EVIDENCE ON THE EFFICACY OF UNDERWATER NOISE ABATEMENT

Cefas Noise and Bioacoustics Team
underwaternoiseadvice@cefas.gov.uk / regulatory_assessment@cefas.cov.uk

Given growing concerns over the effects of unabated pile driving noise on protected species, Cefas have, in their capacity as scientific advisors to the Marine Management Organisation (MMO), taken a fresh look at the scientific evidence relevant to noise abatement for offshore wind farm construction. To inform this review, we have largely drawn on the outcomes of the stakeholder noise abatement workshop held in 2019 (see Merchant and Robinson, 2020) and several more contemporary peer-reviewed papers where available. We have also included key findings from the review of 'noise abatement systems for offshore wind farm construction noise' undertaken by Verfuss et al. (2019). A brief overview of noise abatement systems (NAS) is provided in the first instance, for completeness.

Overview of NAS

1. NAS fall into three main categories:

- **Bubble curtains** are independent from foundations, but a separate vessel and compressor are required which generate their own noise.
    - e.g., typically Big Bubble Curtain (BBC) or Double Big Bubble Curtain (DBBC)

- **Shell-in-shell systems / casings** are integrated into the pile-driver and their efficacy depends on the weight and dimensions of the piles and the seabed composition.
    - e.g. IHC-Noise Mitigation Screen (IHC-NMS)
    - HydroNAS

- **Encapsulated resonator systems** consist of a curtain of resonating elements surrounding the pile, which can be tuned to attenuate particular frequencies. They can be effective and unlike the above systems are unlimited by deep waters or higher water currents. However, they often need to be project specific.
    - e.g. Hydro Sound Damper (HSD)
    - AdBm Noise Abatement System (AdBm-NAS)

- There are also alternative hammers (and hammer adaptations) to the standard impact pile drivers, such as BLUE Piling technology (BLUE Hammer). This technology employs a large body of water rather than the commonly used impact weight to deliver the blow (see Klages et al., 2021). Furthermore, Ørsted has developed a new noise mitigation technology that uses a patented jetting technique to attach to monopile foundations. This reduces resistance in sandy soil, allowing the foundation to sink into the seabed, replacing conventional pile driving. It was tested during the installation of three monopile foundations at the Gode Wind 3 offshore wind farm in the North Sea.

2. Verfuss et al. (2019) report that the Big Bubble Curtain (BBC) is the most commonly applied system to mitigate underwater noise during wind turbine installation (in German waters and in other European countries). The Noise Mitigation Screen (NMS) and Hydrosound damper (HSD) systems have also been applied quite frequently.

3. In Germany, a BBC has often been used in a configuration in which one or two (and in a couple of exceptional cases three) circles of nozzle hoses with increasing radius are laid around the piling position (single or double BBC), and/or in combination with either an NMS or an HSD (see below). All three systems (BBC, NMS and HSD) are commercially available (Verfuss et al., 2019).

Evidence on the efficacy of NAS

NAS can reduce disturbance:

4. Standard mitigation measures (such as the use of acoustic deterrent devices, ramp up and soft start procedures, and marine mammal observers) are used during pile driving operations to mitigate potential injury effects from noise, however no mitigation is used specifically to reduce disturbance. Disturbance is an offence under European Protected Species (EPS) legislation, and significant disturbance of harbour porpoise in their Special Areas of Conservation (SACs) in English waters could lead to an adverse effect on site integrity.

5. In the case of harbour porpoise, the evidence for the efficacy of noise abatement systems in reducing disturbance ranges is particularly strong. Early studies demonstrating reduced disturbance ranges at individual wind farms (Dähne et al., 2017; Nehls et al., 2016) were more widely confirmed by a study of the first seven major wind farms in German waters (Brandt et al., 2018), six of which applied first-generation NAS during construction. **Declines in porpoise abundance in the range 10-15 km were 50% without NAS**, but only 17% when NAS were deployed. The data also supported the conclusion that:

> *The application of first generation NMS* [Noise Mitigation System] *thus reduced the effect range of pile driving and led to a lower decline of porpoise detections over all distances.* (Brandt et al., 2018)

6. These wind farms were constructed between 2010 and 2013, and the authors of the study further note that NAS have evolved significantly since, suggesting that the reductions in disturbance when using more recent NAS alone or in combination, may be even greater.

