innogy

Sofia Offshore Wind Farm

Environmental Appraisal of Increased Hammer Energy Appendix C: Assessment of fish receptors

2020

Document ref: 003230411-01

This document is supplied on and subject to the terms and conditions of the Contractual Agreement relating to this work, under which this document has been supplied, in particular:

Confidentiality

This document is confidential.

Ecodoc Reference: 003230411-01

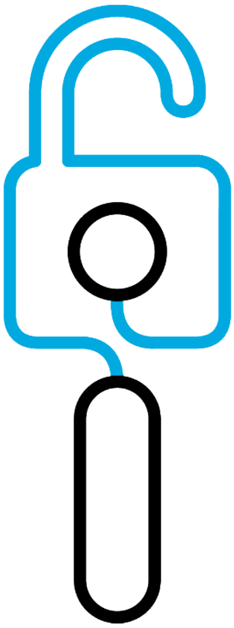
Liability

In preparation of this document innogy Renewables UK has made reasonable efforts to ensure that the content is accurate, up to date and complete for the purpose for which it was contracted. innogy Renewables UK makes no warranty as to the accuracy or completeness of material supplied by the client or their agent.

Other than any liability on innogy Renewables UK detailed in the contracts between the parties for this work innogy Renewables UK shall have no liability for any loss, damage, injury, claim, expense, cost or other consequence arising as a result of use or reliance upon any information contained in or omitted from this document.

Any persons intending to use this document should satisfy themselves as to its applicability for their intended purpose.

The user of this document has the obligation to employ safe working practices for any activities referred to and to adopt specific practices appropriate to local conditions.



Contents

1 Introduction

This document represents Appendix C to the Environmental Appraisal of Increased Hammer Energy (SOWFL, 2020. EcoDoc Ref; 00320484-01), and has been produced in response to all comments received from the Marine Management Organisation (MMO) and their advisors, CEFAS, during the consultation on the original 5,500kJ hammer energy increase proposal in 2018. Specifically, this Appendix therefore, considers the potential impacts of increasing the maximum hammer energy to 4,000 kJ for monopole foundation installation on:

- All fish and shellfish receptors on the assumption that receptors will be mobile when subjected to underwater noise from piling; and
- The potential behavioural impacts on herring (from the Flamborough Head spawning grounds) as a static receptor when subjected to underwater noise from piling.

The information presented within this Appendix has been directly updated from the information provided on the original 5,500kJ proposals (Appendix C to the original Environmental Appraisal and within the SoCG between SOWFL and the MMO) and therefore, will be familiar to the MMO and their statutory consultees.

2 Worst Case Assumptions

3.1 Assumptions Made Within the ES

The worst case scenario for the potential effects from underwater noise during the construction phase on fish and shellfish receptors as detailed in Chapter 13 (Fish and Shellfish Ecology) of the ES (as detailed in Table 5.2 of the ES chapter) may be summarised as follows:

- 200 x 6 pin pile foundations (3.5m pin piles; jacket foundations for WTGs; 1,200 piles) at maximum 2,300kJ hammer energy;
- 5 x 4 pin pile foundations (3.5m diameter pin piles, jacket foundation for met masts; 20 piles) at maximum 1,900kJ hammer energy;
- 4 x 24 pin pile foundations (2.75m diameter pin piles, jacket foundation for Offshore Collector Platform; 96 piles) at maximum 1,900kJ hammer energy;
- 1 x 24 pin pile foundations (2.75m diameter pin piles, jacket foundation for Offshore Converter Platform; 24 piles);
- 2 x 24 pin pile foundations (2.75m diameter pin piles, jacket foundation for Accommodation platform; 48 piles) at maximum 1,900kJ hammer energy;
- Maximum of 2 simultaneous piling operations; and
- Maximum duration of piling (including soft starts) based on the above, was concluded to be approximately 202 days for the installation of pin pile foundations.

