Bilaga 4

Konsekvensbedömning av undervattensbuller - fisk och marina däggdjur

Del 1: Sammandrag på svenska

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Havsbaserad vindkraftspark Laine

Sammanfattning - Konsekvensbedömning av undervattensbuller - fisk och marina däggdjur

OX2 Finland

Date: 5 oktober 2023

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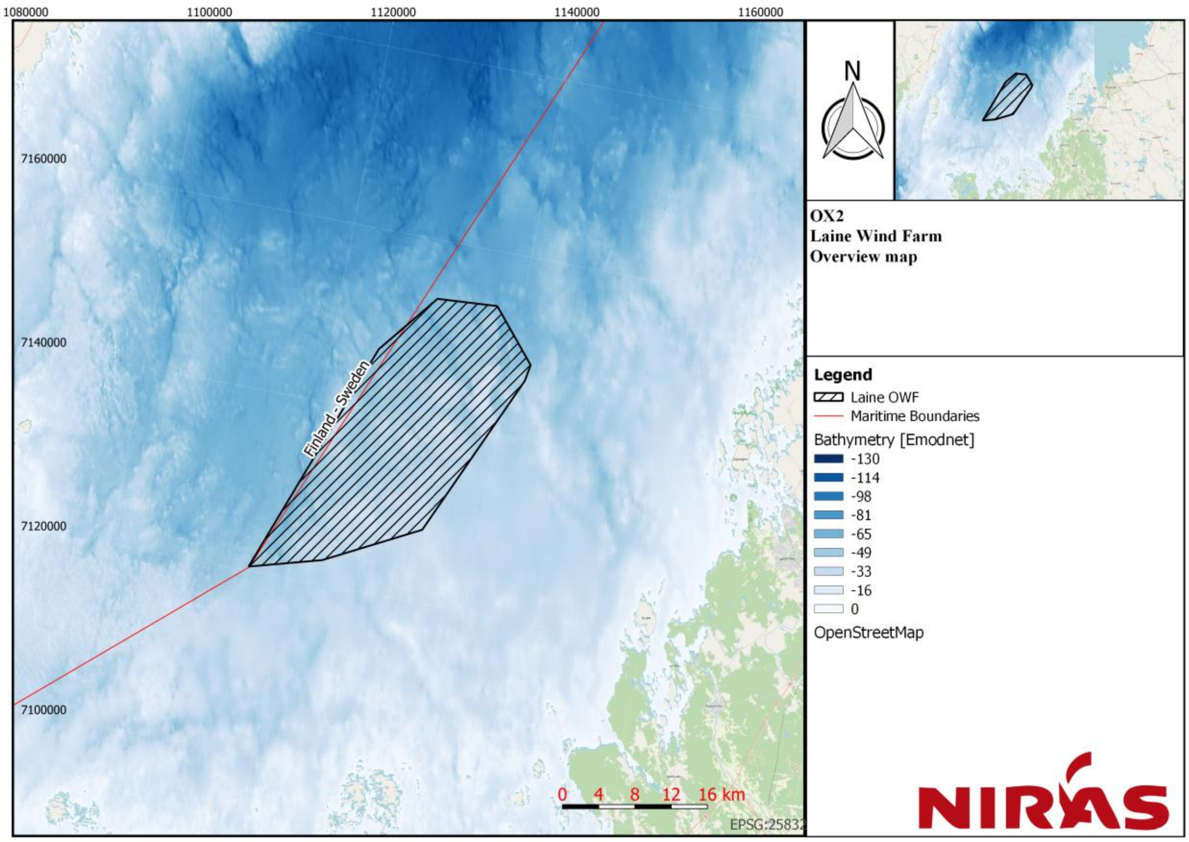
1. Inledning

OX2 AB planerar att etablera den havsbaserade vindkraftsparken Laine i Bottenviken i Finlands ekonomiska zon (EEZ) (Figur 1.1). Denna rapport sammanfattar konsekvensbedömningen av undervattensbuller för fisk och marina däggdjur under bygg- och driftsfasen.

Vindkraftsparken Laine ligger i den finska delen av Bottenviken, cirka 30 km väster om Jakobstad och 25 km från kusten (se Figur 1.1). Projektområdet är cirka 451 km^2 stort. Projektet omfattar installation av upp till 150 vindkraftverk med en effekt på 15-25 MW för varje turbin. Grundläggningstyperna är ännu inte fastställda. Monopilefundament med en diameter på upp till 18 m, jacketfundament med 3 eller 4 ben och upp till 8 m långa pålar, eller alternativa fundament som flytande fundament, gravitationsfundament eller sugkassuner kan användas antingen uteslutande eller i kombination.



Figur 1.1: Översikt över den havsbaserade vindkraftsparken Laine (svart) och det omgivande området.

2. Simulering av undervattensbuller

Under byggtiden är den mest betydande miljöpåverkan på fisk och marina däggdjur undervattensbuller från installationsaktiviteter (t.ex. pålning) och fartygstrafik (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006). Pålning antas ha den mest störande effekten på marina djur. Det kan orsaka maskering av kommunikationssignaler, undvikande reaktioner, TTS (tillfällig) och PTS (permanent) förskjutning av hörtröskeln och i värsta fall akustisk trauma på icke-auditiv vävnad (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006). Dessutom kan pålningsbuller orsaka en tillfällig förlust av livsmiljöer genom att marina däggdjur och fiskar flyttar.

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2.1. Metoder

Riktlinjer för TTS hos fiskarter finns på Tabell 2.1. Här representerar torsk fiskar utan direkt koppling mellan simblåsan och inneröratat, som lax, nors och sik, som alla förekommer i projektområdet. Tröskelvärden för vävnadsskador och hörselnedsättning som leder till dödlighet hos fisk, romkorn och yngel anges också. Fiskarter utan simblåsa, främst bottenlevande arter, är mycket mindre känsliga för buller och man kan förvänta sig att de faktiska toleranströsklarna för demersala fiskar är högre än för pelagiska fiskar. Eftersom informationen om tröskelvärden är mycket begränsad används dock tröskelvärdena för de minst toleranta fiskarterna för alla arter, inklusive demersala arter, i denna analys.

Tabell 2.1: Oviktade tröskelkriterier för fisk (Andersson, et al., 2016), (Popper, et al., 2014).

Arter	Simhastighet [m/s]	Artspecifika oviktade tröskelvärden (Impulsiv)	
		$L_{E,cum,24h,unweighted}$	
		Temporär hörselnedsättning (TTS) [dB]	Skada [dB]
Stationär fisk*	0	186	204
Ung torsk	0,38	186	204
Vuxen torsk	0,9	186	204
Strömming	1,04	186	204
Yngel och ägg	-	-	207

*Fiskar som inte flyr under bullerpåverkan

Baserat på den senaste vetenskapliga litteraturen rekommenderas att $L_{E,cum,24h}$ och frekvensviktning används för att bedöma TTS och PTS hos äkta sälar (se Tabell 2.2). Det finns en generell brist på kvantitativ information om undvikande beteende och påverkansområden för sälar som exponeras för pålningsbuller och de få studier som finns pekar i olika riktningar. Som ett försiktigt angreppssätt har det antagits att sälar reagerar på undervattensbuller från pålning på samma avstånd som tumlare, även om detta sannolikt är ett konservativt angreppssätt. Ett beteendetröskelvärde för tumlare på 103 dB $L_{p,125ms}$ VHF-viktat används därför för sälar (se Tabell 2.2).

Tabell 2.2: Artspecifika viktade tröskelkriterier för öronlösa sälar. Detta är en reviderad version av tabell AE-1 i NOAA (2018) *för att belysa de viktiga arterna i projektområdet* (NOAA, 2018) *inklusive beteendemässig respons. "xx" anger viktningsfunktionen.*

Arter	Artspecifika viktade tröskelvärden (icke-impulsiva)		Artspecifika viktade tröskelvärden (Impulsiv)		
	$L_{E,cum,24h,xx}$		$L_{E,cum,24h,xx}$		$L_{p,125ms,VHF}$
	Temporär hörselnedsättning (TTS) [dB]	Permanent hörselnedsättning (PTS) [dB]	Temporär hörselnedsättning (TTS) [dB]	Permanent hörselnedsättning (PTS) [dB]	Beteende [dB]
Säl (PCW)	181	201	170	185	103

Tröskelvärden som anges som "icke-impulsiva" gäller för kontinuerligt buller (t.ex. fartygsbuller) och även om impulsivt buller förväntas övergå till kontinuerligt buller med avståndet från källan, förväntas denna övergång inte ske inom de avstånd där PTS och/eller TTS potentiellt kan uppstå på grund av dessa aktiviteter.

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För impulsiva källor som pålning gäller strängare tröskelnivåer, som anges i Tabell 2.2, och användning av kriterierna för impulsivt buller ger därför konservativa påverkansintervall. De icke-impulsiva tröskelvärdena kommer inte att behandlas vidare i denna rapport.

2.1.1. Undervattensbuller från pålning

Monopilefundament i stål eller jacketfundament bestående av 3-4 pålar är några av de vanligaste fundamenten vid byggnation av vindkraftsparker till havs eftersom de är lätta att installera på grunda till medelstora vattendjup. Den dominerande metoden som används för att driva ner monopiles och pin-piles i havsbotten är hydraulisk slagpålning, som orsakar höga ljudnivåer under vattnet, som kännetecknas av att de är kortvariga och med en brant ökning av energinivån (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006; Bellmann, et al., 2020)1. Intensiteten i undervattensbullret från pålning beror bland annat på pålens diameter. En påle med större diameter kommer att orsaka pålningsbuller med högre intensitet (Bellmann, et al., 2020).

För att utvärdera effekterna av undervattensbuller från pålning har en detaljerad simulering av undervattensbuller genomförts. En akustisk 3D-modell skapades i dBSea 2.3.4 med hjälp av detaljerad kunskap om batymetri, havsbottnens sedimentsammansättning, vattenpelarens salthalt, temperatur och ljudhastighetsprofiler, samt en källmodell baserad på bästa tillgängliga kunskap.

Simuleringen av undervattensbuller bygger på rekommendationerna från det danska energiministeriet (Energistyrelsen, 2022) samt rekommendationerna från National Marine Fisheries Service (NMFS) (2018) och Southall et al. (2019). I simuleringen av undervattensbuller simuleras den kumulativa ljudexponeringsnivån (SEL_{cum}) under en uppskattad period för en fullständig pålning av en monopile (eftersom det antas att en påle kommer att installeras per dag) och avstånd där PTS och TTS kommer att inträffa uppskattas konservativt.

