Strategic Review of Offshore Wind Farm Monitoring Data Associated with FEPA Licence Conditions

Underwater Noise

ME1117

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Introduction

This report constitutes a review of the monitoring methods and reporting of underwater noise and vibration generated by offshore wind farms (OWFs) around the UK. The aim of the review is to assess how well the monitoring reports conform to the conditions specified in the Food and Environment Protection Act (FEPA) licences; to highlight the key findings of the reports; and to suggest recommendations for improved monitoring strategies and reporting in the future.

There are currently eight UK OWFs for which noise monitoring data is available from various stages of the construction and post-construction process: Barrow, Burbo, Kentish Flats, North Hoyle, Scroby Sands, Gunfleet Sands, Lynn and Inner Dowsing.

Assumptions

It is assumed that the data presented in the reports are a fair representation of what was observed during monitoring, and that any analyses and textual summaries are a fair and accurate representation of the data. Only conformity of the reports to the licence conditions has been assessed. The suitability of the conditions, in terms of ecological issues, has not been assessed on a site-by-site basis unless there are very clear omissions or mistakes.

The conformity to a licence monitoring requirement is only accepted if it is explicitly reported. Conformity is not accepted if it can only be inferred, even if data has been collected that would meet the condition if it were analysed appropriately.

The review will address the following questions:

1. What monitoring reports and datasets are available and where are they held?
2. Which conditions have or have not been successfully applied?
3. What are the key findings at each site?
    i. Are the datasets and reports comparable?
    ii. Which are generic and which are site-specific issues?
    iii. What are the differences between the different sites?
    iv. What has been learnt about interactions at each site?
4. Which monitoring conditions are no longer necessary (negligible impacts) and which need to be strengthened (underestimated impacts)?
5. What can be learnt from the monitoring reporting style and format?
6. Review of findings, conclusions and recommendations

1. Availability of Monitoring Reports and Datasets

Table 1: Availability of monitoring reports and datasets

Site	Year of licence	Monitoring Reports		
		Pre-Construction	Construction	Post-Construction
Barrow	2005	No	Subacoustech Ltd: December 2007 for COWRIE: Report no. 544R0738	Subacoustech Ltd: June 2007 for BOW Ltd: Report no. 753R0109 and Subacoustech Ltd: December 2007 for COWRIE: Report no. 544R0738
Burbo	2005	No	Subacoustech Ltd: October 2006 for COWRIE: Report no. 726R0103	Subacoustech Ltd: December 2007 for COWRIE: Report no. 544R0738 and CMACS Post-Construction Year 1 Monitoring Report 2008 for Seascape Energy
Kentish Flats	2005	No	Subacoustech Ltd: December 2007 for COWRIE: Report no. 544R0738	Subacoustech Ltd: December 2007 for COWRIE: Report no. 544R0738 and Kentish Flats Offshore Wind Farm Monitoring Report August 2007
North Hoyle	2005	Subacoustech Ltd: May 2003 for COWRIE: Report no. 544R0424	Subacoustech Ltd: December 2007 for COWRIE: Report no. 544R0738 and npower Renewables Annual Monitoring Report June 2005.	Subacoustech Ltd: December 2007 for COWRIE: Report no. 544R0738 and npower renewables final annual FEPA report.
Scroby Sands	2003	Subacoustech Ltd: May 2003 for COWRIE: Report no. 544R0424	Subacoustech Ltd: December 2007 for COWRIE: Report no. 544R0738	Subacoustech Ltd: December 2007 for COWRIE: Report no. 544R0738
Gunfleet Sands	2005 (signed 2003)	No	Subacoustech Ltd: November 2008 for Gunfleet Sands Ltd: Report no. 816R0105	None yet
Lynn	2006	Entec UK Ltd: May 2006 for AMEC Wind/RES: Report no. 816R0105	NPL: July 2006 Report no. DQL-AC (RES) 004	None yet
Inner Dowsing	2003	Entec UK Ltd: May 2006 for AMEC Wind/RES: Report no. 816R0105	None yet	

2. Conformity to Licence Conditions

The requirements for the licences issued to each of these wind farm developments are similar, and consist of the following main conditions (see Table 2):

1. **Pre-construction monitoring must be carried out to provide a baseline for subsequent monitoring of the effects of the wind farm. The adequacy of this baseline data must be agreed in writing by the Licensing Authority:**

Each of the FEPA licences for the eight wind farms specified that pre-construction monitoring must be carried out. This is to provide baseline data against which to compare the results of monitoring surveys during the construction and operational phases of the wind farms.

