# REPORT ON THE ENVIRONMENTAL IMPACT ASSESSMENT OF THE BALTICA-1 OFFSHORE WIND FARM

## APPENDIX 3

## THE NUMERICAL MODELLING OF THE PROPAGATION OF NOISE FROM THE PILE-DRIVING IN THE BALTICA-1 OWF AREA

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## ABBREVIATIONS AND DEFINITIONS

| | |
|---|---|
| µPa | micropascal |
| BBC | Big Bubble Curtain |
| dB | decibel – a logarithmic measure of sound intensity/pressure. The decibel value for sound pressure is 10 log10 ($P^2/P_o^2$) where P = the actual pressure and $P_o$ = the reference pressure |
| DBBC | Double Big Bubble Curtain |
| EIA | Environmental Impact Assessment |
| HF | the high-frequency cetacean hearing group (here: the harbour porpoise) (hearing group classification based on the NMFS, 2018) |
| HF-weighted SEL | sound exposure level with high-frequency weighting function according to susceptibility to noise-induced hearing loss in cetaceans (based on NMFS 2018) |
| HSD | Hydro Sound Damper |
| Hz | hertz – the unit of frequency, where 1 Hz is 1 cycle per second and 1 kHz is 1000 cycles per second |
| IQIP-NMS | Noise Mitigation Screen manufactured by IQIP, previously known as an IHC-NMS |
| NMFS | The US National Marine Fisheries Service |
| NOAA | The US National Oceanic and Atmospheric Administration |
| OWF | Offshore Wind Farm |
| PTS | Permanent Threshold Shift – a permanent increase in hearing threshold due to a physical injury of hair cells because of exposure to sound |
| PTS (cumulative) | the permanent shift in hearing threshold due to a cumulative dose of noise exposure |
| PTS (single blow) | the permanent shift of the hearing threshold as a result of a single pile driver blow |
| PW | the hearing group of high-frequency cetaceans in the water (here: the grey seal and harbour seal) (hearing group classification based on the NMFS, 2018) |
| PW-weighted SEL | sound exposure level with frequency weighting function according to the susceptibility to noise-induced hearing loss in seals (based on NMFS 2018, 2020) |

| | |
|---|---|
| RAM | Range-dependent Acoustic Model – a model based on the parabolic equation method, assuming that emitted energy dominates over back-scattered energy |
| SEL | Sound Exposure Level; it is often used when assessing the impact of noise on the marine environment as a measure of the total noise energy normalised to 1 second |
| $SEL_{cum}$ | the cumulative level of sound exposure, i.e. a summation of the sound exposure levels of multiple consecutive events. It is calculated as: $$\mathrm{SEL_{cum}} = \mathrm{SEL} + 10\ \log_{10} n$$ n = the number of pile driver blows |
| SPL | Sound Pressure Level [dB re 1µPa] – the sound pressure expressed in decibels [dB] relative to the reference pressure $P_{ref}$ = 1µPa |
| $SPL_{peak}$ | Peak Sound Pressure Level – the maximum value of a signal amplitude |
| $SPL_{rms}$ | the root mean square (rms) of the sound pressure amplitude |
| SRC | source |
| TL | Transmission Loss (propagation loss) – reduction in sound intensity with the increase in distance |
| TTS | Temporary Threshold Shift – a temporary increase in hearing threshold after exposure to sound; the hearing threshold will return to pre-exposure state after some time |
| TTS (cumulative) | a temporary shift in hearing threshold due to a cumulative dose of noise exposure |
| TTS (single blow) | a temporary shift in the hearing threshold as a result of a single pile driver blow |
| VHF | the very high-frequency cetacean hearing group (here: the harbour porpoise) (hearing group classification based on Southall et al., 2019) |
| VHF-weighted SEL | Sound Exposure Level with Very High-Frequency weighting function according to susceptibility to noise-induced hearing loss in cetaceans (based on Southall et al., 2019) |
| WOA | World Ocean Atlas |
| WOD | World Ocean Database |

# 1 NON-SPECIALIST SUMMARY

Underwater sound is generated during all stages associated with the construction, operation, and decommissioning of an offshore wind farm (OWF). The highest environmental risks are related to underwater noise emitted during construction, due to the relatively high sound levels generated when piles are driven into the seabed. Marine organisms, including fish and mammals, are sensitive to sound, hence the noise associated with the construction of an OWF may affect them even from a considerable distance.

For the purposes of this Report, the acoustic emission associated with piling in the area of the Baltica-1 OWF, which is located in the Polish exclusive economic zone, was examined. The analysis was conducted for three WTG locations in the northern, central, and southern parts of the OWF. Depending on the location, the analyses were carried out for the winter season, which was considered the worst-case scenario in terms of the greatest range of acoustic wave propagation, and the summer season, which, despite the smallest range of underwater noise impact, was considered the farthest-reaching scenario from the point of view of the environmental, i.e. the impact on marine mammals associated with the greatest activity of porpoises.

Based on the acoustic modelling performed, the zones of noise impact (in the form of distance from the sound source expressed in kilometres) on marine mammals (porpoises and seals) and fish with swim bladders were estimated. The noise effects considered included behavioural responses (behavioural changes), and hearing loss in the form of temporary and permanent shifts in the hearing thresholds (TTS, PTS, and reversible hearing loss in the case of fish with swim bladders). As a result, this Report constitutes the technical basis for the Environmental Impact Assessment of the Investment regarding marine mammals and fish.

For modelling purposes, 72 transects with a maximum length of 150 km, extending in all directions from the sound source, were selected. Bathymetric data were obtained from the EMODnet platform. The geological profile of the seabed was determined based on the results of the preliminary environmental surveys conducted within the Baltica-1 OWF area, and the profiles of sound propagation velocity in the soil were determined using publicly available databases.

In the first stage, the worst-case scenario was determined by estimating the acoustic energy emitted depending on the wind turbine generator foundations used (e.g. large-diameter monopile, tripod, and gravity-based structure). The calculation of total acoustic energy emitted at the construction stage involving the driving of a single pile indicated that the worst-case scenario is the option with monopile installation. The calculations were performed for a monopile with a diameter of 12 m and a hammer with an impact energy of 8000 kJ (based on data provided by the Client). The calculated sound source level (the sound level at a distance of 1 m from the source) was expressed as the sound exposure level (SEL), i.e. the emitted acoustic energy (in dB re 1 μPa$^2$s) and the peak sound pressure levels ($SPL_{peak}$ [dB re 1 μPa]). Their values were determined for individual hammer blows, as well as for the estimated maximum number of blows required to drive one foundation into the seabed. The following values were used in the modelling:

- SEL for a single blow = 228.9 dB re 1 μPa$^2$s (in the northern location); 228.4 dB re 1 μPa$^2$s (in the central location); 230.1 dB re 1 μPa$^2$s (in the southern location);
- $SPL_{peak}$ for a single blow = 248.9 dB re 1 μPa (in the northern location); 248.4 dB re 1 μPa (in the central location); 250.1 dB re 1 μPa (in the southern location);

- SEL for a single strike = 267.1 dB re 1 $\mu Pa^2 s$ (in the northern location); 266.5 dB re 1 $\mu Pa^2 s$ (in the central location); 268.2 dB re 1 $\mu Pa^2 s$ (in the southern location).

The cumulative SEL was calculated based on a 24-hour time interval, taking into account the total number of hammer strikes needed to install a monopile.

The emitted sound levels were also estimated when using noise mitigation measures. For this purpose, depending on the location, a single big bubble curtain (BBC), a system consisting of a hydro sound damper (HSD) and a double big bubble curtain (HSD + DBBC), as well as a system consisting of an IQIP noise mitigation screen in combination with a double big bubble curtain (IQIP + DBBC) were taken into account.

Sound propagation modelling was performed for the frequency range of 20 Hz–4 kHz. Higher frequencies were estimated based on the results for the level of 4 kHz and corrected for frequency-dependent propagation losses. Numerical modelling was performed using the MIKE Underwater Acoustic Simulator (UAS) software by DHI.

The peer-reviewed US guidelines for the TTS (temporary threshold shift) and PTS (permanent threshold shift) criteria were used to estimate the impact zones in relation to marine mammals. Behavioural criteria were developed based on a detailed literature review. In addition, an animal motion model and the "ramp-up" procedure were used in the construction noise analysis. The so-called "effective quiet," which is the threshold below which the accumulation of acoustic energy in an animal does not occur, was applied in the construction noise analysis. For fish with swim bladders, the noise criteria were taken from the available expert guidelines and literature review. For fish without swim bladders, no quantitative assessment was feasible. The results of recent studies on the effects of noise on fish without swim bladders have proven that for this group of fish, the relevant auditory stimulus is particle motion rather than pressure. Currently, there are no reliable criteria that provide a basis for performing an impact assessment on fish without swim bladders as a result of particle motion. Therefore, a qualitative assessment was carried out for this group of fish based on a review of the literature available.

## 1.1 The northern location

In general, the noise modelling results conducted for the northern location during the construction stage in the winter season showed higher impact range values than those obtained for the summer season.

According to the analyses conducted for the winter season with no mitigation applied, the impact ranges were generally higher for the harbour porpoise than for the grey seal and the harbour seal. For the harbour porpoise, the largest impact ranges were found for the behavioural response, while for seals, the biggest ranges were calculated for the cumulative TTS. For harbour porpoises, the behavioural response range exceeded the model domain of 150.0 km from the sound source. Considering the cumulative TTS, the maximum impact range was 104 km for the porpoise and 112 km for the seal species. In the case of cumulative PTS, the range was 26.3 km for the porpoise and 2.9 km for the seals.

In the case of fish with swim bladders, the greatest impact ranges were also identified for behavioural response with the cumulative TTS, and they reached the minimum level of 150 km. Taking into account the cumulative reversible hearing loss, the maximum range was 19.2 km.

Calculations made for the scenario with mitigation measures applied indicated a decrease in the ranges of all analysed impacts.

After the application of a bubble curtain, the range of behavioural response in the case of the harbour porpoise remained high, with the cumulative impact ranges of TTS and PTS significantly reduced. For fish with swim bladders, calculations for the application of a BBC showed that the maximum range of behavioural response still exceeded the range of the model domain, as without the use of mitigation measures and for cumulative TTS, the range was still high.

Calculations for the application of the mitigation measures in the form of HSD + DBBC were also performed, because the use of a BBC alone was not sufficient to reduce the impact ranges to an acceptable level, especially in the case of behavioural response. The results of the model analyses after the application of HSD + DBBC showed a decrease in all impact ranges. The maximum range of behavioural response of the harbour porpoise decreased to 20.8 km and in the case of seals, to 3.4 km.

For fish with swim bladders, calculations for the use of HSD + DBBC showed that the maximum distance for behavioural response decreased to 41.3 km. For cumulative TTS, the range decreased to a maximum of 11.6 km.

As the behavioural response range of the harbour porpoise was still relatively high, also in the nearby Natura 2000 site, analyses were conducted for the application of IQIP + DBBC. With the mitigation measures applied, the results showed a decrease in the range of impact of behavioural changes to a maximum distance of 20.8 km for the harbour porpoise and only 1.9 km for seals.

For fish with swim bladders, the introduction of IQIP + DBBC contributed to further decreases in the ranges and zones of impact for both behavioural response and TTS and PTS.

Analyses conducted for the summer season, without mitigation, indicate that, similarly to the winter season, the largest impact distances were found for the behavioural response in the case of the harbour porpoise and the cumulative TTS in the case of seals. However, the maximum impact ranges of individual effects were lower than those obtained for the winter season.

In the case of fish with swim bladders, the largest impact ranges were obtained for the behavioural response and amounted to 118 km. Taking into account the cumulative TTS, the maximum range was 39.1 km. Concerning the cumulative reversible hearing loss, the values obtained for the summer season were lower than the ones calculated for the winter season and amounted to 11.2 km.

Calculations made for the scenario with mitigation measures in the form of BBC applied indicated a decrease in the impact ranges. After the application of a bubble curtain, the maximum range of the behavioural response in the case of the harbour porpoise decreased to 10.7 km. The range of cumulative impacts decreased to levels below 1 km for both mammals.

In the case of fish with swim bladders, the calculations involving the application of a BBC proved that the maximum impact range for behavioural response was limited to 42.3 km. For cumulative TTS, the ranges decreased to a maximum of 19.1 km, and for cumulative reversible hearing loss, they were only 4.0 km.

Calculations made for the HSD + DBBC and IQIP + DBBC mitigation measures applied showed a further reduction in all impact ranges. Thus, the lowest values of the behavioural response decreased to 8.6 km for the harbour porpoise after the introduction of HSD + DBBC and 1.6 km for seals with the

IQIP + DBBC system applied. However, the impacts of cumulative TTS and PTS were similar for both mitigation systems.

For fish with swim bladders, the lowest impact values were obtained after the IQIP + DBBC system was introduced.

Calculations of noise propagation resulting from piling at several locations showed that the ranges and areas of impact of all analysed noise exposure effects (behavioural response, TTS, and PTS) increased with the growing number of piling sources. Such a trend was identified for all animals. The largest ranges and zones of impact were found for the scenario with four sources. The largest impact zones were found for the behavioural response.

Due to the proximity of the Natura 2000 site, Hoburgs bank och Midsjöbankarna, noise levels at the boundary of the area were determined for the harbour porpoise, which is protected in this area. These values were next compared with the thresholds for the cumulative TTS and PTS. For the harbour porpoise, the cumulative TTS threshold level was exceeded at the boundary of the Swedish Natura 2000 site when no mitigation measures were applied and after the application of a BBC. Further analyses showed that even the use of the HSD/IQIP and DBBC systems would not reduce all impacts to the boundary of the Natura 2000 site in the winter season. In the case of cumulative impacts, exceedances of the permissible limits are expected in both seasons analysed after the application of the BBC mitigation system. According to calculations, the HSD + DBBC and IQIP + DBBC systems are only able to reduce noise in the case of piling in two sources located 20 km apart and conducted in the summer season. Importantly, the use of IQIP + DBBC system reduces the ranges of the weighted cumulative TTS and PTS less effectively than HSD + DBBC, which results from worse reducing properties at a frequency of approximately 800 Hz.

Additionally, the analyses of the potential impact of the behavioural response in the area of the nearby Natura 2000 site Hoburgs bank och Midsjöbankarna were carried out. The analyses showed that the area of behavioural response will vary depending on the mitigation measures applied and the season. The largest range can be expected in the winter season, during which the use of the analysed mitigation measures can reduce the percentage of the area affected by the impact to a maximum of 2.5%. In the summer season, the percentage of the area affected by the potential impact will be below 1% if the mitigation measures included in the modelling or other commercially available solutions reducing underwater noise are used, the effects of which are at least as good as the analysed mitigation measures.

## 1.2 THE CENTRAL LOCATION

The modelling of noise generated as a result of piling at the central location was conducted for the summer season.

The results of analyses for a scenario with no mitigation systems, the impact ranges were generally higher for the harbour porpoise than for the grey seal and the harbour seal. For the harbour porpoise, the largest impact ranges were found for the behavioural response, while for seals, the biggest ranges were calculated for the cumulative TTS. In the case of porpoises, the maximum range of this impact was 74.3 km from the sound source. Considering the cumulative TTS, the maximum impact range was 9.8 km for the porpoise and 26.2 km for the seal species. In the case of cumulative PTS, the range was 4.2 km for the porpoise and 0.4 km for seals.

In the case of fish with swim bladders, the greatest impact range was also identified for behavioural response, and it was up to 133 km. Taking into account the cumulative TTS and cumulative reversible hearing loss, the maximum ranges were 47.4 km and 10.6 km, respectively.

Calculations made for the scenario with the HSD + DBBC applied indicated a decrease in the ranges of all analysed impacts. After the application of mitigation measures, the maximum range of the behavioural response decreases to the level of 8.9 km at maximum. The impact range for cumulative TTS lowered to a maximum of 0.2 km for the porpoise and 0.1 km for the two seal species. The impact range for cumulative PTS was 0.1 km for both groups of mammals.

In the case of fish with swim bladders, the calculations for the application of the HSD + DBBC system proved that the maximum impact range for behavioural response was 23.5 km. For cumulative TTS, the ranges decreased to a maximum of 8.0 km, and for cumulative reversible hearing loss, they were only 1.1 km.

For the Natura 2000 site Hoburgs bank och Midsjöbankarna, noise levels that can be expected at the site boundary were determined and compared with thresholds for cumulative TTS and PTS for the harbour porpoise. The cumulative TTS level was exceeded at the boundary of the Swedish Natura 2000 site when no mitigation measures were applied. Further analyses showed that the use of HSD and DBBC will effectively reduce all impacts at the Natura 2000 site boundary during the summer season. For cumulative impacts, the use of HSD + DBBC can reduce noise to acceptable levels in all scenarios analysed.

Additionally, the analyses of the potential impact of the behavioural response in the area of the nearby Natura 2000 site Hoburgs bank och Midsjöbankarna were carried out. The analyses showed that with mitigation in the form of HSD + DBBC applied, the range of the behavioural response will not cross the boundary of the Natura 2000 site.

## 1.3 The southern location

The modelling of noise in the southern location during the construction stage was conducted for the summer season.

The results of analyses for a scenario without mitigation indicate that in the case of the harbour porpoise, the largest impact distances were found for the behavioural response, while for seals they were calculated for the cumulative TTS. In the case of porpoises, the maximum range of this impact was 85.8 km from the sound source. Considering the cumulative TTS, the maximum impact range was 20.3 km for the porpoise and 35.3 km for the seal species. In the case of cumulative PTS, the range was 5.5 km for the porpoise and 0.8 km for seals.

In the case of fish with swim bladders, the greatest impact range was also identified for behavioural response, and it exceeded the model domain range. Taking into account the cumulative TTS and cumulative reversible hearing loss, the maximum ranges were 55.8 km and 14.2 km, respectively.

Calculations made for the scenario with a BBC applied indicated a decrease in the ranges of all the analysed impacts. After the application of mitigation measures, the maximum range of the behavioural response decreases to the level of 12.3 km at maximum. The impact range for cumulative TTS lowered to a maximum of 0.6 km for the porpoise and 1.5 km for the two seal species. The impact range for cumulative PTS was 0.1 km for both groups of mammals.

In the case of fish with swim bladders, the calculations for the application of the BBC system proved that the maximum impact range for behavioural response was 65.9 km. For cumulative TTS, the ranges decreased to a maximum of 33.0 km, and for cumulative reversible hearing loss, they were only 5.2 km.

For the Natura 2000 site Hoburgs bank och Midsjöbankarna, noise levels that can be expected at the site boundary were determined and compared with thresholds for cumulative TTS and PTS for the harbour porpoise. Analyses have shown that without the use of mitigation measures, the assumed limits of cumulative TTS and PTS will not be exceeded, with the TTS limit at only 2 dB below the acceptable limit. The use of the mitigation measure in the form of a BBC will contribute to a significant reduction in noise levels at the boundary of the area discussed.

Additionally, the analyses of the potential impact of the behavioural response in the area of the nearby Natura 2000 site Hoburgs bank och Midsjöbankarna were conducted. The use of the mitigation measure in the form of a BBC will contribute to a significant reduction in noise levels at the boundary of the discussed area.

# 2 INTRODUCTION

This Report constitutes an appendix to the Report on the Environmental Impact Assessment of the Baltica-1 OWF, which concerns marine mammals and fish in the Polish part of the Baltic Sea. The Report contains the results of analyses relevant to the EIA in terms of:

- the numerical modelling of sound emitted by piling for a single noise source, together with estimations of noise impact zones for marine mammals and fish with swim bladders;
- the levels of modelled noise at the boundary of the Hoburgs bank och Midsjöbankarna Natura 2000 site;
- the analyses of the percentage share of the Natura 2000 site Hoburgs bank och Midsjöbankarna where an impact in the form of behavioural response will occur in the case of harbour porpoises.

A numerical model of noise propagation was prepared to enable the above-mentioned analyses. The model is based on batch input data in the form of, among others, bathymetry, physicochemical conditions, and the geological profile. The modelling coverage was 150 km.

The following sound levels are presented in this report:

- sound exposure level (SEL) in relation to 1 μPa$^2$s;
- the peak sound pressure level ($SPL_{peak}$) in relation to 1 μPa;
- cumulative sound exposure levels ($SEL_{cum}$).

The results are presented for three locations with and without noise mitigation measures applied for the winter and summer seasons, depending on the location.

The modelling covers all biologically relevant parts of the frequency spectrum. Impact ranges were calculated for different noise exposure criteria covering harbour porpoises, grey and common seals, and fish with swim bladders. The modelling results are presented in the form of noise maps, tabulated distance compilations, and impact areas.

# 3 METHODOLOGY

## 3.1 GENERAL APPROACH

The adopted approach to assessing the impact range and area has three stages:

- sound source definition (sound intensity and frequency spectrum);
- numerical noise modelling;
- the calculation of biological effects using internationally accepted criteria.

The **definition of the sound source** was based on data on finite elements and publicly available measurement data.

The **numerical modelling of sound propagation** was performed using the proprietary MIKE software by DHI – the Underwater Acoustic Simulator (UAS: MIKE DHI, 2023).

The model focuses on noise propagation in the far field. The UAS software applies the RAM code based on the sound propagation model developed by Collins (Collins, 1993). A detailed description of the underwater acoustic model, including the scientific basis of the model and its assumptions, can be found in the technical documentation for the UAS in the MIKE software (MIKE DHI, 2023).

The sound source properties were combined with a propagation model to calculate sound propagation in angular directions from the piling locations along 72 2D transects. Specific 1/3-octave bands with central frequencies varying from 20 Hz to 4 kHz were modelled, which cover the frequencies most relevant to piling. These bands cover most of the energy from piling. For higher frequencies, propagation losses at 4kHz were applied in combination with a correction for attenuation increasing with increasing frequency (Francois and Garrison, 1982a; 1982b). Based on the numerical model, maps were produced showing the sound exposure levels as a function of distance from the sound source.

As the marine mammals considered in this study use space throughout the water column, the maximum sound levels calculated in the water column for each distance range are presented.

To **calculate biological effects**, the scheme presented by Thomsen et al. (2021) was used. There are, respectively, several overlapping noise impact zones, the sizes of which depend mainly on the relative distance of the animals from the sound source location [Figure 3.1]. This study focuses on **behavioural response** and **hearing loss** (TTS and PTS, as well as reversible hearing loss in fish with swim bladders), as these are the effects that should be considered in light of the existing regulations.

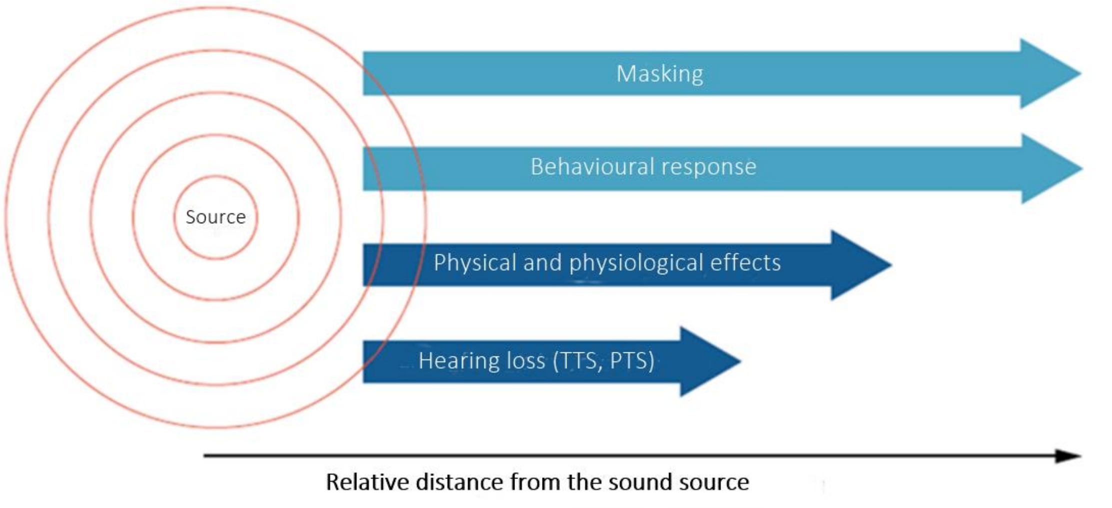



*Figure 3.1. The potential effects of noise at different distances from the sound source (based on Thomsen et al., 2021) (TTS = Temporary Threshold Shift and PTS = Permanent Threshold Shift)*

## 3.2 THE RELEVANT MODEL PARAMETERS

### 3.2.1 Sound levels

A standard result of sound propagation modelling is the transmission loss (TL) for frequencies in the 1/3-octave bands:

$$\mathrm{TL_f} = -20\log_{10}\frac{\mathrm{p_{received}}}{\mathrm{p_{source}}}$$

TL illustrates the cumulative decrease in acoustic intensity due to the propagation of an acoustic pressure wave when moving away from the sound source, i.e. the TL occurring between the source and the sound recipient:

$$\mathrm{SEL^R} = \mathrm{SEL^{SRC}} - \mathrm{TL}$$

where: R is the recipient, and SRC is the sound source.

As transmission losses are frequency-dependent, the sound level is calculated for 1/3-octave bands. In addition, the sound exposure level was also determined:

$$\mathrm{SEL_{oa}^R} = 10\log_{10}\left(\sum_f 10^{0.1\,\mathrm{SEL}_f^{\mathrm{SRC}} - 0.1\,\mathrm{TL}_f}\right)$$

where: $\mathrm{SEL_f^{SRC}}$ refers to the SEL for each 1/3-octave band with centre frequency f.

### 3.2.2 Frequency weighting

Marine mammals are divided in terms of functional hearing groups based on how they perceive sound. The different hearing characteristics associated with the range of sounds that a given group of animals perceives have been collated by the National Marine Fisheries Service (NMFS, 2018; Southall et al., 2007) using frequency weighting expressed as:

$$W(f) = C + 10\log_{10}\left(\frac{(f/f_1)^{2a}}{\left[1+(f/f_1)^2\right]^a\left[1+(f/f_2)^2\right]^b}\right)$$

with the a, b, and C parameters and the f1 and f2 frequencies presented in the table below [Table 3.1]. The weighting curves are shown in the following figure [Figure 3.2]. The hearing range has been provided in the next table [Table 3.1].

The weighted sound exposure level is calculated by weighting each frequency band:

$$\text{weighted SEL} = 10\log_{10}\left(\sum_f 10^{0.1\,\mathrm{SEL}_f - 0.1\,W(f)}\right)$$

*Table 3.1. Functional hearing groups with audible frequency ranges estimated (NMFS, 2018)*

| Functional hearing groups | Estimated hearing range | a | b | $f_1$ [kHz] | $f_2$ [kHz] | C [dB] |
|---|---|---|---|---|---|---|
| Cetaceans using high-frequency sounds (HF) | 275 Hz–160 kHz | 1.8 | 2 | 12 | 140 | 1.36 |
| Pinnipeds in the water (PW) | 50 Hz–86 kHz | 1.0 | 2 | 1.9 | 30 | 0.75 |

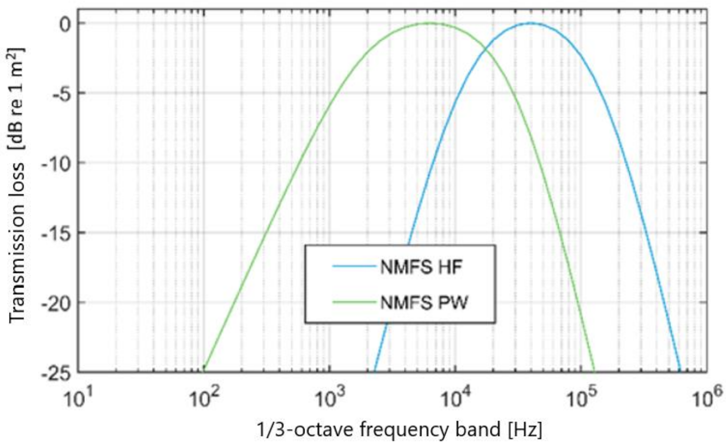



*Figure 3.2. A compilation of weighted functions for the groups of cetaceans using high-frequency (HF) sounds compared to M-weighted functions for pinnipeds in the water (PW)*

### 3.2.3 Cumulative sound exposure level

The noise exposure criteria require consideration of the force from the construction to estimate biological impacts in terms of the noise dose. The cumulative sound exposure level is the best analytical form to describe the "acoustic energy dose" generated by an activity (piling, in this case), as it covers all the acoustic energy emitted. As a rule, acoustic events (e.g. construction noise) added together form a so-called "dose." The term "cumulative sound exposure level" is used in underwater acoustics (Gill et al., 2012). It should not be confused with "cumulative impacts," a term often used to describe impacts generated by activities conducted at separate locations (e.g. from different projects) analysed together. If all hammer strikes are equal, the cumulative sound exposure level (SEL) is determined according to the following formula:

$$\mathrm{SEL_{cum}} = \mathrm{SEL} + 10\ \log_{10} n$$

where SEL is the sound saturation level of a single strike and n is the number of strikes.

Sound exposure levels in the moving receiver method are accumulated along evacuation routes, i.e. along transects for each z-angle:

$$\mathrm{SEL}_c^{\mathrm{moving}} = 10\log\sum_{i=1}^{N} 10^{\frac{(\mathrm{SEL}-\mathrm{TL}(r_0+vt_i))}{10}}$$

where the calculations include $N$ – the SEL from a single blow of a pile driver after applying the NMFS frequency weighting (see Chapter 3.2.2). Transmission losses (TL) can be calculated based on numerical simulations with the distance of $r = r_0 + vt_i$ with the above-mentioned initial distance $\mathrm{r}_0$ and escape velocity $v$; $t_i$ is the time from the beginning of the pile driving operation.

## 3.3 THE APPROACH TO CONSTRUCTION NOISE ASSESSMENT

### 3.3.1 Definition of the sound source

#### 3.3.1.1 Information on the sound source

Since distinct types of foundations (monopile, jacket foundation, gravity-based structure) are being considered for the construction of the Baltica-1 OWF, their comparison was carried out to determine the worst-case scenario for the environment in terms of the level of sound generated. The results of the comparison showed that the greatest potential impact on marine organisms is associated with noise generated at the stage of driving piles into the seabed, i.e. with the installation of monopile and jacket foundations. The analyses further showed that the broadband SEL generated at the source as a result of driving a monopile with the technical parameters specified in the table below [Table 3.2] will be approximately 7 dB higher than in the case of the considered jacket foundation. Therefore, the impact assessment will be based on the monopile installation.

For the modelling of noise propagation, the worst-case scenario was analysed, taking into account the pile diameter, the type of hammer and the number of blows needed to completely drive the pile into the seabed. The cumulative SEL was calculated based on the number of blows needed to fully install the monopile (i.e. 10000 blows). The impact is based on the assumptions shown in the following table [Table 3.2].

*Table 3.2. The levels of underwater sound generated during piling in the Baltica-1 OWF area for individual locations*

| Parameter | The northern location | The central location | The southern location |
|---|---|---|---|
| Pile diameter [m] | 12 | | |
| The number of blows needed to drive in a pile | 10,000 | | |
| The maximum power of the pile driver [kJ] | 8000 | | |
| The maximum SEL [dB re 1 µPa²·s] | 228.9 | 228.4 | 230.1 |
| The maximum $\mathrm{SPL}_{\mathrm{peak}}$ [dB re 1µPa] | 248.9 | 248.4 | 250.1 |
| The maximum $\mathrm{SPL}_{\mathrm{rms}}$ [dB re 1µPa] | 241.1 | 240.6 | 242.3 |
| $\mathrm{SEL}_{\mathrm{cum}}$ [dB re 1 µPa²·s] | 267.8 | 266.5 | 268.2 |

#### 3.3.1.2 Ramp-up procedure – marine mammals and fish

The piling process is usually conducted using variable energy. The energy required is highly dependent on the soil conditions and therefore, it is site-specific. In the case of cumulative sound pressure levels during the construction phase, an example sequence of increasing the hammer energy during piling was modelled in compliance with the following schedule: 15, 55, and 100% of the maximum hammer energy, taking into account the following number of hammer blows for individual penetration depths: 1250, 2500, and 6250.

Sound levels are scaled according to the following formula:

$$\Delta SEL = 10 \log_{10} \frac{Ei}{E0}$$

#### 3.3.1.3 Sound spectrum

The sound source spectrum was developed based on data on finite elements and publicly available measurement data. The numerically derived spectrum was calculated using the model described in the study by von Pein et al. (2021).

The scaled sound source spectrum was obtained by applying frequency-dependent scaling laws for pile diameter and water depth to the measurements conducted by Gündert et al. (2015). The measurements were made in the immediate vicinity of the pile. The scaling of the pile diameter effect leads to higher noise emission at low frequencies due to the difference in sound propagation efficiency (von Pein et al., 2022a). In addition, the impacts of the pile driver energy and weight were scaled.

The sound spectrum used below was developed taking into account the maximum values of the numerically calculated and scaled source spectra. This approach reduces the mismatch at higher frequencies between the numerical model and the measurements. At the same time, it takes into account the change in sound propagation characteristics resulting from pile geometry and pile head vibrations, which affect mainly low frequencies. The resulting broadband SEL source level is 228.9 dB, 228.4 dB, and 230.1 dB for the northern, central, and southern locations, respectively.

The resulting spectrum for the northern location is presented in the figure below [Figure 3.3] together with the weighted spectrum for the high-frequency cetaceans and pinnipeds in the water (see also Chapter 3.2.2).

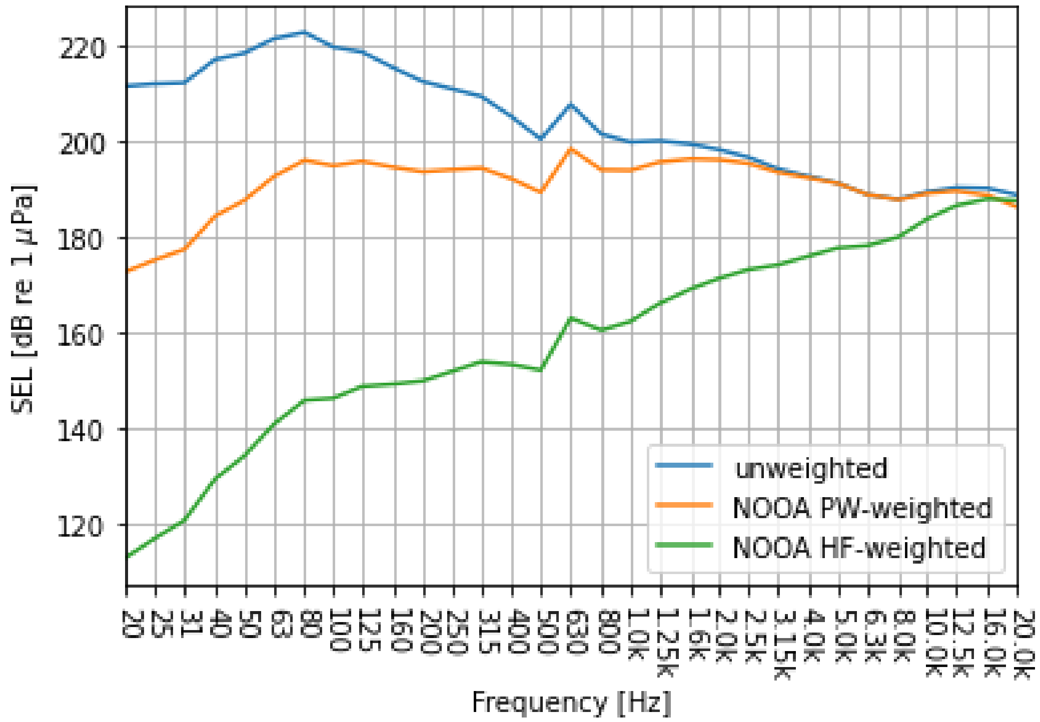



*Figure 3.3.* *The SEL spectra in the 1/3-octave bands of the modelled piling sound in the Baltica-1 OWF in the example of the northern location*

### 3.3.2 Numerical modelling of noise

#### 3.3.2.1 Sound source location

The pile driving modelling was performed for three selected WTG locations, as shown in the figure below [Figure 3.4]. Piling in the northern location was considered the worst-case scenario in terms of the potential impact range of piling within the Baltica-1 OWF on the nearby Natura 2000 site (Hoburgs bank och Midsjöbankarna – SE330308), where the harbour porpoise is protected.

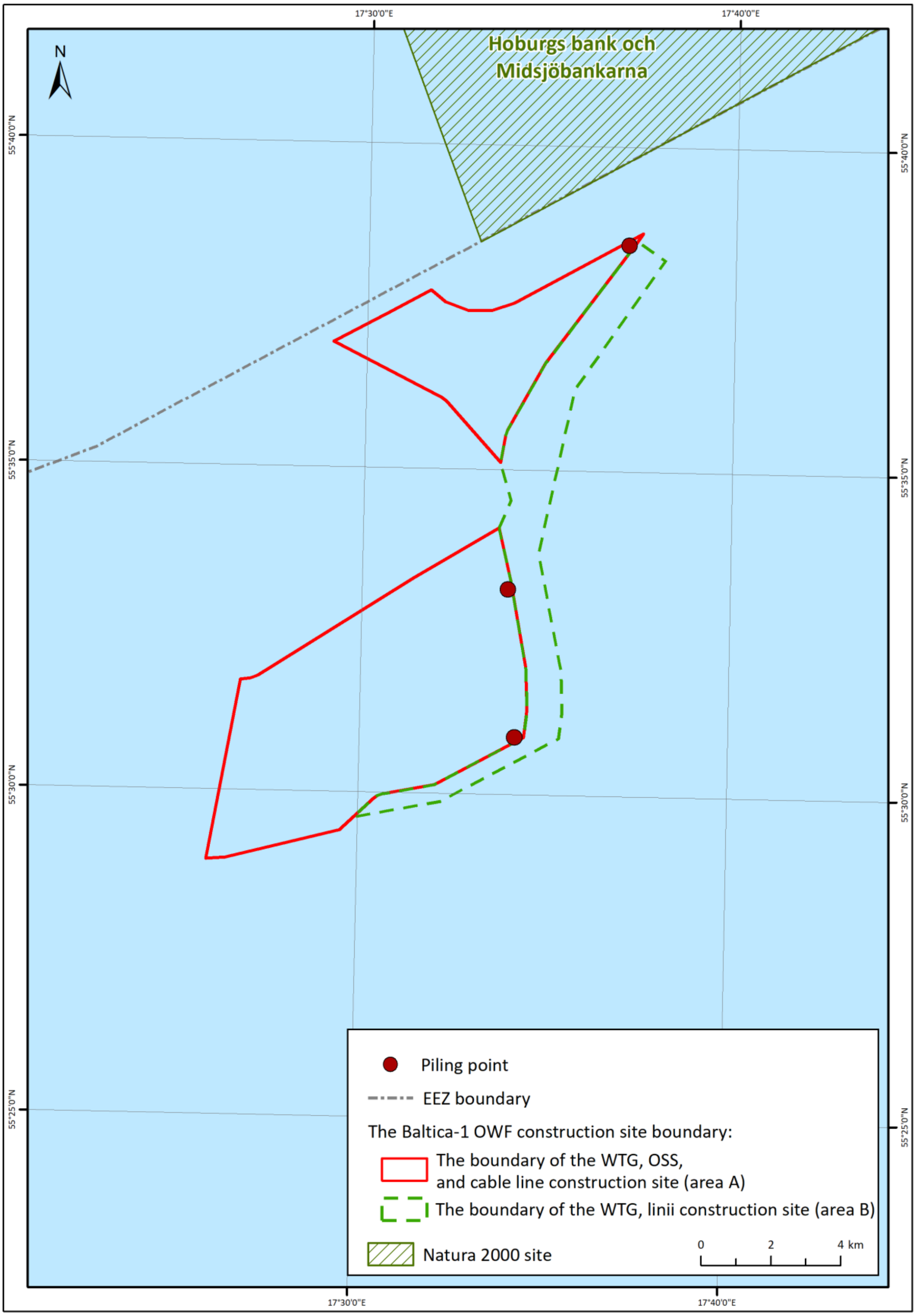



*Figure 3.4. The piling locations within the Baltica-1 OWF for which modelling was conducted*

The coordinates of the selected locations are presented in the table below [Table 3.3]. The northern point is located approximately 2.1 km from the Natura 2000 site Hoburgs bank och Midsjöbankarna.

*Table 3.3. The coordinates of the noise modelling locations within the Baltica-1 OWF area*

| Location | Longitude | Latitude | Depth [m] |
|---|---|---|---|
| Baltica-1 – the northern location | 17.61799 | 55.641568 | -40 |
| Baltica-1 – the central location | 17.56598 | 55.552778 | -37 |
| Baltica-1 – the southern location | 17.570213 | 55.514854 | -46 |

Based on the studies conducted for the offshore wind farm analyses and literature data on piling noise propagation (Thomsen et al., 2006), it was determined that the area of modelling should be located within a maximum distance of 150 km from the sound source in all directions. Therefore, 72 transects of 150 km in length or less were delineated, depending on the barrier formed by the shoreline.

A map showing the directions of noise propagation modelling is shown in the example of the northern location in the figure below [Figure 3.5].

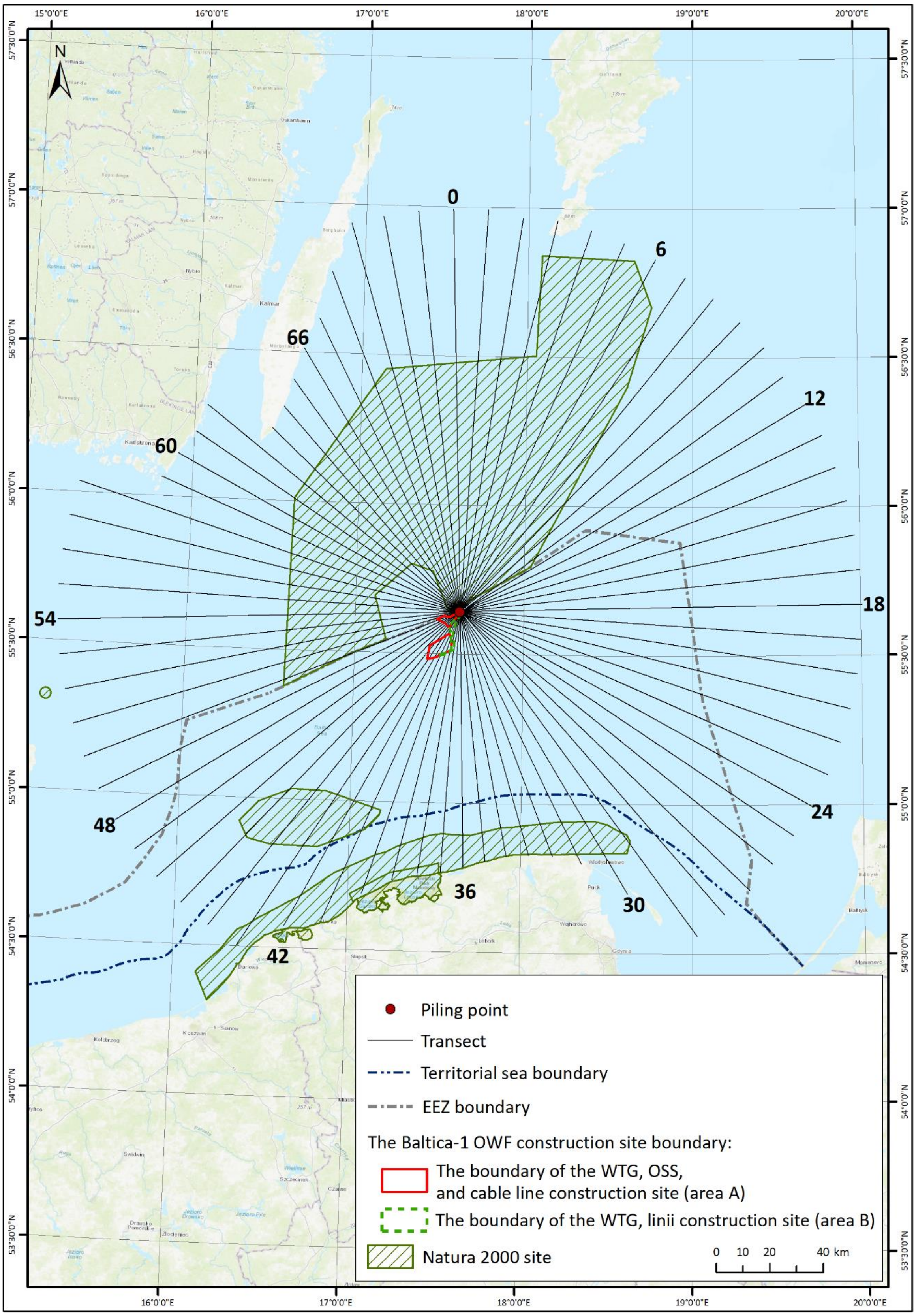



*Figure 3.5. The noise propagation modelling directions for the Baltica-1 OWF in the example of the northern location*

#### 3.3.2.2 Geo-acoustic properties of the soil

A representative seabed profile was developed based on information collected during environmental surveys for the Baltica-1 OWF. Data on the geoacoustic properties of the soil were estimated based on literature data (Jensen et al., 2011) [Table 3.4].

*Table 3.4. The summary of the geological profile used for modelling underwater noise within the Baltica-1 OWF*

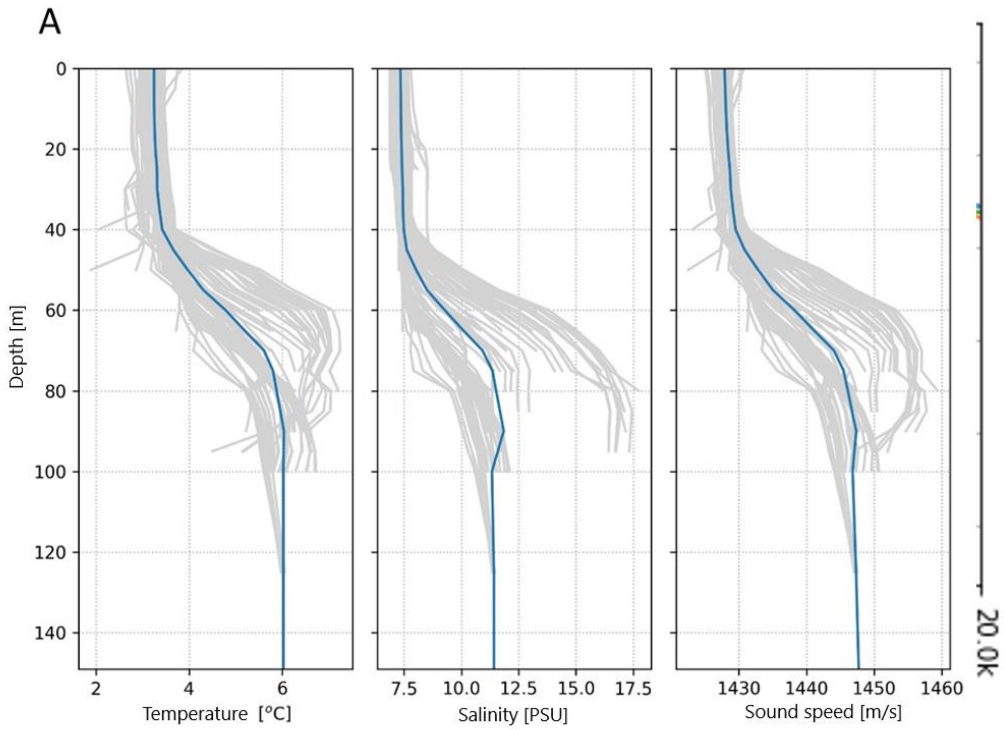
| Depth [m b.g.l.] | Thickness [m] | Layer | Cp [m/s] | ρ [g/cm³] | α [dB/λ] |
|---|---|---|---|---|---|
| 0–0.5 | 0.5 | The fine- and medium-grained sands, silty sands in places (marine, fluvial, and fluvioglacial) | 1500 | 1.7 | 0.3 |
| 0.5–26 | 25.5 | The fine- and medium-grained sands, silty sands in places (marine, fluvial, and fluvioglacial) | 1650 | 1.9 | 0.6 |
| 26–35 | 9 | The fine- and medium-grained sands, silty sands in places (marine, fluvial, and fluvioglacial) | 1750 | 1.8 | 0.6 |
| 35–60 | 25 | Sands with gravel, gravels, and tills (fluvioglacial and glacial) | 1900 | 2 | 0.4 |

*Cp – compressed wave speed, α – compressional attenuation, ρ – density, λ – wavelength*

#### 3.3.2.3 Water column characteristics

Sound propagation in seawater is affected by several factors, including temperature, pressure, salinity and, to a lesser extent, acidity (pH). Therefore, information on these properties is relevant to the assumptions accepted in the model.

Data regarding the pH were obtained from the database of NOAA World Ocean Database (WOD) and the database of the World Ocean Atlas (WOA) was selected as the base for the temperature (Locarnini, 2023) and salinity analyses (Reagan, 2023). Thus extracted temperature and salinity data were converted to sound speed profiles using the UNESCO equation (Fofonoff and Millard, 1983). The vertical profiles of water characteristics and sound profiles used in the winter and spring models are shown in the figure below [Figure 3.6].



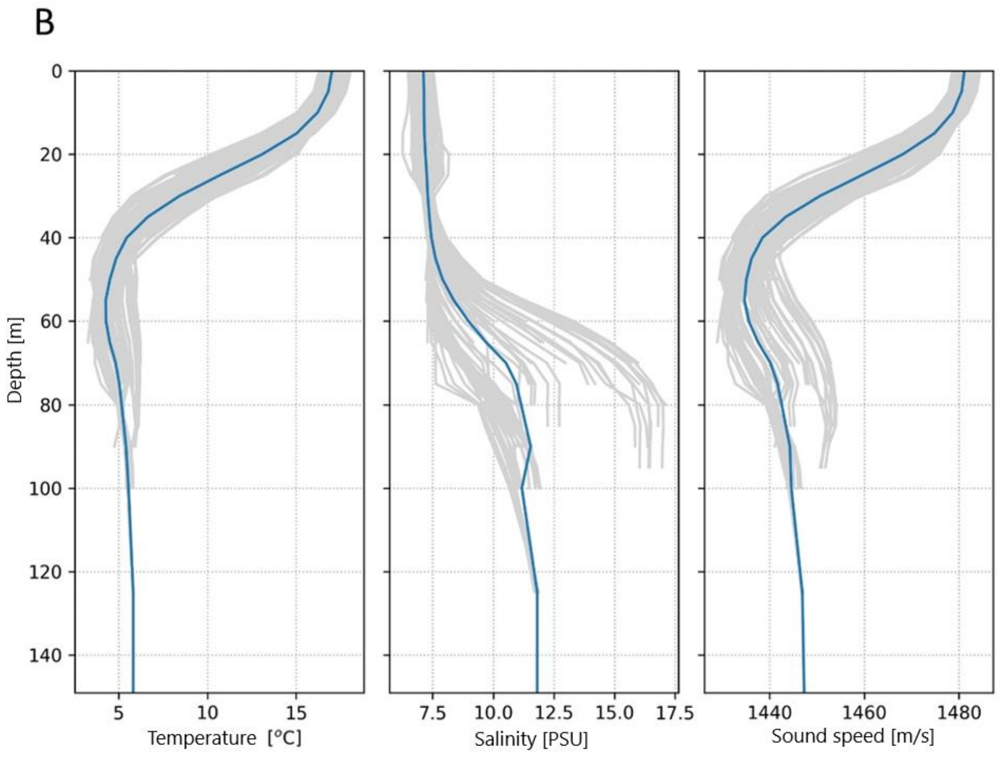




*Figure 3.6. The temperature, salinity, and sound velocity profiles in the Baltica-1 OWF area for the winter season (panel A) and the summer season (panel B) (grey lines – individual profiles; blue line – averaged profile [NOAA World Ocean Atlas, 2023])*

The modelling of underwater noise propagation was conducted, depending on the location, for two seasons: winter and summer, which are the worst-case scenarios in terms of, respectively, sound propagation range and environmental impact, i.e. potential impact on marine mammals and fish.

#### 3.3.2.4 Frequency spectrum

The calculations of sound levels at various distances from the sound source were made for frequencies of up to 4 kHz using a numerical model of underwater acoustic propagation. For higher frequencies, transmission losses at 4 kHz were included after a correction had been made for an increased attenuation (Francois and Garrison 1982a; 1982b).

#### 3.3.2.5 Sound attenuation in water

Sound attenuation in seawater depends on its temperature, salinity, pressure, and acidity (pH). The salinity in the Baltic Sea is more than half that in the open ocean and it is around 8 PSU. The UAS model includes sound attenuation in the water column using the empirical model of Francois and Garrison (Francois and Garrison, 1982a; 1982b), which decomposes the absorption coefficient into three components corresponding to contributions of boric acid, magnesium sulphate, and pure water (Lurton, 2010). Further details, including the equations used, can be found in the scientific documentation gathered for the UAS (MIKE DHI, 2023).

Low salinity levels in the Baltic Sea increase the absorption coefficient for low frequencies (below 500 Hz) and decrease it for high frequencies (above 1.25 kHz) compared to both the UAS model for standard salinity (35) and the simplified model (Richardson et al., 1995) [Figure 3.7].

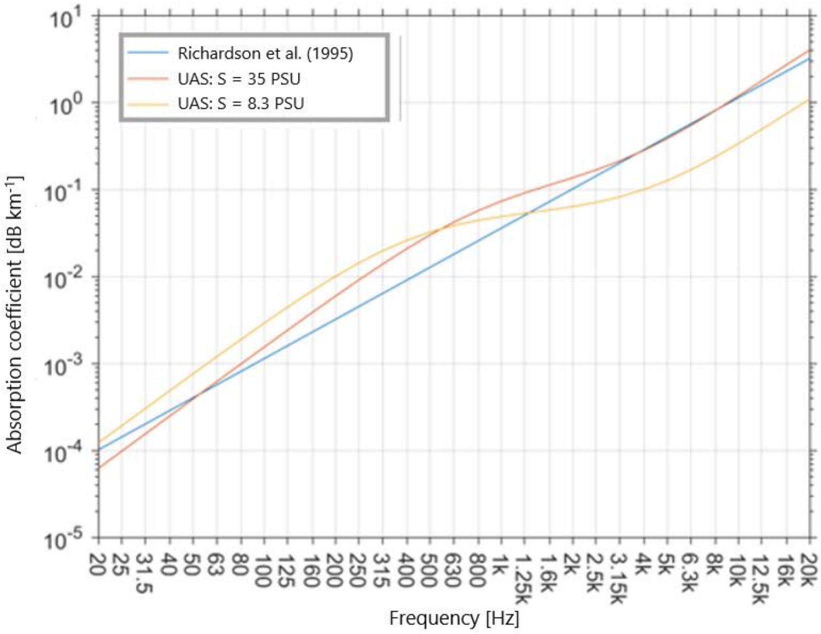



*Figure 3.7.* *The absorption coefficient derived from the model developed by Francois and Garrison (1982a; 1982b) used in the MIKE UAS compared to the simplified model of Richardson et al. (1995). Predictions in the MIKE UAS refer to values in the sound channel (pH = 8 and T = 3.1°C at a depth of approximately 50 m) with salinity as indicated in the legend*

### 3.3.3 Noise mitigation

Different noise mitigation systems can contribute to reducing noise levels while piling. In this analysis, depending on the location, the examples of noise reduction systems or their combinations were used for which data on sound reduction levels exist. All systems refer to secondary noise reduction, i.e. to reducing sound propagation in the water column. It should be emphasised that constantly developing technologies may contribute to the advance of new noise reduction systems in the future. A brief description of the individual systems selected for the analysis is presented below.

A bubble curtain is a plane or "wall" of air bubbles generated around the location where pile driving will take place. Air bubbles in the bubble curtain create an acoustical impedance mismatch which is effective in blocking sound transmission (Spence et al. 2007). In addition, resonance effects lead to additional attenuation of the propagated wave. In this analysis, insertion losses taken from Bellmann et al. (2020) were used. They were modified to take into account the dependence of the BBC reduction level on the water depth. The most up-to-date broadband insertion losses as described by Bellmann et al. (2020), available for a depth of 40 m, were taken into account and scaled to the water depth corresponding to the piling location. The scaling used was taken from von Pein (2024). The spectral reduction was obtained by taking into account the average of the measured insertion losses for different flows based on Bellmann et al. (2020) with a modification at frequencies around 100 Hz to match the broadband reduction.

In addition, the analyses included a patented noise mitigation system in the form of an HSD shield combined with a double big bubble curtain (HSD + DBBC). The HSD shield is made of a specially designed mesh with sound-dampening elements. The mesh is installed around the monopile along its entire height. In this way, the noise is reduced directly at its source. The double bubble curtain consists of two rings of pipes placed on the seabed around the entire installation, at a certain distance from each other. The corresponding insertion losses were taken from Bellmann et al. (2020).

The analyses performed for the northern location required the use of another system, which is characterised by the highest reduction of broadband SEL among the previously discussed noise mitigation measures. The analyses took into account a system consisting of the IQIP shield in combination with the DBBC belonging to the IQIP company, formerly known as IHC. The shield consists of a double-walled casing filled with air. In addition, a double bubble curtain is installed between the casing and the foundation. The considered insertion losses were taken from Bellmann et al. (2020) and slightly modified to match the expected broadband reduction. The high-frequency insertion losses were modified if the IQIP + DBBC results were lower than those obtained with a DBBC alone. The DBBC insertion losses were obtained by adding a 3-dB higher reduction than that assumed for a BBC, as indicated by Bellmann et al. (2020).

The levels of frequency-dependent SEL reduction for all the considered mitigation systems are presented in the figure below [Figure 3.8].

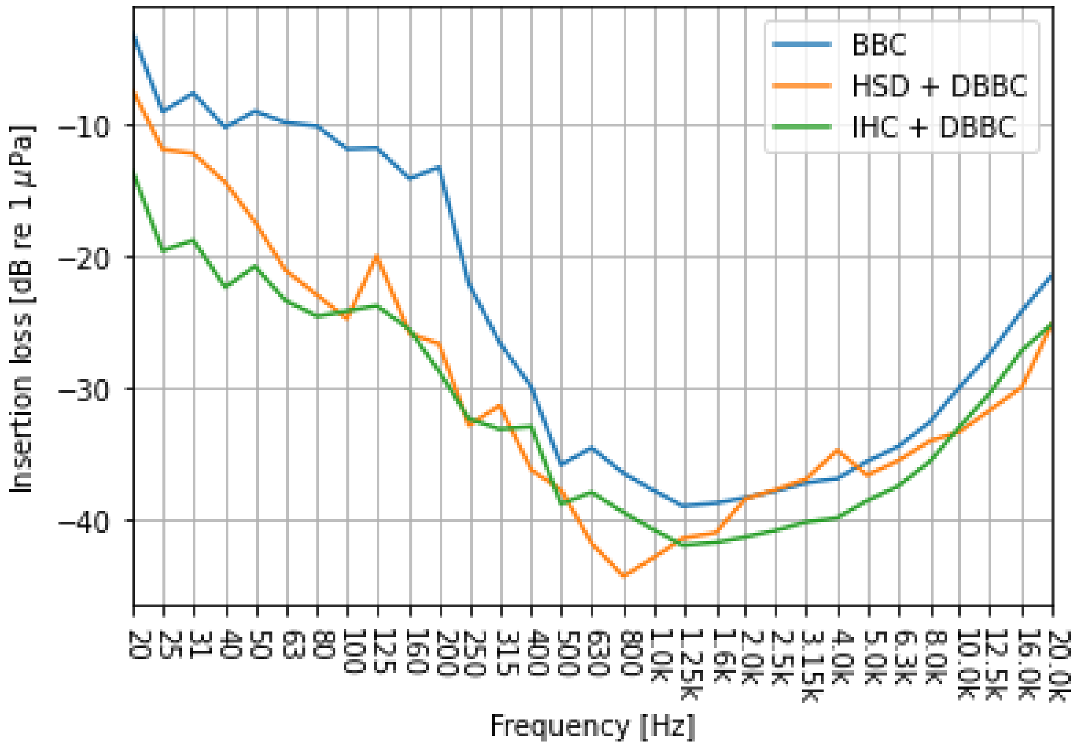



*Figure 3.8. Frequency-dependent SEL reduction for a mitigation system in the form of BBC, HSD + DBBC and IQIP + DBBC (Bellmann, 2020)*

The next table [Table 3.5] includes information on the sound levels at the source as used in the modelling without and with the mitigation measures in the form of BBC, HSD + DBBC, and IQIP + DBBC applied.

*Table 3.5. A summary of source levels with and without BBC, HSD+DBBC and IQIP+DBBC*

| Parameter | The northern location | The central location | The southern location |
|---|---|---|---|
| SEL [dB re 1 μPa$^2$·s] | 228.9 | 228.4 | 230.1 |
| $SPL_{peak}$ [dB re 1 μPa] | 248.9 | 248.4 | 250.1 |
| $SEL_{cum}$ [dB re 1 μPa$^2$·s] | 267.1 | 266.5 | 268.2 |
| BBC SEL [dB re 1 μPa$^2$·s] | 218.8 | - | 220.7 |
| BBC $SPL_{peak}$ [dB re 1 μPa] | 238.8 | - | 240.7 |
| BBC $SEL_{cum}$ [dB re 1 μPa$^2$·s] | 256.9 | - | 258.8 |
| HSD + DBBC SEL [dB re 1 μPa$^2$·s] | 210.6 | 210.1 | - |
| HSD + DBBC $SPL_{peak}$ [dB re 1 μPa] | 230.6 | 230.1 | - |
| HSD + DBBC $SEL_{cum}$ [dB re 1 μPa$^2$·s] | 249.5 | 248.2 | - |
| IQIP + DBBC SEL [dB re 1 μPa$^2$·s] | 206.2 | - | - |
| IQIP + DBBC $SPL_{peak}$ [dB re 1 μPa] | 226.2 | - | - |
| IQIP + DBBC $SEL_{cum}$ [dB re 1 μPa$^2$·s] | 244.3 | - | - |

### 3.3.4 Noise levels at the boundary of the Natura 2000 area

The noise levels received at the boundary of the nearby Natura 2000 site Hoburgs bank och Midsjöbankarna – SE0330308 were analysed as well because this area requires special protection. The analyses were conducted based on $SEL_{cum}$, but they do not take into account the escape model. The calculations were made for the PTS and TTS threshold values for cetaceans from the HF group, due to their conservation status.

The results are presented as differences in noise levels (in dB) between the SEL values calculated at the boundary of the Natura 2000 site and the noise thresholds.

### 3.3.5 Impact on the Natura 2000 site

The analyses also took into account the percentage of the Natura 2000 site Hoburgs bank och Midsjöbankarna – SE0330308, which may be affected by the potentially negative behavioural response possible for the harbour porpoise. For this purpose, the ranges of VHF-weighted $SPL_{125ms}$ were analysed in relation to the behavioural response and the percentage of the impact area that overlaps with the protected area was calculated for the entire analysed Natura 2000 site. The analyses were conducted taking into account mitigation measures for all analysed locations.

### 3.3.6 The propagation modelling of noise from piling at several locations (the cumulative model)

This task involved investigating the impact of piling conducted simultaneously at several locations within and outside the Baltica-1 OWF area" Bałtyk I, Kriegers Flak I, Kriegers Flak II Nord, Kriegers Flak II Syd, Energy Island Bornholm, Njord, Öland-Hoburg I, Baltic Central, Baltic Offshore Beta, Virrus, Neptunus, Södra Victoria, Bornholm Bassin Øst, and Baltic Edge. The numerical modelling results on piling at a single location provided input to the cumulative model. Different scenarios with multiple piling sources were analysed by changing the applied source level and swapping the superposition of individual acoustic fields. Based on these analyses, a generalised conservative estimate of the impact areas for simultaneous piling at different locations was established. The results obtained depend only on the number of simultaneous piling operations regardless of their exact location and the distance from one another. In this way, different combinations of up to four simultaneous piling locations could be analysed. The simulations were performed considering the mitigation measures in the form of BBC, HSD + DBBC system and IQIP + DBBC depending on the location. The noise criteria are identical to the ones used in the assessment of noise from a single location.

#### 3.3.6.1 Overlapping sound fields

Assuming that the transmission losses for all sources are similar, the main task was to identify to what extent the noise from the different locations overlaps, i.e. how different sounds are added together. The three approaches used differed in terms of distance between the sources. They are described in the subsequent subchapters.

#### 3.3.6.2 The overlapping of sound fields from piling sources located close to each other (< 1 km)

Sources located approximately 1 km apart were treated as two sources in one location. Such a situation may occur in the case of conducted piling simultaneously in two locations in the Baltica-1 OWF area. In this case, the two spectra are overlaid at the source location to obtain a cumulative spectrum, to which the transmission loss (TL) level is then referred. For two close sources, the following was obtained: $\mathrm{SEL_{cum}} = \mathrm{SEL} + 3$ dB, i.e. the original noise generated by one source was increased by 3 dB.

#### 3.3.6.3 The overlapping of sound fields from piling sources located at an average distance from each other (20 km)

Due to the variations in the distances from the source and other TL parameters, it is not possible to make a simplification by summing the acoustic fields from two sources at an average distance from each other (i.e. 20 km), as in this case.

Two piling sources were located 20 km apart. This may apply to simultaneous piling in the area of the Baltica-1 OWF with one source located in the northern and the other in the southern part of the farm, as well as simultaneous piling in the nearby OWFs, i.e. Bałtyk I and Södra Victoria. The sound levels for one location were interpolated onto the grid of the other location. All energy levels from each calculation cell were added, i.e. the squares of the amplitudes were summed up. For sound levels in decibels, the summation is carried out in compliance with the following formula:

$$\mathrm{SEL_{cum}} = 10\log_{10}\left(\sum_i 10^{0.1\,\mathrm{SEL}_i}\right)$$

where $\mathrm{SEL}_i$ represents the levels of exposure to sound from different sources in the grid cell under consideration.

#### 3.3.6.4 The overlapping of sound fields from piling sources located at considerable distances from each other

If piling is conducted at two locations far enough apart so that their zones of impact do not overlap, the impact areas of individual sources are added together. The increase in the noise levels related to the distance from the source is then treated as negligible. It should be noted that for very short distances to threshold values (which occur frequently for the PTS), this assumption is also true, even though the distances between the sources can be even less than 20 km. The assumption for sources much further apart requires a minimum distance that is significantly greater than twice the original impact distance for one source.

#### 3.3.6.5 The approaches considered

Based on the three combinations outlined above, the following scenarios were analysed in terms of ranges and areas of impact:

- 2 sources < 1 km apart;
- 2 sources 20 km apart;
- 2 sources at a significant distance.
- 3 sources – 2 sources < 1 km apart and 1 source 20 km away;
- 3 sources – 2 sources 20 km apart and 1 source at a significant distance;
- 4 sources – summed results for three sources and one source.

## 3.4 THE CALCULATION OF BIOLOGICAL IMPACTS

The impact zones are delineated using criteria for acoustic thresholds, which designate noise levels that should not be exceeded so as not to cause impacts on marine organisms. These criteria have been developed mainly for hearing loss, i.e. TTS, PTS, and reversible hearing loss, for marine mammals and fish (Popper et al., 2014; NMFS, 2018, 2023). The criteria for acoustic thresholds relating to behavioural response are not so well established and popular, which has to do with the complexity of responses among individuals. However, there are criteria for changing the behaviour of marine mammals, which were used in the conducted assessment (Russel et al., 2016; Tougaard, 2021).

In addition, following the latest guidelines, DHI has developed a new methodology to assess impact ranges for marine mammals and fish. The assumptions used aim to provide comprehensive results and a more realistic assessment. Chapter 3.4.3 presents their key features and assumptions.

### 3.4.1 Threshold values used in the modelling

#### 3.4.1.1 Porpoises and seals

The acoustic threshold criteria related to the behavioural response are less established and popular, which is related to the complexity of the responses among individuals.

The cumulative SEL was calculated based on a 24-hour interval, considering the number of impacts needed to drive the entire foundation.

The thresholds for behavioural response were taken from Tougaard (2021), taking into account VHF-weighted $SPL_{125ms}$ in the case of the porpoise, and available research on seals (Russell et al., 2016).

A summary of the criteria values can be found in the table below [Table 3.6].

*Table 3.6. An overview of noise exposure criteria used to calculate the impact ranges for marine mammals at the stage of construction*

| Source | Effect | Species | Modelled sound type | SEL / SPL | $SPL_{peak}$ |
|---|---|---|---|---|---|
| NMFS 2018 | PTS | Harbour porpoise | Single and cumulative blow | 155 dB re 1 μPa²s (HF-weighted SEL) | 202 dB re 1 μPa |
| | TTS | Harbour porpoise | Single and cumulative blow | 140 dB re 1 μPa²s (HF-weighted SEL) | 196 dB re 1 μPa |
| | PTS | Harbour seal and grey seal | Single and cumulative blow | 185 dB re 1 μPa²s (PW-weighted SEL) | 218 dB re 1 μPa |
| | TTS | Harbour seal and grey seal | Single and cumulative blow | 170 dB re 1 μPa²s (PW-weighted SEL) | 212 dB re 1 μPa |
| Tougaard, 2021 | Changes in behaviour (behavioural criterion) | Harbour porpoise | Single blow | 103 dB re 1 μPa (VHF-weighted $SPL_{125ms}$) | - |
| Russell et al. 2016 | Changes in behaviour (behavioural criterion) | Harbour seal and grey seal | Single blow | 158 dB re 1 μPa²s (unweighted SEL) | 212 dB re 1 μPa |

#### 3.4.1.2 Fish

The noise exposure criteria for fish, for TTS and reversible hearing loss during the construction stage, were derived from an expert review (Popper et al., 2014), while the behavioural criteria are based on a study by Hawkins et al. (2014).

It should be noted that studies of fish indicate that these organisms are able to rebuild cells responsible for receiving sounds (e.g. Popper et al., 2014, 2019). For this reason, according to reports from scientists studying the impact of underwater noise on fish, the impact defined as permanent threshold shift (PTS) for mammals and sea turtles is not accurate in the case of fish and should be treated as a reversible phenomenon (here: reversible hearing loss).

A summary of noise exposure values for fish with swim bladders is presented in the table below [Table 3.7].

*Table 3.7. An overview of noise exposure criteria used to calculate the impact ranges for fish with swim bladders at the stage of construction*

| Source | Effect | Animal group | Modelled sound type | SEL (unweighted) |
|---|---|---|---|---|
| Popper et al. 2014 | Reversible hearing loss | Fish with swim bladders | Single and cumulative blow | 203 dB re. 1 µPa²s |
| | TTS | Fish with swim bladders | Single and cumulative blow | 186 dB re. 1 µPa²s |
| Hawkins et al. 2014 | Behavioural response (changes in behaviour) | Fish with swim bladders | Single blow | 135 dB re. 1 µPa²s |

For fish without swim bladders, the relevant stimulus for underwater sound is not pressure, but rather a part of the motion of sound wave particles (Popper and Hawkins, 2018). Currently, there are no clear criteria defining the ranges of impact for this group of animals in terms of particle movement, so a quantitative assessment is not possible.

### 3.4.2 Impact ranges and areas

The extent of a given impact is defined as a closed area where specific marine mammals are affected. This region has been termed the impact area $A_{\text{impact}}$and it can be calculated by adding all angular sectors with a radius$r_i$ defined by the distance to the impact thresholds:

$$A_{\text{impact}} = \sum_{i=1}^{72} \pi r_i^2 \frac{d\alpha}{360^\circ}.$$

The angular resolution of $d\alpha = 360°/72 = 5°$ has been used in this study.

### 3.4.3 Additional parameters

#### 3.4.3.1 Animal motion model (Skjellerup et al., 2015) – marine mammals

According to the guidelines of Skjellerup et al. (2015), marine mammals tend to flee from the sound source radially, at a certain speed ($v$ = 1.5 m·s$^{-1}$). The received noise dose then accumulates on the path of the fleeing mammal and, due to increasing distance from the source, is lower than that affecting a static individual, staying in one place during the cumulated blows. Additionally, in their guidelines, Skjellerup et al. (2015) assume an initial radius of $r_0$, which is mammal-free. This radius should be chosen in such a way that mammals can escape without suffering a hearing loss. In this study, the behavioural thresholds of marine mammals in response to piling are captured in the animal motion/escape model.

#### 3.4.3.2 "Effective quiet" – marine mammals

An important concept is the so-called "effective quiet," defined by Finneran (2015) as the highest SPL that will cause neither a significant TTS impact nor a return to TTS levels induced by previous exposure to higher levels. Further, Finneran (2015) indicates that this value may be 124 dB relative to 1 µPa for porpoises and in support of this conclusion, he cites a study by Kastelein et al. (2002). This study does not directly investigate "effective quiet," but rather shows that even very low sound exposures can lead to significant TTS impacts in harbour porpoises when the exposure duration is long. The lowest sound level leading to TTS in porpoises measured to date is 124 dB re 1 µPa. It can therefore be seen as a preliminary value until more accurate data can be obtained. "Effective quiet" was applied to the model during the construction and operation phase with the value of 124 dB was compared with the unweighted SEL.

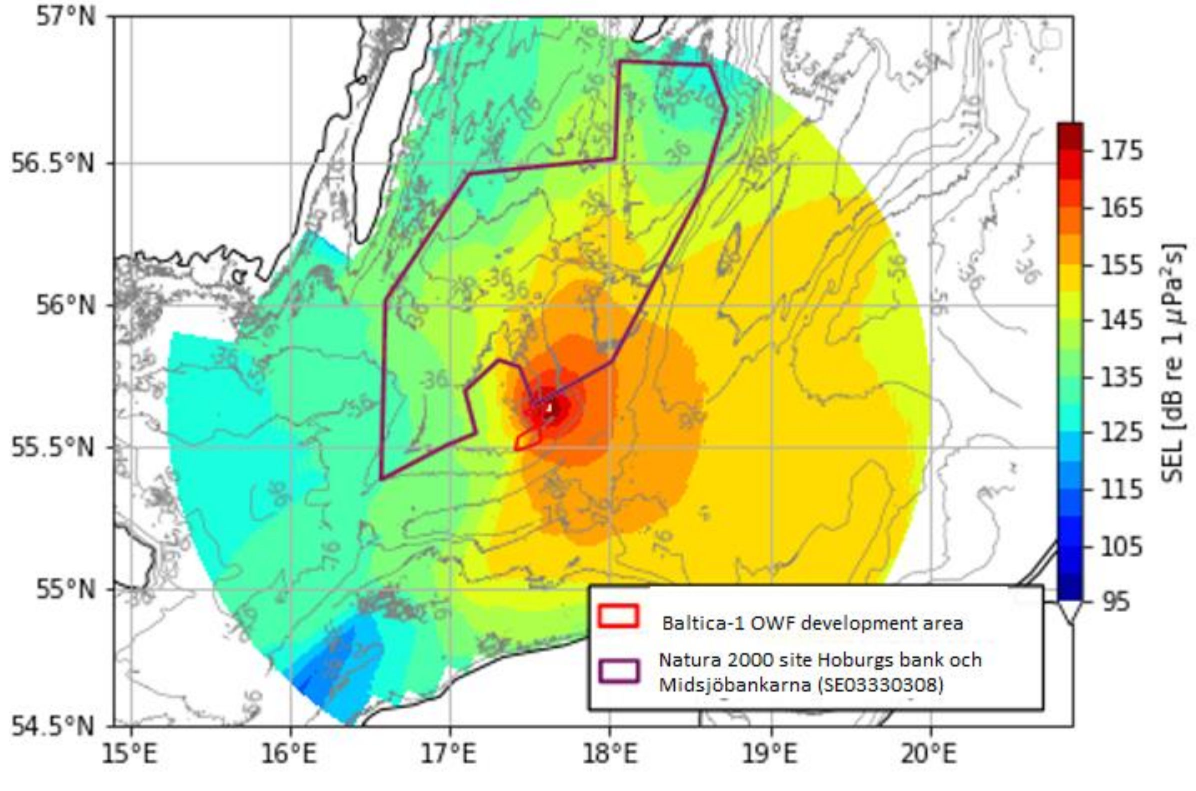
# 4 THE MODELLING RESULTS FOR THE NORTHERN LOCATION

## 4.1 THE MODELLING OF NOISE PROPAGATION FOR PILING IN A SINGLE LOCATION

This chapter presents the results of modelling carried out for the northern location in the Baltica-1 OWF in the winter and summer seasons. The impact ranges for different threshold values are presented in the form of tables, and sound propagation maps are included.

### 4.1.1 The level of exposure to sound generated by a single blow

The SEL value for a single blow did not exceed 150 dB in the winter season and 135 dB in the summer season at the boundary of the modelled area at a distance of 150 km from the sound source. The sound propagated mainly in the directions of north, south-west, and east from the piling site, where the highest sound levels were recorded [Figure 4.1].



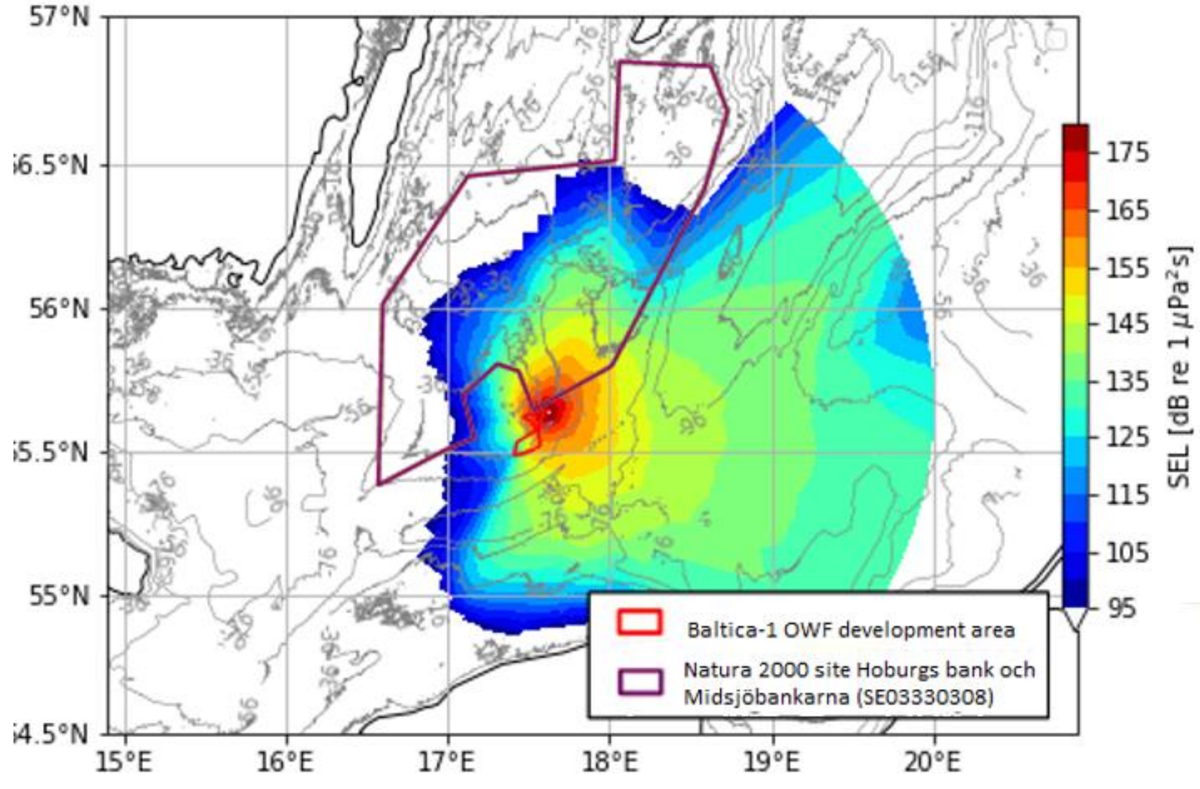




*Figure 4.1. The map of unweighted SEL above the acoustic background for a single blow in the area of the Baltica-1 OWF, in the winter (top) and summer (bottom). Grey lines: isobaths*

#### 4.1.1.1 Harbour porpoise

The impact ranges and areas calculated for the winter season were higher than those obtained for the summer season.

The largest impact ranges were recorded for the behavioural response.

The estimates of cumulative SEL for the TTS and PTS were higher than in the case of a single blow, and TTS ranges exceeded the PTS ranges. The maximum cumulative impact range in the winter season was 104 km, and the values for a single blow were up to 5.4 km for TTS.

For the $SPL_{peak}$, the impact ranges for the TTS and PTS from a single blow were higher for the TTS with a maximum value of 4.0 km, also in the winter season.

The use of mitigation measures contributed to the reduction of the impact ranges and areas of all analysed effects. All the measures used contributed to a significant reduction of impacts causing TTS and PTS, while the smallest impact ranges of the behavioural response were obtained after the application of the HSD + DBBC system.

All ranges calculated for individual threshold values are shown in tabular form [Table 4.1], while noise propagation maps are presented in the following figures [Figure 4.2–Figure 4.9].

