# Chapter 147
# Review of Offshore Wind Farm Impact Monitoring and Mitigation with Regard to Marine Mammals

**Ursula K. Verfuss, Carol E. Sparling, Charlie Arnot, Adrian Judd, and Michael Coyle**

**Abstract** Monitoring and mitigation reports from 19 UK and 9 other European Union (EU) offshore wind farm (OWF) developments were reviewed, providing a synthesis of the evidence associated with the observed environmental impact on marine mammals. UK licensing conditions were largely concerned with mitigation measures reducing the risk of physical and auditory injury from pile driving. At the other EU sites, impact monitoring was conducted along with mitigation measures. Noise-mitigation measures were developed and tested in UK and German waters in German government-financed projects. We highlight some of the review's findings and lessons learned with regard to noise impact on marine mammals.

**Keywords** Offshore wind farm • Impact monitoring • Mitigation • Marine mammals • Licensing procedure

U.K. Verfuss (✉) • C.E. Sparling
Sea Mammal Research Unit (SMRU) Marine Ltd., New Technology Centre, North Haugh, St. Andrews, Fife KY16 9SR, UK
e-mail: ukv@smru.co.uk; ces@smru.co.uk

C. Arnot
Fugro EMU Ltd., Durley, Southampton SO32 2EJ, UK
e-mail: charlie.arnot@fugroemu.com

A. Judd
Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Lowestoft, Suffolk NR33 0HT, UK
e-mail: adrian.judd@cefas.co.uk

M. Coyle
Marine Management Organisation, Newcastle upon Tyne NE4 7YH, UK
e-mail: Michael.Coyle@marinemanagement.org.uk



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## 1 Introduction

In the United Kingdom, postconsent monitoring requirements are incorporated into offshore wind farm (OWF) license conditions. The aims of this monitoring are to validate or reduce uncertainty in the predictions of environmental impacts, focusing on areas of key risk identified in the Environmental Impact Assessment process and to assess the effectiveness of mitigation measures. The Department for Environment, Food and Rural Affairs and the Marine Management Organisation commissioned a review of all postconsent monitoring data collected from UK OWF developments to date to provide a synthesis of the evidence associated with observed environmental impacts and make recommendations for maximizing the effectiveness of the licensing process and future monitoring. This review also covers OWFs built outside the United Kingdom in European Union (EU) waters to provide further insights into the monitoring and mitigation best practices and lessons learned about their impact on the marine environment. We highlight some of the review's findings in relation to the impact of underwater noise on marine mammals, using a comparative approach, incorporating an analysis of progress over time and a summary of lessons learned from the monitoring outcomes.

## 2 Studies Included

Environmental statements, licenses, and monitoring and mitigation reports were reviewed from a total of 19 consented UK OWFs. These sites and their generation year are listed in Table 147.1.

Publicly available reports and publications from nine operating OWFs in Belgium (Thornton Bank), Denmark (Horns Rev I + II, Nysted, Sprogø), Germany (Alpha Ventus, Borkum West II), and The Netherlands (Offshore Windpark Eegmond aan Zee [OWEZ], Prinses Amalia) were reviewed to investigate marine mammal monitoring and mitigation conducted outside the United Kingdom.

**Table 147.1** Generation year and name of the UK offshore wind farm sites reviewed

| Generation year | Offshore wind farm site |
|---|---|
| 2003 | North Hoyle |
| 2004 | Scroby Sands |
| 2005 | Kentish Flats |
| 2006 | Barrow |
| 2007 | Burbo Bank |
| 2008 | Lynn/Inner Dowsing |
| 2009 | Gunfleet Sands I + II, Rhyl Flats, Robin Rigg E + W |
| 2010 | Greater Gabbard, Thanet |
| 2011 | Ormondo, Sheringam Shoal, Walney 1 + 2 |
| 2012 | London Array, Teeside |
| 2013 | Gwynt Y Mor, Lincs, West of Duddon |