- Four of the eight OWFs submitted pre-construction noise monitoring reports; North Hoyle, Scroby Sands, Lynn and Inner Dowsing.
- At the four remaining OWFs, ambient noise measurements were taken at two OWFs between pile-driving activities during the construction phase (Burbo, and Gunfleet Sands OWFs); one took "background" noise measurements when only "a few wind turbines were operational", thus potentially not accurate ambient noise levels (Barrow OWF); and one does not appear to have taken any background measurements at all (Kentish Flats OWF – although a "background" measurement is given in a table 5.3 of the Subacoustech report (Nedwell et al. 2007), it is not clear where this measurement was taken, or when).

Summary: North Hoyle, Scroby Sands, Lynn and Inner Dowsing OWFs carried out pre-construction monitoring and obtained baseline measurements. Burbo, Gunfleet Sands, Barrow and Kentish Flats OWFs took ambient noise measurements during construction, during breaks in pile-driving activities or at a distance from the OWFs, or not at all. It is not clear whether or not any of these OWFs received written agreement from the Licensing Authority for the adequacy of the data.

2. **Monitoring must be carried out each following year for comparative purposes (i.e., construction, plus three years of post-construction (operational) monitoring):**
    - Monitoring of noise generated by pile driving activities during the construction of the OWFs was carried out at all OWFs. Monitoring reports for the assessment of post-construction (operational) noise have been submitted to FEPA for five of the eight OWFs; post-construction reports have not yet been submitted for the most recently built (or still under construction) OWFs (Gunfleet Sands, Lynn and Inner Dowsing).
    - Barrow, Burbo, Kentish Flats, North Hoyle and Scroby Sands OWFs only carried out one year of operational noise monitoring;

it is not clear whether this was agreed with the Licensing Authorities.
- In one case (Burbo), no post-construction monitoring was carried out. Rather Burbo OWF used the results of the nearby North Hoyle OWF, despite itself being composed of smaller turbines and smaller foundation support structures. However, this was agreed by the licensing authority.

Summary: This condition has been partially conformed to in all cases apart from Burbo OWF. but, this was agreed by the Licensing Authority. None of the OWFs have carried out more than one year of post-construction monitoring.

3. **There must be provision made during the construction of the wind farm for the installation of facilities to enable the assessment and monitoring of sub-sea noise and vibration during the operational phase of the wind farm:**
    - In all cases this condition was revised after consultations with the licensing authorities to: "Mobile rather than fixed equipment can be used, but several surveys will be required to take account of seasonal variations and fluctuating wind speeds".

4. **A methodology of sub-sea noise and vibration measurements must be submitted to the Licensing Authority and agreed prior to the end of the construction phase:**

Methodologies were provided by Subacoustech Ltd as part of the COWRIE bidding process and approved by the Licensing Authorities. Subacoustech Ltd carried out the pre-, during- and post-construction surveys at all the OWFs apart from at Lynn and Inner Dowsing. Entec UK Ltd, who carried out the pre-construction surveys at Lynn and Inner Dowsing, followed the Subacoustech methodology. The National Physical Laboratory (NPL), who carried out the construction survey at Lynn, did not mention the Subacoustech methodology, and there is no mention in the report of a methodology having been submitted to the Licensing Authority.

Summary: A methodology was submitted and approved by the Licensing Authorities, and has been used in all noise monitoring surveys apart from the construction survey at Lynn OWF.

5. **Measurements must be made at a variety of locations: immediately adjacent to the turbines; between turbines; within the array; outside the array at varying distances from the turbines. These measurement sites should reflect differences in sediment type, water depth and foundation/tower type:**

This licence condition refers to surveys to be carried out during the operational phases of the wind farms. Post-construction surveys were carried out at four of the eight OWFs; Barrow, Kentish Flats, North Hoyle and Scroby Sands.

- *Barrow:* The post-construction survey carried out at Barrow OWF took measurements adjacent to and between the turbines, and outside the turbines at varying distances. Transects carried out were orthogonal, so may have reflected differences in sediment type and water depth. These latter factors were not mentioned in the report, other than stipulating a water depth of 15 – 20 m across the site, therefore it is not known if measurements taken reflected differences in sediment type or water depth. Foundation type was constant across the site.
- *Kentish Flats:* No measurements of underwater noise were taken between turbines or within the OWF array. Measurements were taken at around 100 m from one of the turbines ("immediately adjacent to"), and to a range of 1 km outside the OWF at various distances. The measurements were taken along two orthogonal transects, possibly complying with the other conditions in this section to cover gradients of depth and sediment type, and although a general site description was included in the introduction, it was not specified whether the water depth and sediment type were constant across the site. Foundation type was constant across the site.
- *North Hoyle:* The post-construction survey carried out at North Hoyle OWF took measurements between and immediately adjacent to the turbines, within the wind farm array, and at various distances outside the array. However, transects were not orthogonal and it is not clear if gradients in water depth or sediment type were covered: these were not discussed in the report other than in a brief introduction that indicated a relatively constant water depth and general sediment type description. Foundation type was constant across the site.
- *Scroby Sands:* Measurements were taken immediately adjacent to and between turbines within the wind farm array, and to a range of ~ 1 km outside the array. Two measurements were taken away from the main transect outside the wind farm; these may have covered different water depths, as water depth was stated to vary considerably across the site, but this was not discussed. No indication of the sediment type of the local environment was given. Foundation type was constant across the site.