*Table 4.1. The impact ranges and areas for the harbour porpoise calculated for the Baltica-1 OWF*

| Season | Mitigation type | Effect | VHF-weighted $SPL_{125ms}$ [dB re 1 µPa] / HF-weighted SEL [dB re 1 µPa²s] | | | unweighted $SPL_{peak}$ [dB re 1 µPa] | |
|---|---|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] | Mean distance [km] | Maximum distance [km] |
| Winter | - | Behavioural response | 133 | 150 | 57086 | - | - |
| | | TTS (single blow) | 3.9 | 5.4 | 49.7 | 3.7 | 4.0 |
| | | TTS (cumulative effect) | 80.0 | 104 | 21047 | - | - |
| | | PTS (single blow) | 0.4 | 0.6 | 0.6 | 1.4 | 1.6 |
| | | PTS (cumulative effect) | 19.7 | 26.3 | 1285 | - | - |
| | BBC | Behavioural response | 20.9 | 28.1 | 1394 | - | - |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.7 | 0.7 |
| | | TTS (cumulative effect) | 0.6 | 0.8 | 1.2 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.2 | 0.2 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.1 | - | - |
| | HSD + DBBC | Behavioural response | 16.4 | 20.8 | 863 | - | - |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 0.3 | 0.3 | 0.23 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | IQIP + DBBC | Behavioural response | 17.3 | 20.8 | 956 | - | - |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 0.3 | 0.4 | 0.3 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |

| Season | Mitigation type | Effect | VHF-weighted $SPL_{125ms}$ [dB re 1 µPa] / HF-weighted SEL [dB re 1 µPa²s] | | | unweighted $SPL_{peak}$ [dB re 1 µPa] | |
|---|---|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] | Mean distance [km] | Maximum distance [km] |
| Summer | - | Behavioural response | 21.4 | 37.3 | 1581 | - | - |
| | | TTS (single blow) | 2.5 | 3.2 | 19.2 | 3.0 | 3.4 |
| | | TTS (cumulative effect) | 6.9 | 8.7 | 150 | - | - |
| | | PTS (single blow) | 0.3 | 0.5 | 0.4 | 1.2 | 1.5 |
| | | PTS (cumulative effect) | 3.6 | 4.3 | 39.8 | - | - |
| | BBC | Behavioural response | 8.6 | 10.7 | 233 | - | - |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 0.5 | 0.6 | 0.7 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | HSD + DBBC | Behavioural response | 7.2 | 8.6 | 164 | - | - |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.2 | 0.2 |
| | | TTS (cumulative effect) | 0.2 | 0.2 | 0.1 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | IQIP + DBBC | Behavioural response | 7.5 | 9.0 | 178 | - | - |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 0.2 | 0.3 | 0.14 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |

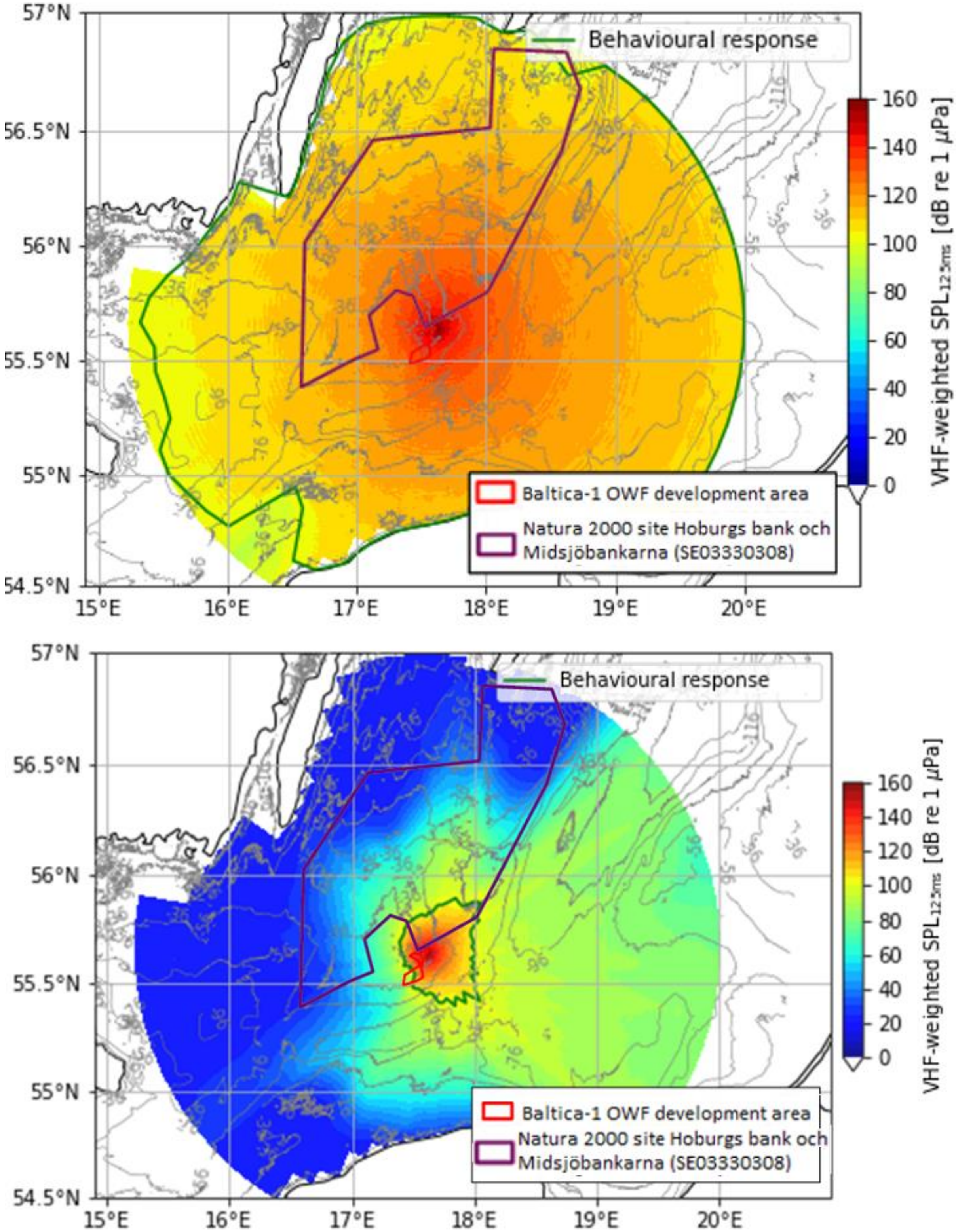



*Figure 4.2. The map of VHF-weighted $SPL_{125ms}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise, in the winter (top) and summer (bottom)*

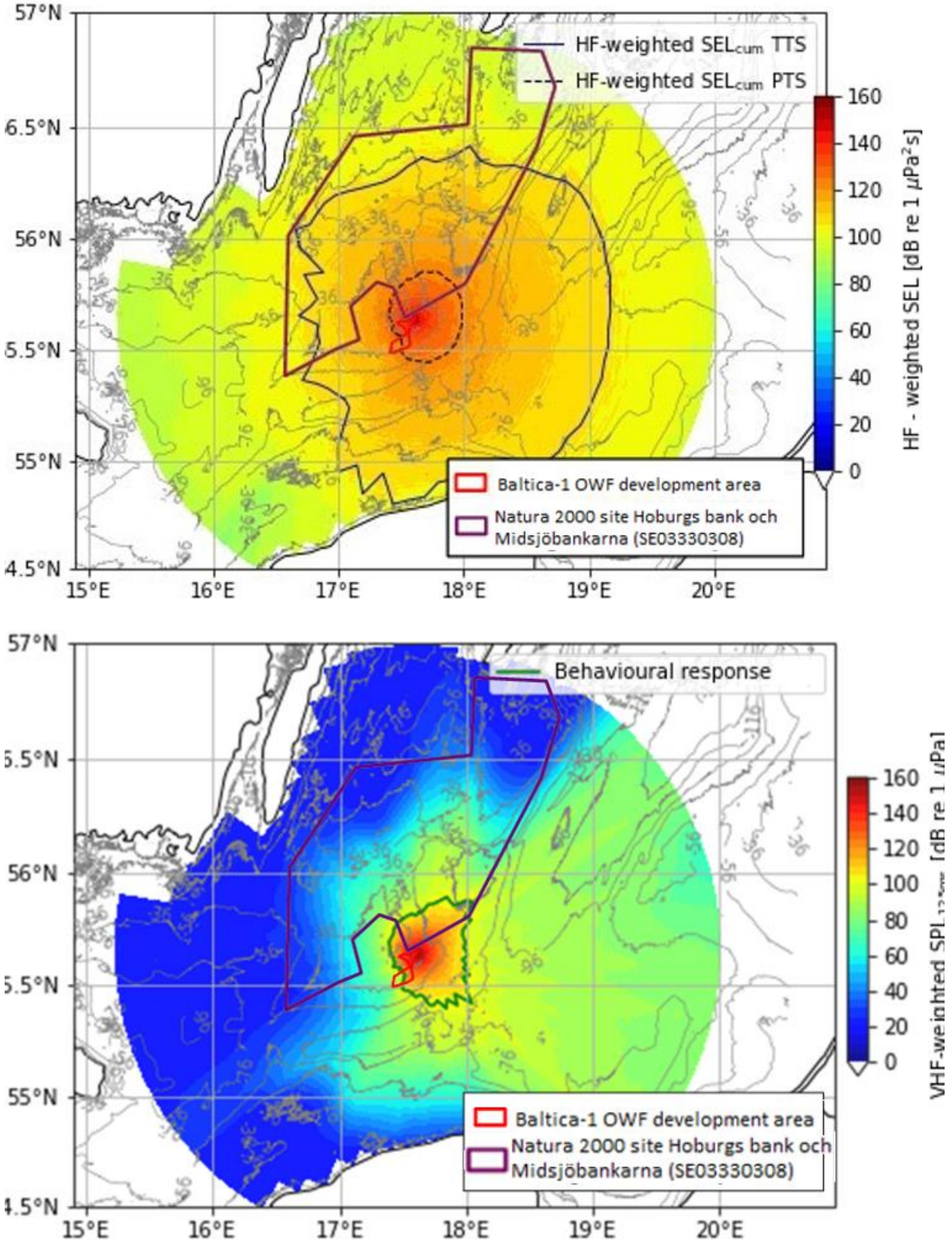



*Figure 4.3.* *The map of HF-weighted $SEL_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise, in the winter (top) and summer (bottom)*

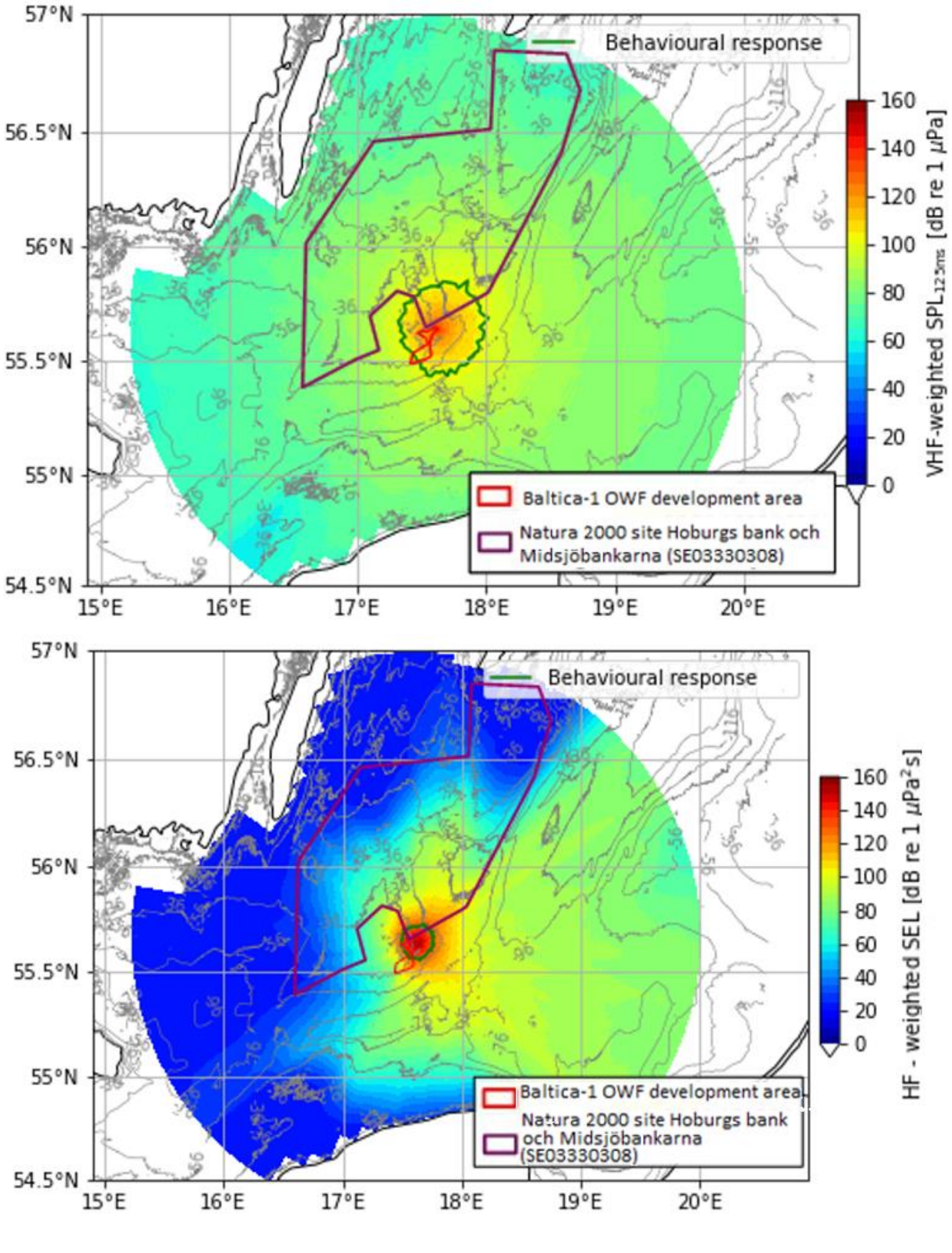
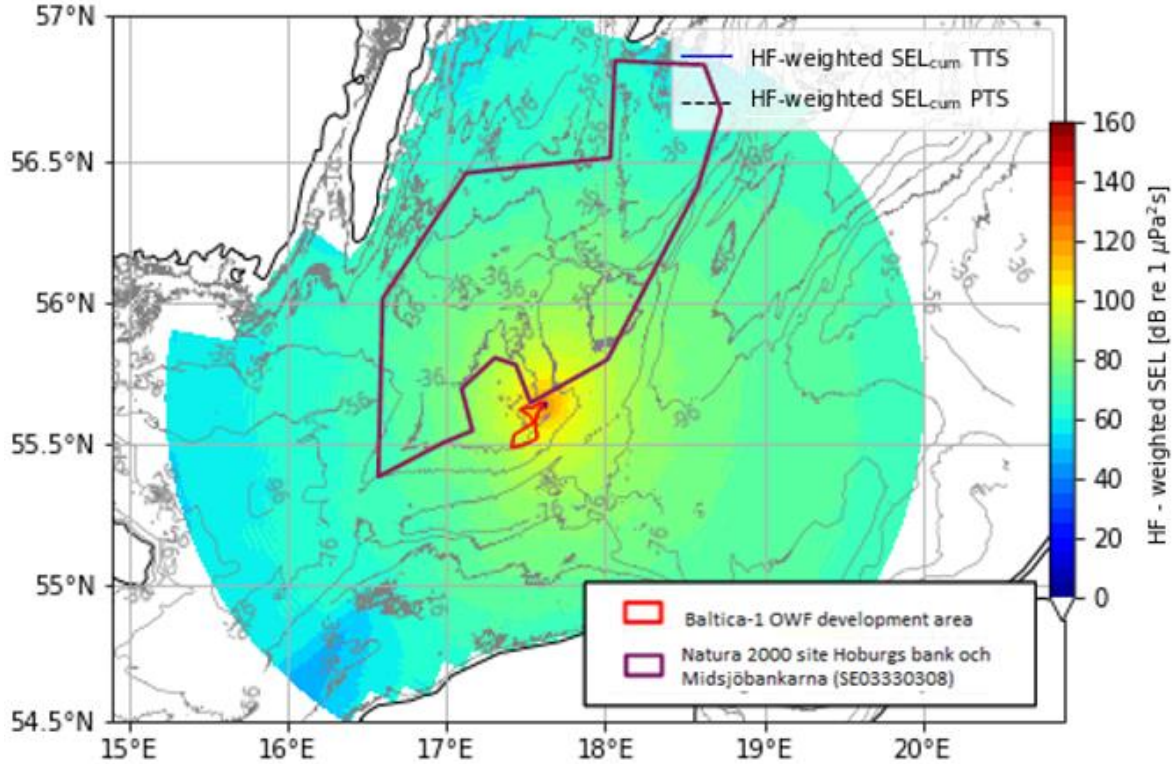



*Figure 4.4. The map of VHF-weighted $SPL_{125ms}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with a BBC applied, in the winter (top) and summer (bottom)*



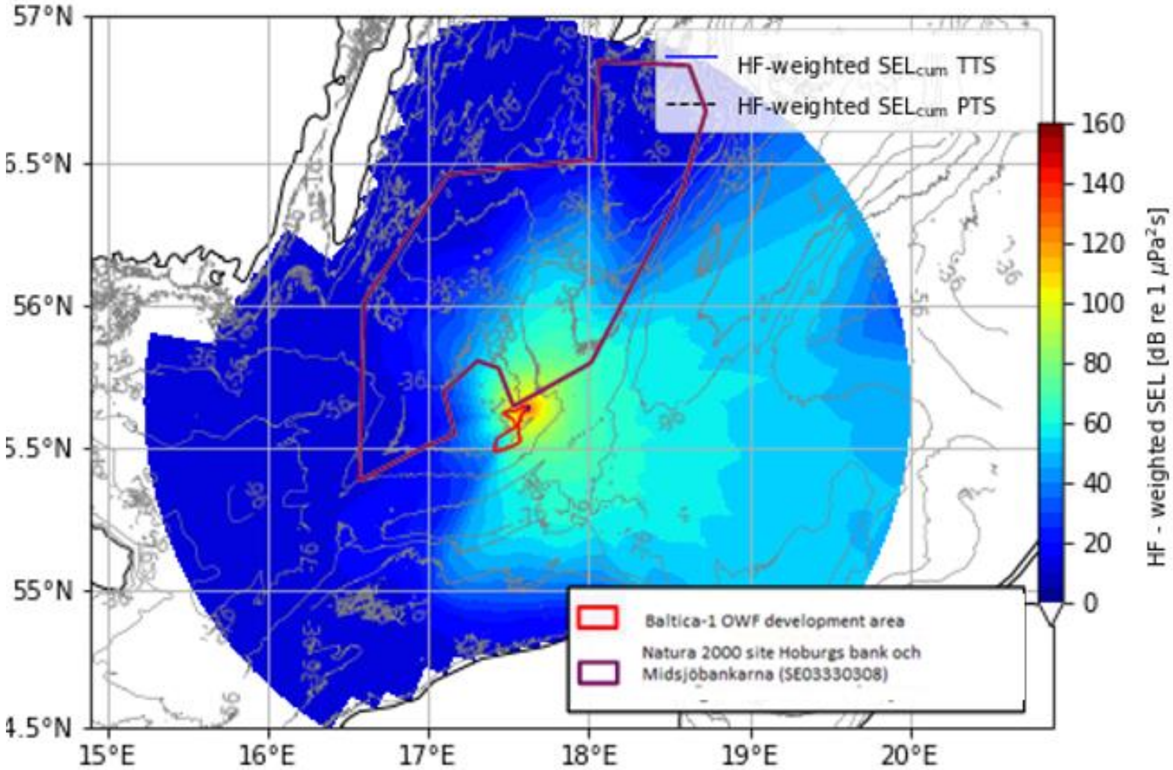
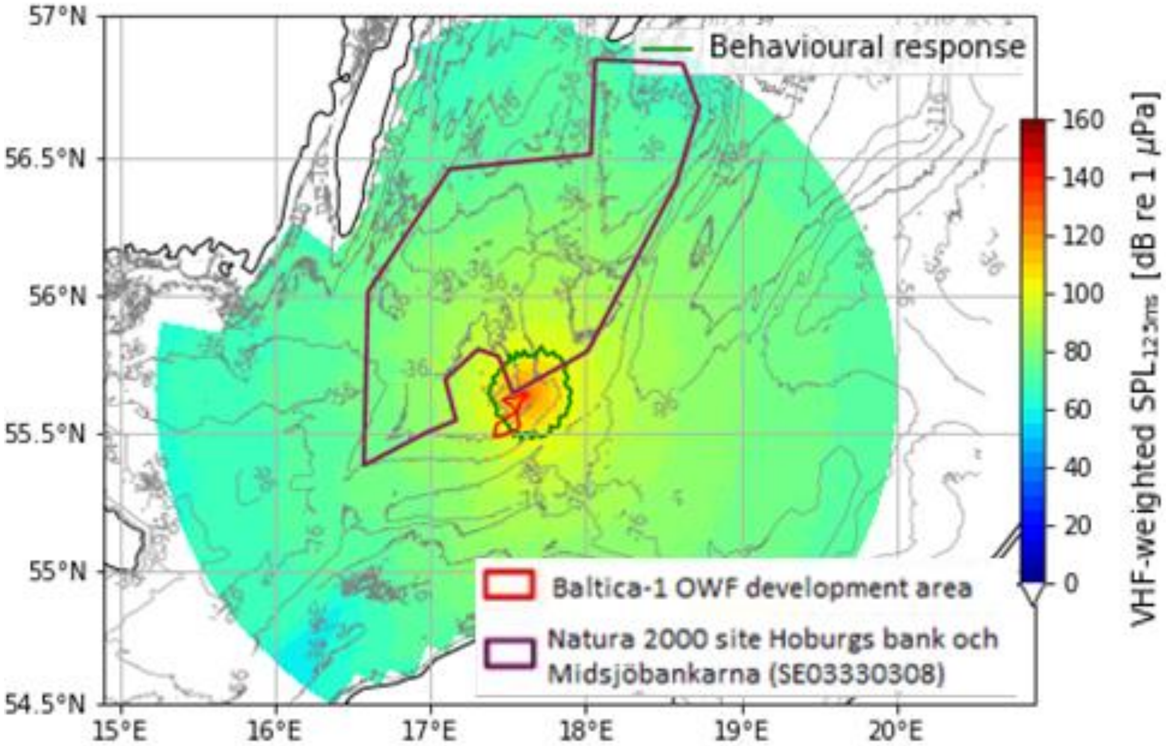




*Figure 4.5. The map of HF-weighted $SEL_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with a BBC applied, in the winter (top) and summer (bottom)*



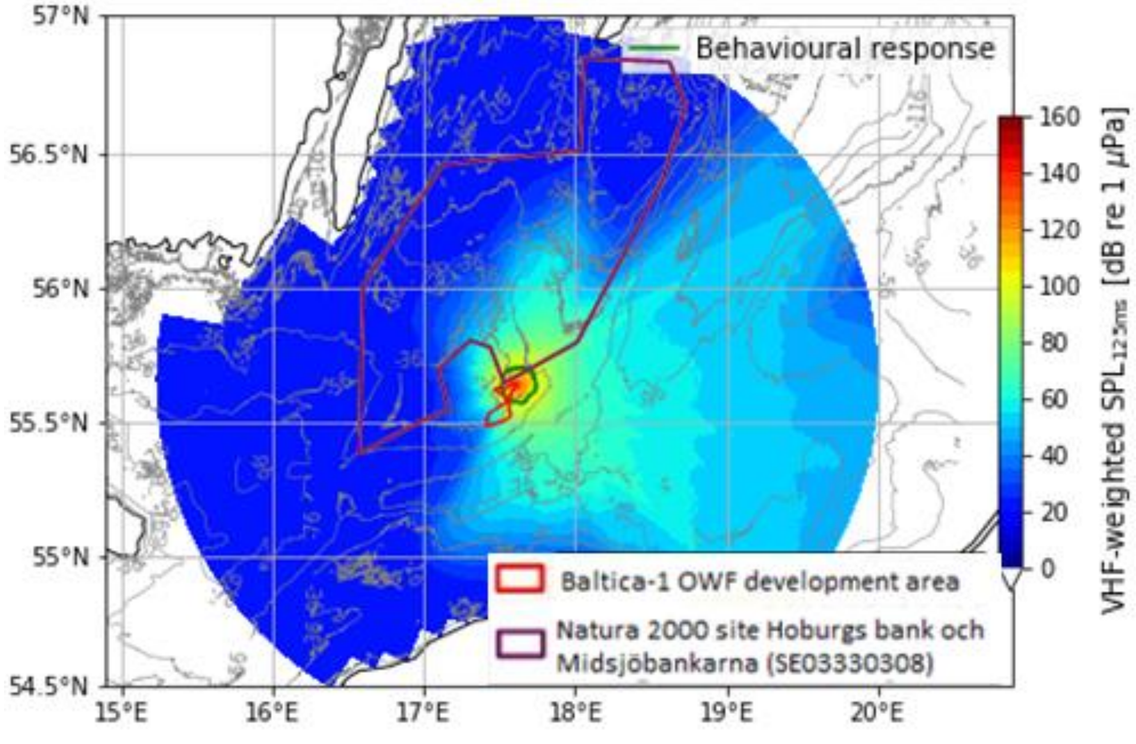




*Figure 4.6.* *The map of VHF-weighted $SPL_{125ms}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

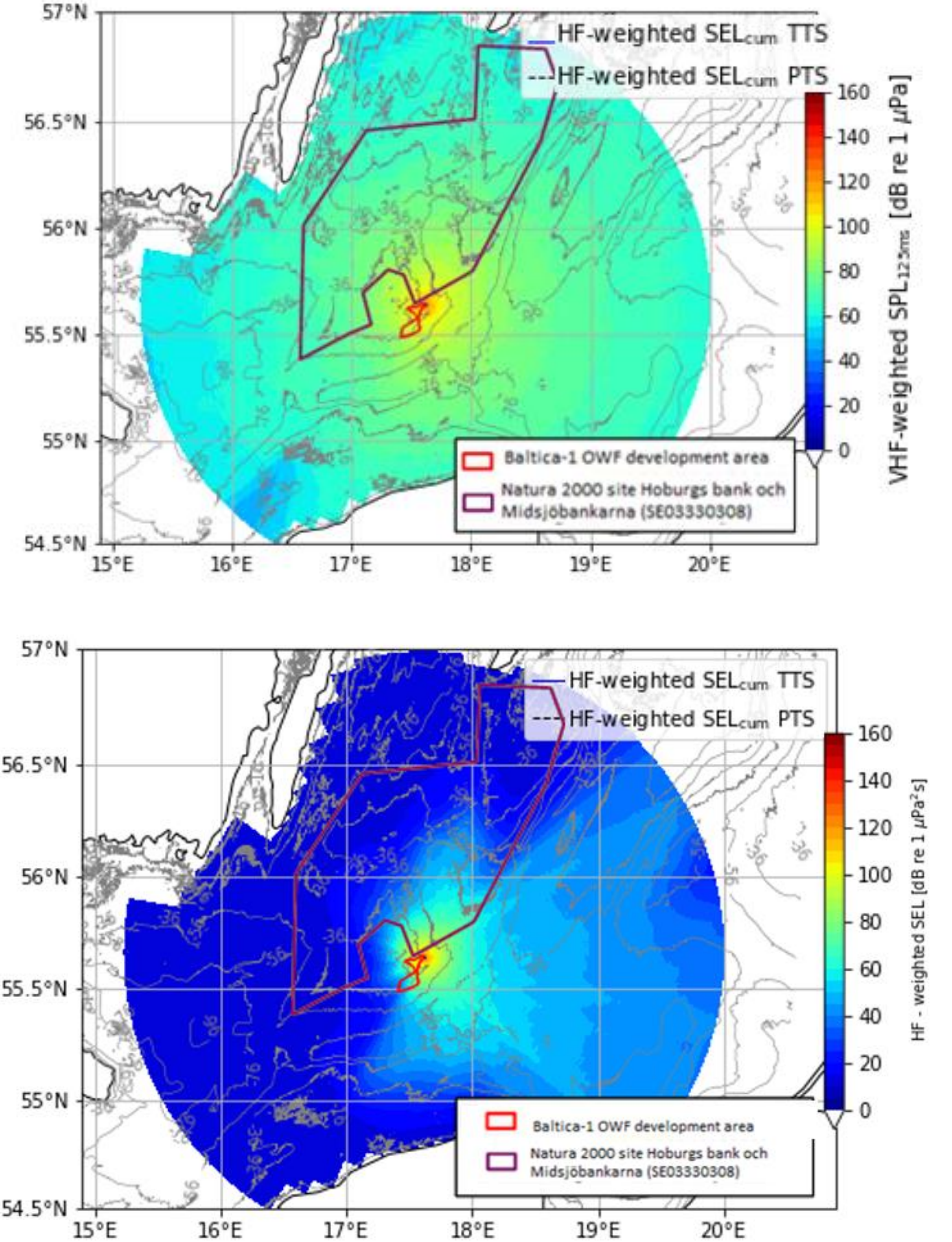



*Figure 4.7. The map of HF-weighted $SPL_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

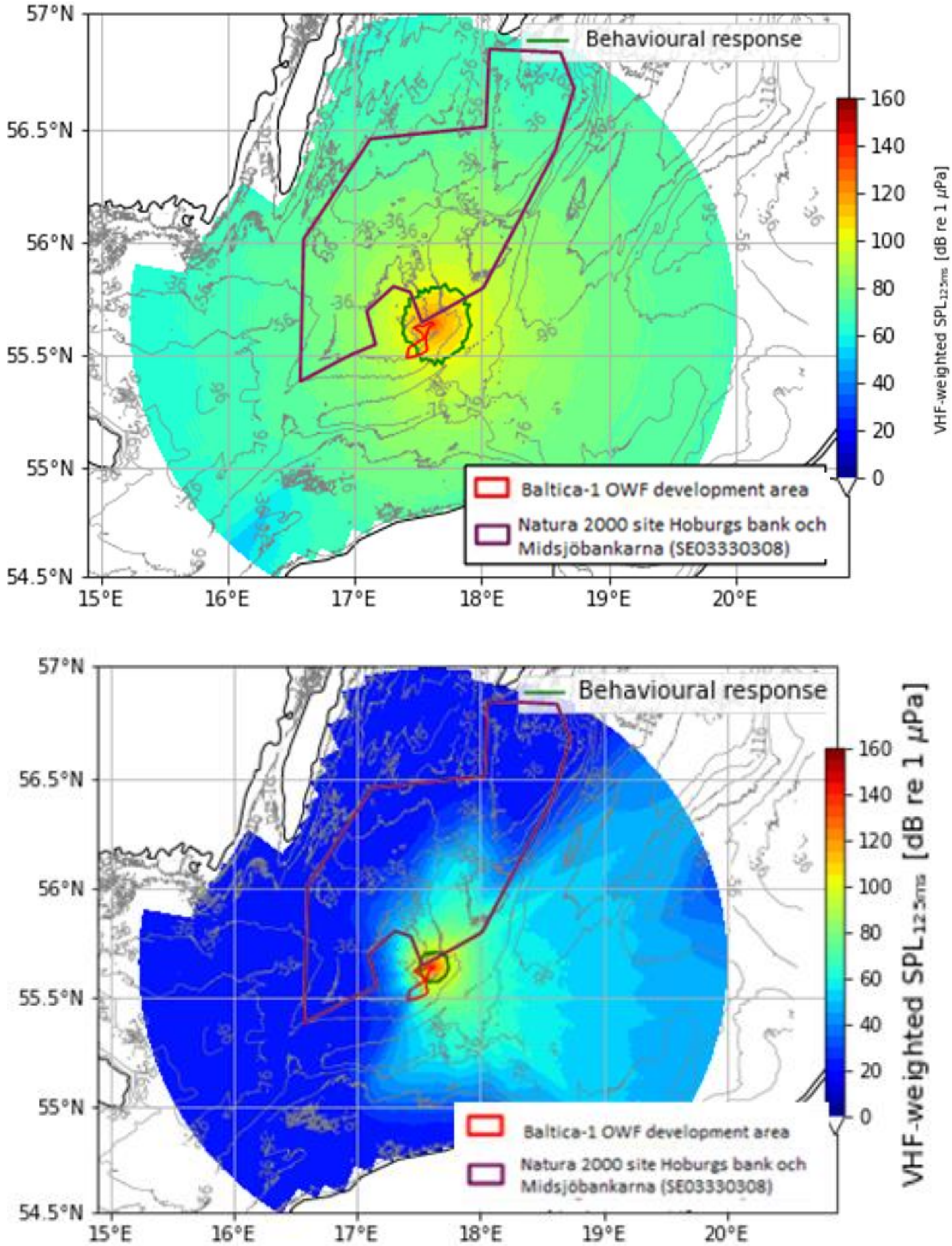
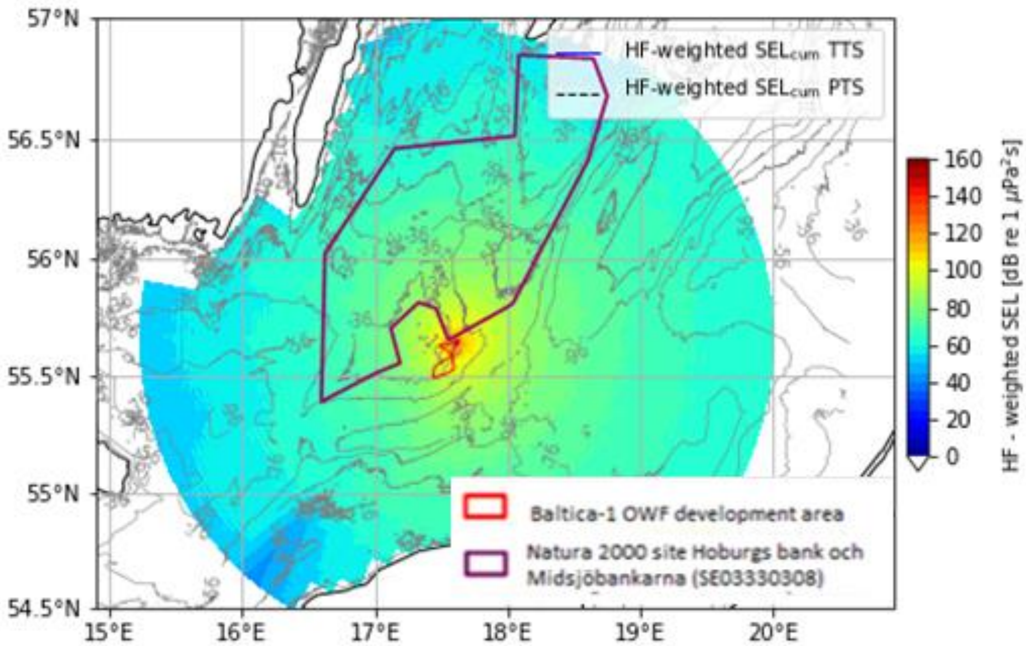



*Figure 4.8. The map of VHF-weighted $SPL_{125ms}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*



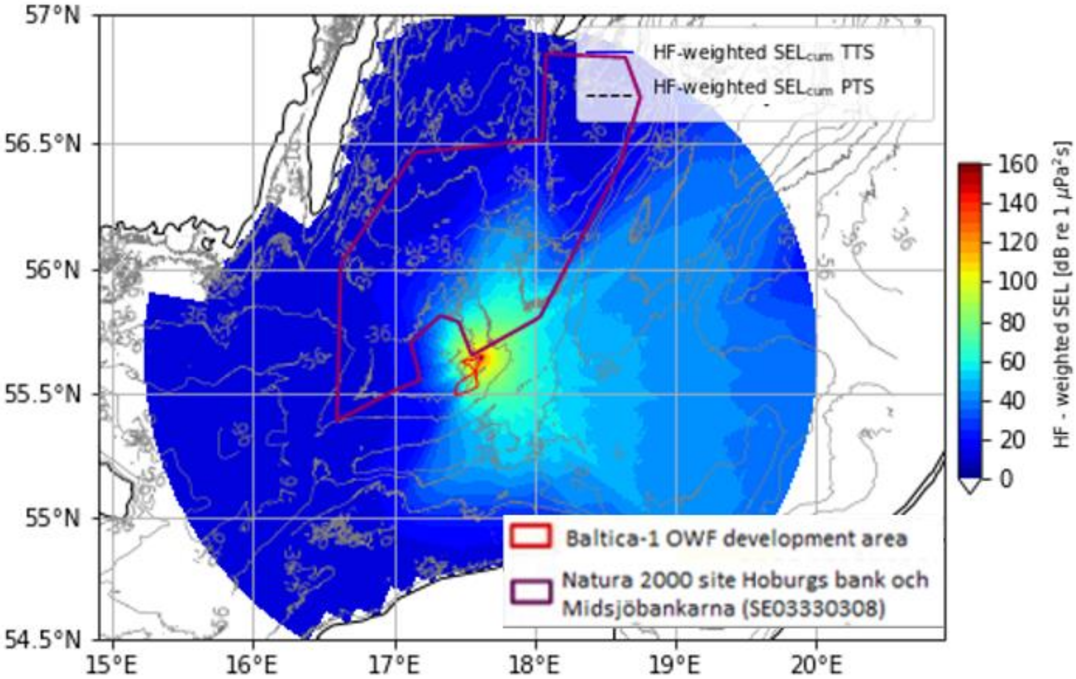




*Figure 4.9. The map of HF-weighted $SPL_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

#### 4.1.1.2 Grey and harbour seal

All impact ranges and areas (except for those of the cumulative TTS) calculated for the grey and harbour seal were lower than those obtained for the harbour porpoise.

The impact ranges and areas calculated for the winter season were higher than those obtained for the summer season.

The largest impact range and associated impact area were obtained for the cumulative TTS in the winter season, which amounted to 18,656 km$^2$.

Impacts calculated for the SEL from a single blow reached a maximum range of only 0.3 km for the TTS.

The use of mitigation measures contributed to the reduction of the impact ranges and areas of all analysed effects. The HSD + DBBC and IQIP + DBBC mitigation systems contributed to a significant reduction of cumulative TTS and PTS impacts of 0.1 km. On the other hand, the smallest impact ranges of behavioural response were obtained after the application of the IQIP + DBBC system.

All ranges calculated for individual threshold values are shown in tabular form [Table 4.2], while noise propagation maps are presented in the following figures [Figure 4.10–Figure 4.17].

*Table 4.2. The impact ranges and areas calculated for the grey seal and harbour seal in the Baltica-1 area*

| Season | Mitigation type | Effect | unweighted SEL / Pw-weighted SEL [dB re 1 µPa²s] | | | unweighted $SPL_{peak}$ [dB re 1 µPa] | |
|---|---|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] | Mean distance [km] | Maximum distance [km] |
| Winter | - | Behavioural response | 26.9 | 39.4 | 2585 | 0.3 | 0.3 |
| | | TTS (single blow) | 0.3 | 0.3 | 0.28 | 0.3 | 0.3 |
| | | TTS (cumulative effect) | 72.2 | 112 | 18656 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 2.3 | 2.9 | 17.0 | - | - |
| | BBC | Behavioural response | 8.7 | 10.3 | 241 | 0.1 | 0.1 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 1.5 | 2.1 | 7.3 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | HSD + DBBC | Behavioural response | 3.2 | 3.4 | 31.3 | 0.1 | 0.1 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | IQIP + DBBC | Behavioural response | 1.6 | 1.9 | 9.6 | 0.1 | 0.1 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| Summer | - | Behavioural response | 13.6 | 19.1 | 605 | 0.3 | 0.3 |
| | | TTS (single blow) | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| | | TTS (cumulative effect) | 16.2 | 21.8 | 867 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.4 | 0.5 | 0.6 | - | - |
| | BBC | Behavioural response | 6.5 | 7.7 | 132 | 0.1 | 0.1 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |

| Season | Mitigation type | Effect | unweighted SEL / Pw-weighted SEL [dB re 1 µPa²s] | | | unweighted $SPL_{peak}$ [dB re 1 µPa] | |
|---|---|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] | Mean distance [km] | Maximum distance [km] |
| | | TTS (cumulative effect) | 0.4 | 0.5 | 0.6 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | HSD + DBBC | Behavioural response | 2.7 | 3.0 | 23.1 | 0.1 | 0.1 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | IQIP + DBBC | Behavioural response | 1.5 | 1.6 | 7.3 | 0.1 | 0.1 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |

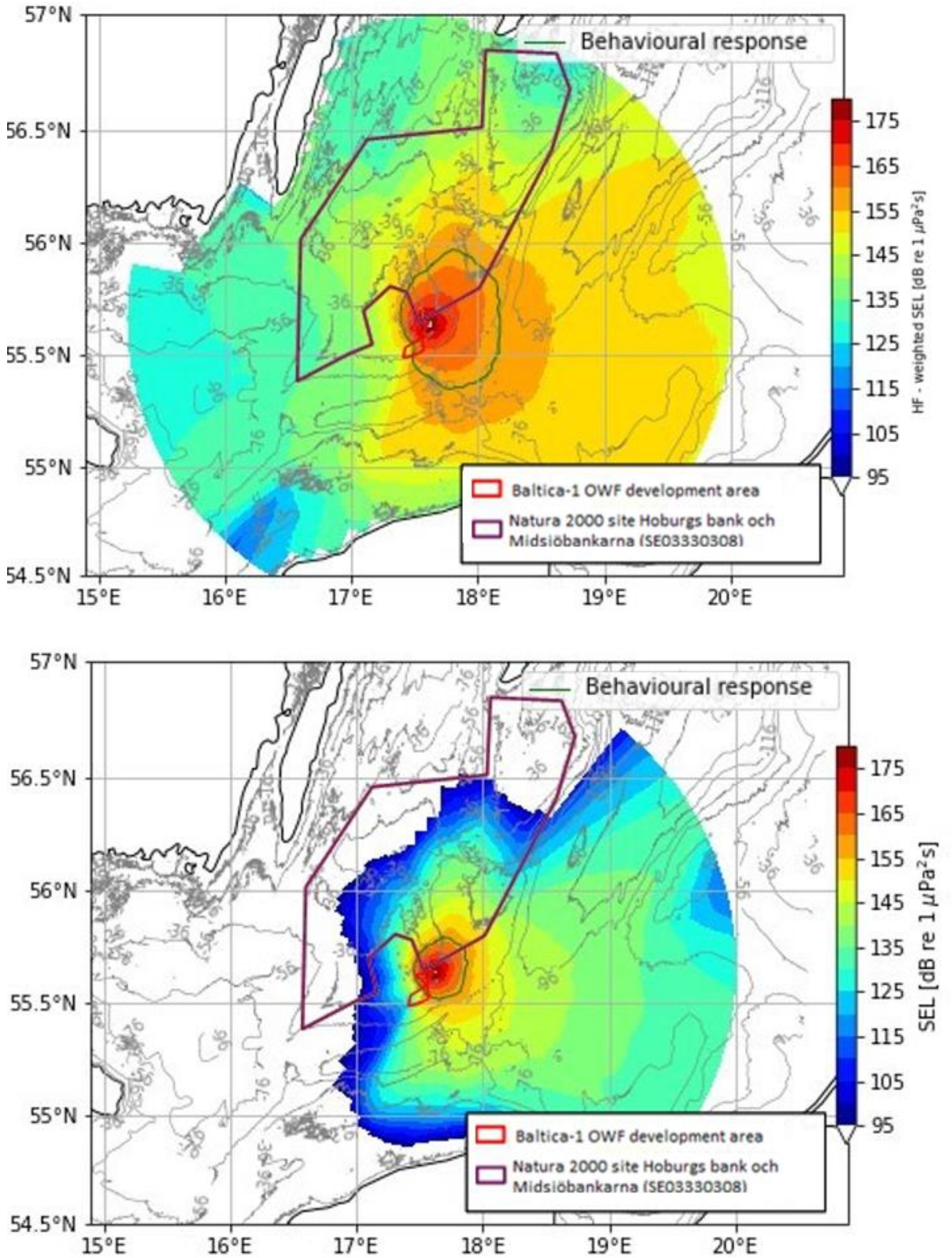



*Figure 4.10. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal, in the winter (top) and summer (bottom)*

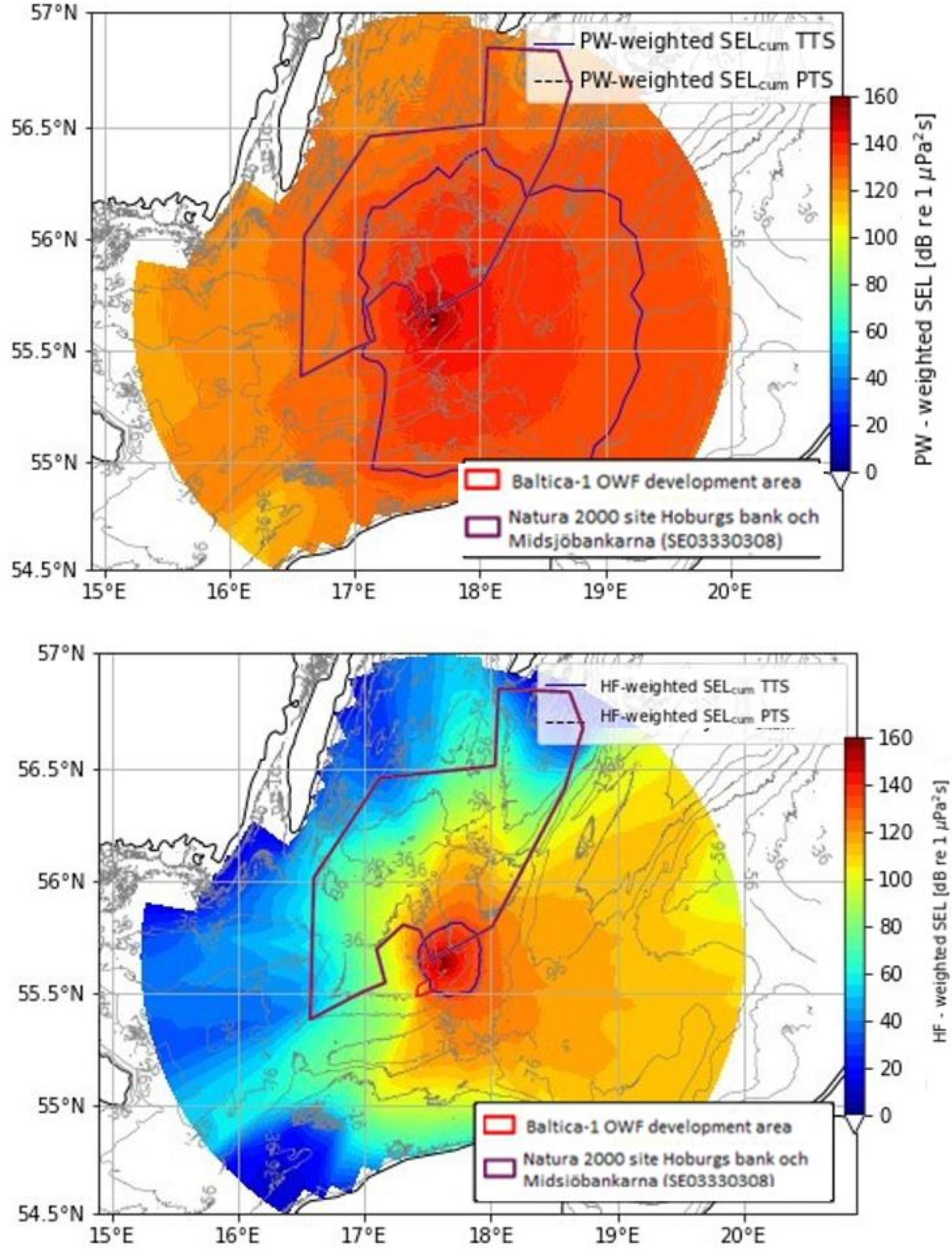
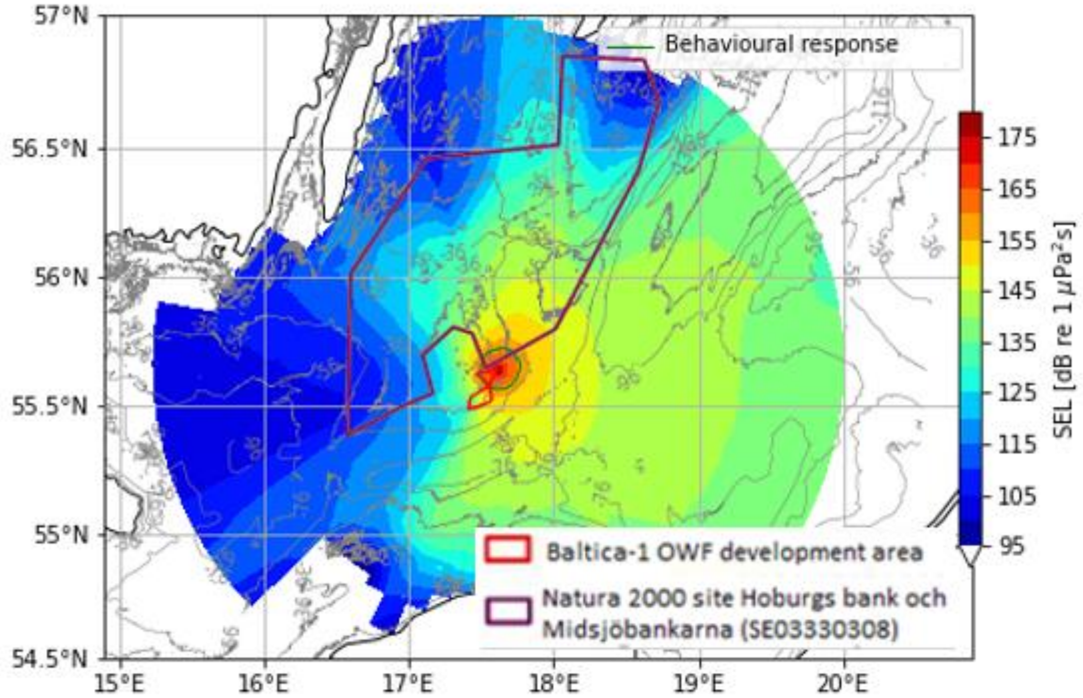



*Figure 4.11. The map of PW-weighted $SEL_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal, in the winter (top) and summer (bottom)*



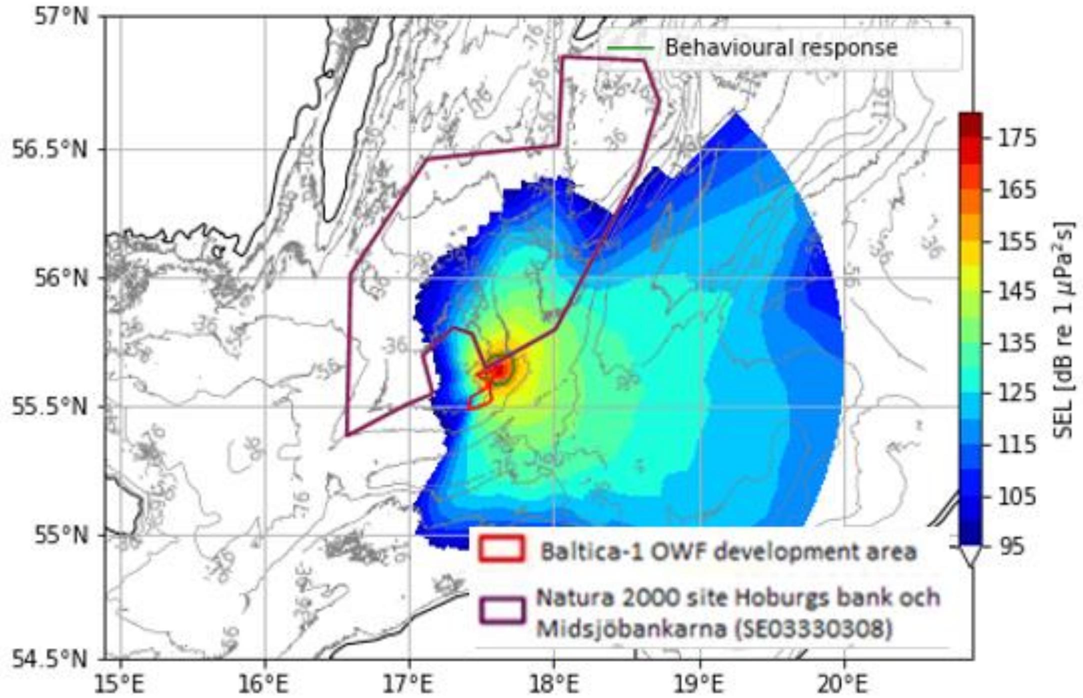




*Figure 4.12. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with a BBC applied, in the winter (top) and summer (bottom)*

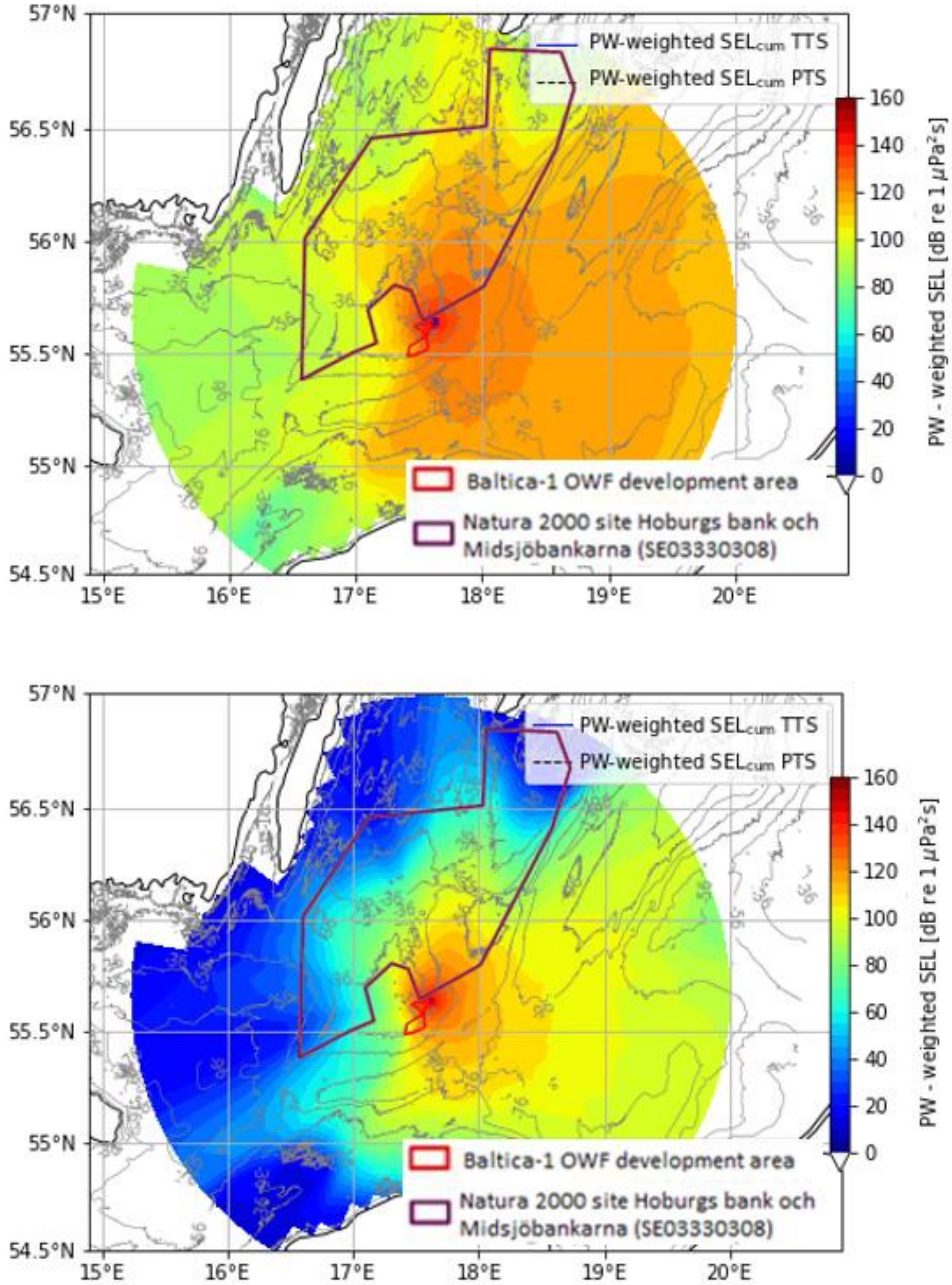



*Figure 4.13. The map of PW-weighted $SEL_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with a BBC applied, in the winter (top) and summer (bottom)*

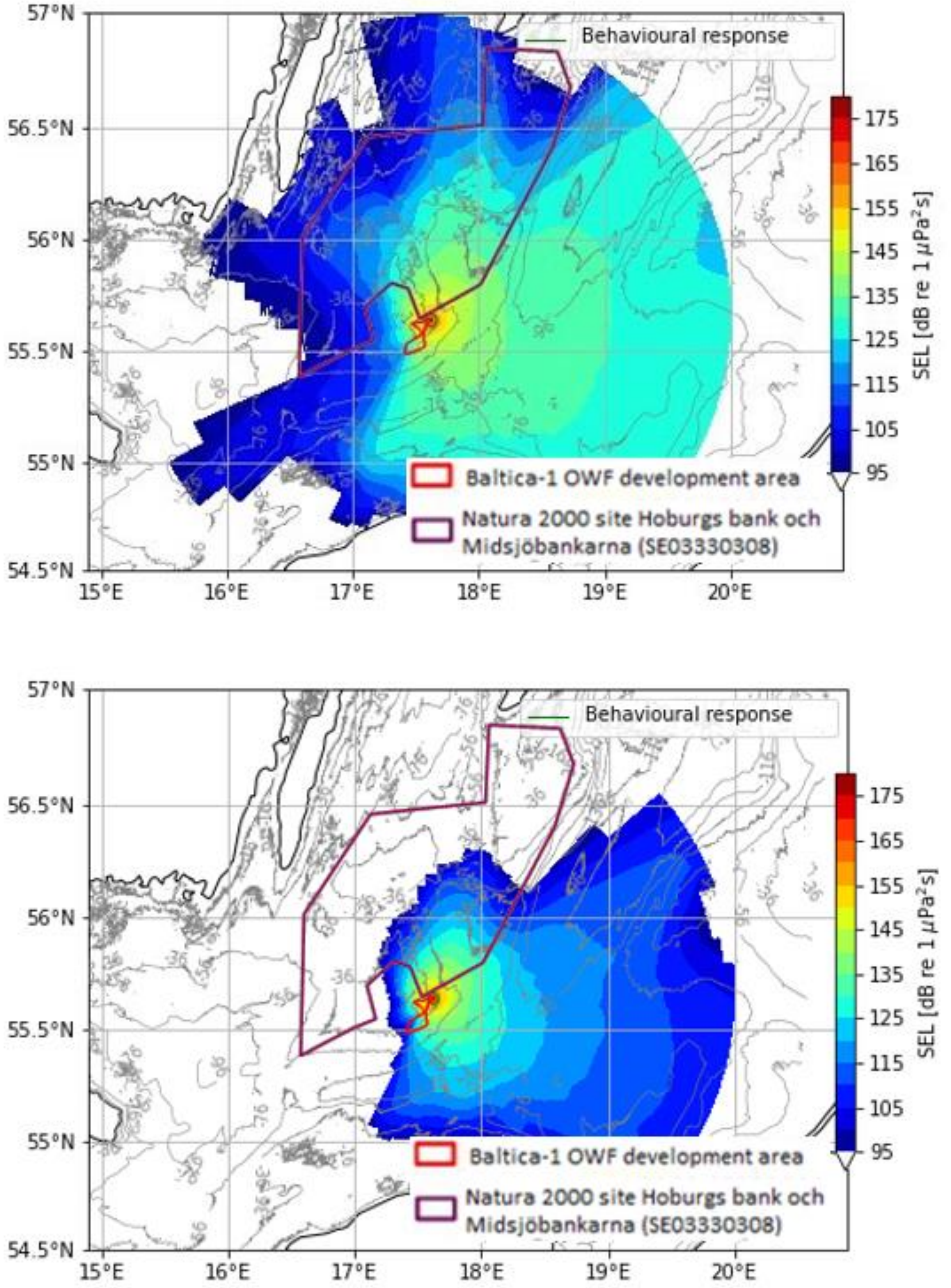



*Figure 4.14. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

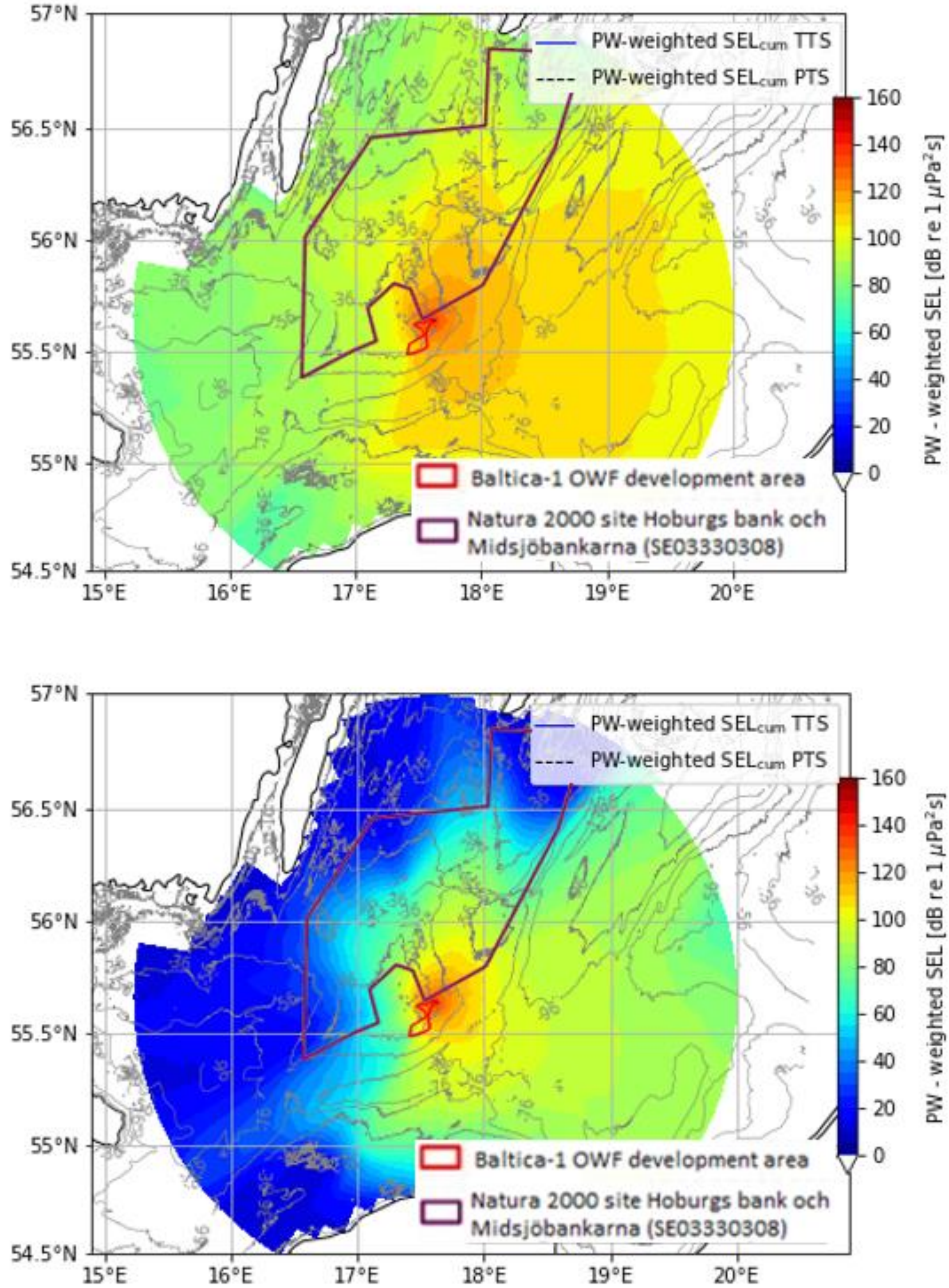



*Figure 4.15. The map of PW-weighted SEL$_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the grey seal harbour seal the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

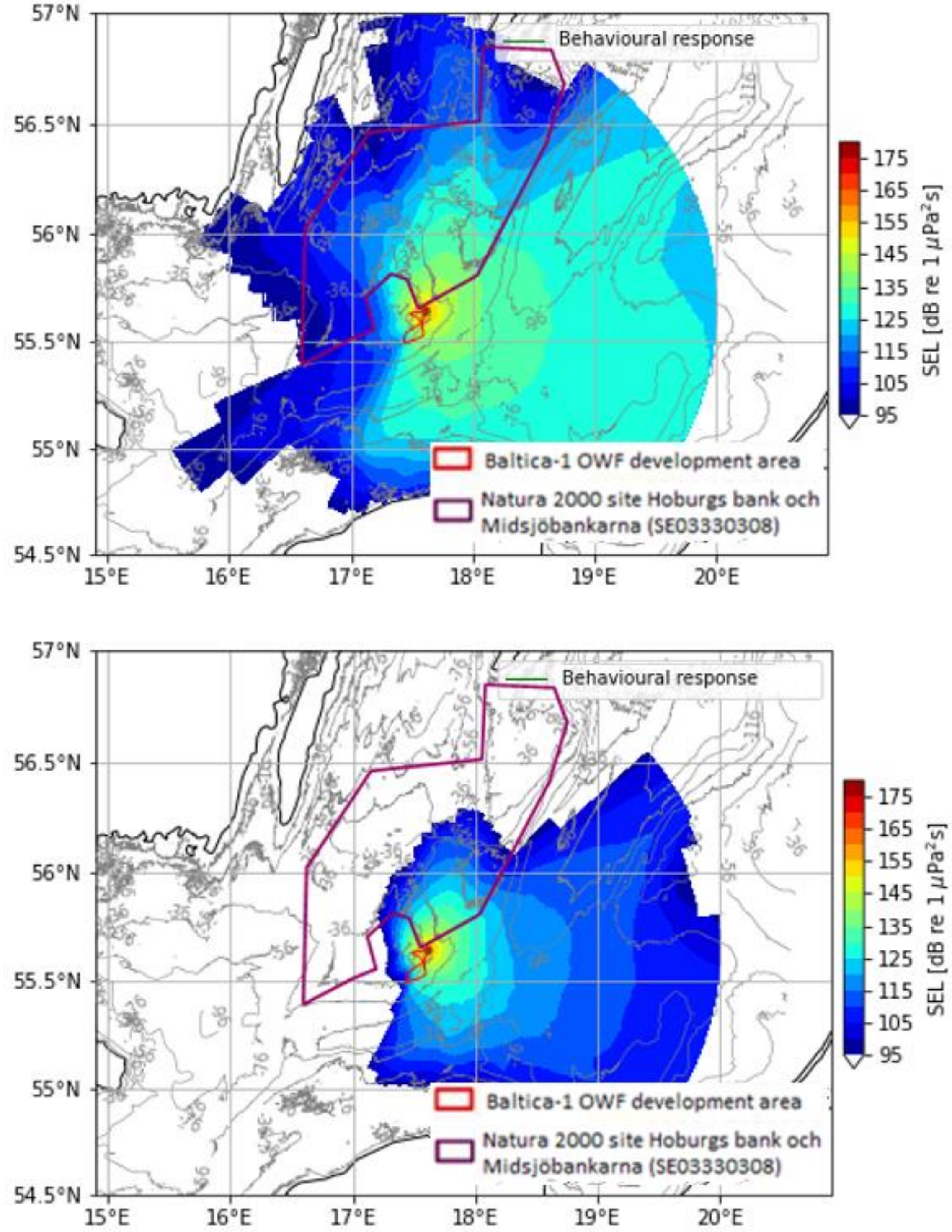



*Figure 4.16.* *The map of unweighted $SEL_{cum}$ above the acoustic background in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

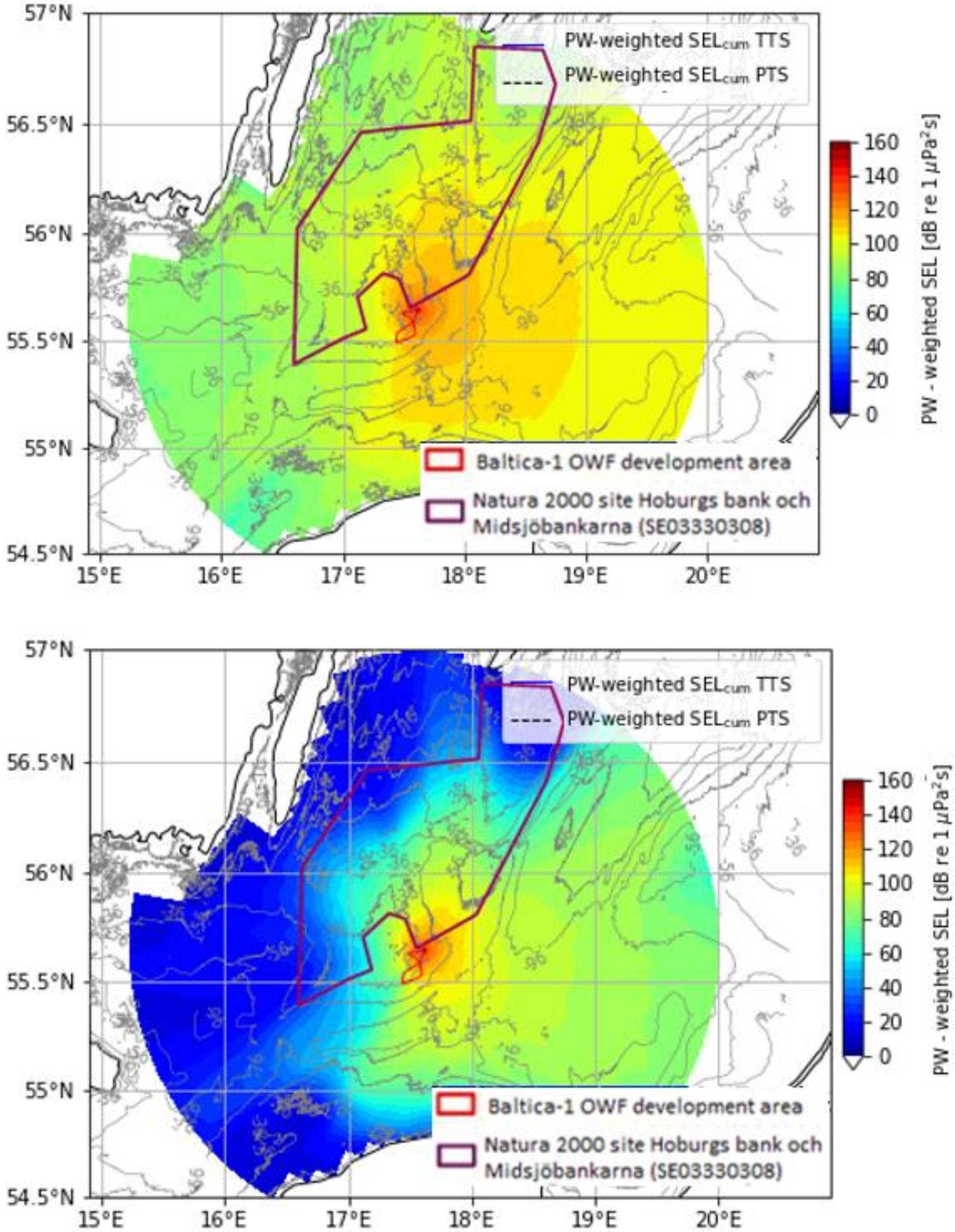



*Figure 4.17.* *The map of PW-weighted $SEL_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the grey seal harbour seal the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

### 4.1.1.3 Fish with swim bladders

All ranges and areas of impact calculated for fish with swim bladders for the winter season were higher than those obtained for the summer season.

The maximum range of behavioural response and cumulative TTS for fish with swim bladders exceeded the model domain range of 150 km from the source, with the largest areas of impact among the analysed effects.

The predicted ranges of cumulative TTS and PTS were higher than the values obtained for a single blow, while the TTS ranges were higher than the ones obtained for the PTS.

The use of mitigation measures contributed to the reduction of the ranges and areas of impact of all analysed effects, and even after the application of the dual system in the form of HSD + DBBC, the ranges of behavioural response and cumulative TTS remained at a relatively high level. The smallest ranges of the impact of behavioural response were obtained after the application of the IQIP + DBBC system.

All ranges calculated for individual threshold values are shown in tabular form [Table 4.3], while noise propagation maps are presented in the following figures [Figure 4.18–Figure 4.21].

*Table 4.3. The ranges and areas of impact calculated for fish with swim bladders in the Baltica-1 OWF area*

| Season | Mitigation type | Effect | unweighted SEL [dB re 1 µPa²s] | | |
|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] |
| Winter | - | Behavioural response | 112 | 150 | 42470 |
| | | TTS (single blow) | 0.6 | 0.7 | 1.3 |
| | | TTS (cumulative effect) | 79.6 | 150 | 27423 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |
| | | Reversible hearing loss (cumulative effect) | 14.0 | 19.2 | 639 |
| | BBC | Behavioural response | 75.4 | 150 | 25820 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 |
| | | TTS (cumulative effect) | 34.9 | 37.5 | 2204 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |
| | | Reversible hearing loss (cumulative effect) | 4.4 | 4.7 | 62.0 |
| | HSD + DBBC | Behavioural response | 28.0 | 41.3 | 2844 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 |
| | | TTS (cumulative effect) | 9.5 | 11.6 | 288 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |
| | | Reversible hearing loss (cumulative effect) | 1.3 | 1.4 | 5.0 |
| | IQIP + DBBC | Behavioural response | 22.5 | 33.2 | 1772 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 |
| | | TTS (cumulative effect) | 7.0 | 8.0 | 158 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |
| | | Reversible hearing loss (cumulative effect) | 0.6 | 0.6 | 1.1 |

| Season | Mitigation type | Effect | unweighted SEL [dB re 1 µPa²s] | | |
|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] |
| Summer | - | Behavioural response | 52.7 | 118 | 11981 |
| | | TTS (single blow) | 0.7 | 0.7 | 1.5 |
| | | TTS (cumulative effect) | 25.6 | 39.1 | 2333 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.01 |
| | | Reversible hearing loss (cumulative effect) | 9.0 | 11.2 | 259 |
| | BBC | Behavioural response | 27.2 | 42.3 | 2676 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 |
| | | TTS (cumulative effect) | 13.8 | 19.1 | 625 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |
| | | Reversible hearing loss (cumulative effect) | 3.7 | 4.0 | 43.4 |
| | HSD + DBBC | Behavioural response | 15.5 | 22.2 | 801 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 |
| | | TTS (cumulative effect) | 7.3 | 8.8 | 169 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |
| | | Reversible hearing loss (cumulative effect) | 1.2 | 1.2 | 4.5 |
| | IQIP + DBBC | Behavioural response | 13.0 | 17.8 | 551 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 |
| | | TTS (cumulative effect) | 5.5 | 6.4 | 95.0 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |
| | | Reversible hearing loss (cumulative effect) | 0.5 | 0.6 | 0.8 |

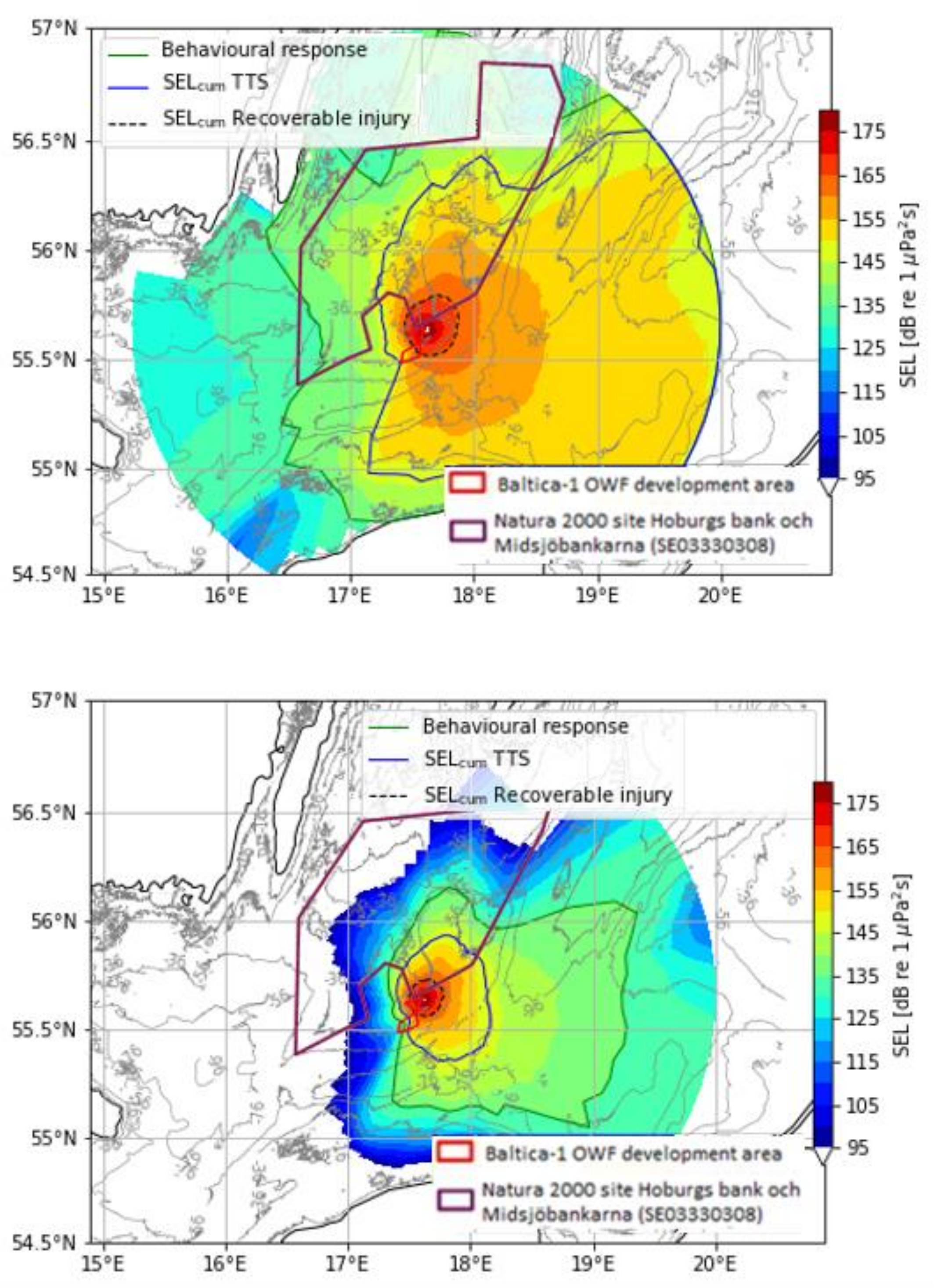



*Figure 4.18. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on fish with swim bladders, in the winter (top) and summer (bottom)*

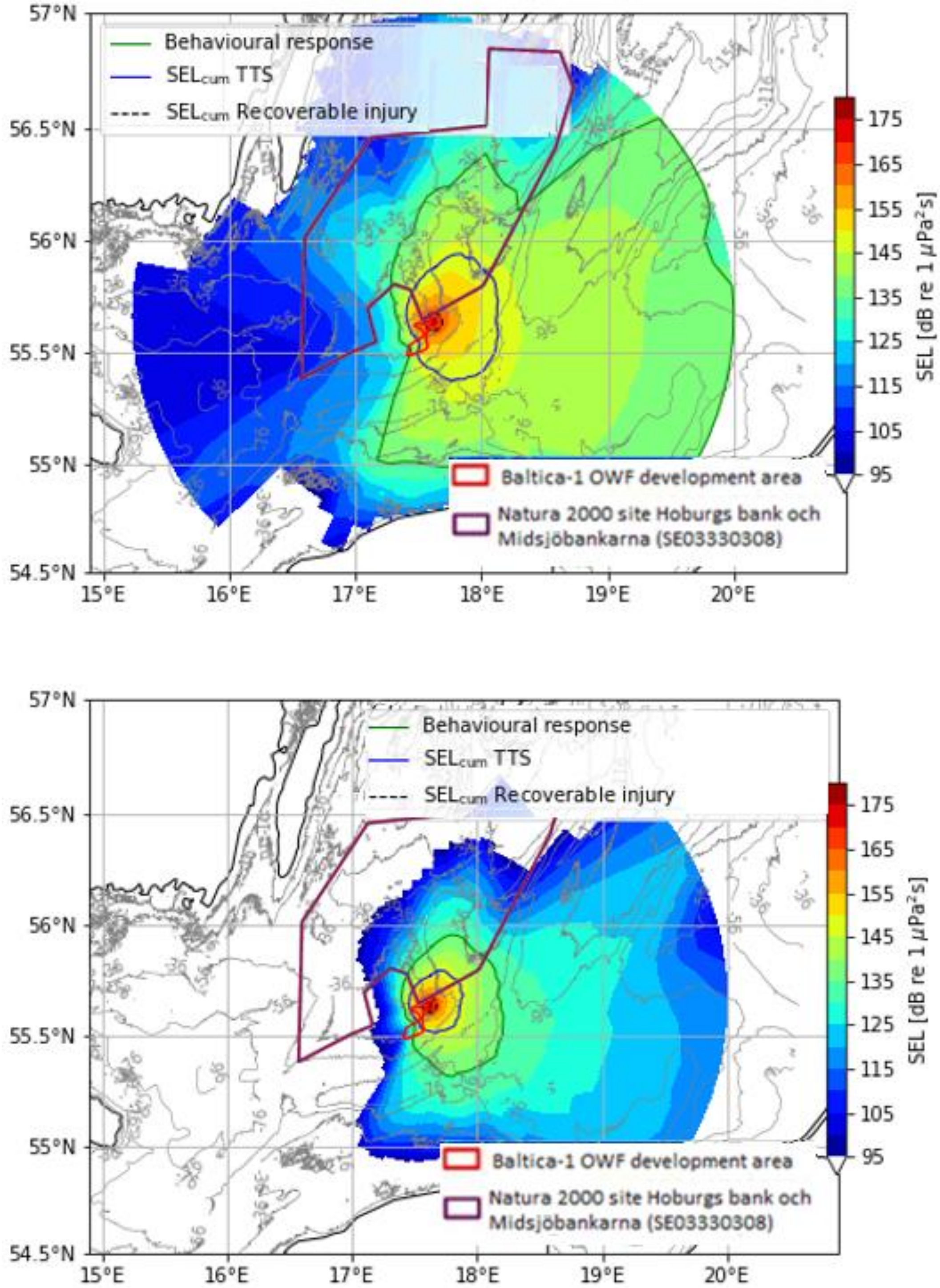



*Figure 4.19. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on fish with swim bladders with a BBC applied, in the winter (top) and summer (bottom)*

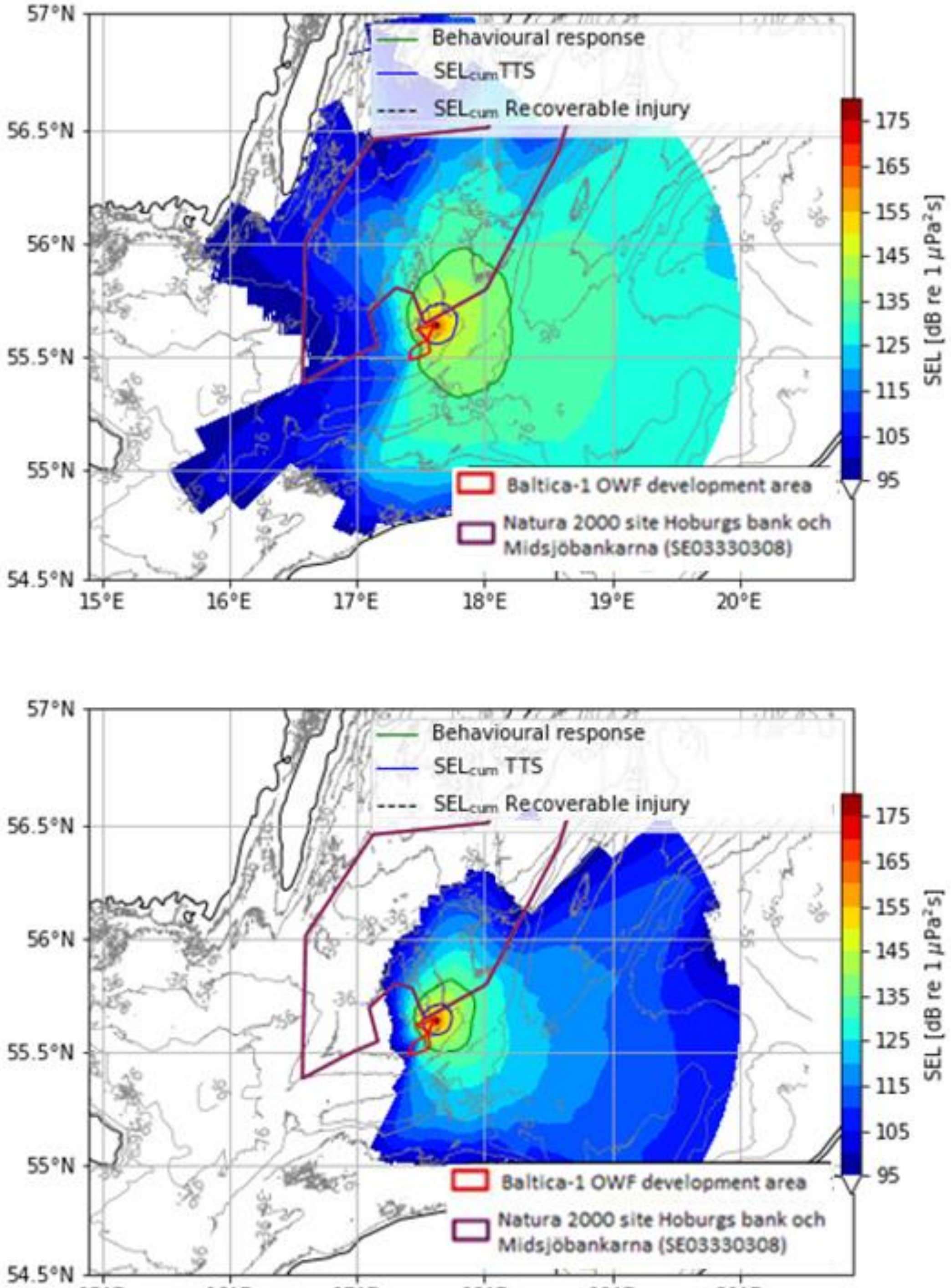



*Figure 4.20. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on fish with swim bladders with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

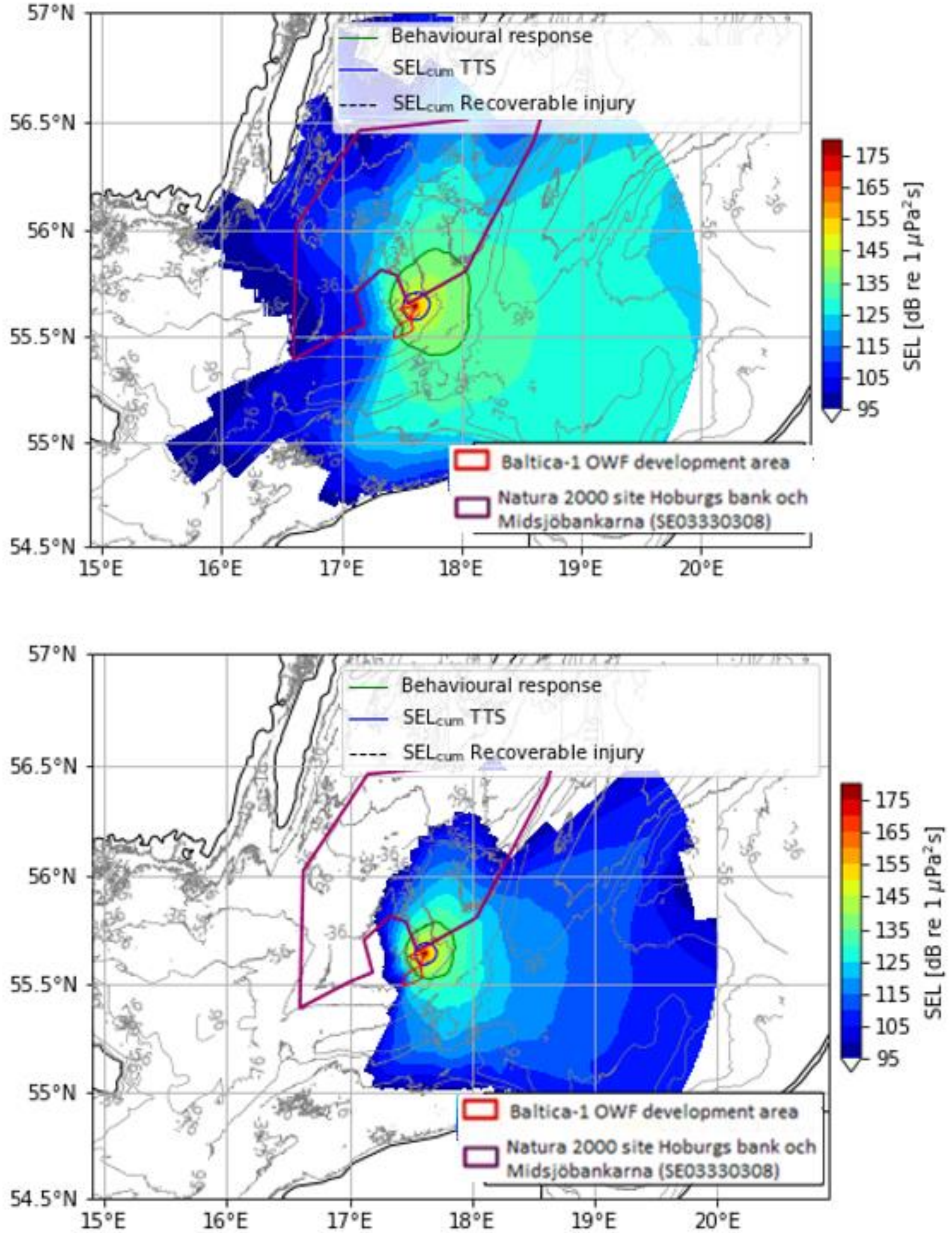



*Figure 4.21. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on fish with swim bladders with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

## 4.2 THE MODELLING OF NOISE PROPAGATION AS A RESULT OF PILING IN SEVERAL LOCATIONS

This chapter presents the results of acoustic modelling in the winter and summer seasons performed for simultaneous piling in the northern location within the Baltica-1 OWF area and outside of it. The use of mitigation measures in the form of BBC, HSD + DBBC and IQIP + DBBC was taken into account. The areas of impact for individual acoustic thresholds and sound propagation maps were presented.

### 4.2.1 Harbour porpoise

As can be seen in the table below [Table 4.4], the areas of impact increased with the number of piling sources, reaching the highest values in the case of four locations. The smallest areas of impact were obtained for the scenario with the HSD + DBBC reduction system applied. Noise propagation maps are presented in the following figures [Figure 4.22–Figure 4.39].