# 3 Outcome

## *3.1 Impact Monitoring: Methods and Lessons Learned*

### UK Sites

Only two impact monitoring studies with regard to marine mammals were prescribed as part of license conditions at UK OWFs. At Scroby Sands, aerial survey haul-out counts were conducted during the summer months before, during (although not directly coinciding with the period of pile driving), and after the construction phases to monitor a mixed haul of *Phoca vitulina* and *Halichoerus grypus* (harbor and gray seals, respectively) situated <2 km away from the OWF site (Skeate and Perrow 2008; Skeate et al. 2012). The data indicated a decline in harbor seal numbers during construction, with numbers remaining lower in the two subsequent years. The numbers of gray seals, however, increased year after year throughout the construction and early operational periods. It is therefore possible that changes in harbor seal numbers were in response to this rather than to any effects of the OWF. There were also regional changes in patterns of haul-out use by harbor seals in the Wash over the same period, so changes at Scroby Sands could have been part of wider regional dynamics.

At Robin Rigg, boat-based surveys for cetaceans were conducted before, during, and after construction (Walls et al. 2013). Density surface models created using sightings data suggested that *Phocoena phocoena* (harbor porpoise), the only frequently sighted cetacean, were displaced from the wind farm site during construction. However, with only 1 year of preconstruction survey, natural variation cannot be ruled out as the reason for the observed change. Furthermore, other parts of the survey area outside the wind farm site also appeared to experience significant declines in harbor porpoise density.

### European Union Outside the United Kingdom

In Belgium, Denmark, Germany, and The Netherlands, impact studies focused on harbor porpoises, but studies were also carried out on harbor and gray seals. Most porpoise studies were conducted using a before-after control-impact (BACI) design, with data collection during a time period before (B) and after (A) the impact in a control (C) and the wind farm impact area (I). In Belgium, Denmark, and Germany, data were also collected during wind farm construction, allowing the determination of the pile-driving impact radius. For the OWF Prinses Amalia, only impact monitoring reports covering the second year of operation were available for review.

Static passive acoustic monitoring (PAM) was the most common methodology used to investigate potential changes in porpoise presence as a result of offshore wind-related impacts using cetacean detectors (T-PODs and C-PODs, Chelonia Ltd.) moored across a control and the predicted impact area. These devices are standalone, archival data loggers that detect and log sound, storing certain parameters of

odontocete echolocation clicks. In Belgium, Denmark and Germany, aerial or boat-based line transect surveys have also been conducted. Seals were studied by tagging animals of nearby haul-out sites with satellite or global system for mobile communications (GSM)/GPS transmitters or by monitoring numbers at the haul-out site.

The primary generic conclusion with regard to the impact of OWFs on marine mammals is that construction activities, especially pile driving, can have a significant impact on marine mammal abundance and distribution (e.g., seals: Edrén et al. 2010; porpoises: Brandt et al. 2011). In contrast, the operation of wind turbines has no significant negative effect (e.g., porpoises: Scheidat et al. 2011; seals: McConnell et al. 2012). The effect of pile driving may extend to distances beyond 20 km from the noise source. Investigations at Borkum West II revealed that a median sound exposure level (SEL) of 144 dB re 1 $\mu Pa^2 \cdot s$ and above evoked a disturbance reaction in porpoises (Pehlke et al. 2013). This result is consistent with experiments in a captive harbor porpoise that revealed a threshold level for aversive behavioral reactions above an SEL of 145 dB re 1 $\mu Pa^2 \cdot s$ (Lucke et al. 2009). The impact-monitoring studies show that harbor porpoises return to the wind farm sites after hours or days once piling ceases, but it is not known if this applies to the animals being displaced or to "new" animals entering the area. In the latter case, the resulting impact may be more severe than in the former (Tougaard et al. 2006). There are limited data on the relationship between piling duration and length of displacement. It is important to note that behavioral changes are not necessarily caused by piling (alone). They can also be induced by other construction activities such as seismic surveys, increased ship traffic, or the deployment of pingers and seal scarers intended to move animals away from an area immediately around the piling to reduce the risk of physical and auditory injury.