I beräkningarna har det antagits att en mjukstartsprocedur kommer att tillämpas. I början av pålningsprocessen utförs pålningsslagen med låg energi. Energin per slag ökar sedan gradvis tills full energi används. Med ökande energimängd ökar det avgivna bullret långsamt, vilket gör att de marina djuren kan flytta sig från byggarbetsplatsen innan bullret blir fysiskt skadligt för dem. Det ingår också i modellen att de utsatta djuren kommer att fly från bullret under pålningen.

Simuleringen av undervattensbuller har genomförts för tre platser i projektområdet (se Figur 2.1). Platserna är valda som värsta tänkbara platser där den största spridningen av undervattensbuller förväntas. Simuleringen utfördes för maj, vilket är det värsta fallet när det gäller ljudutbredning (den månad som har högst ljudutbredning) inom tidsramen för etableringen.

Ljudutsläpp under vatten beräknades för ett monopilefundament med en diameter på 18 m samt för ett jacketfundament förankrat med 4 st. pålar med 8 m diameter.

Installationsscenarierna baseras på ett realistiskt konservativt installationsförfarande i förhållande till den nödvändiga slagenergin (6000 kJ), antalet slag (10 400) och den tid som krävs för att slutföra pålningen samt en realistisk generaliserad mjuk start/upptrappningsfas. Pålinstallationsproceduren för båda fundamenttyperna omfattar en mjukstart vid 10 % av maximal slagenergi, en upprampningsfas vid 20 % - 100 % och en konservativ uppskattning av pålning med 100 % slagenergi.

[1] Beroende på substrattypen i projektområdet kan det vara nödvändigt med förborrning innan monopilepålen kan installeras i havsbotten. I det fallet förväntas undervattensbullret minska avsevärt jämfört med pålning utan förborrning, särskilt det kumulativa undervattensbullret (akustisk energi). Det förväntas dock att installationsperioden kommer att bli längre eftersom det kommer att bli avbrott i pålningsarbetet medan förborrningen pågår.

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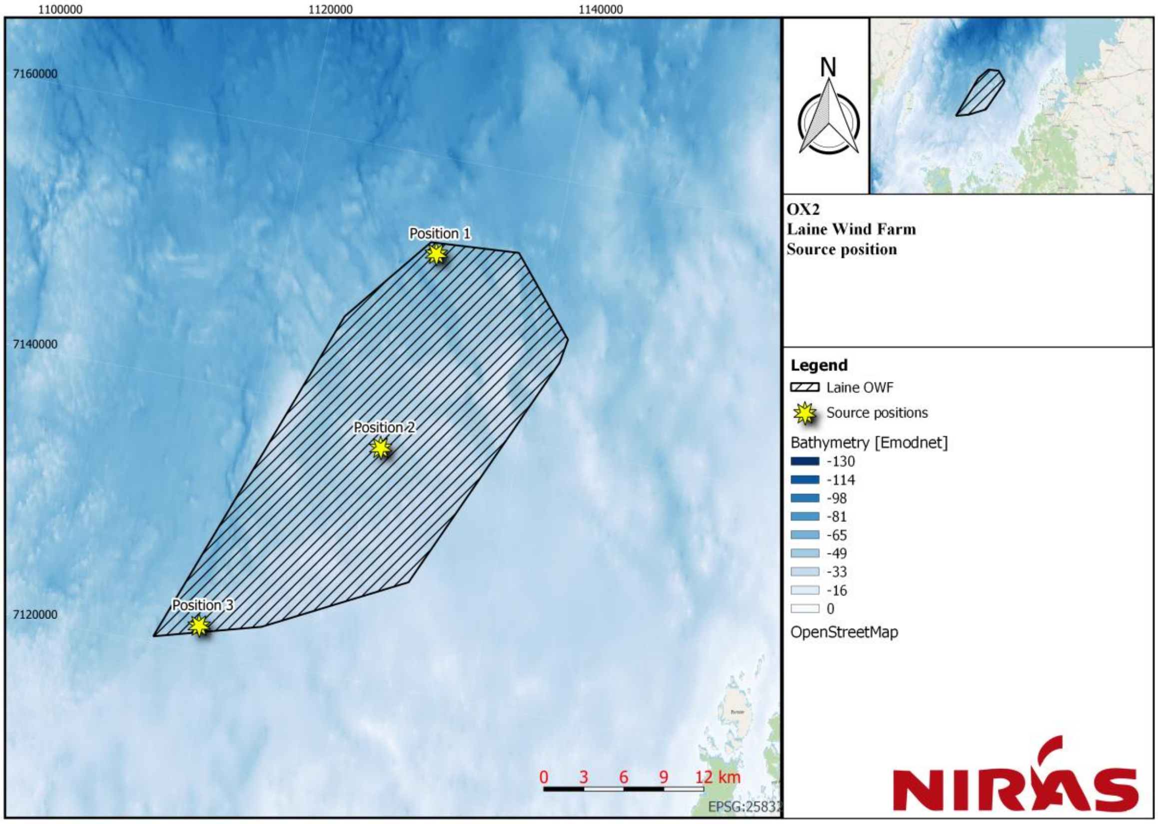

Figur 2.1: Källpositioner som valts för modellering av ljudutbredning (NIRAS, 2023).

För både monopilefundament och jacketfundament inkluderades en dämpningseffekt av typen dubbel stor bubbelridå (DBBC). Simulering utan bullerdämpningssystem inkluderades inte eftersom pålning utan bullerdämpande åtgärder inte anses vara ett möjligt scenario. Det är viktigt att betona att även om ett specifikt system för bullerdämpning har tillämpats i modelleringen av undervattensbuller, kommer installationen inte att vara bunden till det föreslagna systemet för bullerdämpning. Om andra typer av dämpningslösningar tillämpas måste de vara tillräckligt effektiva för att förhindra att de simulerade påverkansavstånden överskrids, eftersom konsekvensbedömningen i denna rapport baseras på de simulerade påverkansavstånden.

2.2. Resultat

Baserat på simuleringen orsakar installationen av en monopile de längsta påverkansområdena för fisk och bedömningen av fisk baseras på installationen av en monopile. De resultat som används för bedömning av fiskpåverkan visas i Tabell 2.3.

Tabell 2.3: Resulterande påverkansavstånd för tröskelvärde på fisk vid användning av DBBC på en 18 m monopile under för det sämsta fallet i månaden maj.

Läge	Avstånd till tröskelvärde		
	Skada (r_{injury})		TTS (r_{TTS})
	Fisk	Yngel och ägg	Fisk
1	< 100–975 m	525 m	6,9–11,5 km
2	< 100–1100 m	650 m	9,4–17,9 km
3	< 100–875 m	525 m	5,9–13,9 km

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Baserat på simuleringen orsakar installation av ett jacketfundament de längsta påverkansavstånden för sälar och följande bedömning för sälar baseras på installation av ett jacketfundament. Resultaten som används för bedömning av påverkan på sälar visas på Tabell 2.4. Den akustiska simuleringen utgår från att marina däggdjur i närheten kommer att röra sig bort från undervattensbullret under pålningen och antar en simhastighet på 1,5 m/s, vilket sannolikt är en försiktig uppskattning för båda sälarterna.

Tabell 2.4: Resulterande avstånd för påverkanströskel för sälar vid användning av DBBC NAS på jacketfundament med 4 x 8 pålar för maj månad som är sämsta fallet.

Läge	**Avstånd till tröskelvärde**			
	PTS (r_{PTS})	TTS (r_{TTS})	Undvikande (r_{behav})	Berört område (undvikande beteende)
	Säl	Säl	Sälar	Sälar
1	< 100 m	< 200 m	7,45 kilometer	122 km^2
2	< 100 m	< 200 m	6,05 km	82 km^2
3	< 100 m	< 200 m	6,05 km	63 km^2

De simulerade konsekvensområdena i värsta tänkbara fall för beteendemässiga undvikande reaktioner för sälar beräknades och visas i Figur 2.

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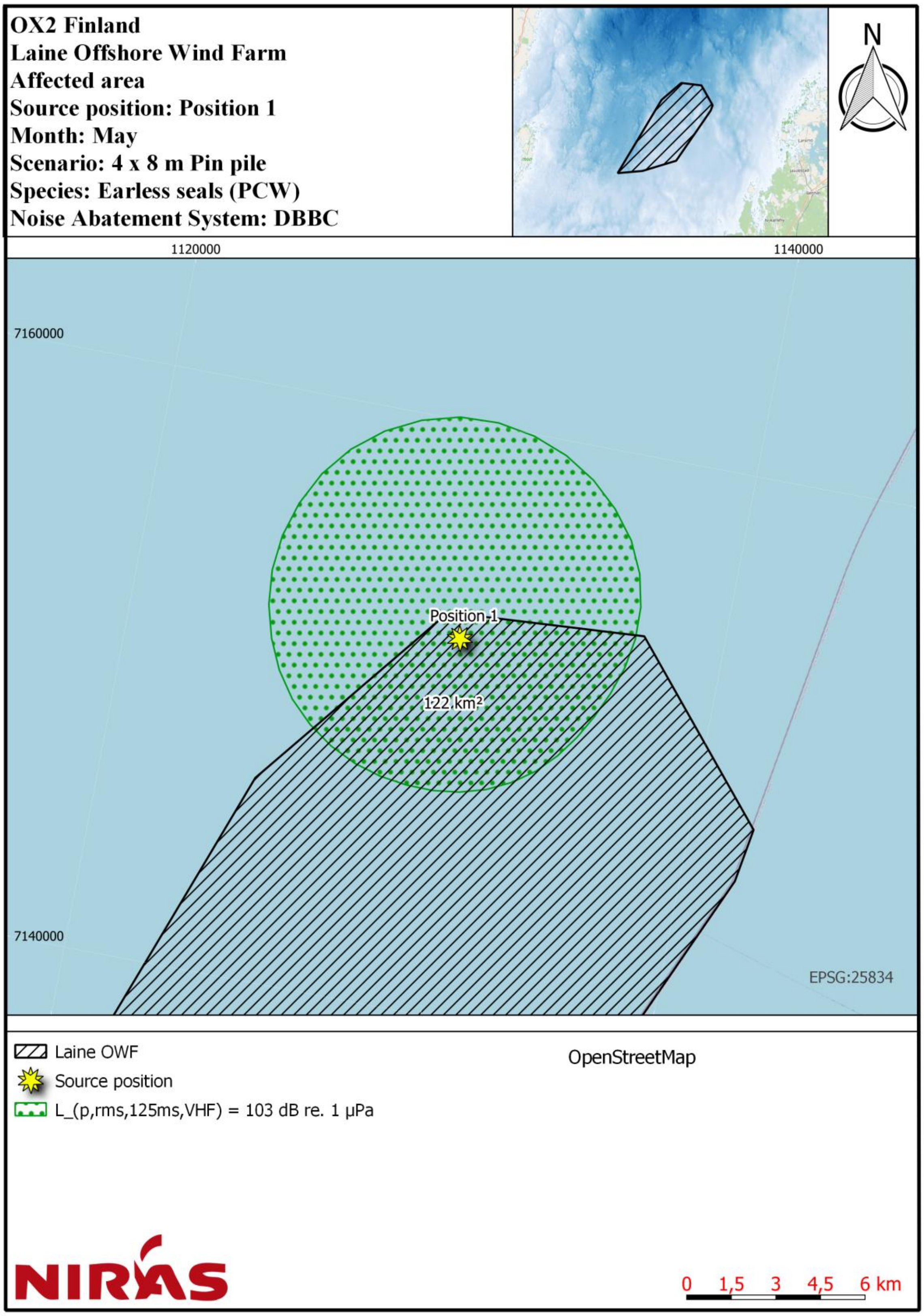

Figur 2.2: Simulerade påverkansområden för beteendemässiga undvikande reaktioner hos sälar (grön linje) i projektområdet för Laine. Simuleringen av undervattensbuller baseras på ett värsta tänkbara scenario och med installation av ett jacketfundament med 4x 8 m pålar med dämpning DBBC.