*Table 4.4. The impact areas for the harbour porpoise in case of simultaneous piling at several locations within and outside the Baltica-1 OWF (numbers in bold: highest values for 2 and 3 sources, respectively; piling with the BBC, HSD + DBBC and IQIP + DBBC mitigation systems applied)*

| **Season** | **Mitigation type** | **Impact area [km²]** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Effect** | **1 source** | **2 sources – < 1 km** | **2 sources – 20 km** | **2 sources – at a significant distance** | **3 sources – 2 < 1 km, 1 = 20 km** | **3 sources – 2 = 20 km, 1 = at a significant distance** | **4 sources** |
| Winter | BBC | Behavioural response | 1394 | 2004 | 2312 | **2788** | 2805 | **3706** | 5100 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | TTS (cumulative effect) | 1.2 | 4.1 | **56.7** | 2.4 | **59.5** | 57.9 | 60.7 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | HSD + DBBC | Behavioural response | 863 | 1295 | 1536 | **1726** | 1879 | **2399** | 3262 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | TTS (cumulative effect) | 0.2 | 0.7 | **40.8** | 0.4 | **45.4** | 41.0 | 45.6 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | IQIP + DBBC | Behavioural response | 956 | 1387 | 1635 | **1912** | 1983 | **2591** | 3547 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | TTS (cumulative effect) | 0.3 | 0.9 | **29.4** | **0.6** | **36.9** | 31.4 | 37.2 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| Summer | BBC | Behavioural response | 233 | 292 | **502** | 466 | 558 | **735** | 968 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | TTS (cumulative effect) | 0.7 | 2 | **37.2** | 1.4 | **44.0** | 37.9 | 44.7 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | HSD + DBBC | Behavioural response | 164 | 209 | **328** | 328 | 373 | **492** | 656 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |

| Season | Mitigation type | Impact area [km²] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Effect | 1 source | 2 sources – < 1 km | 2 sources – 20 km | 2 sources – at a significant distance | 3 sources – 2 < 1 km, 1 = 20 km | 3 sources – 2 = 20 km, 1 = at a significant distance | 4 sources |
| | | TTS (cumulative effect) | 0.1 | **0.4** | 0.2 | 0.2 | **0.8** | 0.3 | 0.9 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | IQIP + DBBC | Behavioural response | 178 | 227 | **357** | 356 | 404 | **535** | 713 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.6 | **0.09** | 0.6 |
| | | TTS (cumulative effect) | 0.1 | **0.6** | 0.3 | 0.3 | **0.9** | 0.4 | 1.0 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |

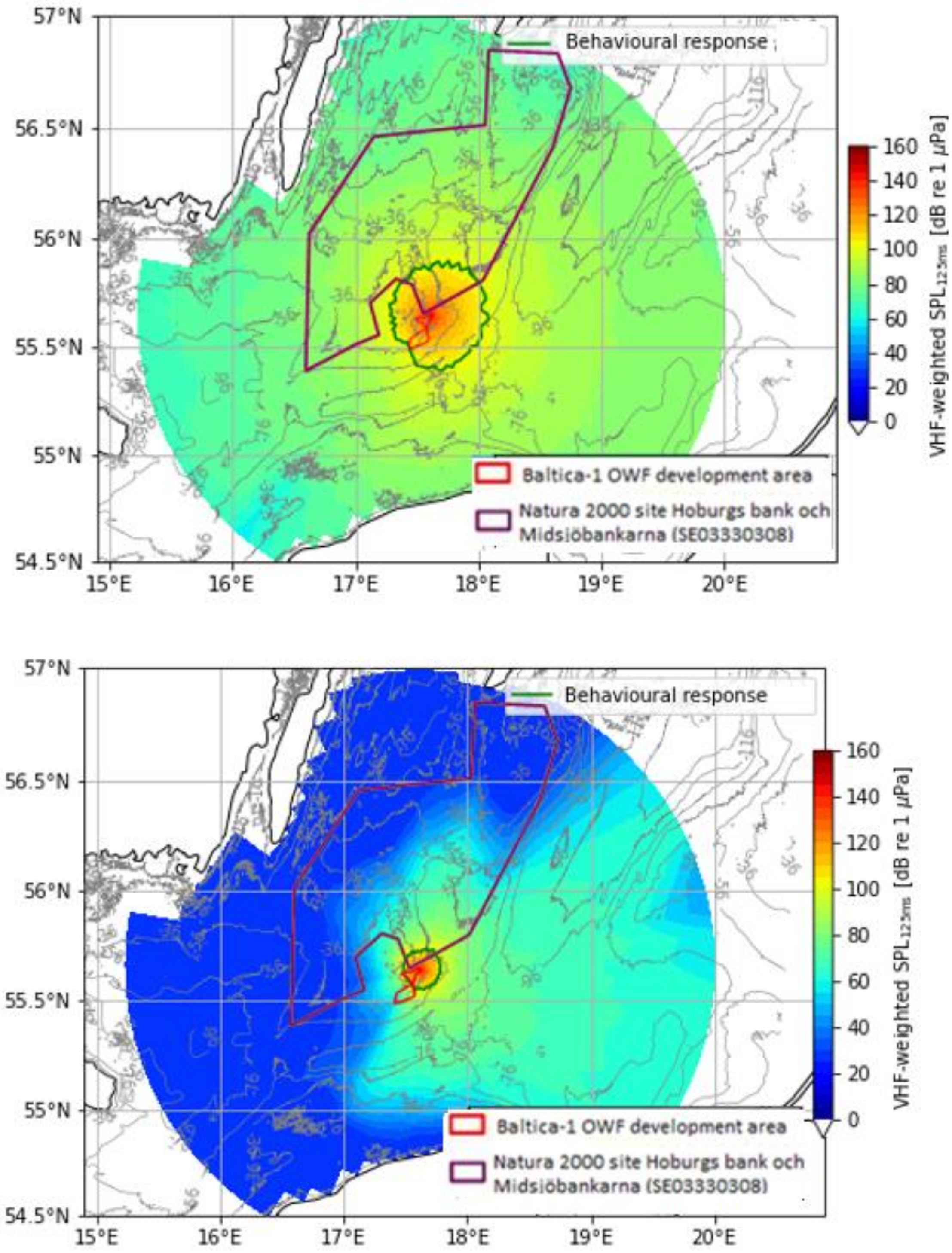



*Figure 4.22. The map of HF-weighted $SPL_{125ms}$ from piling sources located at a small distance from each other in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with a BBC applied, in the winter (top) and summer (bottom)*

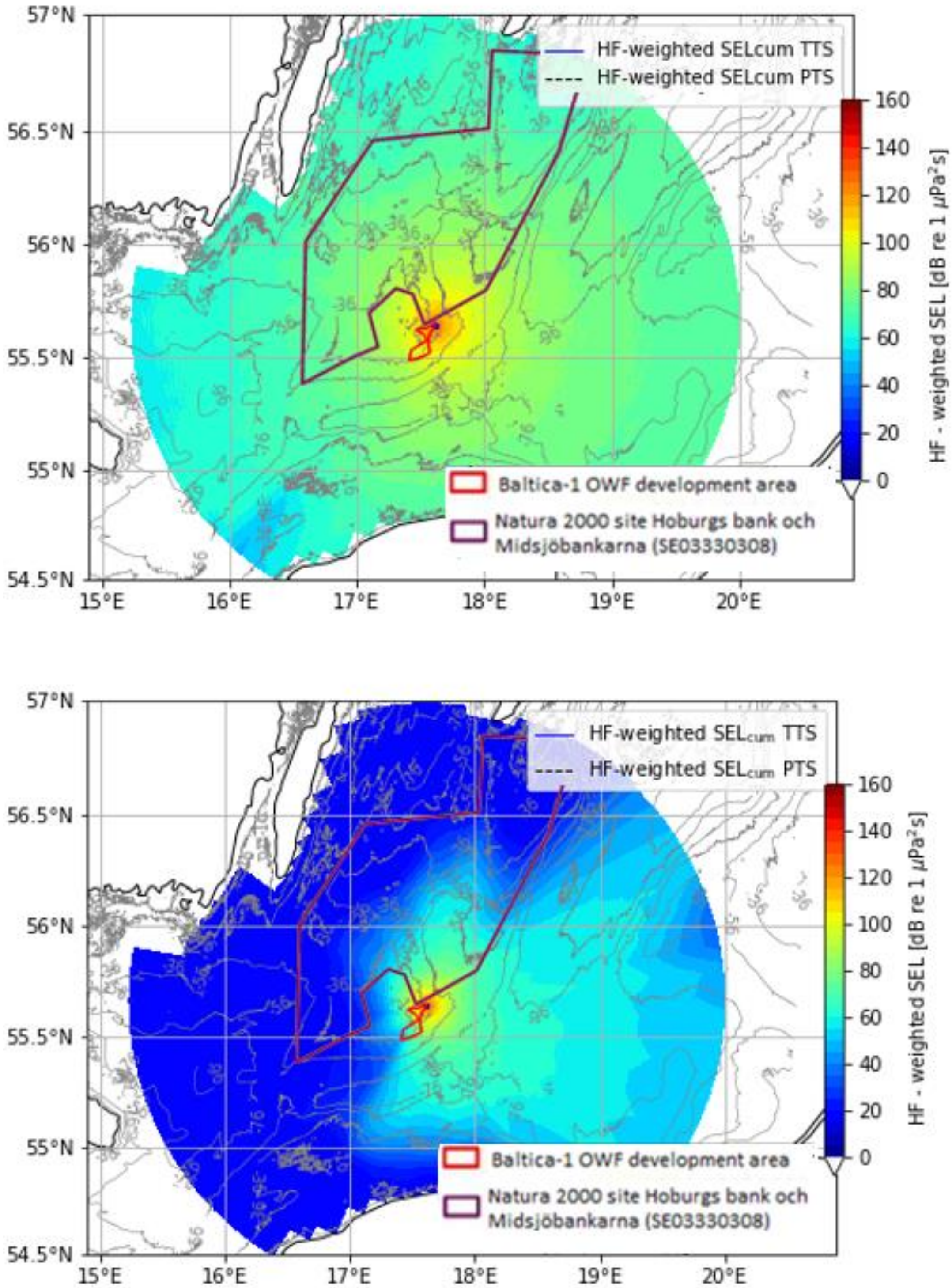



*Figure 4.23.* *The map of HF-weighted SEL$_{cum}$ from cumulated piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with a BBC applied, in the winter (top) and summer (bottom)*

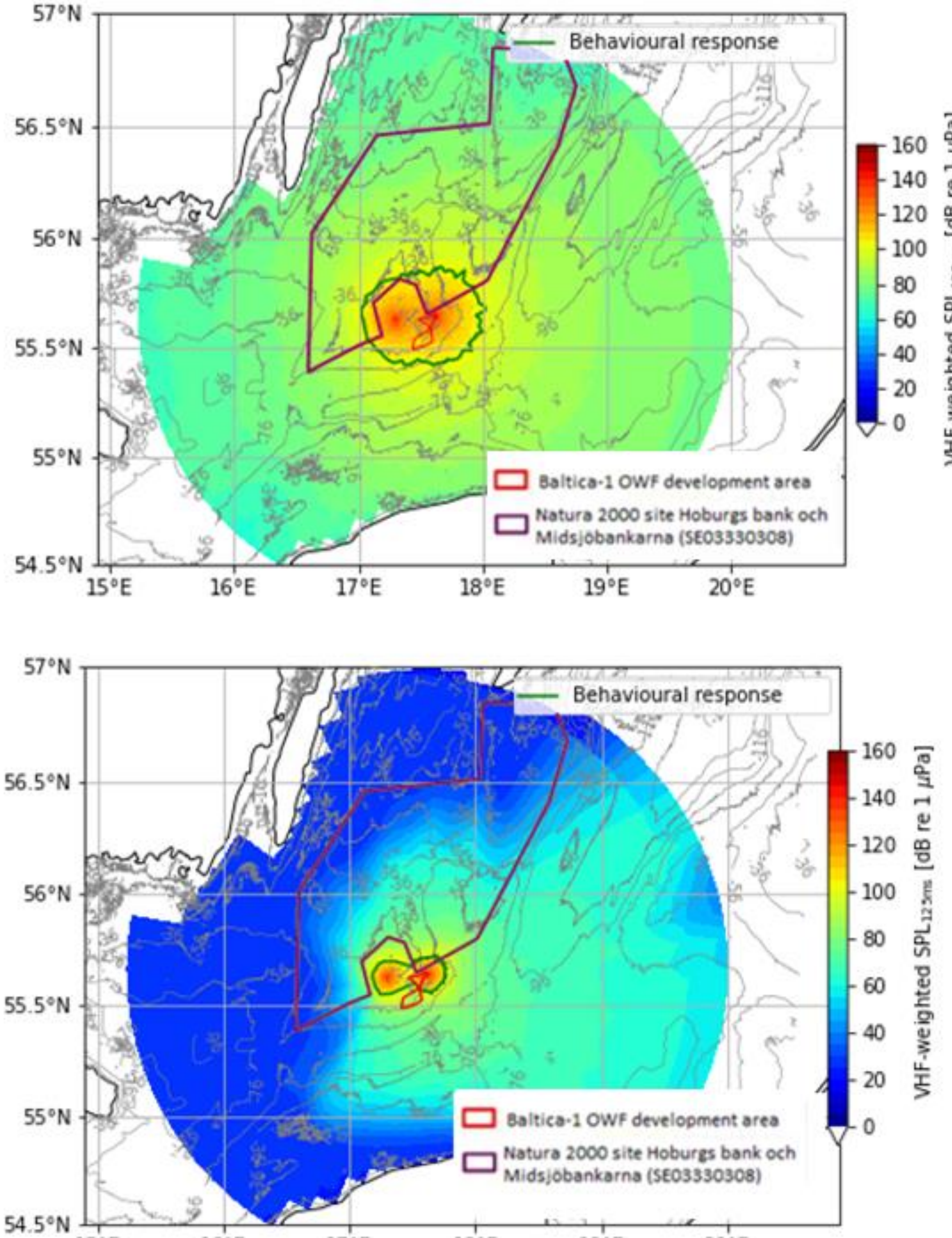



*Figure 4.24.* *The map of VHF-weighted $SPL_{125ms}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the harbour porpoise with a BBC applied, in the winter (top) and summer (bottom)*

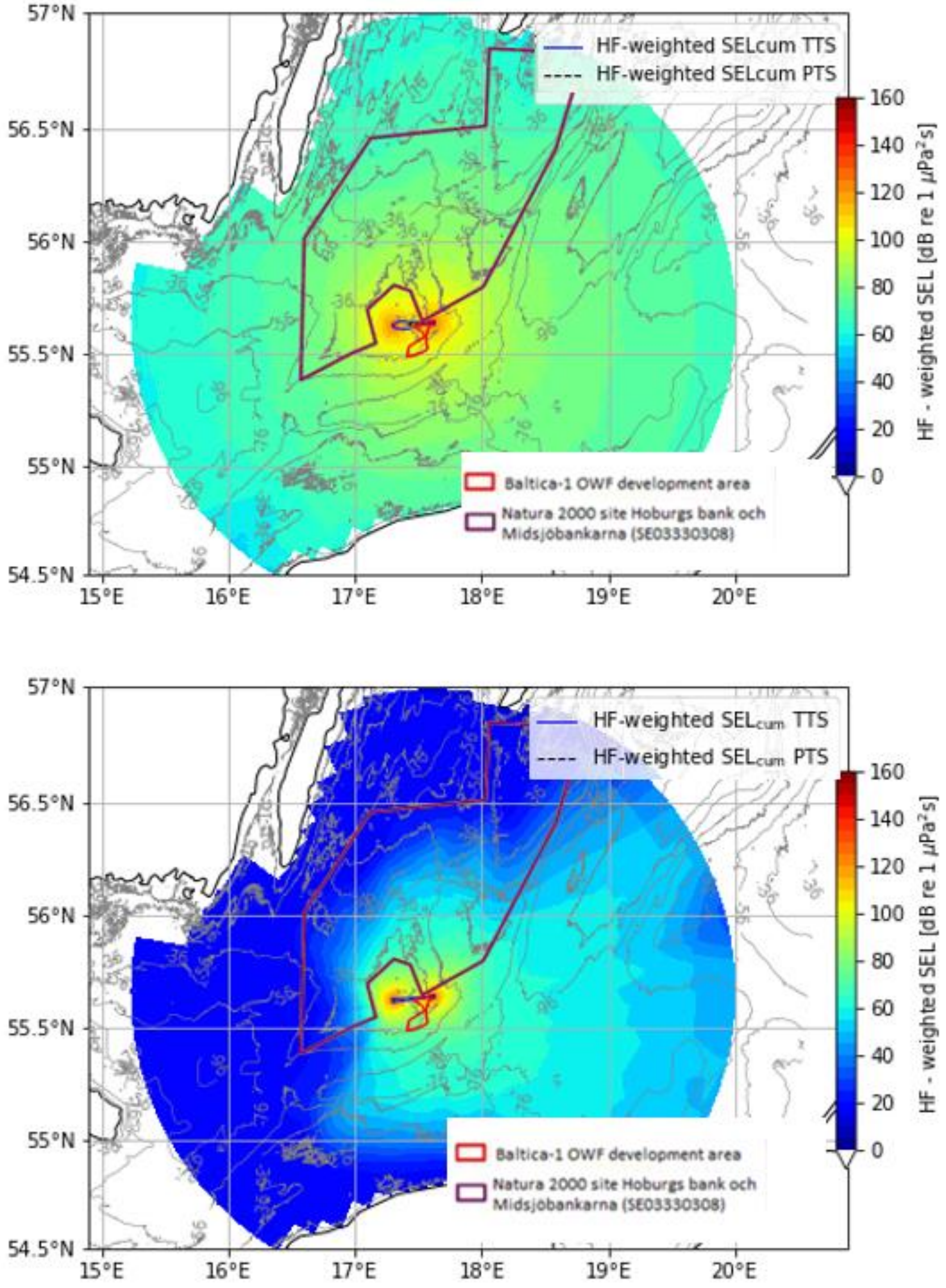



*Figure 4.25.* *The map of HF-weighted SEL $_{cum}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the harbour porpoise with a BBC applied, in the winter (top) and summer (bottom)*

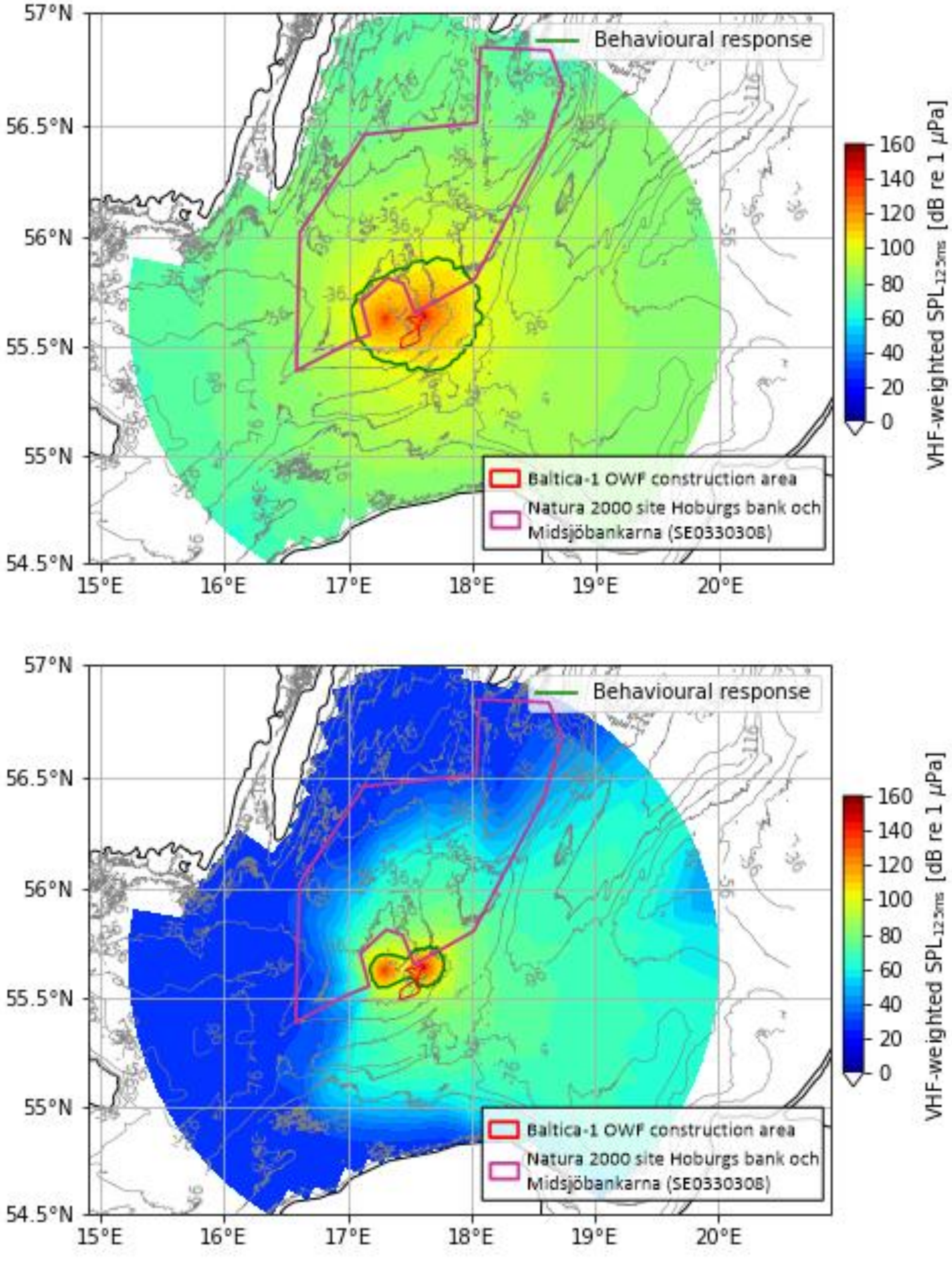



*Figure 4.26.* *The map of VHF-weighted $SPL_{125ms}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the harbour porpoise with a BBC applied, in the winter (top) and summer (bottom)*

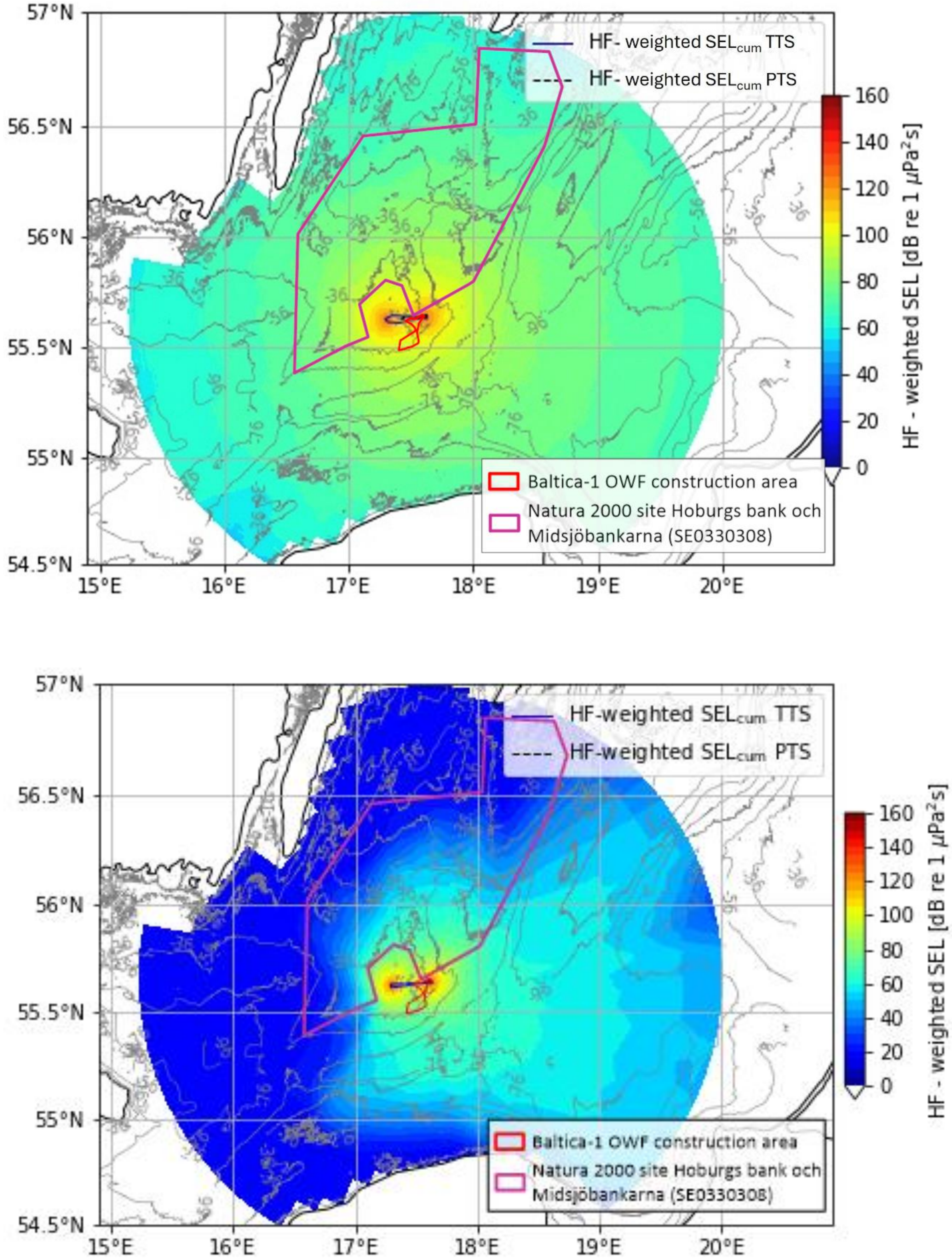
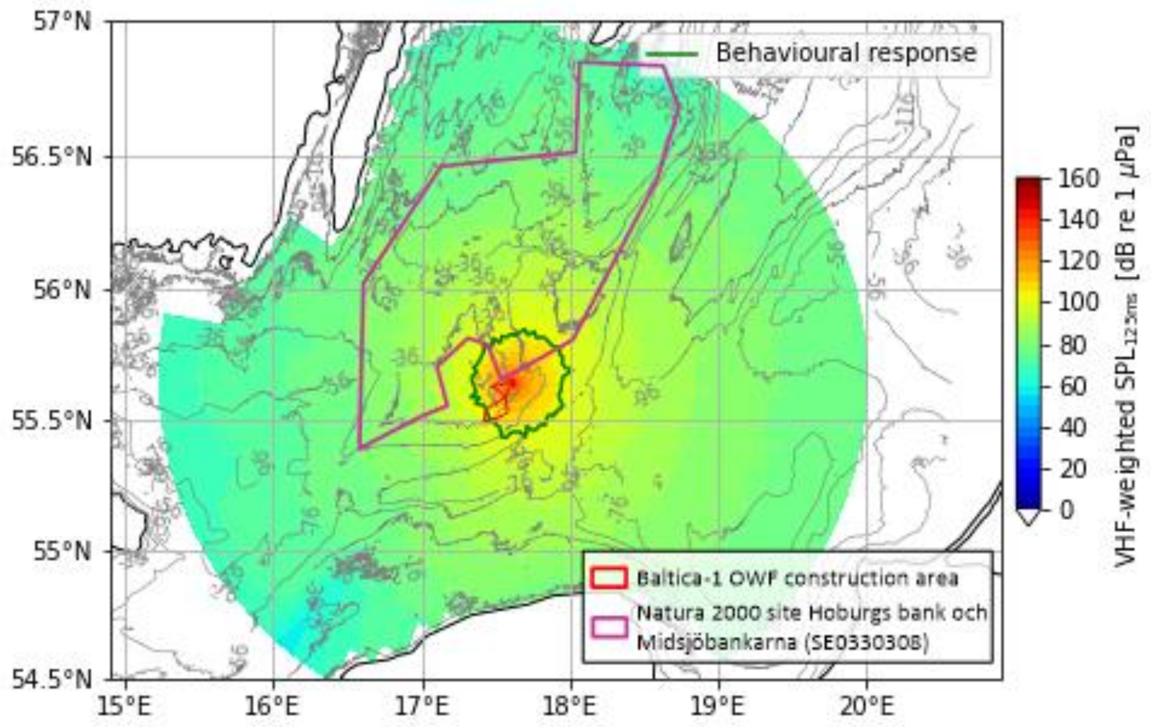



*Figure 4.27. The map of HF-weighted $SEL_{cum}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the harbour porpoise with a BBC applied, in the winter (top) and summer (bottom)*



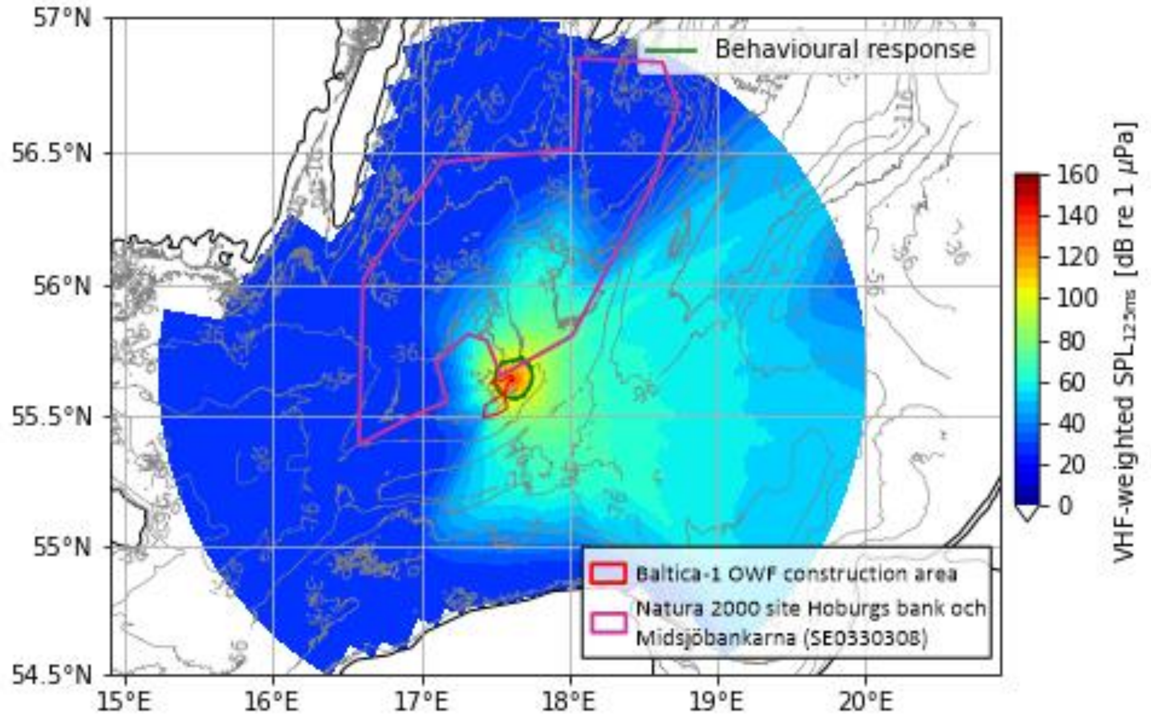




*Figure 4.28. The map of VHF-weighted $SPL_{125ms}$ from piling sources located at a small distance from each other in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

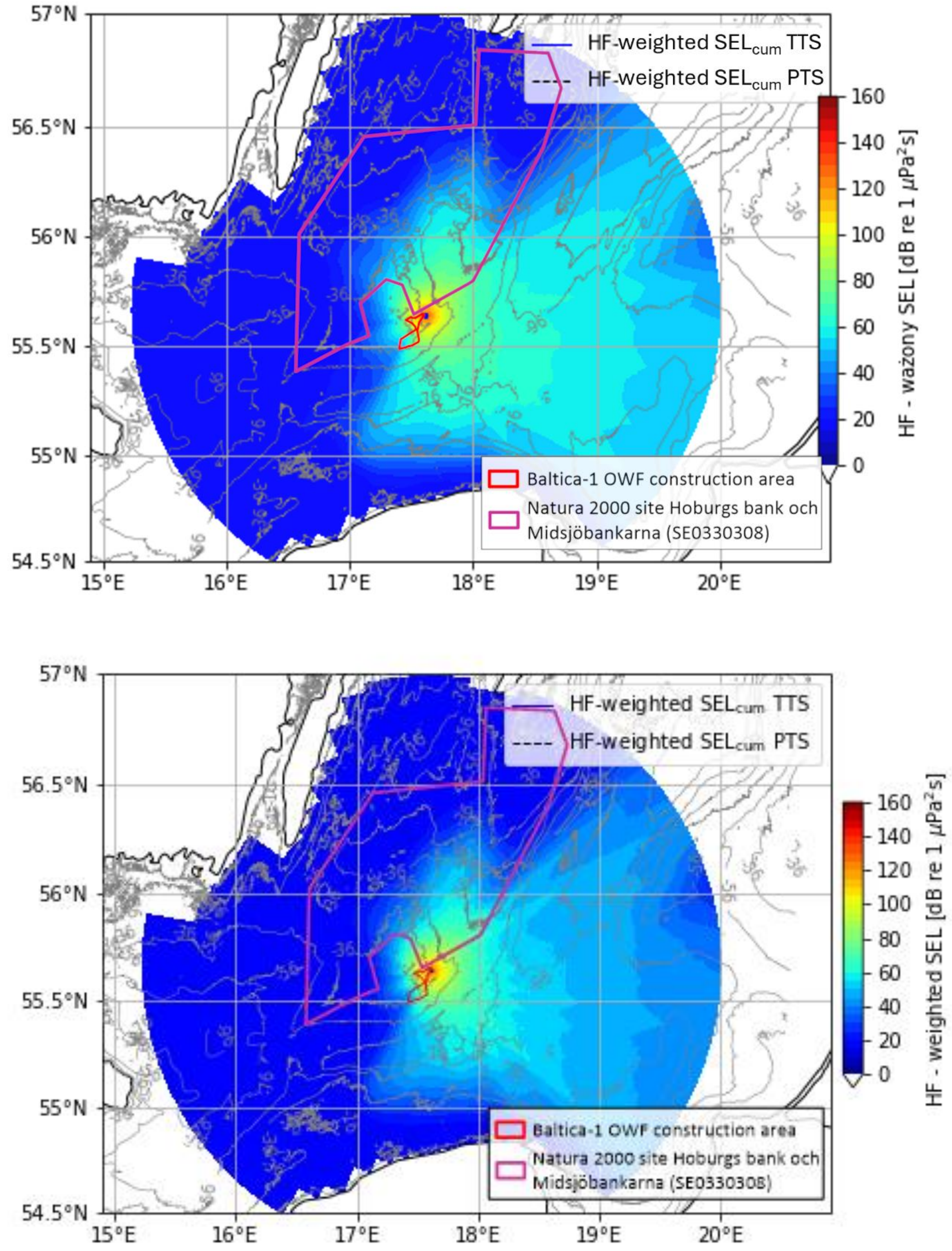



*Figure 4.29. The map of HF-weighted $SEL_{cum}$ from piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

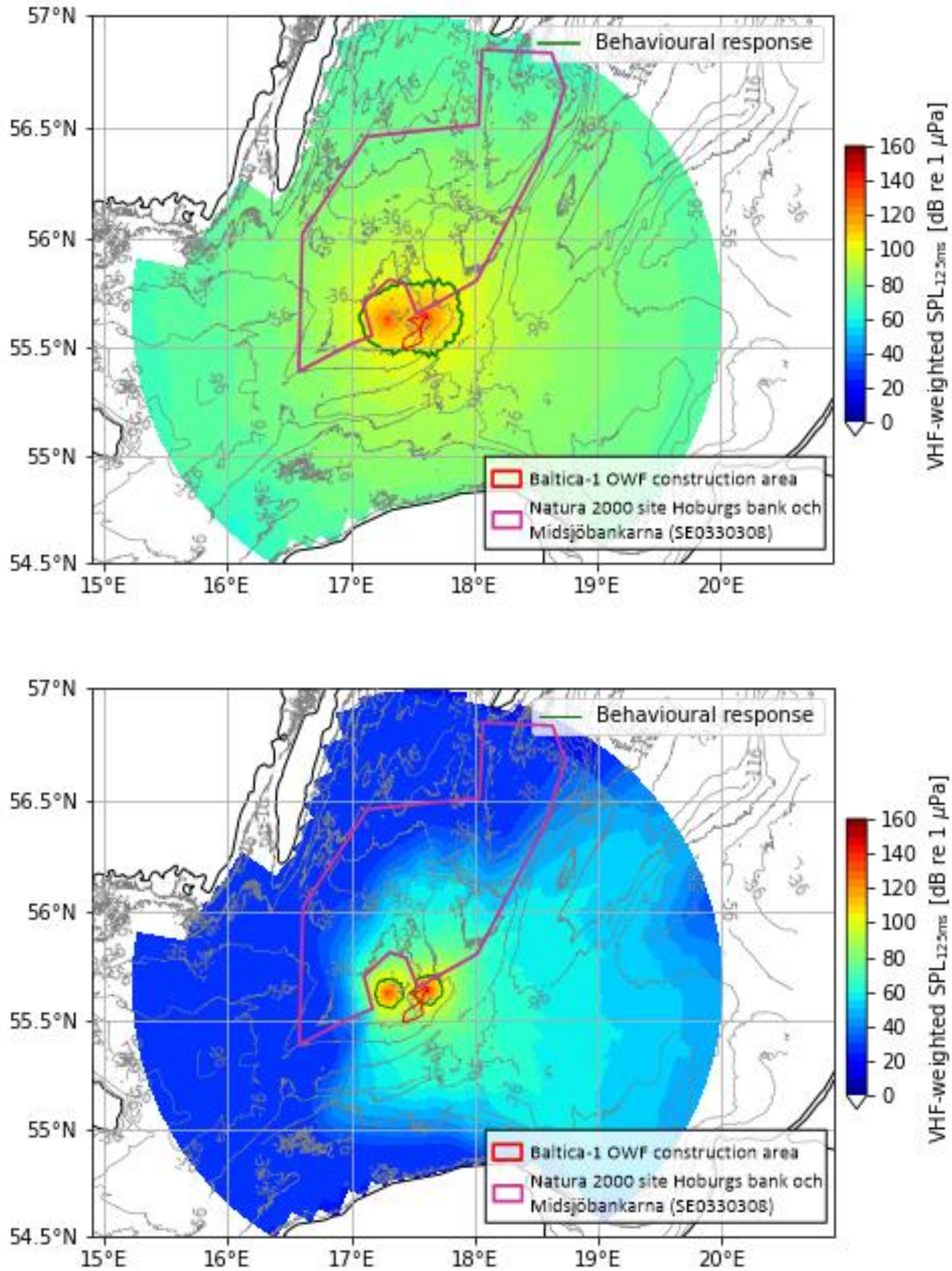
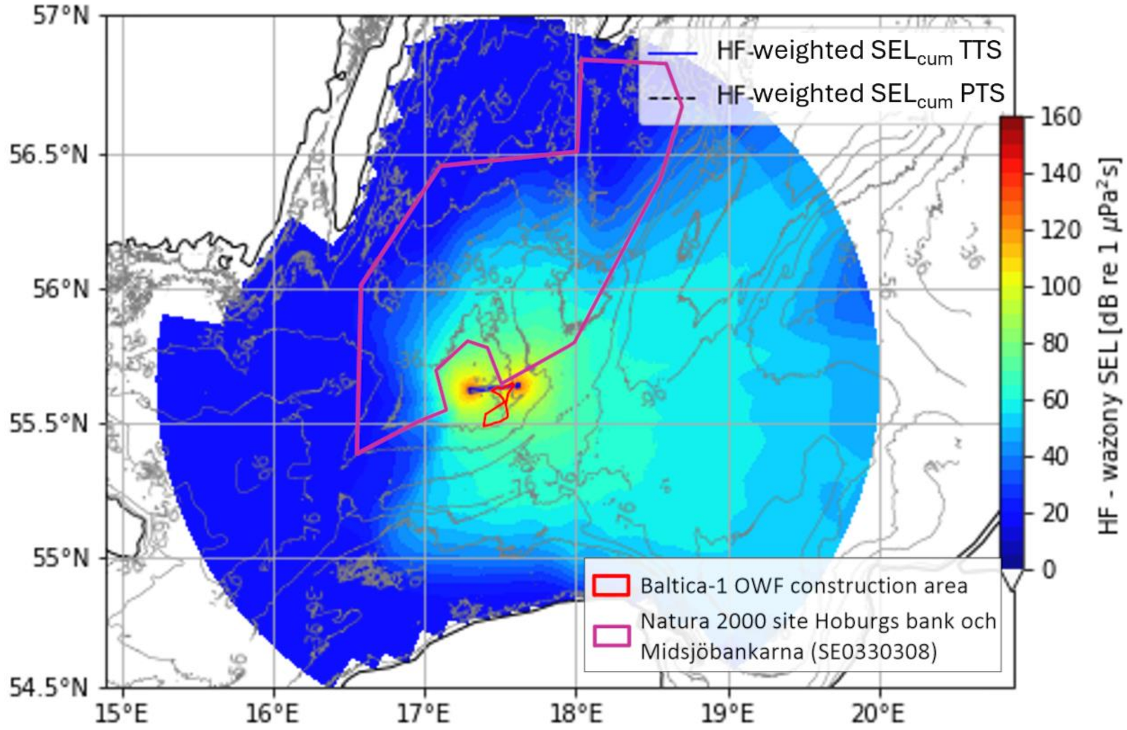



*Figure 4.30. The map of VHF-weighted $SPL_{125ms}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*



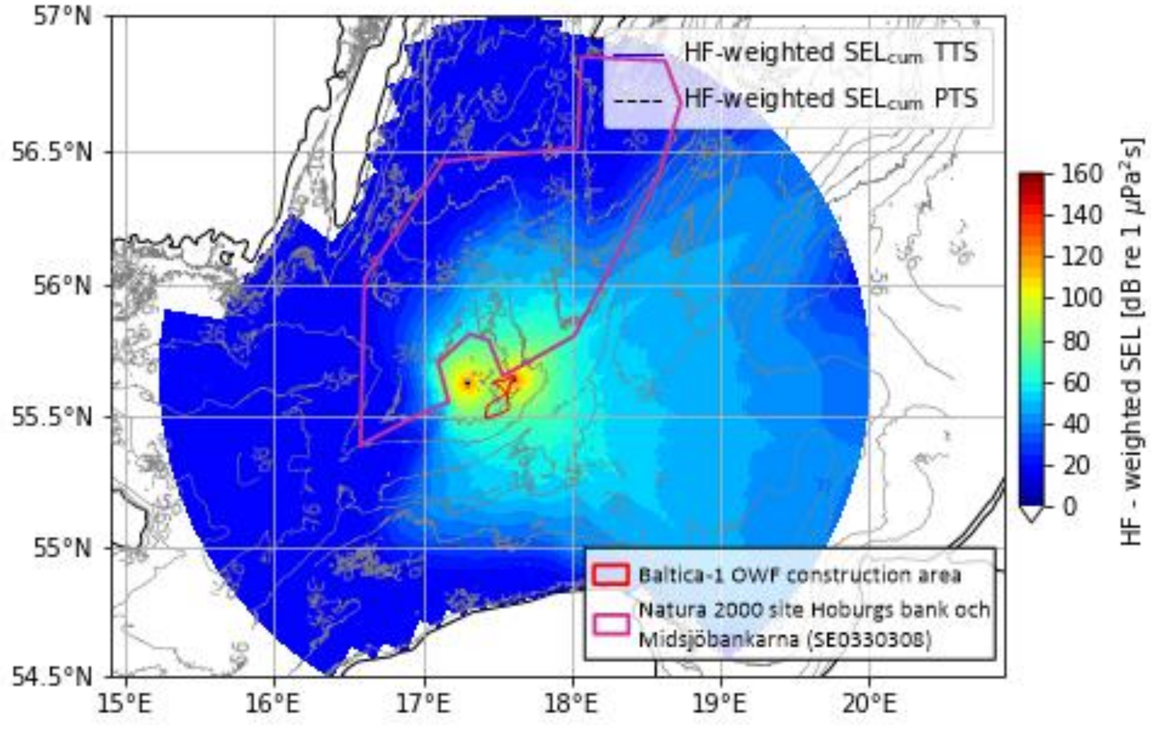
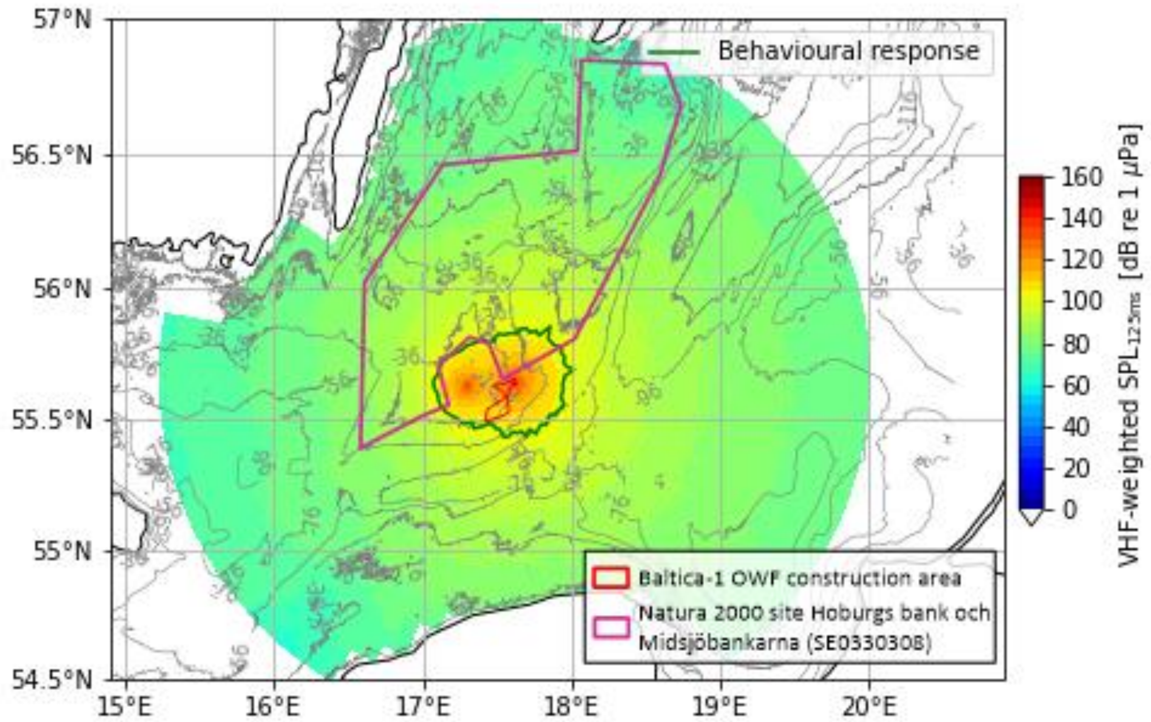




*Figure 4.31. The map of HF-weighted SEL $_{cum}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*



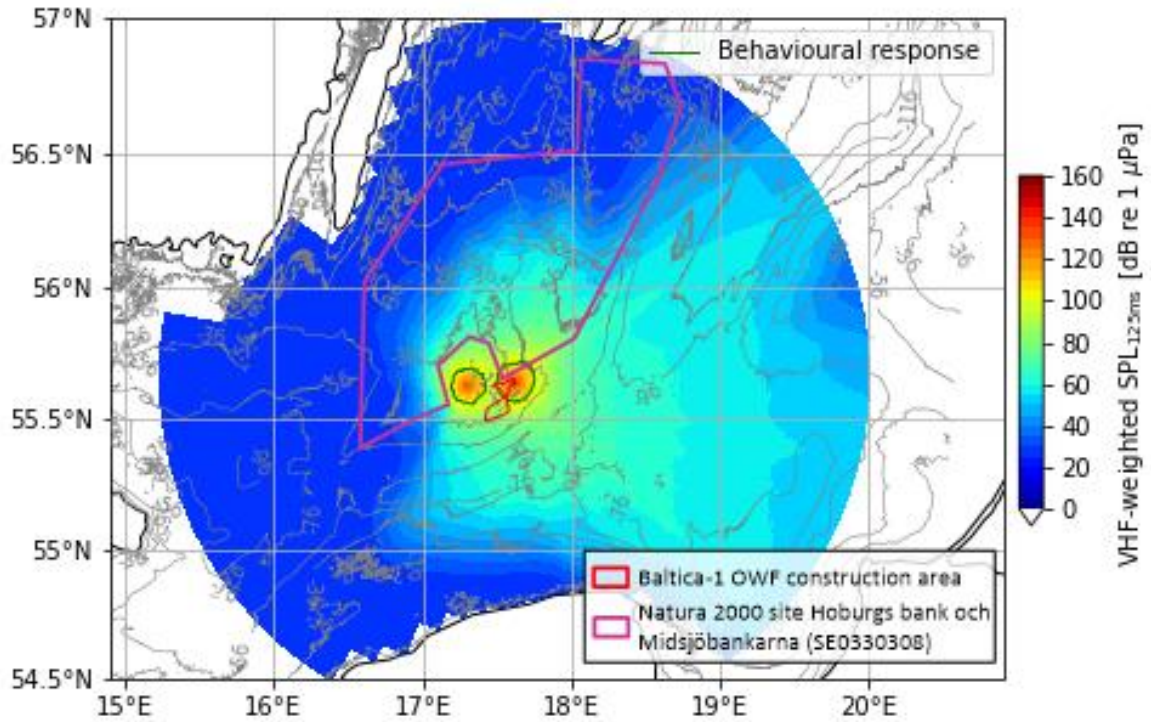




*Figure 4.32. The map of VHF-weighted $SPL_{125ms}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

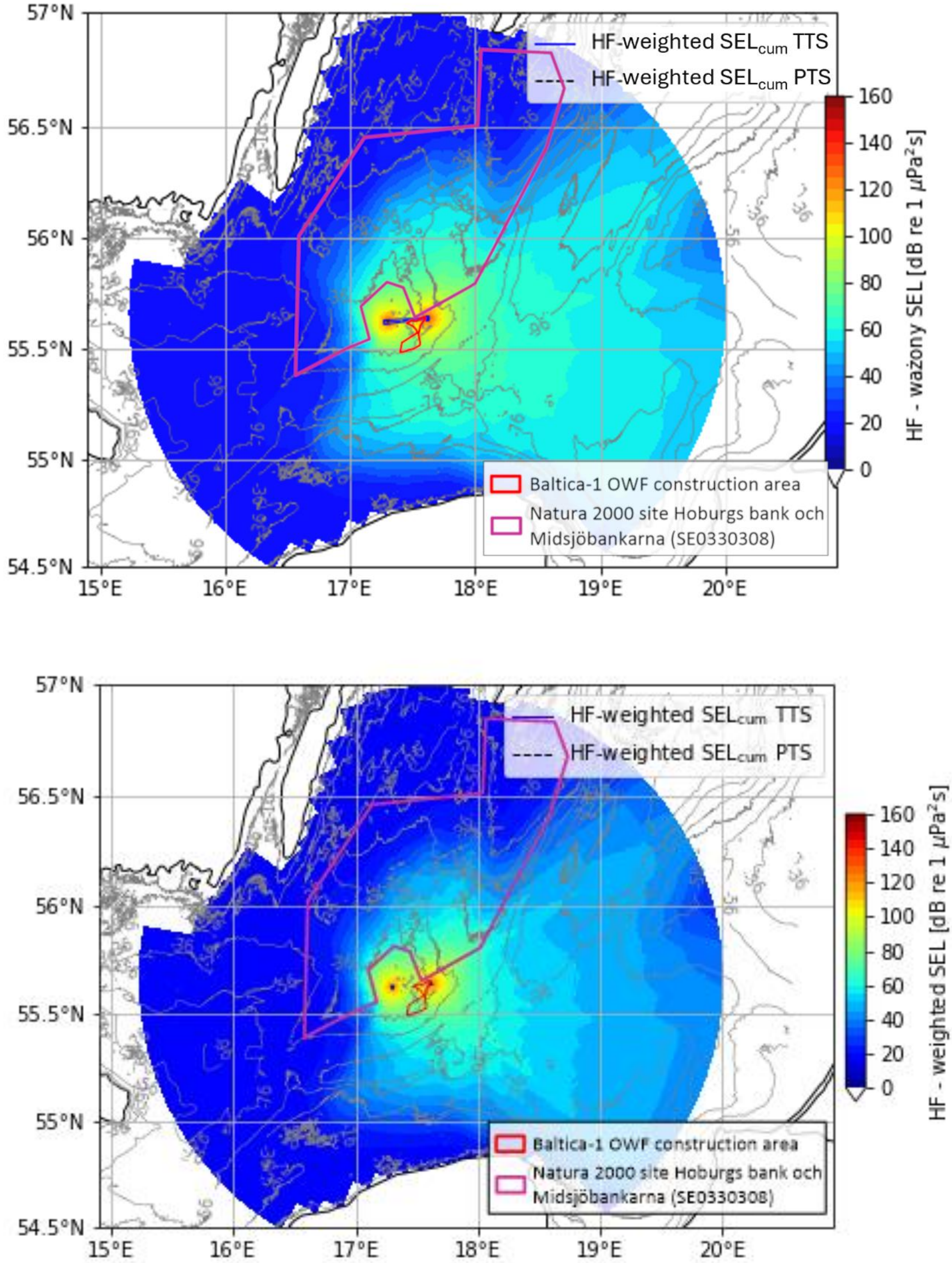
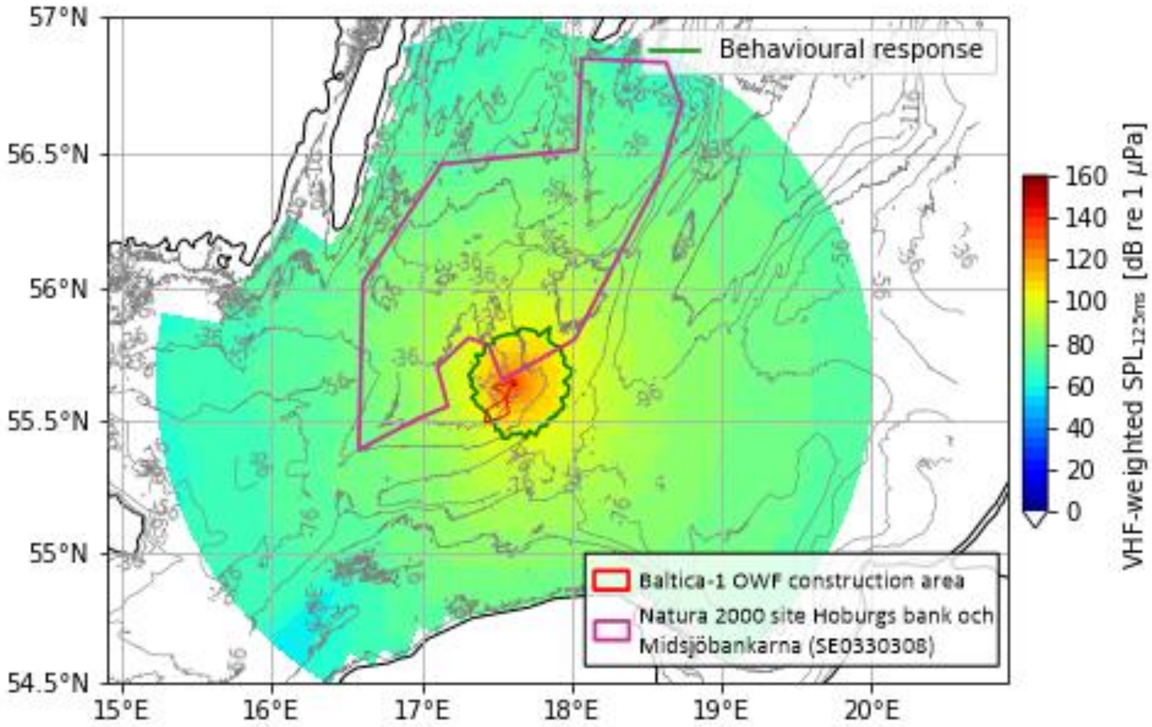



*Figure 4.33. The map of HF-weighted $SEL_{cum}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*



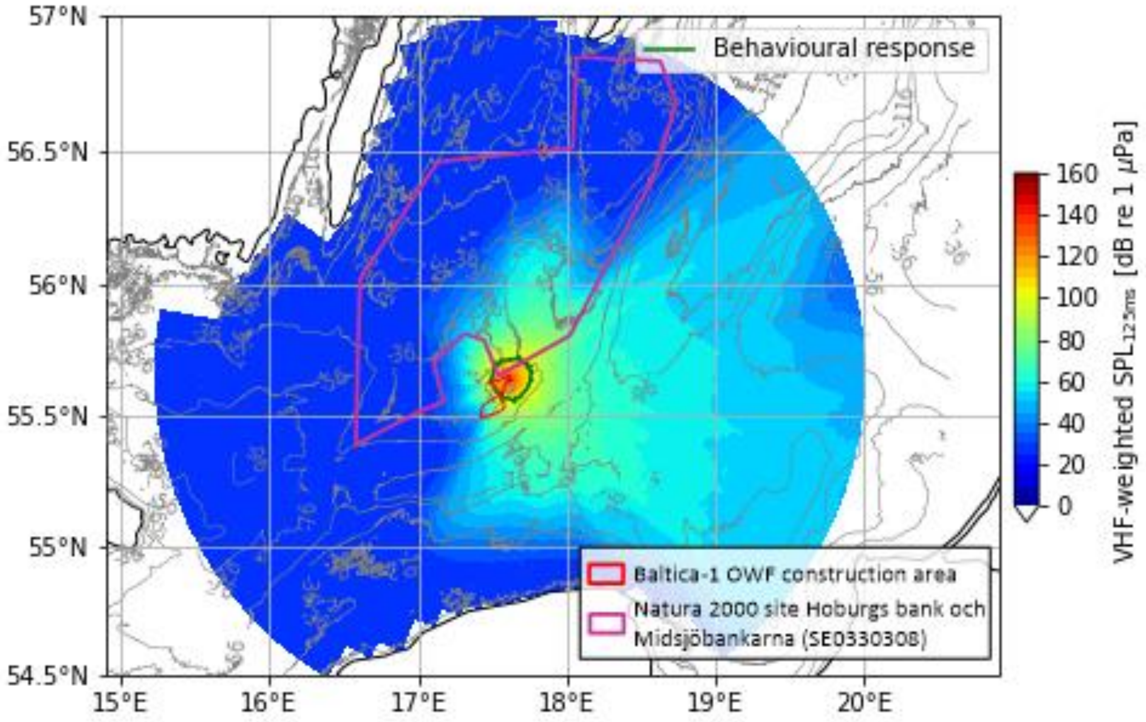




*Figure 4.34. The map of VHF-weighted $SPL_{125ms}$ from piling sources located at a small distance from each other in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

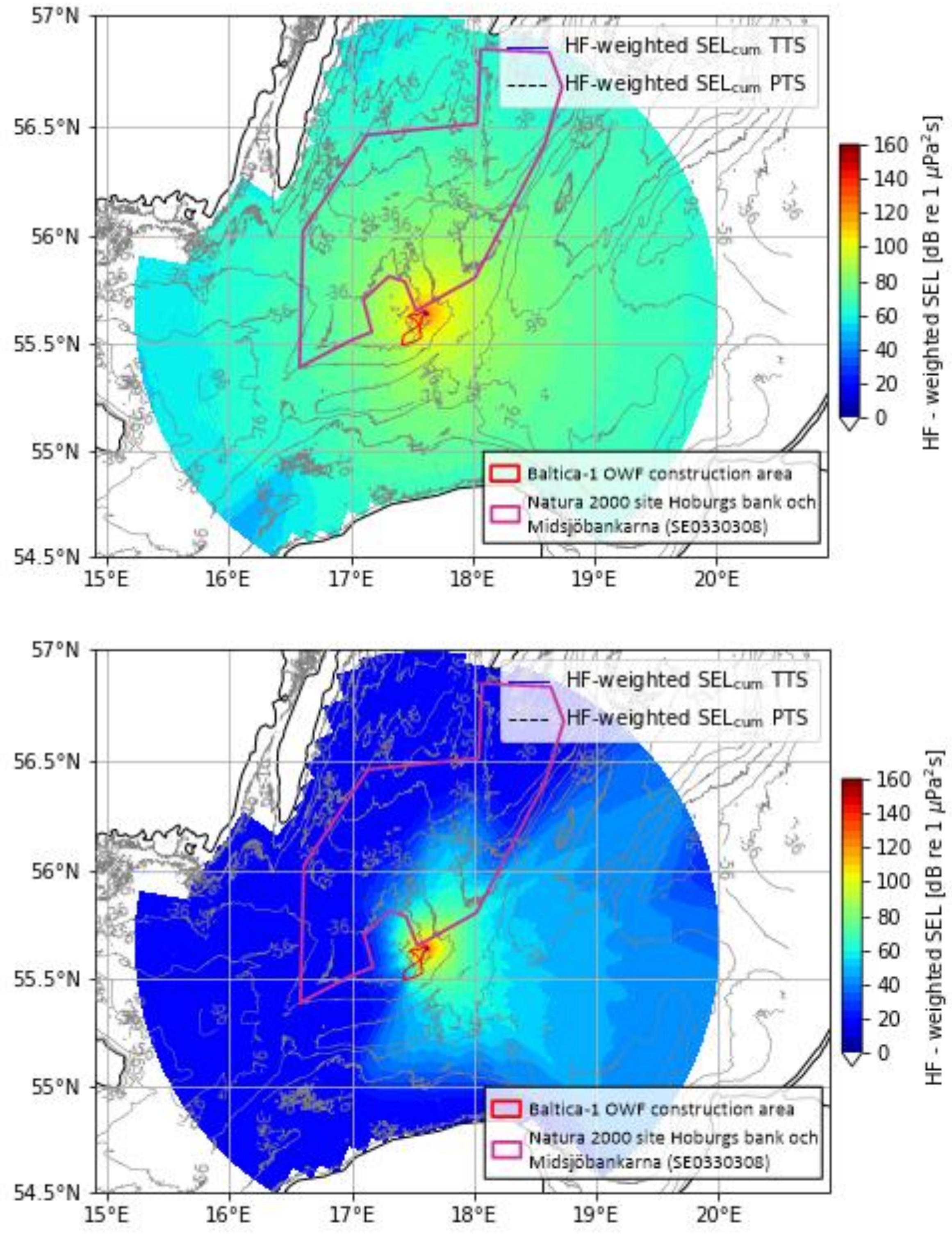



*Figure 4.35.* *The map of HF-weighted $SEL_{cum}$ from piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

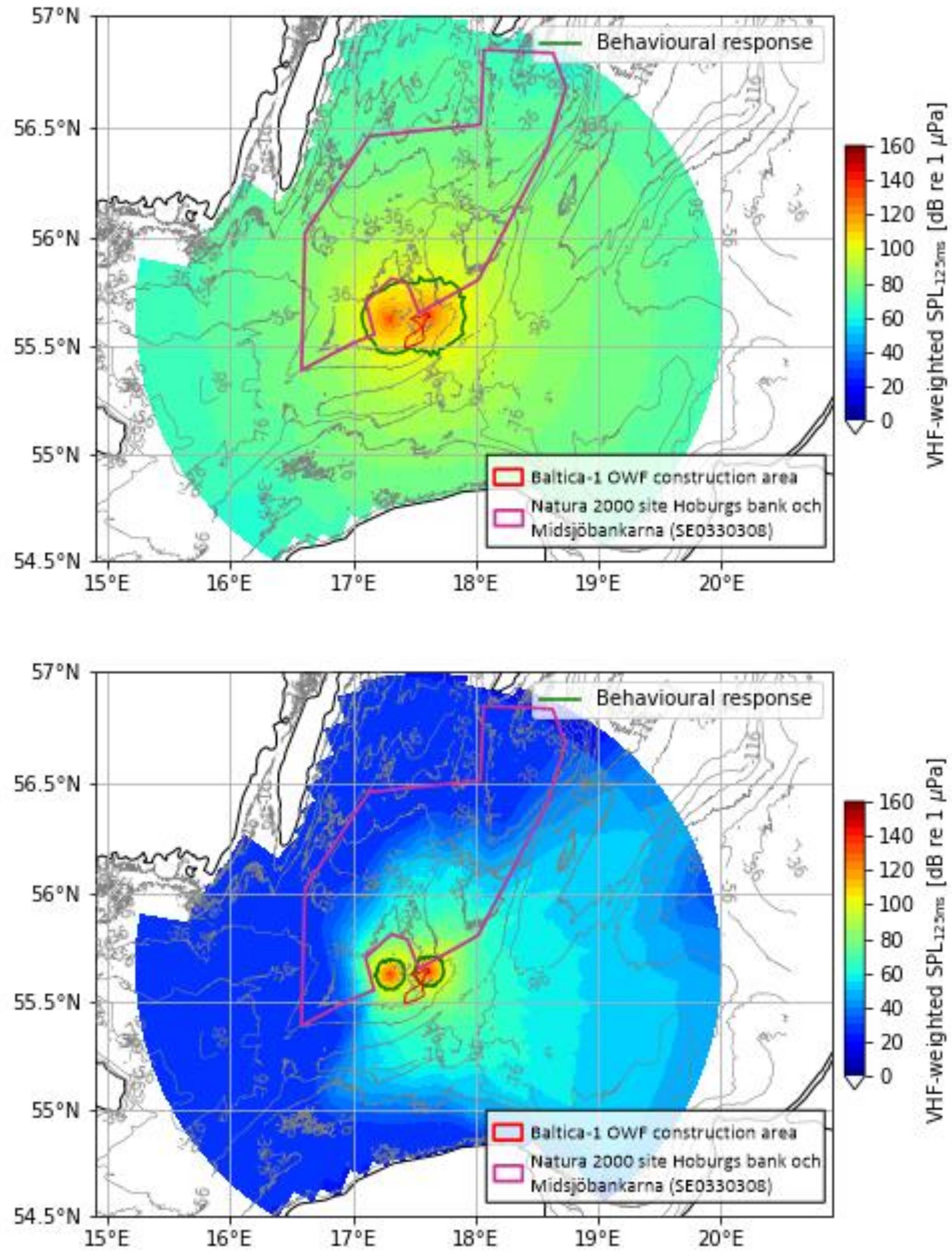



*Figure 4.36. The map of VHF-weighted $SPL_{125ms}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the harbour porpoise with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

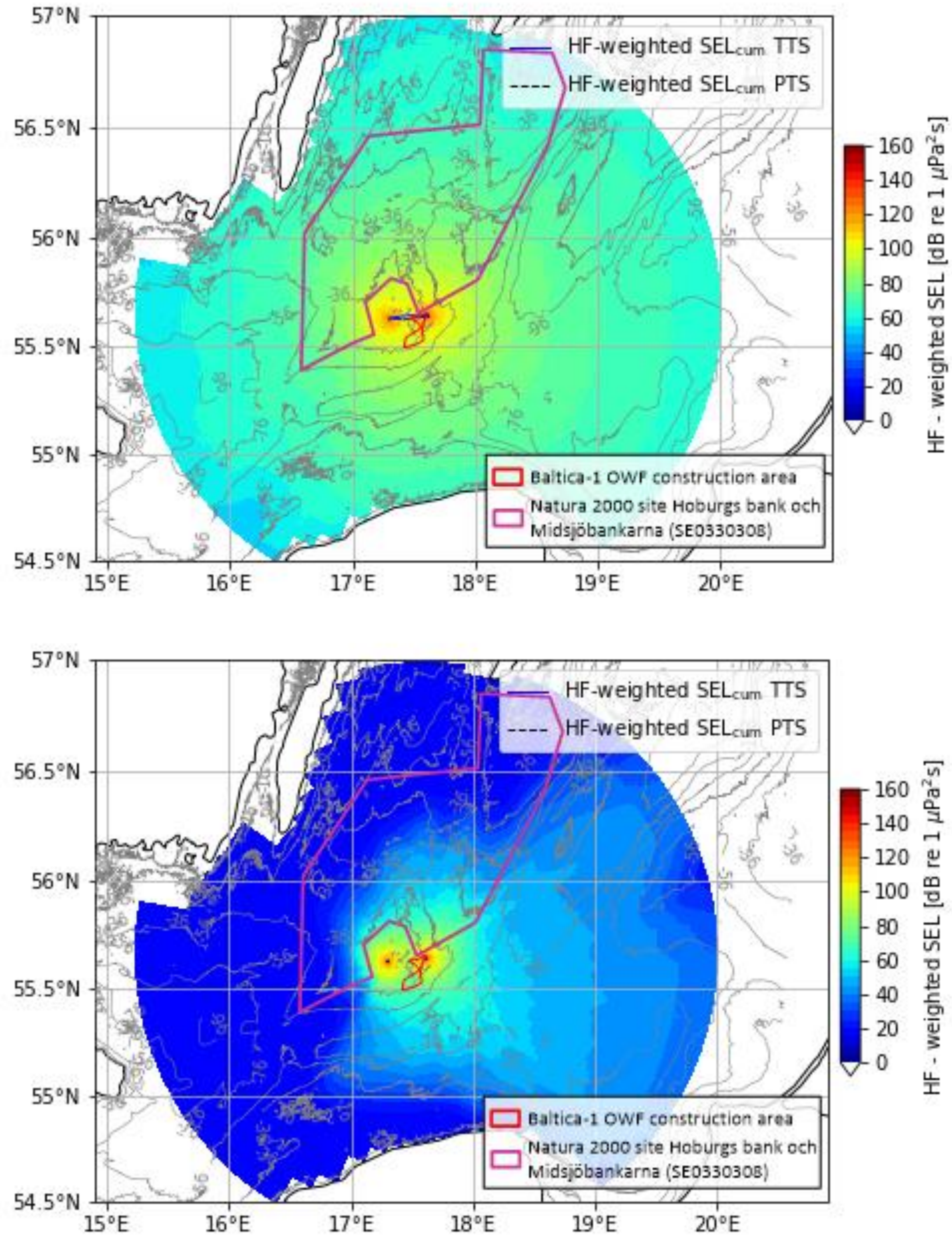



*Figure 4.37. The map of HF-weighted SEL $_{cum}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the harbour porpoise with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

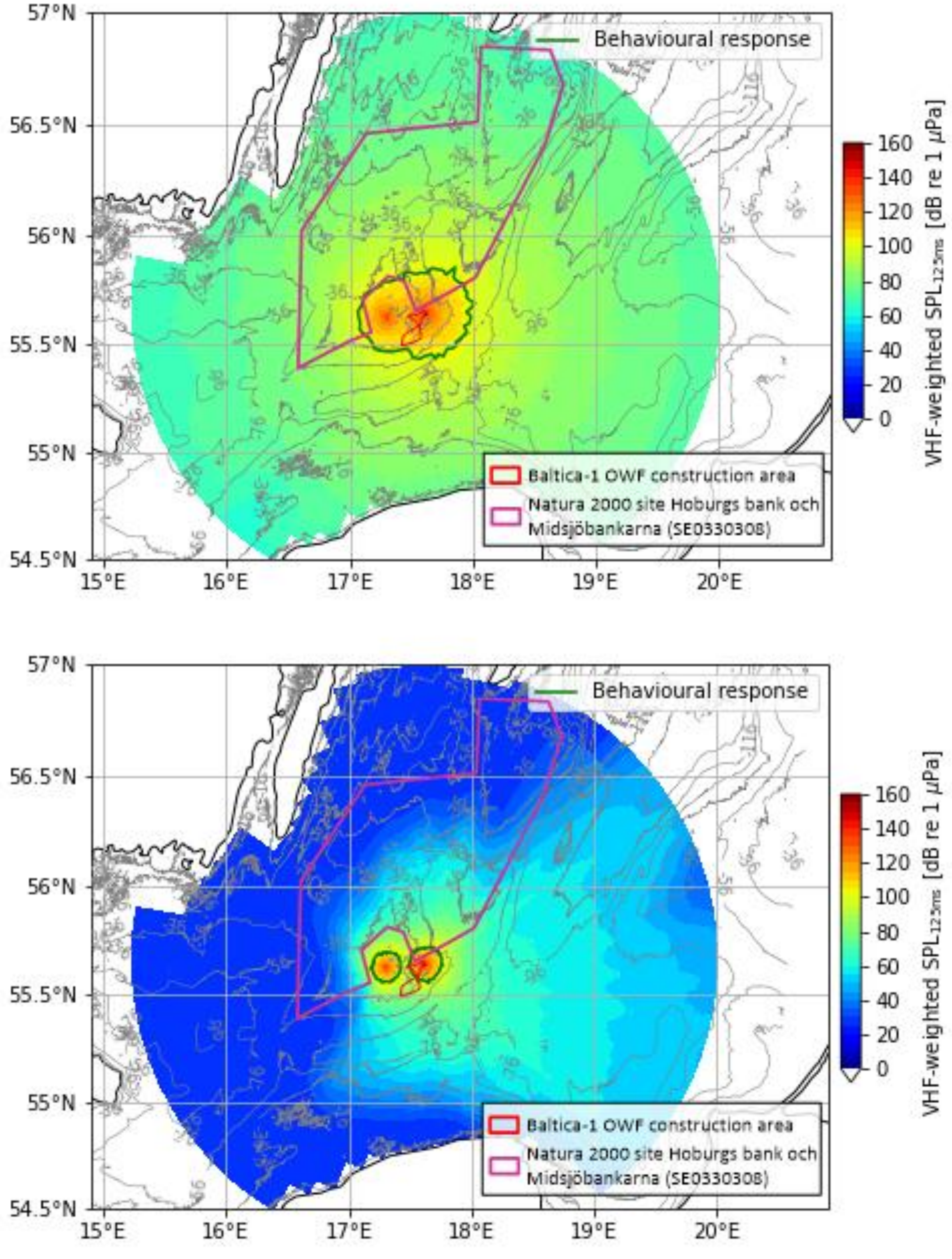



*Figure 4.38. The map of VHF-weighted $SPL_{125ms}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the harbour porpoise with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

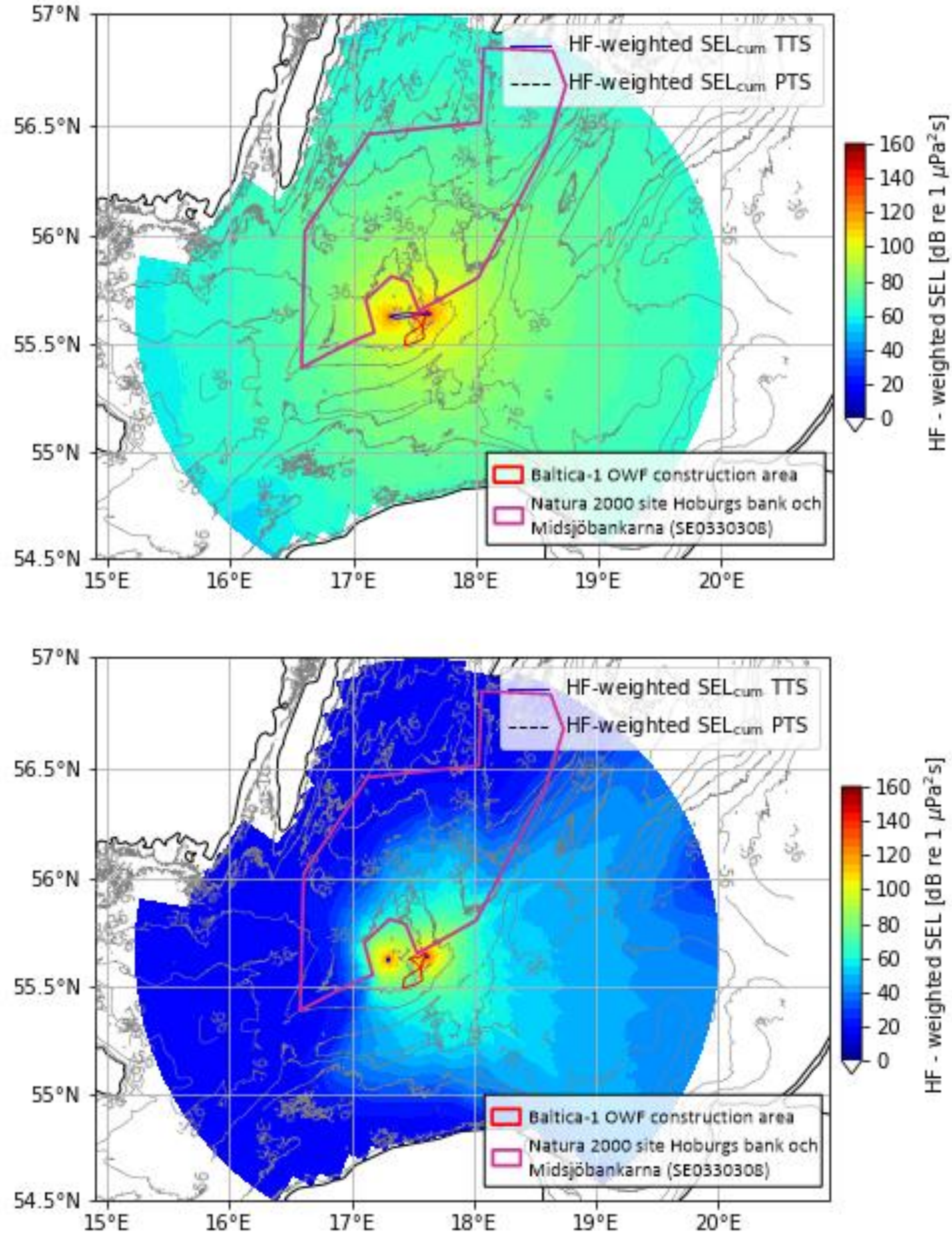



*Figure 4.39.* *The map of HF-weighted $SEL_{cum}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the harbour porpoise with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

### 4.2.2 Grey and harbour seal

Similarly to the results obtained for the harbour porpoise, the impact areas for seals increased with the number of piling sources, reaching the highest values for four locations. The smallest areas of impact were obtained for the scenario with the IQIP + DBBC reduction system applied. The impact areas and noise propagation maps are presented in the table below [Table 4.5] and the following figures [Figure 4.40–Figure 4.57].