Outcomes of the noise abatement workshop held at The Royal Society, London, 2019:

7. Merchant and Robinson (2020) convened a workshop of UK stakeholders at the Royal Society, London in November 2019. The aim of the workshop was to explore the technical feasibility of applying noise abatement measures to offshore wind farm construction (and UXO detonation) to improve the quality of the acoustic habitat in UK seas. Drawing on expertise developed by operators implementing noise abatement measures elsewhere in the North Sea (i.e., Germany, Demark, Netherlands and Belgium), the workshop considered the available technologies and their benefits and assessed what technical challenges there may be to implementing such measures in UK waters.

8. The workshop concluded that **it is feasible to deploy noise abatement technologies at all locations where offshore wind farms are proposed in UK waters.** Available noise abatement technologies have different constraints related to water depth and oceanographic conditions. However, feasible technological solutions are available for water depths throughout UK waters proposed for offshore wind farm construction.

9. **Bubble curtains have been widely demonstrated to be effective in waters up to 45 m.** They become less effective as water depth increases due to dispersion of the bubbles. **Casing based systems (e.g. IHC Noise Mitigation System) are also demonstrated up to 45 m** and are constrained by the availability of large enough systems for the water depth. Encapsulated resonator systems (e.g. Hydrosound damper, AdBm Noise Abatement System) are in principle unlimited by water depth or adverse weather conditions (high current speeds and wave heights).

10. During the workshop, some lessons learned from German offshore wind construction projects since 2009, including a summary of the noise mitigation systems deployed in German waters during 2011- 2018, were presented. The GESCHA 2 project sought to understand the relationship between broadband sound level and harbour porpoise disturbance, and how successful noise abatement measures have been in German waters. **Piling during 2014-2016 was found to be 9 dB quieter overall than during**

2010-2013, **with noise abatement systems reducing noise emissions by 15 dB overall**. A dose-response relationship between noise level and harbour porpoise displacement was identified for noise levels exceeding an SEL05 of 165 dB re 1 μPa^2 s. Half of the animals fled before the onset of an acoustic deterrent device prior to piling, indicating that other activities (e.g. vessel activity related to the operation) lead to displacement prior to piling (for further details see Brandt et al., 2018)). It was noted that the side effects of deploying noise abatement systems also need to be considered. For example, to deploy a bubble curtain, the possibility of additional disturbance of vessels and compressors must be taken into account (although this is likely to be small compared to the reduction in disturbance achieved by the NAS), as well as the additional CO2 produced (see section on NAS considerations below).

11. Moreover, BSH (Germany's Federal Maritime and Hydrographic Agency), which has over 10 years of experience in regulating the German noise thresholds, highlighted that **noise emissions can be significantly reduced by noise abatement systems, up to 24 dB.**

12. The German threshold required sound events to not exceed the following limits at 750m from the source:
    - Unweighted broadband sound exposure level (SEL) of 160 dB re 1μPa^{2}s
    - Peak sound pressure level (SPL) of 190 dB re 1μPa

13. Regulation has led to unprecedented technical innovation by the industry. To date (and since 2014), there is reliable compliance, despite increasing pile diameters and water depths. The regulations offer industry the advantage of installation without temporal restrictions.

Direct experience from BSH (Germany)

14. BSH has kindly provided the following information (via email, 9th February 2024) and specifications in relation to the following NAS:

Noise Mitigation System (IHC-NMS)

15. The IHC-NMS is a near-pile noise mitigation system and has so far been used for pile diameters up to 8 m. IHC-NMS for larger pile diameters are currently under development. The system is very robust and reliable but only applicable for monopiles.

16. The achieved noise reduction with the IHC-NMS proved to be independent from:
    - the water depth (experiences exists up to 40 m water depth),
    - the prevailing current (present application ≤ 0.75 m/s) and
    - the spatial direction (omnidirectional noise reduction).

17. The total length of the IHC-NMS is not automatically variable within a construction project; thus, it has not yet been applied in construction projects with widely varying water depths (Juretzek, pers. comm.).