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2.3. Osäkerheter i modellen

Prognosen för undervattensbuller görs i ett mycket tidigt skede av projektet, och som ett resultat av detta görs vissa antaganden om pålkonstruktion, dämpningsåtgärder och miljöfaktorer, som alla har en inverkan på det undervattensbuller som avges. Osäkerheter finns i alla parametrar, och ett realistiskt antagande om värsta tänkbara fall används. Detta inkluderar en källnivå baserad på genomsnittliga empiriskt uppmätta data, extrapolerade till den föreslagna pålstorleken. Genomsnittliga frekvensspektra för slagpålning. Genomsnittlig dämpning för de åtgärder som tillämpas. När det gäller ljudutbredning väljs konservativa worst case-parametrar i alla avseenden för sediment, salthalt och temperatur, baserat på tillgängliga historiska data, så att den simulerade ljudutbredningen anses vara konservativ. Även om en dämpning motsvarande DBBC tillämpades i denna prognos, bör det noteras att för monopile- och jacketfundament bör en detaljerad beräkning göras för den faktiska dämpningslösning som ska användas, för den faktiska pålinstallation som ska utföras, när den slutliga pålkonstruktionen är tillgänglig.

3. Beskrivning av utgångsläge

3.1. Fisk

Projektområdet Laine ligger i Bottenviken, i den del av Östersjön som har lägst salthalt. Den övergripande artsammansättningen i havet i skärgårdarna i norra Bottenviken liknar den i ett sjösystem (HELCOM, 2018d; Naturvårdsverket, 2012). Det är i en vattenmiljö med en speciell kombination av fysiokemiska förhållanden. Havsmiljön är olämpligt för de flesta marina och sötvattensfiskarter som annars förekommer i Norden, och projektområdet är därför en relativt fiskartsfattig miljö. Miljöegenskaperna i projektområdet för Laine gör att den naturliga mångfalden av fisk i området är relativt låg. Habitatet befolkas huvudsakligen av euryhalina fiskarter som tolererar en mängd olika salthalter medan förhållandena endast är tolerabla eller föredragna för ett litet antal marina och sötvattensarter.

Havsfisk i Bottenviken representeras huvudsakligen av ett bestånd av strömming, vilket också är fallet i Laine-projektområdet (Jorgensen, Hansen, Bekkevold, Ruzzante, & Loeschke, 005; Saulamo & Neuman, 2002). Salthalten i Bottniska viken är också tillräckligt låg för att de annars Östersjöanpassade torskbestånden inte ska kunna leva där. Euryhalina arter i Bottenviken omfattar europeisk sik, atlantlax, öring och ål som alla utnyttjar både marina och sötvattensmiljöer under sin livscykel. Dessa arter är i allmänhet vandrande och förväntas därför använda projektområdet antingen när de söker föda eller när de flyttar genom det. Dessutom är vissa arter av simpa euryhalina och kan påträffas i projektområdet.

I juli 2022 genomfördes två fiskinventeringar i projektområdet med nät med flera maskstorlekar. Sex fiskarter påträffades i projektområdet: Strömming, hornsimpa, rötsimpa, gärs, nors och sik. Strömming och hornsimpa var numerärt dominerande (Figur 3.1), med totalt 71 procent strömming och 21 procent hornsimpa av alla fångade individer. I undersökningen påträffades inga exemplar av atlantlax, siklöja eller ål, även om dessa fiskar sannolikt utnyttjar området i viss utsträckning.

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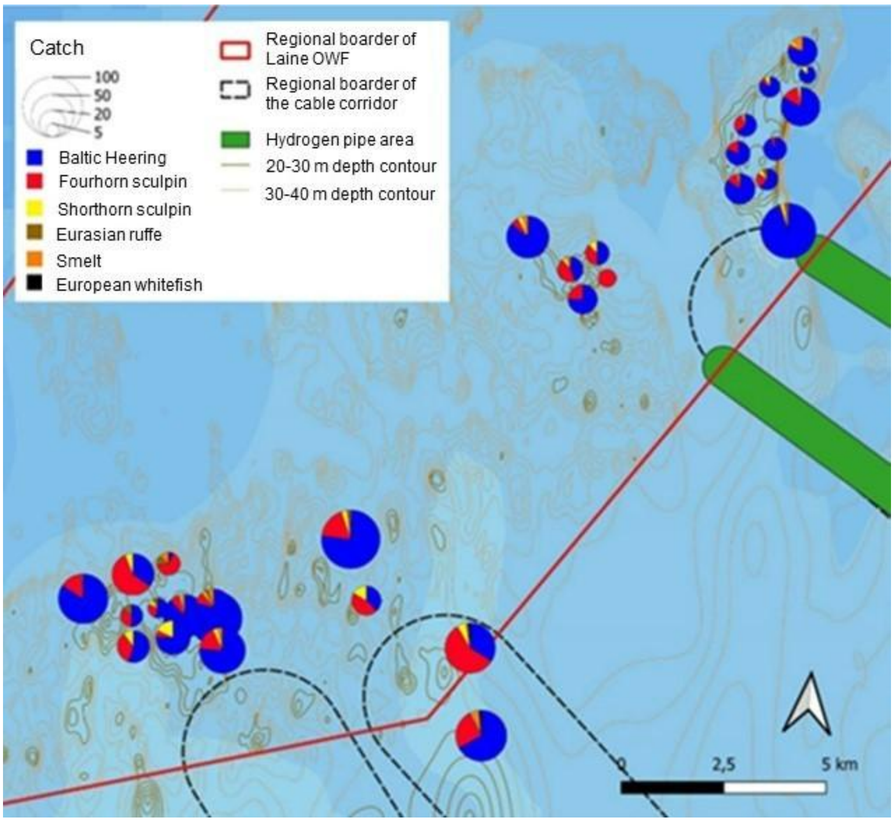

Figur 3.1: De 30 undersökningsplatsernas lägen och fångst i undersökningen i juli 2022.
Figur modifierad från Happo och Vatanen (2022). Se Happo och Vatanen (2022) för ytterligare information.

Laine-projektområdet är artfattigt och används relativt sällan av fisk. Området är olämpligt eller bedöms som ett olämpligt lekområde för alla arter som använder det och det utgör huvudsakligen en del av ett större födosöksområde. Det finns en liten sannolikhet för att strömming, rötsimpa och hornsimpa ibland leker i projektområdet, men överlevnadsförmågan hos avkomman från sådan lek är tveksam. Dessutom skulle omfattningen av sådan lek, om den alls förekommer, vara mycket marginell jämfört med den viktigare leken som förekommer i kustnära miljöer. De närmaste lämpliga lekområdena för fisk finns närmare kusten och därmed flera kilometer från projektområdet. Viss migration genom projektområdet förekommer sannolikt, främst när strömming, nors, lax och sik och kanske ål vandrar genom området. Betydelsen av Laine-projektområdet som lekområde för fisk bedöms därför som mycket låg till låg, medan dess betydelse för vandrande fisk bedöms som låg. Betydelsen för fisk som födosöksområde bedöms som låg till medelhög, eftersom främst strömming, nors och simpor använder området för födosök, vilket även kan vara fallet för gärs, lax och sik.

3.2. Marina däggdjur

Gråsäl (*Halichoerus grypus gry*pus) och vikare (*Phoca hispida botnica)* är de två bofasta marina däggdjursarter som kan förekomma i och runt projektområdet för vindkraftsparken Laine. Tumlare kan förekomma sporadiskt (Naturhistoriska riksmuseet, 2022), men Laines vindkraftsparks område ligger utanför utbredningsområdet för populationen (NAMMCO, 2019) och Bottenviken anses i allmänhet vara av låg betydelse för arten (Sveegaard, et al., 2022). Tumlare beaktas därför inte ytterligare.

Gråsälarna i finska vatten hör till den östersjöpopulationen (HELCOM, 2018b; Olsen, Galatius, Biard, Gregersen, & Kinze, 2016). De förekommer i hela Östersjön och är beroende av kustvatten, där det finns gott om föda och ostörda uppväxtplatser (Galatius, 2017)(Figur 3.2). Populationsuppskattningen för Östersjöpopulationen är för närvarande mellan 52 000–69 000 individer (Suuronen, et al., 2023) och enligt rödlistan över finska arter från