*Table 4.5. The ranges of distance to the threshold values for the grey and harbour seal in the case of simultaneous piling at several locations within and beyond the Baltica-1 OWF area (numbers in bold: the highest values for 2 and 3 sources, respectively; piling with the use of the BBC, HSD + DBBC, and IQIP + DBBC mitigation systems)*

| Season | Mitigation type | Impact area [km$^2$] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Effect | 1 source | 2 sources – < 1 km | 2 sources – 20 km | 2 sources – at a significant distance | 3 sources – 2 < 1 km, 1 = 20 km | 3 sources – 2 = 20 km, 1 = at a significant distance | 4 sources |
| Winter | BBC | Behavioural response | 241 | 429 | **566** | 482 | 756 | **807** | 1048 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | TTS (cumulative effect) | 7.3 | 536 | **679** | 14.6 | **966** | 686 | 973 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | HSD + DBBC | Behavioural response | 31.3 | 61.9 | **64.0** | 62.6 | **126** | 95.3 | 157 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.09 |
| | | TTS (cumulative effect) | 0.03 | **3.7** | 2.8 | 0.06 | **35.4** | 2.8 | 35.4 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.09 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.09 |
| | IQIP + DBBC | Behavioural response | 9.6 | **22.5** | 17.4 | 19.2 | **30.7** | 27.0 | 40.3 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | TTS (cumulative effect) | 0.03 | **15.6** | 11.9 | 0.06 | **16.5** | 11.9 | 16.6 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| Summer | BBC | Behavioural response | 132 | 210 | **264** | **264** | 342 | **396** | 528 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | TTS (cumulative effect) | 0.6 | 193 | **365** | 1.2 | **482** | 366 | 483 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |

| Season | Mitigation type | Impact area [km$^2$] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Effect | 1 source | 2 sources – < 1 km | 2 sources – 20 km | 2 sources – at a significant distance | 3 sources – 2 < 1 km, 1 = 20 km | 3 sources – 2 = 20 km, 1 = at a significant distance | 4 sources |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | HSD + DBBC | Behavioural response | 23.1 | 45.1 | 42.9 | **46.2** | **85.8** | 66.0 | 109 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | TTS (cumulative effect) | 0.03 | **0.1** | 0.06 | 0.06 | **0.2** | 0.09 | 0.2 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | IQIP + DBBC | Behavioural response | 7.3 | **17.4** | 12.8 | 14.6 | **32.0** | 20.1 | 39.3 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | **3.9** | 0.09 | 3.9 |
| | | TTS (cumulative effect) | 0.03 | **3.9** | 2.3 | 0.06 | 0.06 | **2.3** | 2.4 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |

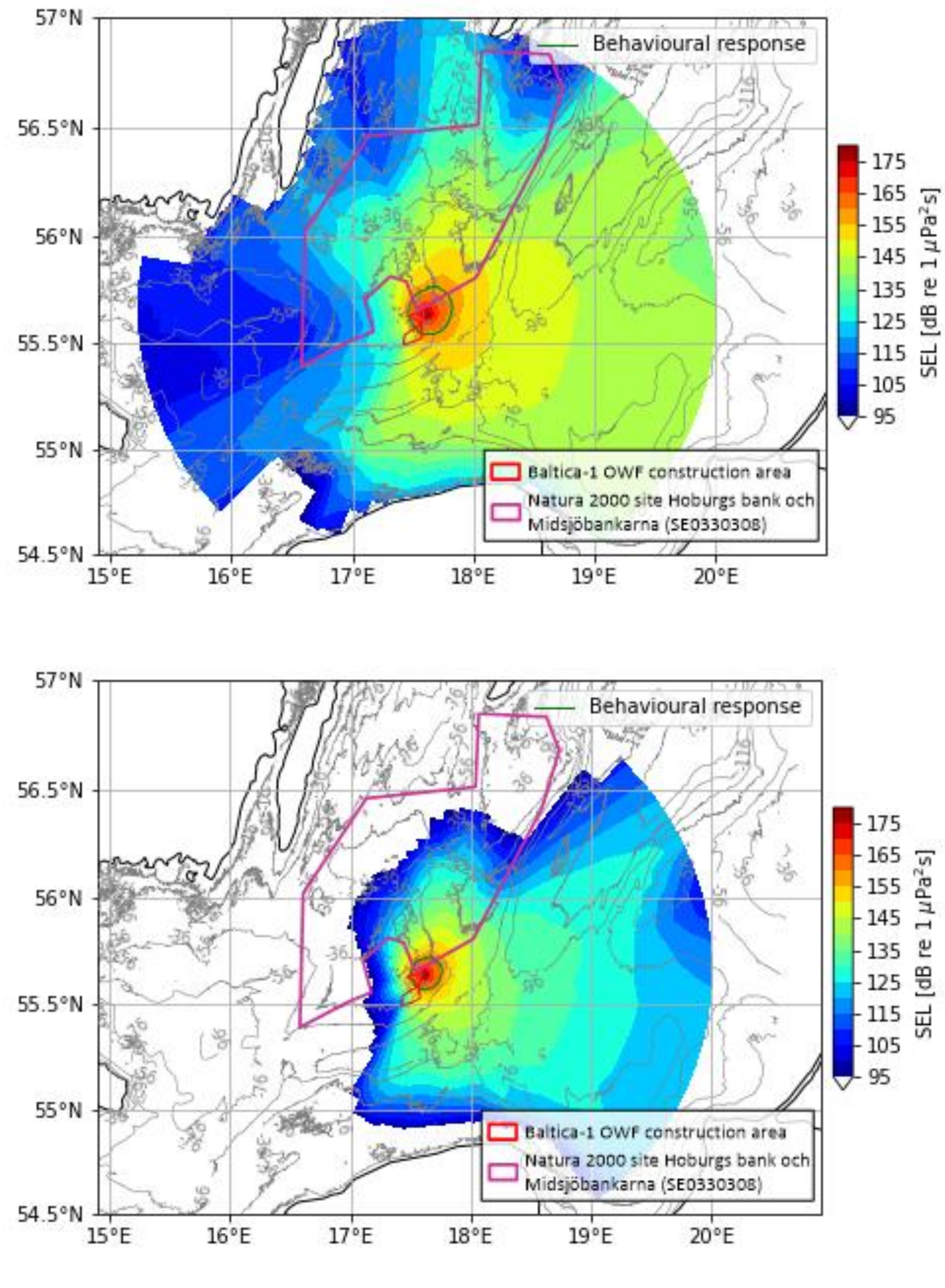



*Figure 4.40. The map of unweighted SEL above the acoustic background for piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with a BBC applied, in the winter (top) and summer (bottom)*

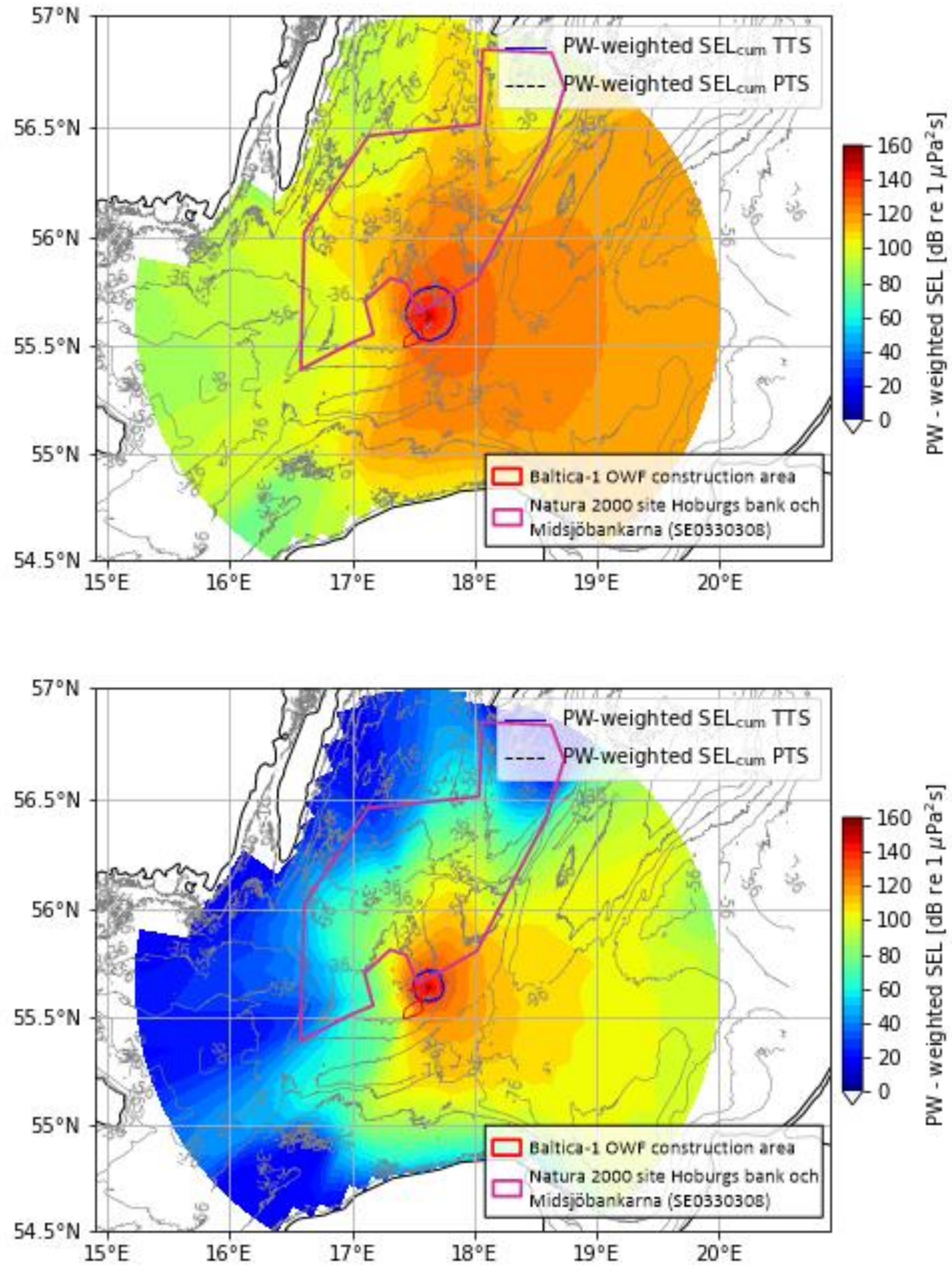



*Figure 4.41.* *The map of PW-weighted $SEL_{cum}$ from piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with a BBC applied, in the winter (top) and summer (bottom)*

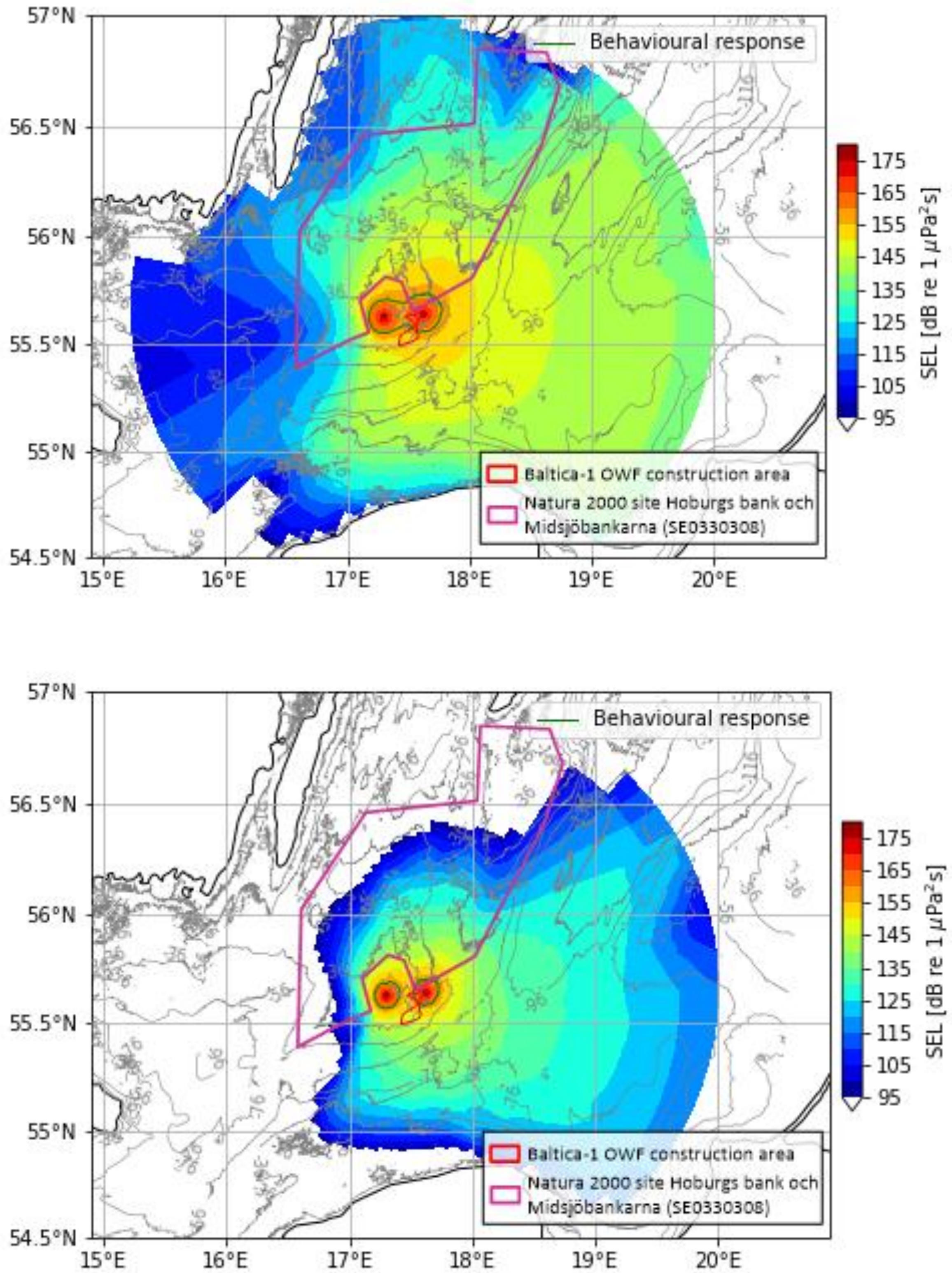



*Figure 4.42. The map of unweighted SEL above the acoustic background for piling sources located 20 km apart and the ranges of impact for the grey seal and harbour seal with a BBC applied, in the winter (top) and summer (bottom)*

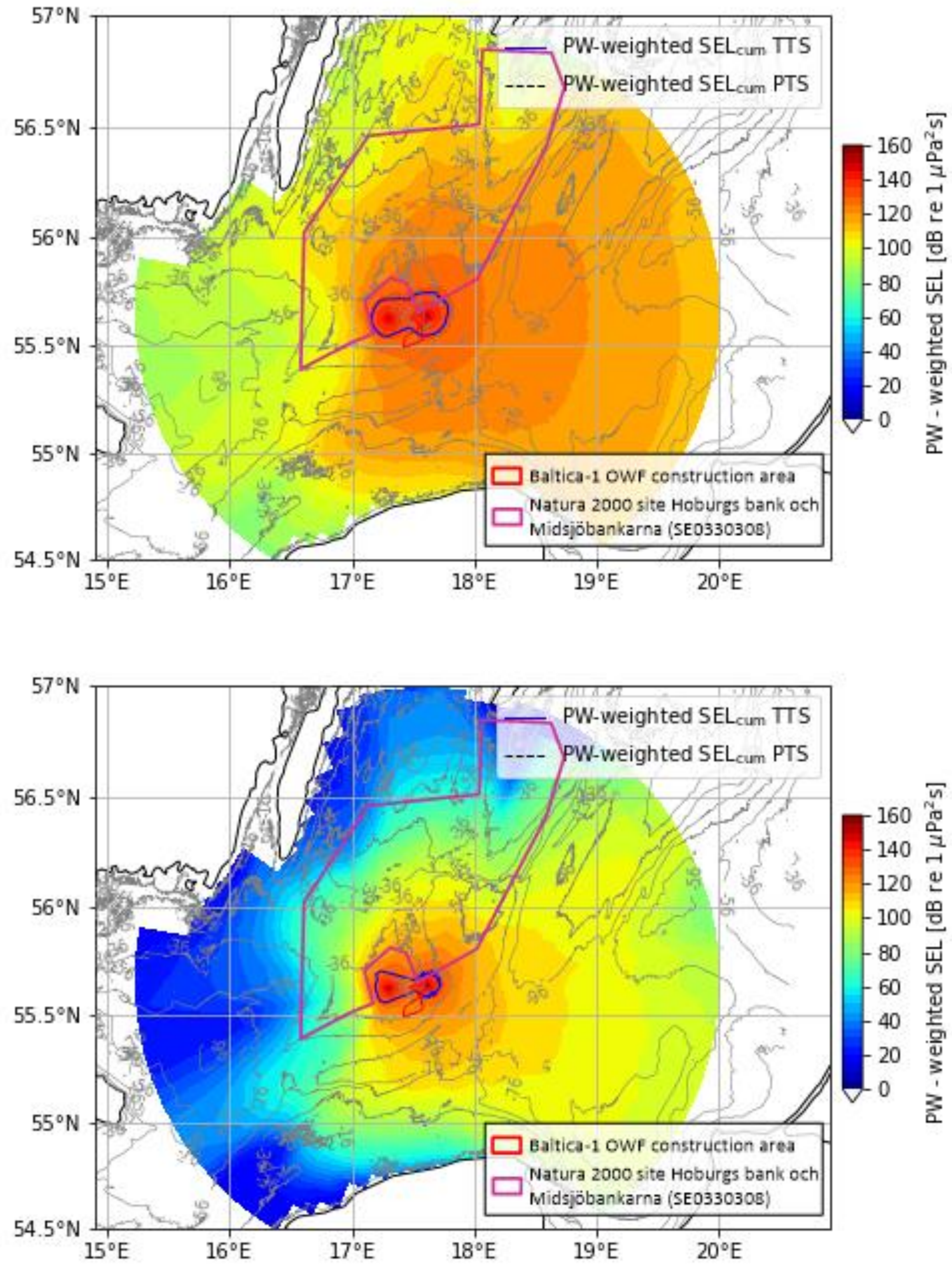
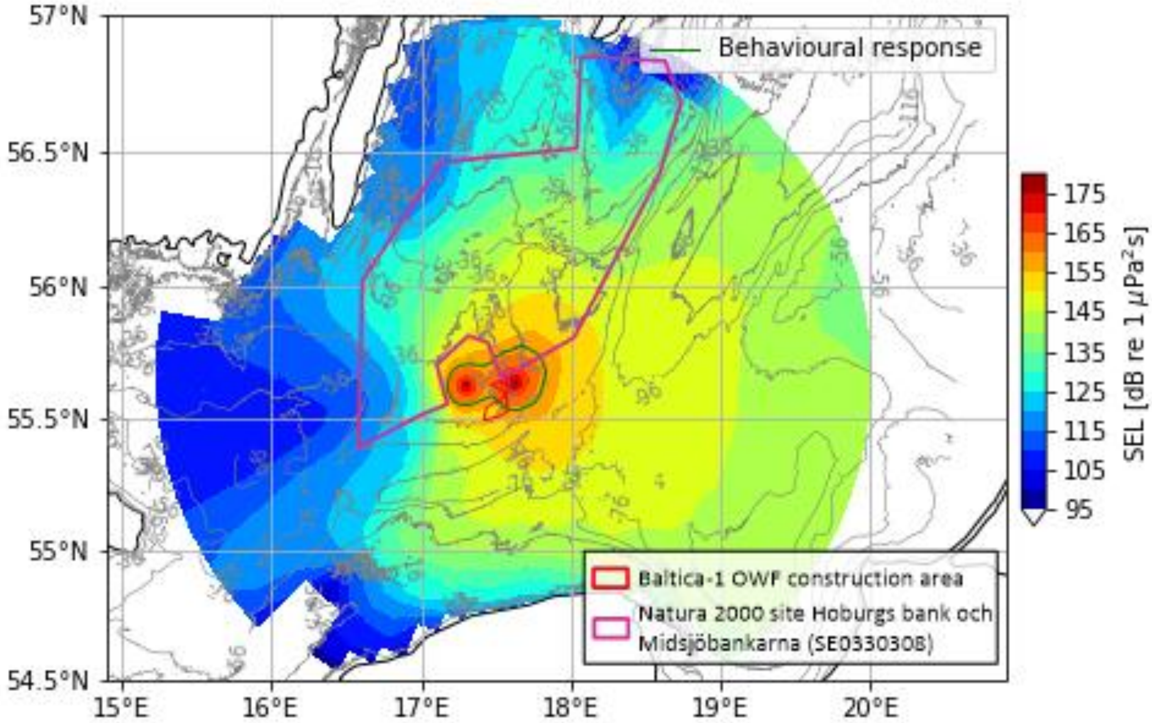



*Figure 4.43. The map of PW-weighted SEL $_{cum}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the grey seal and harbour seal with a BBC applied, in the winter (top) and summer (bottom)*



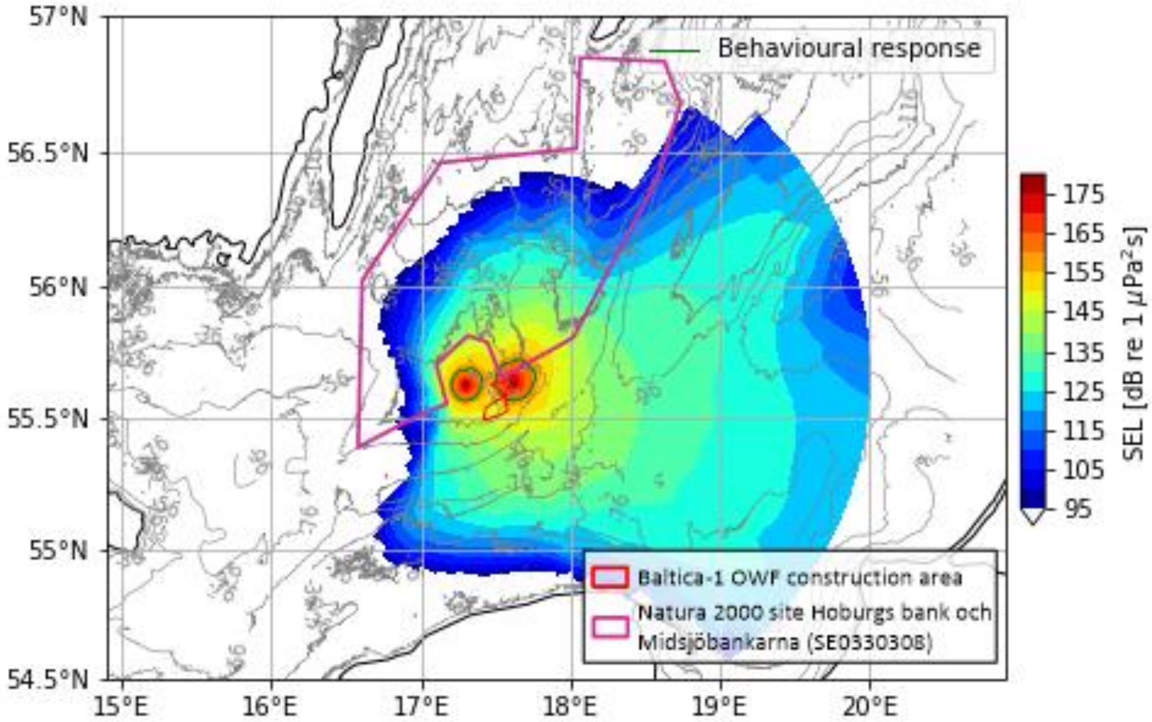




*Figure 4.44. The map of unweighted SEL above the acoustic background for three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the grey seal and harbour seal with a BBC applied, in the winter (top) and summer (bottom)*

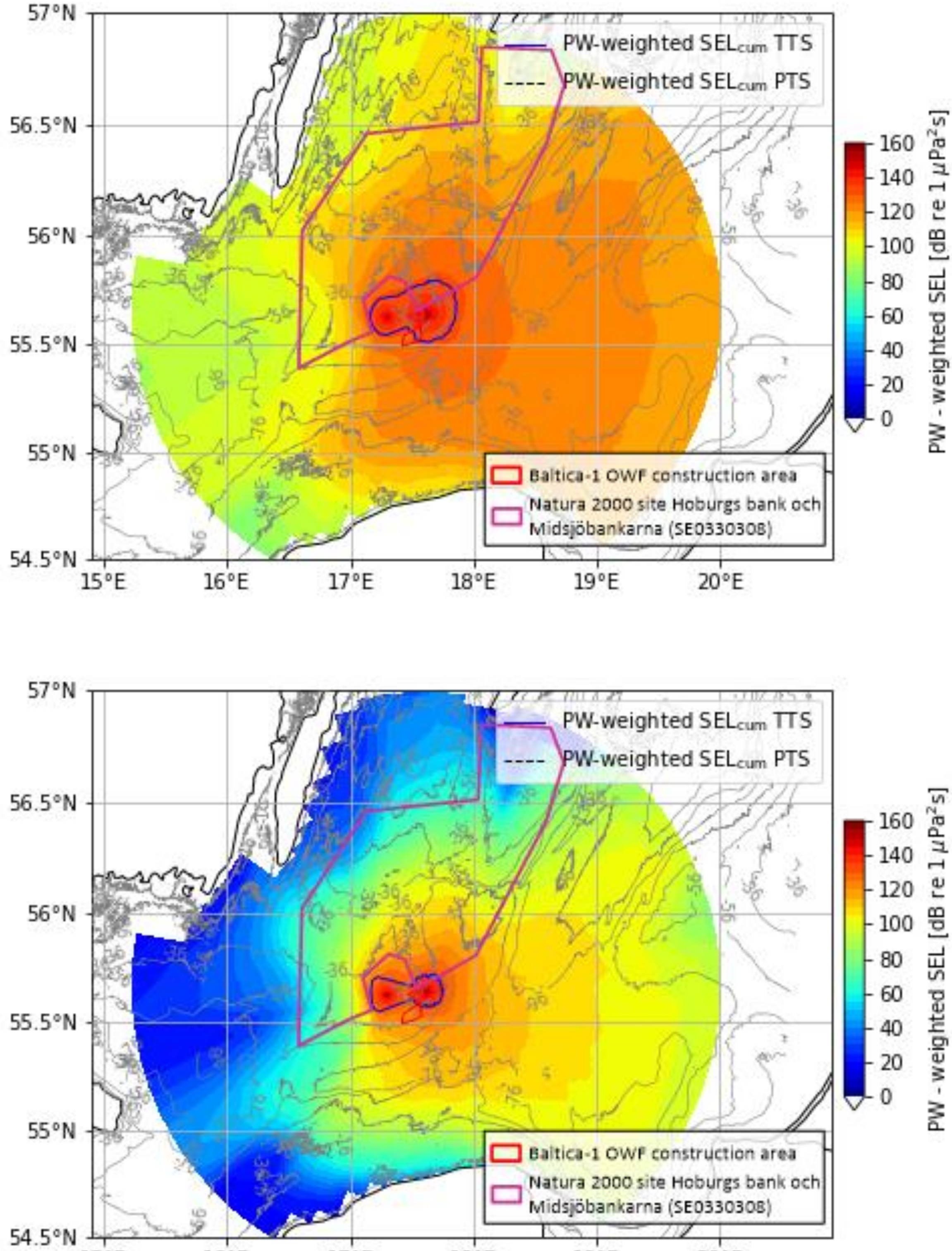



*Figure 4.45.* *The map of PW-weighted $SEL_{cum}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the grey seal and harbour seal with a BBC applied, in the winter (top) and summer (bottom)*

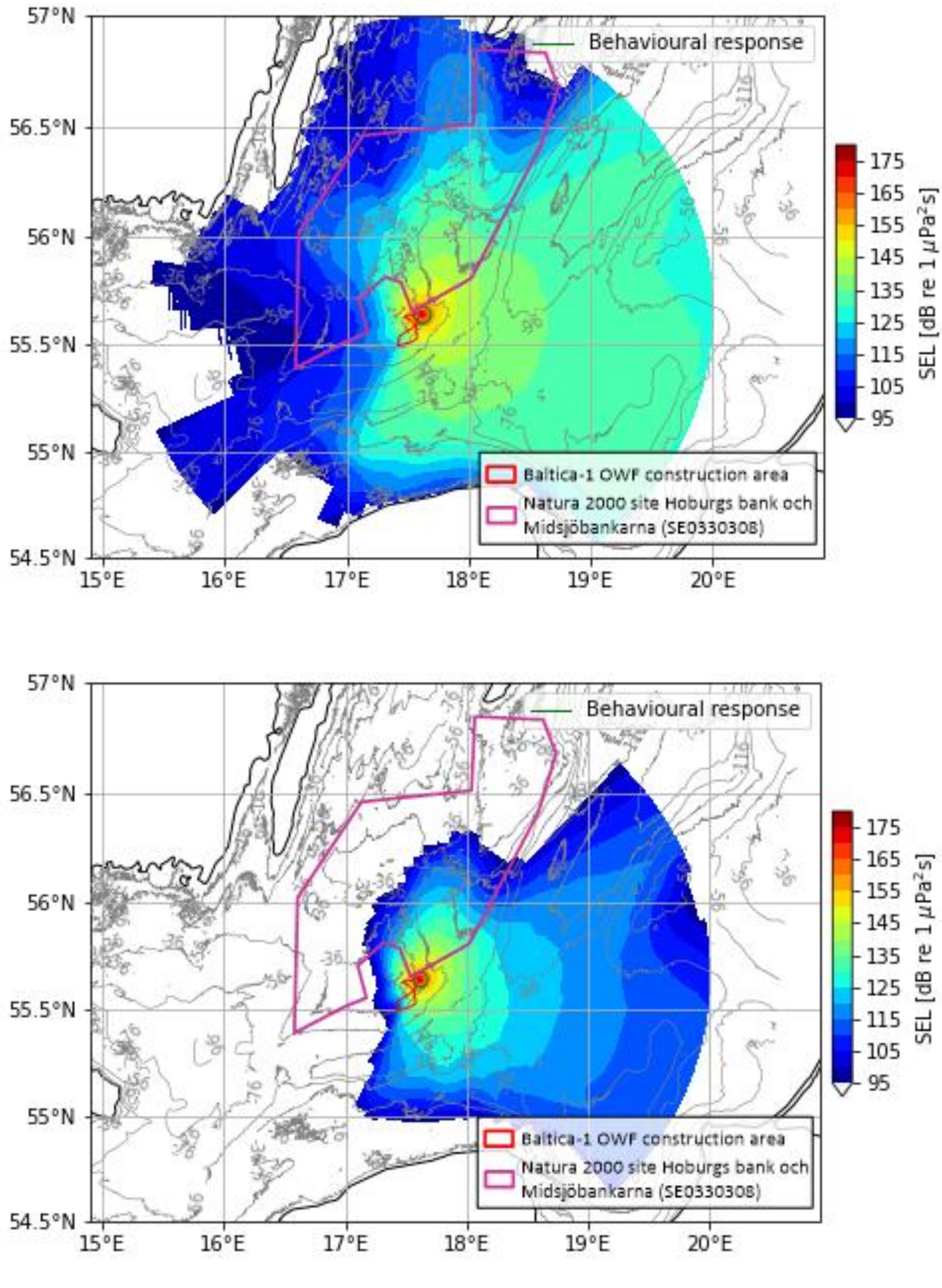



*Figure 4.46. The map of unweighted SEL above the acoustic background for piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

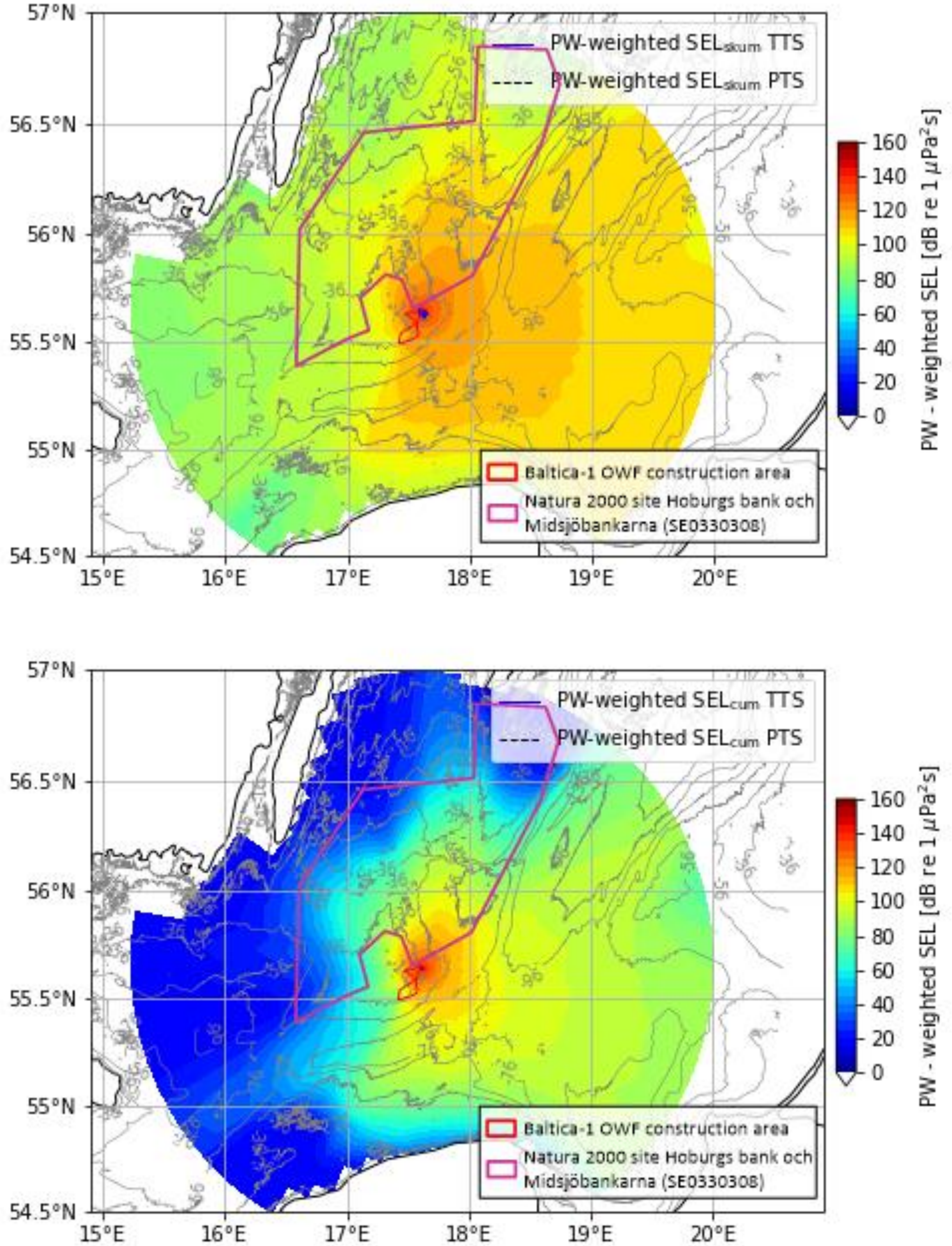



*Figure 4.47. The map of PW-weighted $SEL_{cum}$ from piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

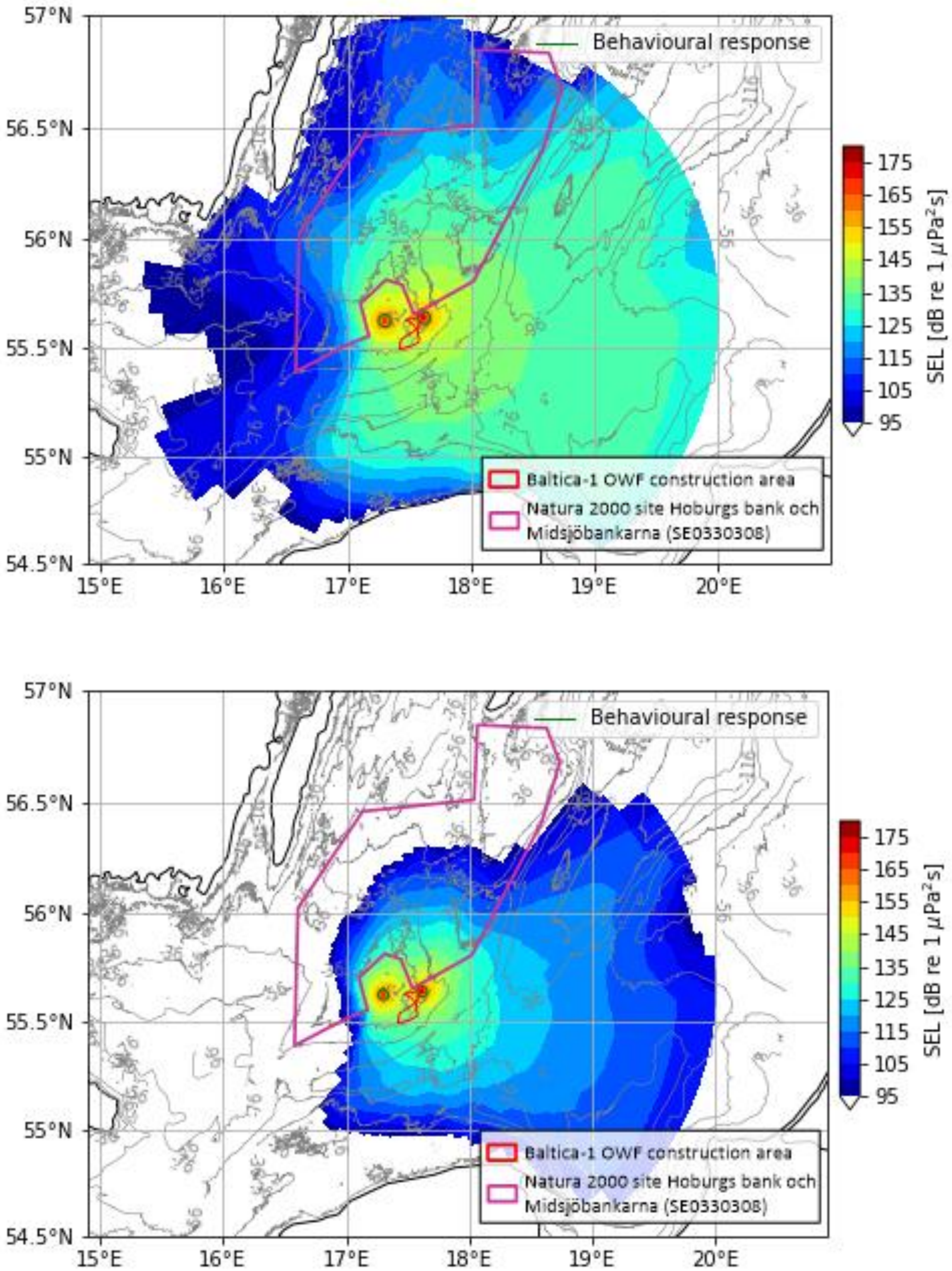
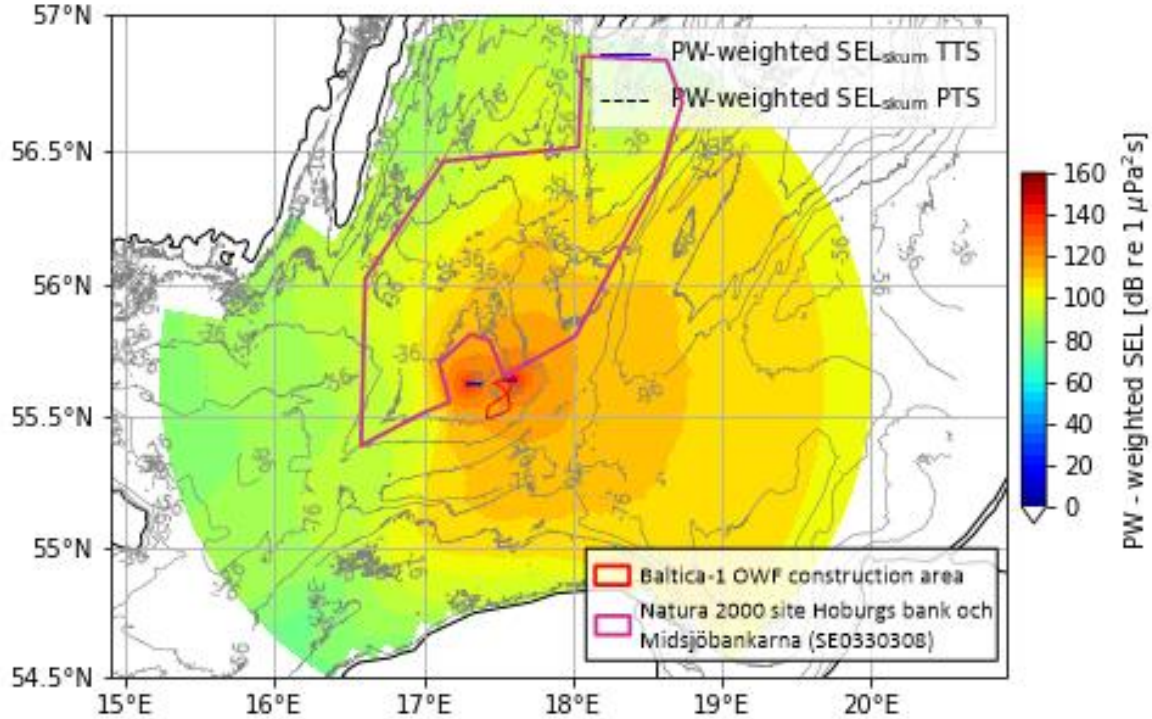



*Figure 4.48. The map of unweighted SEL above the acoustic background for piling sources located 20 km apart and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*



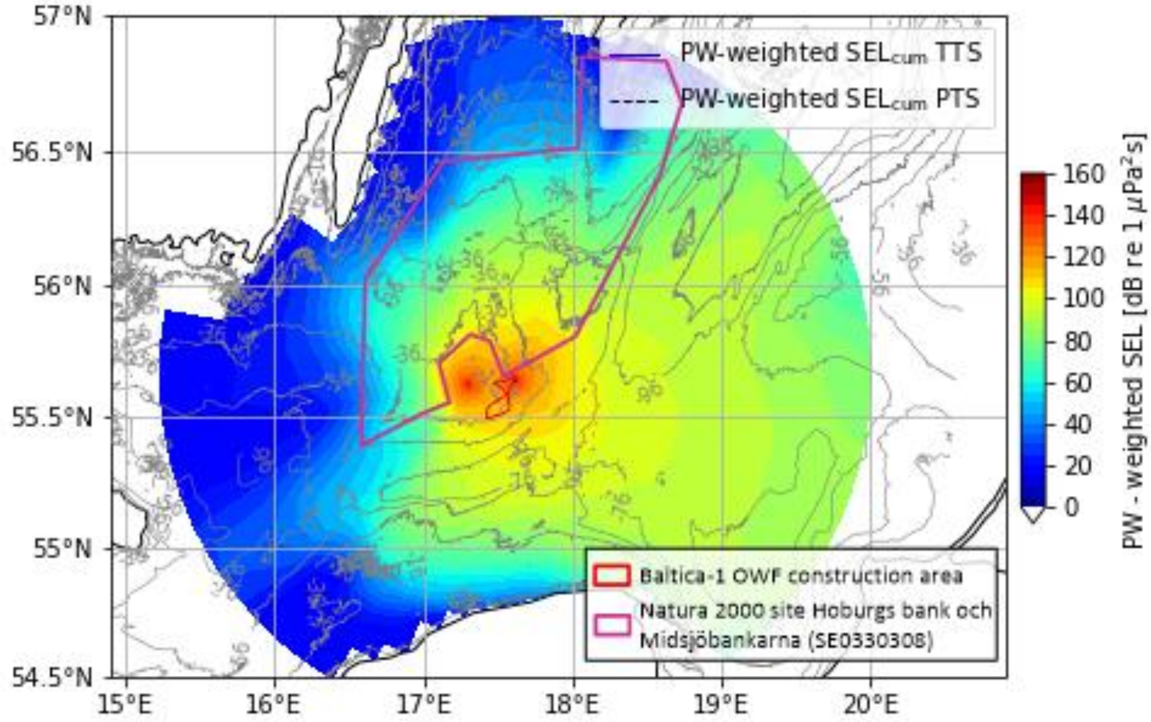
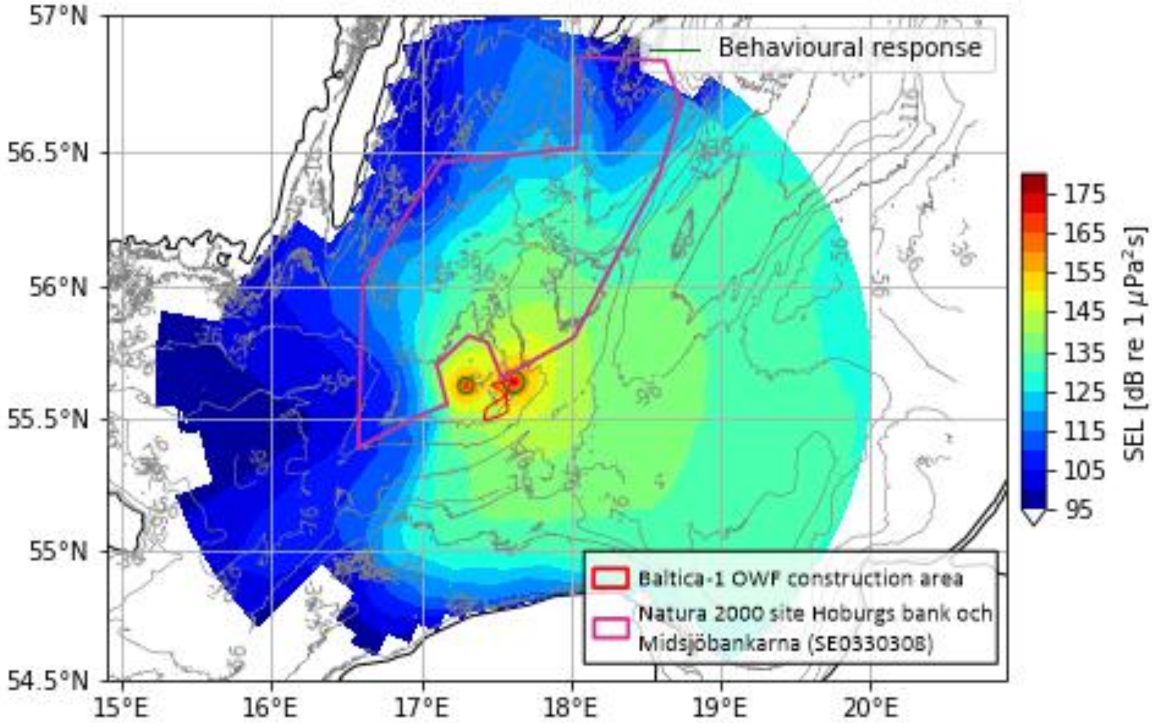




*Figure 4.49. The map of PW-weighted $SEL_{cum}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the grey seal and harbour seal with the HSD+ DBBC system applied, in the winter (top) and summer (bottom)*



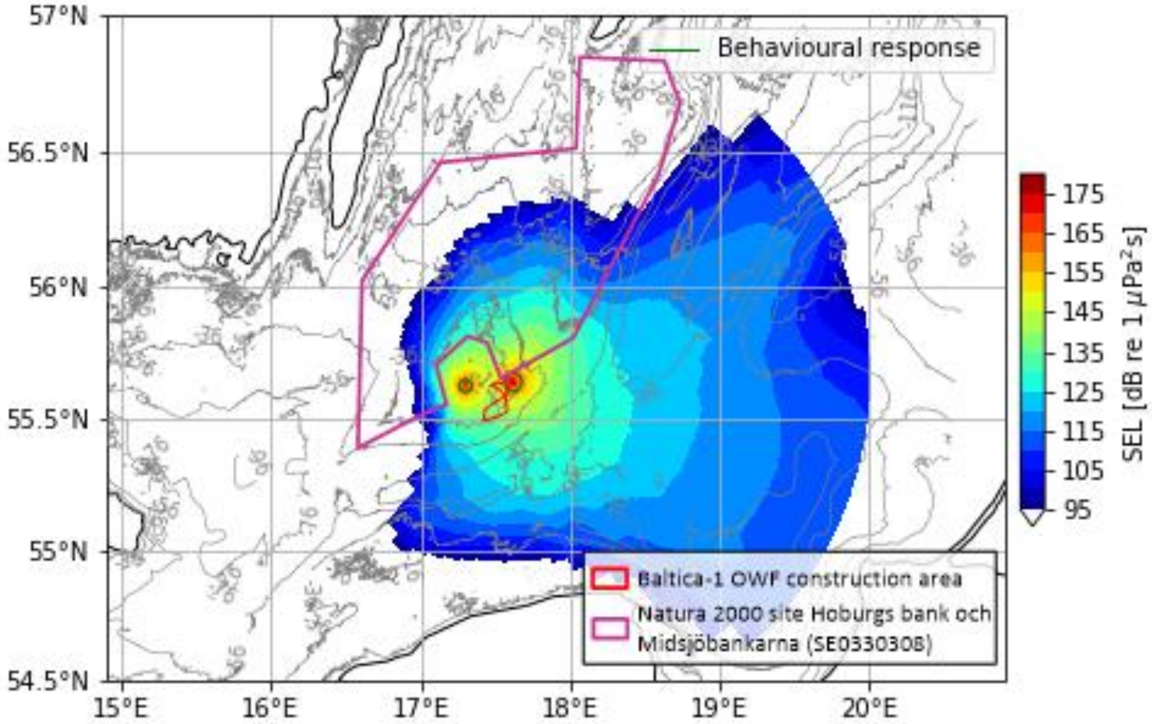




*Figure 4.50. The map of unweighted SEL above the acoustic background for three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

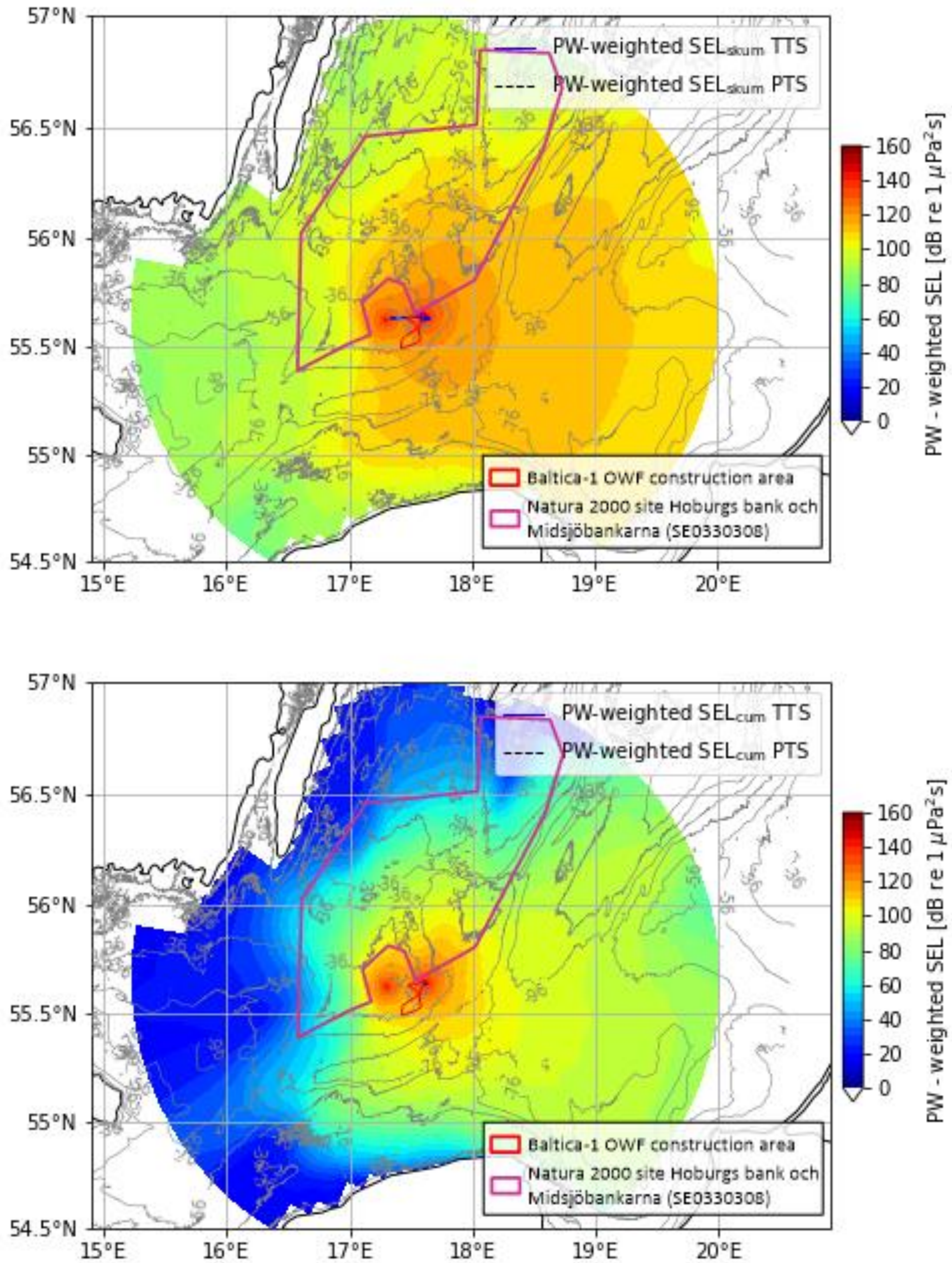



*Figure 4.51. The map of PW-weighted $SEL_{cum}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

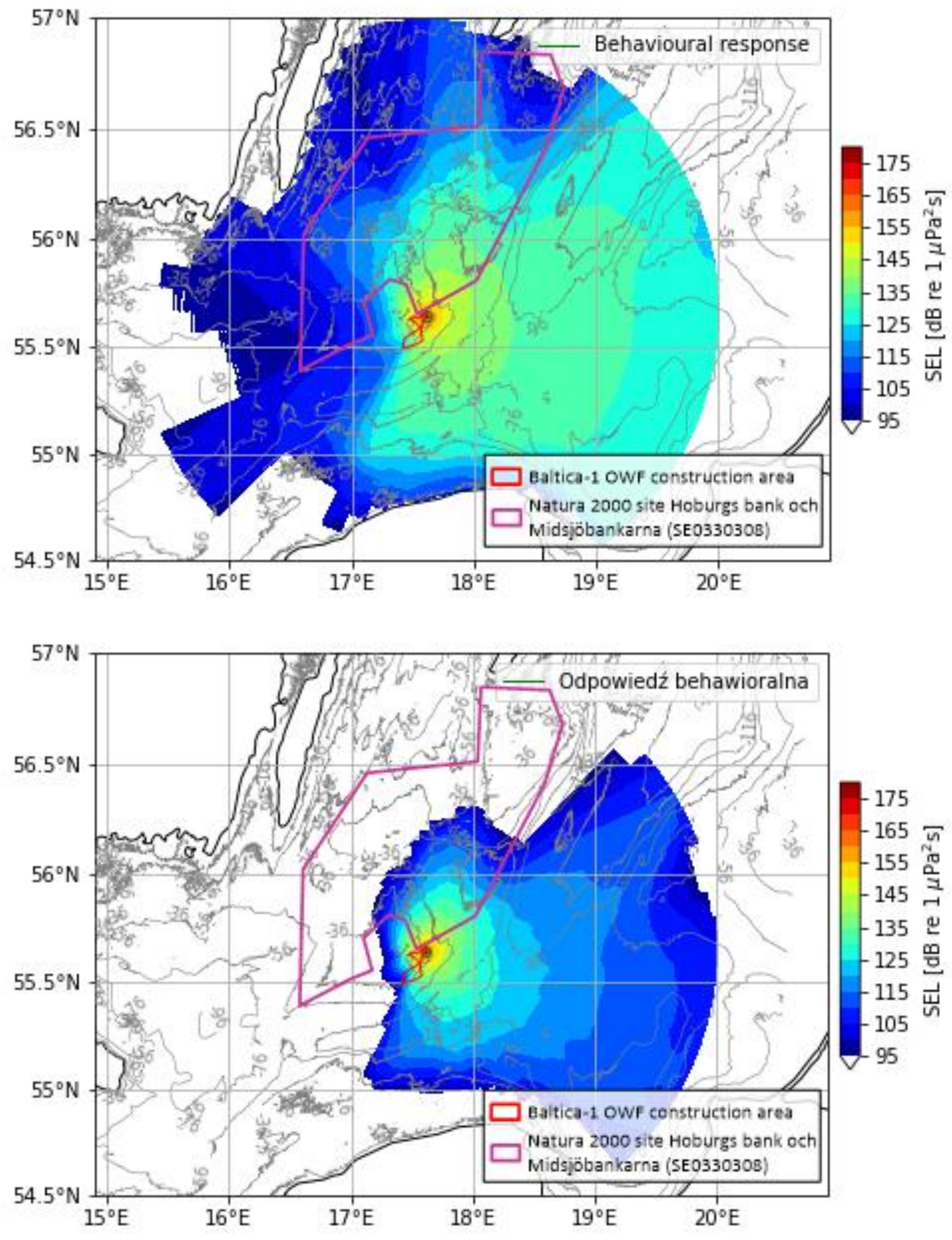



*Figure 4.52. The map of unweighted SEL above the acoustic background for piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

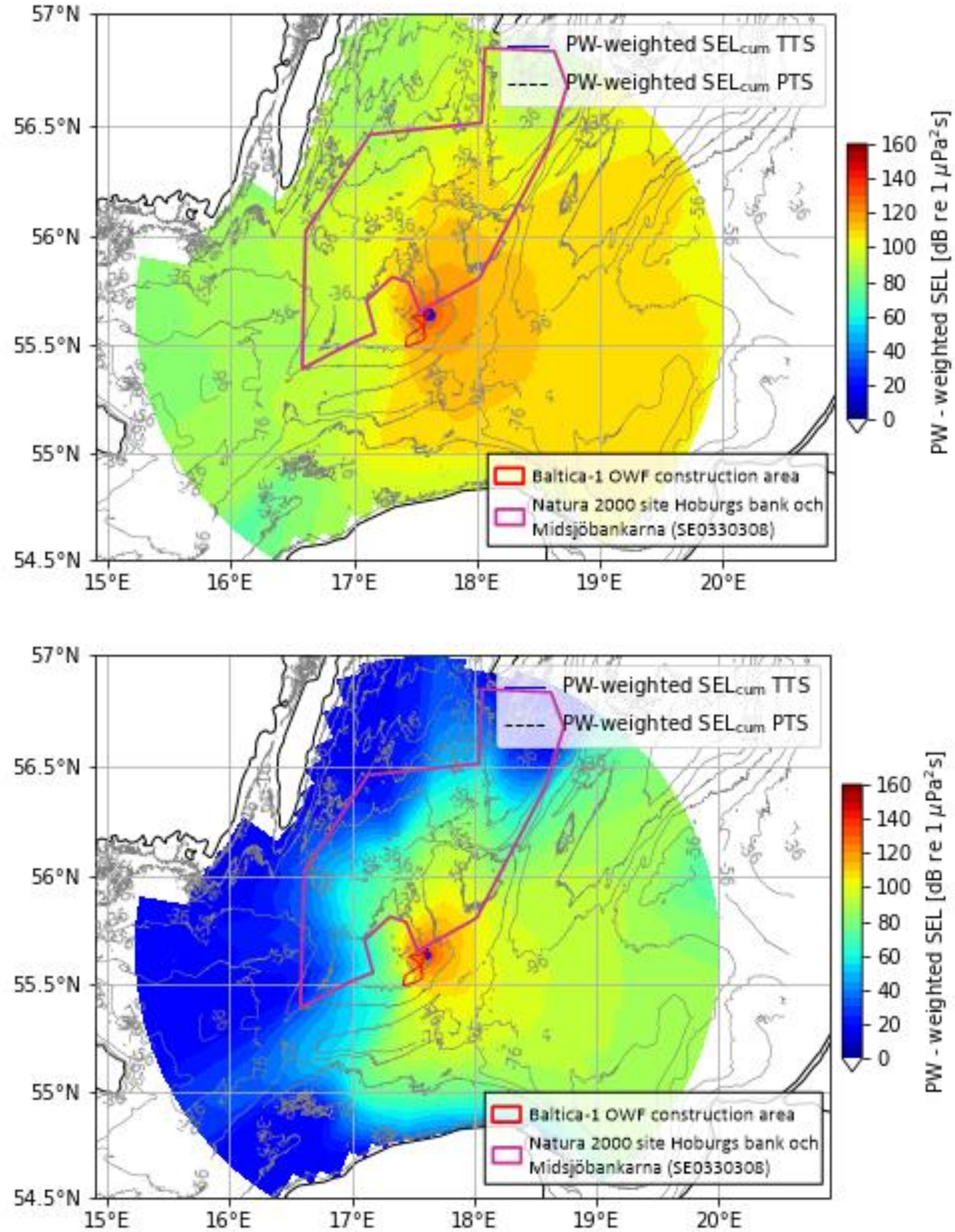



*Figure 4.53. The map of PW-weighted SEL$_{cum}$ from piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

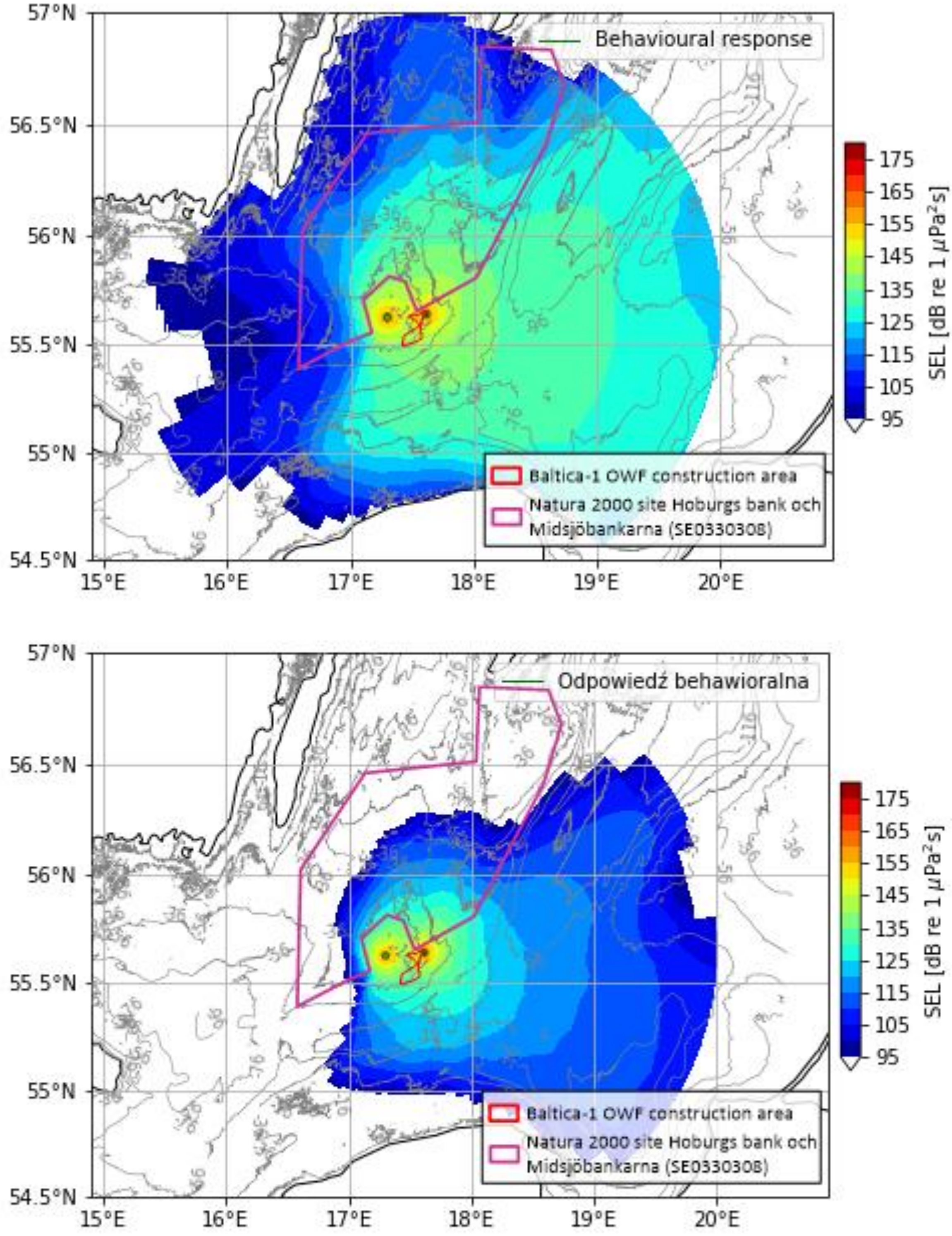



*Figure 4.54. The map of unweighted SEL above the acoustic background for piling sources located 20 km apart and the ranges of impact on the grey seal and harbour seal with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

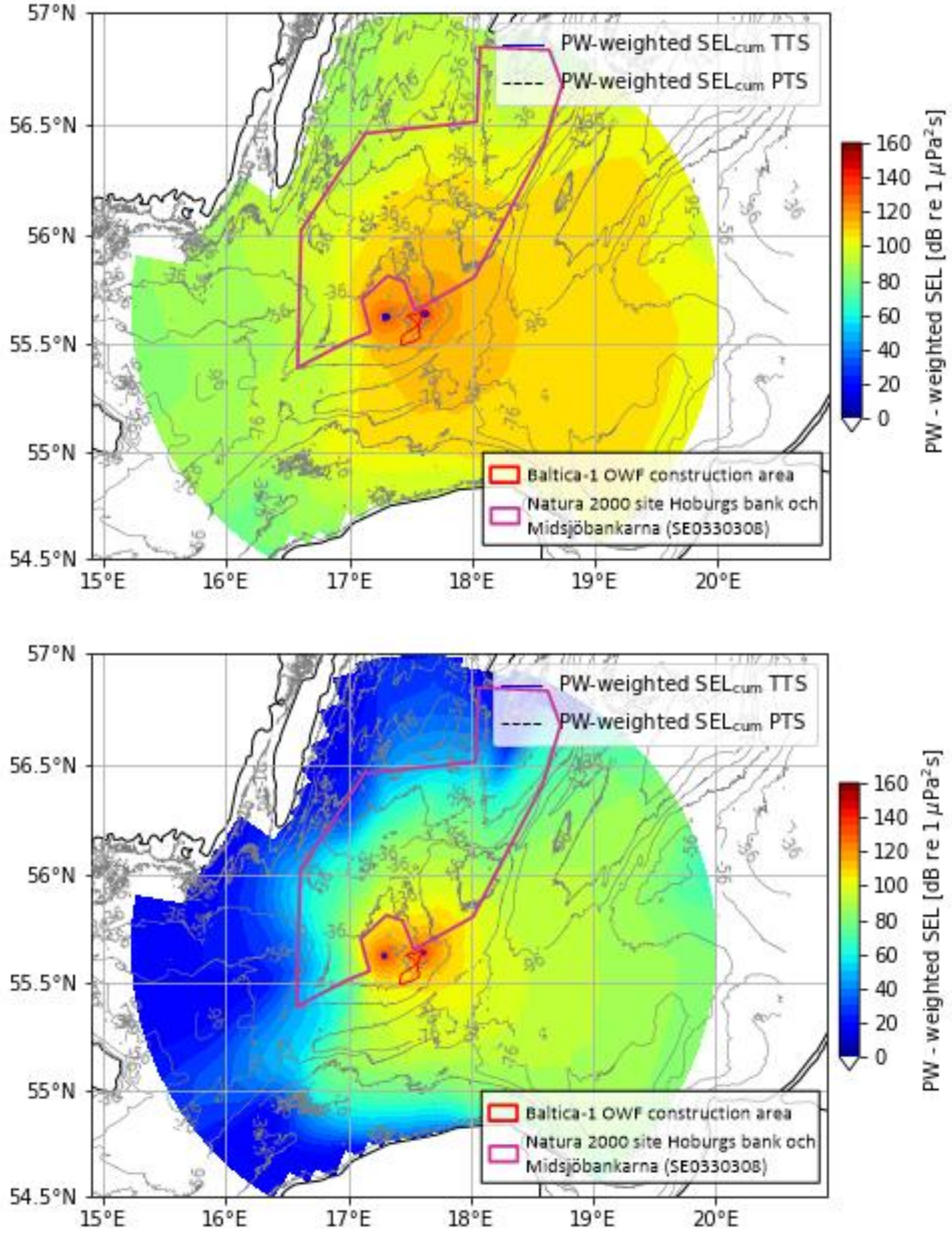
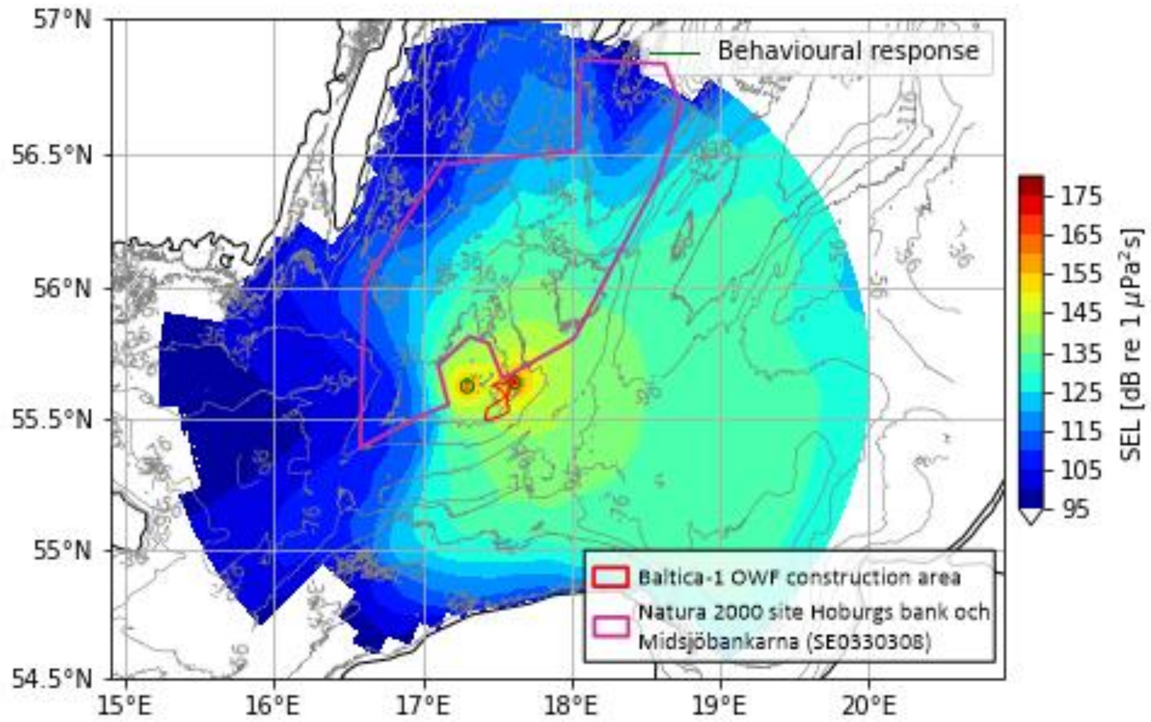



*Figure 4.55. The map of PW-weighted $SEL_{cum}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the grey seal and harbour seal with the IQIP+ DBBC system applied, in the winter (top) and summer (bottom)*



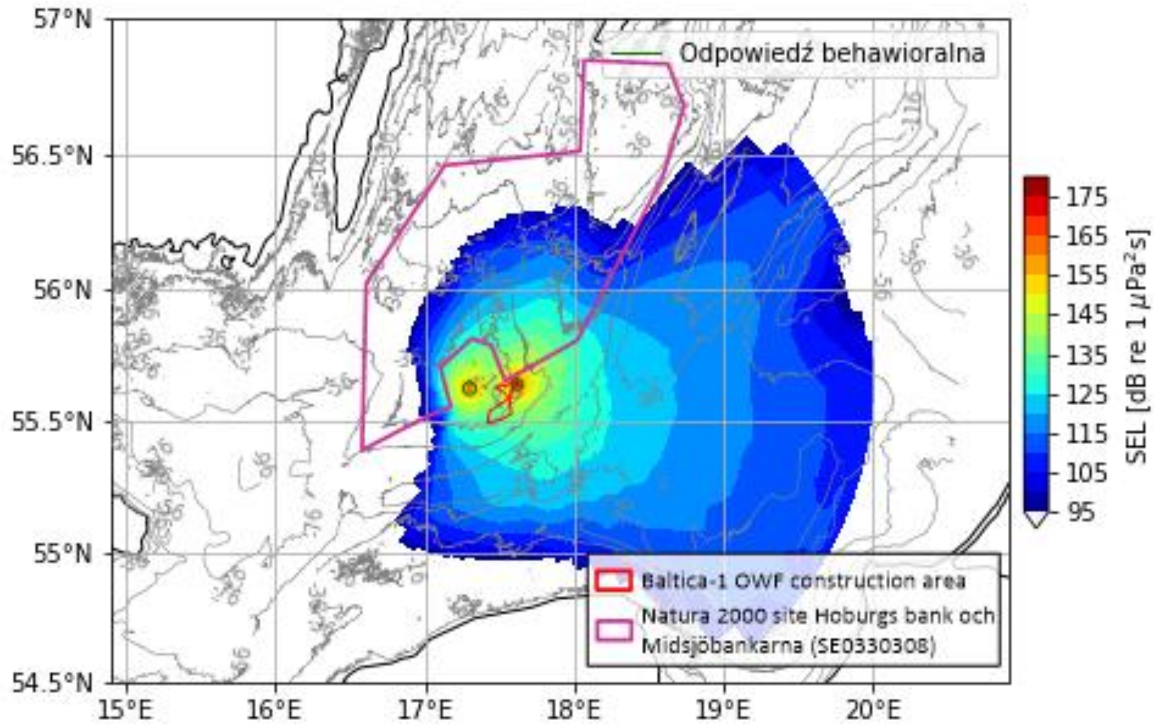
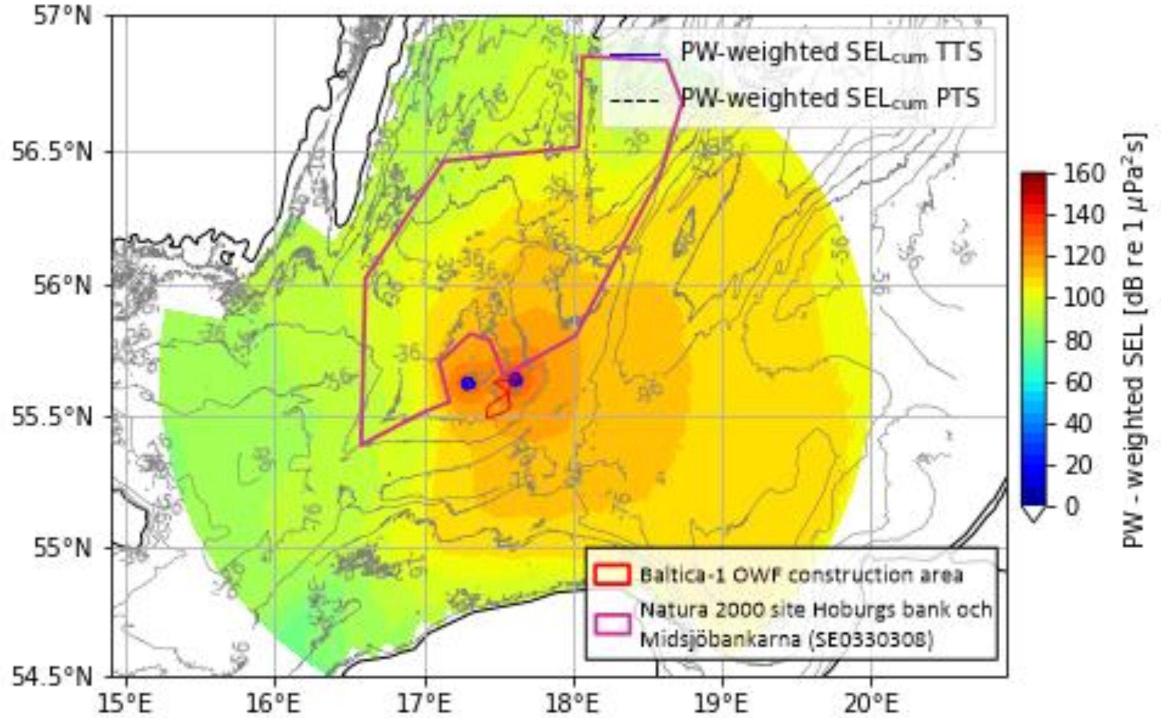




*Figure 4.56. The map of unweighted SEL above the acoustic background for three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the grey seal and harbour seal with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*



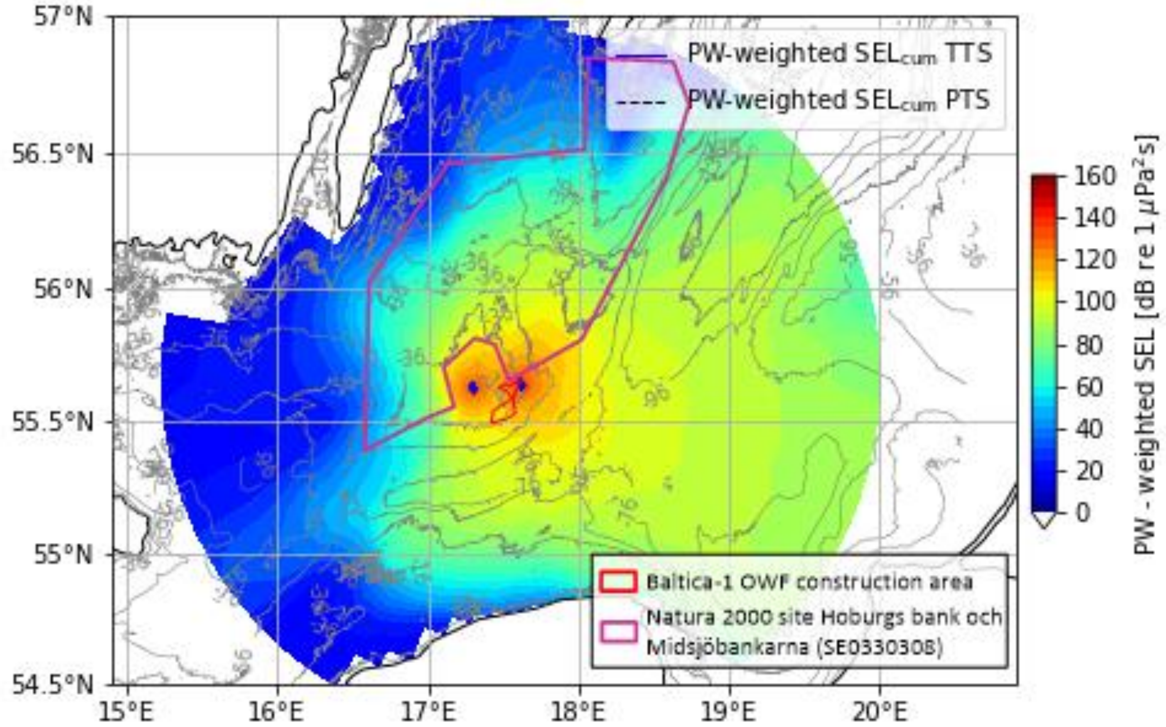




*Figure 4.57. The map of PW-weighted $SEL_{cum}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the grey seal and harbour seal with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

### 4.2.3 Fish with swim bladders

Similarly to the results obtained for the harbour porpoise and seals, the impact areas for fish with swim bladders increased with the number of piling sources, reaching the highest values in the case of four locations. The smallest impact areas were obtained for the scenario with the use of the IQIP + DBBC mitigation system. Impact areas and noise propagation maps are presented in the figure below [Table 4.6] and the following figures [Figure 4.58–Figure 4.66].

*Table 4.6. The ranges of distances to threshold values for fish with swim bladders in the case of simultaneous piling in several locations within and outside the Baltica-1 area (numbers in bold: the highest values for 2 and 3 sources, respectively; piling with the use of the BBC, HSD + DBBC, and IQIP + DBBC mitigation systems)*

| **Season** | **Mitigation type** | **Impact area [km²]** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Effect** | **1 source** | **2 sources – < 1 km** | **2 sources – 20 km** | **2 sources – at a significant distance** | **3 sources – 2 < 1 km, 1 = 20 km** | **3 sources – 2 = 20 km, 1 = at a significant distance** | **4 sources** |
| Winter | BBC | Behavioural response | 25820 | 28199 | **31123** | **51640** | 31989 | **56943** | 82763 |
| | | TTS (single blow) | 0.03 | 0.1 | **0.06** | **0.06** | **0.1** | 0.09 | 0.1 |
| | | TTS (cumulative effect) | 2204 | 4626 | **5034** | 4408 | **7739** | 7238 | 9943 |
| | | Reversible hearing loss (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | Reversible hearing loss (cumulative effect) | 62.0 | **126** | 124 | 124 | **188** | 186 | 250 |
| | HSD + DBBC | Behavioural response | 2844 | 6245 | **6590** | 5688 | **10123** | 9434 | 12967 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | TTS (cumulative effect) | 288 | 459 | **648** | **648** | 849 | **936** | 1224 |
| | | Reversible hearing loss (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | Reversible hearing loss (cumulative effect) | 5.0 | **13.4** | 10.0 | 10.0 | **26.8** | 15.0 | 31.8 |
| | IQIP + DBBC | Behavioural response | 1772 | 3533 | **3939** | 3544 | **6222** | 5711 | 7994 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | TTS (cumulative effect) | 158 | 287 | **393** | 316 | 525 | **551** | 709 |
| | | Reversible hearing loss (single blow) | 0.03 | 0.03 | **2.3** | 0.06 | 0.06 | **2.3** | 2.3 |
| | | Reversible hearing loss (cumulative effect) | 1.1 | 3.1 | 0.06 | **2.2** | **6.3** | 1.2 | 7.4 |
| Summer | BBC | Behavioural response | 2676 | 3981 | 4654 | **5352** | 5820 | **7330** | 10006 |
| | | TTS (single blow) | 0.03 | 0.1 | **0.03** | **0.06** | **0.1** | 0.06 | 0.1 |
| | | TTS (cumulative effect) | 625 | 917 | 1228 | **1250** | 1509 | **1853** | 2478 |

| Season | Mitigation type | Impact area [km$^2$] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Effect** | **1 source** | **2 sources – < 1 km** | **2 sources – 20 km** | **2 sources – at a significant distance** | **3 sources – 2 < 1 km, 1 = 20 km** | **3 sources – 2 = 20 km, 1 = at a significant distance** | **4 sources** |
| | | Reversible hearing loss (single blow) | 0.03 | 0.03 | 0.03 | **0.06** | **0.06** | **0.09** | 0.09 |
| | | Reversible hearing loss (cumulative effect) | 43.4 | 76.0 | **86.8** | **86.8** | 119 | **130** | 173 |
| | HSD + DBBC | Behavioural response | 801 | 1136 | 1528 | **1602** | 1842 | **2329** | 3130 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | TTS (cumulative effect) | 169 | 257 | **391** | 338 | 477 | **560** | 729 |
| | | Reversible hearing loss (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | Reversible hearing loss (cumulative effect) | 4.5 | **11.0** | 9.0 | 9.0 | **15.5** | 13.5 | 20.0 |
| | IQIP + DBBC | Behavioural response | 551 | 803 | **1102** | **1102** | 1354 | **1653** | 2204 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | TTS (cumulative effect) | 95 | 156 | **257** | 190 | 313 | **352** | 447 |
| | | Reversible hearing loss (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | Reversible hearing loss (cumulative effect) | 0.8 | **2.7** | 1.6 | 1.6 | **2.7** | 2.4 | 3.5 |

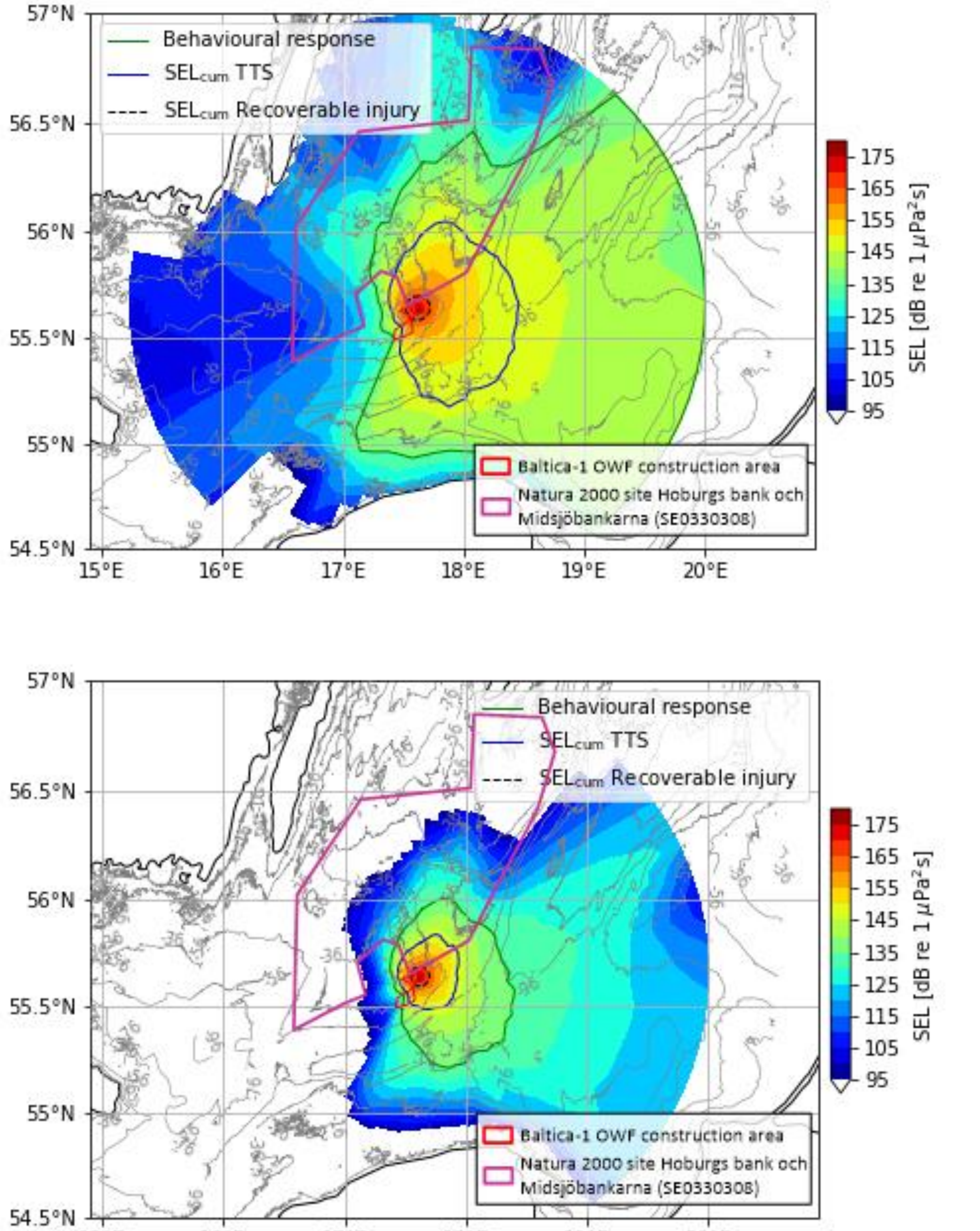



*Figure 4.58. The map of unweighted SEL above the acoustic background for piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on fish with swim bladders with a BBC applied, in the winter (top) and summer (bottom)*

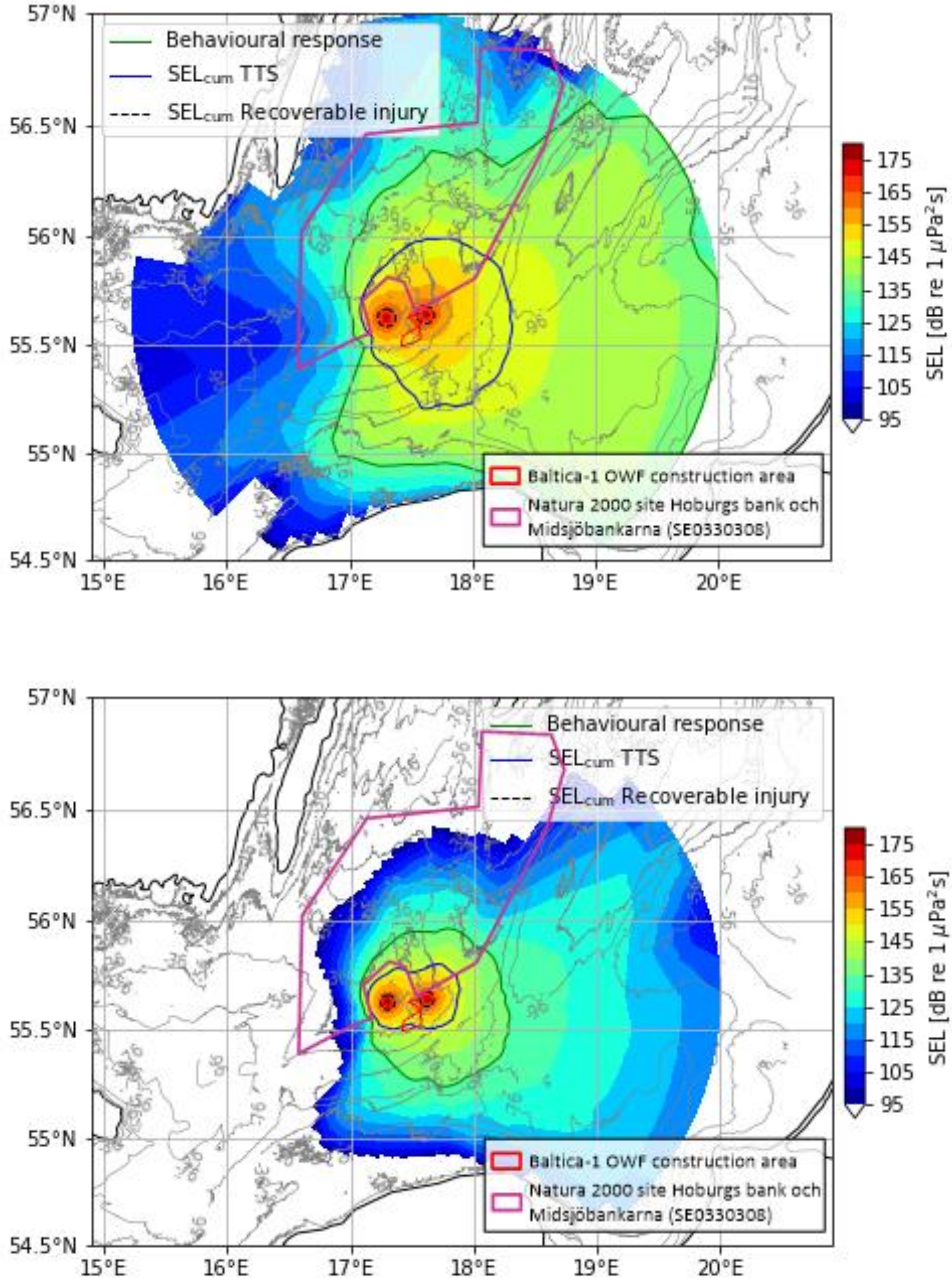



*Figure 4.59. The map of unweighted SEL above the acoustic background for piling sources located 20 km apart and the ranges of impact on fish with swim bladders with a BBC applied, in the winter (top) and summer (bottom)*