Summary: There is some variation between the post-construction surveys carried out at the four OWFs. It is unclear whether any of them fully comply with this licence condition, as none give any information regarding measurement locations with respect to variations in sediment type or water depth – it is possible, however, that this data exists in the datasets.

The surveys carried out at Barrow, North Hoyle and Scroby Sands OWFs comply with the first part of the condition (to take measurements adjacent to and between turbines within the OWF, and at varying distances outside). However, the survey carried out at Kentish Flats OWF did not conform to this.

6. **Detailed post-construction data of the frequency and magnitude of underwater noise generated by the operational wind farms must be collected and reported. The choice of sites for installing monitoring equipment should reflect the different conditions such as sediment type, water depth and pile type. This data would help to elucidate interactions between the provision of new habitat and fish aggregation effects, with noise generation. The data would also be used to determine the effects of distance, depth and background sources on noise propagation:**
    - *Barrow:* Detailed frequency and magnitude data of underwater noise emissions along two transects within the wind farm were presented and discussed, and the range at which the noise was no longer detected above ambient noise levels was also given (~ 600 m). The authors also discussed potential interactions with marine fish and mammals based on the fauna's hearing ability (dB_{ht}). In the condensed COWRIE overview report, (Nedwell, Parvin et al. 2007), submitted six months later, the data from other, orthogonal, transects outside the wind farm were discussed, and detailed frequency and magnitude data presented. The potential influence of water depth on noise propagation was briefly discussed; however the influence of sediment type on sound propagation was not addressed.
    - *Kentish Flats:* Detailed data were presented on the frequency and magnitude of underwater sound generated by the OWF. Measurements were taken along two orthogonal transects, and the effects of distance on sound propagation were discussed; low-frequency sound generated by the OWF could still be detected at the greatest ranges from the OWF at which sound was measured (~ 1 km). The study did not locate the range at which the sound generated by the OWF could no longer be detected above ambient noise levels, but did consider the potential impacts on marine fish and mammals.
    - *North Hoyle:* Detailed frequency and magnitude data were collected along one transect within and outside the wind farm. Although the effects of distance on sound propagation, and potential impacts on marine mammals and fish were discussed, the effects of water depth and sediment type were ignored. It is possible that in only collecting data along one transect, insufficient data were collected to examine these factors. The potential influence of distant shipping on the recordings was mentioned.
    - *Scroby Sands:* Detailed data of the frequency and magnitude of sound generated by the OWF are presented in the post-construction survey report (Nedwell, Parvin et al. 2007). Data were taken along a single transect, and water depth was recorded; a comparison between the interactions between the water depth and sound propagation at all sites was briefly discussed. The potential influence of sediment type was not

discussed. The data were compared to measured "ambient" noise data (taken between 925 and 1850 m from the wind farm) to elucidate the effects of distance from the wind farm on sound propagation. Potential interactions with marine fish and mammals were considered.

Summary: All post-construction survey reports collected and presented detailed data of the frequency and magnitude of underwater sound generated by the OWFs, for the measurements that they carried out. All of the reports addressed potential impacts of the levels of sound recorded on marine mammals and fish, however, none examined the interaction between sound generation and the provision of new habitats. The influence of water depth on sound propagation was briefly discussed, and although the influence of geology and bathymetry were mentioned, conclusions were not supported with data .

Table 2: Conformity of the wind farms to monitoring requirements.