It is key to note that whilst monopile foundations had a maximum hammer energy of 3,000kJ (and therefore, greater noise propagation range to the 2,300kJ maximum hammer energy from the pin pile foundations), the pin pile foundation construction scenario was deemed to represent the "worst case" scenario for the effects on fish and shellfish receptors from percussive piling. The justification for this being that the increased duration of noise exposure was more important (in defining worst case) than maximum range of exposure to noise. This point was agreed to by the MMO and its advisors as evidenced by the Statement of Common Ground between Forewind (the Applicant) and the MMO during the examination of the Project: 5-D-1 "The worst case scenario as defined in Table 5.1. (ref 6.13) is appropriate for the EIA"[1].

[1] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010051/EN010051-001322-Forewind%20-%20SocG%20with%20MMO.pdf

3.2 Assumptions Made Within the Increased Hammer Energy Report

The Non-Material Change (NMC) application and supporting documentation makes clear that the increase in hammer energy will only apply to monopole foundations. For pin pile foundations, 2,300 kJ will remain the maximum hammer energy. Within the NMC application the Environmental Appraisal of Increased Hammer Energy Report (SOWFL, 2020) Sofia Offshore Wind Ltd (SOWFL) therefore, does not seek to revisit the ES assumptions with regard to worst case scenario for underwater noise effects on fish, especially given the agreements reached on this assumption with the key stakeholders during the examination phase. Therefore, whilst the Increased Hammer Energy report makes reference to fish and shellfish being a sensitive receptor, no new assessment is undertaken, and the assessment and conclusions presented within the original ES were considered to remain valid for these receptors.

3.3 Consultation on the Increased Hammer Energy Proposals

Whilst no 'new' consultation on the proposed hammer energy increase to 4,000kJ has been undertaken since discussions concluded on the 5,500kJ proposals, SOWFL are cognisant of those discussions. Therefore, whilst it stands by the original conclusion drawn within the Increased Hammer Energy Report (that the worst case assumptions made in the ES remain valid), further context is provided within this Appendix to address those matters raised by the MMO and CEFAS in 2018. It is important to note that in doing so, SOWFL does not consider it appropriate to present an entirely new assessment on fish and shellfish resource, as to do so would undermine the existing assessment and agreements. Rather, the aim of this note is to establish whether there would be any significant increase in noise propagation ranges from the monopole scenario at 4,000kJ maximum hammer energy that would result in a change in the worst case assumptions made within the ES or not.

The following sections therefore, consider the noise modelling outputs from the ES with regard to fish and shellfish resource, and then updated outputs from the 4,000kJ modelling to enable a comparison of sorts to be made, noting that modelling techniques and threshold criteria are not directly like for like (as detailed below).

3 ES Assessment

4.1 Original Noise Modelling

In order to assess the impacts of underwater noise on fish and shellfish receptors during the construction phase, the National Physics Laboratory (NPL) used the Energy Flux model (Weston 1976). Twenty-seven locations were modelled across the Sofia site, and for each location pile driving noise was modelled for a hammer operating at up to 2,300kJ for pin pile installation and a hammer of up to 3,000kJ for monopoles.

Due to the limited data on the hearing capabilities of specific species of fish, generic criteria were used to model the ranges at which injury and behavioural effects were likely to occur, and species were divided into pelagic and demersal fish. The model utilised the criteria outlined by Popper et al. (2006) and Carlson et al. (2007) for injury in species of fish; and McCauley et al. (2000) and Pearson et al. (1992) for behavioural response in fish. The corresponding ranges modelled for each impact criterion are detailed in Table 4.1.

Impact Criterion		Potential Range of Impact	
		2300kJ Hammer Energy	3000kJ Hammer Energy
Instantaneous injury/PTS (peak pressure level 206dB re 1µPa)	Pelagic Species	<200m	<250m
	Demersal Species	<200m	<250m
Startle response (peak pressure level 200dB dB re 1µPa)	Pelagic Species	<500m	<600m
	Demersal Species	<500m	<600m

Impact Criterion		Potential Range of Impact	
		2300kJ Hammer Energy	3000kJ Hammer Energy
Possible avoidance of area[2](peak pressure level 168 - 173dB re 1µPa)	Pelagic Species	~9.5 – 19.5 km	~10.0 – 21.0km
	Demersal Species	7.5 – 15.5 km	8.0 – 17.5km