## *3.2 Mitigation Measures*

### UK Sites

In the United Kingdom, the licensing conditions for marine mammals have been largely related to mitigation measures, required to reduce the risk of physical and auditory injury from pile driving. A clear progression in the mitigation requirements was noticeable in the licensing conditions through time (2003–2010), likely connected to an increasing awareness of the severity of the possible impact of construction noise on marine mammals. Although early licenses contained no requirements for marine mammal mitigation, later licenses detailed prescribed mitigation measures by requiring soft starts and/or a delay to the start of piling when marine mammals were sighted close to the construction site. Licenses dated from 2007 onward prescribed detailed mitigation measures, including soft starts, monitoring of an exclusion zone with dedicated marine mammal observers (MMOs) and PAM, and enhanced PAM during piling at times with low visibility (e.g., at nighttime, unfavorable weather conditions). The size of the mitigation monitoring zone was not detailed within the licenses, but when described in the marine mammal mitigation

protocol or monitoring report (7 cases), its radius was 500 m. Although the use of acoustic deterrent devices (ADDs) such as pingers or seal scarers was not mandatory in any of the licenses, they were deployed at three sites to displace marine mammals from the construction site. Where the marine mammal mitigation measures were detailed (four reports), very few instances of detections were reported, with only one acoustic and one visual harbor porpoise detection, each at a different site, causing a delay in piling.

### European Union Outside the United Kingdom

In Belgium and The Netherlands, seasonal restrictions for pile driving from January to April (Belgium) or May (The Netherlands) have been applied to protect sensitive periods for key species such as the harbor porpoise and seals. Germany and Belgium have prescribed threshold values for impulsive (pile-driving) noise: the Belgian indicator of the Marine Strategy Framework Directive Descriptor 11 for impulsive noise requires emitted impulsive sound to be below 185 dB re 1 µPa zero-to-peak sound pressure level (SPL) at 750 m from the source. Exceeding this level leads to the requirement for noise-mitigation measures (Degraer et al. 2012). In Germany, emitted impulsive sounds must not exceed threshold levels of 160 dB re 1 $\mu Pa^2 \cdot s$ (SEL) or of 190 dB re 1 µPa peak to peak (SPL) at 750 m from the piling site (UBA 2011). This threshold is based on a temporary threshold shift (TTS) found in a harbor porpoise at 164 dB re 1 $mPa^2 \cdot s$ SEL and 199 dB re 1 µPa SPL (Lucke et al. 2009). Information on the extent to which these thresholds have been met during OWF construction is limited. There is also the requirement for acoustic deterrent devices and soft-start procedures to ensure the absence of marine mammals within close range before piling (Verfuss et al. 2012). To meet the prescribed thresholds, noise-mitigation techniques reducing the transmitted sound have been developed, applied, and evaluated (further discussed in Section 3.2.3). ADDs such as pingers and/or seal scarers have been used in most studies reviewed in conjunction with pile driving to deter harbor porpoises and seals out of the impact area. Gravity-based (and therefore low-noise) foundations have been used at the Danish OWFs Sprogø and Nysted.

### Noise-Mitigation Measures to Reduce the Transmitted Piling Noise

The German Federal Government is funding strategic research on the development and testing of noise-mitigation measures during pile driving. A sound-mitigation system "hydro sound damper" (HSD) was tested at the UK London Array OWF under offshore conditions at water depths of 15–18 m (Remmers and Bellmann 2013). The noise reduction achieved was 7–13 dB SEL and 7–15 dB peak SPL. The ESRa research project tested five different noise-mitigation systems in Lübeck Bay at 8.5 m depth, achieving significant reduction effects with all systems, with values between 7 and 9 dB in the broadband SEL (Wilke et al. 2012). Pehlke et al. (2013) successfully deployed and tested different "big bubble curtain" (BBC) configurations at the wind

