisite for the later detection of any effects of those developments.

The ability to detect differences is a function of the amount of information available in the baseline and operational/construction periods. It is important to ensure that there is sufficient baseline data available because our ability to detect differences is very approximately proportional to the product of the sample sizes in the two periods. The most efficient distribution of effort would be to have equal sample sizes in the two periods. Halving the baseline effort would require doubling the effort in the operational/construction periods in order to maintain the power to detect changes.

At present SMRU are involved in a telemetry study of the movements of harbour seals in the southern North Sea as part of a DECC funded investigation into the effects of piling noise and wind farm operations. This should provide better estimates of the scale and intensity of any effects and improve our ability to design future telemetry studies.

Cetaceans: There have been few studies of the effects of operational wind farm noise on cetaceans. There is some consistency in the results of the three major studies for which data are available. However these address the effects on only one species, the harbour porpoise. Clearly there is still a need for additional information on the responses of harbour porpoises and these could potentially be addressed by similar studies to those conducted in Denmark and the Netherlands. As described above for seals, such studies require pre-disturbance baseline information. It is important that the data collection methods and the temporal and spatial extent of the baseline studies are appropriate to allow comparison with operation/construction phase data in order to identify changes. Longer term monitoring programmes need to be established to collect appropriate information during construction and operational phases.

The development of offshore wind farms in the central and northern North Sea and other waters around Scotland means that information will be required on the effects on several other cetacean species e.g. bottlenose, white beaked and Risso's dolphins, Killer whales and minke whales. As minke whales are low frequency specialists they may be more likely to respond to long term disturbance due to operational noise and/or other effects.

All of these species are locally less abundant than porpoises and little is known about most of their distributions or abundances in Scottish waters. Estimating effects on these other species will be more difficult. A necessary first step will be to refine estimates of their distribution and abundance at relevant scales. The precision of these estimates will determine the feasibility of detecting effects. Alternatively it may be possible to develop appropriate tracking techniques to directly investigate responses to operational activities at wind farms. However this would be a large and potentially expensive research undertaking and it would seem sensible to bring together experts on the various species and in the different research methods required to study them in order to develop a research programme.

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