Table 3.1 Summary of impact range for hearing sensitive pelagic (mid-water) and demersal (near or on the seabed) fish using the criteria Popper et al. (2006) and Carlson et al. (2007) for injury in species of fish; and McCauley et al. (2000) and Pearson et al. (1992) for behavioural response in fish (Forewind 2014b)

4.2 Impacts on Fish and Shellfish

Based on the ranges produced by the NPL model, the worst case piling assumptions (based around timing, duration, and number of events) and the baseline information informing the sensitivity of receptors, the ES concluded that the impacts of underwater noise on all fish and shellfish receptors were not significant in terms of the Environmental Impact Assessment (EIA) as summarised in Table 4.2. The worst case scenario as outlined in the ES was considered within the SoCG between Forewind and MMO and agreed as being appropriate for the EIA[3].

Potential Effect	Receptor	Magnitude	Sensitivity	Impact
Construction Noise	Adult and juvenile fish	Negligible	Low	Negligible
	Larvae	Negligible	Medium	Minor adverse
Behavioural	Adult and juvenile fish	Low	Low	Minor adverse
	Herring	Low	Medium	Minor adverse
	Sandeel	Low	Medium	Minor adverse
	Diadromous species	Low	Low	Minor adverse
	Other fish species	Low	Low	Minor adverse
Prey Species/feeding	Fish in general	Low	Low	Minor adverse
General	Shellfish	Low	Low	Minor adverse

Table 3.2: Construction noise impact assessment on fish and shellfish receptors taken from the ES (Forewind, 2014a)

4 Sofia Assessment

As previously noted in this report, the worst case scenario as detailed in the ES considered that temporal disturbance from construction noise had a greater effect on fish and shellfish than the maximum range disturbance. Furthermore, the worst case scenario as outlined by the ES was agreed to by both Forewind and the MMO in the SoCG.

An increase in maximum hammer energy to 4,000 kJ for the installation of monopoles will have no impact on the worst case scenario as stated in the ES, since it refers to the installation of multi-leg pin piles due to the longer installation period associated with this foundation type. Notwithstanding this, the effect of a 4,000 kJ hammer energy on fish and shellfish receptors has been modelled by Subacoustech as set out in the following sections of this report.

5.1 Updated model for a maximum hammer energy of 4,000kJ

[2] Some particularly insensitive species of fish might only exhibit avoidance behaviour at lesser ranges

[3] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010051/EN010051-001322-Forewind%20-%20SocG%20with%20MMO.pdf

It has not been possible to secure use of the model used by NPL, therefore, Subacoustech have used the INSPIRE model to predict the noise levels and associated impacts at an increased hammer energy of 4,000 kJ (with the validation process between the two models presented in Appendix A to the Increased Hammer Energy Report (SOWFL, 2019).

It is important to note that since the original (NPL) modelling work for the ES, new threshold criteria have been adopted (Popper et al, 2014). Therefore, effects of noise on fish have been assessed using criteria from Popper et al. (2014), which gives specific criteria for mortality and potential mortal injury, recoverable injury and Temporary Threshold Shift (TTS), masking and behaviour from various stimuli, including impact piling. Species of fish are grouped by whether they have a swim bladder and whether that swim bladder is involved in hearing. The criteria are given as unweighted SPL_{peak}, and SEL_{cum} values and are summarised in Table 5.1.

Type of animal	Mortality & potential mortal injury	Recoverable injury	TTS
Fish: no swim bladder	> 219 dB SEL_{cum} > 213 dB SPL_{peak}	> 216 dB SEL_{cum} > 213 dB SPL_{peak}	>> 186 dB SEL_{cum}
Fish: swim bladder not involved in hearing	210 dB SEL_{cum} > 207 dB SPL_{peak}	203 dB SEL_{cum} > 207 dB SPL_{peak}	> 186 dB SEL_{cum}
Fish: swim bladder involved in hearing	207 dB SEL_{cum} > 207 dB SPL_{peak}	203 dB SEL_{cum} > 207 dB SPL_{peak}	186 dB SEL_{cum}

Table 4.1 Assessment criteria for species of fish from Popper et al. (2014) for impact piling noise

Where insufficient data is available (which is the case for masking and behavioural effects from impact piling), qualitative criteria (from Popper et al., 2014) have been given, summarising the effect of the noise as having either a high, moderate or low effect on an individual in either the near-field (tens of metres), intermediate-field (hundreds of metres), or far-field (thousands of metres). This also includes information for masking and behavioural effect. These qualitative effects are reproduced in Table 5.2.