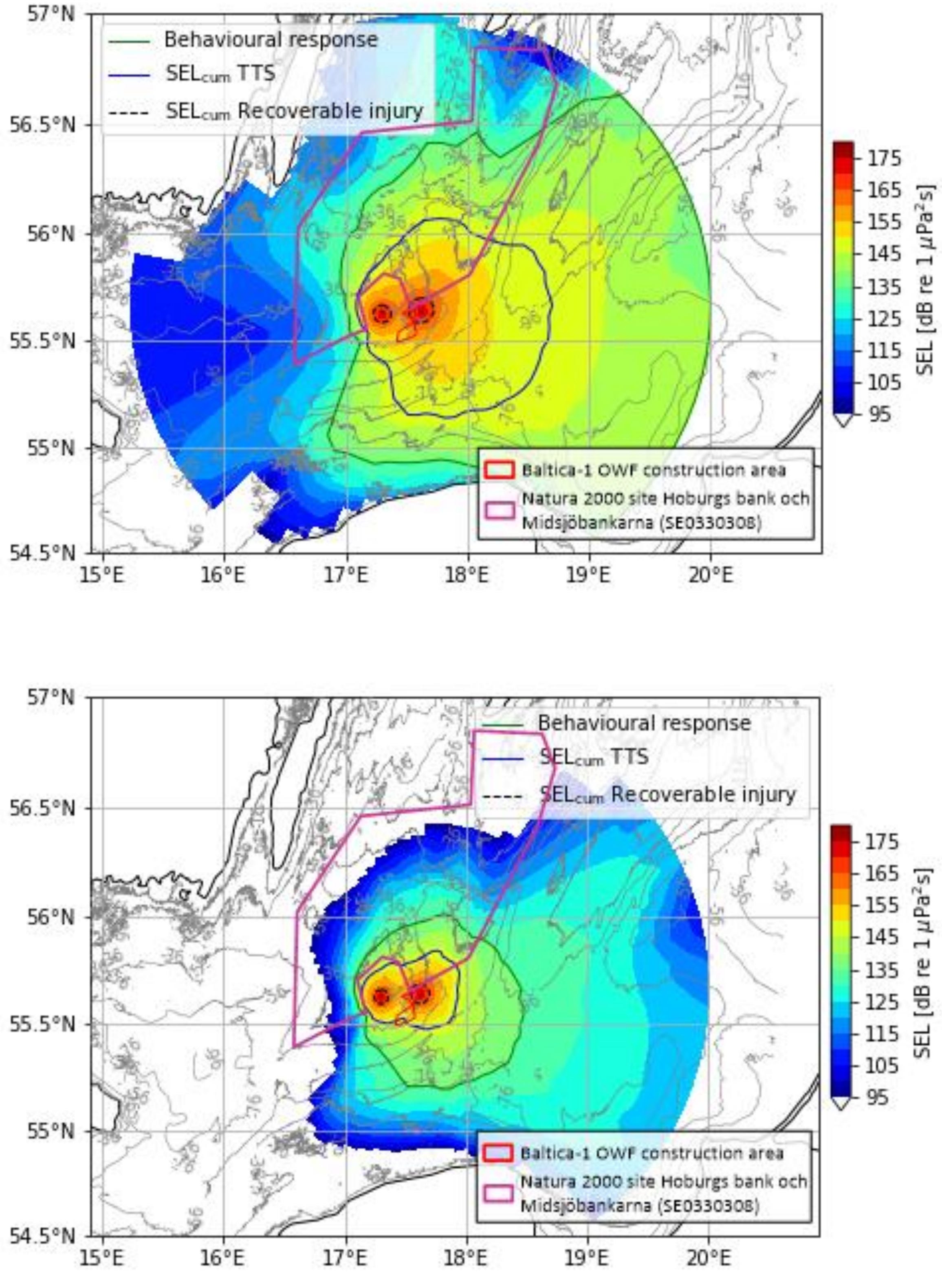
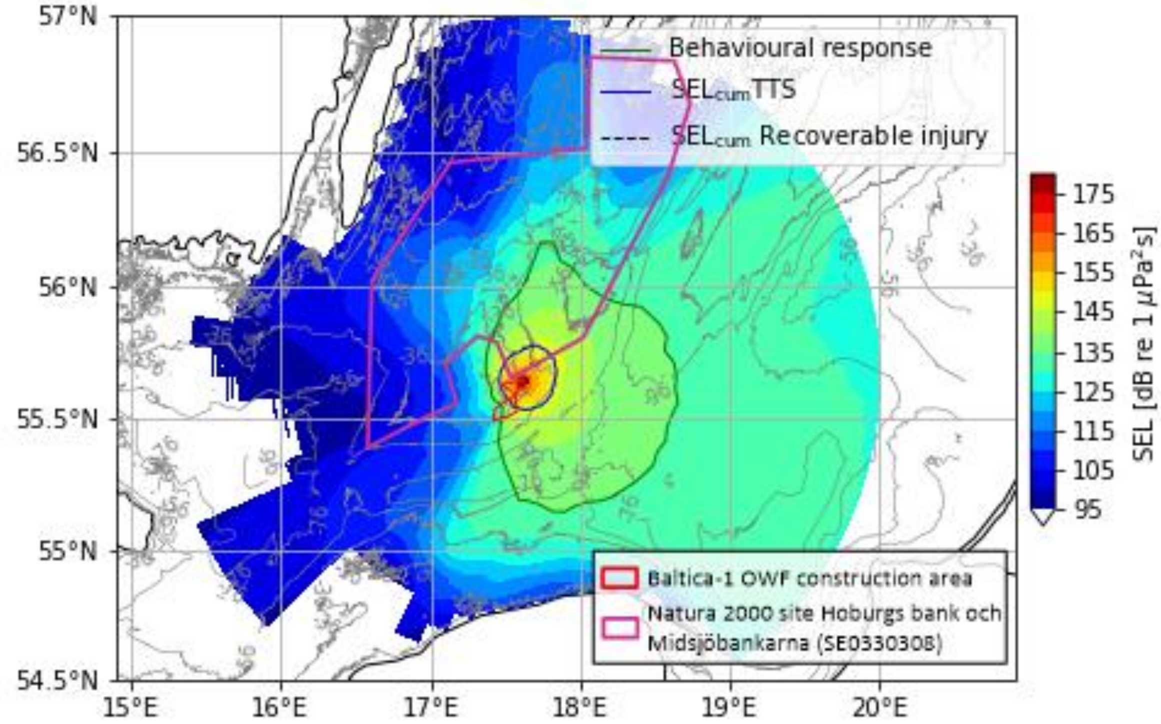



*Figure 4.60. The map of unweighted SEL above the acoustic background for three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on fishes with swim bladders with a BBC applied, in the winter (top) and summer (bottom) seasons*



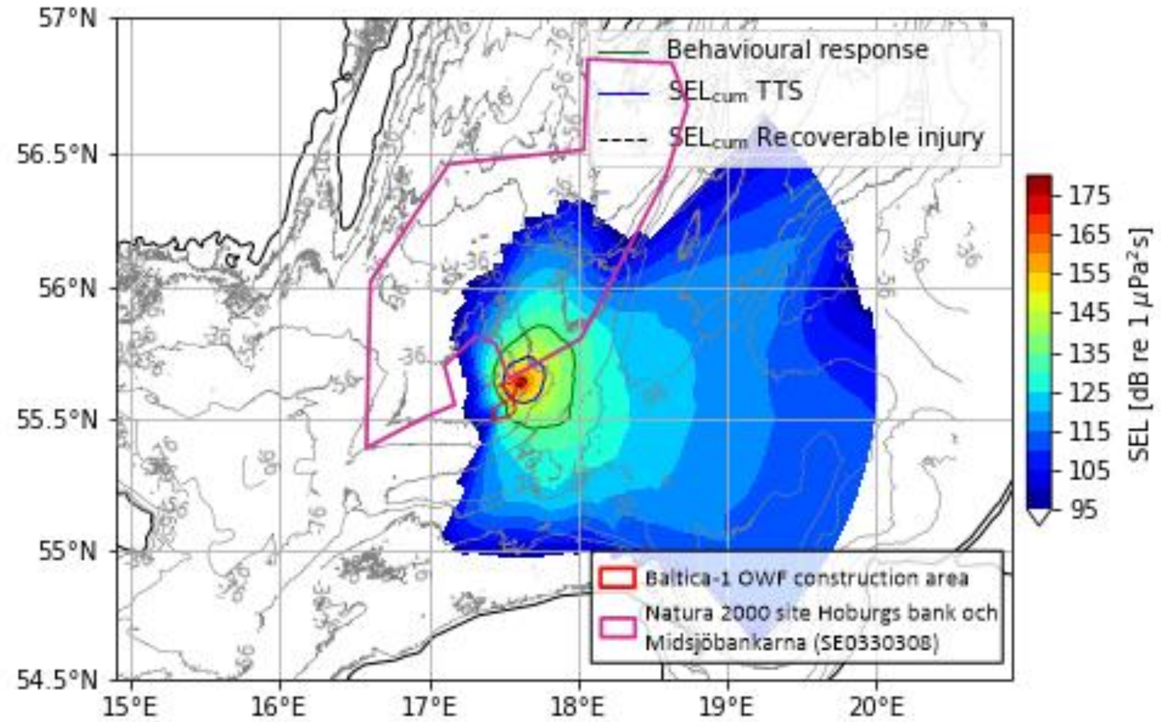




*Figure 4.61. The map of unweighted SEL above the acoustic background for piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on fish with swim bladders with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*

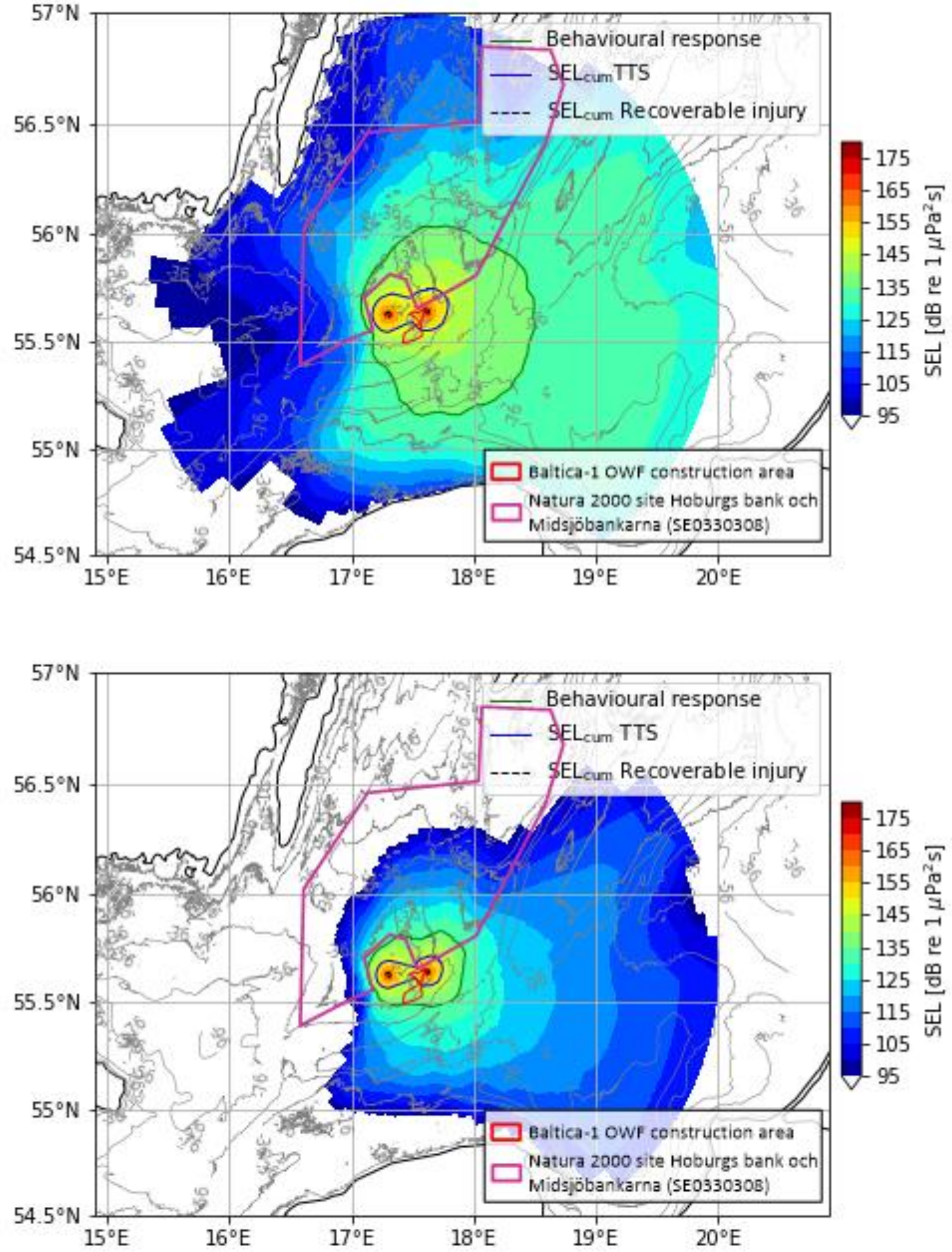
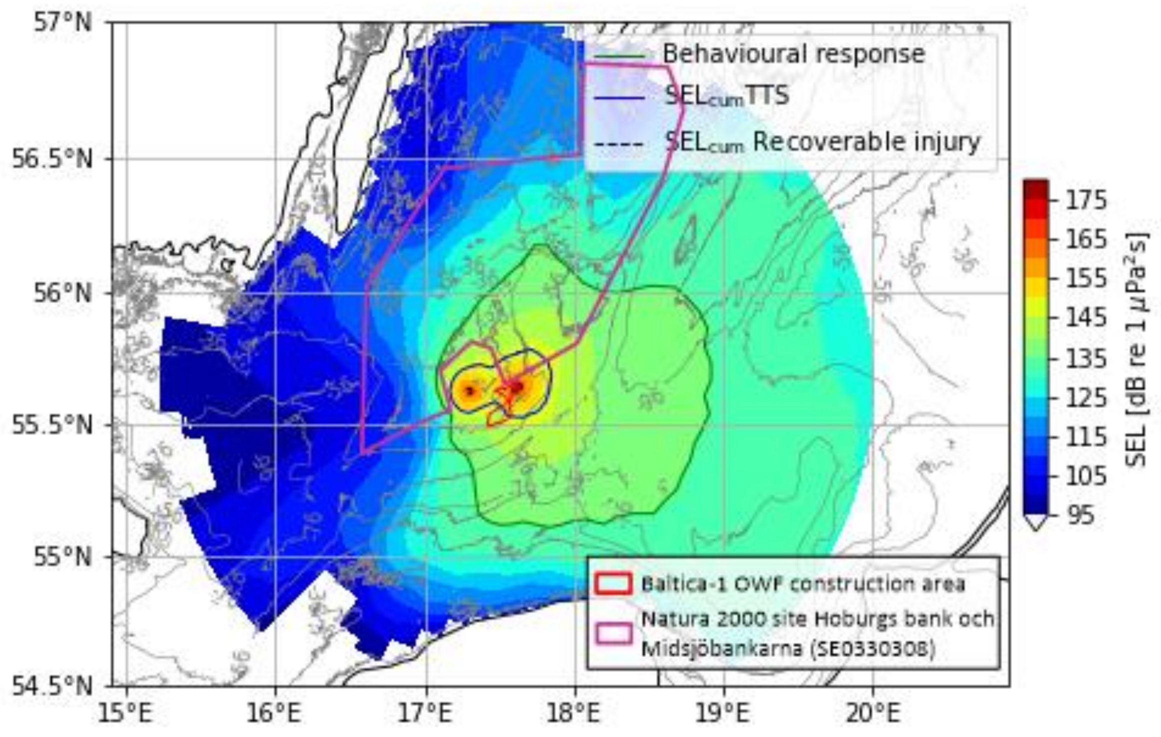



*Figure 4.62. The map of unweighted SEL above the acoustic background for piling sources located 20 km apart and the ranges of impact on fish with swim bladders with the HSD + DBBC system applied, in the winter (top) and summer (bottom)*



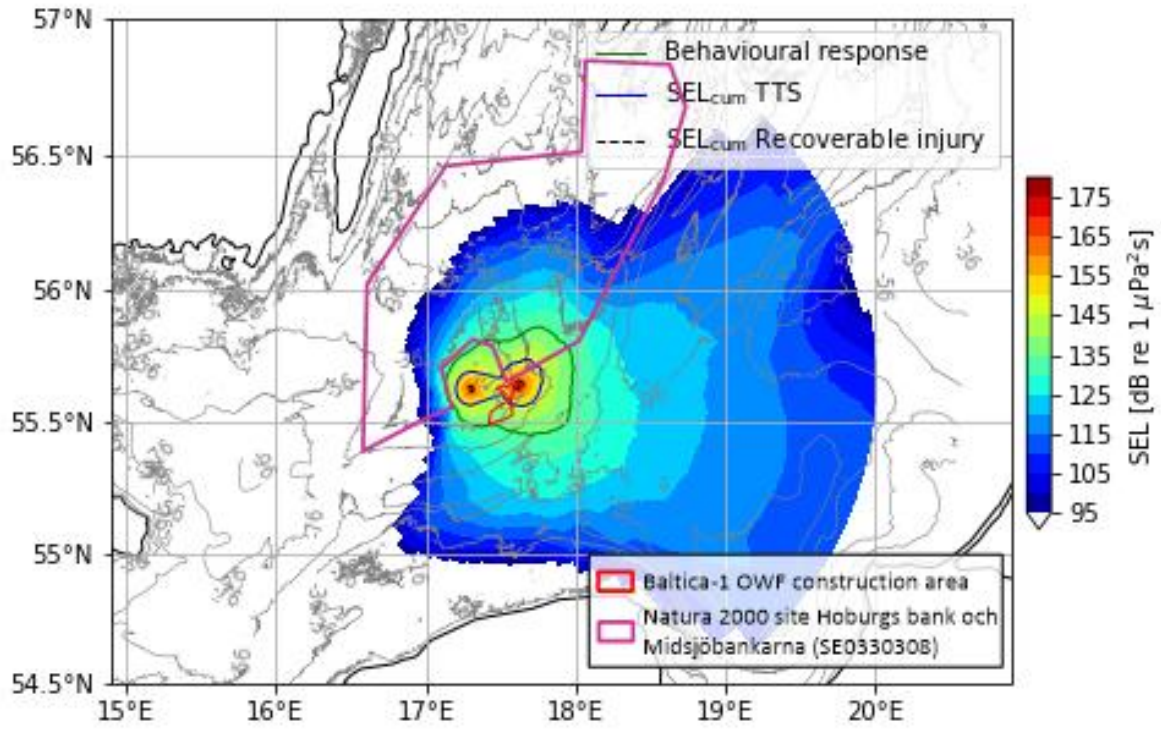




*Figure 4.63. The map of unweighted SEL above the acoustic background for three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on fish with swim bladders with the HSD + DBBC system applied, in the winter (top) and summer (bottom) seasons*

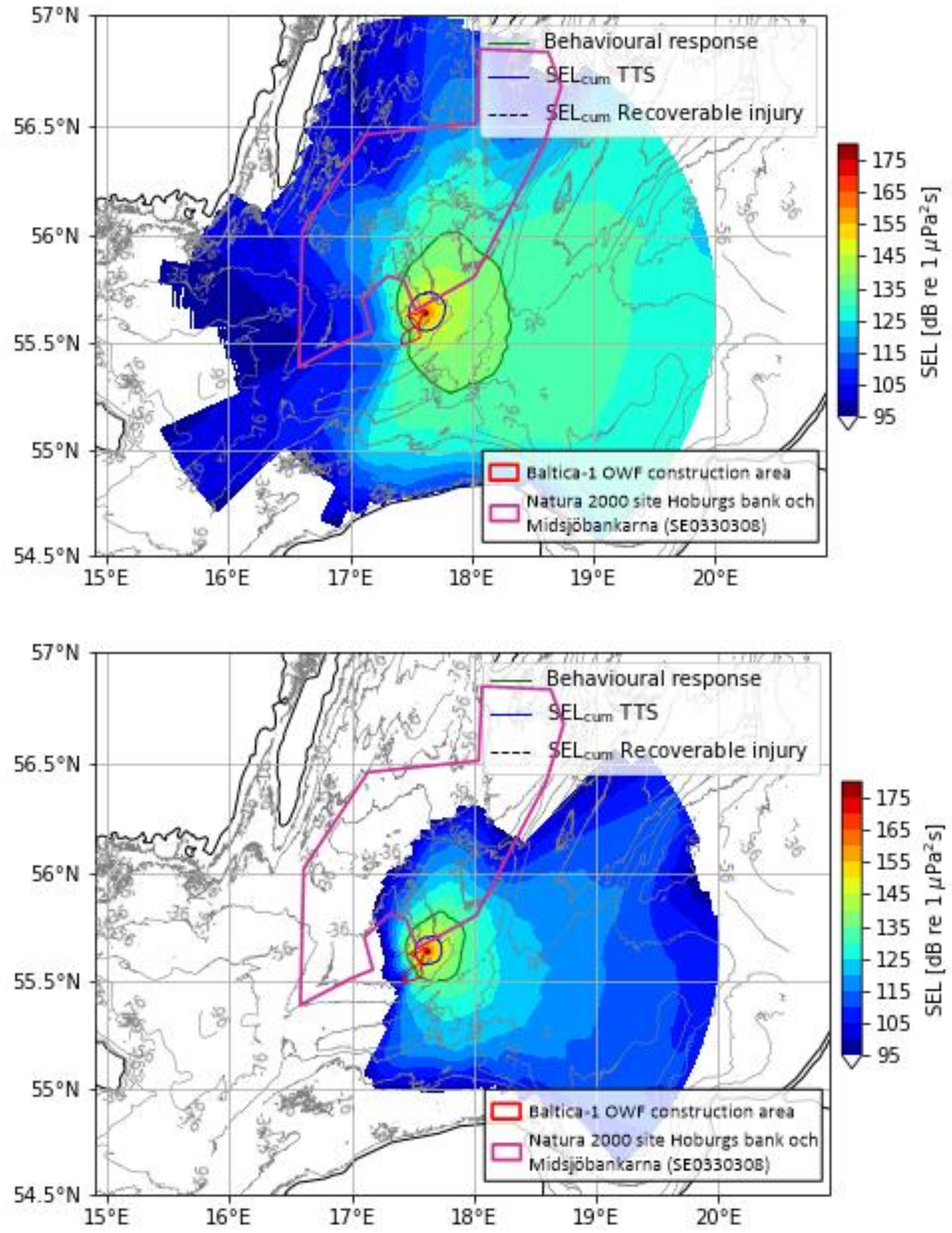



*Figure 4.64. The map of unweighted SEL above the acoustic background for piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on fish with swim bladders with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

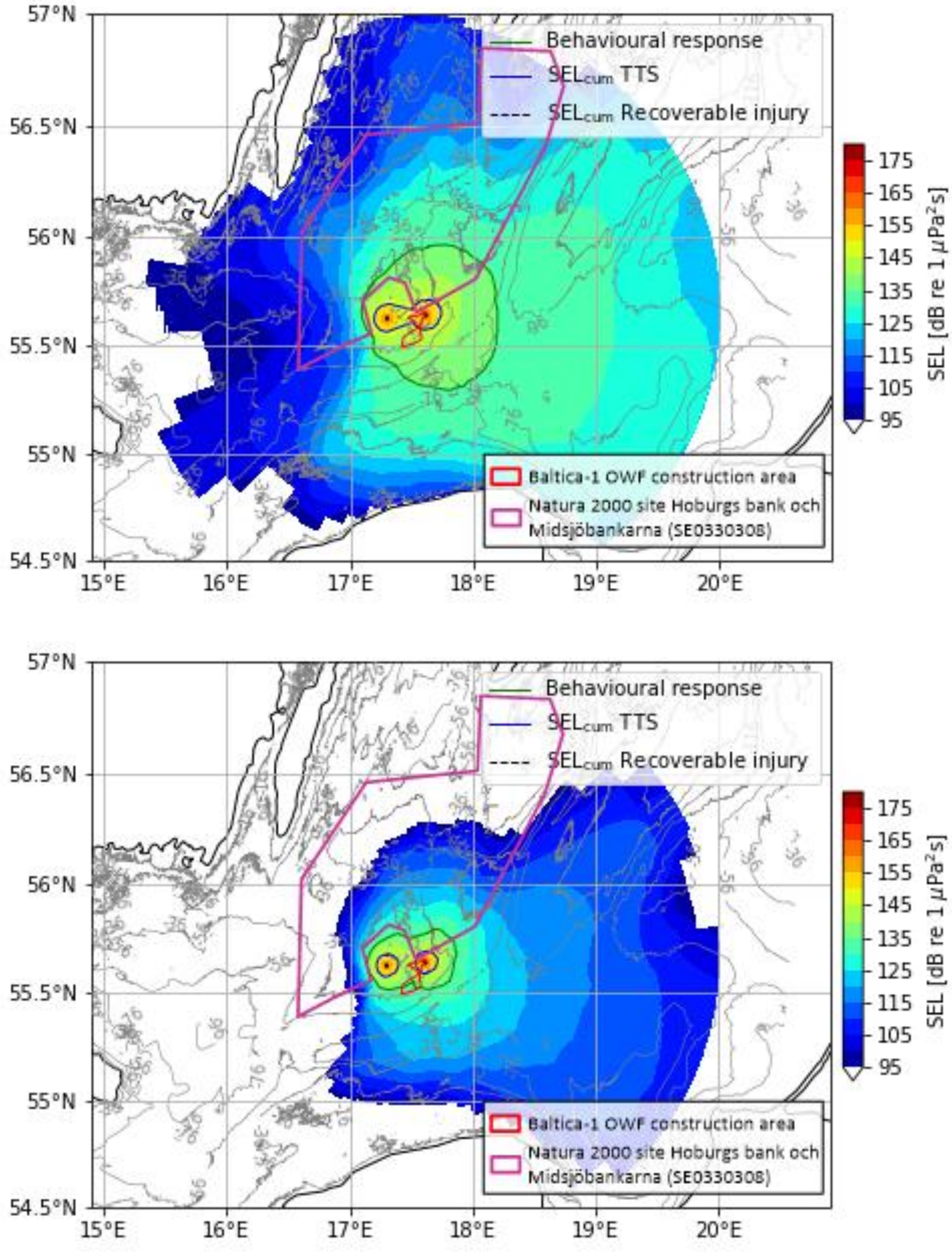



*Figure 4.65. The map of unweighted SEL above the acoustic background for piling sources located 20 km apart and the ranges of impact on fish with swim bladders with the IQIP + DBBC system applied, in the winter (top) and summer (bottom)*

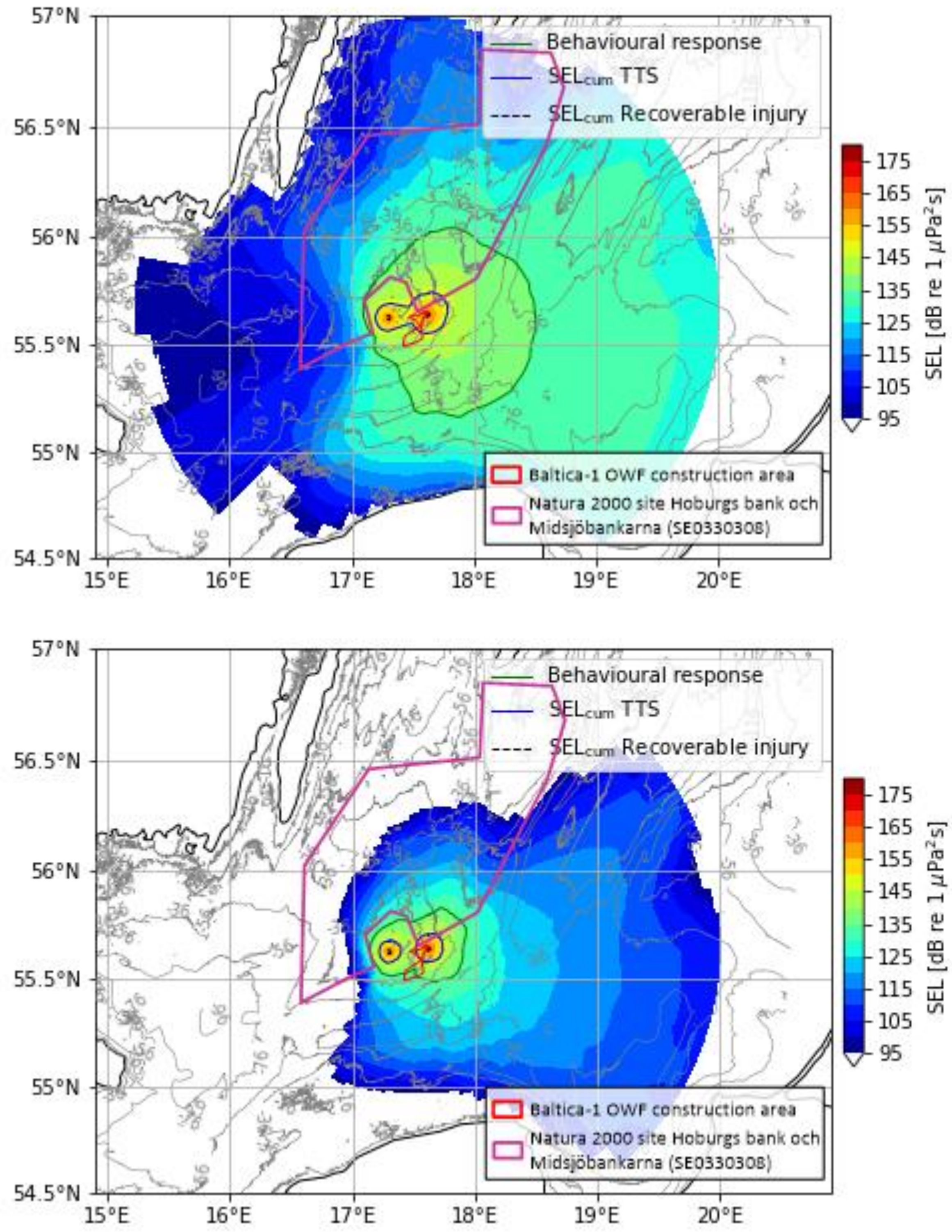



*Figure 4.66. The map of unweighted SEL above the acoustic background for three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on fish with swim bladders with the IQIP + DBBC system applied, in the winter (top) and summer (bottom) seasons*

## 4.3 Noise levels at the boundary of the Natura 2000 area

Presented below are levels of noise heard at the boundary of the Natura 2000 site Hoburgs bank och Midsjöbankarna in the winter and summer seasons. Analyses were conducted for the harbour porpoise, as it is subject to protection in the above-mentioned area, and additionally, the threshold values for this species are the lowest among the analysed mammals.

### 4.3.1 Piling in a single location

The tables below present the differences between the calculated sound values at the boundary of the Natura 2000 site and the threshold values for scenarios without any mitigation measures applied [Table 4.7] and with the mitigation systems taken into account [Table 4.8]. The corresponding graphs for the cumulative TTS and PTS are presented in the following figures [Figure 4.67–Figure 4.72].

All graphs present a characteristic logarithmic decline taking into account the oscillation levels. The combination of oscillations of individual 1/3-octave bands, with the simultaneous use of "effective silence", can lead to significant fluctuations in the case of the scenario with mitigation measures included. This is caused by the oscillation of the 1/3-octave band for the unweighted SEL around the value of 124 dB. In the case where the 1/3-octave band has a dominant impact on the HF-weighted SEL, the results show a large variability, as between individual ranges the acoustic energy of the band is included or omitted in the calculation of the cumulative HF-weighted SEL. The effect of local interference can cause the dominant 1/3 octave band to oscillate around the value of 124 dB, which leads to major differences between the cumulative HF-weighted SEL in the scenario with mitigation measures.

Based on the presented results, it is shown that in the case of piling at a single location, the cumulative TTS threshold values for harbour porpoise will be exceeded at the boundary of the Swedish Natura 2000 site in both analysed seasons if no mitigation measures are used and after the application of a single bubble curtain. Only the application of the HSD + DBBC or IQIP + DBBC system showed a decrease in PTS at the boundary of the Natura 2000 area to an acceptable level, however, the cumulative TTS, even after the application of the above-mentioned noise reduction system, remained at a prominent level in the winter season.

*Table 4.7. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the cumulative TTS and PTS limits without any mitigation measures applied*

| **Season** | **Effect** | **SEL threshold value at the boundary of the Natura 2000 site [dB re 1 µPa²s]** | **Without mitigating measures** | |
|---|---|---|---|---|
| | | | **The modelled HF-weighted SEL value at the boundary of the Natura 2000 site [dB re 1 µPa²s]** | **The difference in the modelled level of HF-weighted SEL and the threshold value [dB]** |
| Winter | TTS (cumulative effect) | 140 | 183.6 | +43.6 |
| | PTS (cumulative effect) | 155 | | +28.6 |
| Summer | TTS (cumulative effect) | 140 | 180.1 | +40.1 |
| | PTS (cumulative effect) | 155 | | +25.1 |

*Table 4.8. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the SEL-based weighted TTS and PTS limits for the harbour porpoise with mitigation measures applied*

| **Season** | **Effect** | **The threshold SEL value at the boundary of the Natura 2000 site [dB re 1 µPa²s]** | **The modelled HF-weighted SEL value at the boundary of the Natura 2000 site [dB re 1 µPa²s]** | | | **The difference in the modelled level of HF-weighted SEL and the threshold value [dB]** | | |
|---|---|---|---|---|---|---|---|---|
| | | | **BBC** | **HSD + DBBC** | **IQIP + DBBC** | **BBC** | **HSD + DBBC** | **IQIP + DBBC** |
| Winter | TTS (cumulative effect) | 140 | 158.2 | 150.9 | 153.4 | +18.2 | +10.9 | +13.4 |
| | PTS (cumulative effect) | 155 | | | | +3.2 | -4.1 | -1.6 |
| Summer | TTS (cumulative effect) | 140 | 154.0 | 122.7 | 122.1 | +14.0 | -17.3 | -17.9 |
| | PTS (cumulative effect) | 155 | | | | -1.0 | -32.3 | -32.9 |

#### 4.3.1.1 The distances to threshold values in the scenarios with mitigation (BBC) applied

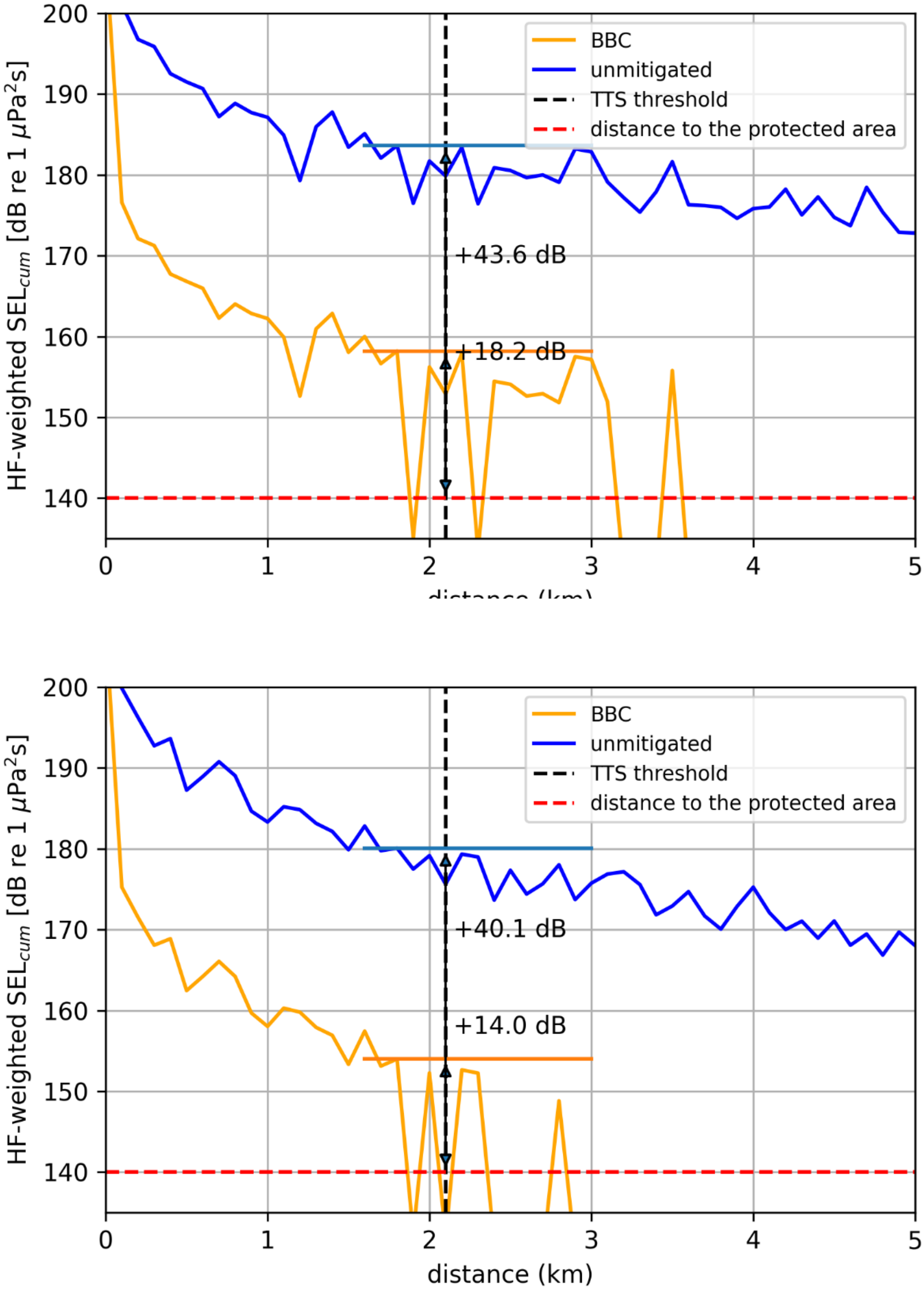



*Figure 4.67. The propagation of piling noise within the Baltica-1 OWF area in relation to the TTS limits for the porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

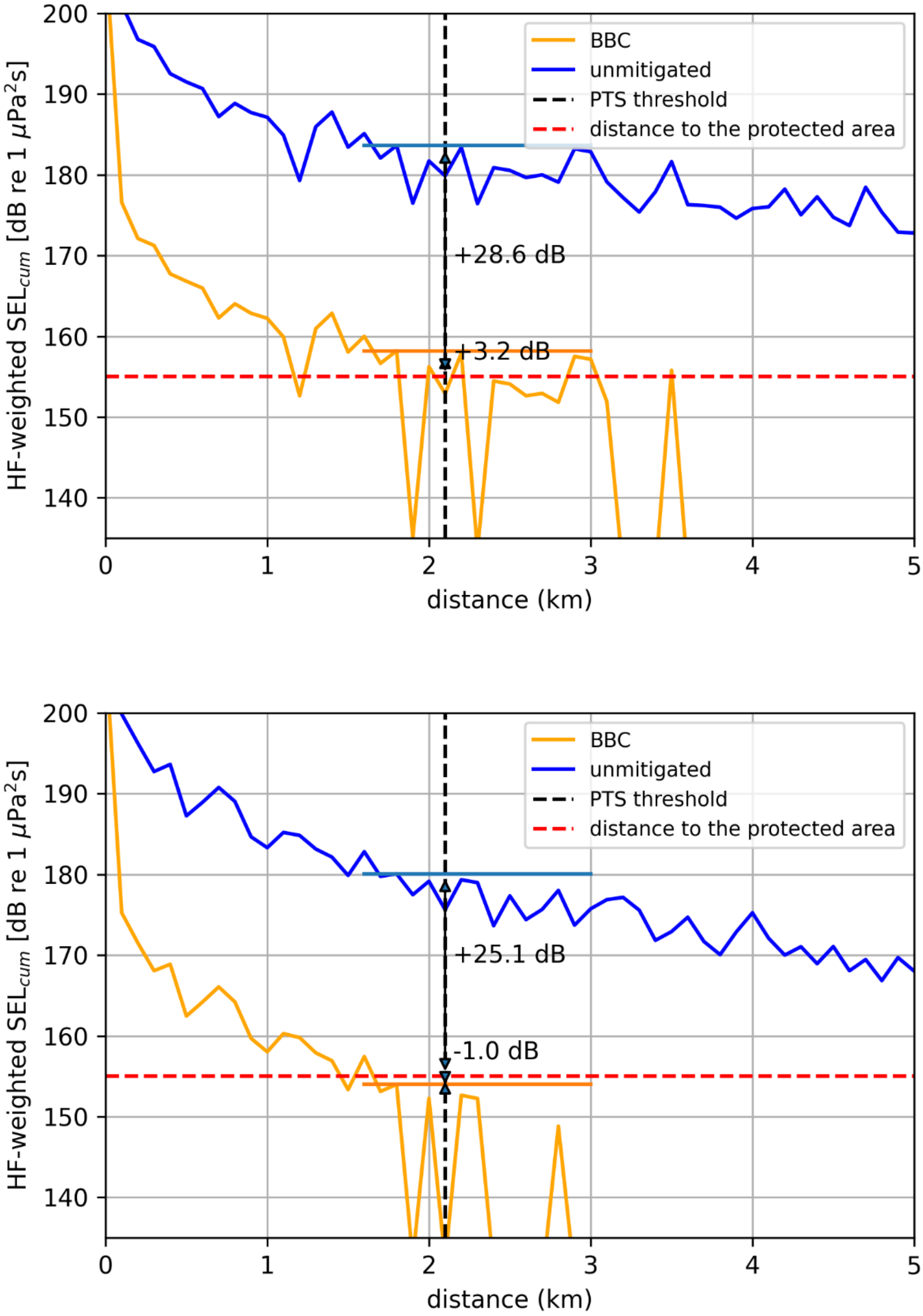



*Figure 4.68. The propagation of piling noise within the Baltica-1 OWF area in relation to the PTS limits for the porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

#### 4.3.1.2 The distances to threshold values for the scenario with mitigation measures (HSD + DBBC) applied

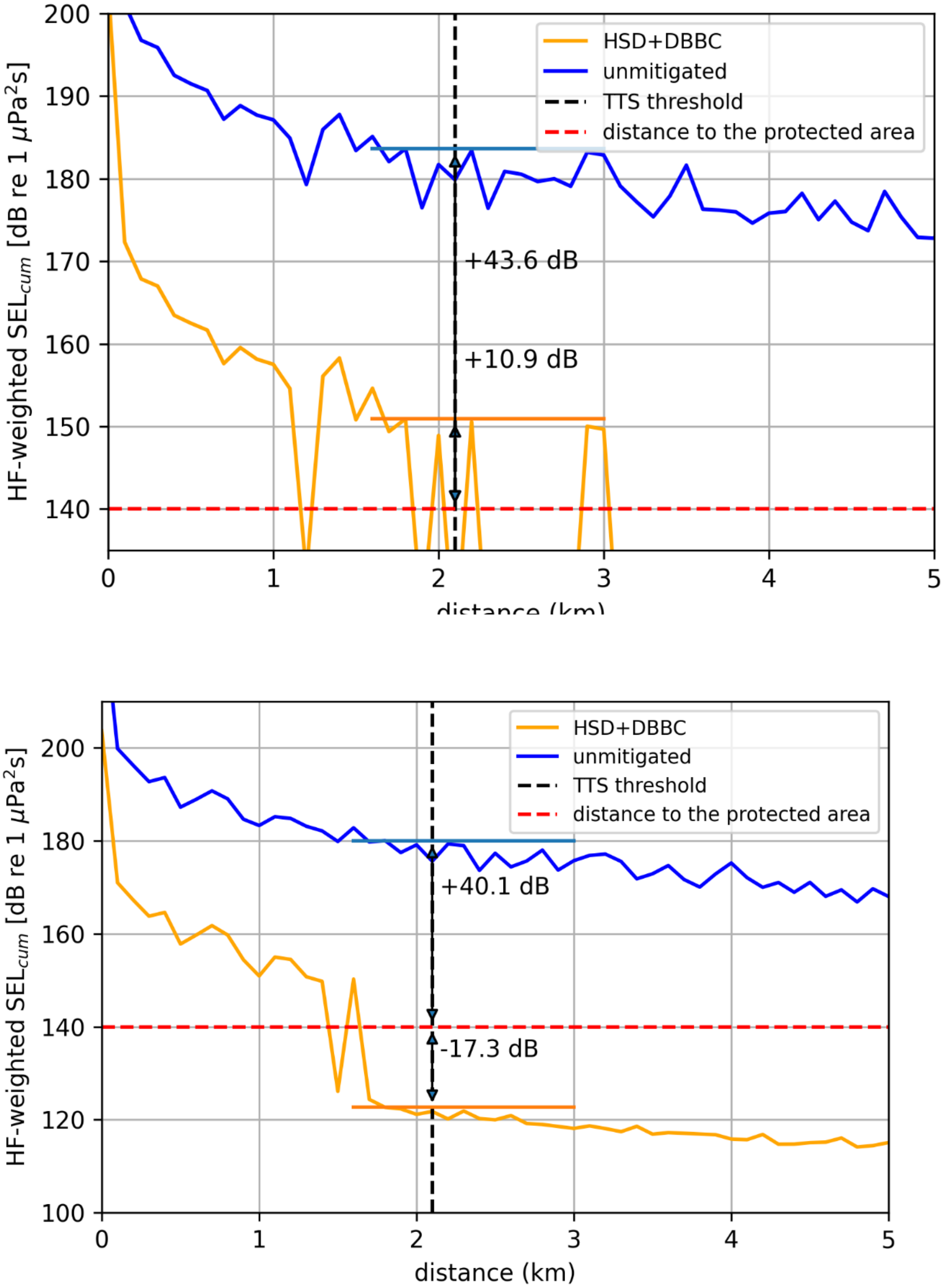



*Figure 4.69. The propagation of piling noise within the Baltica-1 OWF area in relation to the TTS limits for the porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

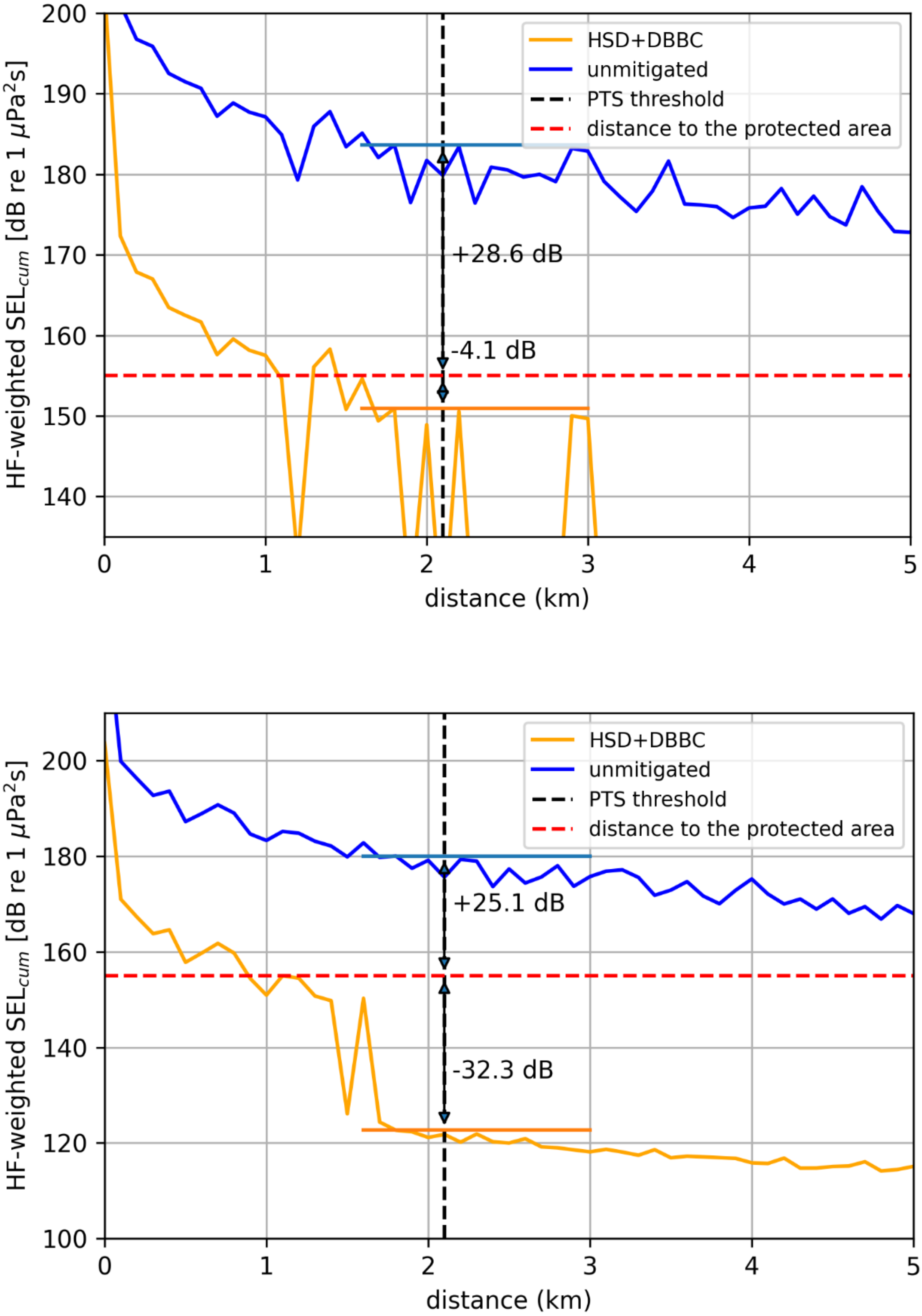
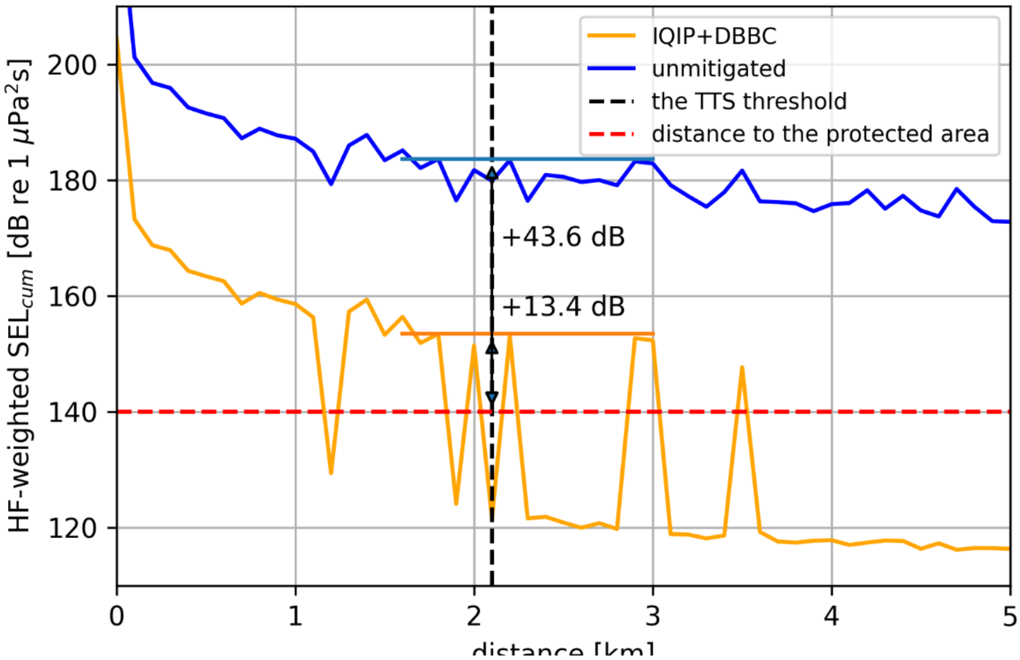



*Figure 4.70. The propagation of piling noise within the Baltica-1 OWF area in relation to the PTS limits for the porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

#### 4.3.1.3 The distances to threshold values for the scenario with mitigation measures (IQIP + DBBC) applied



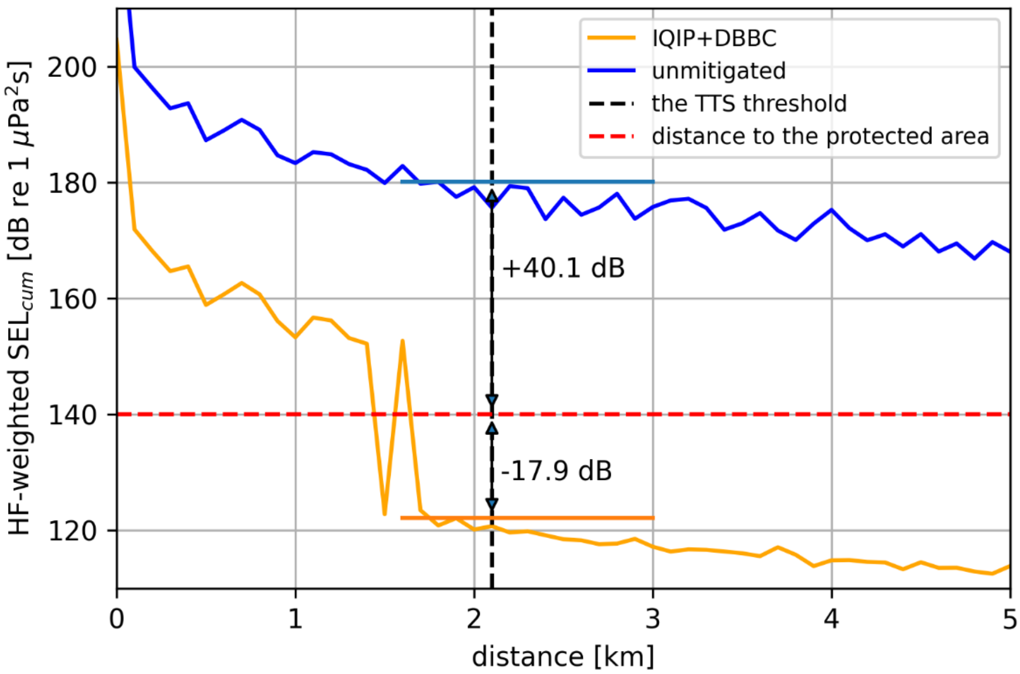




*Figure 4.71. The propagation of piling noise within the Baltica-1 OWF area in relation to the TTS limits for the porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

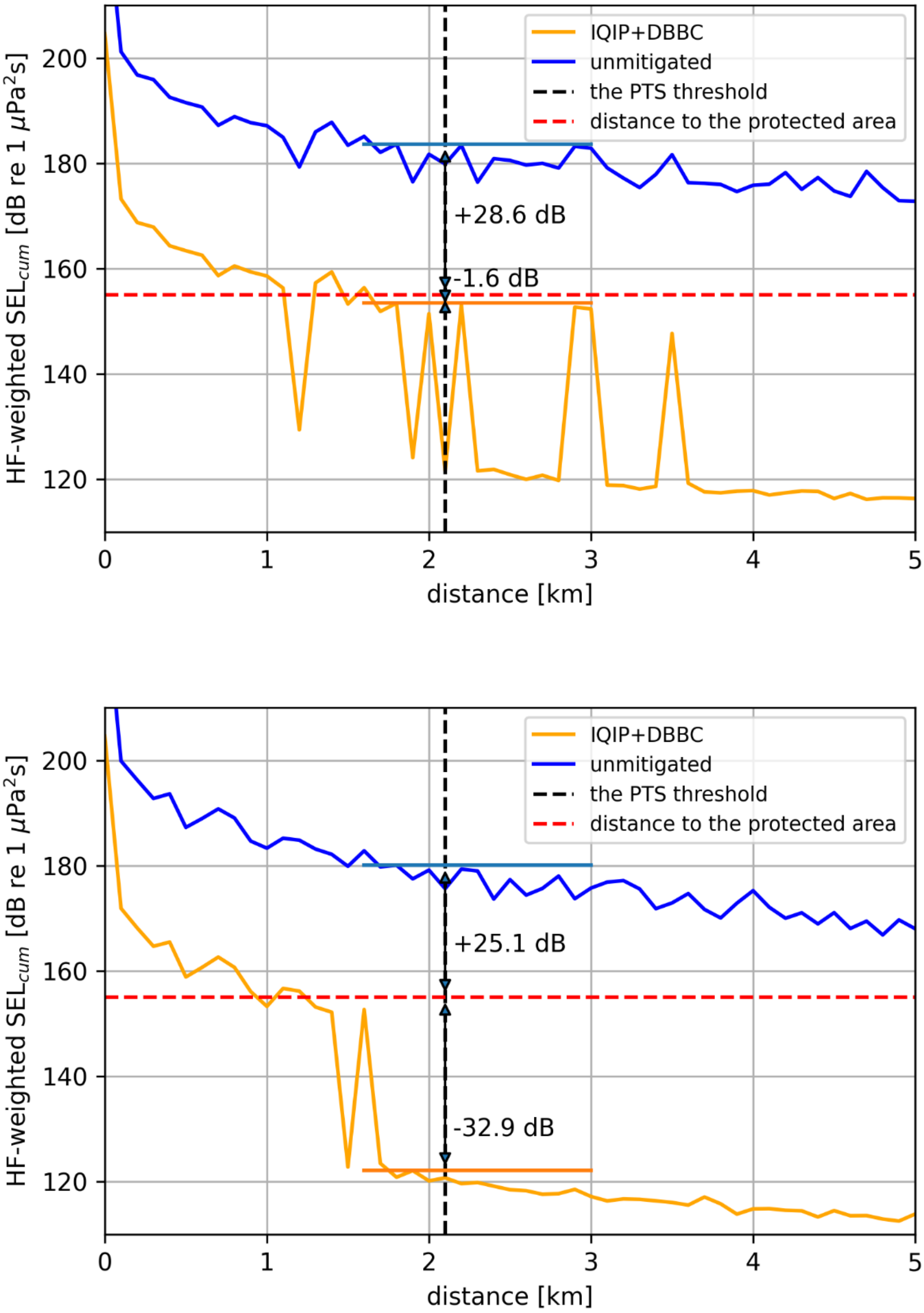



*Figure 4.72. The propagation of piling noise within the Baltica-1 OWF area in relation to the PTS limits for the porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

### 4.3.2 Piling in several locations

The differences in noise levels between the modelled SEL values at the boundary of the Natura 2000 site Hoburgs bank och Midsjöbankarna and the threshold values were calculated also for simultaneous piling works in several locations. The results for the different numbers of piling locations are presented in the table below [Table 4.9] for the scenario without mitigation measures applied and in the following table [Table 4.10] for the scenario with mitigation. The corresponding graphs for the TTS and PTS are presented in the following figures [Figure 4.73–Figure 4.90].

Based on the obtained results, it was concluded that in the case of piling works in several locations, the TTS threshold values at the boundary of the Natura 2000 site in question will be exceeded. This applies to all scenarios analysed. The TTS and PTS thresholds can only be expected not to be exceeded in the case of simultaneous piling at two locations 20 km apart with the HSD + DBBC or IQIP + DBBC system used as a mitigation measure in the summer season.

*Table 4.9. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the TTS and PTS limits for the harbour porpoise in the case of simultaneous piling in several locations within and outside the Baltica-1 area without any mitigation measures applied*

| Season | Sound sources | Effect | SEL threshold value at the boundary of the Natura 2000 site [dB re 1 μPa²s] | Without mitigating measures | |
|---|---|---|---|---|---|
| | | | | The modelled HF-weighted SEL at the boundary of the Natura 2000 site [dB re 1 μPa²s] | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] |
| Winter | 2 sources – <1 km | TTS (cumulative effect) | 140 | 186.6 | +46.6 |
| | | PTS (cumulative effect) | 155 | | +31.6 |
| | 2 sources – 20 km | TTS (cumulative effect) | 140 | 183.7 | +43.7 |
| | | PTS (cumulative effect) | 155 | | +28.7 |
| | 3 sources – 2 <1 km, 1 = 20 km | TTS (cumulative effect) | 140 | 186.7 | +46.7 |
| | | PTS (cumulative effect) | 155 | | +31.7 |
| Summer | 2 sources – <1 km | TTS (cumulative effect) | 140 | 183.1 | +43.1 |
| | | PTS (cumulative effect) | 155 | | +28.1 |
| | 2 sources – 20 km | TTS (cumulative effect) | 140 | 180.1 | +40.1 |
| | | PTS (cumulative effect) | 155 | | +25.1 |
| | 3 sources – 2 <1 km, 1 = 20 km | TTS (cumulative effect) | 140 | 183.1 | +43.1 |
| | | PTS (cumulative effect) | 155 | | +28.1 |

*Table 4.10. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the TTS and PTS limits for the harbour porpoise in the case of simultaneous piling in several locations within and outside the Baltica-1 area with the mitigation measures applied*

| Season | Sound sources | Effect | The threshold SEL value at the boundary of the Natura 2000 site [dB re 1 μPa²s] | The modelled HF-weighted SEL value at the boundary of the Natura 2000 site [dB re 1 μPa²s] | | | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | BBC | HSD + DBBC | IQIP + DBBC | BBC | HSD + DBBC | IQIP + DBBC |
| Winter | 2 sources – < 1 km | TTS (cumulative effect) | 140 | 161.5 | 156.6 | 157.9 | +21.5 | +16.6 | +17.9 |
| | | PTS (cumulative effect) | 155 | | | | +6.5 | +1.6 | +2.9 |
| | 2 sources – | TTS (cumulative effect) | 140 | 158.2 | 150.9 | 153.4 | +18.2 | +10.9 | +13.4 |

| Season | Sound sources | Effect | The threshold SEL value at the boundary of the Natura 2000 site [dB re 1 µPa²s] | The modelled HF-weighted SEL value at the boundary of the Natura 2000 site [dB re 1 µPa²s] | | | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | BBC | HSD + DBBC | IQIP + DBBC | BBC | HSD + DBBC | IQIP + DBBC |
| | 20 km | PTS (cumulative effect) | 155 | | | | +3.2 | -4.1 | -1.6 |
| | 3 sources – 2 < 1km, 1 = 20 km | TTS (cumulative effect) | 140 | 161.5 | 156.6 | 157.9 | +21.5 | +16.6 | +17.9 |
| | | PTS (cumulative effect) | 155 | | | | +6.5 | +1.6 | +2.9 |
| Summer | 2 sources – < 1 km | TTS (cumulative effect) | 140 | 157.8 | 150.6 | 153.0 | +17.8 | +10.6 | +13.0 |
| | | PTS (cumulative effect) | 155 | | | | +2.8 | -4.4 | -2.0 |
| | 2 sources – 20 km | TTS (cumulative effect) | 140 | 154.0 | 122.7 | 122.1 | +14.0 | -17.3 | -17.9 |
| | | PTS (cumulative effect) | 155 | | | | -1.0 | -32.3 | -32.9 |
| | 3 sources – 2 < 1km, 1 = 20 km | TTS (cumulative effect) | 140 | 157.8 | 150.6 | 153.0 | +17.8 | +10.6 | +13.0 |
| | | PTS (cumulative effect) | 155 | | | | +2.8 | -4.4 | -2.0 |

#### 4.3.2.1 The distances to threshold values in the scenarios with mitigation (BBC) applied

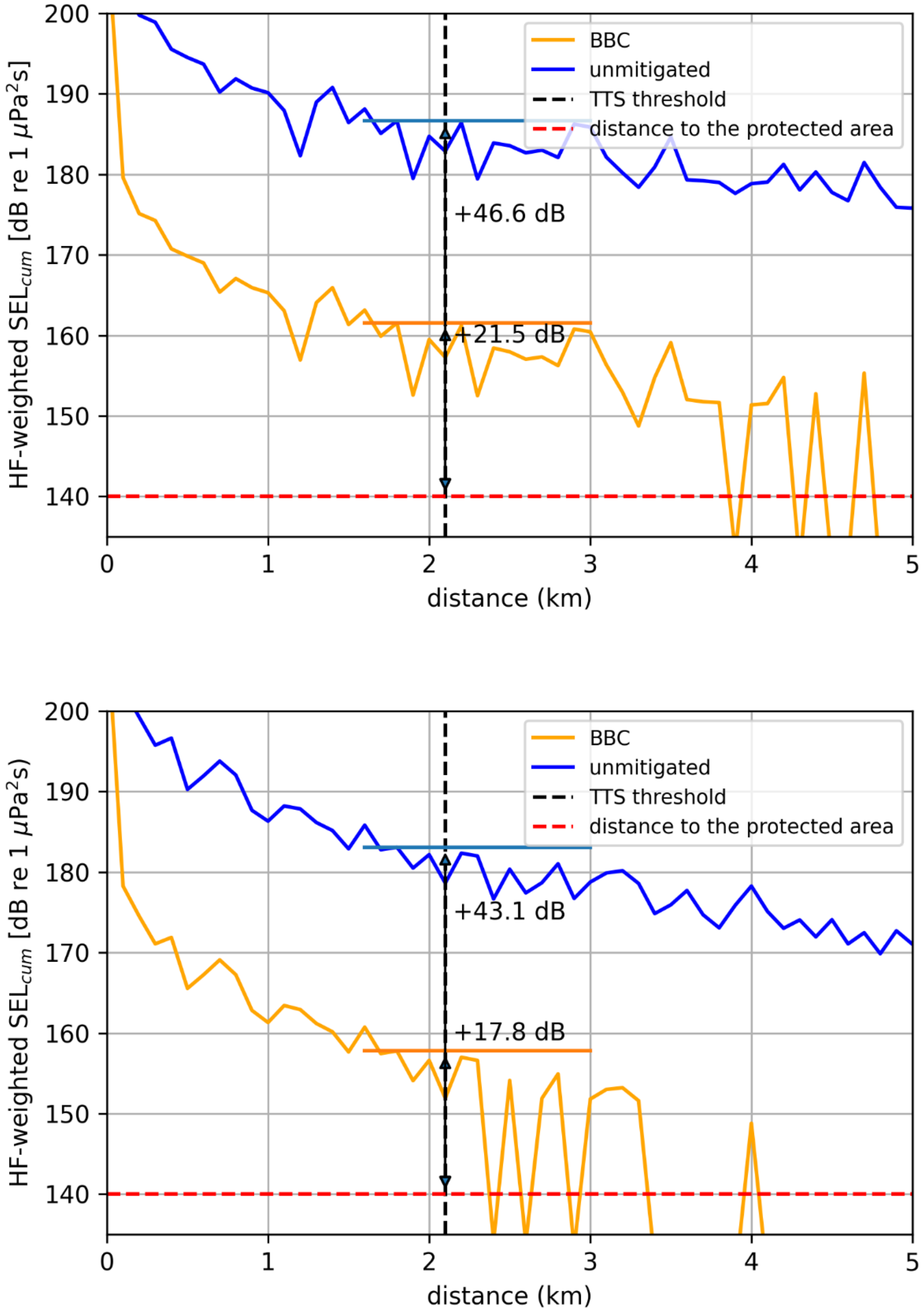
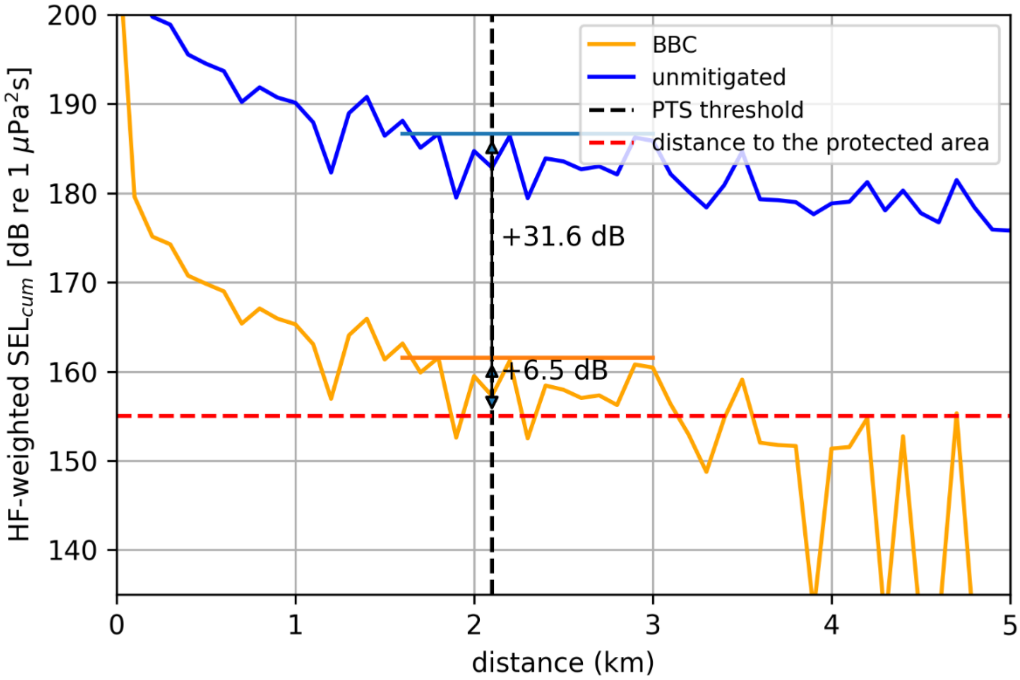



*Figure 4.73. Noise propagation during simultaneous piling in two close locations within the Baltica-1 OWF area, in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*



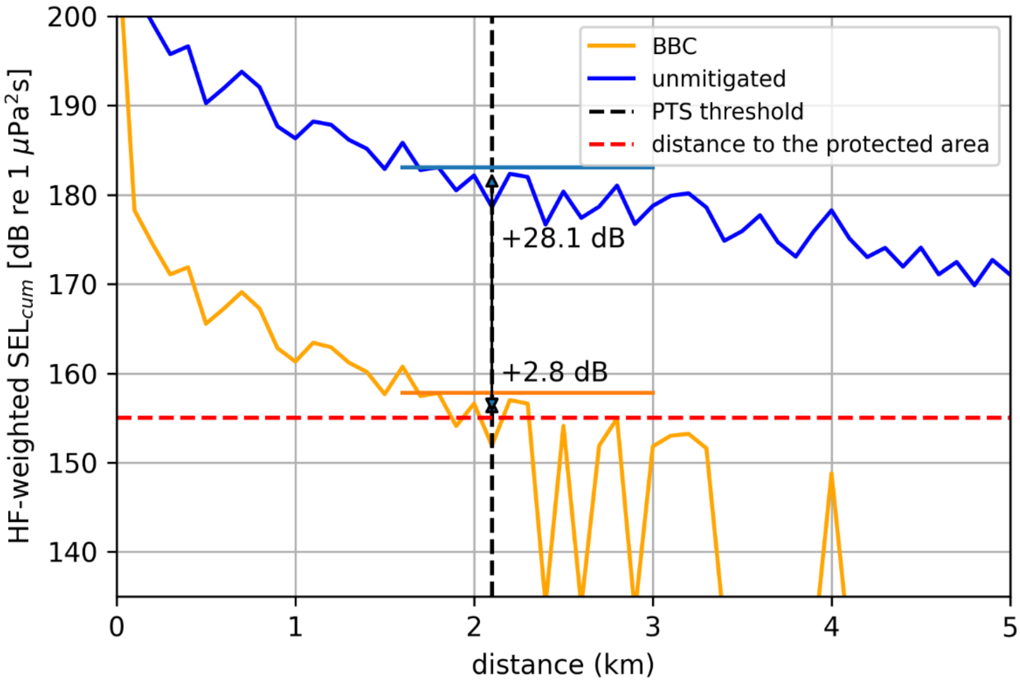
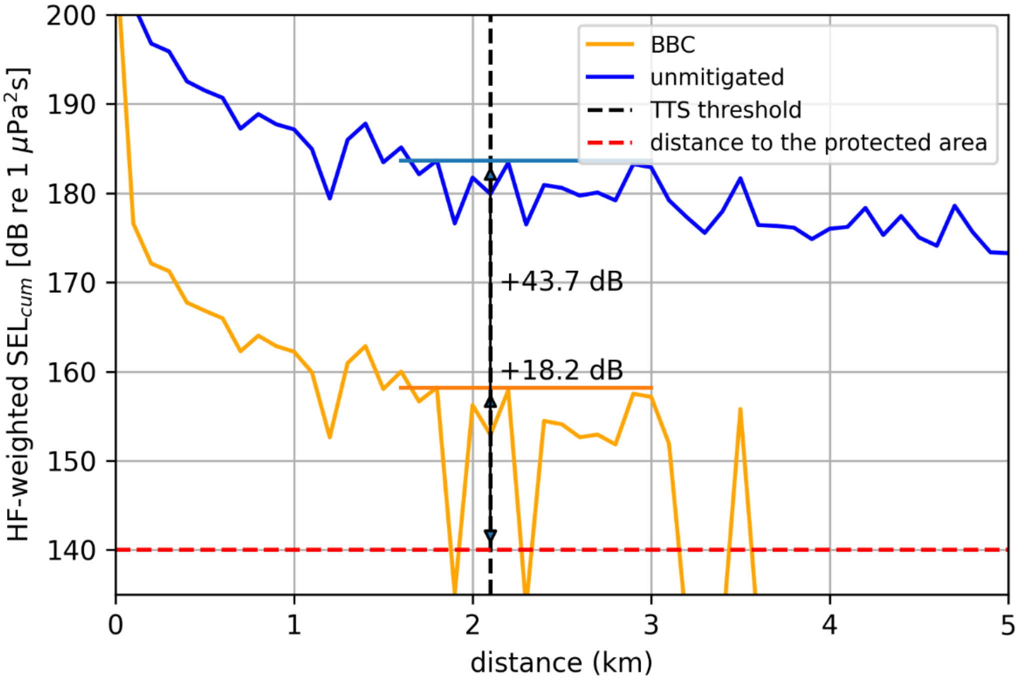




*Figure 4.74. Noise propagation during simultaneous piling in two close locations within the Baltica-1 OWF area, in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*



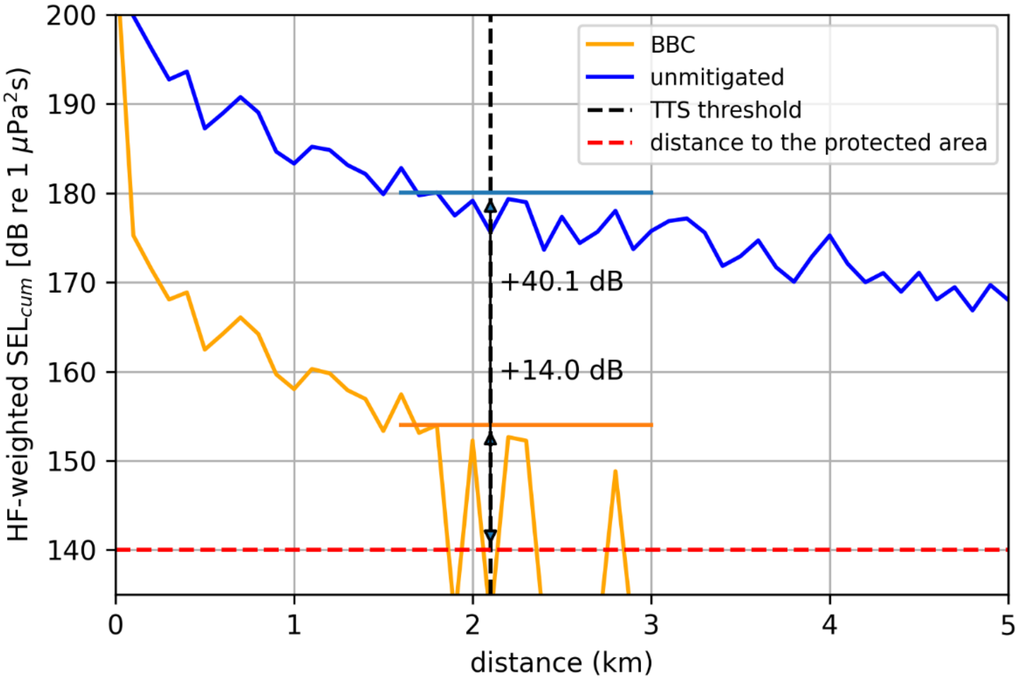




*Figure 4.75. Noise propagation during simultaneous piling in two locations 20 km apart from each other in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

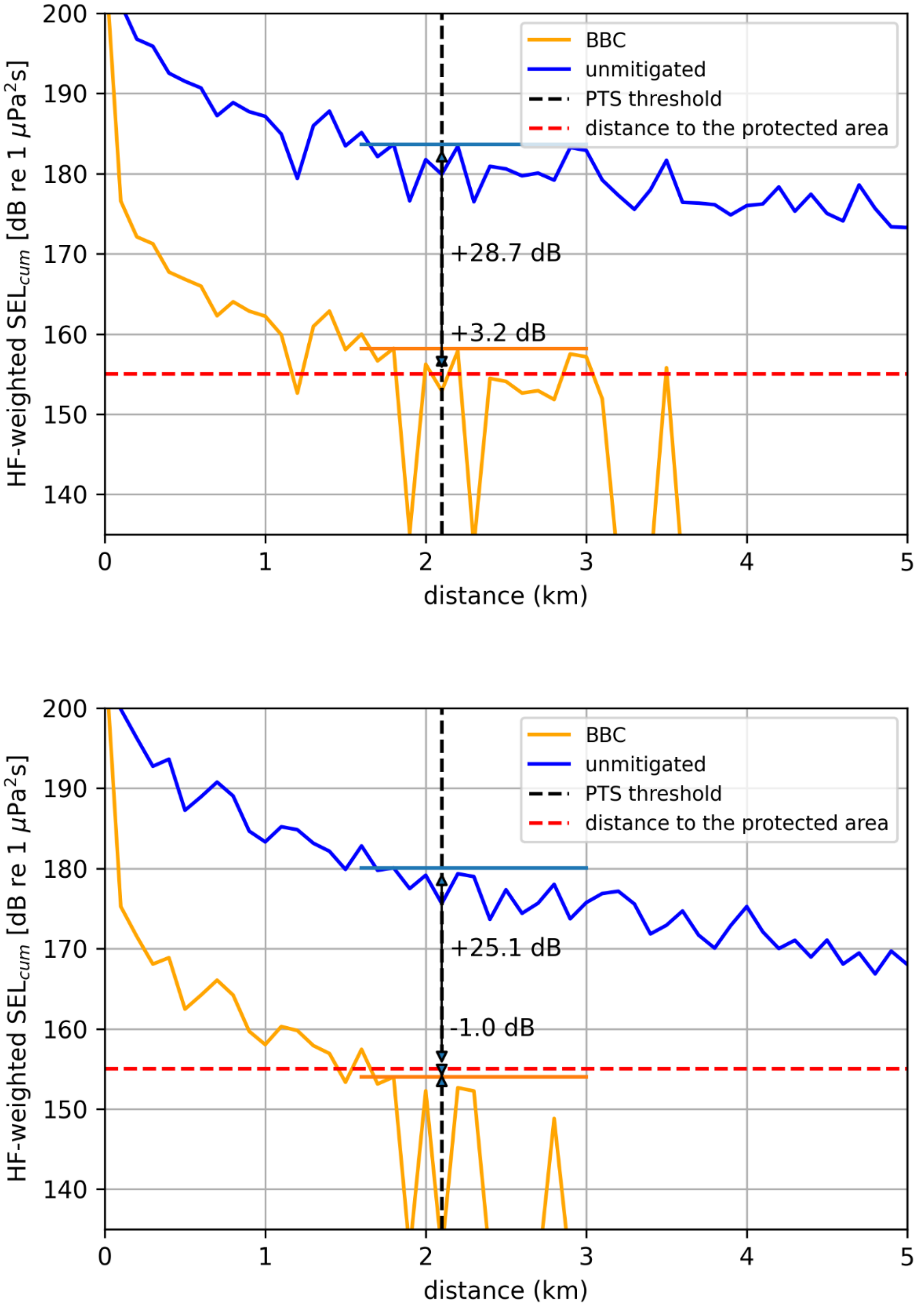



*Figure 4.76. Noise propagation during simultaneous piling in two locations 20 km apart from each other in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

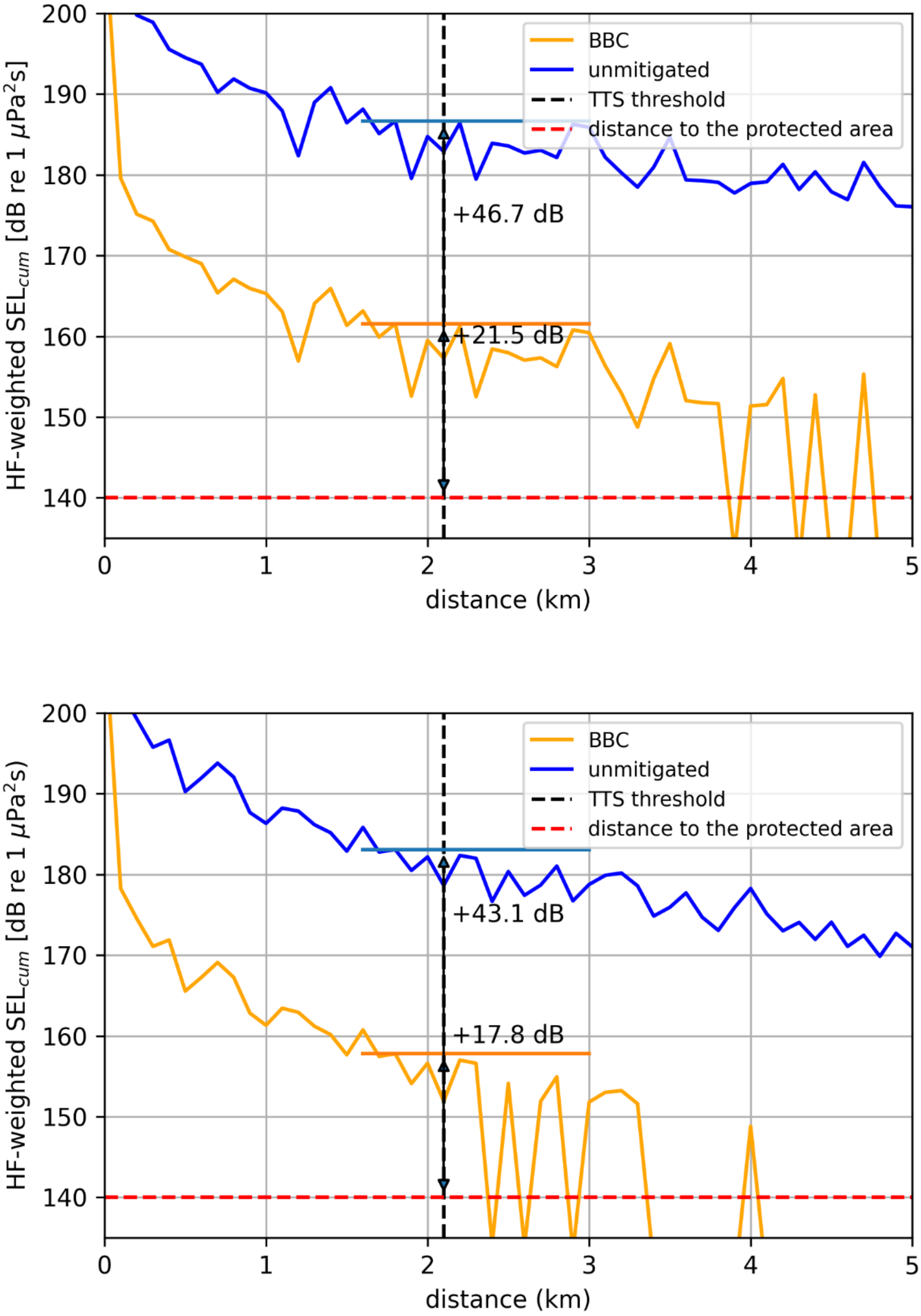



*Figure 4.77. Noise propagation during simultaneous piling in two close locations and another one 20 km away in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

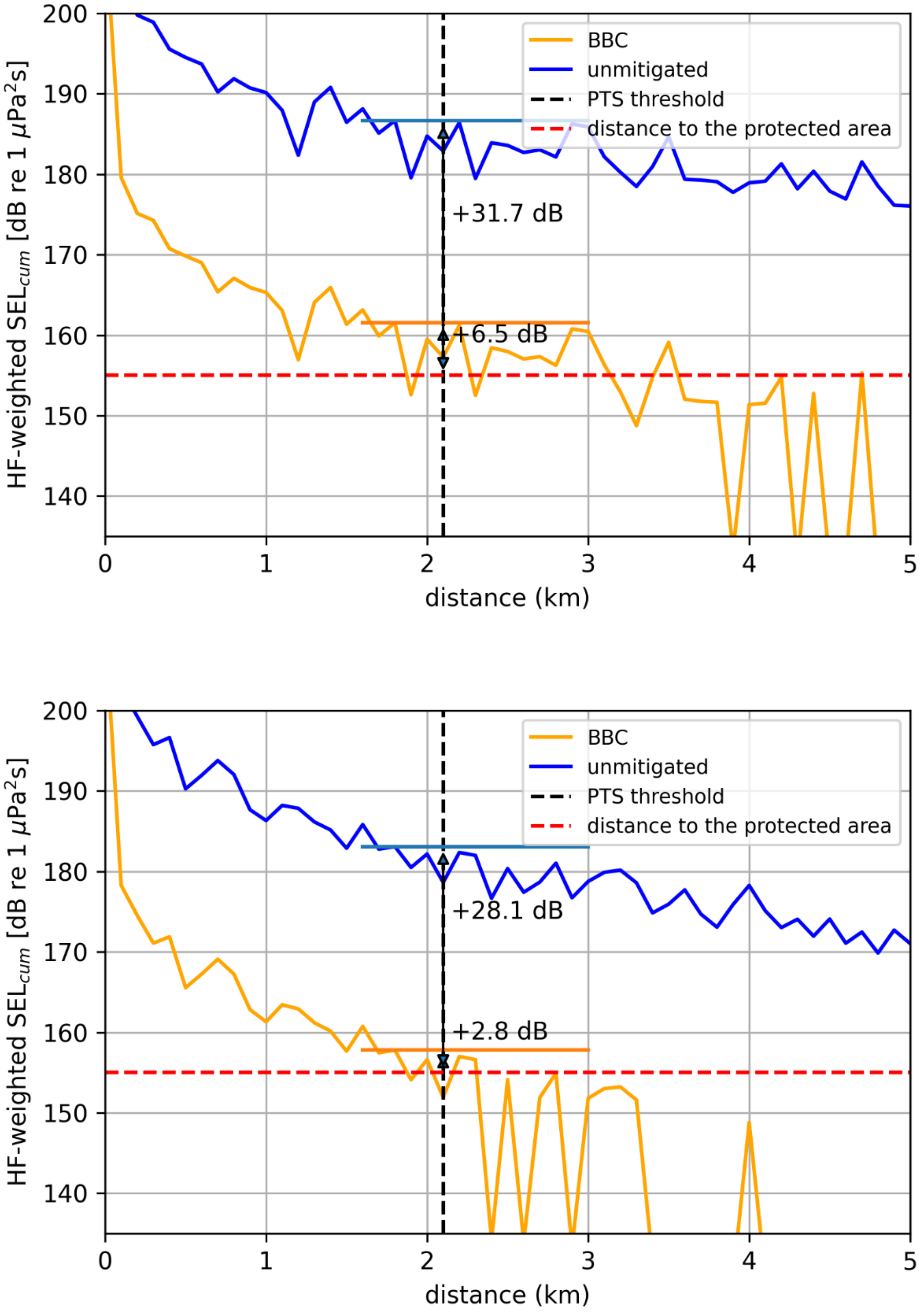



*Figure 4.78.* *Noise propagation during simultaneous piling in two close locations and another one 20 km away in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