	Wind farm							
License Condition	**Barrow**	**Burbo**	**Kentish**	**North**	**Scroby**	**Gunfleet Sands**	**Lynn**	**Inner Dowsing**
1. Pre-construction monitoring carried out?	N	N	N	Y	Y	N	Y	Y
Baseline measurements obtained?	Y	Y	N	Y	Y	Y	Y	Y
2. Monitoring carried out during construction?	Y	Y	Y	Y	Y	Y	Y	N
Monitoring carried out post-construction?	Y	N	Y	Y	Y	n/a*	n/a*	n/a*
3. Methodologies submitted to Licensing Authority?	Y	Y	Y	Y	Y	Y	?	?
4. Measurements made at a variety of locations (post-construction)	Y	N	Y	Y	Y	n/a*	n/a*	n/a*
Immediately adjacent to turbines?	Y	N	Y	Y	Y	n/a*	n/a*	n/a*
Between turbines?	Y	N	N	Y	Y	n/a*	n/a*	n/a*
Within wind farm array?	Y	N	N	Y	Y	n/a*	n/a*	n/a*
At varying distances outside array?	Y	N	Y	Y	Y	n/a*	n/a*	n/a*
Reflection of different sediment types?	?	N	?	?	?			
Reflection of different water depths?	?	N	?	?	?			
5. Detailed post-construction data of frequency and magnitude of underwater sound generated?	Y	N	Y	Y	Y	n/a*	n/a*	n/a*
Reflection of a variety of locations (as condition 4)	N	N	N	N	N			

* Not applicable as these OWFs are not yet in the operational phase.

3. Key Findings

From the construction monitoring reports from all seven OWFs, the following conclusions may be drawn:

- The peak-to-peak source SPL from pile-driving activities during construction at each of the wind farms is much higher than ambient noise levels (more than 100 dB higher where these data were presented);

- Sound from pile-driving operations can be detected by instrumentation headphones at ranges from 10 km up to 25 km away (Nedwell, Parvin et al. 2007); this variation may be a function of sediment type, water depth, pile diameter or ambient noise, and/or interactions between these factors;

- Based on the interpretation of the hearing thresholds of marine fish and mammals in the monitoring reports, the behavioural impact ranges (based on $90dB_{ht}$ peak-to-peak level) of the harbour porpoise (with relatively sensitive hearing) and the bass (with relatively insensitive hearing) are 2.5 – 10 km and 0.4 – 2 km respectively. This review concludes that these ranges do not appear to show any link to pile diameter, water depth or the absorption coefficient (in terms of decibels absorbed per m, dB/m).

- The authors of the monitoring reports found that driving larger diameter piles (ranging from 4.0 – 4.7 m) into the sediment resulted in greater source sound pressure levels (SPLs) than driving smaller diameter piles. The results presented in this report do not appear to agree with this conclusion (see Table); however, when looking at all monitoring reports, it can be seen that source SPLs were lower during pile-driving activities at Lynn OWF (Robinson and Lepper 2006), where piles were just 2.0 m diameter.

- In their review of Barrow, North Hoyle, Scroby Sands, Kentish Flats and Burbo OWFs, Subacoustech (Nedwell, Parvin et al. 2007) reported that, in general, underwater sound absorption was inversely proportional to water depth, suggesting that the propagation of underwater sound (and hence its potential impact on marine life) would be greater in deeper water. However, the range of water depths on which this relationship is based is relatively small, at ~ 14 m.

- Nedwell et al. (2007) also reported that absorption was affected by the geology and bathymetry of the area; however, they do not present information to support this conclusion.

The most significant conclusions from the construction noise monitoring reports are that a) the sound generated during pile-driving activities is far

higher than the ambient noise levels, and b) that propagation of this sound is quite variable. Both of these facts highlight the importance of a dedicated monitoring programme during the construction phases of OWF development: the current level of knowledge is not enough to predict the extent of the impact of construction noise on marine fauna, as the generation and propagation of the sound appears to depend on many, possibly interacting, factors.