Type of animal	Masking	Behaviour
Fish: no swim bladder	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder not involved in hearing	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate

Table 4.2 Summary of the qualitative effects on fish from impact piling noise from Popper et al. (2014) (N=Near-field, I=Intermediate-field, F=Far-field)

The outputs from the updated 4,000kJ modelling are presented in Table 5.3 (for SPL_{peak}) and Table 5.4 (for SEL_{cum}).

Fish - SPL_{peak} impact criterion		2300 kJ hammer energy	3000 kJ hammer energy	4,000 kJ hammer energy
Injury (fish: no swim bladder) unwtd SPL_{peak} (> 213 re 1 µPa)	Maximum	100 m	120 m	140 m
	Minimum	90 m	110 m	130 m
	Mean	95 m	120 m	140 m
Injury (fish: with swim bladder) unwtd SPL_{peak} (> 207 re 1 µPa)	Maximum	220 m	250 m	300 m
	Minimum	210 m	240 m	290 m

Fish - SPL_{peak} impact criterion		2300 kJ hammer energy	3000 kJ hammer energy	4,000 kJ hammer energy
	Mean	220 m	250 m	300 m

Table 4.3 Predicted unweighted SPL_{peak} impact ranges for fish using criteria from Popper et al. (2014)

Fish - SEL_{cum} impact criterion (Sequence 3)		2300 kJ hammer energy	3000 kJ hammer energy	4,000 kJ hammer energy
Mortality (Fish: no swim bladder) unwtd SEL_{cum} (> 219 re 1 µPa²s)	Maximum	< 50 m	< 50 m	< 50 m
	Minimum	< 50 m	< 50 m	< 50 m
	Mean	< 50 m	< 50 m	< 50 m
Recoverable injury (fish: no swim bladder) unwtd SEL_{cum} (> 216 re 1 µPa²s)	Maximum	< 50 m	< 50 m	< 50 m
	Minimum	< 50 m	< 50 m	< 50 m
	Mean	< 50 m	< 50 m	< 50 m
Mortality (Fish: swim bladder not involved in hearing) unwtd SEL_{cum} (210 re 1 µPa²s)	Maximum	< 50 m	< 50 m	< 50 m
	Minimum	< 50 m	< 50 m	< 50 m
	Mean	< 50 m	< 50 m	< 50 m
Mortality (Fish: swim bladder involved in hearing) unwtd SEL_{cum} (207 re 1 µPa²s)	Maximum	< 50 m	< 50 m	< 50 m
	Minimum	< 50 m	< 50 m	< 50 m
	Mean	< 50 m	< 50 m	< 50 m
Recoverable injury (fish: with swim bladder) unwtd SEL_{cum} (203 re 1 µPa²s)	Maximum	< 50 m	< 50 m	< 50 m
	Minimum	< 50 m	< 50 m	< 50 m
	Mean	< 50 m	< 50 m	< 50 m
TTS (all fish) unwtd SEL_{cum} (186 re 1 µPa²s)	Maximum	14.6 km	16.7 km	19.0 km
	Minimum	11.5 km	12.9 km	14.4 km
	Mean	13.0 km	14.7 km	16.7 km

Table 4.4 Predicted unweighted SEL_{cum} impact ranges for fish using criteria from Popper et al. (2014) assuming a fleeing speed of 1.5 ms^{-1} for potential ramp up sequence 3

Lethal / Injurious effects

The results (Tables 5.3 and 5.4) show that for lethal and or injurious effects even at an increased hammer energy of 4,000 kJ the impact ranges using the Popper et al. (2014) criteria are calculated to be no greater than 300 m (SEL_{peak}) or <50 m (SEL_{cum}). Lethal and injurious ranges in the ES were predicted to be up to or less than 250 m (see Table 4.1).