Hydro Sound Damper (HSD)

18. The HSD system is a near-pile noise mitigation system and has so far been used for water depths of up to 45 m and pile diameters of up to 9.5 m. It has only reached a state of the art for monopiles. The noise reduction of the system is constant and reliable, but mostly only at low frequencies. The system is therefore only suitable for combined use with a Bubble Curtain system. It is offshore-suitable and mostly faultless and robust. The project-specific design has a major influence on the sound reduction achieved. The HSD system can also be used for variable depths of 23 m to 41 m within a construction area without any problems and without modifications.

19. The achieved noise reduction with the HSD system proved to be independent of:
    - the water depth (up to 45 m), based on the different layouts of the HSD elements at the net,
    - the prevailing current (experiences up to a maximum of 0.75 m/s are available) and
    - the spatial direction (omnidirectional noise reduction).

20. It is worth noting that the handling, particularly the deployment of the lowering and lifting device under offshore conditions, can be complicated. The lifting device and the ballast box were previously manufactured especially for each project, so that the procedure for the pile-positioning and the HSD deployment was very variable. Prior to the start of an installation, port tests and sometimes also offshore tests are always required by BSH. These tests are used to check the functionality of the system, especially for the lifting device including ballast box and the HSD-net (Juretzek, pers. comm.).

Big Bubble Curtain (BBC)

21. A BBC can be a very effective, robust and offshore-suitable NAS, but each bubble curtain must be individually adapted to each construction project with regard to site-specific and technical-constructional characteristics, such as current, water depth and installation process. It has been used in water depths of up to 45 m. At water depths of more than 40 m, the required air volume becomes challenging due to the static pressure.

22. Most current projects use a Double Big Bubble Curtain (DBBC), but there are also attempts to just use a larger diameter BBC hose instead. The sound reduction of the system is strongest in the high-frequency range (see below for further information on frequency).

23. When used under offshore conditions, the following advantages of the BBC became apparent:
    - independent deployment of the nozzle hoses from the installation vessel by a variable deployment procedure,
    - supplied air volume can be varied by the number and type of compressors used (airwater-mixture),
    - the NAS is independent of the foundation type and the installation vessel,
    - applicable in different water depths.

24. Additional vessel capacity is however necessary for the deployment and the operation of the Bubble Curtain. In the case where currents are above approximately 0.75 m/s, the noise reduction in current direction significantly decreases due to drifting effects. The result is a direction dependent noise reduction of the applied Bubble Curtain. Strong currents require an elliptical arrangement of the hoses (Juretzek, pers. comm.).

25. For monopile diameters from 6 m or water depths greater than 25 m, the use of two independent noise mitigation systems - a near-to-pile and a far-from-pile noise mitigation system - has proven to comply with the German noise mitigation values.

<u>Reports of effective combined NAS:</u>

26. Juretzek et al. (2021) demonstrate the effectiveness of noise abatement systems applied during recent construction projects in the German Bight **in a water depth of approximately 40 m.** The authors were able to confirm their significant reduction potential of sound pressure levels in comparison to unmitigated pile driving based on standardised monitoring data. All but one pile in the data pool were installed using a combination of two noise abatement systems**: a noise mitigation screen (IHC-NMS)** and **a double big bubble curtain (DBBC).** The study further reported that with one noise abatement system (IHC-NMS), the sound emission of pile driving noise, measured at a distance of 1500 m, is significantly reduced over the entire spectral range considered. **With the combination of two systems (IHC-NMS and DBBC), the sound pressure level is reduced even further.** Only the combination of both noise abatement systems leads to compliance with the dual threshold values. The authors highlight that both configurations also yield a particularly strong decrease in measured sound pressure levels for the higher frequency range. **The most significant energy reduction is observed at frequencies above approximately 250 Hz when both noise abatement systems are used.**

<u>Frequency is an important factor to consider for NAS:</u>

27. It is evident that some NAS are more effective for some marine species than others. This is dependent on the frequency range at which noise energy will be reduced compared to the unmitigated noise (Verfuss et al., 2019). A reduction of noise energy in the lower frequency range reduces the risk of impact on species with low frequency hearing (such as some fish species, harbour seals and baleen whales). A reduction of noise energy in the higher frequency range will be more effective for species with high frequency hearing (such as the harbour porpoise) (Verfuss et al., 2019).