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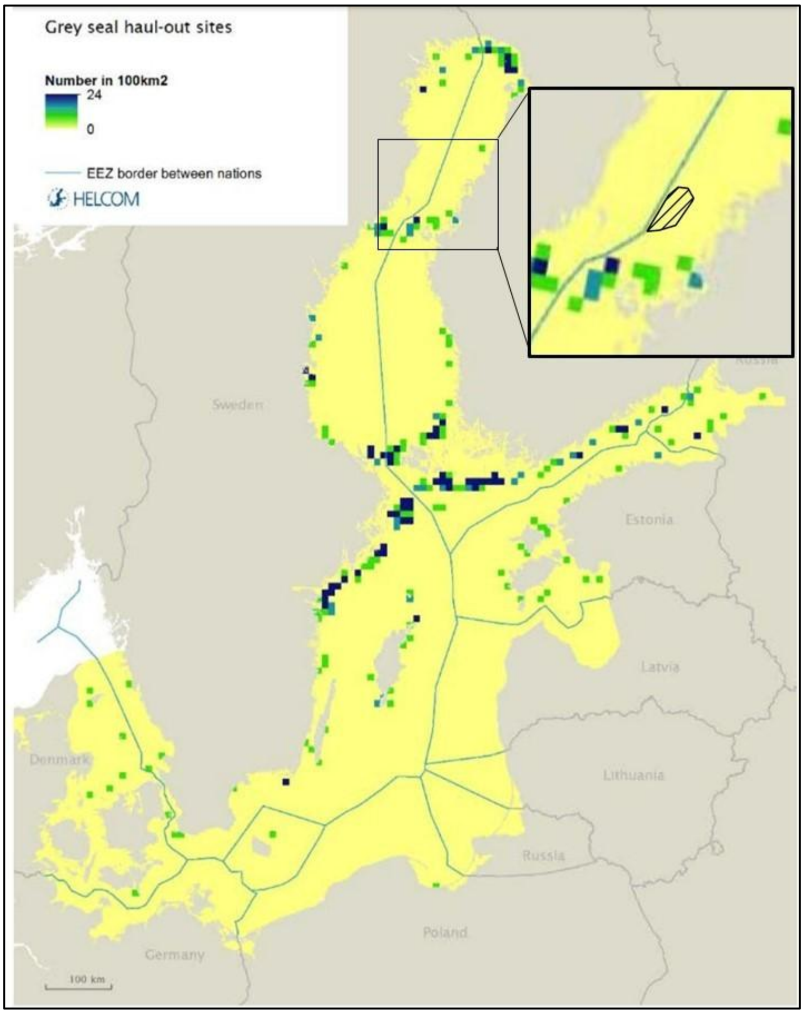
2019 är gråsälspopulationen i Östersjön klassificerad som livskraftig (LC) (Ympäristöministeriö & Suomen ympäristökeskus, 2019). Tillväxttakten har avtagit till cirka 6 procent under de senaste åren och visar att populationen har närmat sig bärkraften i Östersjön (HELCOM, 2018b). En tydlig ökande trend i populationerna kan ses i alla delar av Östersjön.

Östersjögråsälen föder sina ungar i februari och mars (Härkönen, et al., 2007). I Östersjön föder gråsälarna oftast på drivis, men i vissa områden föder sälarna också på land under år med otillräckligt havsistäcke (Jüssi, Härkönen, Helle, & Jüssi, 2008). Gråsälar byter också päls på isen och vid vistelseområdena från april till juni och tillbringar mycket tid på land vid vistelseområdena under den perioden (HELCOM, 2013a). Gråsälar använder vanligtvis särskilda korridorer för att förflytta sig mellan sina födosöksområden till havs och sina vistelseplatser på land (Jones, et al., 2015). De kan förflytta sig långa sträckor och närvaron av gråsälar i ett område behöver inte nödvändigtvis betyda att individen har en stark platstrohet till det givna området (McConnell, Lonergan, & Dietz, 2012; Galatius, 2017).



Figur 3.2: Gråsälens vistelseplatser i Östersjön och Kattegatt samt Projektområdet för vindkraftsparken Laine (svart linje polygon). Kartan omfattar alla för närvarande kända vistelseplatser. Modifierad från (HELCOM, 2018a).

De vikare som påträffats i projektområdet för vindkraftsparken Laine tillhör den geografiskt isolerade östersjöpopulationen (HELCOM, 2013b). De högsta koncentrationerna finns i den centrala norra delen av Bottenviken och cirka 70 % av populationen finns i den nordligaste delen av Bottenviken, medan resten finns i Finska viken

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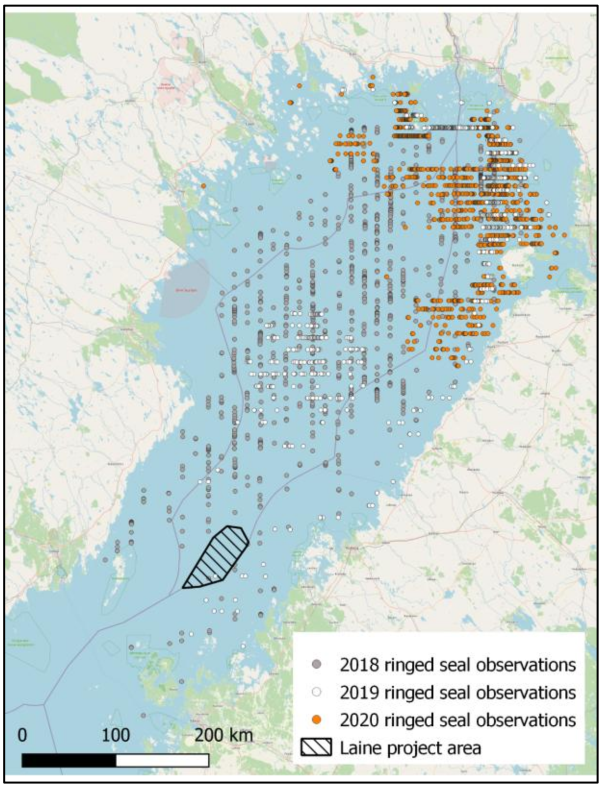
(5 %) och Rigabukten (25 %) (Härkönen, et al., 2014). Populationen beräknas uppgå till 11 500 individer med en ökande trend (Härkönen, 2015). Undersökningar under de senaste årens exceptionellt milda vintrar har dock visat att populationsstorleken sannolikt överstiger 20 000 djur i Bottenviken (HELCOM, 2018b). Enligt IUCN:s internationella rödlista över hotade arter är vikaren listad som *livskraftig* (LC). Enligtrödlistan över finska arter klassificeras dock Östersjöns vikarepopulation som *sårbar* (VU) (Ympäristöministeriö & Suomen ympäristökeskus, 2019) och klimatförändringar väntas bli en framtida utmaning för vikare, eftersom de är beroende av is under fortplantningssäsongen (HELCOM, 2013b).

Utbredningen av vikare under vintern är starkt kopplad till utbredningen av havsis som är lämplig för att bygga lyor. Honorna föder sina kutar i lyorna och bildandet av denna typ av is är avgörande för att denna art ska lyckas med sin fortplantning (HELCOM, 2018a). Klimatologiska modeller förutspår en minskning av havsisbildningen och kortare istäckta säsonger i framtiden. Detta kommer sannolikt att kraftigt minska populationstillväxten i Bottenviken (Sundqvist, Harkonen, Svensson, & Harding, 2012).

Under sommaren tillbringar vikarsälarna cirka 90 procent av sin tid i vattnet - de äter, förflyttar sig och vilar, och vissa djur förflyttar sig långa sträckor på flera hundra kilometer under perioden efter pälsbytet (Oksanen, Neimi, Ahola, & Kunnasranta, 2015). Två kluster av "hot spots" för födosök har hittats. En sydväst om Laine och en norr om Laine i norra delen av Bottenviken.

Observationer av vikare under de senaste flygräkningarna i Bottenviken i april 2018, 2019 och 2020 visas på Figur 3.3 och endast ett fåtal vikare sågs i projektområdet för vindkraftsparken Laine under denna period.



Figur 3.3: Räknade vikarsälar som tillhörde östersjöpopulationen 2018, 2019 och 2020.
Flyginventeringarna genomfördes i april under samtliga år (modifierad från Havs- och vattenmyndigheten och SMHI).

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Både vikare och gråsäl från Östersjön använder projektområdet för vindkraftsparken Laine för regelbunden vistelse och reproduktion (HELCOM, 2013). Fortplantningen hos båda arterna är starkt kopplad till istäcket. Fortplantning i projektområdet kommer därför i hög grad att bero på omfattningen av havsistäcket. Kvantitativa uppgifter om projektområdets relativa betydelse för gråsälarna finns inte tillgängliga. Projektområdet för vindkraftsparken Laine ligger cirka 23 km norr om den närmaste vistelseplatsen för gråsälar vid Mickelsörarna och det förväntas därför att gråsälar använder projektområdet året runt och att området potentiellt kan användas som födosöksområde eller flyttkorridor mellan gråsälarnas vistelseplatser. Vindkraftsparken Laine anses dock inte vara ett viktigt födosöksområde för vare sig gråsäl eller vikare, vilket stöds av det faktum att Laine-projektområdet är fiskartsfattigt och relativt sällan används av fisk. Området bedöms därför vara av låg till medelhög betydelse för Östersjögråsäl och av medelhög betydelse för Östersjövikare.

4. Konsekvensbedömning

4.1. Metoder för konsekvensbedömning

Ett systematiskt tillvägagångssätt har använts för att hitta och bedöma den planerade verksamhetens potentiella påverkan, effekter och konsekvenser på fisk och marina däggdjur och för att beskriva skyddsåtgärder för att lindra påverkan. I den här rapporten används begreppen *känslighet*, *påverkan*, *effekt* och *konsekvens*.

- **Känslighet**: Mottagarens eller artens känslighet för den givna påverkan.
  Bedömningen av mottagarens känslighet baseras på aktuell vetenskaplig kunskap samt information från utfört fältarbete. En mottagares känslighet kan vara låg, måttlig eller hög. En mottagares känslighet bedöms utifrån:
  - Mottagarens status, inklusive populationstrender, abundans och förekomster.
  - Mottagarens känslighet för den givna miljöpåverkan och dess förmåga att anpassa sig till trycket. I denna situation undervattensbuller.
  - Mottagarens känslighet under olika perioder av året (mottagaren kan t.ex. vara känsligare under parningssäsongen eller under migrationsperioder).

- **Storlek och omfattning av påverkan och effekt*:***
  Påverkan: Avser förändringen i den fysiska miljön till följd av verksamheten i projektet. Till exempel: genererat buller, utsläpp av föroreningar, förlust av värdefulla naturmiljöer, ökad trafik inom området. Påverkan kan ske på lokal, regional eller nationell nivå och dessutom vara antingen kortsiktig, tillfällig eller permanent.
  Effekt: Beskriverden betydelse som påverkan bedöms ha på miljöns befintliga värden. Därav en beskrivning av omfattningen av påverkan. Vilken eller vilka effekter som kommer att uppstå till följd av påverkan måste ses i relation till de specifika förhållandena i det påverkade området. Alltså, vad gör miljön värdefull, vilka värden påverkas och hur känsliga är de. Om ett område har lågt värde förväntas påverkan ha liten effekt. Om området däremot är värdefullt eller känsligt förväntas effekten av en viss påverkan bli större.

- **Konsekvens:** är en bedömning av vilken betydelse miljöeffekterna av en viss påverkan kommer att ha för de berörda intressena, t.ex. klimatet, människors hälsa eller den biologiska mångfalden. Vid bedömning av konsekvenserna utgår bedömningen från omfattningen av påverkan, betydelsen för miljövärdena och hur stor påverkan förväntas bli. Bedömningen jämförs med ett alternativ där inga åtgärder vidtas, ett så kallat nollalternativ. Nollalternativet beskriver den förväntade framtida utvecklingen av området om projektet inte genomförs.