Whilst a direct like for like comparison is not feasible (for reasons stated above), for all of the SEL_{cum} 4,000 kJ scenarios modelled the range remains well within that predicted within the ES. For SEL_{peak} outputs, the range is within that predicted within the ES for the > 213 re 1 µPa scenario (up to 110 m), but is marginally greater for the > 207 re 1 µPa (up to 300 m).

The fish and shellfish chapter of the original ES concluded (at paragraph 6.9.2) that "juvenile and adult fish are expected to avoid the localised areas where the highest noise levels will be reached during piling activity" and therefore, a negligible impact was predicted. The maximum PTS range for SEL_{peak} when considering a maximum hammer energy of 4,000 kJ remain within a few hundred metres from the piling location, and therefore, the conclusion drawn in the ES remains valid, particularly when considering the fact that there will be a soft start and ramp up to the piling before maximum hammer energy is reached (if at all).

Behavioural effects

As Popper et al. (2014) concluded that there is insufficient data available to apply quantitative thresholds for behavioural effects of noise on fish, a direct comparison of the NPL and INSPIRE model output is not possible, given that different metrics were calculated. Therefore, in order allow for an examination of the impact of an increased hammer energy, the TTS impact criterion has been selected as the closest possible comparison to the possible avoidance response modelled by NPL. It has previously been demonstrated to and recognised by the MMO and Cefas (in relation to other offshore wind farm developments) that the modelled noise propagation contours for both the 186dB SEL_{cum} metric threshold and the 168dB SPL_{peak} metric threshold as identified by McCauley et al. (2000) and defined as representing the outer limit for moderate disturbance, are comparable in terms of spatial extent. Although the metrics themselves are not analogous, the areas of potential effect generated by the modelling can be used to inform the assessment of both criteria in general terms. This comparative approach has been developed in relation to other offshore wind farm developments where it has not been possible to carry out exactly like-for-like modelling.

Using the INSPIRE model, the maximum range of TTS (all fish) unwtd SEL_{cum} of 186 re 1 µPa2s was found to be 19.0 km for a hammer energy of 4,000 kJ, which is within the range of propagation distances predicted within the ES modelling for both demersal and pelagic species in response to a peak level of 173 dB re 1µPa (Table 4.1, above).

As previously stated, the ES considered that the temporal disturbance from construction noise has a greater effect on fish and shellfish than the maximum range disturbance. The worst case scenario outlines a piling duration of 202 days for pin pile installation, which is significantly greater (185%) than the 71 days required for monopole installation and therefore, this component of the impact magnitude will be greatly reduced.

Accordingly, it is the conclusion of this assessment that there is no evidence to suggest that the magnitude of effect on fish receptors (as presented in the original ES and agreed to by the MMO) would increase as a result of the proposed increased maximum hammer energy to 4,000 kJ. As a result the impact assessment as presented in the original ES and summarized in Table 4.2 above, remains a valid worst case assessment.

5.1 Effects on Flamborough Head herring spawning

As part of the consultation on the original 5,500kJ application, the MMO and CEFAS requested further information from SOWFL specifically related to the potential effects of the increase in hammer energy on the Flamborough Head herring spawning ground for the Sofia Offshore Wind Farm (SOWF) and that as part of this a modelling scenario should be run assuming that the receptor remains in static form when exposed to underwater noise.