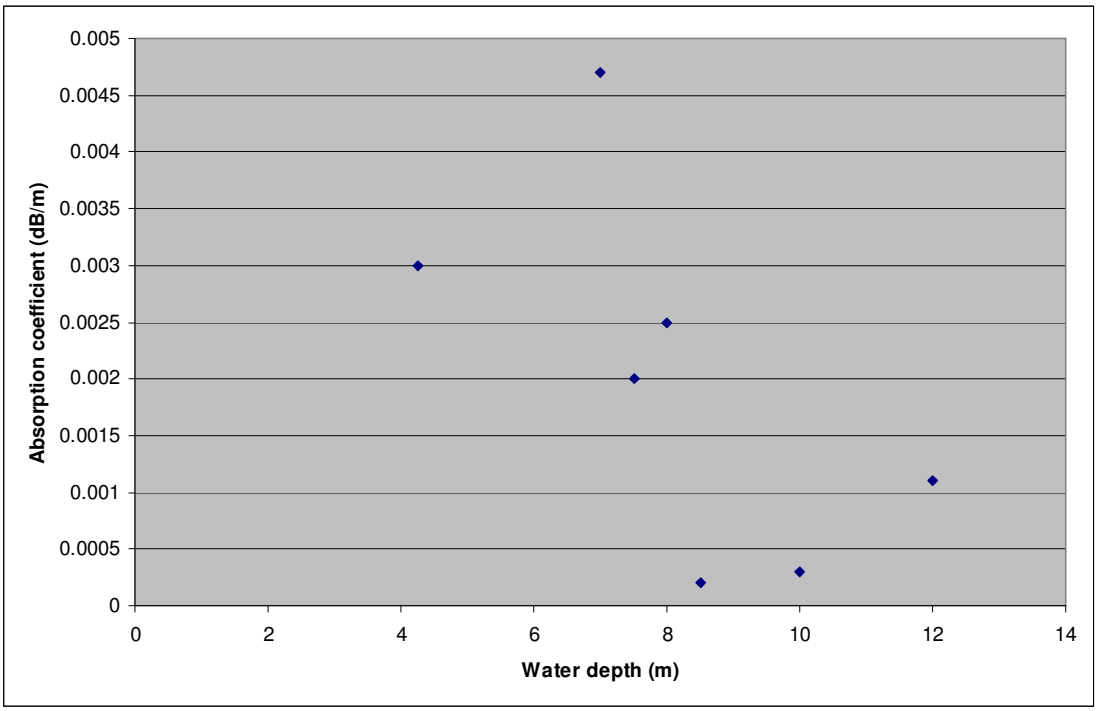

Figure 1: Relationship between the absorption coefficient and water depth.

Table 3: Key findings from construction noise monitoring reports.

Site (Reporting body)	Pile diameter (m)	Water depth (m)	Sediment type (m)	Ambient noise levels (dB re. 1 µPa at 1 m)	Construction noise (dB re. 1 µPa)						
					Calculated peak-to-peak source level (dB re. 1 µPa @ 1m)	At distance		Absorption coefficient (R)	Geometric spreading loss factor (N)	Behavioural impact range (based on 90 db_{ht} peak-to-peak level) (km)	
						Distance from source (km)	Sound level			Bass (relatively insensitive hearing)	Harbour porpoise (relatively sensitive hearing)
Barrow (Subacoustech)	4.7	10 – 20	?	(122)*	252	12.8	174	0.0003	18	2	10
Burbo (Subacoustech)	4.7	7 - 24	?	140	249	5.0	143	0.0047	21	0.5	5
North Hoyle (Subacoustech)	4.0	10-15	Gravely sand	(120)	249	-	-	0.0011	17	-	9
Scroby Sands (Subacoustech)	4.2	3.5 – 30	?	(132)	257	-	-	0.003	20	-	-
Kentish Flats (Subacoustech)	4.3	5 – 8	Sand and silt deposits	(113)	243	7.5	150	0.002	20	0.4	2.5
Gunfleet Sands (Subacoustech)	4.7	~ 2 - 15	?	113	245	10.0	~ 150	0.0025	18		6.5 – 9
Lynn (NPL)	2.0	3 - 7	Chalk	70.5 – 97.6	224 - 236	1.9	191	0.0002	-	-	-

*Brackets indicate ambient noise levels taken from Nedwell et al. (2007)'s overview of OWFs.

All of the underwater sound monitoring surveys carried out during the operational phases of wind farms (Barrow, Kentish Flats, North Hoyle and Scroby Sands) showed that there was very little difference between the sound levels within the wind farm arrays and outside them. Table 3 (below) illustrates these differences: in one case (Scroby Sands), the sound level even appears to be higher outside the array than within. This is likely to be the result of a combination of relatively high ambient noise in this area, and natural temporal and spatial variations in underwater sound. In general, the authors of the monitoring reports considered that the maximum increase in sound generated by the four OWFs (8 dB increase at North Hoyle), was no greater than might be expected from natural variations in ambient noise levels.

In terms of species-specific perceived sound levels (dB_{ht}), in no case were the levels of underwater sound generated by the operational wind farms found to be high enough to elicit either a strong or mild avoidance response in any of the marine mammals or fish considered (bass, salmon, dab, cod, herring, harbour porpoise, bottlenose dolphin and common seal).

Table 3: Key findings from operational noise monitoring reports.