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Inledningsvis görs en screening av påverkan, där det beskrivs vilken typ av påverkan den planerade aktiviteten kan ha. För att göra den samlade bedömningen av effekter och konsekvenser görs en bedömning av artens (recipientens) känslighet. Därefter bedöms graden av påverkan (och effekt) som verksamheten antas ha på arten. Bedömningen av de potentiella konsekvenserna på grund av aktiviteten görs genom att väga mottagarens känslighet mot omfattningen av påverkan och effekten. Utifrån detta görs slutligen en bedömning av vilka miljökonsekvenser projektet kan få Tabell 4.1.

Tabell 4.1: Den bedömningsmatris som används för att bedöma den potentiella konsekvensen av en viss påverkan.

Betydelsen av konsekvensen		Storlek och omfattning av påverkan						
		Hög Negativ	**Måttlig Negativ**	**Låg negativ**	**Obetydlig**	**Låg positiv**	**Måttligt positiv**	**Hög positiv**
Mottagarnas känslighet	Låg	Måttlig	Låg	Mindre	Försumbar	Mindre	Låg	Måttlig
	Måttlig	Hög	Måttlig	Låg	Försumbar	Låg	Måttlig	Hög
	Hög	Mycket hög	Hög	Måttlig	Försumbar	Måttlig	Hög	Mycket hög

Mottagarens känslighet bedöms i förhållande till den relevanta påverkan under de olika stadierna av det planerade projektet. För att bedöma storleken och omfattningen av påverkan baseras bedömningarna på *värsta tänkbara scenarier* där påverkan förväntas bli som störst.

4.2. Konsekvensbedömning - Undervattensbuller under byggtiden - Pålning

Totalt kommer 150 fundament att installeras i projektområdet. I teorin kommer installationen av fundamenten genom pålning att ta cirka 5 månader (av effektivt arbete) med cirka sex timmars pålning per dag, under antagandet att ett fundament installeras per dag utan några pauser (150 fundament = 150 dagar ~ 5 månader). I praktiken kommer dock den totala tiden för installation av ett fundament att vara längre och ta cirka 2 dagar. De sex timmarna per dag för ett fundament och de fem månaderna för alla fundament avser endast den tid då pålning sker och inte det övriga byggnadsarbetet i samband med installationen av fundamentet. Den totala installationstiden för fundamenten kommer att vara längre än 5 månader. Dessutom kan installationsperioden bli längre på grund av t.ex. dåliga väderförhållanden, vilket medför dagar då pålning inte är möjlig.

4.2.1. Fisk

De värsta effekterna av trycket från undervattensbuller från pålning (PTS och skador) kommer att drabba individer som befinner sig i närheten av pålningsaktiviteten. Därav <100–1100 m för fisk och <650 m för ägg och yngel (Tabell 2.3). Utöver detta kommer majoriteten av fiskarna att fly från tryckkällan och återvända när ljudet har upphört, och eventuellt uppleva TTS som är reversibelt över tid (Monroe, Rajadinakaran, & Smith, 2015; Smith, Kane, & Popper, 2004). Påverkansavstånden för TTS i fisk kommer att inträffa upp till 5,9–17,9 km från bullerkällan beroende på fiskart.

För närvarande finns det mycket begränsad kunskap om de kortsiktiga och långsiktiga konsekvenserna av PTS och TTS hos fisk. I den naturliga miljön är dödligheten hos fiskyngel och ägg mycket hög och även om det kan förekomma en viss förlust av tillskott på grund av dödlighet hos ägg och yngel nära källan till trycket, anses detta vara mycket begränsat och förväntas inte ha någon betydande effekt på populationsnivå. Projektområdet bedöms ha mycket låg till låg betydelse som lekområde för fisk, och fiskyngel eller ägg som driver in i projektområdet har sannolikt inte hög naturlig överlevnad på grund av de olämpliga förhållandena i området. Därför

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bedöms dödligheten hos fiskägg och fiskyngel som orsakas av undervattensbuller från pålning vara försumbar och utan konsekvenser för fisk och fiskpopulationer.

Risken för att stora mängder fisk ska drabbas av antingen PTS eller dödlighet bedöms som försumbar på grund av de mycket korta påverkansavstånden (mindre än 100–1100 m) i kombination med Laine-projektområdets artfattiga karaktär.

Nära pålningskällan med höga nivåer av undervattensbuller, men inte inom det område där fiskar skadas, kommer trycket att utlösa en undvikande reaktion som gör att unga och vuxna fiskar flyr från trycket och eventuellt upplever en TTS. Eftersom Laine-projektområdet är artfattigt och relativt sällan används av fisk bedöms känsligheten vara låg.

Storleken och omfattningen av påverkan från pålningsbuller bedöms som måttligt negativ, på grund av de relativt långa påverkansavstånden för TTS (upp till 17,9 km). Sammantaget bedöms konsekvensen av undervattensbuller från pålning i projektområdet för vindkraftsparkenLaine vara låg för fisk och kommer inte att påverka fiskpopulationerna på kort eller lång sikt (Tabell 4.2).

Tabell 4.2: Konsekvensbedömning av undervattensbuller från pålning under byggfasen på fisk i Laine havsbaserade vindkraftspark.

Påverkan	Känslighet hos mottagaren	Storlek och omfattning av påverkan	Konsekvenser
Pålning-fisk	Låg	Måttligt negativ	Låg

4.2.2. Marina däggdjur

Simuleringsresultaten visar att om sälar befinner sig inom mindre än 100 m och 200 m från pålningsplatsen, när pålningen utförs med ett bullerdämpningssystem som motsvarar DBBC och med tillämpning av en mjuk start- och upprampningsfas, kan de på motsvarande sätt riskera att utveckla PTS och TTS (Tabell 2.4). På grund av de mycket korta avstånden är risken för att utveckla PTS eller TTS hos sälar mer eller mindre obefintlig.

Som en försiktighetsåtgärd har man antagit att sälar reagerar på undervattensbuller från pålning på samma avstånd som tumlare (inom 7,45 km i den aktuella simuleringen). Det förväntas att både vikare och gråsälar kan förekomma i projektområdet, men eftersom avståndet till närmaste vistelseområde för både vikare och gråsälar är mer än 20 km från projektområdet anses området inte vara ett särskilt viktigt område för någon av arterna. Detta stöds av det faktum att området är fiskartsfattigt och relativt sällan används av fisk, vilket gör området till ett födosöksområde av låg kvalitet för sälar. Det kan förekomma fortplantande vikare och gråsälar i projektområdet, men de kommer bara att finnas där under vintrar med tillräckligt istäcke. Det förväntas inte att det är möjligt att installera fundament under perioder då havsis har bildats i projektområdet och någon störning av fortplantningen för vikare kommer därför inte att inträffa.

Risken för att sälar ska uppleva antingen PTS eller TTS bedöms som försumbar på grund av de mycket korta påverkansavstånden (mindre än < 200 m).

Beteendemässiga reaktioner orsakade av undervattensbuller från pålning kan variera från små förändringar i aktivitetsnivå till flyktreaktioner, där individer helt undviker området. Sälarnas känslighet för påverkan på beteendet bedöms vara måttlig eftersom det förväntas att sälarna i viss utsträckning kommer att undvika det påverkade området. Den teoretiska installationsperioden för fundamenten genom pålning kommer att vara cirka 5 månader (av effektivt arbete). Detta förutsätter att ett fundament installeras per dag utan uppehåll och 6 timmars daglig pålning. Som beskrivits kommer dock den totala installationstiden för fundamenten att vara längre

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än 5 månader. Den tillfälliga habitatförlustens varaktighet och de kvarstående beteendemässiga undvikande reaktionerna hos båda arterna anses dock vara kortsiktiga, eftersom sälarna kan återvända till området efter att installationen av fundamentet har slutförts.

Storleken och omfattningen av påverkan från pålningsbuller bedöms som liten negativ, på grund av de relativt korta påverkansavstånden samt att det påverkade området inte utgör ett viktigt födosöksområde för varken vikare eller gråsäl. Det är ett relativt litet område av deras hemområde som påverkas tillfälligt, vilket medför en låg sannolikhet för förekomst av beteendemässiga undvikande reaktioner. Sammantaget bedöms konsekvensen av undervattensbuller från pålning i projektområdet för vindkraftsparken Laine vara låg för sälar och kommer inte att påverka populationerna på kort eller lång sikt (Tabell 4.3).

Tabell 4.3: Konsekvensbedömning av undervattensbuller från pålning under byggfasen på sälar i Laine havsbaserade vindkraftspark.

Påverkan	Känslighet hos mottagaren	Storlek och omfattning av påverkan	Konsekvenser
Pålning	Måttlig	Låg negativ	Låg

4.3. Konsekvensbedömning - Undervattensbuller från fartygstrafik

Under vindkraftsparkens byggnation och driftunderhåll förväntas en ökning av fartygstrafiken för både små och stora fartyg inom och i närheten av projektområdet för vindkraftsparken Laine. Utbredningen av undervattensbullret i det omgivande vattnet beror på frekvensinnehållet i undervattensbullret, den omgivande miljön (t.ex. temperatur, salthalt och djup) och faktorer som fartygets hastighet, storlek, last etc. (Wisniewska, et al., 2016; Erbe, et al., 2019; Urick, 1983).

Det förväntas att både små och snabba båtar samt större, mer långsamtgående fartyg kommer att användas. Projektområdet för vindkraftsparken ligger i ett område med fartygstrafik och ligger i närheten av eller överlappar de viktigaste sjöfartsrutterna i norra delen av Bottenviken (Figur 4.1). Projektområdet Laine förväntas därför domineras av lågfrekvent fartygsbuller. Baserat på data från BIAS-projektet bedöms undervattensbullernivån mätt i frekvensbandet 500 Hz ligga över 85-95 dB re 1uPa i huvuddelen av projektområdet (50 % av tiden), särskilt under vinterperioden, då ljudet tenderar att färdas längre, jämfört med sommarperioden.