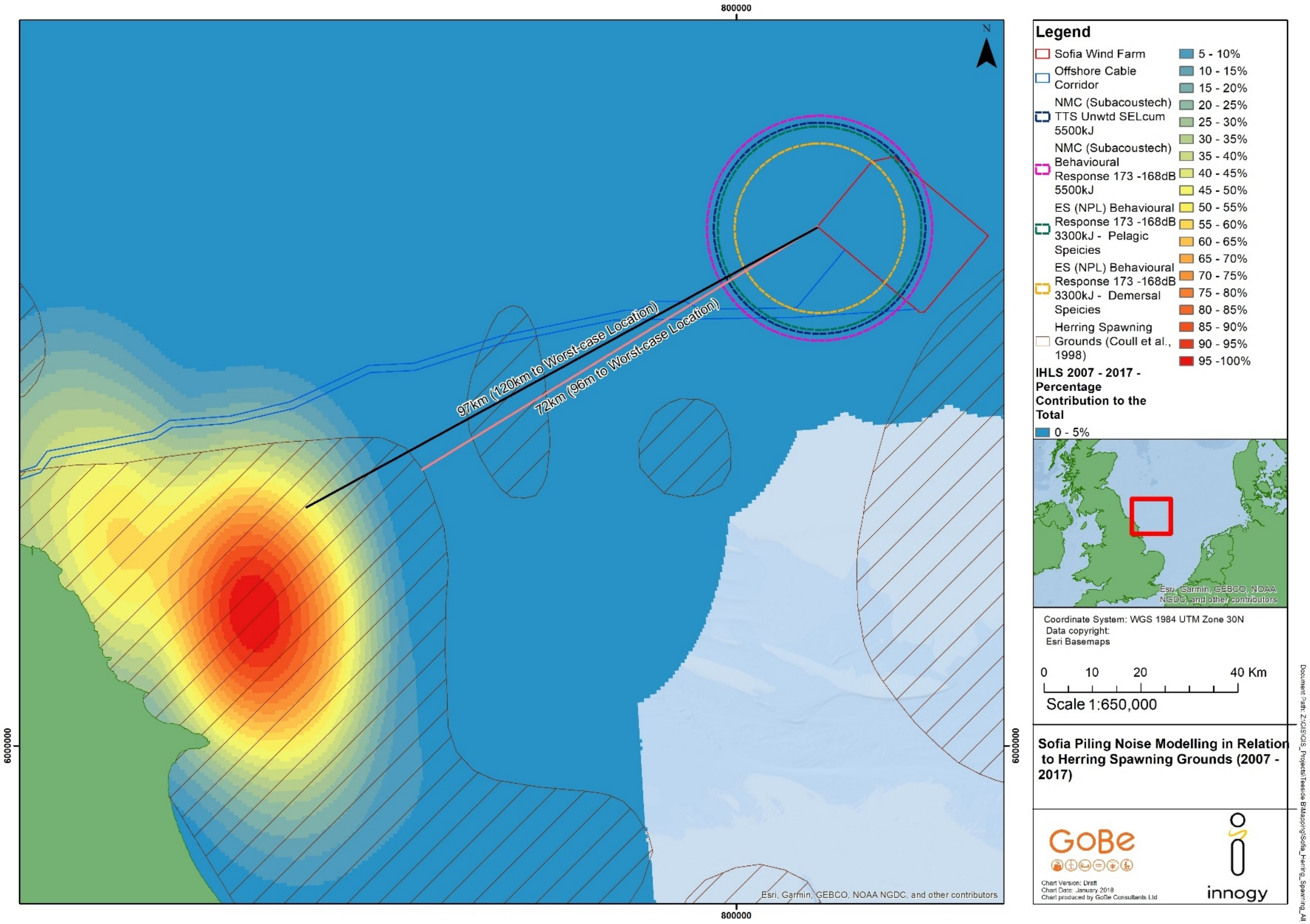
SOWFL considered that the assessment it undertook as part of the original NMC application was adequately robust and appropriate and that further modelling was not merited based on those findings. Notwithstanding this, further modelling (including assuming stationary fish) was undertaken, without prejudice to the primary assessment on potential effects on fish, in an effort to close out all residual matters raised by CEFAS.

SOWFL continue to strongly opine that the use of the SEL_{cum} stationary fish model is not representative of how an active fish such as herring is likely to respond if disturbed, and it therefore, presents an over-precautionary unrealistic method of assessing underwater effects. However, updated static fish modelling has been undertaken in support of this 4,000kJ hammer energy appraisal.

Before, discussing the latest modelled outputs, it is important to consider the context of the SOWFL wind farm array location in relation to the Flamborough Head spawning ground, and Figure 1 presents this further contextual information along with the original fish modelling outputs from the NMC application work.