Site	Operational noise (dB re. 1 µPa)			
	In close proximity		At distance	
	Location	Sound level	Location	Sound level
Barrow	Within array	124	Outside array	122
Kentish Flats	Within array	114	Outside array	113
North Hoyle	Within array	128	Outside array	120
Scroby Sands	Within array	130	Outside array	132

Comparability of Datasets and Reports

The reports were quite comparable, because all but two of the surveys were carried out by Subacoustech Ltd, who used the same methods for each. Of the remaining two surveys, one (Entec UK Ltd for the Lynn and Inner Dowsing pre-construction survey) used the Subacoustech method to obtain and report data. The other report, for the construction monitoring survey of Lynn OWF was conducted by the National Physical Laboratory, who did not quote Subacoustech methods, but used a similar method to collect and analyse the data.

The overview report submitted to COWRIE (Nedwell, Parvin et al. 2007) also presented a comparison of the impacts of underwater sound generated from four OWFs during the construction phase and the operational phase, looking at the influence of factors such as water depth ranges and pile diameter.

Generic and Site-Specific Issues, and Differences between Sites

All licences were identically worded, or were very similar, and all issues highlighted by the monitoring conditions (e.g., distance of sound propagation from operational wind farms) were applicable to all wind farms. It should be noted that none of the sites investigated vibration effects, some only made passing reference when describing monopile and foundation colonisation studies. Differences in the extent of sound propagation at each site were discussed in the overview report by Subacoustech (Nedwell, Parvin et al. 2007): the authors concluded that the extent of sound propagation was dominated by geological and bathymetric effects (though they did not explain the geological effects). The authors also concluded that, during the pile-driving activities, shallower sites tended to be associated with a higher degree of sound absorption probably brought about by greater interaction of the sound with the sea bed.

The differences and similarities between each site during the construction and operational phases are shown in Table 3 and Table 3.

Barrow OWF appears to be the site at which the sound generated during the construction phase of the development propagated the furthest (absorption coefficient = 0.0003), and consequently is the site at which marine mammals and fish were likely to be affected at the greatest range (10 km). The sound absorption during pile-driving activities at Lynn OWF site was similarly low (absorption coefficient = 0.0002), however, no information was given regarding the potential range of impact on marine fauna.

Kentish Flats and Gunfleet Sands OWFs exhibited similarly high absorption coefficients (0.002 and 0.0025 respectively), and generated similar source SPLs (245 and 243 dB re. 1 µPa at 1 m respectively). However, the range of impact on marine mammals (harbour porpoises) was not similar, at 2.5 km and 6.5 – 9.0 km respectively. This is possibly related to the water depth surrounding the sites; the water depths surrounding Gunfleet Sands OWF site is greater than at Kentish Flats, possibly allowing greater sound propagation in the deeper water layers.

Interactions at each Site

Although not a specific condition (“This data would help to elucidate interactions between the provision of new habitat and fish aggregation effects, with noise generation”), all but one of the monitoring reports (NPL report for the construction survey of Lynn OWF), discussed the potential interactions of underwater sound propagation with marine fish and mammals. None of the reports addressed any interactions between new habitats with sound generation. The Kentish Flats OWF post-construction monitoring report stated that data collected by Subacoustech and submitted to COWRIE as the overview report would be interpreted with regard to the findings of the benthic ecology, fish monitoring and epifaunal colonisation surveys. This report has not been seen to be included in this review, however.

A brief discussion on the interactions between water depth and pile diameter with underwater sound propagation was included in the overview report (Nedwell, Parvin et al. 2007), but interactions between geology and bathymetry were only briefly mentioned.

4. Necessity or Strengthening of Monitoring Requirements

Recommend which monitoring conditions are no longer necessary (because impacts have been demonstrated to be negligible):

The monitoring conditions specified in each of the OWF licences are either identical or very similar: to carry out pre-construction baseline monitoring and monitoring during the construction and operational phases; to submit methodologies for underwater sound monitoring to be agreed by the Licensing Authorities; and to take detailed measurements of the frequency and magnitude of the underwater sound at a variety of locations in order to reflect the differences in various factors across each site; and to report these data in monitoring reports.

The propagation of underwater sound is affected by several factors, such as the sound source characteristics (spectral, temporal etc.), but also by the local environment characteristics. The sound velocity profile of the water column (a function of the temperature and salinity), the water column depth, the ambient noise regime, sediment type and bathymetry can have both solitary and cumulative effects on the propagation of underwater sound, (and therefore on the range at which an effect may be expected on local marine fauna). In particular, more accurate models of noise absorption can be made with knowledge of the local sound velocity variations and the acoustic properties of the sea bottom (sediment type). Importantly, all of these parameters are site-specific.

It is therefore vital to characterise each site in terms of these parameters prior to any OWF development, and to monitor each site during the construction and operational phases, referring to its original baseline measurements.