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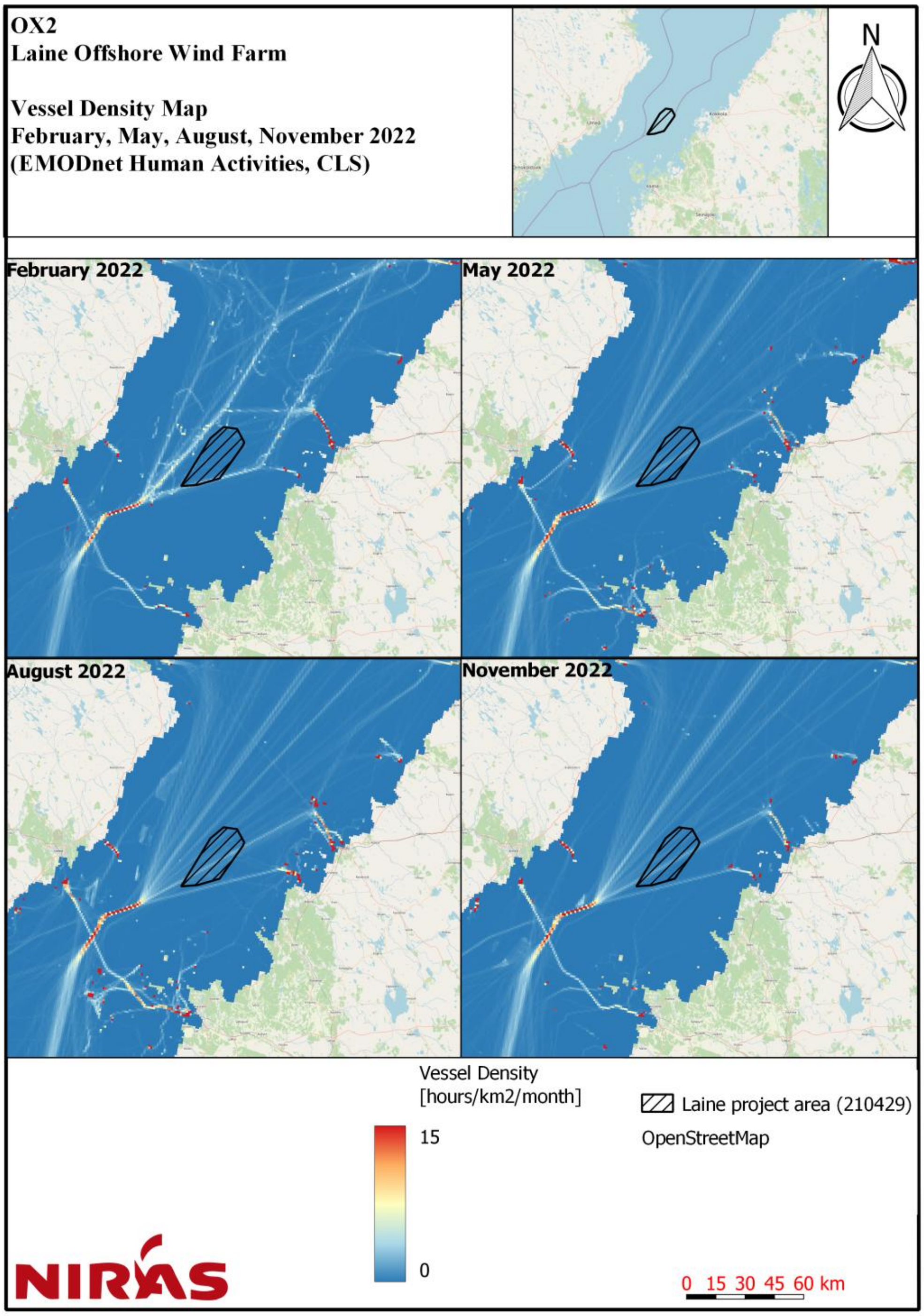

Figur 4.1: Karta över fartygstäthet från 2022, från EMODnet baserat på AIS-data från CLS.

4.3.1. Konsekvensbedömning - fisk

Projektområdet för vindkraftsparken Laine gränsar till och överlappar de viktigaste sjöfartsvägarna i Bottenviken. Området förväntas alltså redan vara dominerad av fartygstrafik som skapar undervattensbuller och fiskarna i området är sannolikt anpassade till en viss mängd undervattensbuller från fartyg. Laine-projektområdet är fiskartsfattigt och används relativt sällan av fisk, och både pelagiska och demersala fiskars känslighet för undervattensbuller från fartygsaktivitet är låg. Storleken och omfattningen av påverkan från fartygsbuller bedöms som försumbar eftersom beteendemässiga reaktioner kommer att ske relativt nära fartyget. Sammantaget bedöms

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konsekvensen av undervattensbuller från fartygsbuller vara försumbar för fisk och kommer inte att påverka populationerna på kort eller lång sikt (Tabell 4.4).

Tabell 4.4: Konsekvensbedömning av undervattensbuller från fartyg på fisk i området för vindkraftsparken Laine.

Påverkan	Känslighet hos mottagaren	Storlek och omfattning av påverkan	Konsekvenser
Buller från fartyg	Låg	Försumbar	Försumbar

4.3.2. Konsekvensbedömning - sälar

Den största effekten av fartygsbuller är sannolikt beteendeförändringar hos sälar, t.ex. förändringar i deras födosöksmönster i närheten av fartygen (Richardson, Greene, Malme, & Thompson, 1995; Wisniewska, et al., 2016).

Sälarnas känslighet för fartygsbuller bedöms vara låg eftersom påverkan på deras beteende är begränsad och mycket kortvarig. Området bedöms inte vara ett viktigt födosöksområde för vare sig vikare eller gråsäl och undvikande förväntas endast ske i närheten av fartygen. Storleken och omfattningen av påverkan från fartygsbuller bedöms därför som liten negativ. Detta måste också ses mot bakgrund av det faktum att projektområdet gränsar till och överlappar de viktigaste sjöfartsvägarna i Bottenviken. Den extra påverkan från byggnadsrelaterad fartygstrafik och fartygstrafik under driftunderhåll kommer därför att vara blygsam. Sammantaget bedöms konsekvensen av undervattensbuller från fartygsbuller i projektområdet för vindkraftsparken Laine vara liten för sälar och kommer inte att påverka populationerna på kort eller lång sikt (Tabell 4.5).

Tabell 4.5: Bedömning av konsekvenserna av undervattensbuller från fartygstrafik på sälar i Laine vindkraftsparkområdet.

Påverkan	Känslighet hos mottagaren	Storlek och omfattning av påverkan	Konsekvenser
Fartygsbuller	Låg	Låg negativ	Mindre

4.4. Konsekvensbedömning - Undervattensbuller från vindkraftverk i drift

Undervattensbuller från havsbaserade vindkraftverk kommer i första hand från två källor: mekaniska vibrationer i nasellen (växellåda etc.) som överförs genom tornet och utstrålas i det omgivande vattnet och undervattensbuller från servicebåtar i vindkraftsparken.

4.4.1. Konsekvensbedömning fisk

Driftbullrets karaktär och styrka gör det sannolikt att det kan höras (detekteras) av ljudkänsliga pelagiska fiskar som t.ex. clupeider (skarpsill och strömming) samt hörselgeneralister på ett avstånd av upp till några hundra meter från källan, medan det för demersala fiskar med endast små eller inga simblåsor som t.ex. simpor (Cottidae) endast detekteras inom korta avstånd <50 m (DFU, 2000).

Även om både pelagiska och bentiska fiskarter kan höra undervattensljuden från vindkraftverkens mekaniska komponenter finns det inget som tyder på att de skulle reagera beteendemässigt och fly eller förflytta sig från området. Tvärtom observerades en ökad förekomst och ett ökat antal arter vid den havsbaserade vindkraftsparken Horns Rev 1 nära vindkraftverken jämfört med det närliggande referensområdet (Stenberg et.al., 2011), möjligen på grund av goda födo- och tillflyktsmöjligheter runt vindkraftsparkens fundament. Dessutom har potentiell tillvänjning till driftljuden från vindkraftverk observerats för andra havsbaserade vindkraftsparker (Stenberg et.al., 2011; Hvidt et.al., 2006; Phys.org, 2023).

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Undervattensbullret under drift är inte tillräckligt högt för att ha någon effekt på fiskens tidiga livsstadier (fiskägg och yngel), och därför kommer de tidiga livsstadierna inte att påverkas av undervattensbuller från vindkraftsparkens drift. Både pelagiska och demersala fiskar kan förmodligen höra undervattensbullret från vindkraftverkens mekaniska komponenter, men de verkar inte påverkas nämnvärt. Känsligheten för undervattensbuller för både pelagisk och bentisk fisk rankas därför som låg. Eftersom det inte finns några indikationer som tyder på en skillnad i fisksamhällen nära vindkraftverk i drift jämfört med det omgivande området, bedöms storleken och omfattningen av påverkan som försumbar. Sammantaget bedöms konsekvenserna av undervattensbullret under drift vara försumbara för fisk och kommer inte att påverka fiskpopulationerna på kort eller lång sikt (Tabell 4.6)

Tabell 4.6: Bedömning av konsekvenserna av undervattensbuller från fartygstrafik på fisk i området för Laine vindkraftspark.

Påverkan	**Känslighet hos mottagaren**	**Storlek och omfattning av påverkan**	**Konsekvenser**
Driftbuller	Låg	Försumbar	Försumbar

4.4.2. Konsekvensbedömning - sälar

Det antas att sälar kommer att kunna höra driftsbullret på ett avstånd av några kilometer under tysta förhållanden. Eftersom omgivningsbullret förväntas vara relativt högt inom projektområdet på grund av sjötrafiken, förväntas omgivningsbullret dock vara den begränsande faktorn i lågfrekvensområdet. Dessutom verkar sälar vara relativt toleranta mot undervattensbuller från vindkraftsparker som är i drift (Kastelein, 2011; Southall, et al., 2019). Det finns inga studier av hur vikare reagerar på driftbuller från vindkraftverk. Märkta knubbsälar har dock visat sig söka föda runt turbinfundament (Russell, et al., 2014). Gråsälar har också rapporterats följa antropogena strukturer som undervattenskablar och söka föda längs kablarna (Russell, et al., 2014). Det förväntas därför att gråsälar kommer att reagera på vindkraftsparker på liknande sätt som knubbsälar.

Det förväntas att skydd mot bottenerosion runt fundamentet kommer att användas vid etableringen av vindkraftverket. Det nya hårdbottensubstratet förväntas vidare fungera som ett konstgjort rev som kommer att locka till sig fiskarter som är knutna till hårdbotten och stenrev och potentiellt öka bytesdjuren för sälar. Sälars känslighet för undervattensbuller från en vindkraftspark som är i drift är låg eller försumbar, baserat på befintlig kunskap om sälars beteende i havsbaserade vindkraftsparker. Området är inte ett viktigt födosöksområde för vare sig vikare eller gråsäl. Storleken och omfattningen av påverkan från driftsbuller bedöms som försumbar. Detta måste också ses mot bakgrund av att projektområdet ligger i anslutning till och överlappar de viktigaste sjöfartsrutterna i Bottenviken. Den extra påverkan av undervattensbuller från driften av vindkraftparken kommer därför att vara blygsam. Sammantaget bedöms konsekvenserna av undervattensbullret under drift vara försumbara för sälar och kommer inte att påverka populationerna på kort eller lång sikt (Tabell 4.7)

Tabell 4.7: Bedömning av konsekvenserna av undervattensbuller under drift på säl i området för Laine vindkraftspark.