For clarity, SOWFL confirm that the Flamborough Head herring spawning ground lies some 96km from the closest point of the array based on the Coull et al (1998) data (and 75km from the furthest modelled behavioural response contour that was established within the NMC application assessment), and 120km from the 50-55% spawning effort contour, based on the 10 year (2007-2017) International Herring Larvae Survey (IHLS) dataset (and 100km from the furthest modelled behavioural response contour).

Figure 1: SOWF UWN modelling in relation to Flamborough Head spawning ground



The latest modelling work for the 4,000kJ appraisal has been undertaken by Subacoustech Ltd and has produced the following outputs:

- SPL_{peak} outputs;
- SEL single strike (SEL_{ss}) outputs; and
- SEL_{cum} stationary fish outputs (using Popper et al (2014)).

Tables 5.5, 5.6 and 5.7 present the output of the modelling undertaken. For the SPL_{peak} and SEL_{ss} the most precautionary criteria that could theoretically be used for herring is that established in Hawkins et al (2014), noting that it is widely accepted to be overly precautionary as the studies was undertaken in a calm sea lough and therefore, not representative of open ocean environments such as the in the southern North Sea. The SEL_{cum} outputs are as presented in the NMC application (i.e., based on Popper et al (2014) 186dB) but assume a static receptor, which again is overly precautionary.

Using these criteria, the worst case behavioural impact ranges for the three modelled parameters are set out below:

- SPL_{peak}: maximum possible impact range at 160dB-165dB is 34km – 26km;
- SEL_{ss}: maximum possible impact range at 135dB-145dB is 71km – 36km; and
- SEL_{cum} stationary fish: maximum possible impact range at 186dB is 31km.

As noted above, the closest point of the Flamborough herring spawning ground based on the more precautionary Coull et al data) to the array area is 96km. This modelling has demonstrated that even when using criteria that is accepted as being unrealistically precautionary assumptions (in the case of the Hawkins criteria) and the assumption that fish will remain static when exposed to noise, the distance of the spawning grounds remains significantly beyond any modelled theoretical impact range. It can therefore, be concluded with confidence that there is no pathway for behavioural effects from piling at SOWF to manifest on the Flamborough Head herring spawning grounds.

Table 5.5: SPLpeak outputs (yellow highlights indicate range based on Hawkins criteria)

	Unweighted SPLpeak								
	200 dB	195 dB	190 dB	185 dB	180 dB	175 dB	170 dB	165 dB	160 dB
4000 kJ single strike									
Area (km²)	1.8	6.9	24	76	210	490	980	1800	2900
Maximum Range (m)	770	1500	2800	5000	8400	13000	19000	26000	34000
Minimum Range (m)	760	1500	2800	4900	8100	12000	17000	22000	27000
Mean Range (m)	770	1500	2800	4900	8200	12000	18000	24000	31000
400 kJ single strike									
Area (km²)	0.12	0.46	1.8	6.9	24	76	210	490	980
Maximum Range (m)	200	390	770	1500	2800	5000	8400	13000	19000
Minimum Range (m)	190	380	760	1500	2800	4900	8100	12000	17000
Mean Range (m)	200	390	770	1500	2800	4900	8200	12000	18000

Table 5.6: SELss outputs (yellow highlights indicate range based on Hawkins criteria)

	Unweighted SELss									
	180 dB	175 dB	170 dB	165 dB	160 dB	155 dB	150 dB	145 dB	140 dB	135 dB
4000 kJ single strike										
Area (km²)	1.6	7.6	32	110	350	840	1700	3200	5400	8900
Maximum Range (m)	730	1600	3200	6100	11000	17000	25000	36000	51000	71000
Minimum Range (m)	720	1600	3200	6000	10000	16000	22000	28000	34000	41000
Mean Range (m)	730	1600	3200	6100	11000	16000	24000	32000	41000	53000
400 kJ single strike										
Area (km²)	0.08	0.35	1.6	7.6	32	110	350	840	1700	3200
Maximum Range (m)	160	340	730	1600	3200	6100	11000	17000	25000	36000
Minimum Range (m)	150	330	720	1600	3200	6000	10000	16000	22000	28000
Mean Range (m)	160	340	730	1600	3200	6100	11000	16000	24000	32000

Table 5.7: SELcum modelling outputs assuming a stationary receptor (maximum range highlighted yellow)