The findings of the reports considered in this review suggest that the sound generated during the operational phases of the OWF development is only slightly elevated above ambient noise levels, and is predicted to have a negligible effect on local marine fauna. In light of this, the monitoring of operational noise from OWFs may be required, but may not be necessary as a standard licence condition at all sites. This should be reviewed on a case-by-case basis; as previously mentioned the propagation of underwater sound can be affected by many factors, which may be site-specific. In addition to this, as OWF technology advances, there may be changes to the structure and operation of OWFs, and therefore potentially also to the frequency and magnitude of sound emitted. It may also be sensible to carry out sufficient sampling over one year during OWF operation to address the potential influence of seasonality.

The Licensing Authority should consider the optimal route to ensuring that such data and assessments are undertaken, i.e. licence conditions, specific research projects or a combination of the two.

Recommend where monitoring conditions may need to be strengthened (because impacts have been underestimated):

It appears as though there is a "gradient" of acceptability for some of the licence conditions, most notably in the completion of a pre-construction baseline survey. A baseline survey is defined as one that is taken to establish initial conditions against which variations in those conditions during the course of the study may be compared. Only four of the eight OWFs considered in this report carried out a pre-construction baseline survey, despite this being one of the first monitoring conditions to be set out in the licence.

Of the remaining four OWFs, two gathered "ambient" noise data during breaks in pile-driving activity. It is not clear in either report how the increased activity around the OWF development sites (related to other installation processes) may have affected these "background" measurements. It is therefore not clear whether or not either of these OWF surveys fulfilled this condition.

Another of the OWF surveys gathered ambient noise data when "only a few turbines were operational". Although this study showed that there was no change in average SPLs with distance from the OWF, which suggests that there was no sound being generated from the OWF above ambient noise levels, this does not technically constitute a baseline survey. The final OWF (Kentish Flats) survey has not presented any data on the collection of baseline data, although some has been collected.

The completion of a pre-construction baseline survey is already a licence condition and so it is not possible to strengthen or emphasise it; the more stringent enforcement of this condition by the Licensing Authority would be the recommendation in this case. In addition to this development of a standard methodology for baseline noise surveys would assist cross-site comparisons.

There are two licence conditions relating to the collection and use of metadata to choose measurement locations. Both state that the measurement locations should reflect variations in sediment type, water depth and pile type, and that these data would be used to investigate interactions with sound propagation. As previously mentioned, local environmental conditions relating to sediment type, bathymetry and water depth can affect underwater sound propagation. Some of the OWF monitoring surveys planned orthogonal transects, which ought to have offered the opportunity to examine gradients in these factors, but beyond a brief paragraph, interactions between the local environment and sound propagation were not discussed. It would be beneficial to the understanding of underwater sound propagation (and thus impacts on marine fauna) to include a section specifically addressing interactions with sediment type, water depth, and bathymetry.

These two licence conditions also state that measurements should be taken immediately adjacent to, and between, turbines within the OWFs, and at varying distances outside them. Some OWF surveys did not take measurements at some of these locations, but though it may have been justifiably related to safety issues, no explanations were given.

The recommendation in this case would again be for a greater enforcement of these existing license conditions, the inclusion of a recommendation to collect bathymetric data, and the discussion of interactions between sound propagation and these local environmental conditions. Emphasis should also be placed on the proper reporting of data collected (as it is possible that the necessary data in these cases exists in the datasets but is not reported), and on explanations for any deviations from conditions.

Although potential interactions between marine mammals and fish with the propagation of underwater sound from the OWFs were considered in most OWF monitoring reports, none of the reports examined the noise data in relation to marine mammal monitoring reports, benthic or fish survey reports. In order to gain a more holistic view of the impacts of underwater sound on local marine fauna, it is important to consider the interactions between the data reported in all of these studies.

The compilation of a monitoring report during the construction phase of OWF development is listed in all of the licences; however, it is not reinforced in the more detailed supplementary conditions or annex, unlike conditions relating to the operational phase. In light of the findings of the reports, which suggest that the construction phase is the least predictable and potentially most harmful to marine life, it may be advisable to strengthen conditions relating to monitoring during the construction phase.

5. Monitoring Reporting Style and Format

On the whole, the manner in which the monitoring surveys were reported was quite confusing. In several cases (Barrow, Burbo, Kentish Flats, North Hoyle and Scroby Sands), reports were submitted by the OWFs to the Licensing Authorities, invariably referencing the overview report submitted to COWRIE by Subacoustech in 2007 (Nedwell, Parvin et al. 2007). Some of the information relevant to the fulfilment of the licence conditions could be found in the individual OWF reports, and some only in the COWRIE report. In none of these OWF reports was it possible to find out exactly what measurements had been taken where – charts were often the best indication of where measurements were taken in relation to turbines, but these rarely showed a scale or bathymetric information, and never both. Non-fulfilment of conditions (e.g. not collecting data from within a wind turbine array) was not explained, even though there may have been justifiable causes.