#### 4.3.2.2 The distances to threshold values for the scenario with mitigation measures (HSD + DBBC) applied

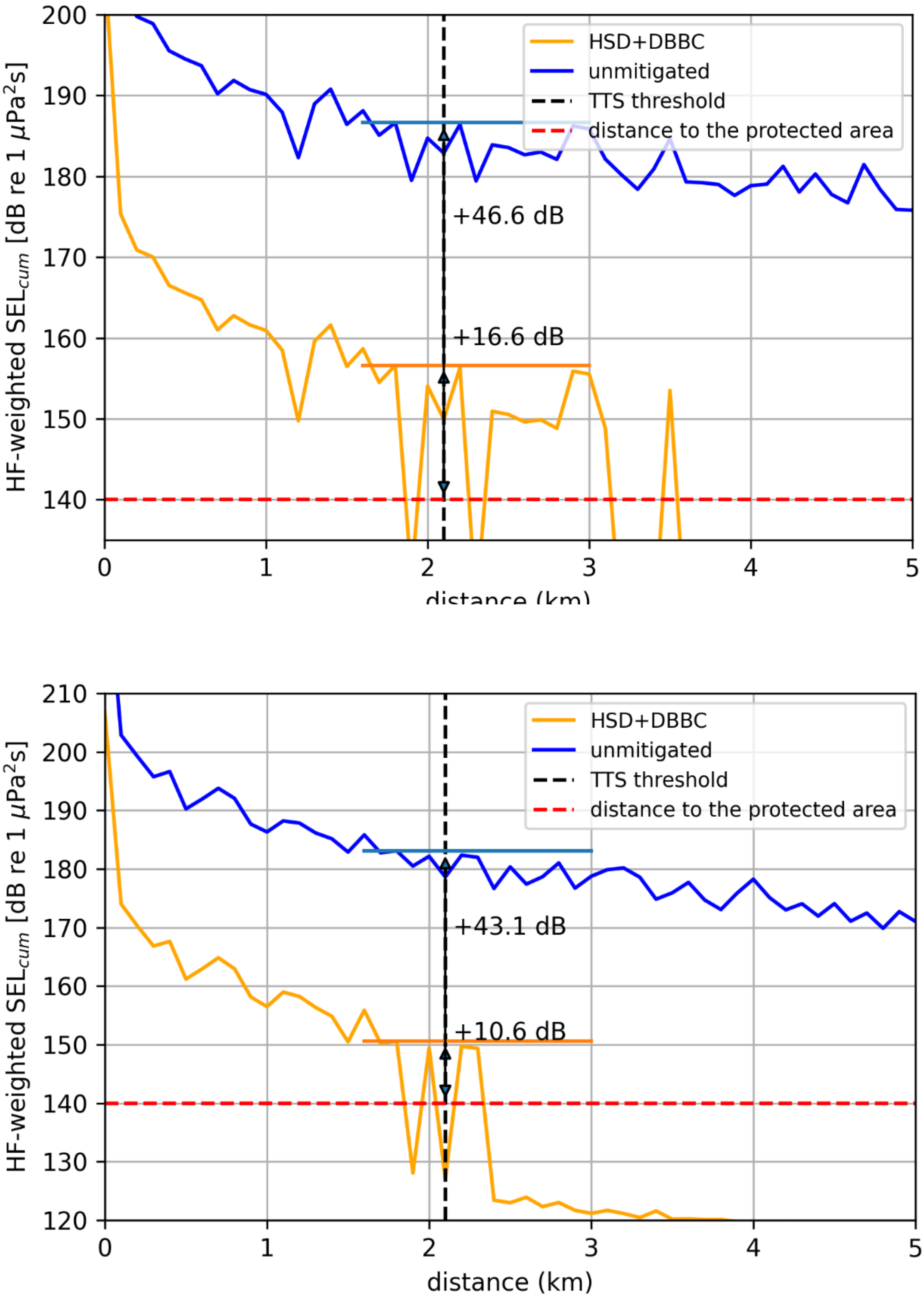



*Figure 4.79. Noise propagation during simultaneous piling in two close locations within the Baltica-1 OWF area, in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

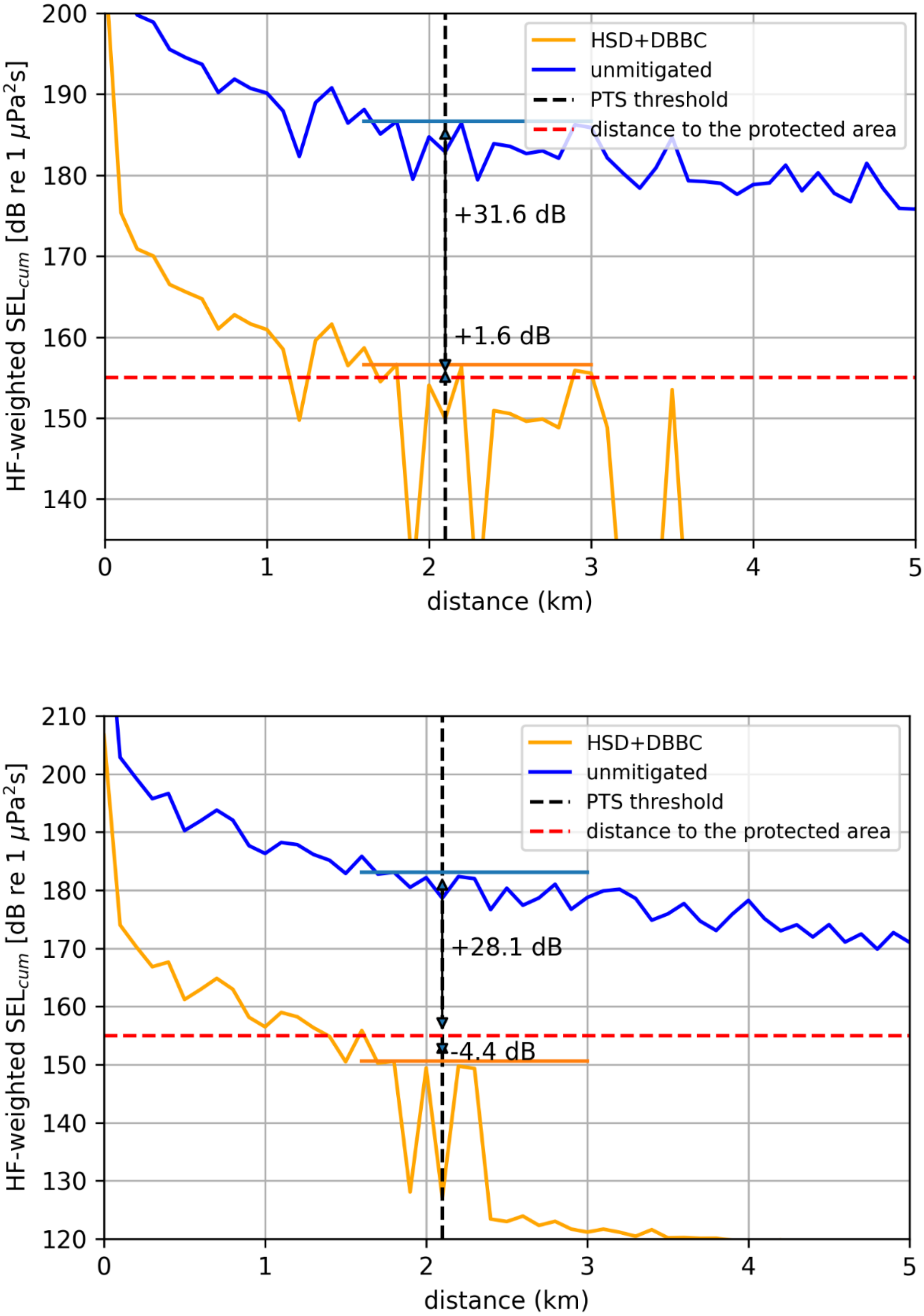
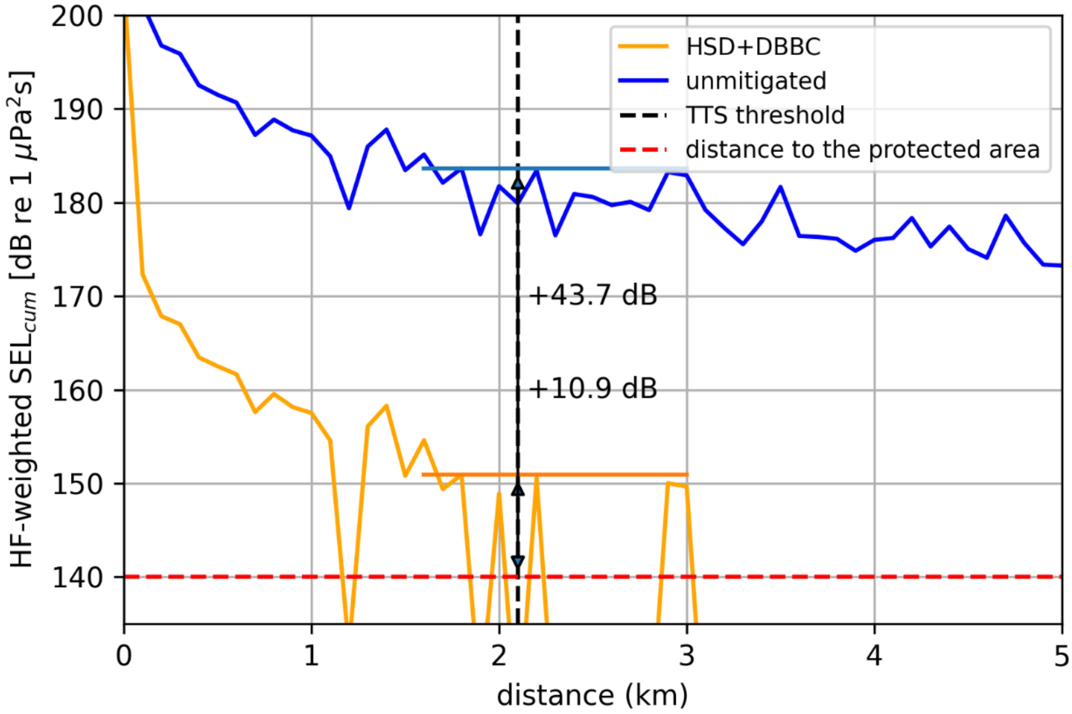



*Figure 4.80. Noise propagation during simultaneous piling in two close locations within the Baltica-1 OWF area, in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*



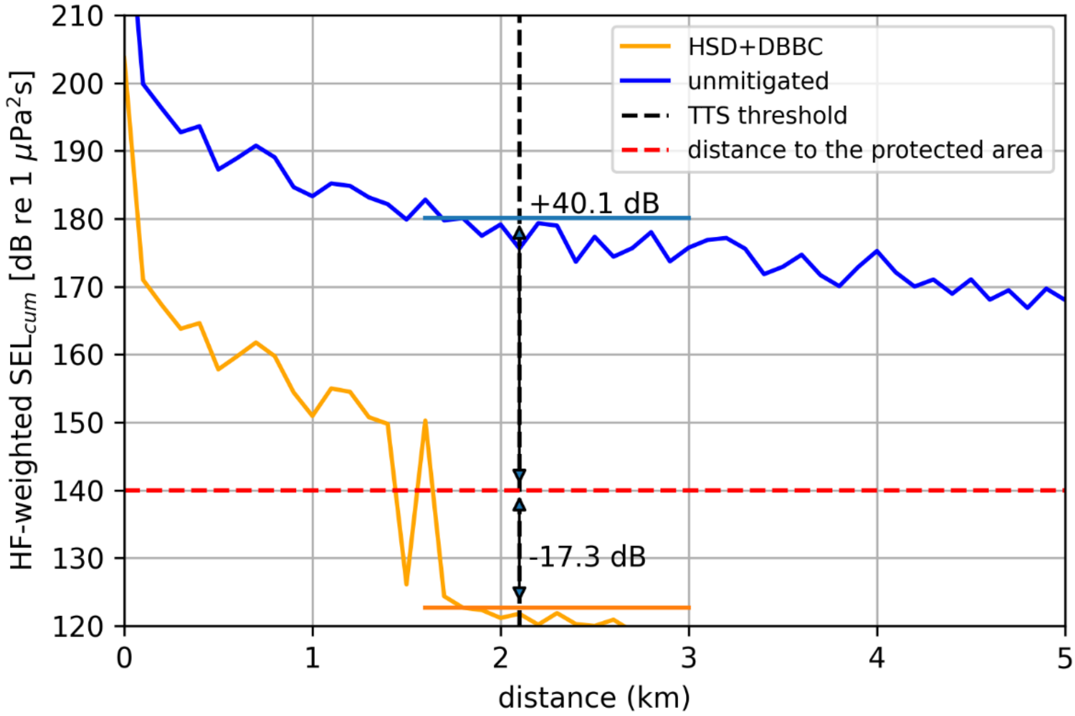
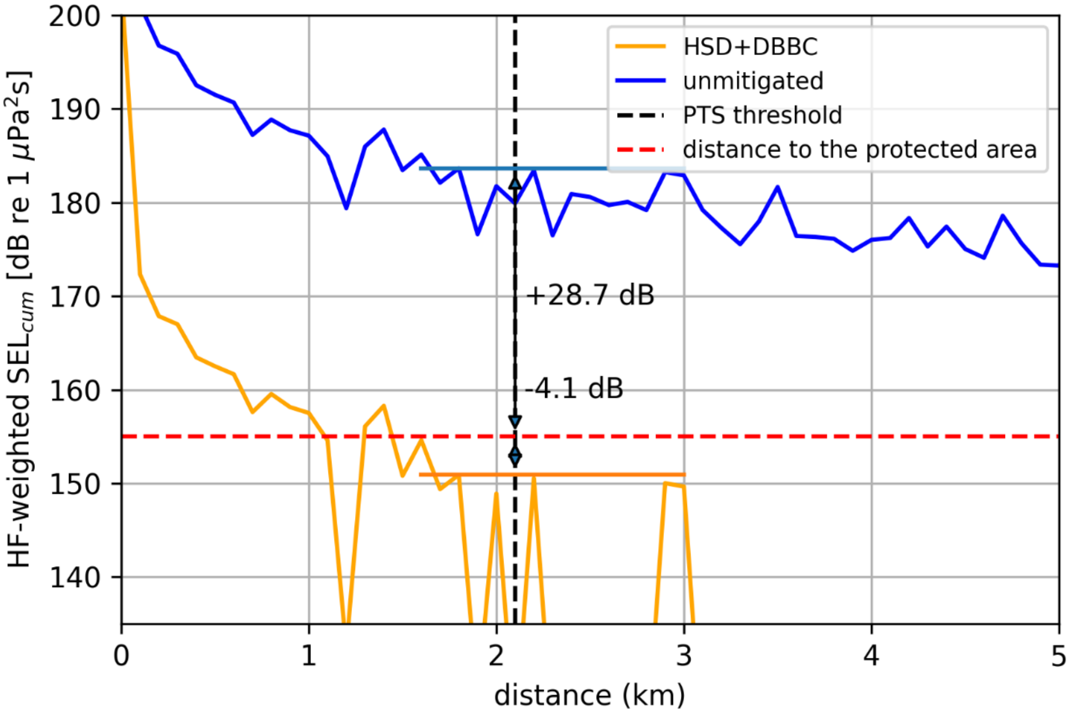




*Figure 4.81. Noise propagation during simultaneous piling in two locations 20 km apart in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*



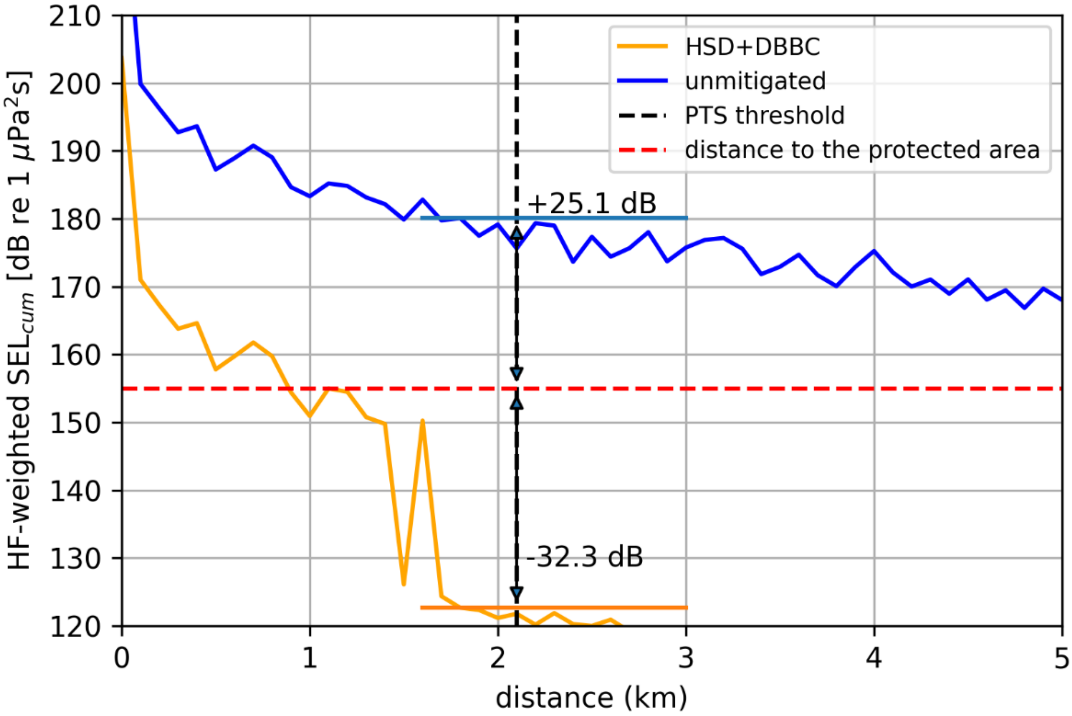




*Figure 4.82. Noise propagation during simultaneous piling in two locations 20 km apart in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

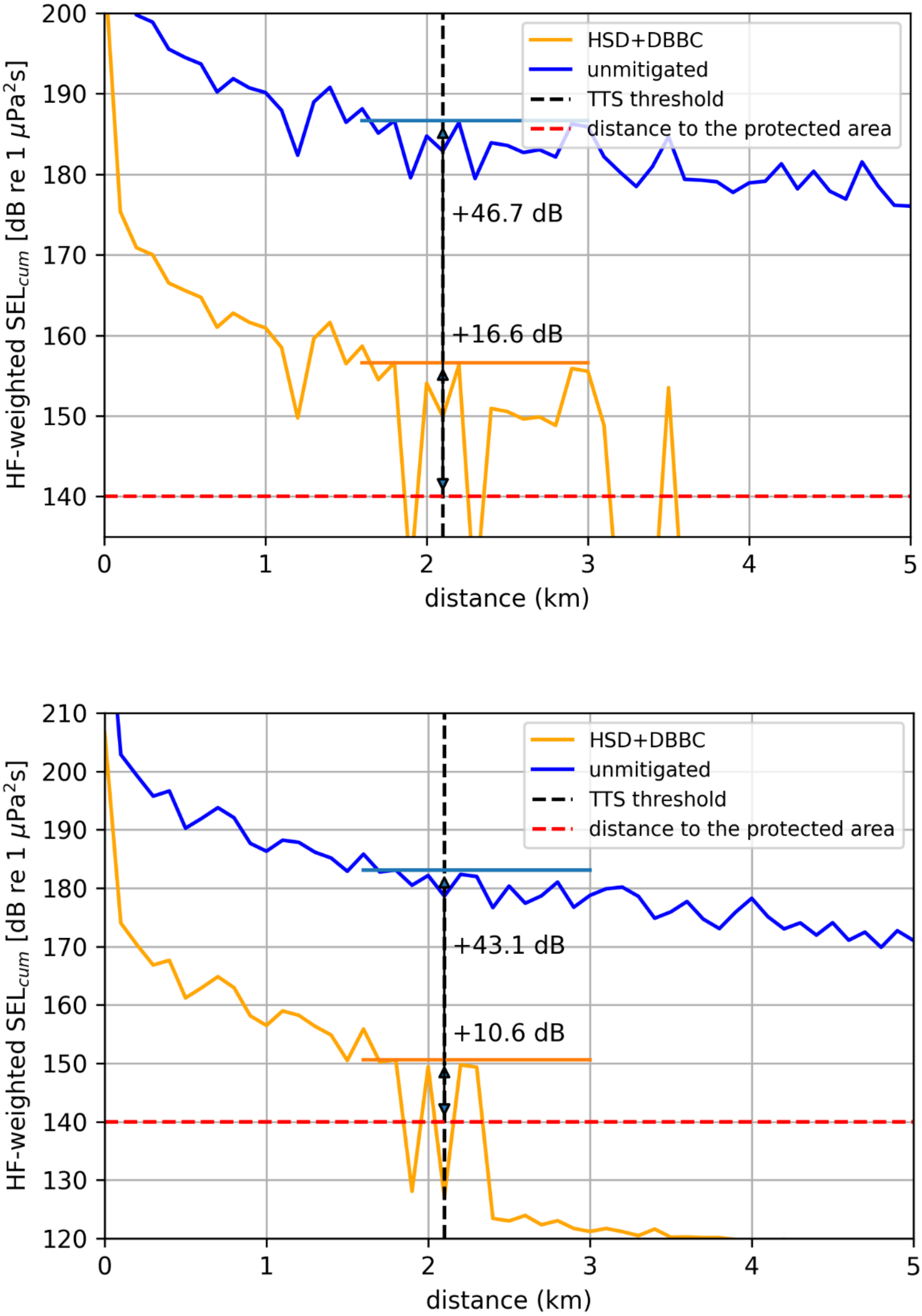



*Figure 4.83. Noise propagation during simultaneous piling in two close locations and another one 20 km away, in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

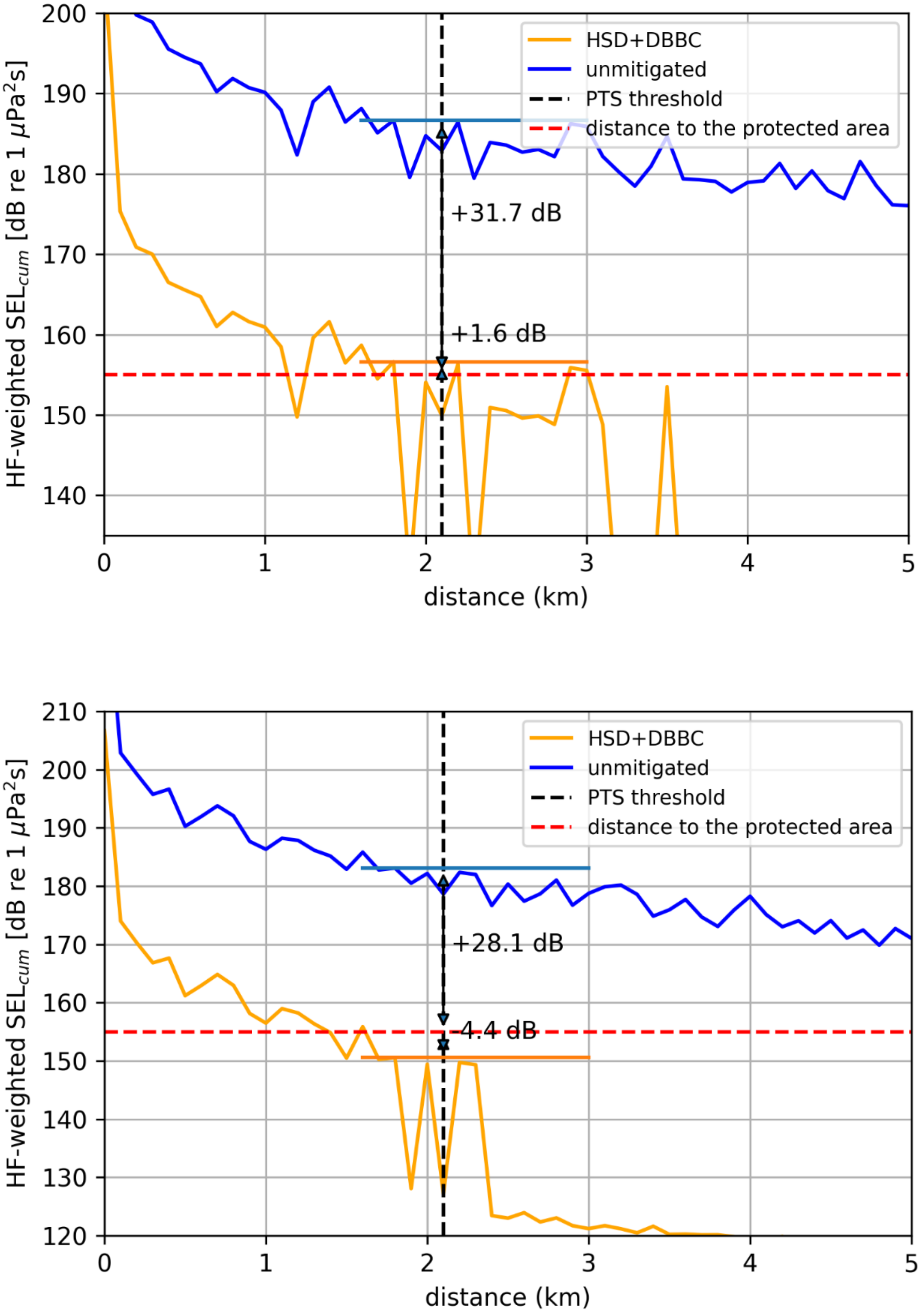



*Figure 4.84.* *Noise propagation during simultaneous piling in two close locations and another one20 km away, in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

#### 4.3.2.3 The distances to threshold values for the scenario with mitigation measures (IQIP + DBBC) applied

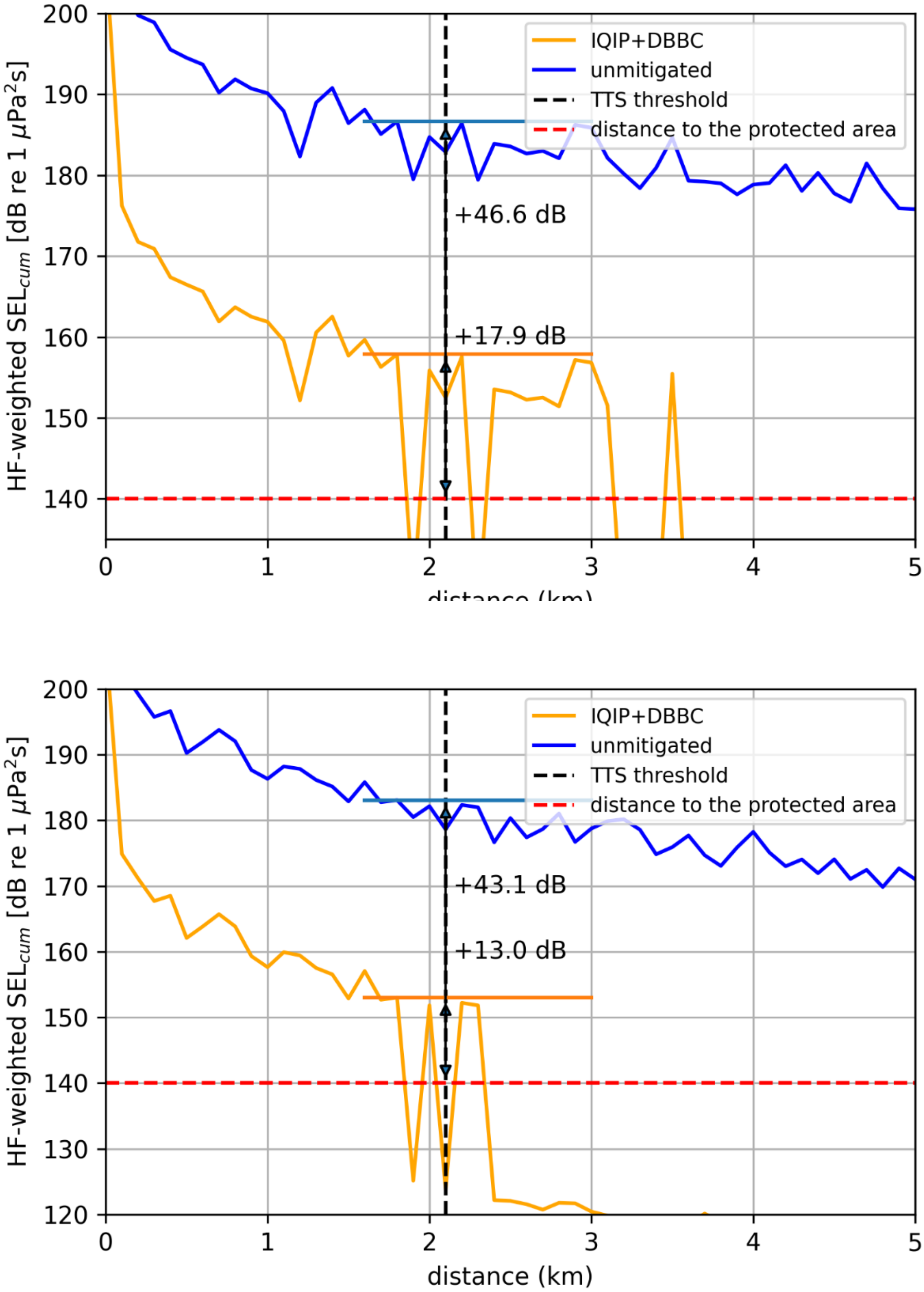
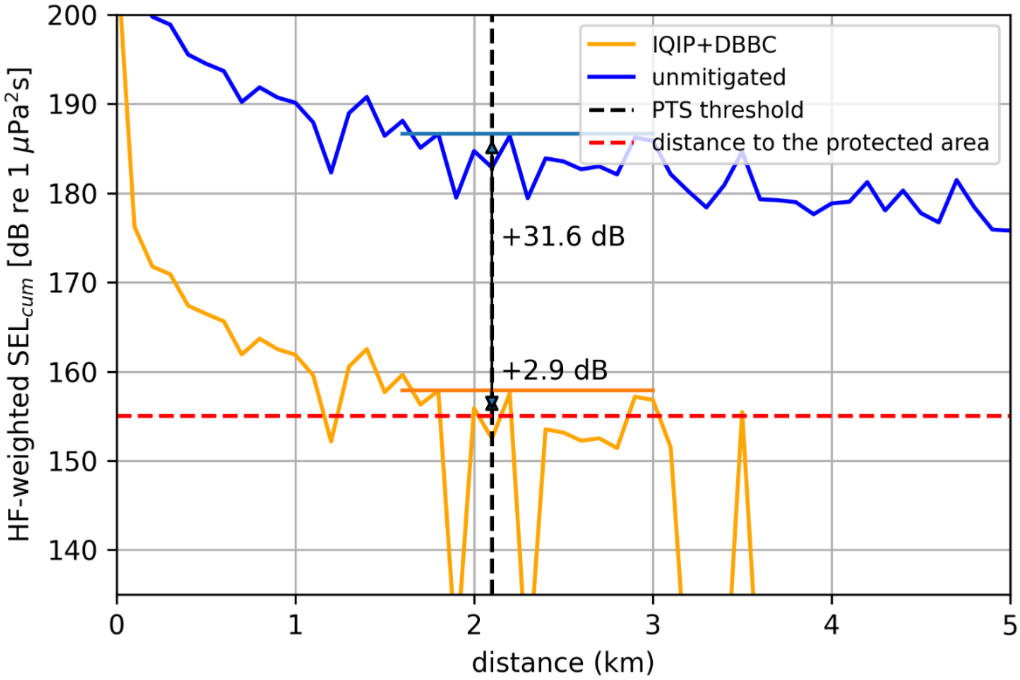



*Figure 4.85. Noise propagation during simultaneous piling in two close locations within the Baltica-1 OWF area, in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*



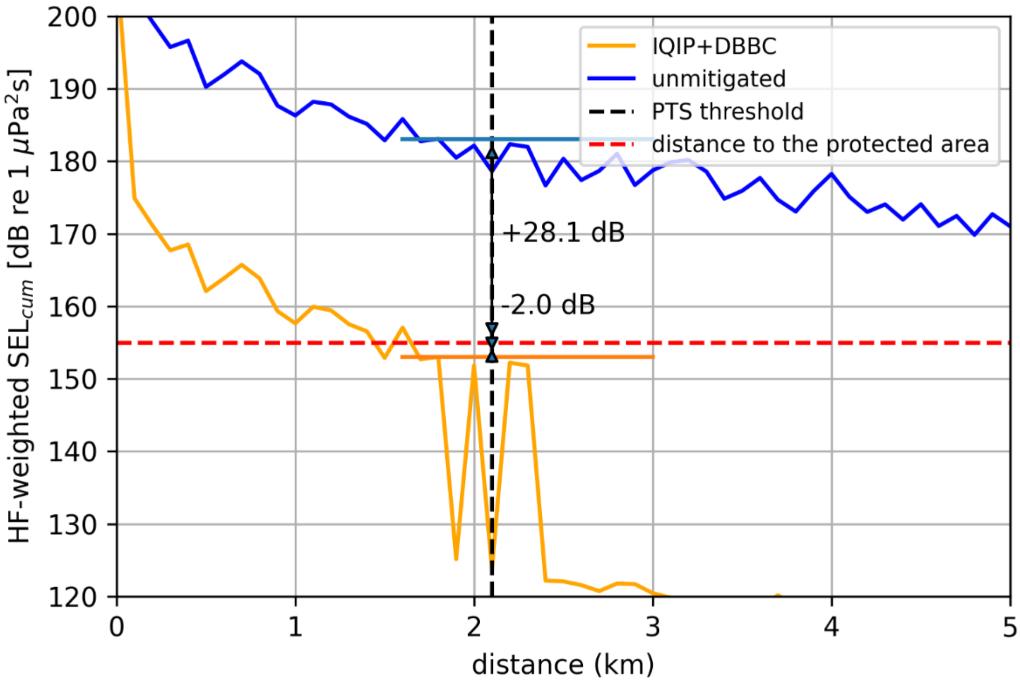
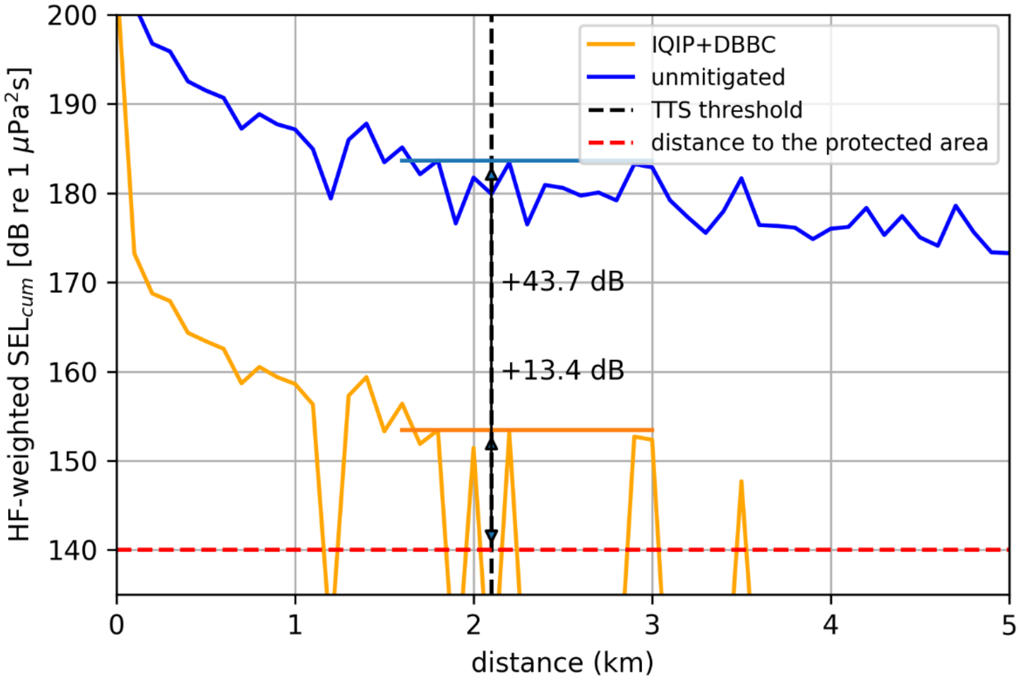




*Figure 4.86.* *Noise propagation during simultaneous piling in two close locations within the Baltica-1 OWF area, in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*



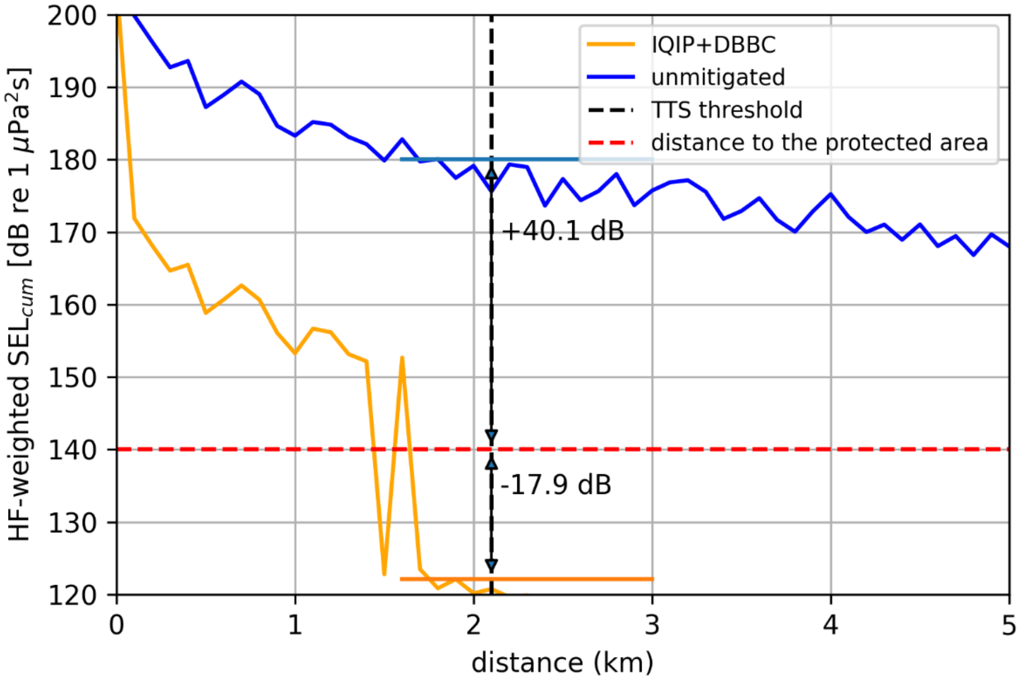




*Figure 4.87. Noise propagation during simultaneous piling in two locations 20 km apart, in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

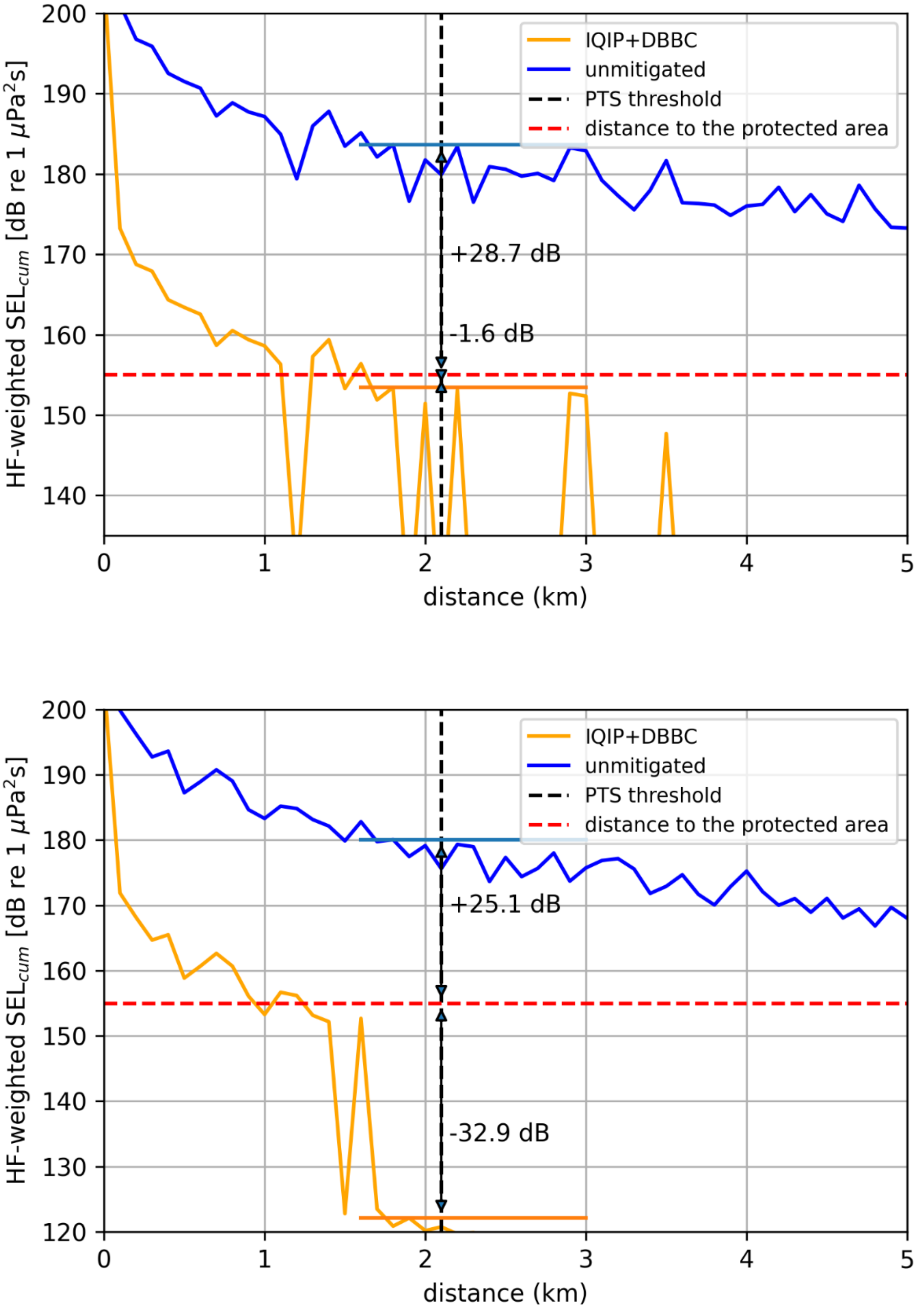
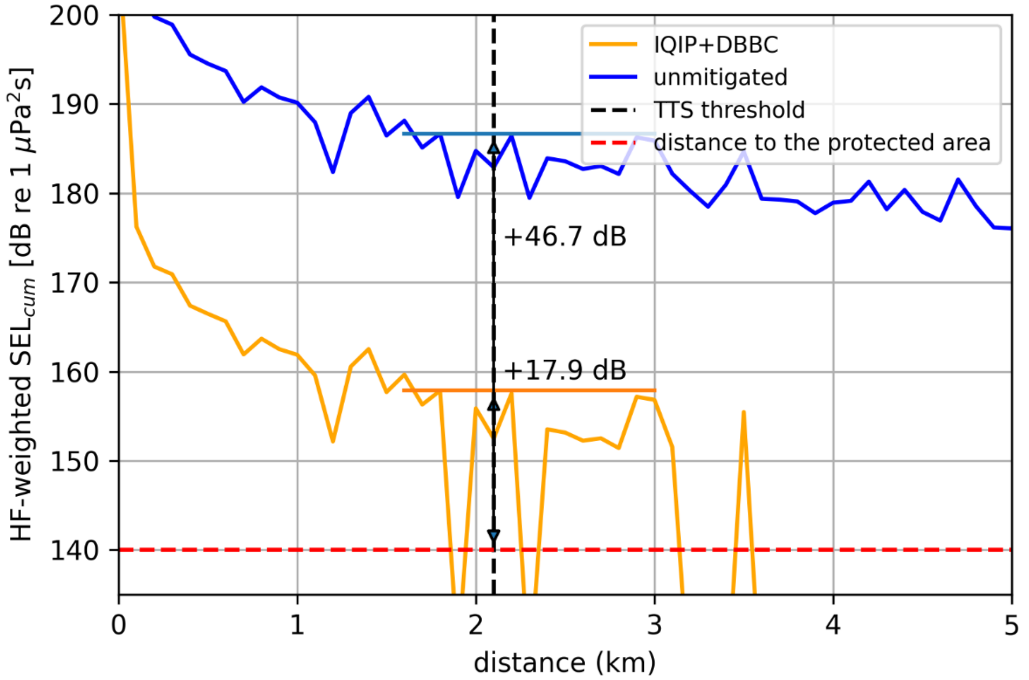



*Figure 4.88.* *Noise propagation during simultaneous piling in two locations 20 km apart, in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*



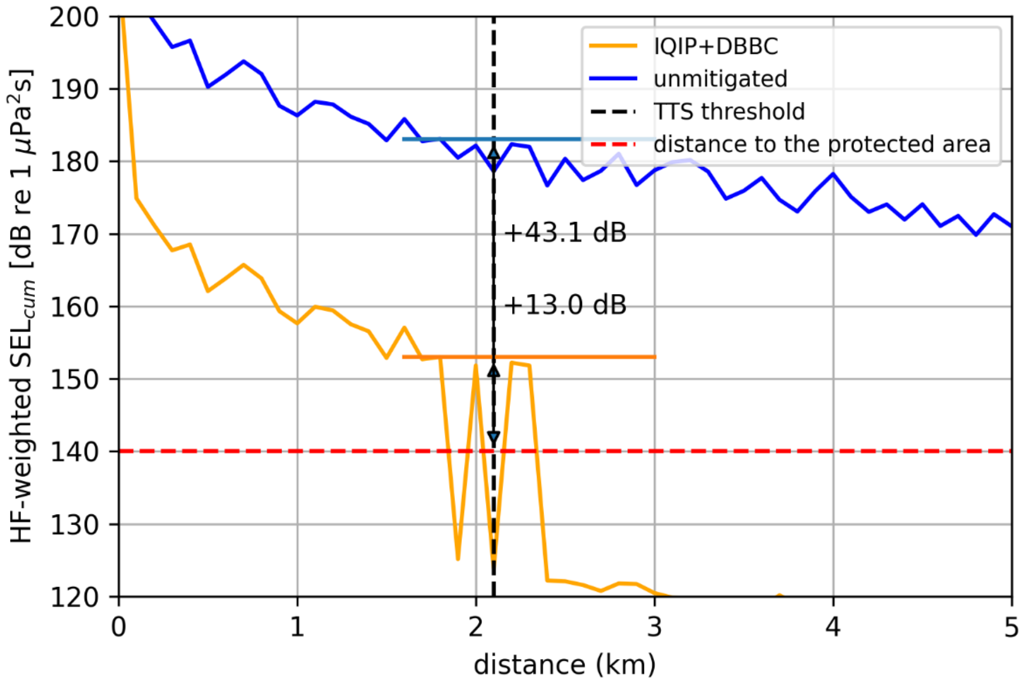




*Figure 4.89. Noise propagation during simultaneous piling in two close locations and another one 20 km away in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

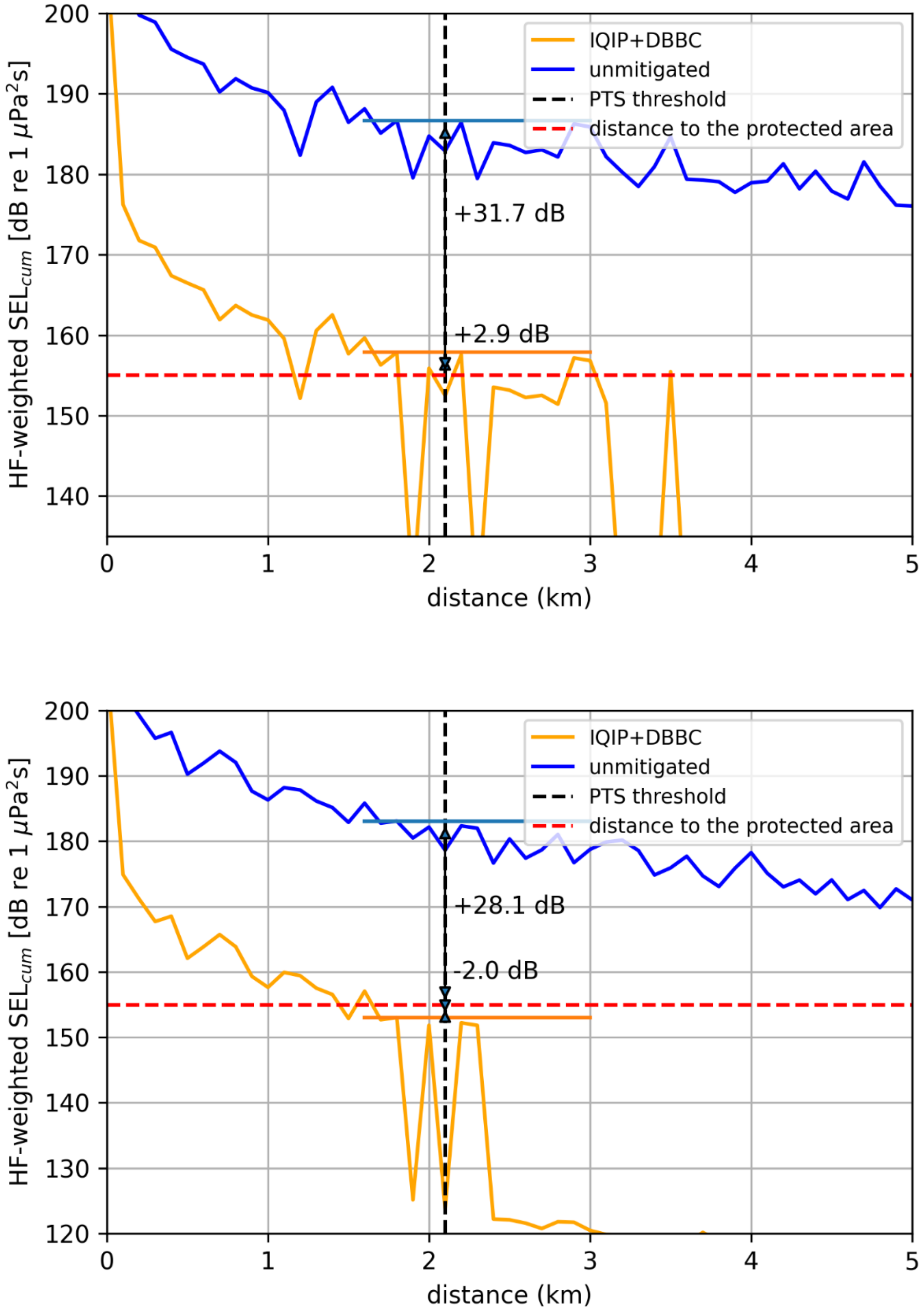



*Figure 4.90.* *Noise propagation during simultaneous piling in two close locations and another one 20 km away in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna, in the winter (top) and summer (bottom)*

## 4.4 Impact on the Natura 2000 site

Additional analyses of impact in the Swedish Natura 2000 site were conducted for the behavioural response. The analyses showed that the result of piling in one location in the area of behavioural response will vary depending on the mitigation measures applied and the season. The largest range can be expected in the winter season, during which none of the analysed mitigation measures can reduce the percentage of protected site affected by the impact below 1%. In the summer season, the impact will cover less than 1% of the area if the mitigation measures in the form of BBC, HSD + DBBC, or IQIP + DBBC system are applied.

The impact ranges and the corresponding percentages of coverage of the Swedish Natura 2000 site are presented below [Table 4.11].

*Table 4.11. The ranges and areas of impact causing the behavioural response in the harbour porpoise calculated for the Baltica-1 OWF and the percentage of coverage of the Natura 2000 site Hoburgs bank och Midsjöbankarna*

| Season | Mitigation type | Effect | Threshold value | Mean distance [km] | Maximum distance [km] | Impact area [$km^2$] | The percentage of coverage of the Natura 2000 site [%] | The value of VHF-weighted $SPL_{125ms}$ at the boundary of the Natura 2000 site |
|---|---|---|---|---|---|---|---|---|
| Winter | BBC | Behavioural response | 103 SPL VHF-weighted | 20.9 | 28.1 | 1394 | 3.8 | 124.8 |
| | HSD + DBBC | Behavioural response | 103 SPL VHF-weighted | 16.4 | 20.8 | 863 | 2.5 | 120.5 |
| | IQIP + DBBC | Behavioural response | 103 SPL VHF-weighted | 17.3 | 20.8 | 956 | 2.6 | 121.5 |
| Summer | BBC | Behavioural response | 103 SPL VHF-weighted | 8.6 | 10.7 | 233 | 0.6 | 120.7 |
| | HSD + DBBC | Behavioural response | 103 SPL VHF-weighted | 7.2 | 8.6 | 164 | 0.4 | 116.4 |
| | IQIP + DBBC | Behavioural response | 103 SPL VHF-weighted | 7.5 | 9.0 | 178 | 0.5 | 117.4 |

# 5 THE MODELLING RESULTS FOR THE CENTRAL LOCATION

## 5.1 THE MODELLING OF NOISE PROPAGATION FOR PILING IN A SINGLE LOCATION

This chapter presents the results of modelling conducted for the central location in the Baltica-1 OWF area in the summer seasons. The impact ranges for different threshold values are presented in the form of tables, and sound propagation maps are included.

### 5.1.1 The level of exposure to sound generated by a single blow

The SEL value for a single blow did not exceed 135 dB at the boundary of the modelled area, at a distance of 150 km from the sound source. The sound propagated mainly in the directions of north, south-west, and east from the piling site, where the highest sound levels were recorded [Figure 5.1].

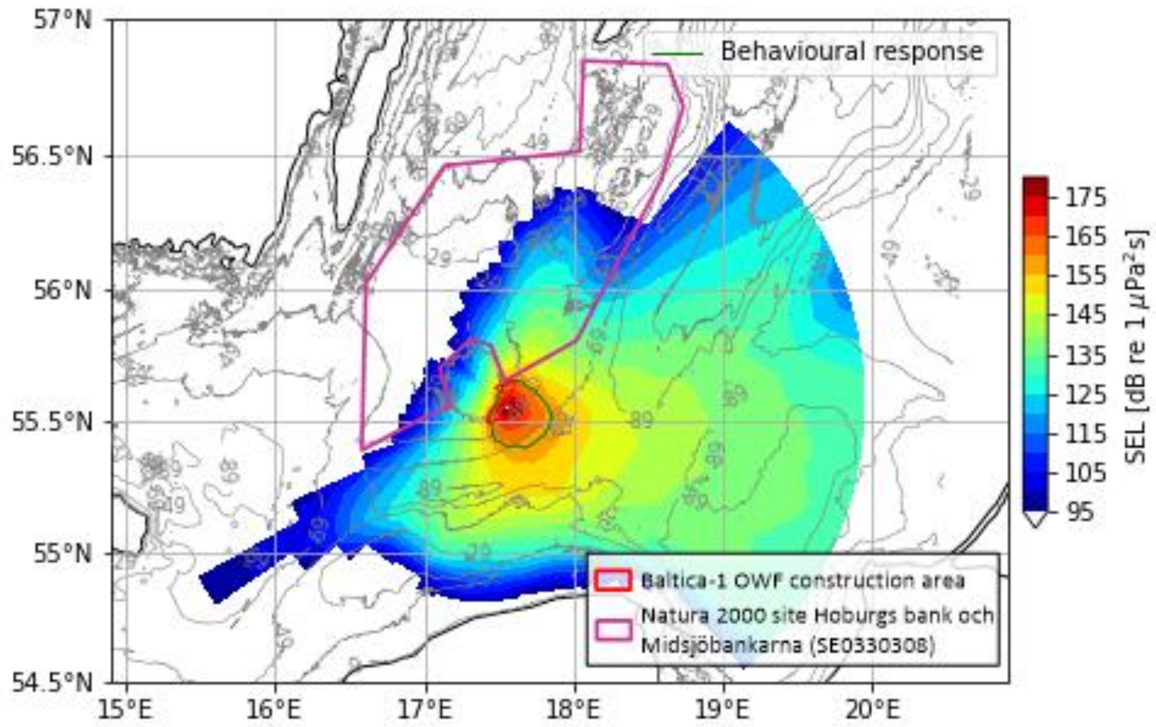



*Figure 5.1. The map of unweighted SEL above the acoustic background for a single blow in the area of the Baltica-1 OWF, in the summer season. Grey lines: isobaths*

#### 5.1.1.1 Harbour porpoise

As far as the harbour porpoise is concerned, the largest impact ranges were recorded for the behavioural response.

The estimates of cumulative SEL for the TTS and PTS were higher than in the case of a single blow, and TTS ranges exceeded the PTS ranges. The maximum range of cumulative impacts was 9.8 km and the values for a single blow did not exceed 3.2 km in the case of TSS.

For the $SPL_{peak}$, the maximum impact ranges for the TTS and PTS from a single blow were higher for the TTS with a maximum value of 3.0 km.

The application of mitigation in the form of HSD + DBBC helped reduce the range of all the impacts analysed. The values of cumulative TTS and PTS were reduced to 0.2 km and next to 0.1 km.

All ranges calculated for individual threshold values are shown in tabular form [Table 5.1], while noise propagation maps are presented in the following figures [Figure 5.2–Figure 5.5].

*Table 5.1. The impact ranges and areas for the harbour porpoise calculated for the Baltica-1 OWF*

| Season | Mitigation type | Effect | VHF-weighted SPL [dB re 1 µPa] / HF-weighted SEL [dB re 1 µPa²s] | | | unweighted $SPL_{peak}$ [dB re 1 µPa] | |
|---|---|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] | Mean distance [km] | Maximum distance [km] |
| Summer | - | Behavioural response | 26.0 | 74.3 | 2867 | - | - |
| | | TTS (single blow) | 2.3 | 3.2 | 16.5 | 2.7 | 3.0 |
| | | TTS (cumulative effect) | 6.3 | 9.8 | 133 | - | - |
| | | PTS (single blow) | 0.3 | 0.5 | 0.3 | 1.1 | 1.2 |
| | | PTS (cumulative effect) | 3.2 | 4.2 | 33.4 | - | - |
| | HSD + DBBC | Behavioural response | 6.5 | 8.9 | 138 | - | - |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.2 | 0.2 |
| | | TTS (cumulative effect) | 0.2 | 0.2 | 0.1 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |

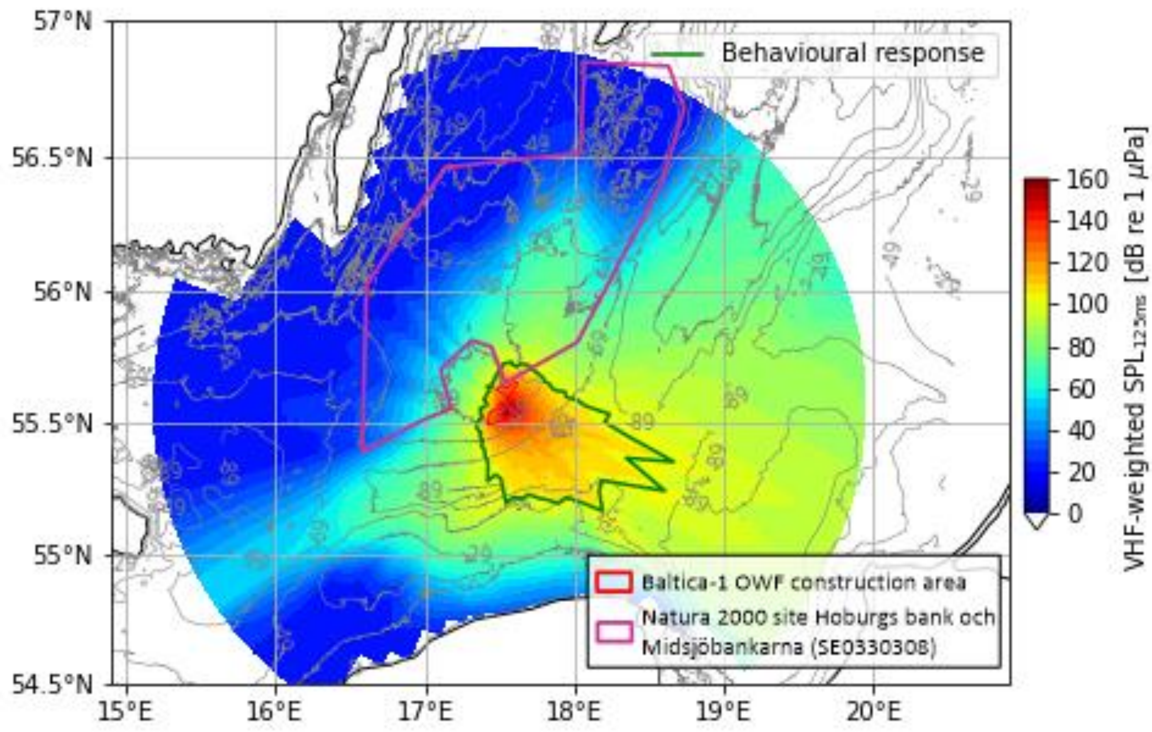



*Figure 5.2. The map of VHF-weighted $SPL_{125ms}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise*

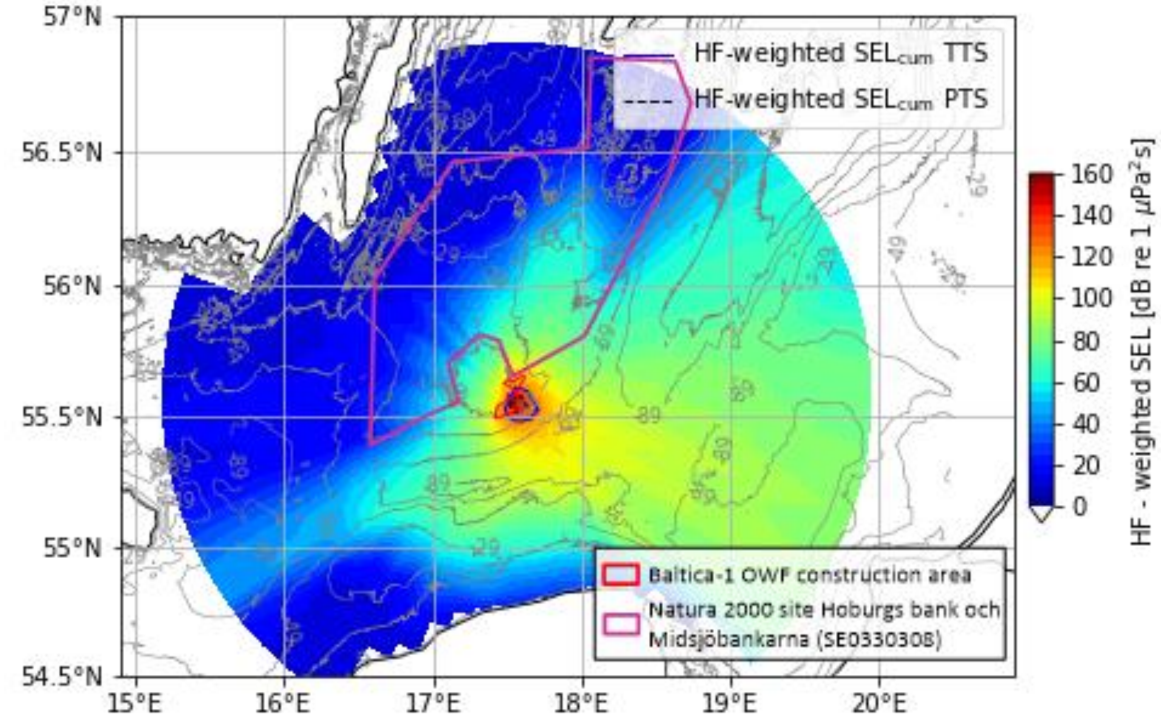



*Figure 5.3. The map of HF-weighted $SEL_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise*

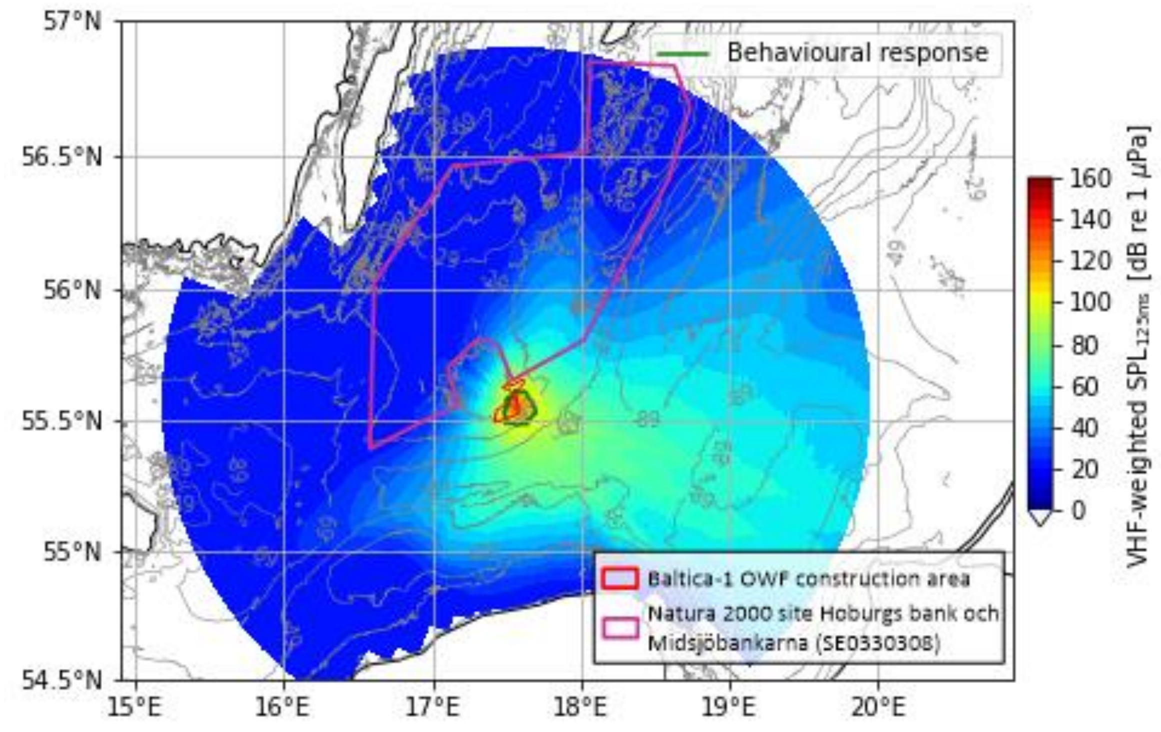



*Figure 5.4. The map of VHF-weighted $SPL_{125ms}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied*

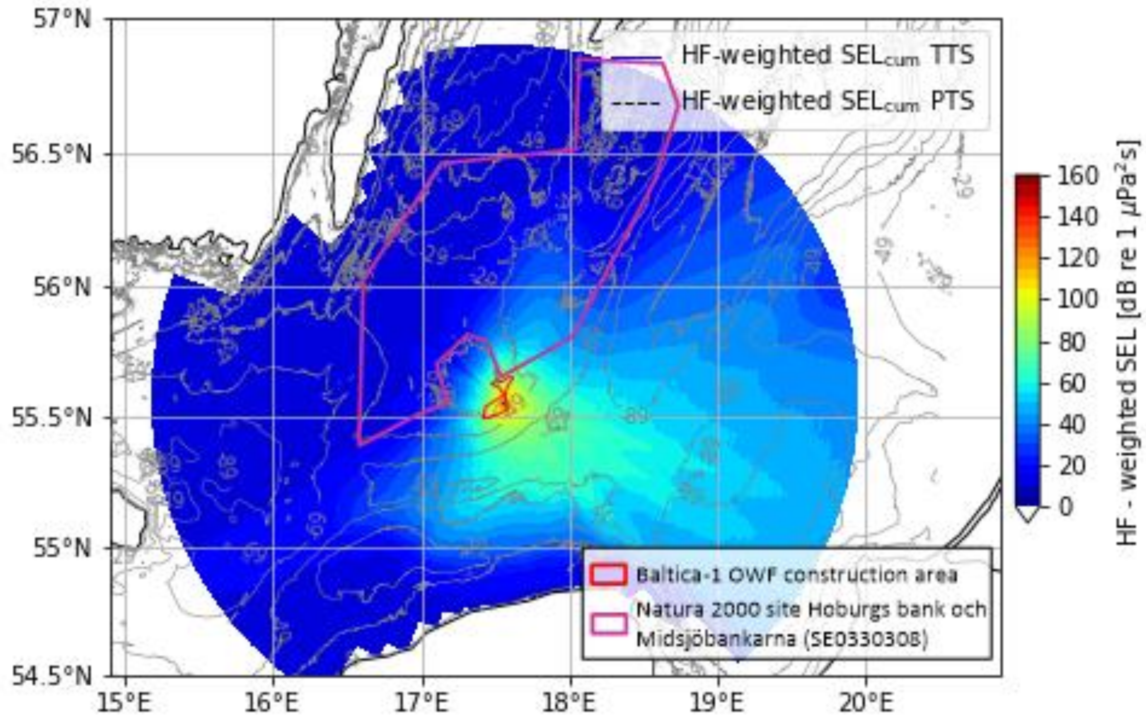



*Figure 5.5. The map of HF-weighted SEL $_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied*

#### 5.1.1.2 Grey and harbour seal

All impact ranges and areas (except for those of the cumulative TTS) calculated for the grey and harbour seal were lower than those obtained for the harbour porpoise.

The largest impact range and the corresponding area were estimated for the cumulative TTS, and it was 921 km$^2$.

The impact ranges calculated for the SEL from a single blow reached a maximum range of only 0.3 km for the TTS.

The use of mitigation in the form of HSD + DBBC helped to significantly reduce the range of all the impacts analysed. All impacts based on weighted SEL were reduced to 0.1 km.

All ranges calculated for individual threshold values are shown in tabular form [Table 5.2], while noise propagation maps are presented in the following figures [Figure 5.6–Figure 5.9].

*Table 5.2. The impact ranges and areas calculated for the grey seal and harbour seal in the Baltica-1 area*

| Season | Mitigation type | Effect | unweighted SEL / PW-weighted SEL/ [dB re 1 µPa²s] | | | unweighted SPL$_{peak}$ [dB re 1 µPa] | |
|---|---|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] | Mean distance [km] | Maximum distance [km] |
| Summer | - | Behavioural response | 12.4 | 19.1 | 540 | 0.2 | 0.2 |
| | | TTS (single blow) | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 |

| Season | Mitigation type | Effect | unweighted SEL / PW-weighted SEL/ [dB re 1 µPa²s] | | | unweighted $SPL_{peak}$ [dB re 1 µPa] | |
|---|---|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] | Mean distance [km] | Maximum distance [km] |
| | | TTS (cumulative effect) | 16.1 | 26.2 | 921 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.3 | 0.4 | 0.4 | - | - |
| | HSD + DBBC | Behavioural response | 2.4 | 2.6 | 18.3 | 0.1 | 0.1 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |

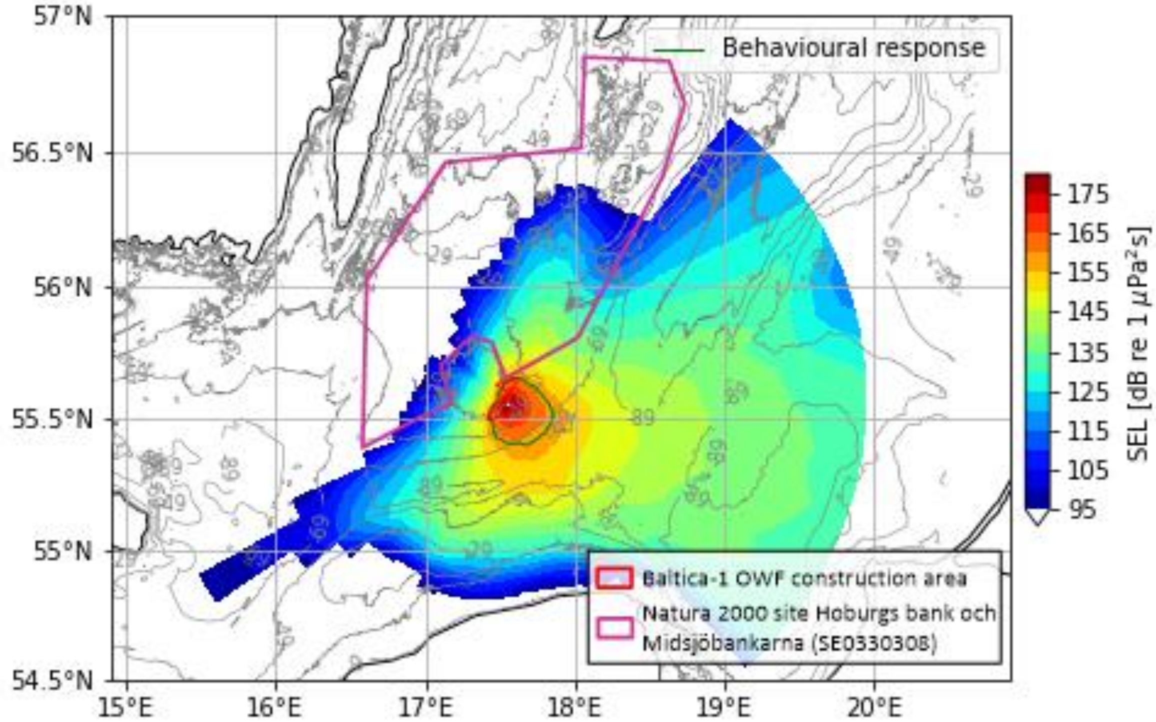



*Figure 5.6. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal*

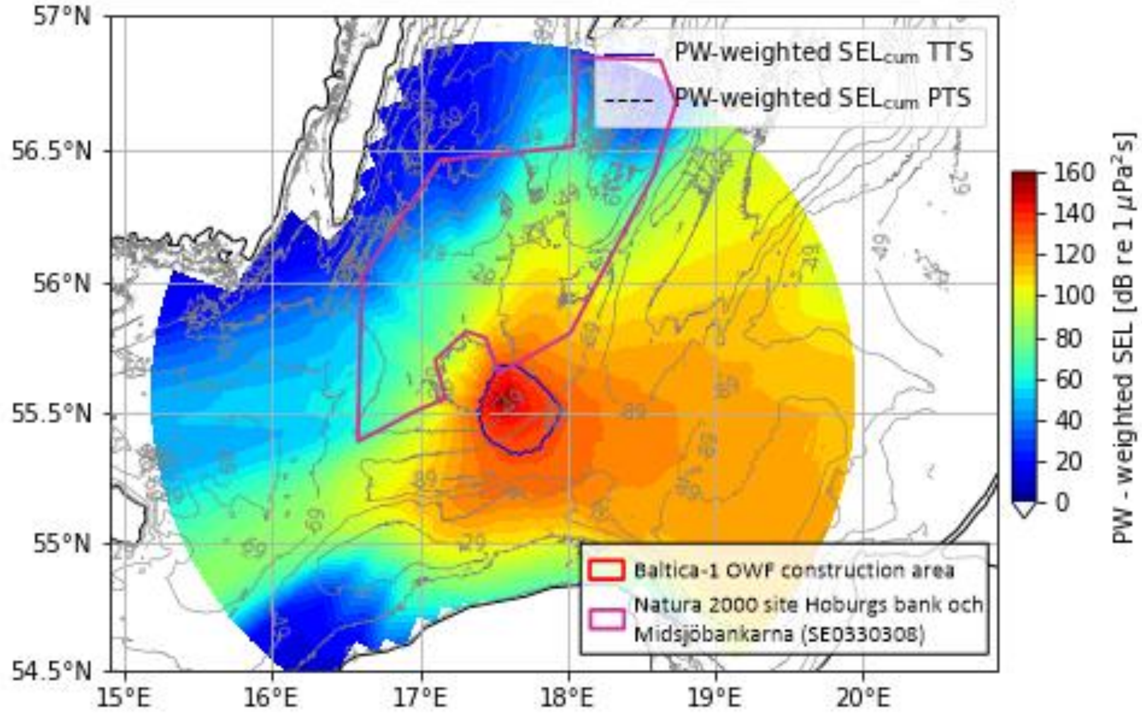



*Figure 5.7. The map of PW-weighted $SEL_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal*

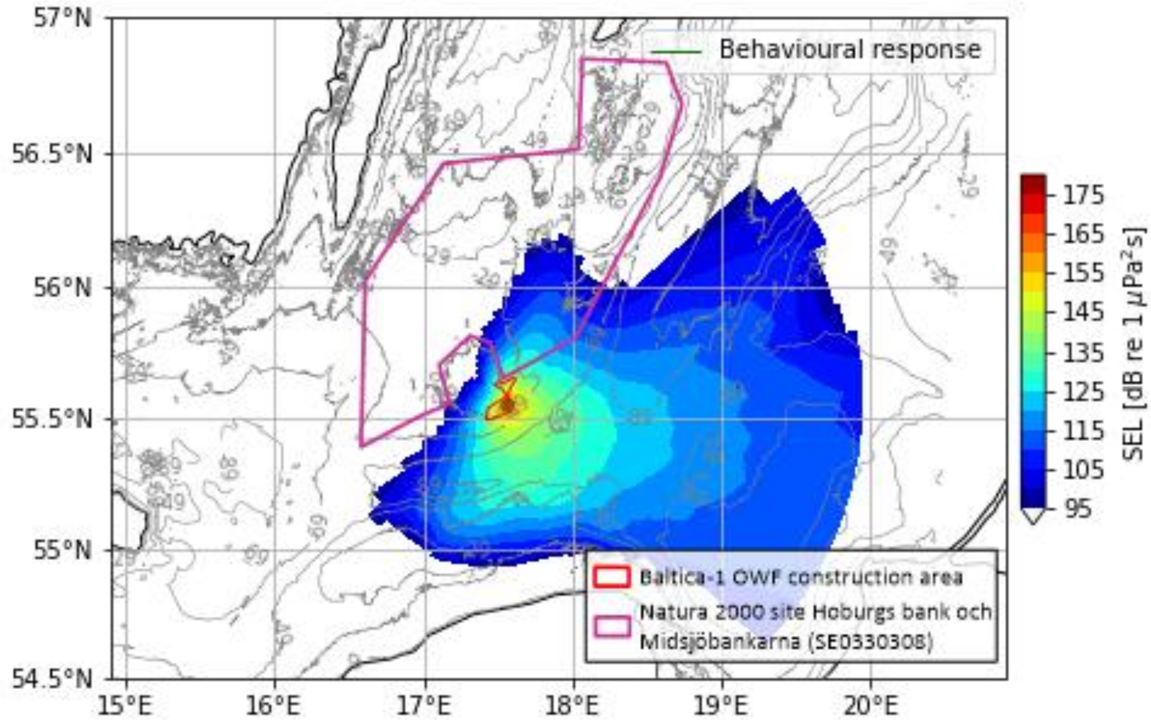



*Figure 5.8. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied*

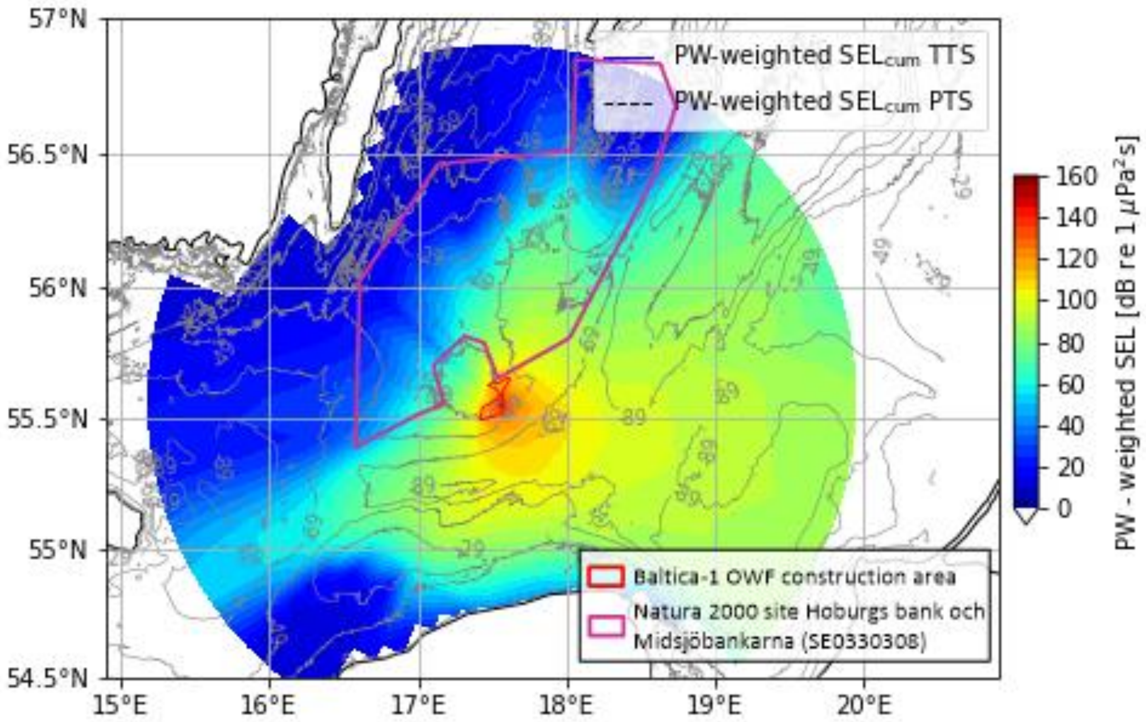



*Figure 5.9. The map of PW-weighted SEL $_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied*

### 5.1.1.3 Fish with swim bladders

The largest ranges of impact on fish with swim bladders were found for the behavioural response, the maximum range of which was 133 km.

The predicted ranges of cumulative TTS and PTS were higher than the values obtained for a single blow, while the TTS ranges were higher than the ones obtained for the PTS.

The application of mitigation in the form of HSD + DBBC helped reduce the range of all the impacts analysed. However, the impact range of the behavioural response and the cumulative TTS remained at relatively elevated levels of 23.5 km and 8.0 km, respectively.

All ranges calculated for individual threshold values are shown in tabular form [Table 5.3], while noise propagation maps are presented in the following figures [Figure 5.10–Figure 5.11].

*Table 5.3. The ranges and areas of impact calculated for fish with swim bladders in the Baltica-1 OWF area*

| Season | Mitigation type | Effect | unweighted SEL [dB re 1 μPa²s] | | |
|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] |
| Summer | - | Behavioural response | 52.1 | 133 | 12398 |
| | | TTS (single blow) | 0.6 | 0.6 | 1.0 |
| | | TTS (cumulative effect) | 26.7 | 47.4 | 2820 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |

| Season | Mitigation type | Effect | unweighted SEL [dB re 1 µPa²s] | | |
|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] |
| | | Reversible hearing loss (cumulative effect) | 7.9 | 10.6 | 208.5 |
| | HSD + DBBC | Behavioural response | 14.5 | 23.5 | 774 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 |
| | | TTS (cumulative effect) | 6.3 | 8.0 | 132 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |
| | | Reversible hearing loss (cumulative effect) | 1.1 | 1.1 | 3.8 |

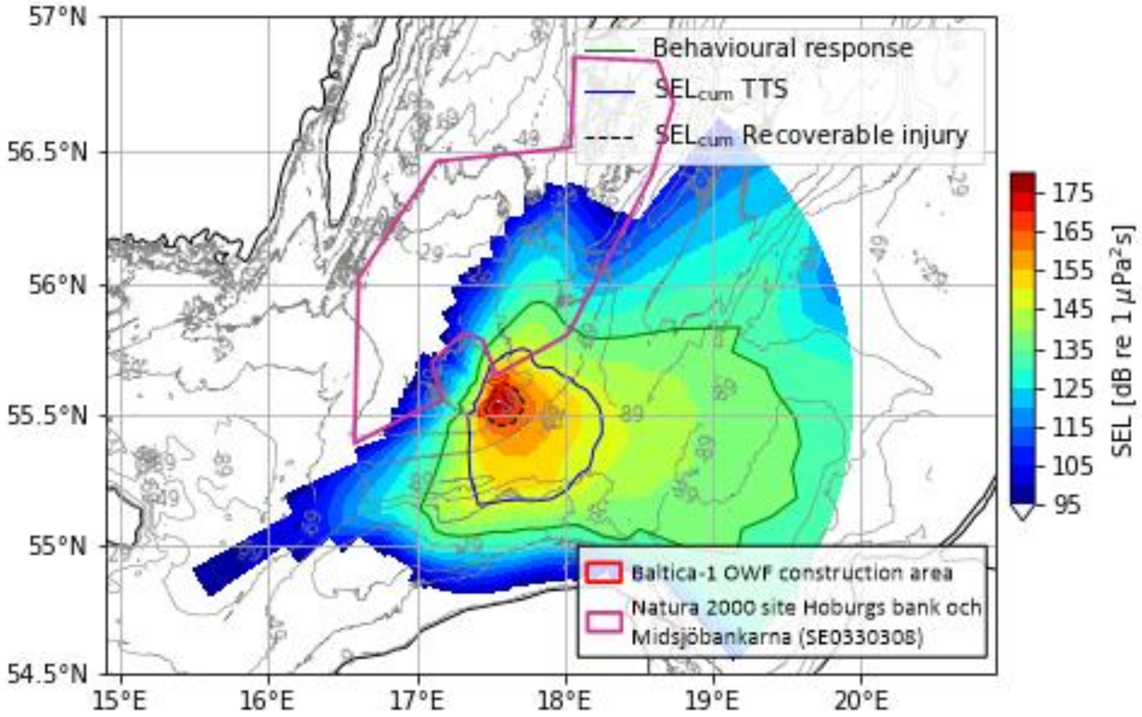



*Figure 5.10. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on fishes with swim bladders*

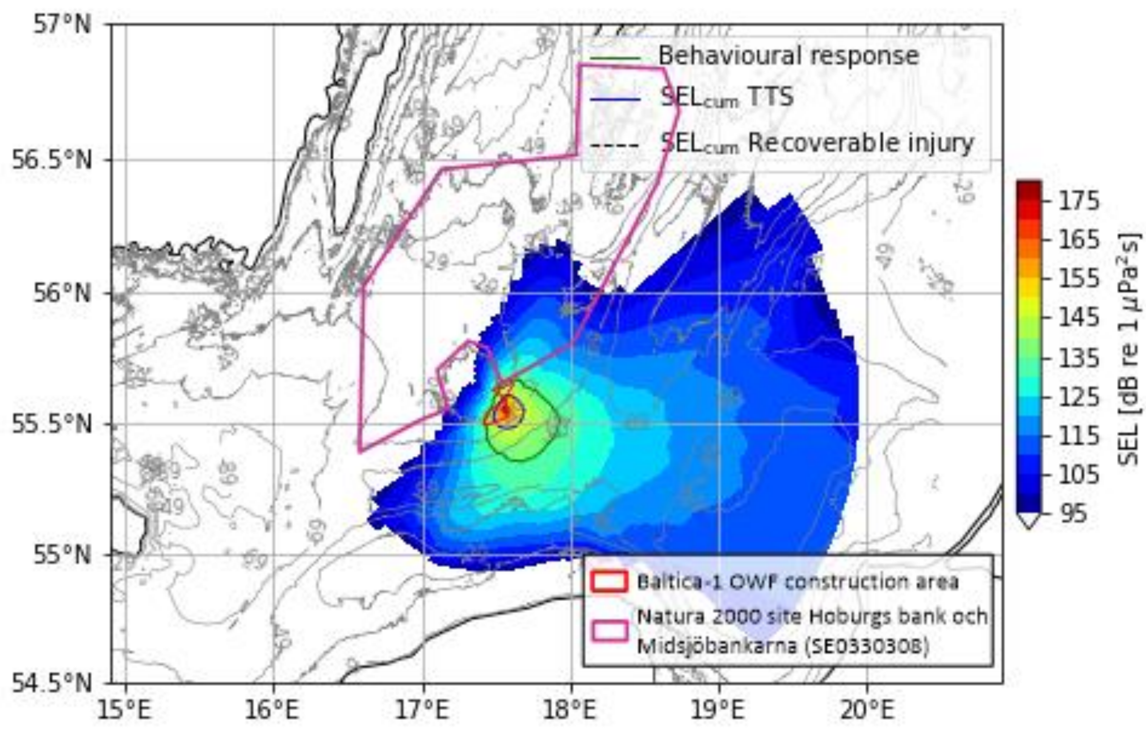



*Figure 5.11. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on fish with swim bladders with the HSD + DBBC system applied*

## 5.2 The modelling of noise propagation as a result of piling in several locations

This chapter presents the results of acoustic modelling in the summer season performed for simultaneous piling in the central location within the Baltica-1 OWF area and outside of it. The use of mitigation measures in the form of HSD + DBBC was taken into account. The ranges of impact for individual acoustic thresholds and sound propagation maps are presented.