	Unweighted SELcum (stationary animal model)					
	219 dB	216 dB	210 dB	207 dB	203 dB	186 dB
4000kJ Sequence 3 (5h30m)						
Area (km²)	1.7	4.2	25	55	150	2500
Maximum Range (m)	740	1200	2800	4300	7000	31000
Minimum Range (m)	730	1200	2800	4200	7000	26000
Mean Range (m)	740	1200	2800	4200	6900	28000

5 Conclusion

This Appendix has considered the implications of an increased hammer energy (of 4,000kJ) for monopole foundation installation on fish and shellfish receptors, through a comparison with the evidence presented in the original ES. In undertaking this assessment updated threshold criteria (from Popper et al, 2014) and modelling techniques (SEL_{cum}) have been applied.

The assessment of cumulative sound exposure presented within this report has identified that:

- For lethal / injurious effects, whilst for some outputs the maximum range may increase as a result of the 4,000kJ hammer energy the effects remain very much within the localised area and therefore, the rationale for the conclusion reached within the ES remains valid.
- For behavioural effects the updated ranges predicted for a 4,000kJ hammer energy scenario are within those ranges predicted within the ES (see Table 4.1 above) that underpinned the subsequent impact assessment. Furthermore, it has been identified that under the 4,000kJ hammer energy scenario (to which this report relates), the duration of effect will be reduced by 185% from that considered within the ES.

As a result of these findings, the significance of these impacts will be no greater than that concluded within the original ES, when a 4,000kJ maximum hammer energy is applied for monopole foundations.

Further bespoke modelling has been undertaken to explore potential impacts on the Flamborough Head herring spawning grounds in anticipation of CEFAS raising the same queries as raised on the original 5,500kJ application. All modelling outputs have demonstrated that there will not be any behavioural effects on the spawning ground as a result of the use of a maximum hammer energy of 4,000kJ.

6 References

Carlson T, Hastings M, Popper A N (2007). Memorandum – Update on recommendations for revised interim sound exposure criteria for fish during pile driving activities. Sent to California Dept. of Trans. And Washingron Dept. of Trans.

Coull, K.A., Johnstone, R., and S.I. Rogers. (1998). Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd.

Forewind 2014a. Environmental Statement Chapter 13 Fish and Shellfish Ecology. F-OFC-CH-013 Issue 4.1

Forewind 2014b. Environmental Statement Chapter 5 Appendix A Underwater Noise Modelling

Hawkins et al. (2014) Responses of free-living coastal pelagic fish to impulsive sounds. J. Acoust. Soc. Am., Vol. 135, No. 5

McCauley R D, Fewtrell K, Duncan A J, Jenner C, Jenner M-N, Penrose J D, Prince R I T, Adhitya A, Murdoch J, McCabe K (2000). Marine seismic surveys – A study of environmental implications. Appea Journal, pp 692-708.

Pearson W H, Skalski J R, Malme C I (1992). Effects of sounds from a geophysical survey device on behaviour of captive rockfish (Sebastes spp.). Can. J. Fish. Aquat. Sci., 49, pp. 1343-1355.

Popper A N, Hawkins A D, Fay R R, Mann D A, Bartol S, Carlson T J, Coombs S, Ellison W T, Gentry R L, Halvorson M B, Løkkeborg S, Rogers P H, Southall B L, Zeddies D G, Tavolga W N (2014). Sound Exposure Guidelines for Fishes and Sea Turtles. Springer Briefs in Oceanography, DOI 10. 1007/978-3-319-06659-2.

SOWFL, 2020. Environmental Appraisal of Increased Hammer Energy

Weston, D (1976) Propagation in water with uniform sound velocity but variable-depth lossy bottom. Journal of Sound and Vibration, 47,pp.473-483.

Innogy Renewables UK Limited

Windmill Hill Business Park
Whitehill Way
Swindon
Wiltshire SN5 6PB
T +44 (0)8456 720 090
www.innogy.com

Registered office:
Innogy Renewables UK Limited
Windmill Hill Business Park
Whitehill Way
Swindon
Wiltshire SN5 6PB
Registered in England and Wales no. 02550622