28. NAS that have been proven at full-scale use (BBC, HSD, NMS and BLUE Hammer) can reduce the sound exposure level of a single strike at **50 Hz by 6 to 7 dB** – a frequency in the range at which fish and low frequency cetaceans (such as minke whale) are particularly sensitive (Verfuss et al., 2019). The **efficacy increases with increasing frequency,** making these systems suitable for all marine mammals and fish sensitive to higher frequencies. In particular, **the BBC and NMS are most effective at higher frequencies (e.g., 10 kHz),** which makes these systems especially effective in reducing impacts to the harbour porpoise (and other high frequency cetaceans) (Verfuss et al., 2019).

Key findings from Verfuss et al. (2019):

29. The purpose of the study was to undertake a review of available underwater NAS in relation to their applicability for piling operations for offshore wind farm construction in Scottish waters. Parameters of interest included the efficacy in noise reduction and the resulting benefit to marine fauna.

30. As reported in Verfuss et al., Bellmann et al. (2018) provides information on the noise reduction efficacy of BBC, NMS and HSD for the installation of piles at or below 40 m water depth. At such sites, **a reduction in the single strike sound exposure level (SELss) of 7 to 18 dB can potentially be achieved** when using a BBC, NMS or HSD. Moreover, a noise reduction of **at least 10 dB can be guaranteed for all three systems (BBC, HSD and NMS)** (Bellmann, pers. comm.). Bellmann et al. highlight that the efficacy can be increased by using a combination of NAS (e.g., BBC and NMS, or BBC and HSD), which supports the findings presented by Juretzek et al. (2021).

Other considerations of NAS

31. As noted above, the side effects of deploying noise abatement systems need to be considered. Although mitigating noise impacts, some NAS induce other impacts.

Compressors, for example are required for BBCs, which also consume fuel (and hence increase the carbon footprint of the operation) and produce noise (primarily airborne). An additional vessel is also required (Verfuss et al., 2019).

32. We are aware that some developers have argued that NAS would not reduce overall disturbance for the following reasons:

    i. Using NAS would increase the overall piling duration, through additional deployment time and delays waiting for the right conditions for NAS, thereby increasing disturbance duration.
    ii. Additional vessels would increase vessel-based disturbance.
    iii. Acoustic deterrent devices would still be needed, so NAS would not alleviate disturbance from these.

33. In response to the first two arguments above [32(i) and 31(ii)], it is important to note that reductions in the disturbance area reported in the literature from the use of NAS – e.g. 75% (Dähne et al., 2017) or as high as 90% (Nehls et al., 2016) – are likely to far exceed any increased disturbance due to extended duration or additional vessels.

34. Regarding 32(iii), it is true that the use of acoustic deterrent devices (ADDs) should be carefully considered in the context of the proposed activity, particularly if NAS are deployed. This is because the extent of marine mammal displacement from ADDs may exceed the range of displacement from the activity itself if noise abatement measures are applied (Dähne et al., 2017). Given the evidence of displacement prior to piling due to the presence of construction vessels (Brandt et al., 2018), there is a case to be made that the use of ADDs may be counterproductive for activities with small disturbance areas.

Summary

35. See also Annex I of this review for a summary table on NAS specifications.

- Bubble curtains, casing based systems (e.g. IHC Noise Mitigation System) and encapsulated resonator based systems (e.g. Hydro Sound Damper) have been demonstrated to be effective in waters up to 45 m (Merchant and Robinson, 2020, Juretzek, pers. comm.).
- For noise abatement systems, specifically the BBC, NMS and HSD, a reduction of at least 10 dB can be guaranteed. Others have reported NAS to reduce noise emissions by 15 dB overall, and in some cases, up to 24 dB.

- A combination of two systems (such as the IHC-NMS and DBBC, for example) can have a greater reduction on the sound pressure levels.
- Frequency is an important factor when considering the efficacy of NAS.
- The BCC and NMS are most effective at higher frequencies (e.g., 10 kHz), which makes these systems especially effective in reducing impacts to the harbour porpoise (and other high frequency cetaceans).