### 5.2.1 Harbour porpoise

As can be seen in the table below [Table 5.4], the areas of impact increased with the number of piling sources, reaching the highest values in the case of four locations. Noise propagation maps are presented in the following figures [Figure 5.12–Figure 5.17].

*Table 5.4. The areas of impact on the harbour porpoise in case of simultaneous piling at several locations within and outside the Baltica-1 OWF (numbers in bold: the highest values for 2 and 3 sources, respectively; piling with the HSD + DBBC mitigation system applied)*

| **Season** | **Mitigation type** | **Impact area [km$^2$]** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Effect** | **1 source** | **2 sources – < 1 km** | **2 sources – 20 km** | **2 sources – at a significant distance** | **3 sources – 2 < 1 km, 1 = 20 km** | **3 sources – 2 = 20 km, 1 = at a significant distance** | **4 sources** |
| Summer | HSD + DBBC | Behavioural response | 138 | 181 | **276** | 276 | 319 | **414** | 552 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | 0.06 | 0.06 | **0.09** | 0.1 |
| | | TTS (cumulative effect) | 0.1 | **0.5** | 0.2 | 0.2 | **0.6** | 0.3 | 0.7 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | 0.06 | 0.06 | **0.09** | 0.09 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | 0.06 | 0.06 | **0.09** | 0.1 |

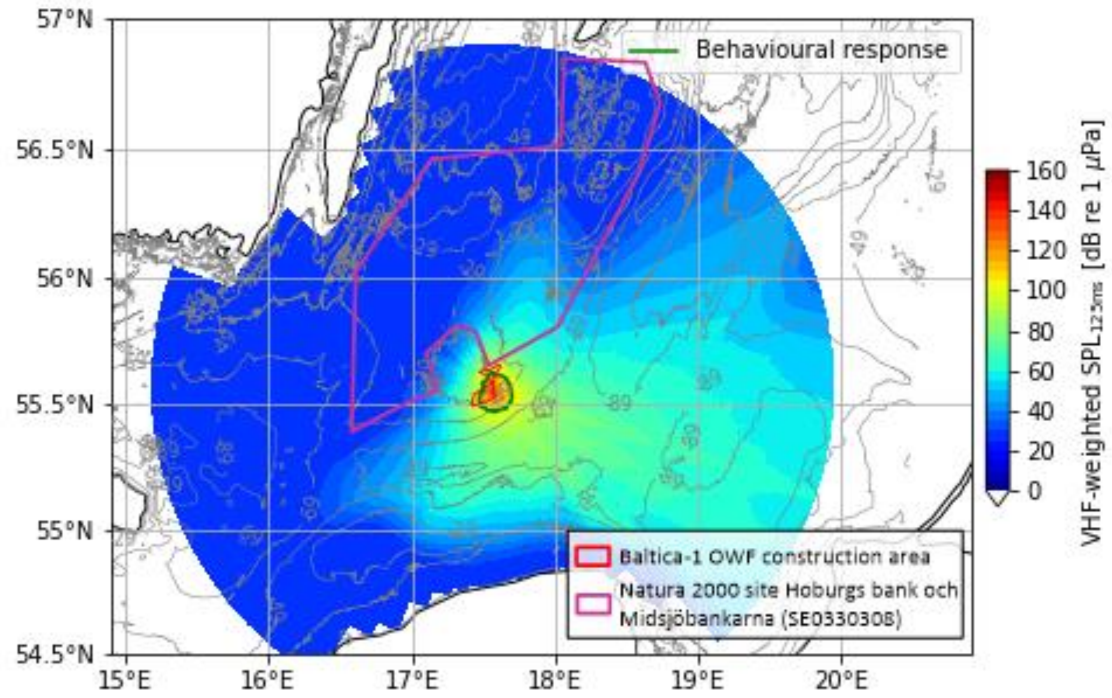



*Figure 5.12. The map of VHF-weighted $SPL_{125ms}$ from piling sources located at a small distance from each other in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied*

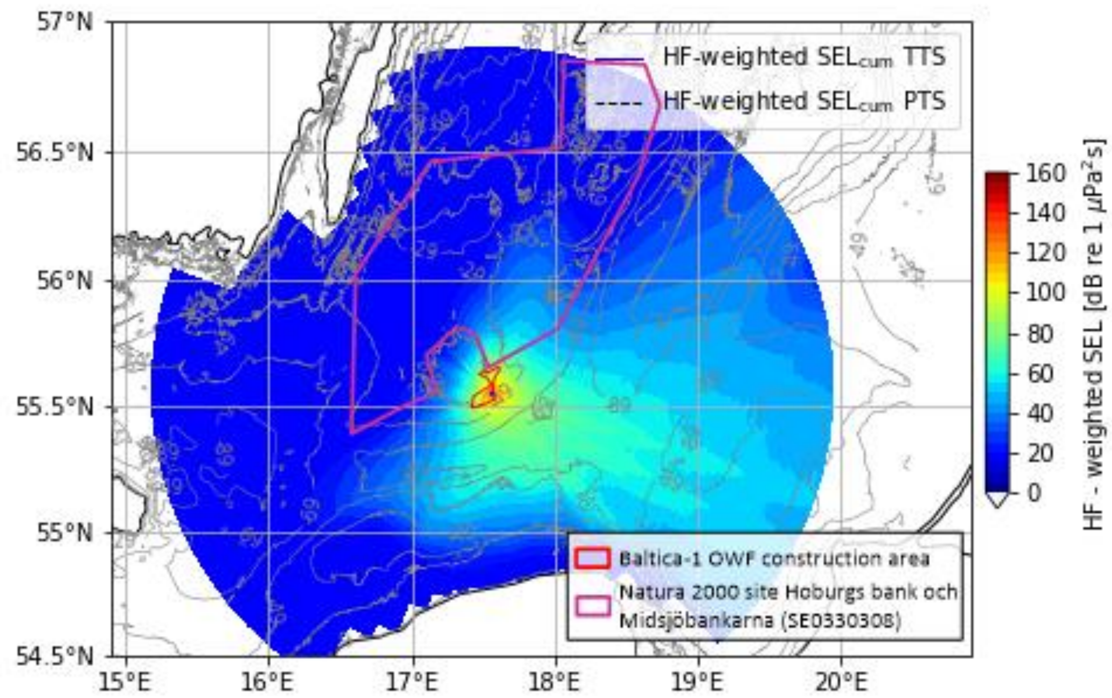



*Figure 5.13. The map of HF-weighted $SEL_{cum}$ from piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied*

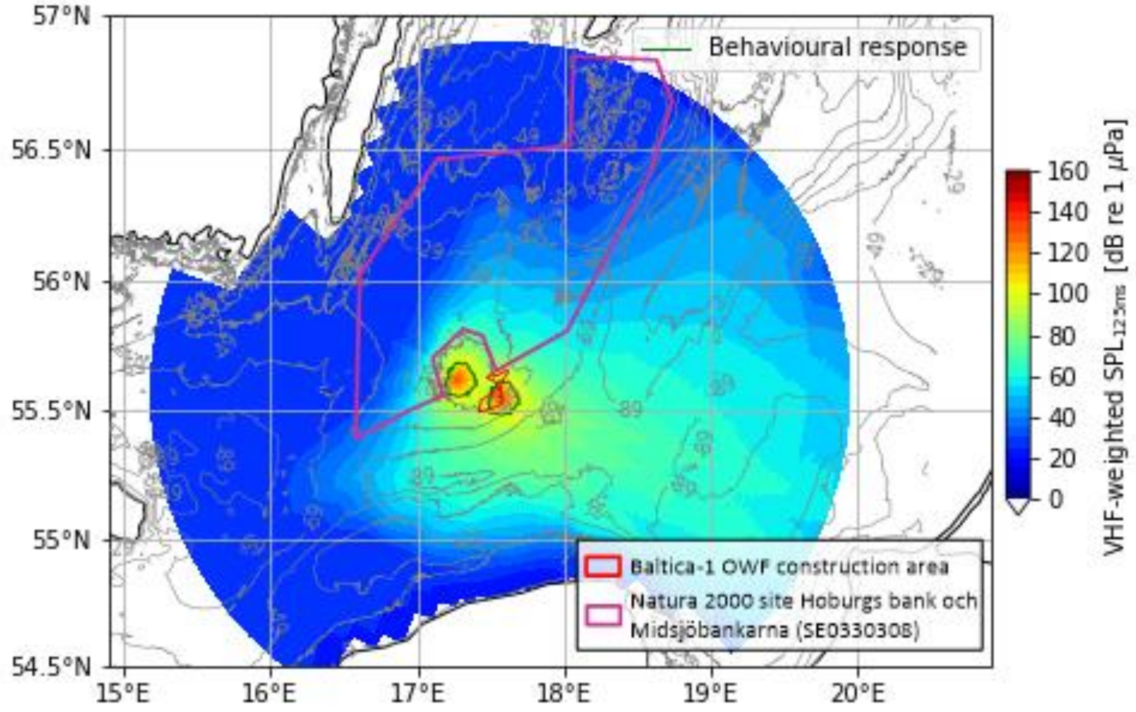



*Figure 5.14. The map of VHF-weighted $SPL_{125ms}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied*

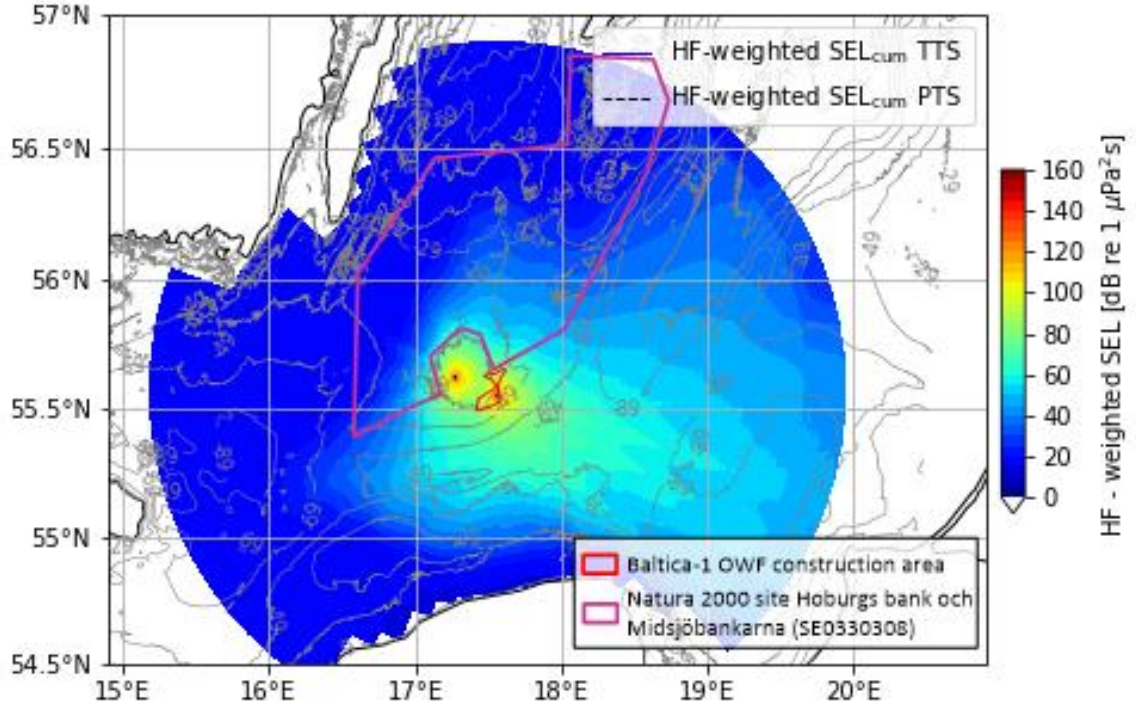



*Figure 5.15. The map of HF-weighted $SEL_{cum}$ from piling sources located at a distance of 20 km from each other and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied*

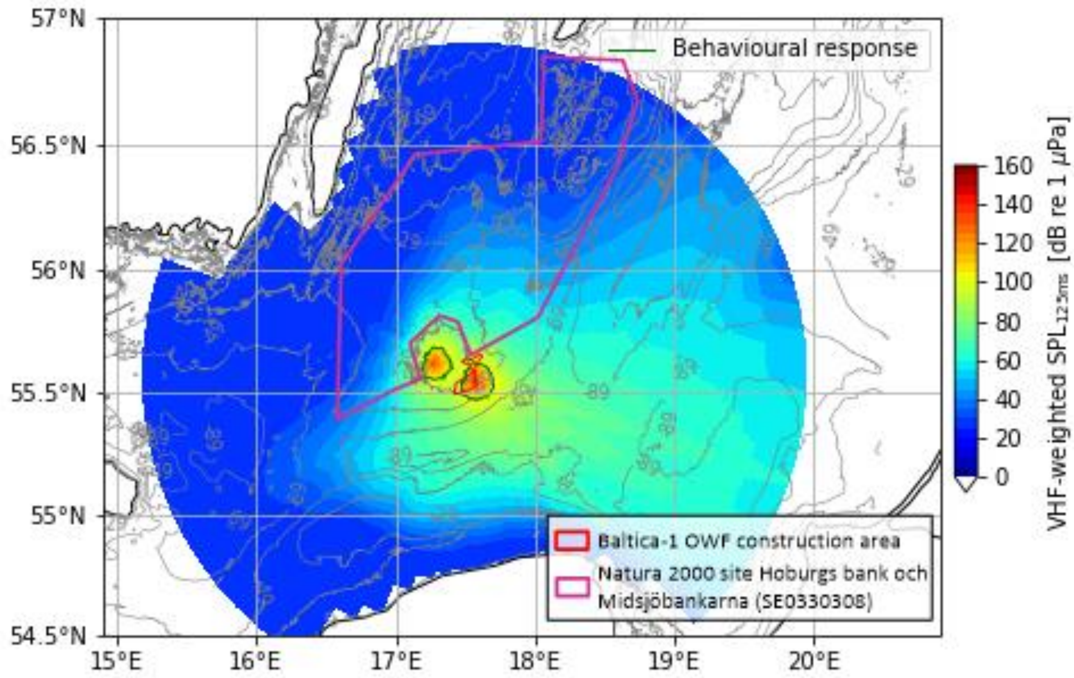



*Figure 5.16.* *The map of VHF-weighted $SPL_{125ms}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied*

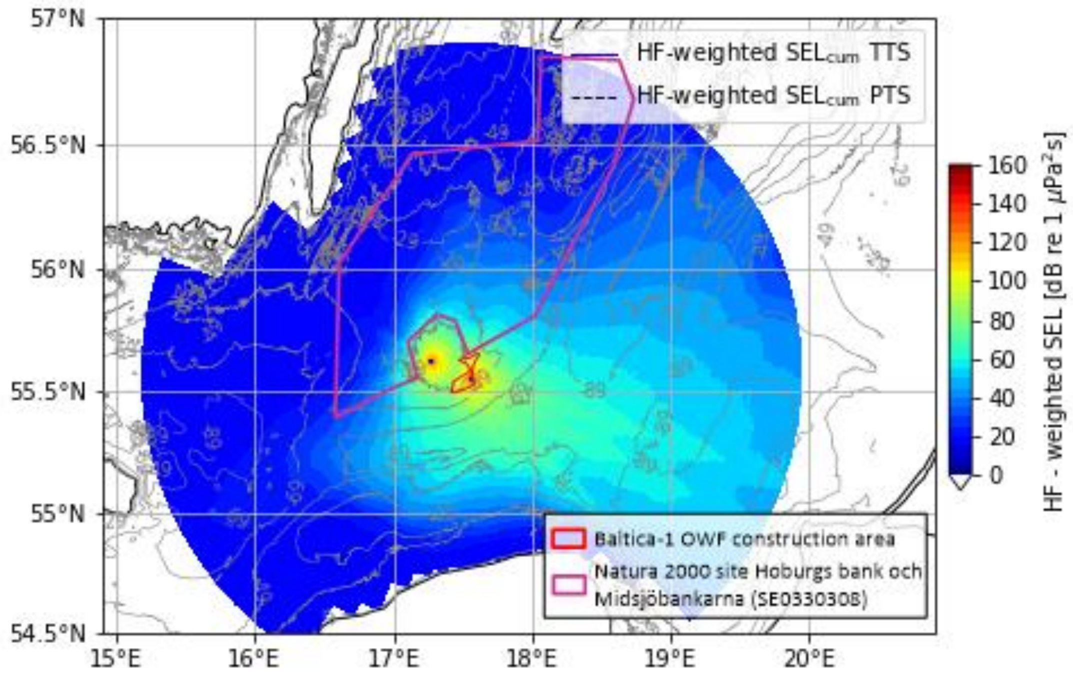



*Figure 5.17.* *The map of HF-weighted $SEL_{cum}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the harbour porpoise with the HSD + DBBC system applied*

### 5.2.2 Grey and harbour seal

Similarly to the results obtained for the harbour porpoise, the impact areas for seals increased with the number of piling sources, reaching the highest values for four locations. Impact areas and noise propagation maps are presented in the figure below [Table 5.5] and the following figures [Figure 5.18–Figure 5.23].

*Table 5.5. The areas of impact on the grey seal and common seal in the case of simultaneous piling at several locations within and outside the Baltica-1 OWF (numbers in bold: the highest values for 2 and 3 sources, respectively; piling with the HSD + DBBC mitigation system applied)*

| **Season** | **Mitigation type** | **Impact area [km²]** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Effect** | **1 source** | **2 sources – < 1 km** | **2 sources – 20 km** | **2 sources – at a significant distance** | **3 sources – 2 < 1 km, 1 = 20 km** | **3 sources – 2 = 20 km, 1 = at a significant distance** | **4 sources** |
| Summer | HSD + DBBC | Behavioural response | 18.3 | 35.5 | 33.9 | **36.6** | **68.4** | 52.2 | 86.7 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.09 |
| | | TTS (cumulative effect) | 0.03 | **1.5** | 0.2 | 0.06 | **2.2** | 0.2 | 2.27 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.09 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.09 |

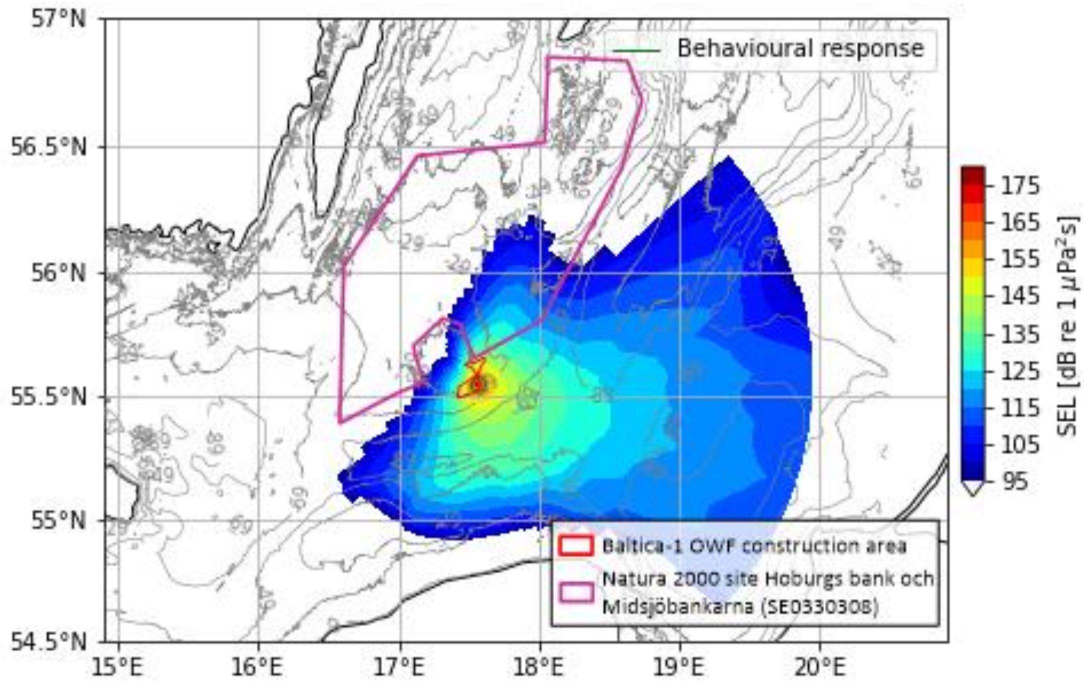



*Figure 5.18. The map of unweighted SEL above the acoustic background for piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied*

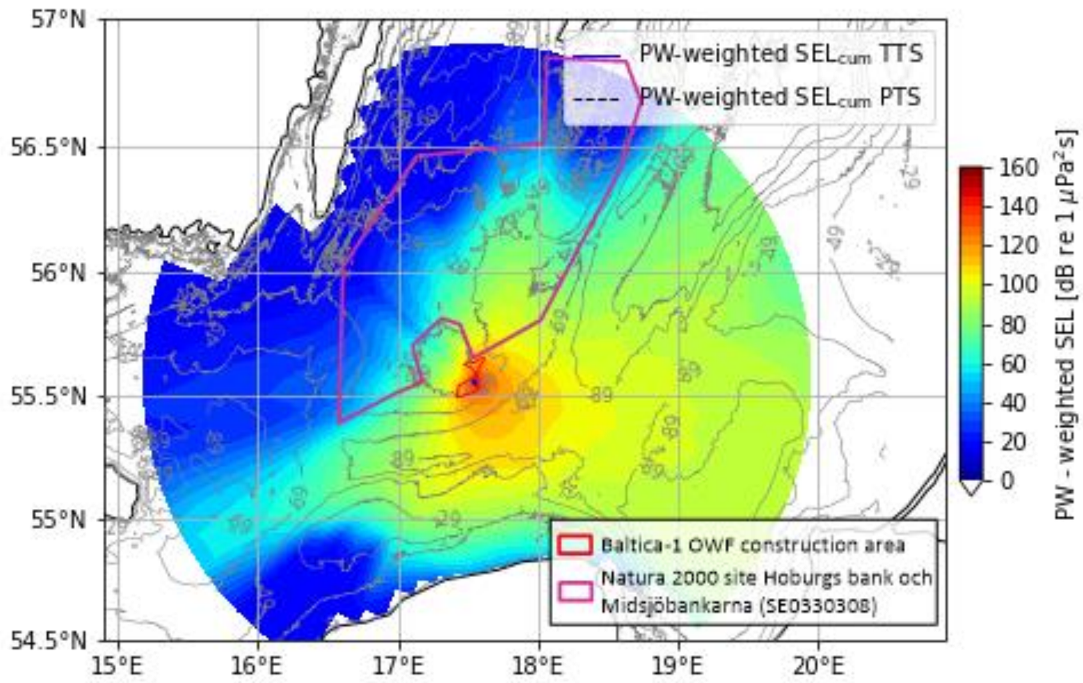



*Figure 5.19. The map of PW-weighted $SEL_{cum}$ from piling sources located close to each other within the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied*

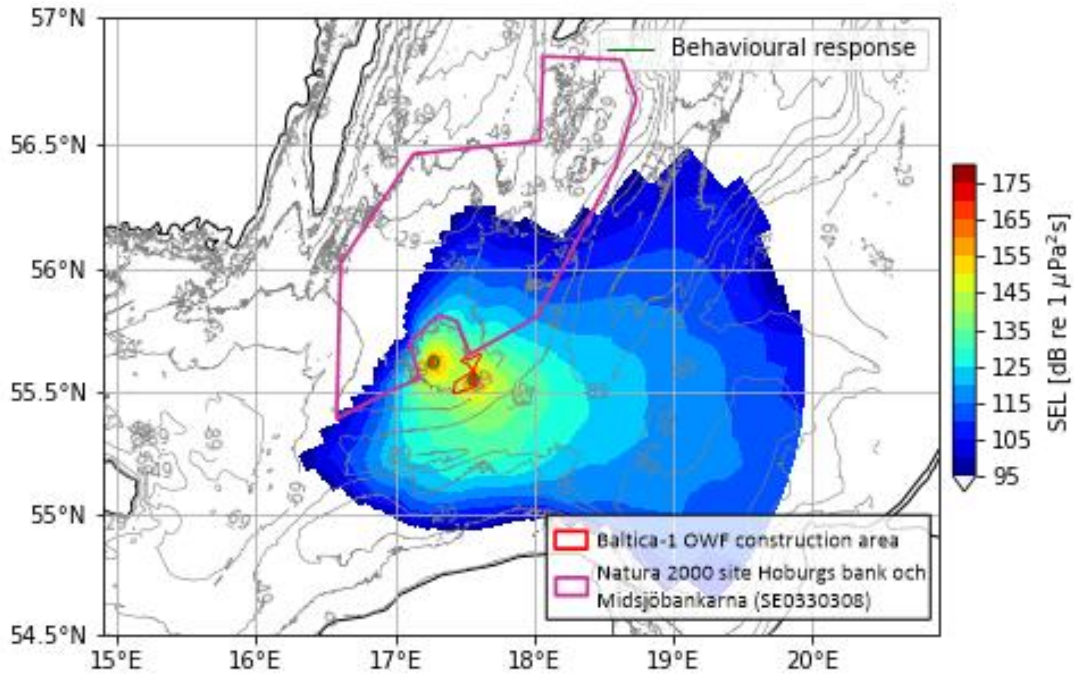



*Figure 5.20.* *The map of unweighted SEL above the acoustic background from piling sources located 20 km apart and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied*

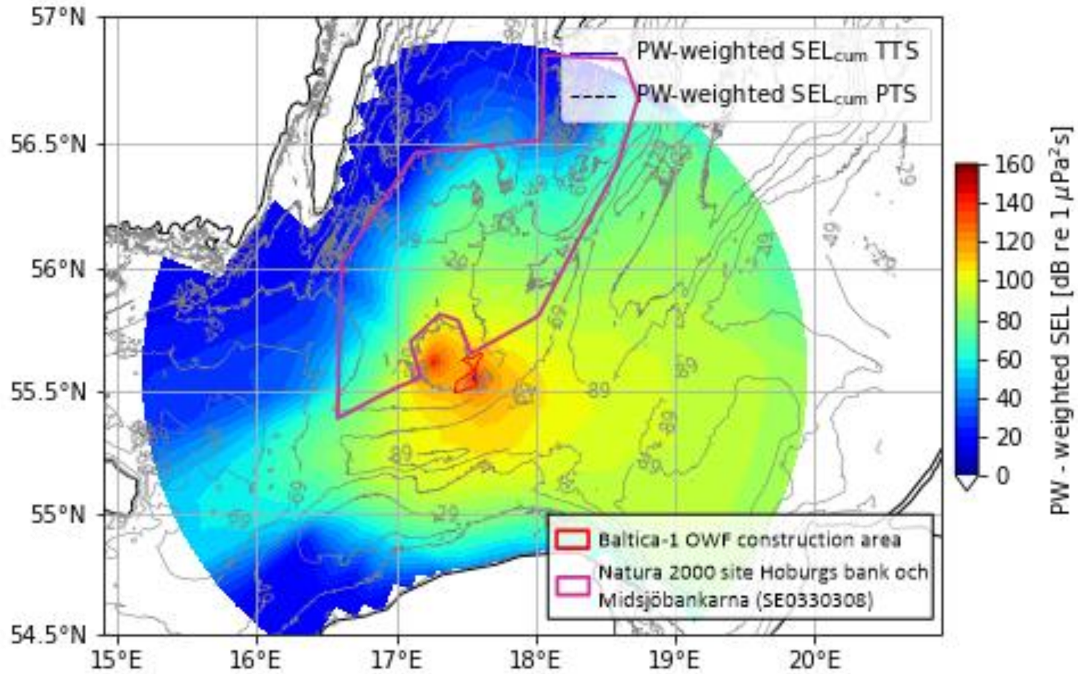



*Figure 5.21.* *The propagation map of PW-weighted $SEL_{cum}$ noise above the ambient noise from piling sources located 20 km apart and the impact ranges for the grey seal and harbour seal with the HSD + DBBC system applied*

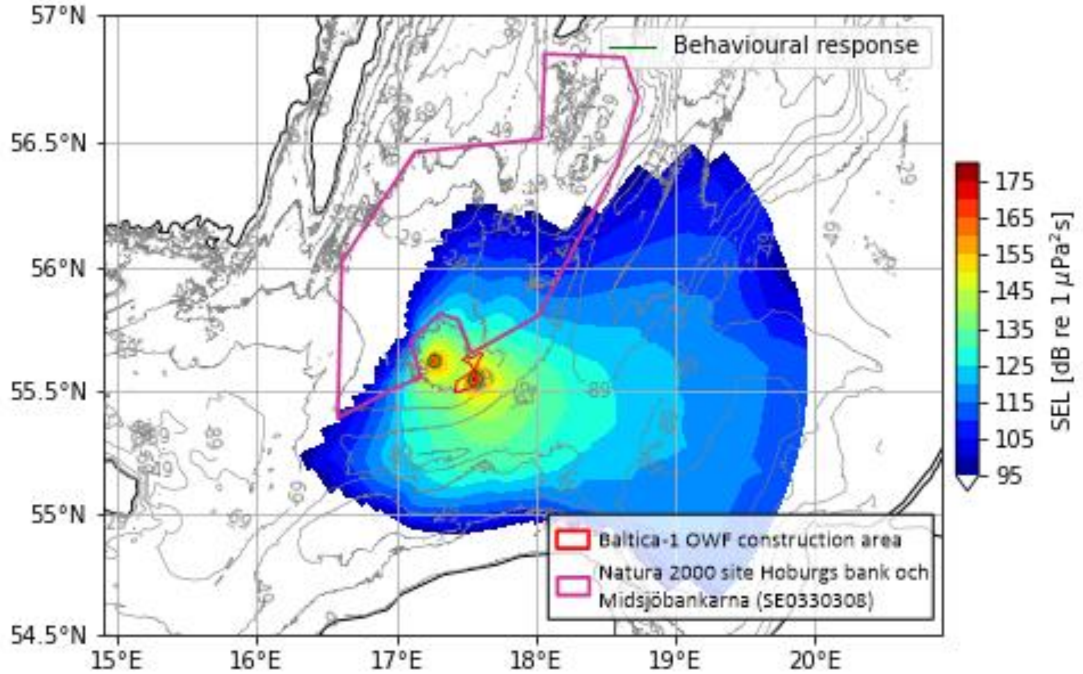



*Figure 5.22. The map of unweighted SEL above the acoustic background for three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied*

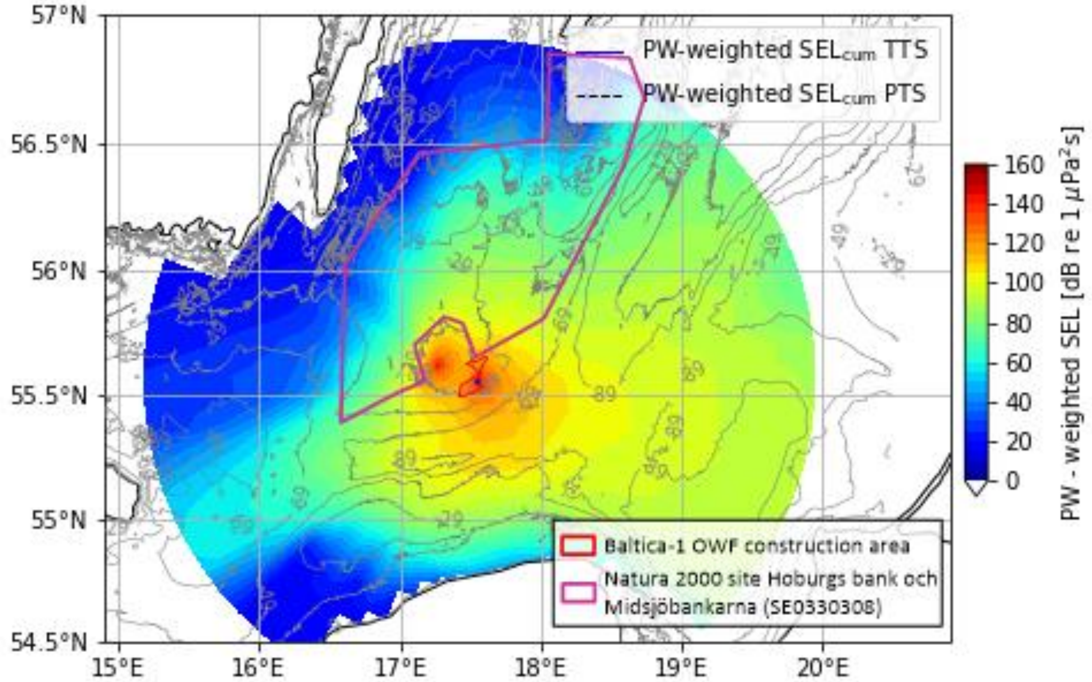



*Figure 5.23. The map of PW-weighted $SEL_{cum}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the grey seal and harbour seal with the HSD + DBBC system applied*

### 5.2.3 Fish with swim bladders

Similarly to the results obtained for the harbour porpoise and seals, the impact areas for fish with swim bladders increased with the number of piling sources, reaching the highest values in the case of four locations. The impact areas and noise propagation maps are presented in the table below [Table 5.6] and the following figures [Figure 5.24–Figure 5.26].

*Table 5.6. The areas of impact on fish with swim bladders in the case of simultaneous piling at several locations within and outside the Baltica-1 OWF (numbers in bold: the highest values for 2 and 3 sources, respectively; piling with the HSD + DBBC mitigation system applied)*

| **Season** | **Mitigation type** | **Impact area [km$^2$]** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Effect** | **1 source** | **2 sources – < 1 km** | **2 sources – 20 km** | **2 sources – at a significant distance** | **3 sources – 2 < 1 km, 1 = 20 km** | **3 sources – 2 = 20 km, 1 = at a significant distance** | **4 sources** |
| Summer | HSD + DBBC | Behavioural response | 774 | 1175 | **1548** | **1548** | 1949 | **2723** | 3497 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | TTS (cumulative effect) | 132 | 206 | **335** | 264 | 409 | **467** | 599 |
| | | Reversible hearing loss (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | Reversible hearing loss (cumulative effect) | 3.8 | 8.5 | **7.6** | **7.6** | **17.0** | 11.4 | 20.7 |

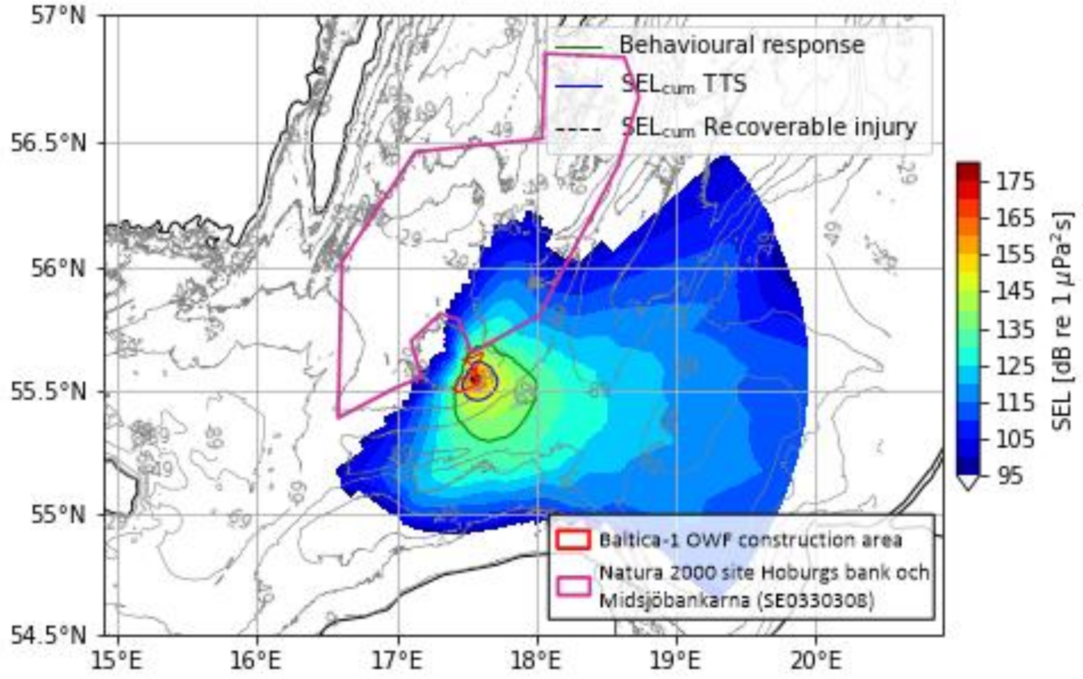



*Figure 5.24.* *The map of unweighted SEL above the acoustic background for piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on fish with swim bladders, with the HSD + DBBC system applied*

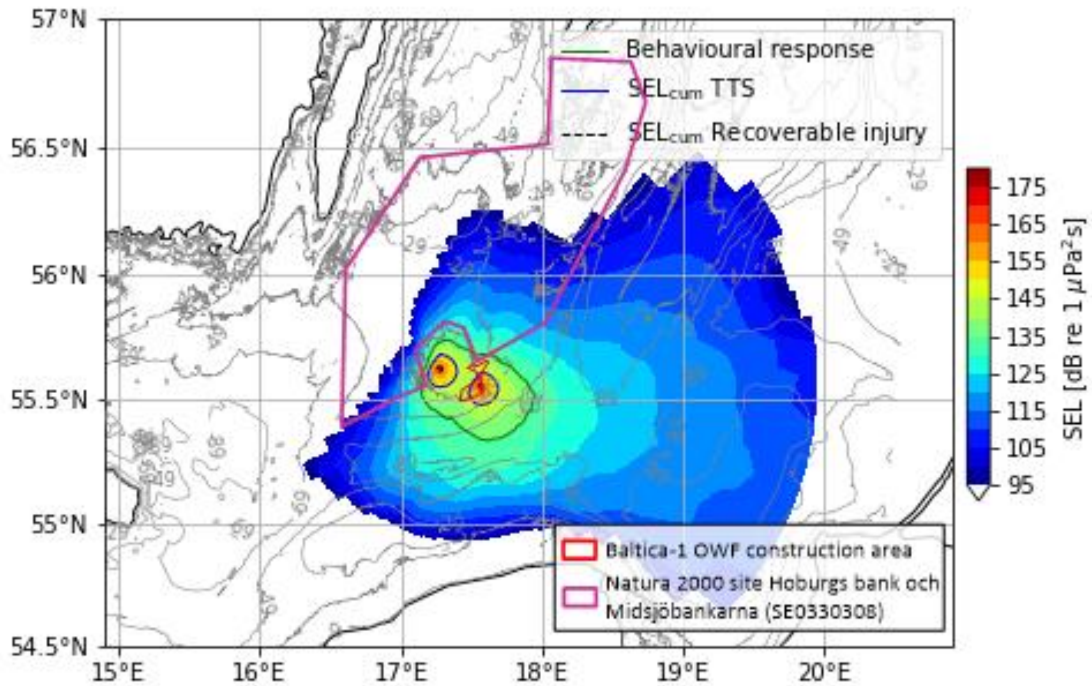



*Figure 5.25.* *The map of unweighted SEL above the acoustic background from piling sources located 20 km apart and the ranges of impact on fish with swim bladders with the HSD + DBBC system applied*

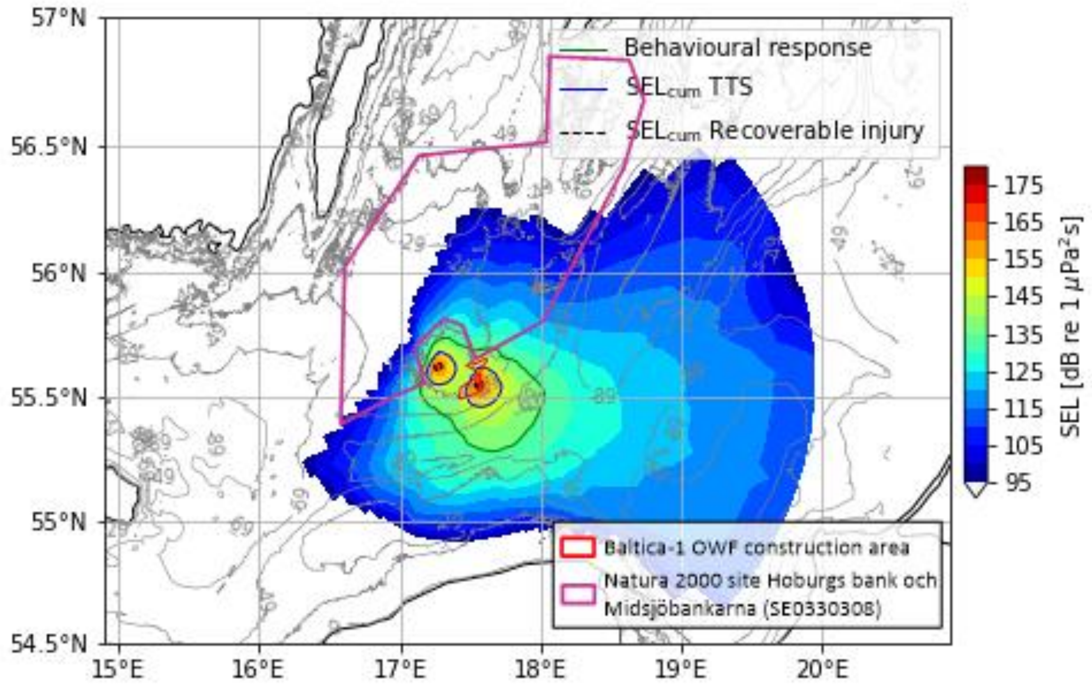



*Figure 5.26. The map of unweighted SEL above the acoustic background for three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on fish with swim bladders with the HSD + DBBC system applied*

## 5.3 Noise levels at the boundary of the Natura 2000 area

Presented below are levels of noise heard at the boundary of the Natura 2000 site Hoburgs bank och Midsjöbankarna in the summer season. Analyses were carried out for the harbour porpoise, as it is subject to protection in the above-mentioned area, and additionally, the threshold values for this species are the lowest among the analysed mammals.

### 5.3.1 Piling in a single location

The tables below present the differences between the calculated sound values at the boundary of the Natura 2000 site and the threshold values for scenarios without any mitigation measures applied [Table 5.7] and with the mitigation systems taken into account [Table 5.8]. The corresponding graphs have been developed for the TTS and PTS and presented in the following figures [Figure 5.27–Figure 5.28].

Based on the presented results, it is shown that in the case of piling at a single location, the threshold values of cumulative TTS for the harbour porpoise will be exceeded at the boundary of the Swedish Natura 2000 if no mitigation measures are used. The use of the HSD + DBBC system showed a reduction in the noise level at the boundary of the Natura 2000 area to an acceptable level concerning both analysed impacts.

*Table 5.7. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the cumulative TTS and PTS limits without any mitigation measures applied*

| Season | Natura 2000 site | Effect | The threshold value of SEL at the boundary of the Natura 2000 site [dB re 1 μPa²s] | Without mitigating measures | |
|---|---|---|---|---|---|
| | | | | The modelled value of HF-weighted SEL at the boundary of the Natura 2000 site [dB re 1 μPa²s] | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] |
| Summer | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 150.8 | +10.8 |
| | | PTS (cumulative effect) | 155 | | -4.2 |

*Table 5.8. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the SEL-based weighted TTS and PTS limits for the harbour porpoise with mitigation measures applied*

| Season | Natura 2000 site | Effect | SEL threshold value at the boundary of the Natura 2000 site [dB re 1 μPa²s] | With the HSD + DBBC system | |
|---|---|---|---|---|---|
| | | | | The modelled value of HF-weighted SEL at the boundary of the Natura 2000 site [dB re 1 μPa²s] | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] |
| Summer | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 105.2 | -34.8 |
| | | PTS (cumulative effect) | 155 | | -49.8 |

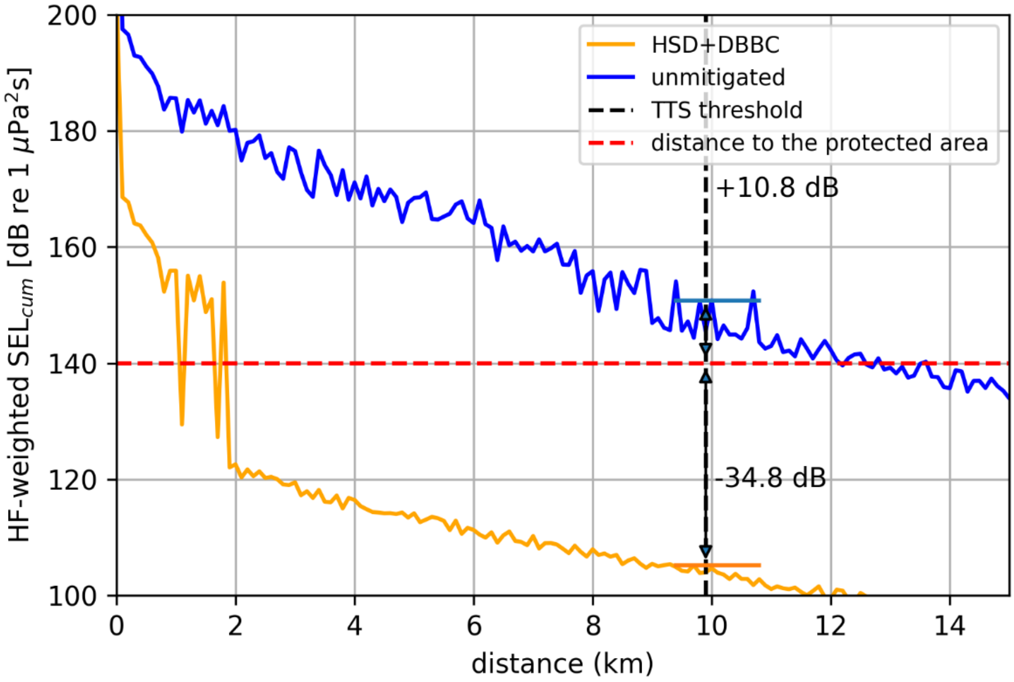



*Figure 5.27. The propagation w piling noise within the Baltic-1 OWF area in relation to the TTS limits for the porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

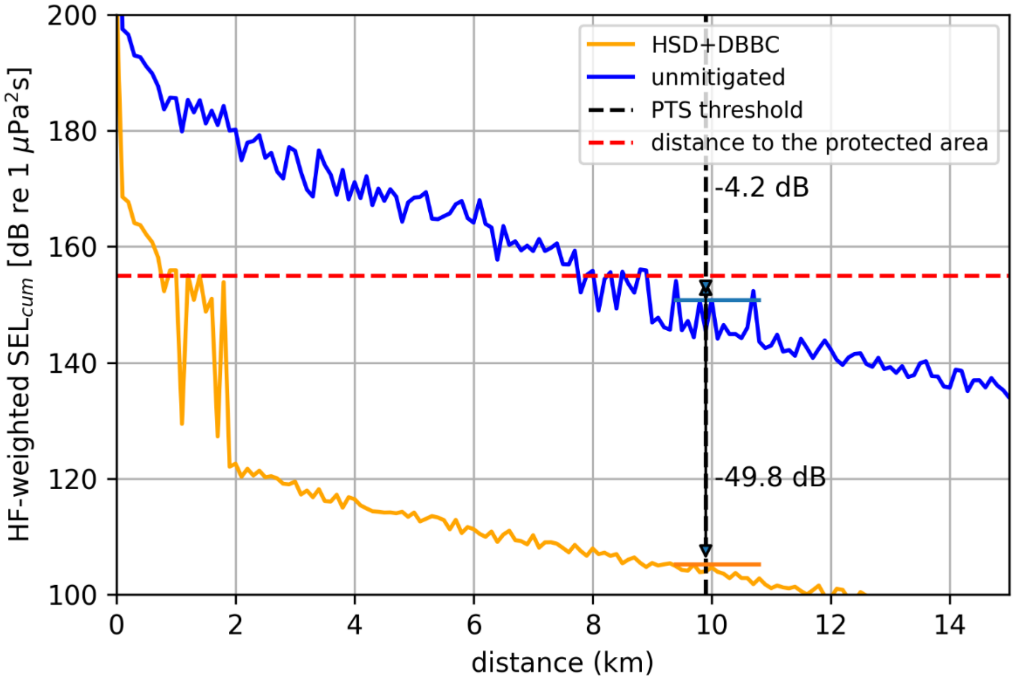



*Figure 5.28. The propagation w piling noise within the Baltic-1 OWF area in relation to the PTS limits for the porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

### 5.3.2 Piling in several locations

The differences in noise levels between the threshold values and the modelled values at the boundary of the Natura 2000 site Hoburgs bank och Midsjöbankarna were calculated also for simultaneous piling in several locations. The results for different numbers of piling locations are presented in the table below [Table 5.9] for the scenario without mitigation measures applied, and in the following table [Table 5.10] for the scenario with mitigation. The corresponding graphs for the TTS and PTS are presented in the following figures [Figure 5.29–Figure 5.34].

Based on the results obtained, it was concluded that in the case of piling at several locations, the threshold values for the TTS and PTS will be exceeded at the boundary of the Natura 2000 site in question. However, the application of a mitigation system in the form of HSD + DBBC showed a decrease in the noise level at the boundary of the Natura 2000 site to an acceptable level concerning both analysed impacts in all scenarios.

*Table 5.9. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the TTS and PTS limits for the harbour porpoise in the case of simultaneous piling in several locations within and outside the Baltica-1 area without any mitigation measures applied*

| Season | Sound sources | Natura 2000 site | Effect | SEL threshold value at the boundary of the Natura 2000 site [dB re 1 µPa²s] | Without mitigating measures | |
|---|---|---|---|---|---|---|
| | | | | | The modelled HF-weighted SEL at the boundary of the Natura 2000 site [dB re 1 µPa²s] | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] |
| Summer | 2 sources – <1 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 156.0 | +16.0 |
| | | | PTS (cumulative effect) | 155 | | +1.0 |
| | 2 sources – 20 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 150.9 | +10.9 |
| | | | PTS (cumulative effect) | 155 | | -4.1 |
| | 3 sources – 2 <1 km, 1 = 20 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 156.0 | +16.0 |
| | | | PTS (cumulative effect) | 155 | | +1.0 |

*Table 5.10. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the TTS and PTS limits for the harbour porpoise in the case of simultaneous piling in several locations within and outside the Baltica-1 area with the mitigation measures applied*

| Season | Sound sources | Natura 2000 site | Effect | The threshold value of SEL at the boundary of the Natura 2000 site [dB re 1 µPa²s] | With the HSD + DBBC system | |
|---|---|---|---|---|---|---|
| | | | | | The modelled HF-weighted SEL at the boundary of the Natura 2000 site [dB re 1 µPa²s] | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] |
| Summer | 2 sources – < 1 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 108.7 | -31.3 |
| | | | PTS (cumulative effect) | 155 | | -46.3 |
| | 2 sources – 20 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 106.2 | -33.8 |
| | | | PTS (cumulative effect) | 155 | | -48.8 |
| | 3 sources – 2 < 1km, 1 = 20 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 109.2 | -30.8 |
| | | | PTS (cumulative effect) | 155 | | -45.8 |

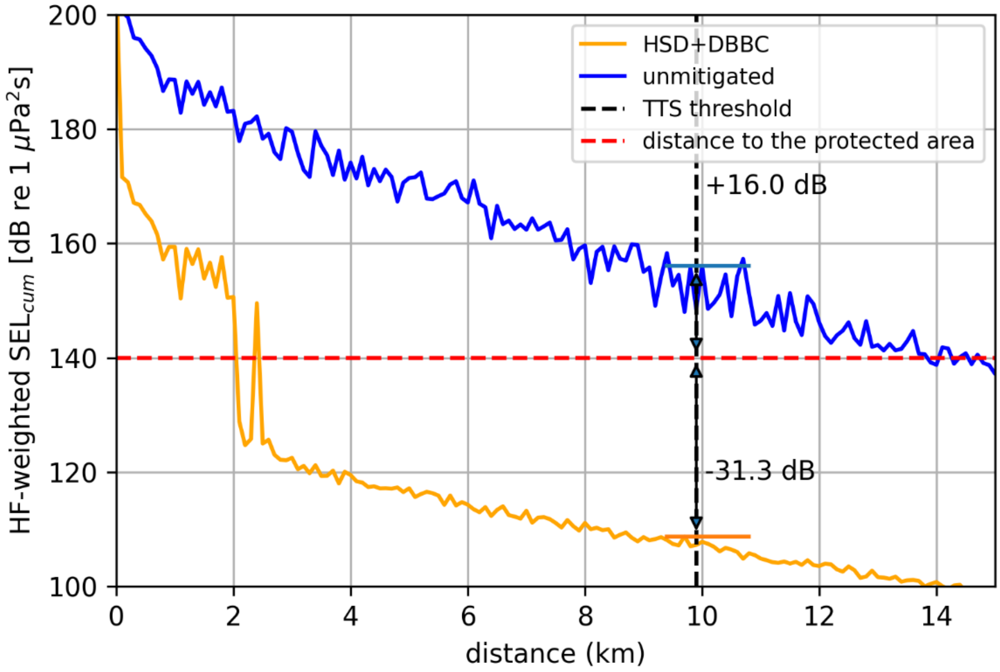



*Figure 5.29. The propagation of piling noise from simultaneous piling in two close locations within the Baltica-1 OWF area in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

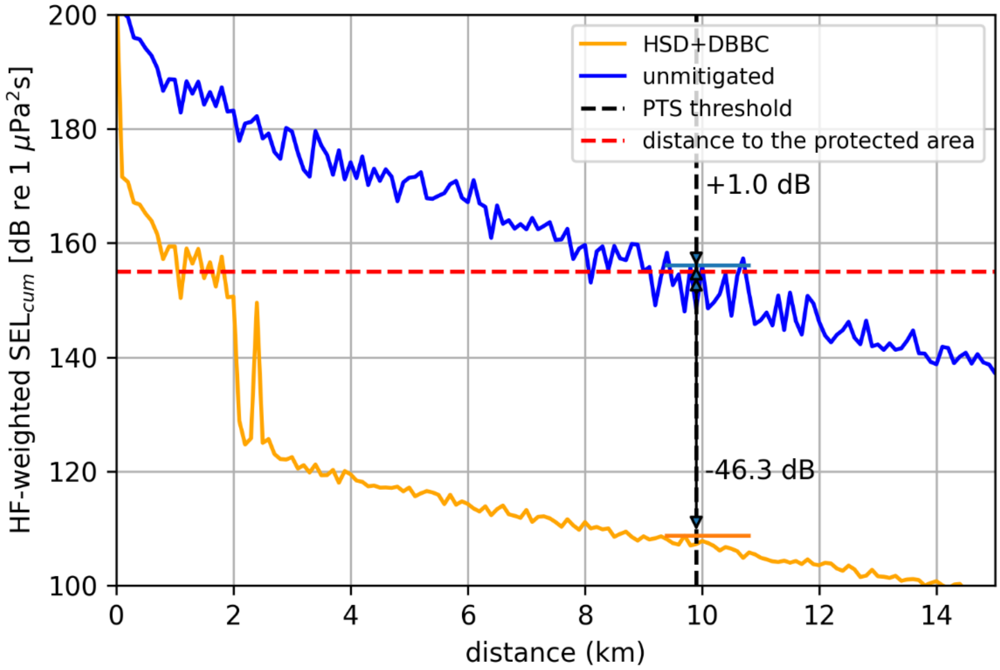



*Figure 5.30. The propagation of piling noise from simultaneous piling in two close locations within the Baltica-1 OWF area in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

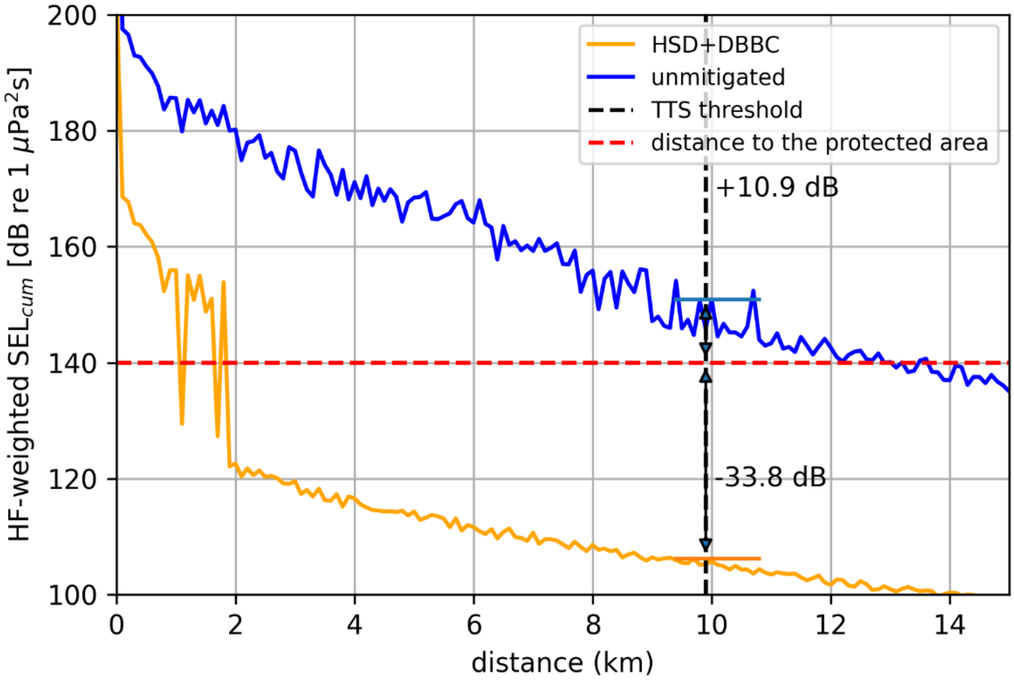



*Figure 5.31. Noise propagation during simultaneous piling in two locations 20 km apart in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

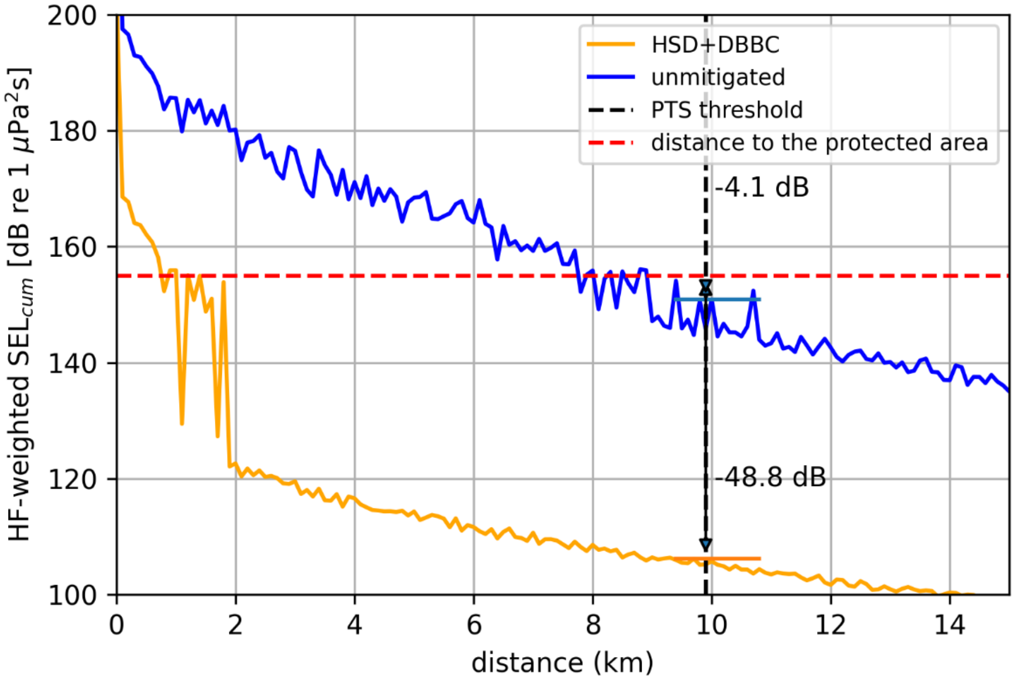



*Figure 5.32. Noise propagation during simultaneous piling in two locations 20 km apart in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

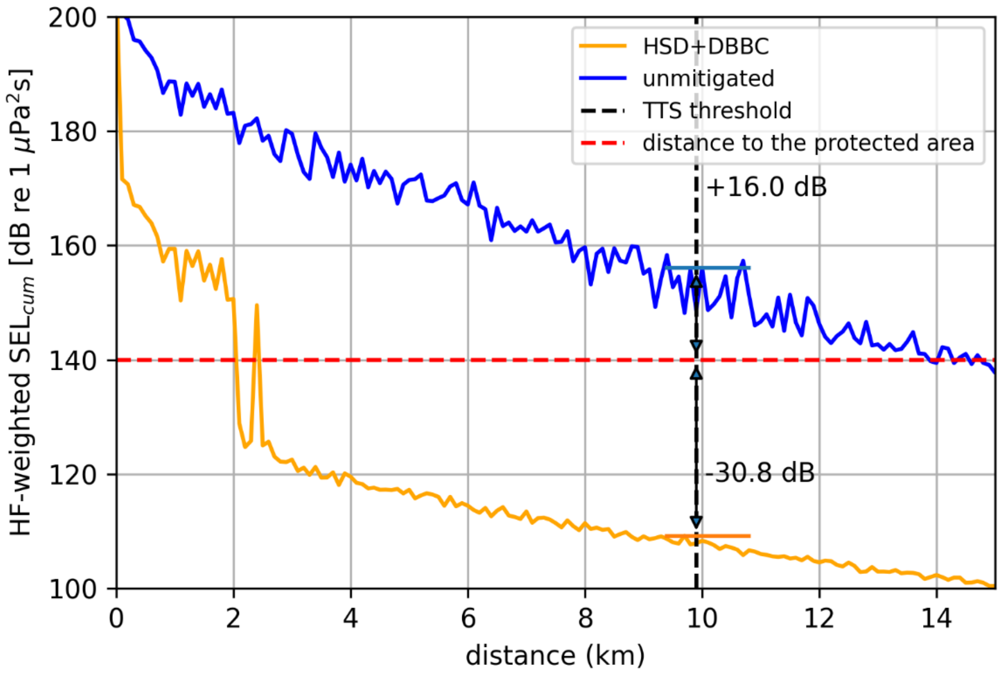



*Figure 5.33. Noise propagation during simultaneous piling in two close locations and one located 20 km away within the Baltica-1 OWF area in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

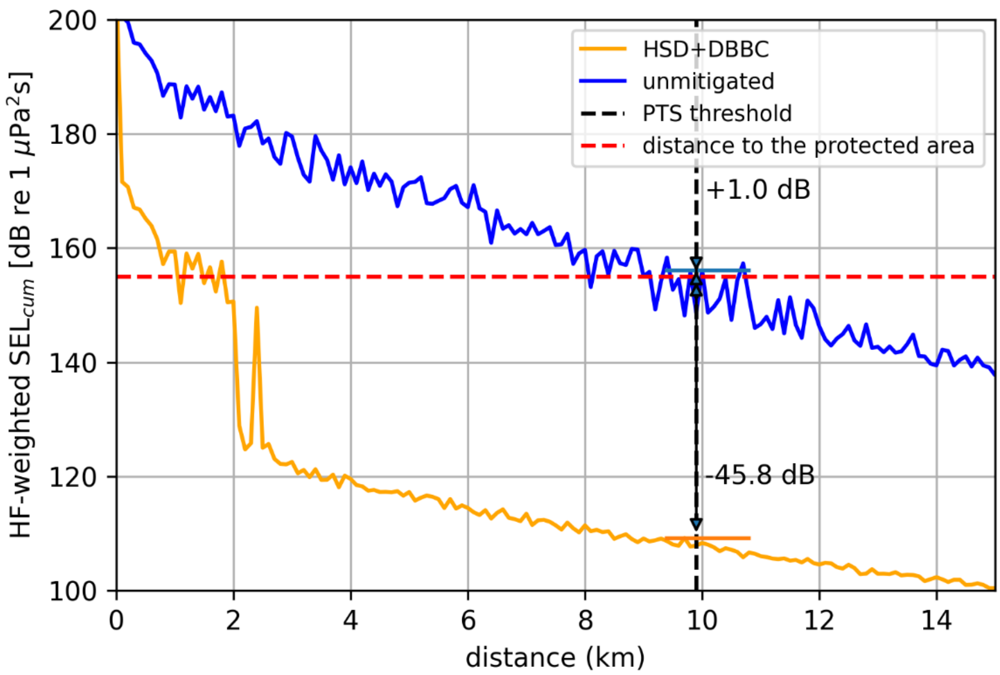



*Figure 5.34. Noise propagation during simultaneous piling in two close locations and one located 20 km away within the Baltica-1 OWF area in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

## 5.4 The impact within the Natura 2000 site

The analyses of impact in the Swedish Natura 2000 site were conducted for the behavioural response. They showed that as a result of piling in one location, the range of impact of the behavioural response will not cover the Natura 2000 site if mitigation measures in the form of HSD + DBBC are applied.

The impact ranges and the corresponding percentages of coverage of the Swedish Natura 2000 site are presented below [Table 5.11].

*Table 5.11. The ranges and areas of impact causing a behavioural response in the harbour porpoise, calculated for the central location in the Baltica-1 OWF area and the percentage of coverage of the Natura 2000 site Hoburgs bank och Midsjöbankarna*

| **Season** | **Mitigation type** | **Effect** | **Threshold value** | **Mean distance [km]** | **Maximum distance [km]** | **Impact area [km$^2$]** | **The percentage of coverage of the Natura 2000 site [%]** | **The value of VHF-weighted $SPL_{125ms}$ at the boundary of the Natura 2000 site** |
|---|---|---|---|---|---|---|---|---|
| Summer | HSD + DBBC | Behavioural response | 103 SPL VHF-weighted | 6.5 | 8.9 | 138 | 0 | 87.0 |

# 6 THE MODELLING RESULTS FOR THE SOUTHERN LOCATION

## 6.1 THE MODELLING OF NOISE PROPAGATION FOR PILING IN A SINGLE LOCATION

This chapter presents the results of modelling carried out for the southern location within the Baltica-1 OWF in the summer season. The impact ranges for different threshold values are presented in the form of tables, and sound propagation maps are included.

### 6.1.1 The level of exposure to sound generated by a single blow

The SEL value for a single blow did not exceed 130 dB at the boundary of the modelled area, at a distance of 150 km from the sound source. The sound propagated mainly in the directions of north and southeast from the piling site; this is where the highest sound levels were recorded [Figure 6.1].

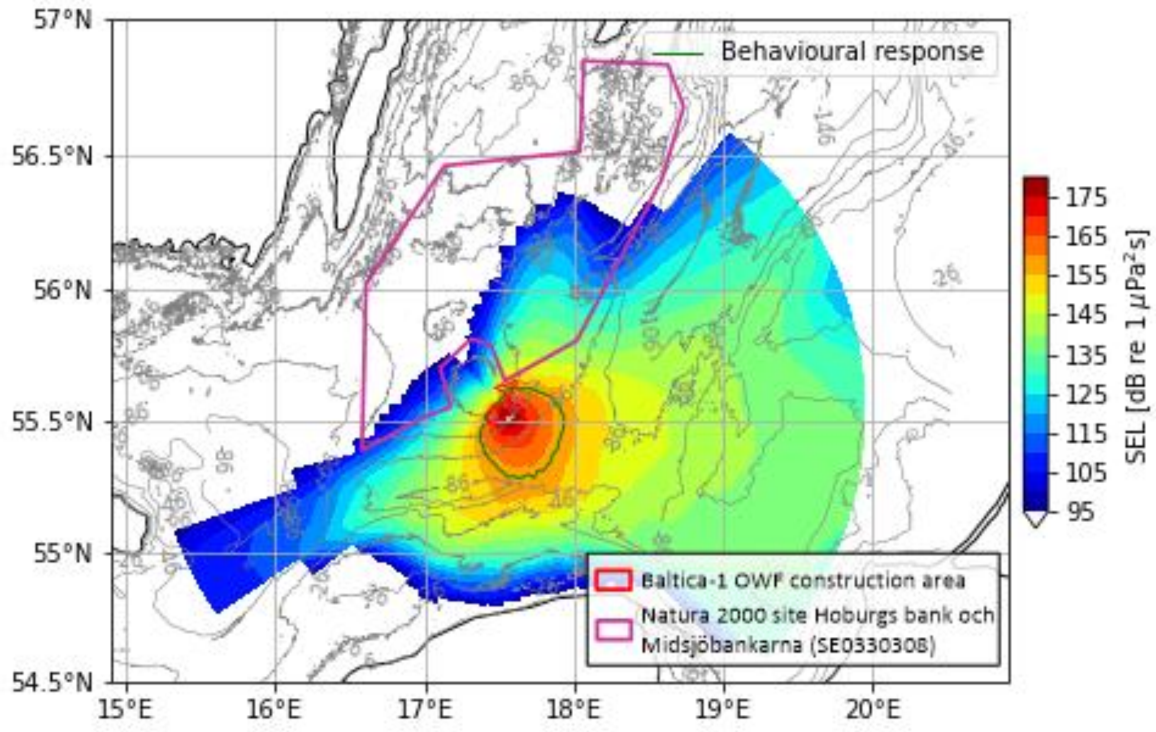



*Figure 6.1. The map of unweighted SEL above the acoustic background for a single blow in the area of the Baltica-1 OWF, in the summer season. Grey lines: isobaths*

#### 6.1.1.1 Harbour porpoise

As far as the harbour porpoise is concerned, the largest impact ranges were recorded for the behavioural response.

The estimates of cumulative SEL for the TTS and PTS were higher than in the case of a single blow, and TTS ranges exceeded the PTS ranges. The maximum range of cumulative impacts was 20.3 km and the values for a single blow did not exceed 3.5 km in the case of TSS.

For the $SPL_{peak}$, the maximum impact ranges for the TTS and PTS from a single blow were higher for the TTS with a maximum value of 4.0 km.

The use of a mitigation measure in the form of a BBC contributed to a reduction in the impact ranges of all the analysed effects.

All ranges calculated for individual threshold values are shown in tabular form [Table 6.1], while noise propagation maps are presented in the following figures [Figure 6.2–Figure 6.5].

*Table 6.1. The distances to threshold values for the harbour porpoise in the Baltica-1 OWF area*

| Season | Mitigation type | Effect | VHF-weighted SPL [dB re 1 µPa] / HF-weighted SEL [dB re 1 µPa²s] | | | unweighted SPL [dB re 1 µPa] | |
|---|---|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] | Mean distance [km] | Maximum distance [km] |
| Summer | - | Behavioural response | 28.6 | 85.8 | 3417 | - | - |
| | | TTS (single blow) | 2.6 | 3.5 | 20.8 | 3.6 | 4.0 |
| | | TTS (cumulative effect) | 8.0 | 20.3 | 229 | - | - |
| | | PTS (single blow) | 0.3 | 0.6 | 0.3 | 1.4 | 1.6 |
| | | PTS (cumulative effect) | 3.8 | 5.5 | 46.7 | - | - |
| | BBC | Behavioural response | 8.8 | 12.3 | 251 | - | - |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.8 | 0.8 |
| | | TTS (cumulative effect) | 0.5 | 0.6 | 0.7 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.3 | 0.3 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |

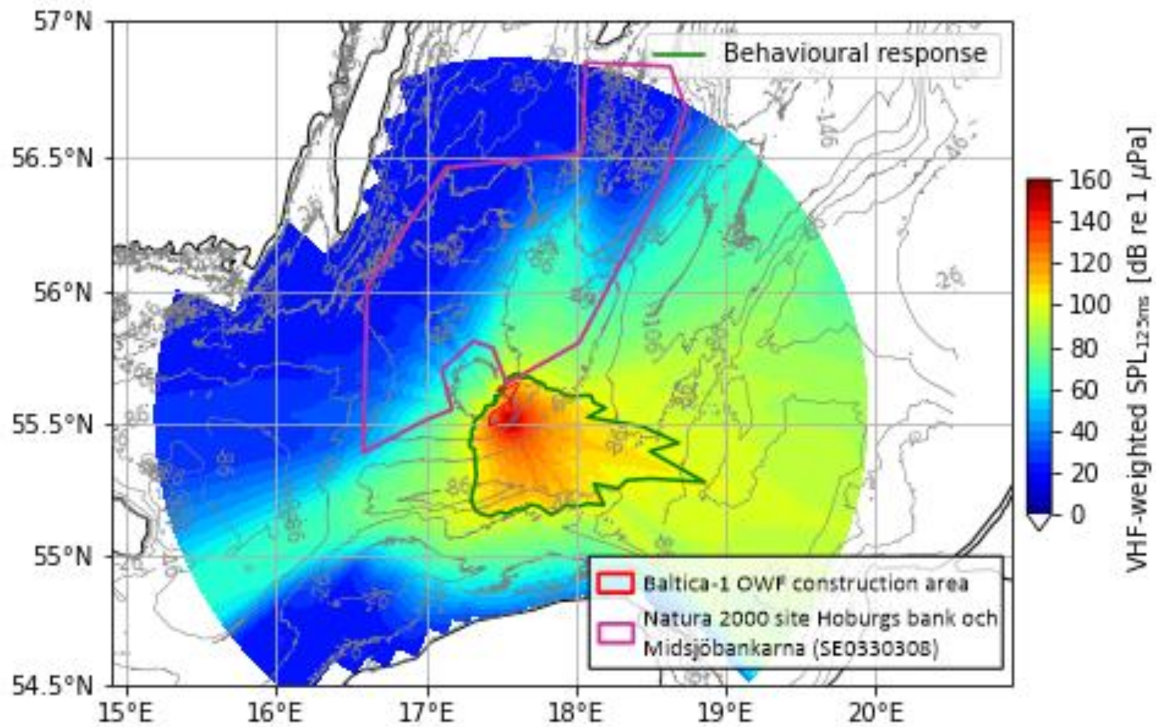



*Figure 6.2. The map of VHF-weighted $SPL_{125ms}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise*

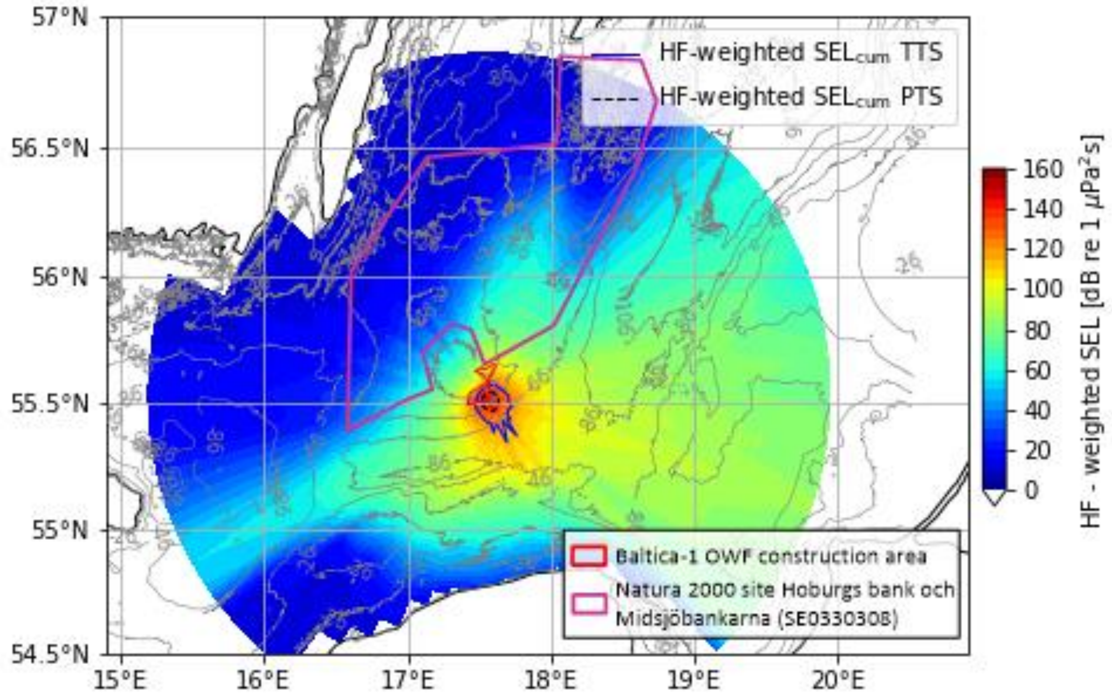



*Figure 6.3. The map of HF-weighted $SEL_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise*

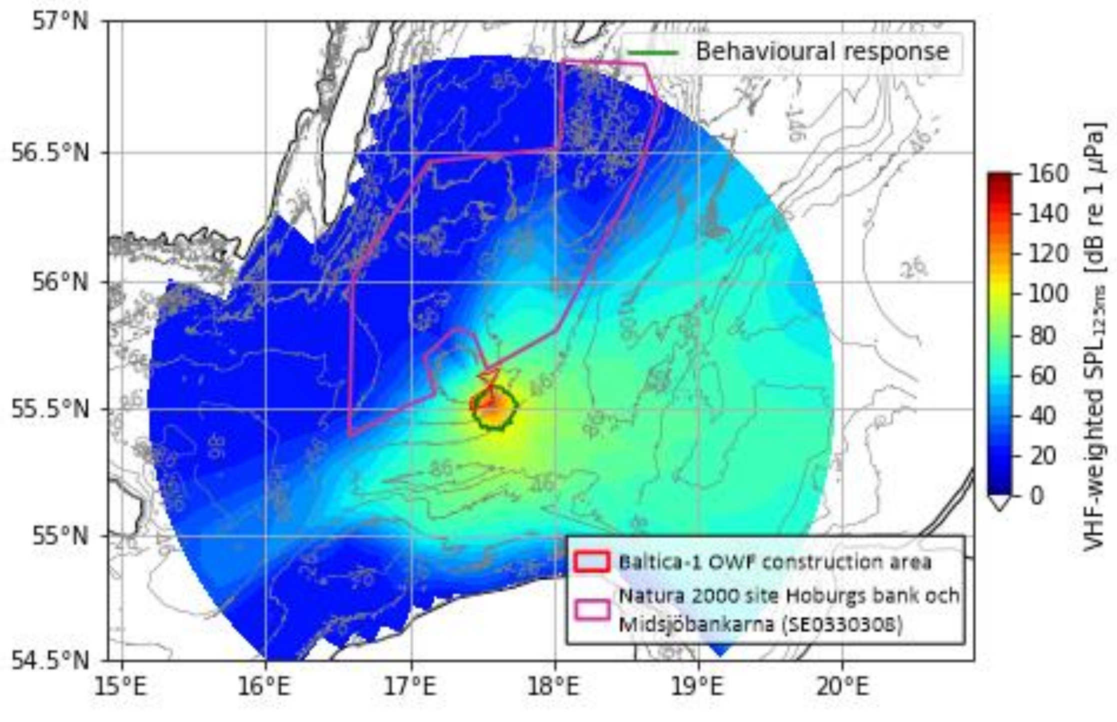



*Figure 6.4. The map of VHF-weighted $SPL_{125ms}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with a BBC applied*

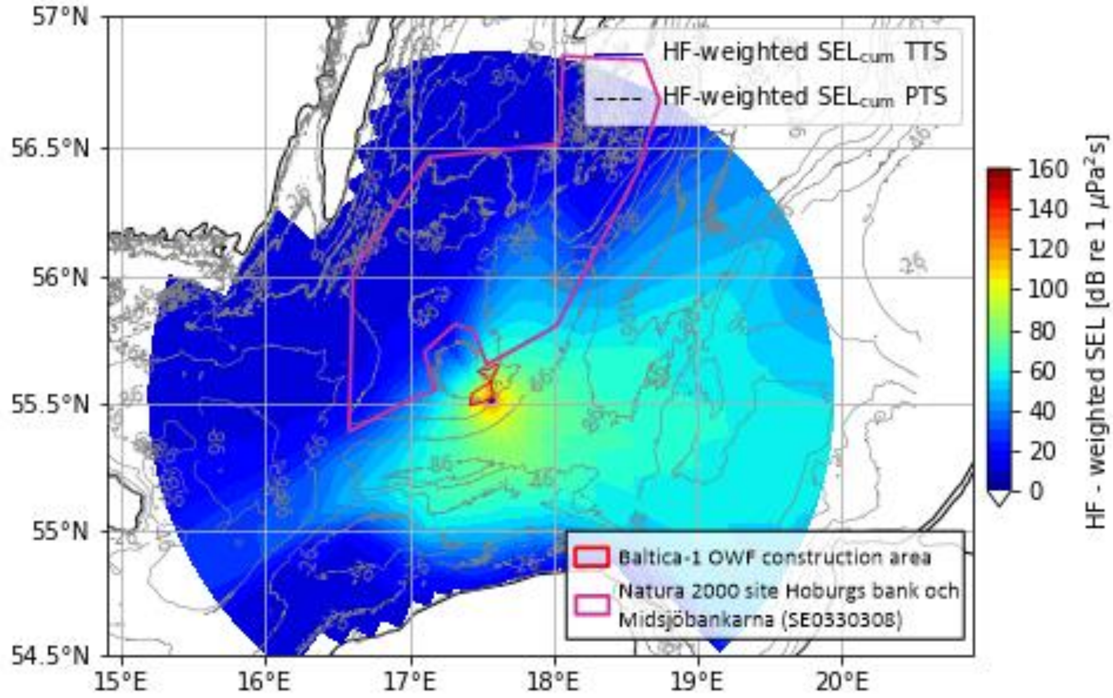



*Figure 6.5. The map of HF-weighted SEL $_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with a BBC applied*

#### 6.1.1.2 Grey and harbour seal

All impact ranges and areas (except for those of the cumulative TTS) calculated for the grey and harbour seal were lower than those obtained for the harbour porpoise.

The largest impact range and the corresponding area were estimated for the cumulative TTS, and it was 1486 km$^2$.

The impact ranges calculated for the SEL from a single blow reached a maximum range of only 0.3 km for the TTS.

All ranges calculated for individual threshold values are shown in tabular form [Table 6.2], while noise propagation maps are presented in the following figures [Figure 6.6–Figure 6.9].