Påverkan	**Känslighet hos mottagaren**	**Storlek och omfattning av påverkan**	**Konsekvenser**
Driftbuller	Låg	Försumbar	Försumbar

4.5. Kumulativa effekter

Bedömningen av kumulativa effekter baseras på konsekvensbedömningen av projektet i kombination med andra lokala eller regionala projekt eller planer, som kan bidra till en kumulativ miljöpåverkan. När flera planerade projekt inom samma område påverkar samma mottagare i miljön samtidigt uppstår kumulativ påverkan. För vindkraftsparken Laine kan kumulativ påverkan från undervattensbuller uppstå om andra vindkraftsparker eller projekt som orsakar samma typ av påverkan byggs samtidigt. Bedömningen baseras på projekt som har erhållit bygglov

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samt projekt i planeringsfasen och där de havsbaserade vindkraftsparkerna byggs samtidigt. Det finns en planerad havsbaserad vindkraftspark relativt nära utvecklingsområdet för vindkraftsparken Laine. Den planerade havsbaserade vindkraftsparken finns listad på Tabell 4.8.

Tabell 4.8: Projekt som beaktas för kumulativ bedömning.

Vind-kraftspark/ut-vecklare	Land	Totalt planerat max MW/max antal turbiner	Minsta avstånd till Laine vind-kraftspark	Tillståndsfas	Förväntat byggår
Kappa/Njord	Sverige	1325 MW/74 turbiner	1 kilometer	MKB-dokument under arbete	2031-2033

Eftersom Laine OWF:s byggfas är planerad till 2029-2031 kommer det inte att finnas någon överlappning i byggfasen för de två havsbaserade vindkraftsparkerna. Därför kommer ingen samtidig pålning att ske under byggtiden i de två projektområdena. De kumulativa effekterna förväntas därför vara försumbara för vindkraftsparkerna Laine och Kappa.

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NIRAS

Laine offshore wind farm

Underwater noise impact assessment - fish and marine mammals

OX2 Finland

Date: 5 October 2023

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Summary

OX2 AB plans to establish Laine offshore wind farm (OWF) in the Bay of Bothnia. Construction and operation of the OWF subjects marine animals in the area to disturbance with noise, mainly from pile driving, increased ship traffic and noise from operation of the turbines. The present report therefore assesses modelled sound pressure data against spatio-temporal distributions of animals and the sensitivity of these to underwater noise in the Laine OWF project area to provide an overall assessment of the size, extent and consequences of the emitted noise regime.

Field surveys and information from various sources were used to shed light on the animal community inhabiting or migrating through the area. Two species of mammals (grey seal and ringed seal) and a relatively small number of fish species used the area, of which herring and sculpins were numerically dominant. Fish mainly used the OWF project area for foraging, as the area was too deep, cold and far offshore to support successful hatching and growing of eggs and offspring. For both ringed and grey seals, the nearest haul out sites were >20 km from the OWF project area, and the seals were only assessed to use the project area to a limited extent, mainly due to the scarcity of fish in it compared to more near-coastal or shallower regions in the Bothnian Bay.

Pile driving had the shortest duration of the three assessed types of noise, but also the highest levels of size. Pile driving can potentially cause avoidance responses, temporary and permanent hearing threshold shift, and in the worst-case acoustic trauma to non-auditory tissue.

For fish, the modelled threshold distance for acoustic trauma was <100 - 1100 m for adult or juvenile fish and 525 – 650 m for eggs and larvae. The modelled limit for temporary hearing threshold shift in fish was 6 – 17.9 km. The size and extent of the impact from pile driving was assessed as moderate negative for fish, and the overall consequences of pile driving during construction of the OWF was set to low, mainly due to the scarcity of fish and the lack of spawning in the area.

The modelled distance limit for permanent or temporary hearing threshold shifts in seals was <100 m and <200 m, respectively while the threshold for avoidance behaviour was 6 – 7.45 km. The size and extent of the impact from pile driving was assessed as low negative for seals and the overall consequences of pile driving during construction of the OWF was set to low due to the scarcity of seals in the project area and experiences from other OWFs.

Vessel noise is less intense than pile driving noise, but more prolonged and widespread. The project area for Laine OWF is overlapping with intensively used shipping routes, and the relatively low number of animals in the area are likely adapted to a certain amount of vessel noise. The size and extent and the consequences of the impact from vessel noise for Laine OWF was therefore assessed to be negligible for fish. For seals, the size and extent of the impact from vessel noise was assessed as low negative and the consequences to be minor.

Noise emissions associated with the operation of wind turbines are both aerodynamic noise and mechanical noise, which form the least audible levels of noise of those included in this report. Studies from other offshore wind farms have documented that the cumulative noise level from several operating wind turbines is well below the ambient noise level in areas with high ambient noise levels from ships and high wind speeds, which is also expected to be the case in the Laine OFW. Both the size and extent and the consequences of the operational noise was therefore assessed to be negligible for fish and seals in the area.

Table 0.1 summaries the results of the impact assessment of underwater noise during construction and operation for both fish and seals

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Table 0.1 Impact assessment of underwater noise during construction and operation of Laine Offshore Wind Farm.

Impact	Sensitivity of the recipient	Size and extent of the impact	Consequence
Piledriving - fish	Low	Moderate negative	Low
Piledriving - seals	Moderate	Low negative	Low
Ship Noise - fish	Low	Negligible	Negligible
Ship Noise - seals	Low	Low negative	Minor
Operational Noise - fish	Low	Negligible	Negligible
Operational Noise - seals	Low	Negligible	Negligible

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1. Introduction

OX2 AB plans to establish Laine offshore wind farm in the Bay of Bothnia in Finland's exclusive economic zone (EEZ) (Figure 1.1). This report presents the details of the Environmental Impact Assessment (EIA) for fish and marine mammals from underwater noise related to the construction and operational phase. The report provides a brief baseline description of marine mammals and fish in the Bay of Bothnia and within the project area for Laine offshore wind farm. The baseline descriptions of fish and marine mammals are based on existing knowledge as well as fish surveys using multimesh gillnets in the wind farm area. The baseline chapter provides an assessment of the area's importance for the relevant fish and marine mammal species.

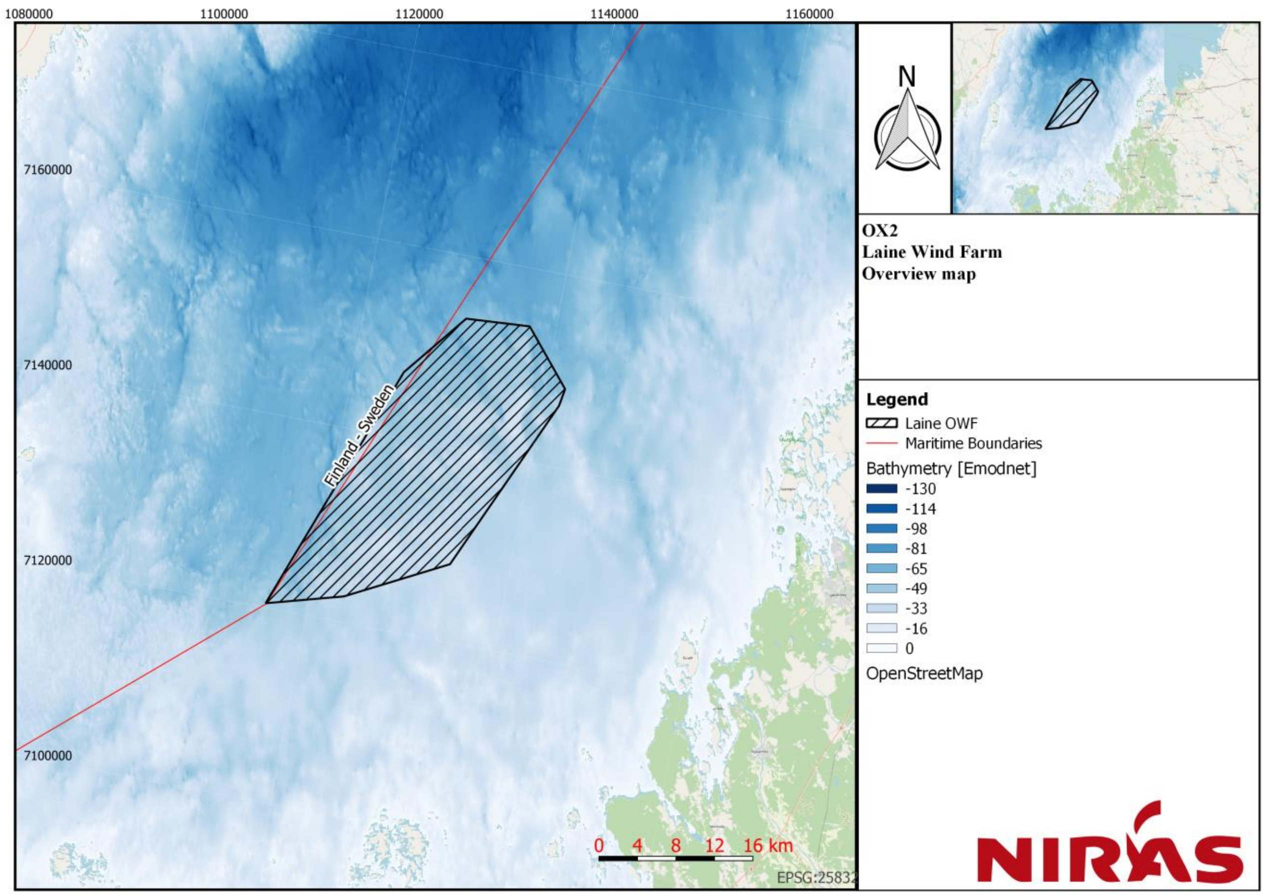

Figure 1.1: Overview of Laine offshore wind farm site (black) and surrounding area.

To assess the impact on marine mammals and fish from the installation of foundations a site-specific underwater noise modelling has been conducted and a brief description of the modelling is provided in section 4.2. For a more detailed description of the underwater noise modelling see the technical report (NIRAS, 2023). Descriptions of other underwater noise emitting activities related to the construction and operational phase is based on existing knowledge and a description is provided in this report. In chapter 4 and 5 impact assessments of underwater noise during the construction and operational phase on fish and marine mammals are provided.