Charts showing measurement locations (with reference to the OWF if applicable), local bathymetry, with a scale and latitude/longitude, would be a useful addition to these reports, in combination with a table detailing metadata, for example:

Table 5: Example of table to be included in monitoring reports.

Measurement Station	Date	Location			Water depth (m)	Distance from ref. point (m)	Sediment type?*	Time of day	Sea state	Wind speed	No. operational turbines (if applicable)	Turbine velocity	Shipping traffic observed?
		RE: array	Lat.	Long.									
A		Outside											
B		Outside											
C		Between turbines											
D		Between turbines											
E		Etc.											
F etc.													

* This data be obtained by carrying out grab samples and PSA

From a reviewing point of view (and so probably also to those responsible for approving these reports) it would be useful to have such information included in these formats in order to help assess conformity to some parts of the licence. Additionally, it would be useful to be able to find all the necessary information relating to a particular stage of the process in one place, i.e., a pre-construction survey report, a construction survey report, post-construction survey reports. Whilst the licences all stated that collaborative studies could be used as a means to meet some of the conditions, and whilst the COWRIE report does meet many of the conditions, it is clear that the COWRIE report was not written with the licence conditions in mind – and given that it was not commissioned to this end, this is justifiable.

It would be useful if the monitoring reports were written up with a view to explaining how they have approached, and how they have fulfilled (or not) the various licence conditions, i.e., writing the report to answer the questions rather than writing, or referencing, a report, and assuming the answers will be drawn from it.

Of the eight OWFs, one pre-construction survey (the Lynn and Inner Dowsing Offshore Windfarms baseline report provided a clear overview of what had been done and which licence conditions had been met.

It would be useful to be able to see a checklist for each phase of the development process for each OWF, showing which conditions had been met, which had been altered and agreed by the Licensing Authority, and which had been declined. It would also be useful to include in the appendices of these reports, either the full datasets, or a list detailing information contained in the datasets.

6. Review of Findings; Conclusions and Recommendations

The main issues that have been brought up by this review are the level of enforcement of the existing licence conditions, and the style and format of the monitoring reports:

- **Necessity of existing licence conditions:**
  In light of the findings of the reports, which indicate that sound generated during the operational phase of the OWF developments is only slightly above ambient noise levels and is predicted to have negligible effects on marine fauna, it may no longer be necessary to carry out post-construction monitoring for three years: this condition could be downgraded to a non-standard condition, its inclusion in licences to be assessed on a case-by-case basis.

- **Enforcement of existing licence conditions:**
  The conditions set out in the licences are adequate; however, the enforcement of them is perhaps not as stringent as is necessary. It appears as though some of the conditions have been ignored, particularly those relating to a pre-construction baseline survey (and three years post-construction monitoring surveys), and to the choice of measurement locations. In some cases, it may be sufficient to change the wording of the condition (from "should" to "must" for example); in others, a more strict approval process from the Licensing Authority may be necessary. It is not clear where deviations from, or non-fulfilment of, conditions has been agreed with the Licensing Authorities.

- **Strengthening of existing licence conditions:**
  It would be advisable to strengthen existing conditions relating to the monitoring and reporting of sound generated during the construction phase of OWF developments. It is during this phase that the potentially most harmful levels of sound are emitted, and the propagation of this sound appears to be very site specific.

  It would also be advisable to reinforce the importance of analysing interactions between underwater sound generation and propagation with local environmental conditions (water depth, sediment type, etc.) and habitats and species, and to use reports from the marine mammal monitoring, benthic and fish surveying reports to achieve this.

- **Monitoring reporting style and format:**
  The reporting of the monitoring surveys needs to be clearer, and more comprehensive. Referring to a condensed overview report may not be the best way to assure the Licensing Authorities that licence conditions have been fulfilled, as it is hard to find out what data has been collected, and where etc. A template report, whereby licence conditions are discussed in terms of the approach and fulfilment of them might ease this, as would some kind of checklist. Better reporting style (in terms of charts, tables etc.) would be useful, as would including an appendix with a comprehensive list of data collected/existing in datasets.

References

Nedwell, J. R., S. J. Parvin, et al. (2007). Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters. Subacoustech Report No. 544R0738 to COWRIE Ltd.

Robinson, S. P. and P. A. Lepper (2006). Underwater noise monitoring during the test pile installation at Lynn & Inner Dowsing, April 2006. NPL Report, National Physical Laboratory