farm Borkum West II in water depths of 27–33 m, reporting a noise reduction of 9–13 dB in SEL and 10–17 dB in SPL with configuration BBC2. In 73% of the foundations, the piling noise was kept below the German SEL threshold value of 160 dB re 1 $\mu Pa^2 \cdot s$, and it was always below 163 SEL re 1 $\mu Pa^2 \cdot s$ and the SPL threshold value of 190 dB re 1 μPa peak to peak. Using the disturbance threshold of 144 dB re 1 $\mu Pa^2 \cdot s$ SEL, the behavioral impact radius was calculated to be 15 km for unshielded ramming operations and 4.8 km with the BBC. Applying the noise-mitigation measure therefore reduced the impact area (and likely the number of animals affected) by 90% (Pehlke et al. 2013).

## 4 Conclusions

The mitigation measures taken in the reviewed countries suggest a general consensus that piling noise is potentially the most harmful impact to marine mammals in OWF projects, with the potential to cause auditory injury or behavioral disturbance and displacement. Construction noise can result in impacts up to several tens of kilometers away from the construction site with no noise-reduction techniques applied. The advantages and disadvantages of the different mitigation measures are described below.

Mitigation measures reducing noise, like the BBC, can significantly minimize the behavioral impact area and keep the auditory injury impact within a limited area around the sound source. However, it will not eliminate the impact. The applicability of this technique under challenging conditions such as greater depths and stronger currents than found in the areas tested to date and the effect of its use on construction schedules remains to be fully assessed.

Monitoring an exclusion zone with a delay to the commencement of piling on a marine mammal sighting is intended to reduce the risk of instantaneous auditory injury. It does not prevent behavioral disturbance and displacement and may not always prevent cumulative noise exposure (over whole piling events), leading to auditory injury. However, the exclusion zone that would have to be considered to avoid auditory injury may be beyond the scale of what can be effectively monitored when pile driving is conducted without any kind of noise-reducing methods. Furthermore, MMOs and PAM may not detect all animals present within the monitored zone, and PAM undertaken at times with low visibility will only be effective for vocalizing mammals and will therefore not be appropriate for baleen whales or seals.

Pingers, seal scarers, and soft starts, when employed as a mitigation measure, are also intended to reduce the risk of instantaneous auditory injury. They rely on the evocation of strong behavioral reactions to move animals away from the zone of impact rather than preventing behavioral impacts such as displacement and/or disturbance to normal activities. Brandt et al. (2013) showed that the deployment of a Lofitech seal scarer does have a deterrent effect on harbor porpoises and can therefore greatly reduce the risk of physical injury for porpoises during offshore piling. Nevertheless, animals can habituate to these devices, which would result in a

decrease of the effectiveness of such devices over time. Furthermore, not all animals may respond, especially if other factors, such as food availability, may motivate the animals to stay within the impact zone.

Seasonal restriction of pile-driving activities, at times with high animal densities or at sensitive times for specific species, may be the only option in particularly sensitive areas where an OWF project would otherwise not go ahead because of predicted negative impacts on protected species. However, given the extensive future construction schedules, e.g., as for UK round 3 wind farms, such restrictions would likely render many projects unviable.

Low-noise emission foundations such as gravity-based designs or floating turbines, which basically do not or hardly require piling, are recommended whenever feasible but especially when animals are present in high numbers and in areas of particular importance to marine mammals. This solution would greatly reduce the need for any other marine mammal impact mitigation measures but may not be applicable at every OWF site.

All mitigation measures discussed above are based on the avoidance of instantaneous auditory injury, and they may even enhance the behavioral impact and displacement of animals. Unfortunately, very little is currently known about the individual or population consequences of auditory injury or disturbance/displacement. It is currently uncertain which impacts have more severe consequences for individuals and ultimately populations (auditory injury or displacement/disturbance) and it is likely that the balance will differ between species and sites. There are several planned initiatives aimed at reducing this uncertainty over the coming years (e.g., Offshore Renewables Joint Industry Programmes [ORJIP]) projects), but these will rely on empirical data being collected during future construction and therefore it is imperative that mitigation and monitoring at a site-specific level be geared toward gaining an understanding of these issues.

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