References

Bellmann, M., Kuhler, R., Matuschek, R., Muller, M., Betke, K., Schuckenbrock, J., Gundert, S. & Remmers, P. (2018). Noise mitigation during large foundations (Monopile L & XL): Technical options for complying with noise limits. In: CONSERVATION, G. F. A. F. N. (ed.) International conference on noise mitigation for the construction of increasingly large offshore wind turbines: Technical options for complying with noise limits. Berlin: German Federal Agency for Nature Conservation.

Brandt, M. J., Dragon, A. C., Diederichs, A., Bellmann, M. A., Wahl, V., Piper, W., Nabe-Nielsen, J., & Nehls, G. (2018). Disturbance of harbour porpoises during construction of the first seven offshore wind farms in Germany. *Marine Ecology Progress Series*, *596*, 213–232. https://doi.org/10.3354/meps12560.

Dähne, M., Tougaard, J., Carstensen, J., Rose, A., & Nabe-Nielsen, J. (2017). Bubble curtains attenuate noise from offshore wind farm construction and reduce temporary habitat loss for harbour porpoises. *Marine Ecology Progress Series*, *580*, 221–237. https://doi.org/10.3354/meps12257.

Juretzek, C., Schmidt, B. and Boethling M. (2021). Turning Scientific Knowledge into Regulation: Effective Measures for Noise Mitigation of Pile Driving. J. Mar. Sci. Eng. 2021, 9, 819. https://doi.org/10.3390/jmse9080819.

Klages, E., Lippert, S. and von Estorff, O. (2021). A noise-reduced impact hammer for offshore pile driving. Proceedings of Meetings on Acoustics, Vol. 44, 070016 (2021). 2021 Acoustical Society of America. https://doi.org/10.1121/2.0001482.

Merchant, N.D., Robinson, S.P. (2020). Abatement of underwater noise pollution from pile-driving and explosions in UK waters. Report of the UKAN workshop held on Tuesday 12 November 2019 at The Royal Society, London. 31pp. doi: 10.6084/m9.figshare.11815449.

Nehls, G., Rose, A., Diederichs, A., Bellmann, M., & Pehlke, H. (2016). Noise mitigation during pile driving efficiently reduces disturbance of marine mammals. In *The Effects of Noise on Aquatic Life II* (pp. 755–762). Springer.

Verfuss, U.K., Sinclair, R.R. & Sparling, C.E. (2019). A review of noise abatement systems for offshore wind farm construction noise, and the potential for their application in Scottish waters. Scottish Natural Heritage Research Report No. 1070.

Weblinks

Table 1. Full URLs for weblinks used in the text.

Weblink text	Full URL
Blue Piling technology	https://www.hvrengineering.com/projects/blue-piling-hammer/
Ørsted patented jetting technology	https://orsted.com/en/media/news/2024/07/orsted-successfully-pilots-new-technology-that-fur-13959650

Annex I – Summary table of NAS specifications

System	Frequency	Water depths	Notes on pile size	Other environmental parameters	Limitations / Notes
Noise Mitigation System (IHC-NMS)		Experience of up to 40 m depth in Germany. Up to 45 m in Merchant and Robinson (2020)	Experience of monopiles of up to 8 m diameter in Germany.	Current speed: present application ≤ 0.75 m/s.	This system is only applicable for monopiles.
Hydro Sound Damper (HSD)	The noise reduction of the system is constant and reliable, but mostly only at low frequencies.	Experience of up to 45 m depth in Germany.	Experience of monopiles of up to 9.5 m diameter in Germany.	Current speed: present application ≤ 0.75 m/s.	This system is only applicable for monopiles, and only suitable for combined use with a Bubble Curtain system. The handling, particularly the deployment of the lowering and lifting device under offshore conditions, can be complicated.
Big Bubble Curtain (BBC)		Experience of up to 45 m depth in Germany.		In the case where currents are above approximately 0.75 m/s, the noise reduction in current direction significantly decreases due to drifting effects	Each Bubble Curtain must singly be adapted to each construction project with regard to site-specific and technical-constructional characteristics, such as current, water depth and installation process.