*Table 6.2. The distances to the threshold values for the grey seal and harbour seal calculated for the Baltica-1 OWF area*

| Season | Mitigation type | Effect | unweighted SEL / Pw-weighted SEL [dB re 1 µPa²s] | | | unweighted SPL$_{peak}$ [dB re 1 µPa] | |
|---|---|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km$^2$] | Mean distance [km] | Maximum distance [km] |
| Summer | - | Behavioural response | 16.9 | 27.5 | 1011 | 0.3 | 0.3 |
| | | TTS (single blow) | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| | | TTS (cumulative effect) | 20.2 | 35.3 | 1486 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |

| Season | Mitigation type | Effect | unweighted SEL / Pw-weighted SEL [dB re 1 µPa²s] | | | unweighted SPL$_{peak}$ [dB re 1 µPa] | |
|---|---|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] | Mean distance [km] | Maximum distance [km] |
| | | PTS (cumulative effect) | 0.5 | 0.8 | 0.9 | - | - |
| | BBC | Behavioural response | 8.1 | 10.0 | 210 | 0.1 | 0.1 |
| | | TTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | TTS (cumulative effect) | 1.1 | 1.5 | 3.8 | - | - |
| | | PTS (single blow) | 0.1 | 0.1 | 0.03 | 0.1 | 0.1 |
| | | PTS (cumulative effect) | 0.1 | 0.1 | 0.03 | - | - |

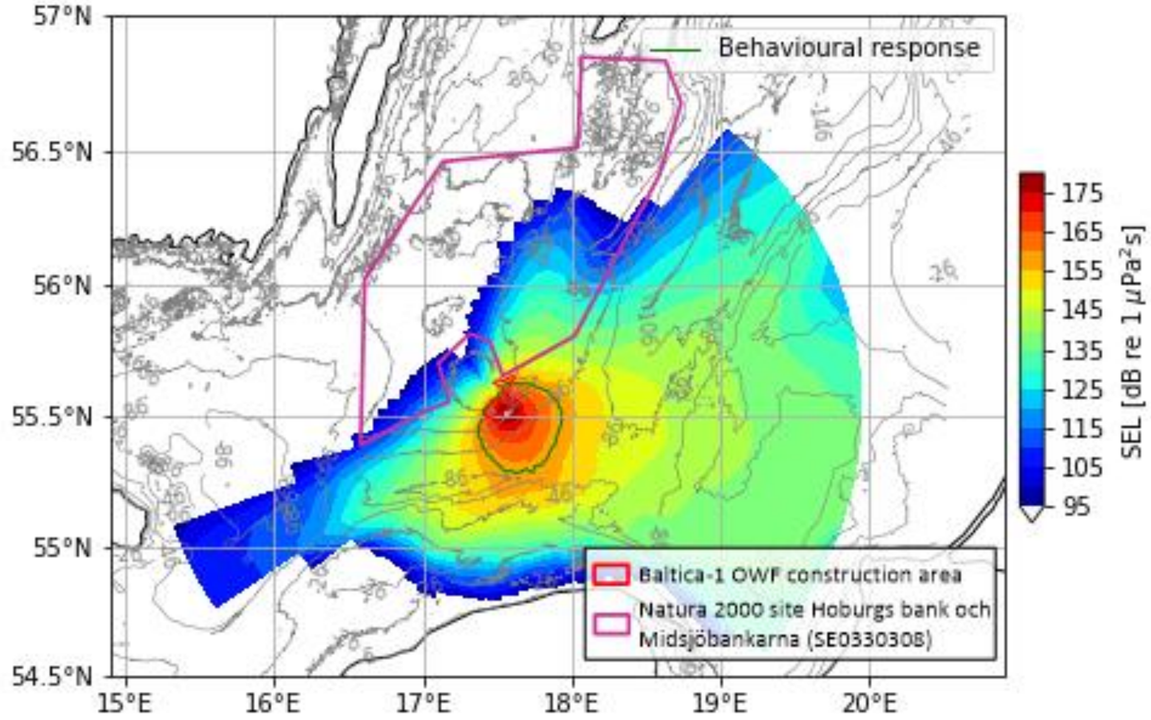



*Figure 6.6. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal*

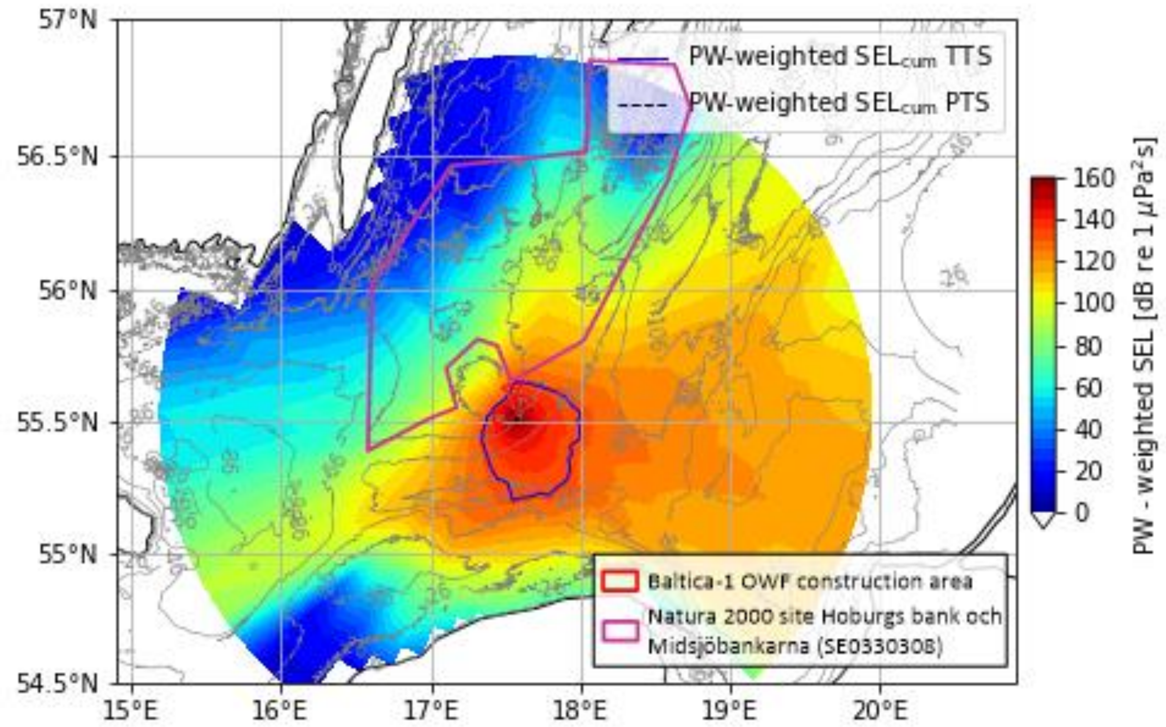



*Figure 6.7.* *The map of PW-weighted SEL$_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal*

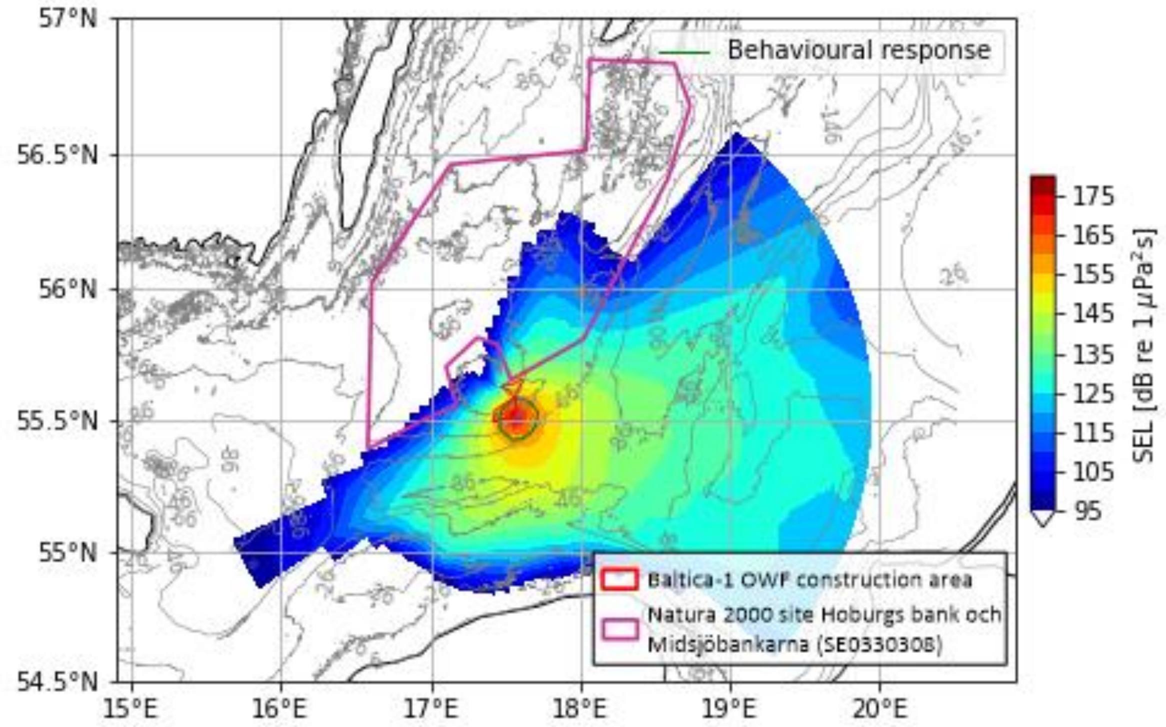



*Figure 6.8.* *The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with a BBC applied*

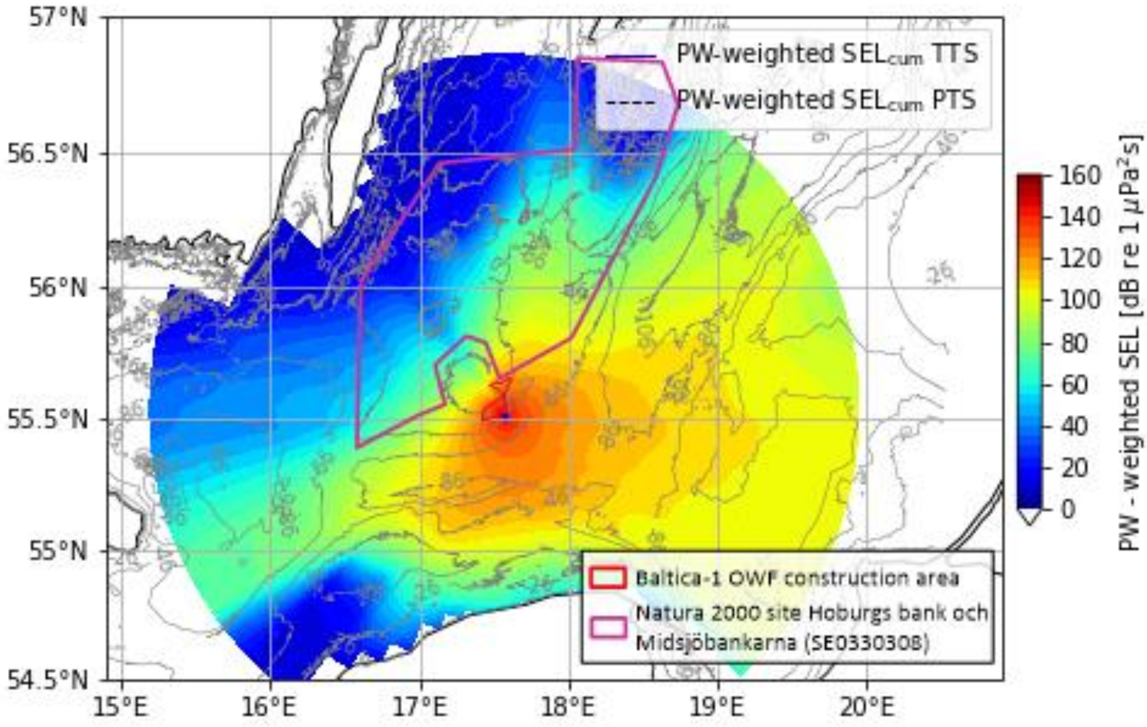



*Figure 6.9.* *The map of PW-weighted SEL $_{cum}$ in the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with a BBC applied*

### 6.1.1.3 Fish with swim bladders

The maximum range of behavioural response and cumulative TTS for fish with swim bladders exceeded the model domain range of 150 km from the source, with the largest areas of impact among the analysed thresholds.

The predicted ranges of cumulative TTS and PTS were higher than the values obtained for a single blow, while the TTS ranges were higher than the ones obtained for the PTS.

All ranges calculated for individual threshold values are shown in tabular form [Table 6.3], while noise propagation maps are presented in the following figures [Figure 6.10–Figure 6.11].

*Table 6.3.* *The ranges and areas of impact calculated for fish with swim bladders in the Baltica-1 OWF area*

| Season | Mitigation type | Effect | unweighted SEL [dB re 1 µPa²s] | | |
|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] |
| Summer | - | Behavioural response | 60.9 | 150 | 17026 |
| | | TTS (single blow) | 0.7 | 0.7 | 1.5 |
| | | TTS (cumulative effect) | 32.9 | 55.8 | 4169 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |
| | | Reversible hearing loss (cumulative effect) | 10.7 | 14.2 | 378 |

| Season | Mitigation type | Effect | unweighted SEL [dB re 1 µPa²s] | | |
|---|---|---|---|---|---|
| | | | Mean distance [km] | Maximum distance [km] | Impact area [km²] |
| | BBC | Behavioural response | 36.5 | 65.9 | 5197 |
| | | TTS (single blow) | 0.2 | 0.2 | 0.1 |
| | | TTS (cumulative effect) | 18.7 | 33.0 | 1278 |
| | | Reversible hearing loss (single blow) | 0.1 | 0.1 | 0.03 |
| | | Reversible hearing loss (cumulative effect) | 4.8 | 5.2 | 73.1 |

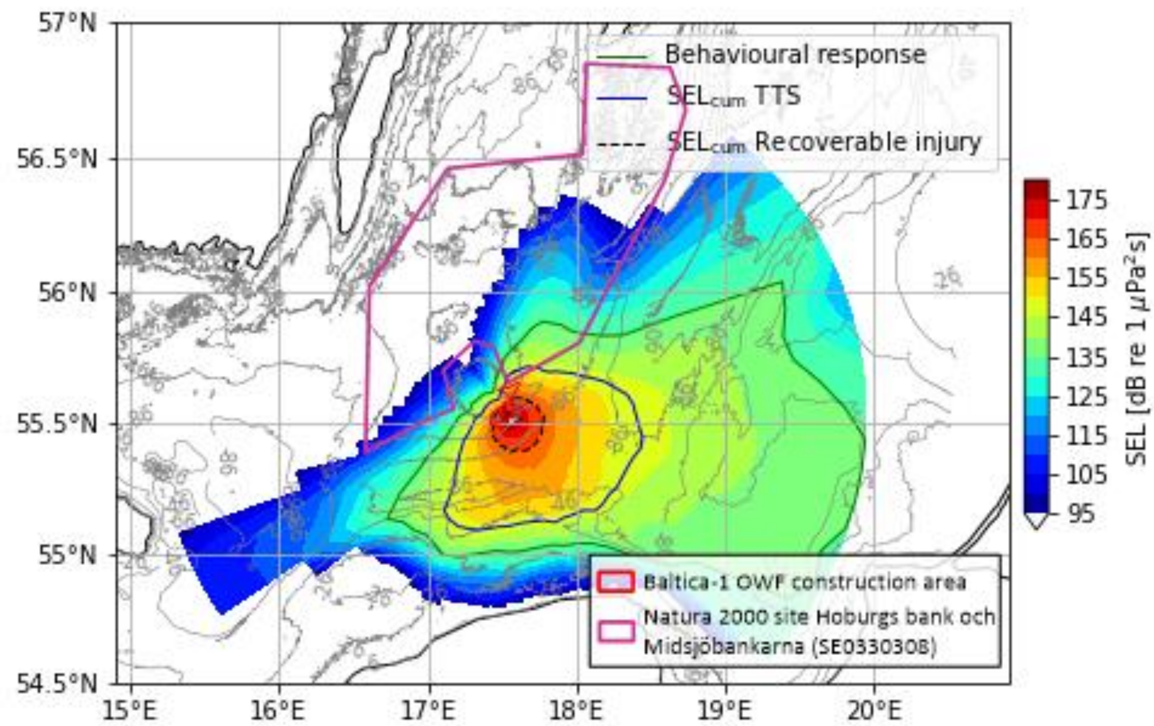



*Figure 6.10. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on fishes with swim bladders*

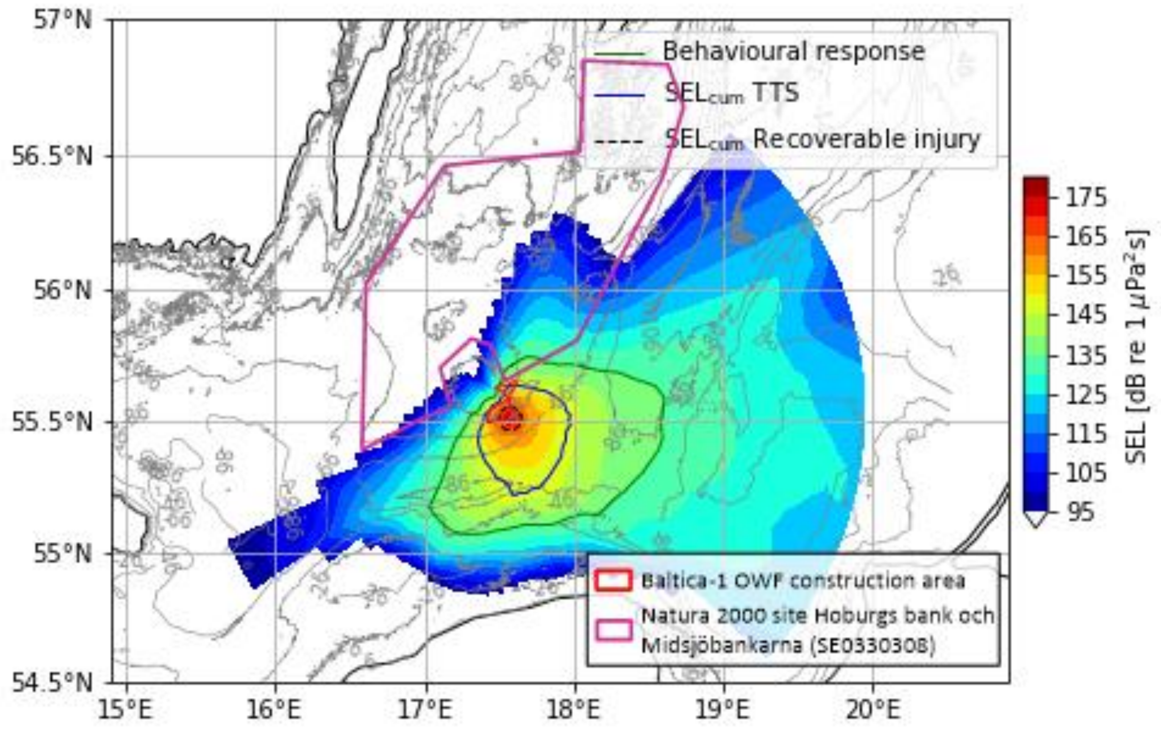



*Figure 6.11. The map of unweighted SEL above the acoustic background in the Baltica-1 OWF area and the ranges of impact on fish with swim bladders with a BBC applied*

## 6.2 THE MODELLING OF NOISE PROPAGATION AS A RESULT OF PILING IN SEVERAL LOCATIONS

This chapter presents the results of acoustic modelling in the summer season performed for simultaneous piling in several locations within the Baltica-1 OWF area and outside of it. The use of mitigation measures in the form of BBC was taken into account. The ranges of impact for individual acoustic thresholds and sound propagation maps are presented.

### 6.2.1 Harbour porpoise

As can be seen in the table below [Table 6.4], the areas of impact increased with the number of piling sources, reaching the highest values in the case of four locations. Noise propagation maps are presented in the following figures [Figure 6.12–Figure 6.17].

*Table 6.4. The areas of impact on the harbour porpoise in the case of simultaneous piling at several locations within and outside the Baltica-1 OWF area (numbers in bold: the highest values for 2 and 3 sources, respectively; piling with a mitigation system applied)*

| **Season** | **Mitigation type** | **Impact area [km$^2$]** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Effect** | **1 source** | **2 sources – < 1 km** | **2 sources – 20 km** | **2 sources – at a significant distance** | **3 sources – 2 < 1 km, 1 = 20 km** | **3 sources – 2 = 20 km, 1 = at a significant distance** | **4 sources** |
| Summer | BBC | Behavioural response | 251 | 329 | **541** | 502 | 612 | **792** | 1043 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | TTS (cumulative effect) | 0.7 | 2.2 | **45.0** | 1.4 | **46.8** | 45.7 | 47.5 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.1 |

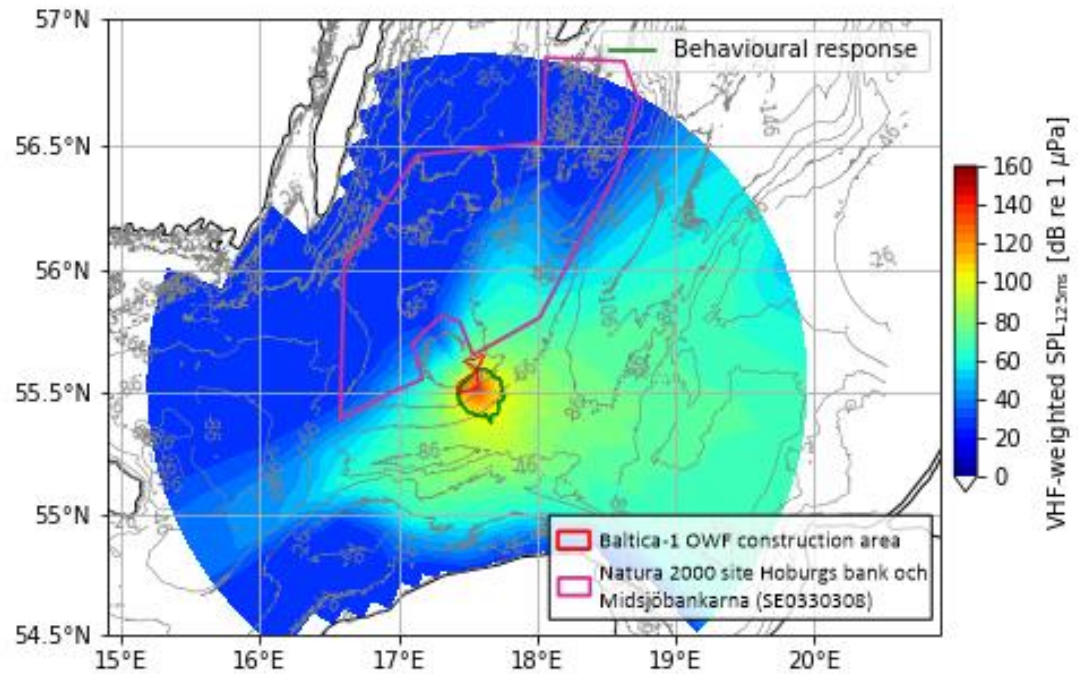



*Figure 6.12. The map of VHF-weighted $SPL_{125ms}$ from piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with a BBC applied*

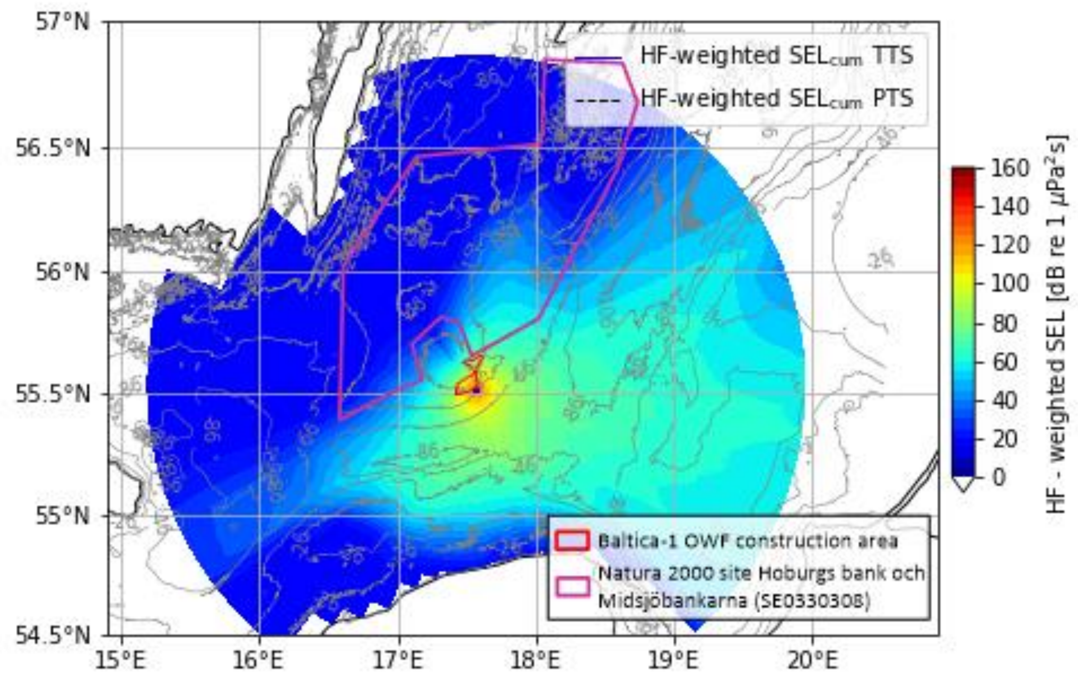



*Figure 6.13. The map of HF-weighted $SEL_{cum}$ from piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the harbour porpoise with a BBC applied*

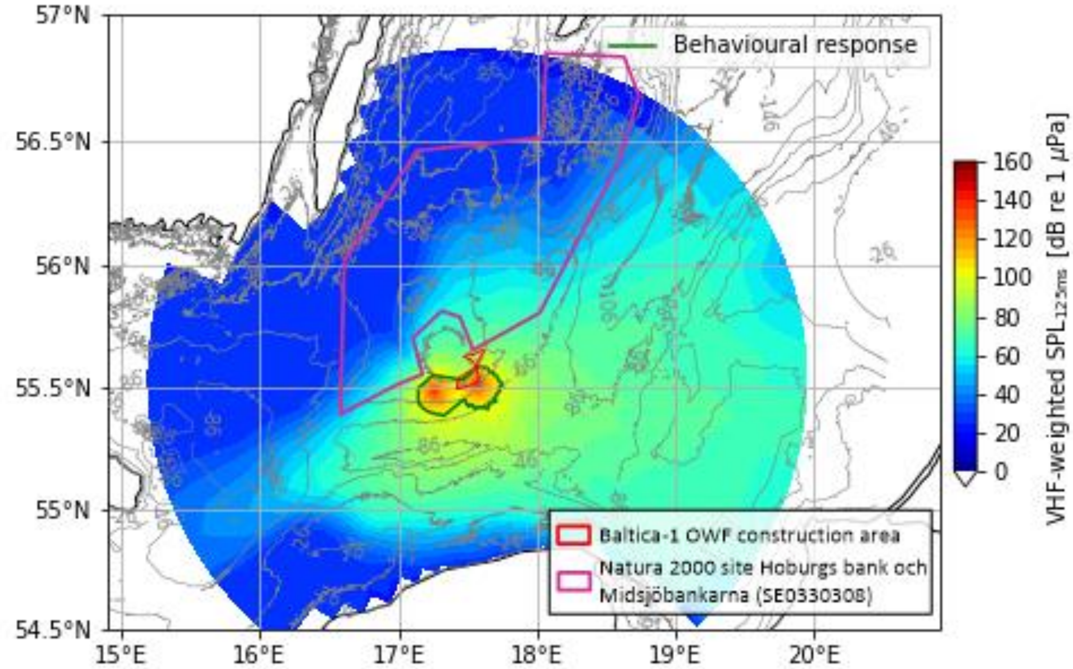



*Figure 6.14. The map of VHF-weighted $SPL_{125ms}$ from piling sources located 20 km apart and the ranges of impact on the harbour porpoise with a BBC applied*

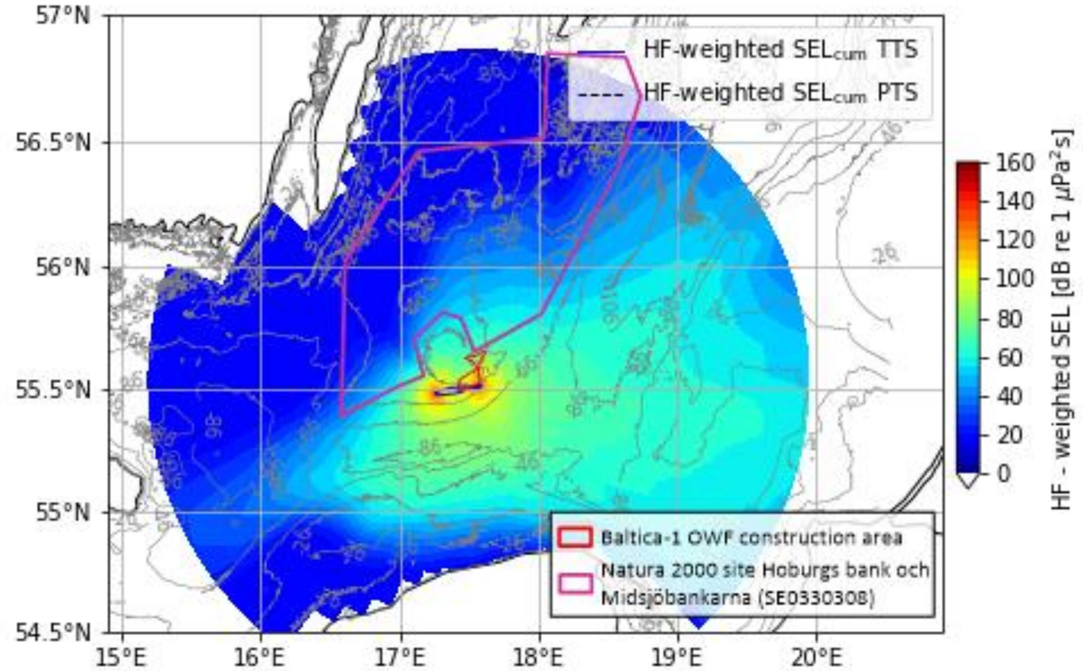



*Figure 6.15. The map of HF-weighted $SEL_{cum}$ from piling sources located 20 km apart and the ranges of impact on the harbour porpoise with a BBC applied*

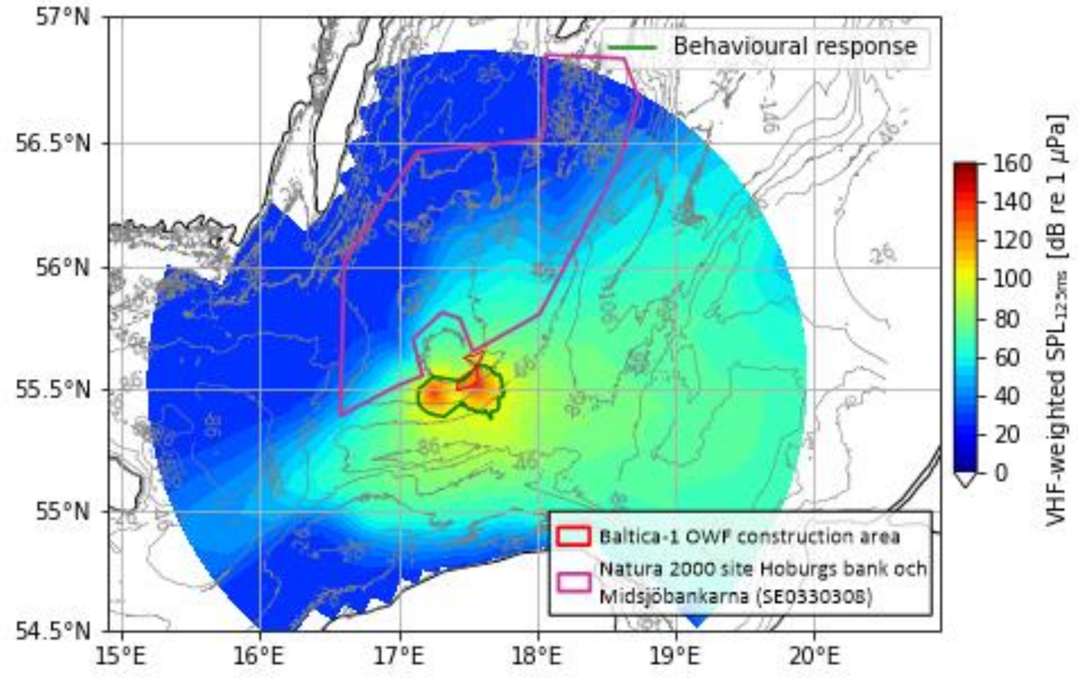



*Figure 6.16. The map of VHF-weighted $SPL_{125ms}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the harbour porpoise with a BBC applied*

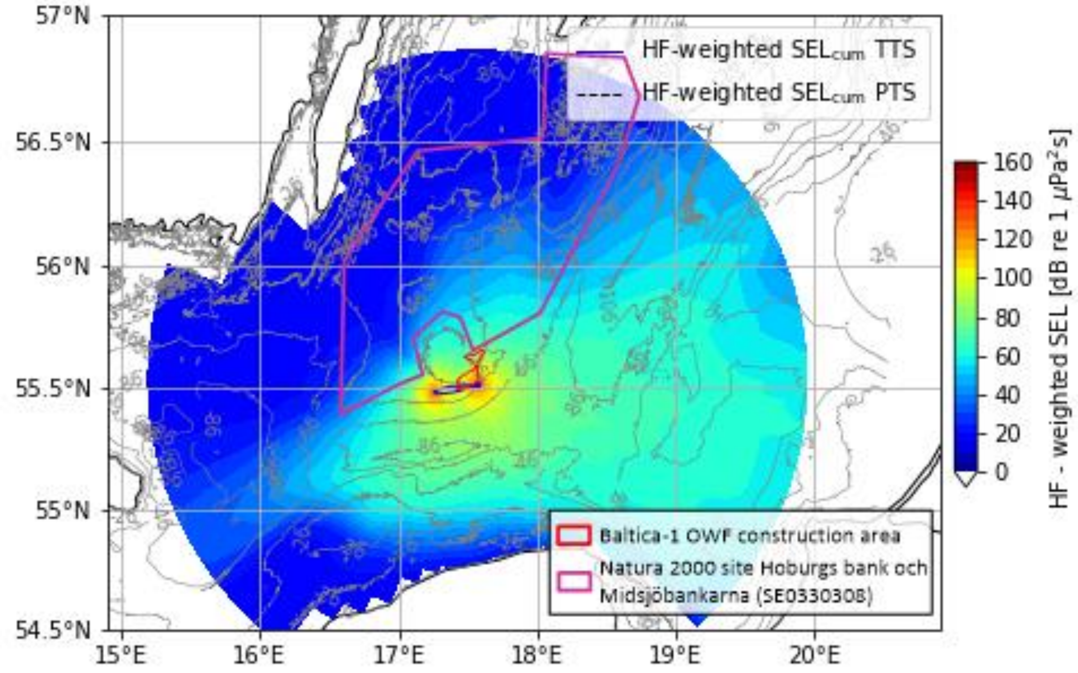



*Figure 6.17. The map of HF-weighted $SEL_{cum}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the harbour porpoise with a BBC applied*

### 6.2.2 Grey and harbour seal

Similarly to the results obtained for the harbour porpoise, the impact areas for seals increased with the number of piling sources, reaching the highest values for four locations. Impact areas and noise propagation maps are presented in the figure below [Table 6.5] and the following figures [Figure 6.18–Figure 6.23].

*Table 6.5. The areas of impact on the grey seal and harbour seal in the case of simultaneous piling at several locations within and outside the Baltica-1 OWF area (numbers in bold: the highest values for 2 and 3 sources, respectively; piling with a mitigation system applied)*

| Season | Mitigation type | Impact area [km$^2$] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Effect | 1 source | 2 sources – < 1 km | 2 sources – 20 km | 2 sources – at a significant distance | 3 sources – 2 < 1 km, 1 = 20 km | 3 sources – 2 = 20 km, 1 = at a significant distance | 4 sources |
| Summer | BBC | Behavioural response | 210 | 347 | **464** | 420 | 482 | **674** | 692 |
| | | TTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.09 |
| | | TTS (cumulative effect) | 3.8 | 306 | **402** | 7.6 | **561** | 406 | 565 |
| | | PTS (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.09 |
| | | PTS (cumulative effect) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.09** | 0.09 |

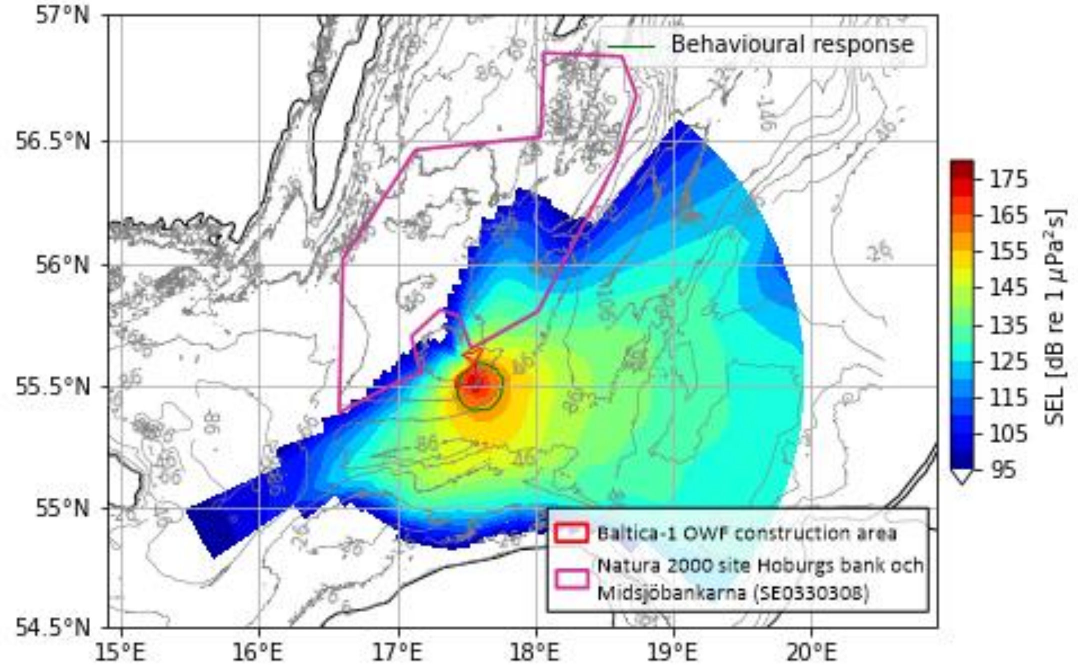



*Figure 6.18.* *The map of unweighted SEL above the acoustic background for piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with a BBC applied*

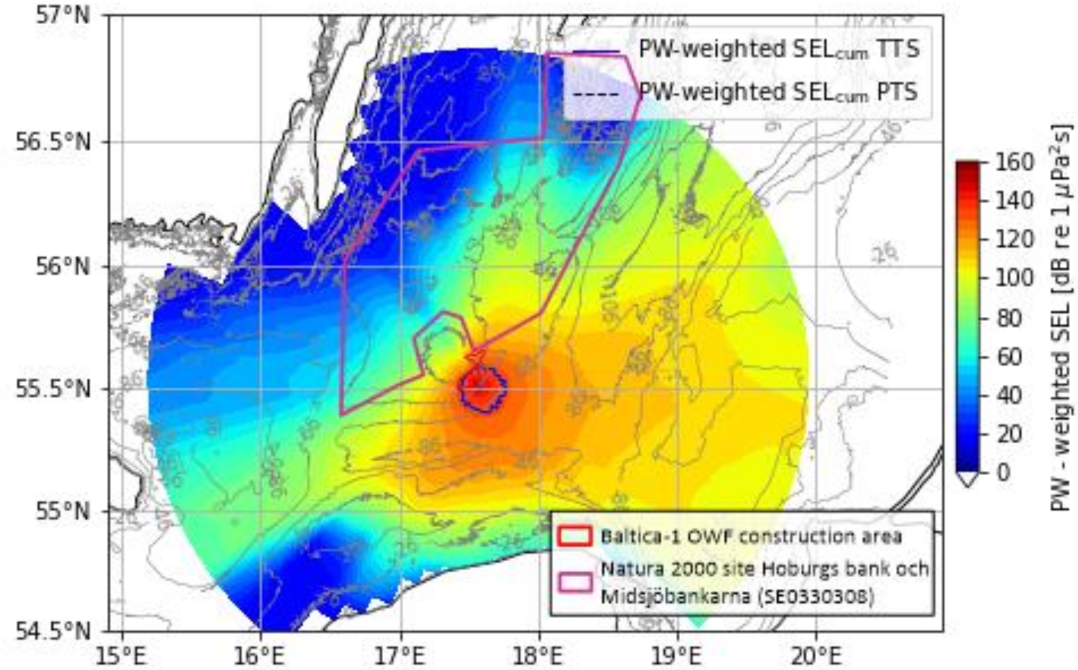



*Figure 6.19.* *The map of PW-weighted $SEL_{cum}$ for piling sources located at a small distance from each other within the Baltica-1 OWF area and the ranges of impact on the grey seal and harbour seal with a BBC applied*

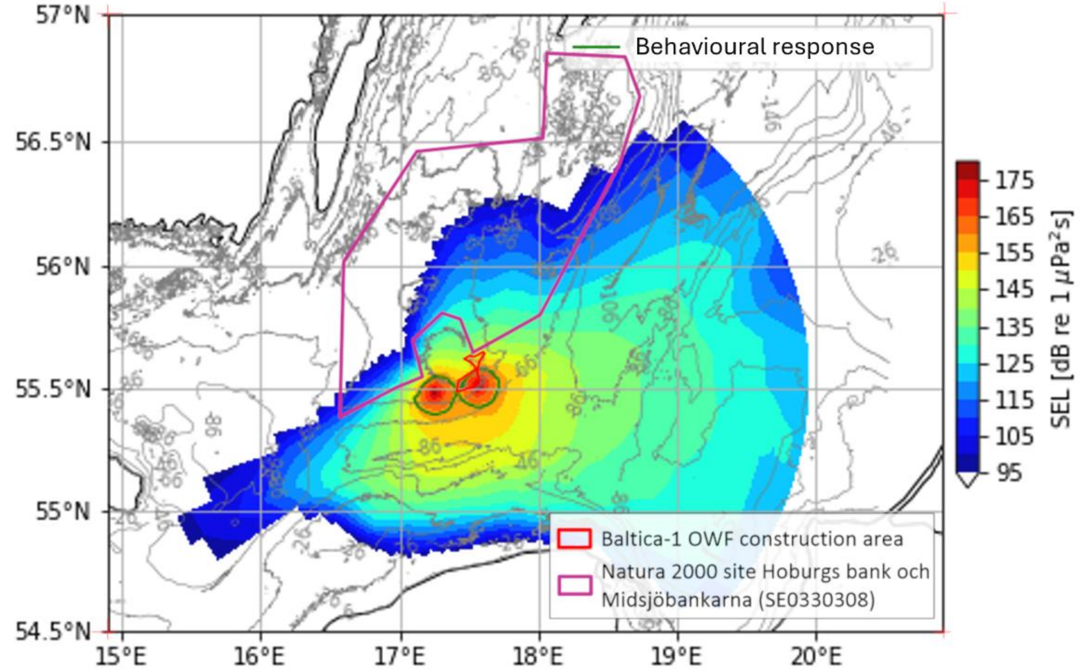



*Figure 6.20. The map of unweighted SEL above the acoustic background for piling sources located at a distance of 20 km from each other and the ranges of impact for the grey seal and harbour seal with a BBC applied*

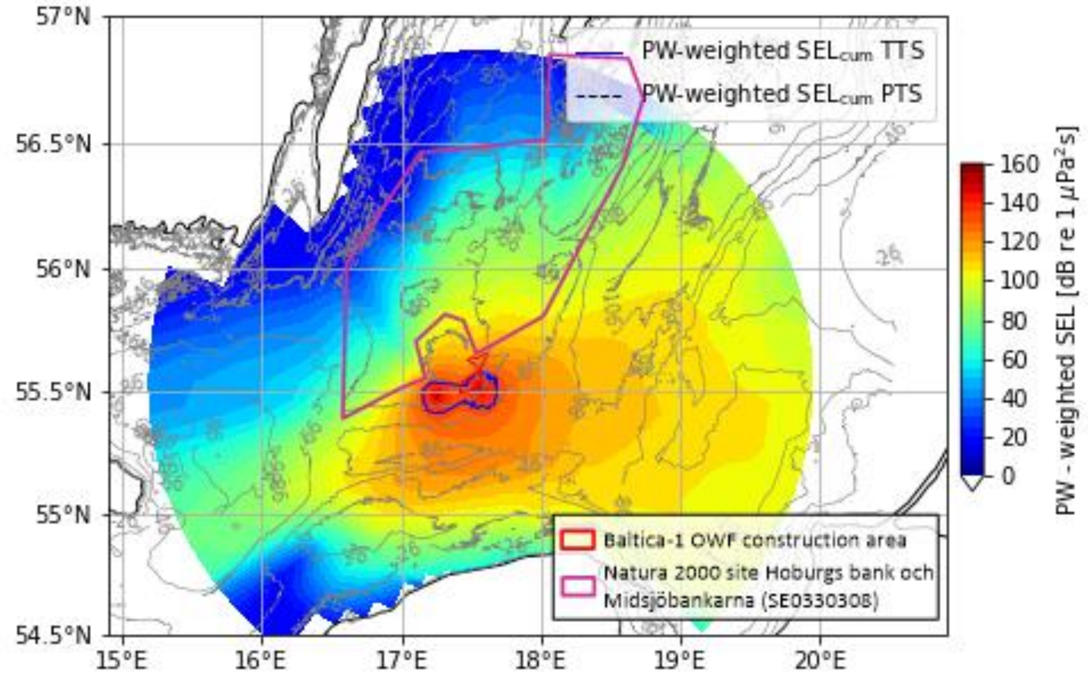



*Figure 6.21. The map of PW-weighted SEL$_{cum}$ for piling sources located 20 km apart and the impact ranges for the grey seal and harbour seal with a BBC applied*

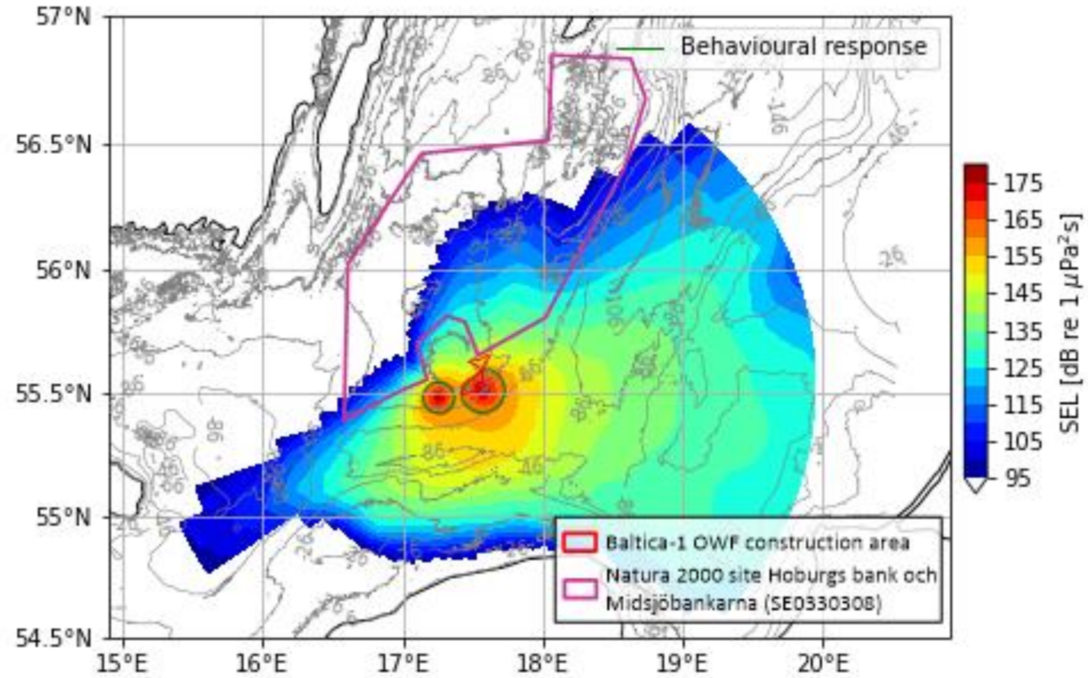



*Figure 6.22. The map of unweighted SEL above the acoustic background for three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the grey seal and harbour seal with a BBC applied*

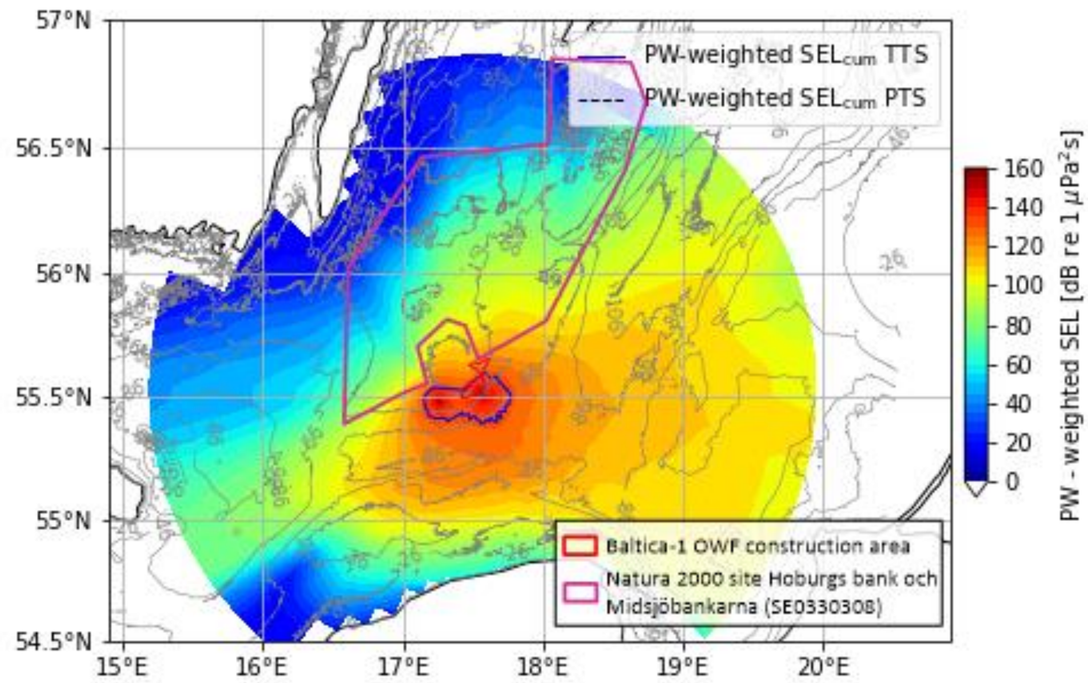



*Figure 6.23. The map of PW-weighted $SEL_{cum}$ from three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on the grey seal and harbour seal with a BBC applied*

### 6.2.3 Fish with swim bladders

Similarly to the results obtained for the harbour porpoise and seals, the impact areas for fish with swim bladders increased with the number of piling sources, reaching the highest values in the case of four locations. The impact areas and noise propagation maps are presented in the table below [Table 6.6] and the following figures [Figure 6.24–Figure 6.26].

*Table 6.6. The areas of impact on fish with swim bladders in the case of simultaneous piling at several locations within and outside the Baltica-1 area (numbers in bold: the highest values for 2 and 3 sources, respectively; piling with a BBC mitigation system applied)*

| **Season** | **Mitigation type** | **Impact area [km$^2$]** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Effect** | **1 source** | **2 sources – < 1 km** | **2 sources – 20 km** | **2 sources – at a significant distance** | **3 sources – 2 < 1 km, 1 = 20 km** | **3 sources – 2 = 20 km, 1 = at a significant distance** | **4 sources** |
| Summer | BBC | Behavioural response | 5197 | 7110 | **17131** | 10394 | 9163 | **22328** | 27525 |
| | | TTS (single blow) | 0.1 | **0.3** | 0.1 | 0.2 | **0.3** | 0.2 | 0.4 |
| | | TTS (cumulative effect) | 1278 | 1955 | **4820** | 2556 | 5471 | **6098** | 7376 |
| | | Reversible hearing loss (single blow) | 0.03 | 0.03 | **0.06** | **0.06** | 0.06 | **0.1** | 0.1 |
| | | Reversible hearing loss (cumulative effect) | 73.1 | 127 | **170** | 146 | 203 | **243** | 316 |

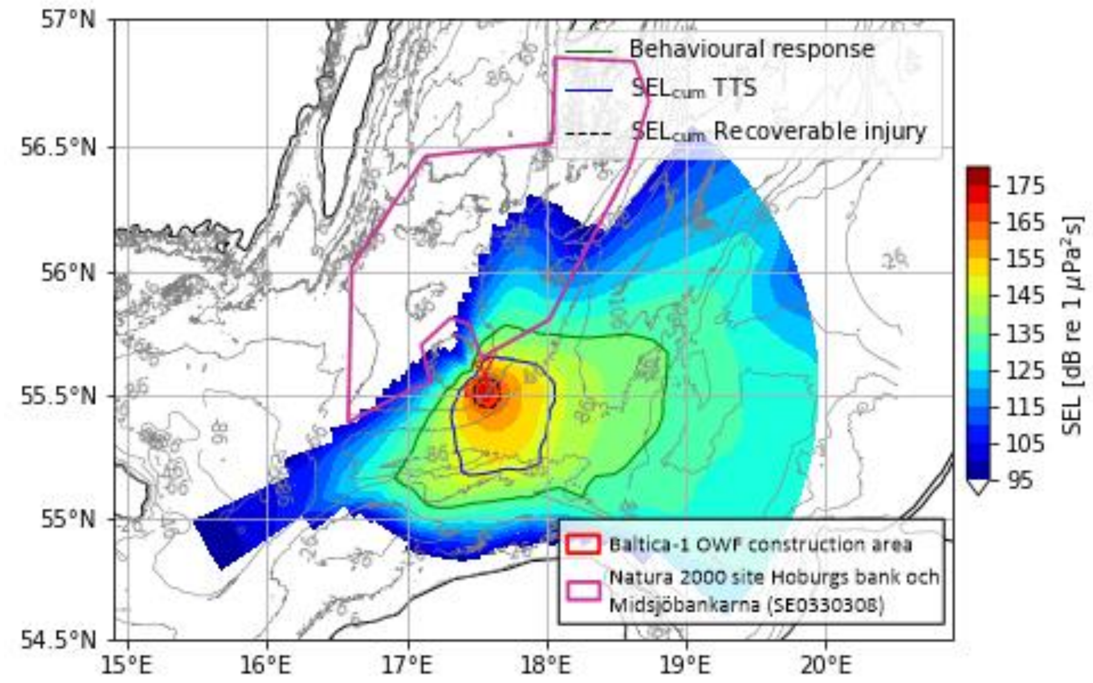



*Figure 6.24. The map of unweighted SEL above the acoustic background for piling sources located at a small distance from each other within the Baltica-1 area and the ranges of impact on fish with swim bladders with a BBC applied*

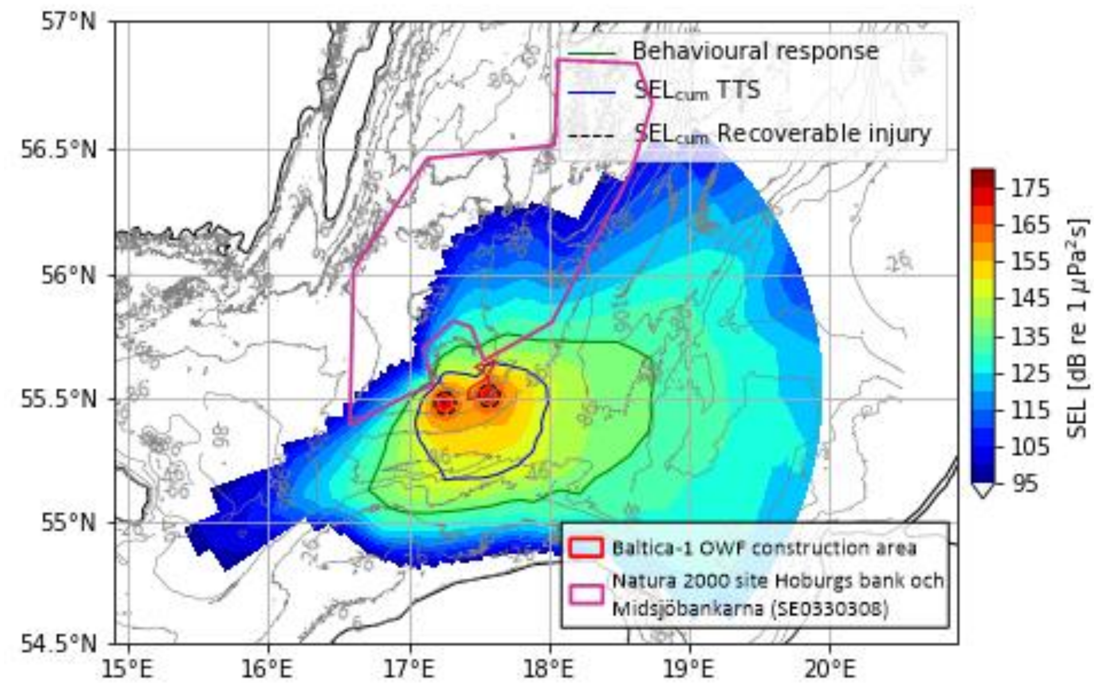



*Figure 6.25. The map of unweighted SEL above the acoustic background for piling sources located 20 km apart and the ranges of impact on fish with swim bladders with a BBC applied*

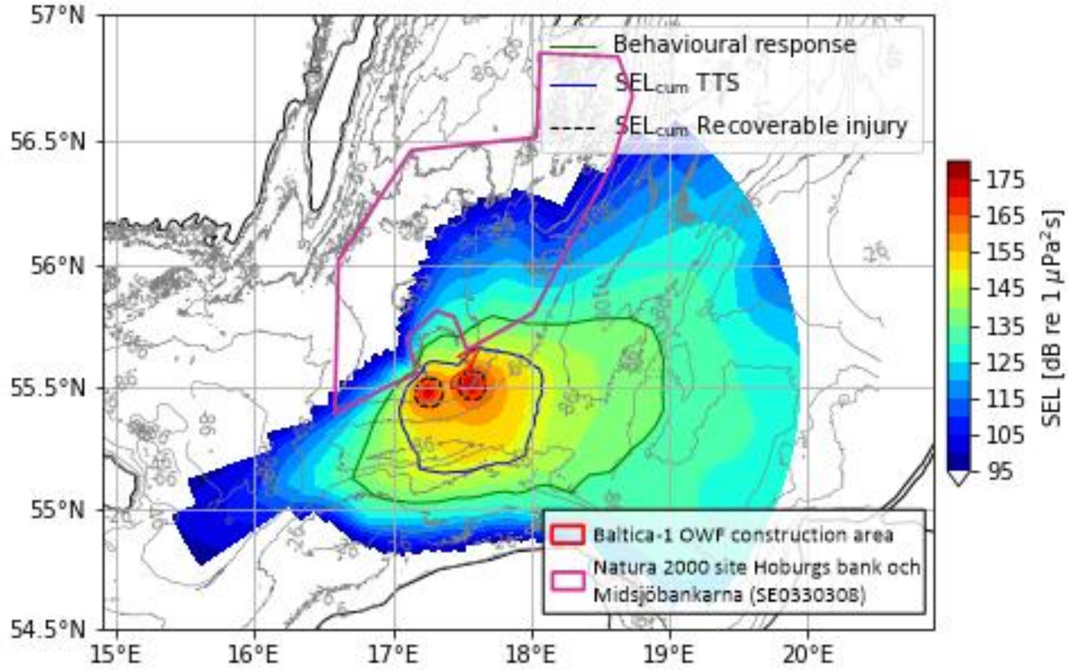



*Figure 6.26. The map of unweighted SEL above the acoustic background for three piling sources, two of which are located at a small distance from each other and the third is 20 km away, and the ranges of impact on fish with swim bladders with a BBC applied*

## 6.3 Noise levels at the boundary of the Natura 2000 area

Presented below are levels of noise heard at the boundary of the Natura 2000 site Hoburgs bank och Midsjöbankarna in the summer season. Analyses were conducted for the harbour porpoise, as it is subject to protection in the above-mentioned area, and additionally, the threshold values for this species are the lowest among the values for the analysed mammals.

### 6.3.1 Piling in a single location

The tables below present the differences between the calculated sound values at the boundary of the Natura 2000 site and the threshold values for scenarios without any mitigation measures applied [Table 6.7] and with the mitigation systems taken into account [Table 6.8]. The corresponding graphs have been developed for the TTS and PTS and presented in the following figures [Figure 6.27–Figure 6.28].

Based on the presented results, it is shown that in the case of piling at a single location, the threshold values of cumulative TTS and PTS will not be exceeded at the boundary of the Swedish Natura 2000 even if no mitigation measures are used. The use of mitigation in the form of a BBC will further contribute to reducing noise to levels well below the determined limits.

*Table 6.7. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the cumulative TTS and PTS limits without any mitigation measures applied*

| Season | Natura 2000 site | Effect | The threshold value of SEL at the boundary of the Natura 2000 site [dB re 1 μPa²s] | Without mitigating measures | |
|---|---|---|---|---|---|
| | | | | The modelled HF-weighted SEL value at the boundary of the Natura 2000 site [dB re 1 μPa²s] | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] |
| Summer | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 138.0 | -2.0 |
| | | PTS (cumulative effect) | 155 | | -17.0 |

*Table 6.8. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the SEL-based weighted TTS and PTS limits for the harbour porpoise with mitigation measures applied*

| Season | Natura 2000 site | Effect | SEL threshold value at the boundary of the Natura 2000 site [dB re 1 μPa²s] | With a BBC | |
|---|---|---|---|---|---|
| | | | | The modelled HF-weighted SEL value at the boundary of the Natura 2000 site [dB re 1 μPa²s] | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] |
| Summer | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 112.6 | -27.4 |
| | | PTS (cumulative effect) | 155 | | -42.4 |

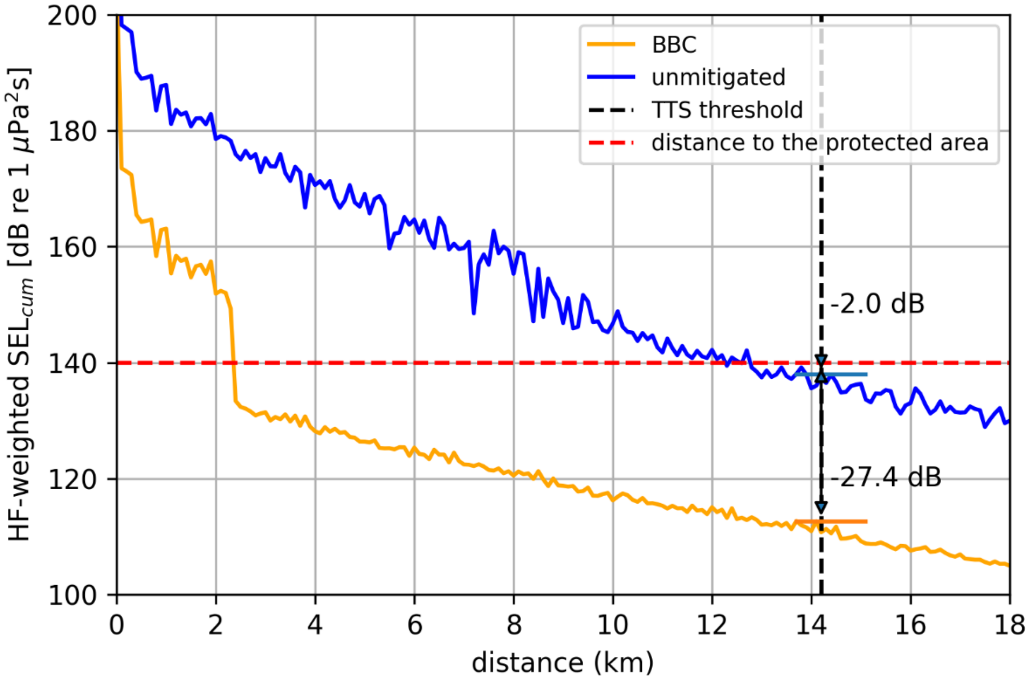



*Figure 6.27. The propagation w piling noise within the Baltic-1 OWF area in relation to the TTS limits for the porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

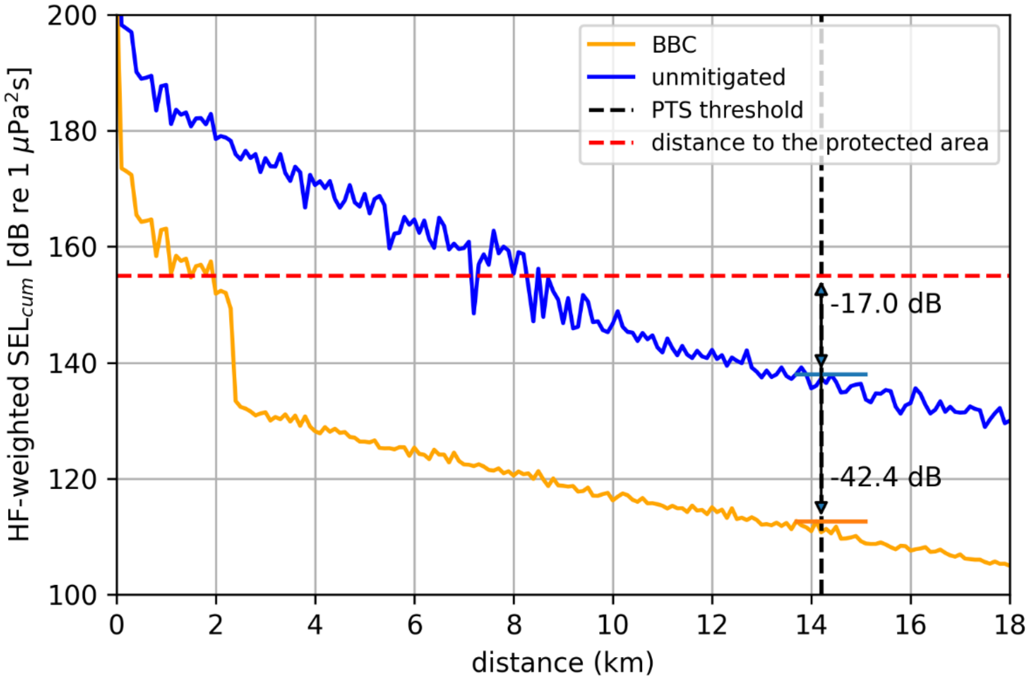



*Figure 6.28. The propagation w piling noise within the Baltic-1 OWF area in relation to the PTS limits for the porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

### 6.3.2 Piling in several locations

The differences in noise levels between the threshold values and the modelled values at the boundary of the Natura 2000 site Hoburgs bank och Midsjöbankarna were calculated also for simultaneous piling in several locations. The results for different numbers of piling locations are presented in the table below [Table 6.9] for the scenario without mitigation measures applied, and in the following table [Table 6.10] for the scenario with mitigation. The corresponding graphs for the TTS and PTS are presented in the following figures [Figure 6.29–Figure 6.34].

Based on the obtained results, it was concluded that in the case of piling works in several locations, the TTS threshold values will be exceeded on the boundary of the Natura 2000 site in question if two pilings are conducted at a short distance from each other. The use of a mitigation measure in the form of BBC will contribute to reducing noise levels below the designated limit in all analysed scenarios.

*Table 6.9. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the TTS and PTS limits for the harbour porpoise in the case of simultaneous piling in several locations within and outside the Baltica-1 area without any mitigation measures applied*

| Season | Sound sources | Natura 2000 site | Effect | SEL threshold value at the boundary of the Natura 2000 site [dB re 1 µPa$^2$s] | Without mitigating measures | |
|---|---|---|---|---|---|---|
| | | | | | The modelled HF-weighted SEL at the boundary of the Natura 2000 site [dB re 1 µPa$^2$s] | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] |
| Summer | 2 sources – <1 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 141.5 | +1.5 |
| | | | PTS (cumulative effect) | 155 | | -13.5 |
| | 2 sources – 20 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 138.1 | -1.9 |
| | | | PTS (cumulative effect) | 155 | | -16.9 |
| | 3 sources – 2 <1 km, 1 = 20 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 141.6 | +1.6 |
| | | | PTS (cumulative effect) | 155 | | -13.4 |

*Table 6.10. The differences in noise levels recorded at the boundary of the Natura 2000 site according to the TTS and PTS limits for the harbour porpoise in the case of simultaneous piling in several locations within and outside the Baltica-1 area with the mitigation measures applied*

| Season | Sound sources | Natura 2000 site | Effect | The threshold value of SEL at the boundary of the Natura 2000 site [dB re 1 µPa$^2$s] | With a BBC | |
|---|---|---|---|---|---|---|
| | | | | | The modelled HF-weighted SEL at the boundary of the Natura 2000 site [dB re 1 µPa$^2$s] | The difference in the modelled level of HF-weighted SEL and the threshold value [dB] |
| Summer | 2 sources – < 1 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 115.6 | -24.4 |
| | | | PTS (cumulative effect) | 155 | | -39.4 |
| | 2 sources – 20 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 113.1 | -26.9 |
| | | | PTS (cumulative effect) | 155 | | -41.9 |
| | 3 sources – 2 < 1km, 1 = 20 km | Hoburgs bank och Midsjöbankarna | TTS (cumulative effect) | 140 | 115.9 | -24.1 |
| | | | PTS (cumulative effect) | 155 | | -39.1 |

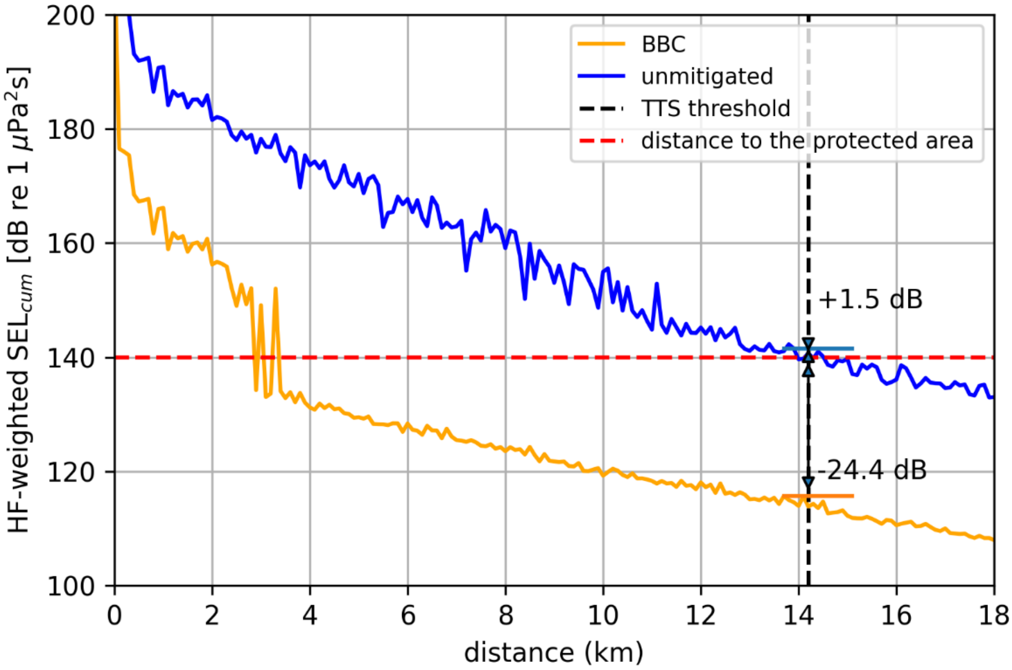



*Figure 6.29.* *The propagation of piling noise from simultaneous piling in two close locations within the Baltica-1 OWF area in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

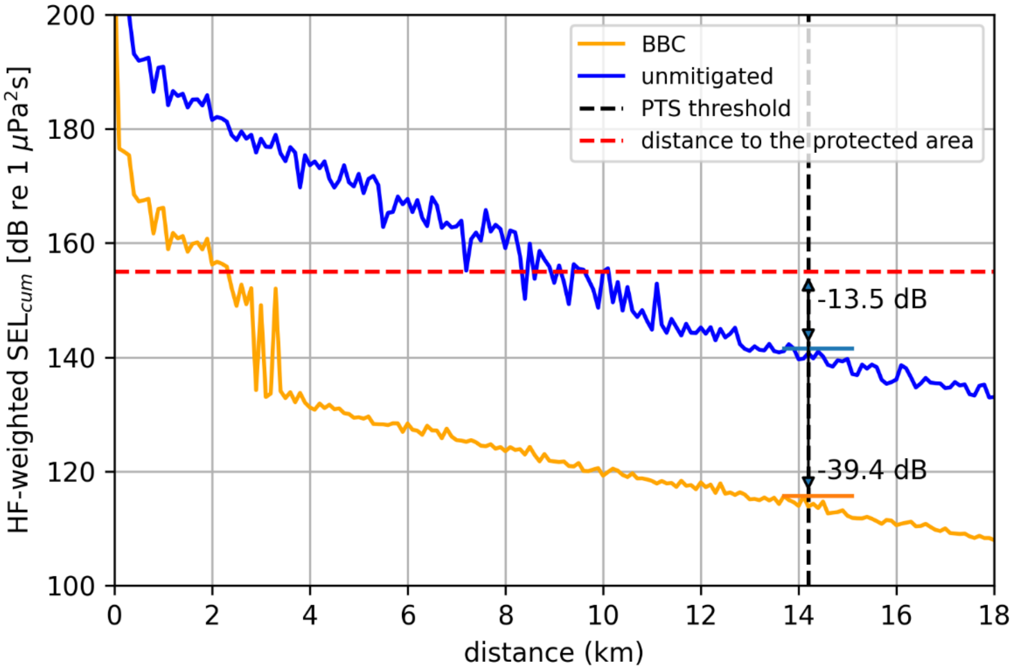



*Figure 6.30.* *The propagation of piling noise from simultaneous piling in two close locations within the Baltica-1 OWF area in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

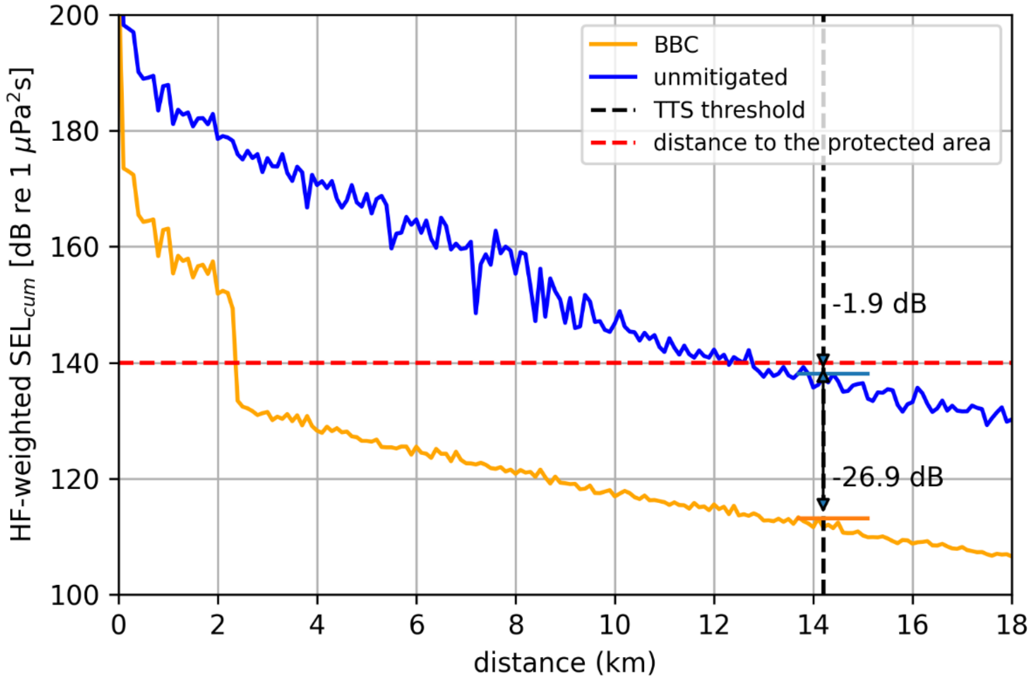



*Figure 6.31.* *Noise propagation during simultaneous piling in two locations 20 km apart in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

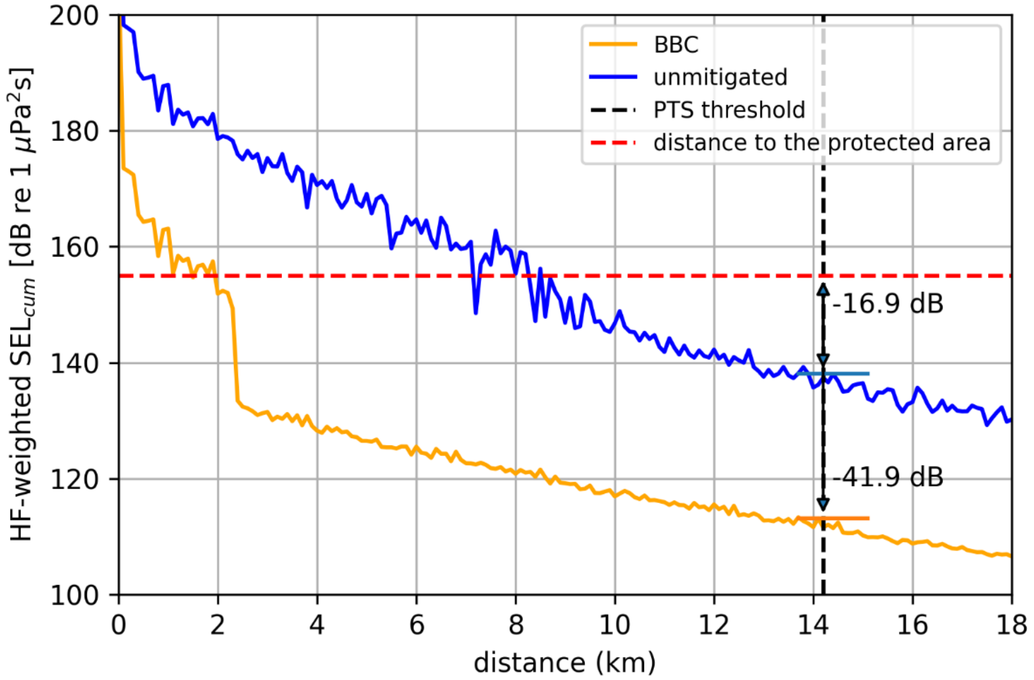



*Figure 6.32.* *Noise propagation during simultaneous piling in two locations 20 km apart in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

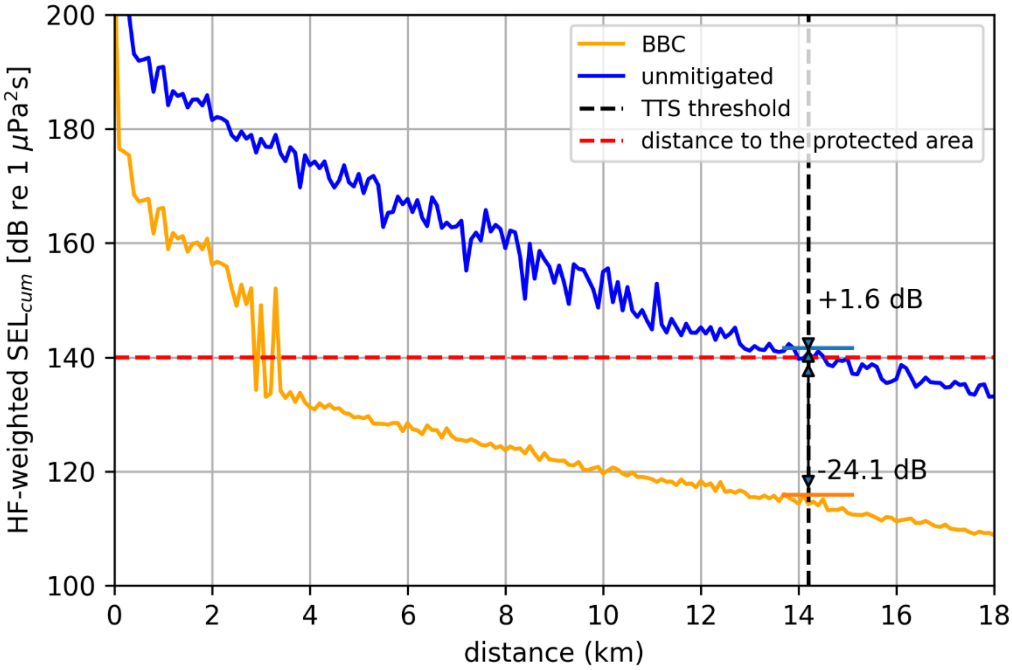



*Figure 6.33.* *Noise propagation during simultaneous piling in two close locations and one located 20 km away within the Baltica-1 OWF area in relation to the TTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

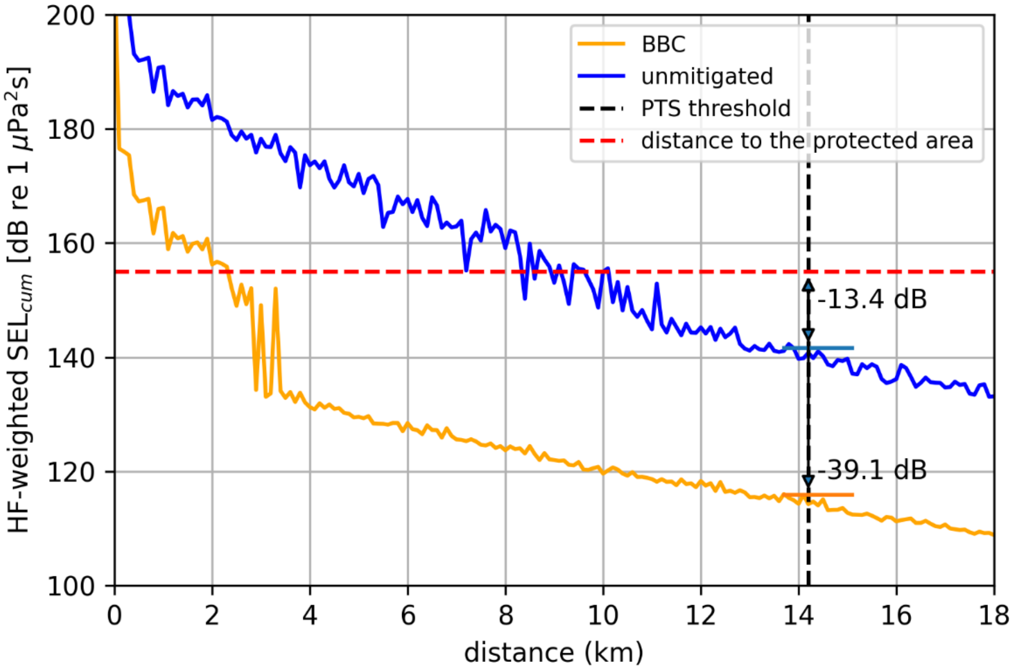



*Figure 6.34.* *Noise propagation during simultaneous piling in two close locations and one located 20 km away within the Baltica-1 OWF area in relation to the PTS limits for the harbour porpoise in the Swedish Natura 2000 site Hoburgs bank och Midsjöbankarna*

## 6.4 IMPACT ON THE NATURA 2000 SITE

The analyses of impact in the Swedish Natura 2000 site were conducted for the behavioural response. They showed that as a result of piling in one location, the range of impact causing behavioural response will not cover the Natura 2000 site if mitigation measures in the form of a BBC are applied.

The impact ranges and the corresponding percentages of coverage of the Swedish Natura 2000 site are presented below [Table 6.11].

*Table 6.11. The ranges and areas of impact causing a behavioural response in the harbour porpoise, calculated for the southern location in the Baltica-1 OWF area and the percentage of coverage of the Natura 2000 site Hoburgs bank och Midsjöbankarna*

| Season | Mitigation type | Effect | Threshold value | Mean distance [km] | Maximum distance [km] | Impact area [$km^2$] | The percentage of coverage of the Natura 2000 site [%] | The value of VHF-weighted $SPL_{125ms}$ at the boundary of the Natura 2000 site |
|---|---|---|---|---|---|---|---|---|
| Summer | BBC | Behavioural response | 103 SPL VHF-weighted | 8.8 | 12.3 | 251 | 0 | 85.6 |

# 7 THE SUMMARY OF THE RESULTS AND CONCLUSIONS

To conclude, this analysis has shown that the piling planned to be conducted in the Baltica-1 offshore wind farm area could cause considerable impact ranges and associated impacts on harbour porpoises, seals, and fish with swim bladders. This applies particularly to the results obtained for the winter season and the northern location, where the ranges of the analysed effects in relation to marine mammals and fish with swim bladders were the highest among the analysed scenarios. It should be noted that, in the case of fish, there are still large gaps in knowledge regarding the impact of underwater noise on this group of animals. For this reason, the ranges of impacts obtained in the modelling should be treated with caution. The results presented in the Report may be overestimated, as they are based on conservative assumptions.

The results of the analysis indicated that ranges relative to threshold values were generally higher for the harbour porpoise than those for seal species due to lower threshold values for individual effects and different sound-weighting functions for cetaceans, which use higher frequency sounds than phocids. The largest ranges of impact for marine mammals were obtained for the behavioural response, except for the cumulative TTS for seals. This is due to the good propagation of frequencies, which dominate in the results based on PW-weighted levels combined with the high number of considered blows. The results obtained for the threshold values based on SEL were higher than those obtained for $SPL_{peak}$. For the fish species, the highest ranges and areas of impact were recorded for the behavioural response.

The results obtained further indicate that the planned piling in the northern part of the Baltica-1 OWF may have a potentially negative impact on the nearby Natura 2000 site if mitigation measures with adequate effectiveness are not applied, in particular, if piling takes place in the winter season.

As shown in the Report, the use of a mitigation measure in the form of a big bubble curtain is likely to lead to an insufficient reduction of noise from piling, especially in the winter season in the northern location. The ranges of impact related especially to the cumulative TTS and behavioural response in all the animal groups discussed remain at a high level. Only the application of the HSD + DBBC or IQIP + DBBC system will lead to a significant reduction in the ranges of impact in relation to the cumulative effects. It is worth emphasising that the application of the IQIP + DBBC system, due to the highest reductions in broadband SEL among all the systems analysed, is characterised by the highest reduction in the value of unweighted SEL, i.e. the behavioural response in seals and all effects in fish with swim bladders, while the expected reductions in cumulative TTS and PTS in the harbour porpoise and seals may be lower than in the case of HSD + DBBC.

It is also important that in the case of piling in the northern location, noise levels at the boundary of the Natura 2000 site Hoburgs bank och Midsjöbankarna are above the threshold values for the TTS and PTS for the harbour porpoise in both analysed seasons. Only the use of a noise reduction system in the form of HSD + DBBC or IQIP + DBBC may reduce the range of cumulative PTS and TTS for the harbour porpoise in the summer season, while none of the analysed measures is sufficient to reduce cumulative TTS in the winter season. The use of the above-mentioned systems does not always provide sufficient reduction of noise levels in the case of simultaneous piling in multiple locations, regardless of the season when piling takes place. In the case of the central and southern locations, due to the greater distance from the protected area, the effectiveness of the mitigation measures used is greater and, as the analyses have indicated, the use of the HSD + DBBC system in the central location and a single big bubble curtain in the southern location will effectively contribute to reducing noise levels at the boundary of the protected area to an acceptable level.

The estimations of the impact causing a behavioural response in the Natura 2000 site showed that even after the use of noise mitigation measures, the impact on the harbour porpoise may cover at least 2.5% of the area in winter in the case of the northern location. In the case of the summer season, this percentage may be reduced to 0.4% after appropriate mitigation measures are applied. In the case of the central and southern locations, with reductions in the form of HSD + DBBC and BBC, respectively, no impact on the area discussed is expected.

Based on the simulations for a single location, the impact areas for harbour porpoises, seals, and fish with swim bladders were calculated for up to four locations of simultaneous piling at different distances from each other. The results of cumulative simulations were used to define the farthest-reaching scenario for a maximum of four piling locations, which were independent of the distances between the sources and particular locations within the following OWF areas: Bałtyk I, Kriegers Flak I, Kriegers Flak II Nord, Kriegers Flak II Syd, Energy Island Bornholm, Njord, Öland-Hoburg I, Baltic Central, Baltic Offshore Beta, Virrus, Neptunus, Södra Victoria, Bornholm Bassin Øst, and Baltic Edge. The maximum estimated ranges of impact areas are valid for all distances between piling sites, regardless of their location within different OWFs.

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