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1.1. Project area

Laine OWF site is in the Finnish part of the Bay of Bothnia, about 30 km west of Pietarsaari and 25 km from the shoreline (see Figure 1.1). The project area is approximately 451 km^2.

The project includes installation of up to 150 wind turbines within the project area with a capacity of 15-25 MW for each turbine. Foundation types for the turbines have not yet been decided, however a number of options are considered. Monopile foundations up to 18 m diameter, 3- or 4-legged jacket foundations with up to 8 m pin piles, or alternative foundations such as floating, gravitation or suction bucket could be used either exclusively or in combination.

1.2. Assessment methods

A systematic approach has been used to find and assess the potential impacts, effects and consequences of the planned activity on fish and marine mammals and to describe protective measures to mitigate the impact. In the present report the terms *sensitivity*, *impact*, *effect* and *consequence* are used.

- **Sensitivity**: The sensitivity of the recipient or species to the given impact.
  The assessment of the recipient's sensitivity is based on the current scientific knowledge as well as information from conducted field work. A recipient's sensitivity can be low, moderate or high. A recipient's sensitivity is assessed based on:
    - The recipient's status including population trends, abundance and occurrences.
    - The recipient's sensitivity to the given environmental impact and its ability to adapt to the pressure. In this situation underwater noise.
    - The recipient's sensitivity during different periods of the year (for example, the recipient may be more sensitive during mating season or during migration periods).

- **Size and extent of the impact and effect*:***
  Impact: Refers to the change in the physical environment due to project activity. For example: generated noise, discharge of pollutants, loss of valuable natural environments, increase in traffic within the area. The impact can be at a local, regional or national level and furthermore either short term, temporary or permanent.

  Effect: Describes the significance that the impact is assessed to have on the existing values of the environment. Hence, a description of the extent of the impact. Which effect(s) that will occur because of the impact must be seen in relation to the specific conditions of the affected area. Hence, what makes the environment valuable, which values are affected and how sensitive are they. If an area has little value, the impact is expected to have little effect. If, however, the area is valuable or sensitive the effect of a given impact is expected to be higher.

- **Consequence:** is an assessment of what importance the environmental effects, from a given impact, will have for the interests involved, such as the climate, human health or biodiversity. In assessing the consequences, the assessment is based on the extend of the impact, the significance for the environmental values and how large the impact is expected to be. The assessment is held up against a "no-action" alternative, a so-called zero alternative. The zero alternative describes the expected future development of the area if the project is not implemented.

Initially, a screening of the impact is made, describing what type of impact the planned activity may have. To make the overall assessment of effects and consequences, an assessment of the species' (recipient's) sensitivity

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is made. Thereafter, the degree of impact (and effect) that the activity is assumed to have on the species is assessed. The assessment of the potential consequences following the activity is made by weighing the recipient's sensitivity up against the extent of the impact and the effect. Based on this, it is finally assessed what environmental consequences the project may have (Table 1.1).

Table 1.1: The assessment matrix used to assess the potential consequence of a given impact.

The significance of the consequence		Size and extent of the impact						
		High Negative	**Moderate Negative**	**Low negative**	**insignificant**	**Low positive**	**Moderate positive**	**High positive**
Recipients' sensitivity	**Low**	Moderate	Low	Minor	Negligible	Minor	Low	Moderate
	Moderate	High	Moderate	Low	Negligible	Low	Moderate	High
	High	Very High	High	Moderate	Negligible	Moderate	High	Very High

The sensitivity of the recipient is assessed in relation to the relevant impacts during the different stages of the planned project. To assess the size and extent of the impacts, the assessments are based on *worst case scenarios* where the impacts are expected to be highest.

2. Fish – baseline description

This chapter contains background information on the fish community inhabiting or using the project area. A general intro and assessment of the area and the overall structure of its fish community is given, followed by results from fish surveys in the project area. Finally, the fish species that use the project area are described and the importance of the project area as habitat for the species is assessed.

2.1. Fish ecology in the project area

Ninety-five percent of the world's fish species are adapted to life in waters of either very low salinity (freshwater species) or full sea level salinities (marine species). The remaining five percent are so-called euryhaline fish that can survive a wide range of salinities (McCormick, Farrell, & Brauner, 2013).

The high discharge of freshwater into the Baltic Sea and the limited sea water exchange between the Baltic Sea and the North Sea, makes the Baltic Sea brackish with salinities decreasing from 30 PSU at the North Sea border to almost 0 PSU in the archipelagos of the northern Bay of Bothnia (Emeis, Struck, Blanz, Kohly, & Voß, 2003).

The brackish water of the Baltic Sea imposes physiological stress on both marine and freshwater organisms. The overall species composition of the sea changes from something resembling a normal marine environment in the Western Baltic to something resembling a lake system in the archipelagos of the northern Bay of Bothnia (HELCOM, 2018d; Naturvårdsverket, 2012)(Figure 2.1).

Some examples of genetic adaptation and diversification exist in the Baltic Sea, where populations of marine species such as herring and Atlantic cod have pushed their salinity tolerance and adapted themselves to a life in

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the brackish waters (Johannesson & André, 2006). In addition to this, a number of euryhaline species such as Atlantic salmon, brown trout and European eel that may utilize both marine and freshwater during their lifecycle, inhabit the sea.

The Baltic Sea is thus a complex ecological fish niche and a relatively species-poor environment with a geographical change in fish community composition (HELCOM, 2018d; Naturvårdsverket, 2012).

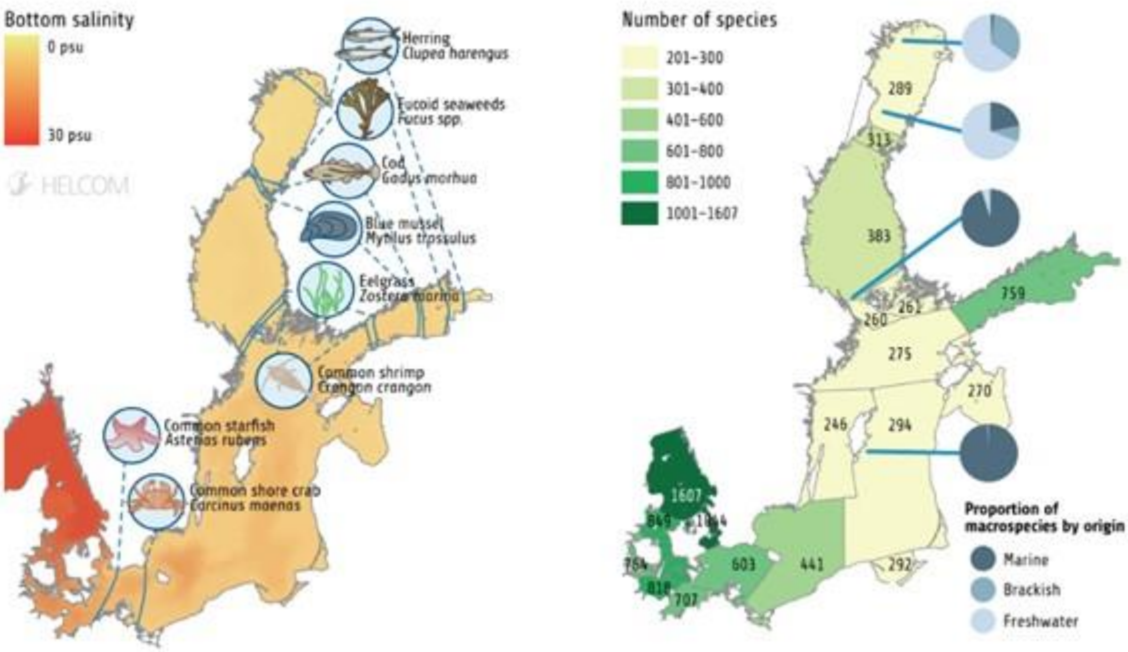

Figure 2.1: Left panel: Bottom salinity of the Baltic Sea with distribution limits of selected species. Right panel: Overall number of species present and the proportion of species by origin (marine, brackish or freshwater) in the Baltic Sea. Figure from (HELCOM, 2018d). The Bay of Bothnia is dominated by freshwater species, but is relatively species-poor.

The Laine project area is in the Bay of Bothnia, in the least saline end of the Baltic Sea. It is in an aquatic environment with a special mix of physio-chemical conditions. The offshore habitat is unsuitable for most marine and freshwater fish species otherwise found in Nordic regions, and the project area is thus a relatively species-poor environment with a peculiar mix of fish species inhabiting it.

The fish community found in the Bay of Bothnia area is dominated by species typically associated with freshwater systems. Key freshwater species such as pike, perch and pikeperch are, however, not common in the offshore area, despite being important predatory fish in the coastal areas of the Bay of Bothnia (Appelberg, Holmquist, & Forsgren, An alternative strategy for coastal fish monitoring in the Baltic Sea., 2003; Naturvårdsverket, 2010). These species prefer relatively warm water and tend to seek out such conditions, mainly through residency in coastal or shallow areas. The offshore location of the Laine project area and the low bottom water temperatures there during summer, reduce the suitability of the project area as habitat for these species (Happo & Vatanen, 2022; Mattila, Halonen, & Vatanen, 2022; Saulamo & Neuman, 2002). This is also the case for several other freshwater species found in surveys in near-coastal environments of the Bay of Bothnia (Appelberg, Holmquist, & Forsgren, An alternative strategy for coastal fish monitoring in the Baltic Sea., 2003). The number of freshwater species using the offshore habitats of the project area is therefore relatively small.

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Marine fish in the Bay of Bothnia are mainly represented by a population of herring, which is also the case in the Laine project area (Jorgensen, Hansen, Bekkevold, Ruzzante, & Loeschke, 005; Saulamo & Neuman, 2002). Other marine species such as snake pipefish, Viviparous blenny (eelpout) and sprat that have been caught in surveys roughly 100 km south of the project area are only expected to stray sporadically northwards into the less saline waters of the project area (Appelberg, Holmquist, & Forsgren, An alternative strategy for coastal fish monitoring in the Baltic Sea., 2003; HELCOM, 2018d; Naturvårdsverket, 2010). The salinity in the Bay of Bothnia is also sufficiently low to exclude the otherwise Baltic Sea-adapted populations of cod from inhabiting it.

Euryhaline species in the Bay of Bothnia includes European whitefish, Atlantic salmon, brown trout and European eel that all utilize both marine and freshwater environments during their lifecycle. These species are generally migratory and thus expected to use the project area either while foraging or migrating through it. Additionally, some species of sculpin are euryhaline despite living their entire life in marine or brackish waters. These species may all be found in offshore environments and thus in the project area.

The low diversity of fish in the Bay of Bothnia also makes the list of commercially exploited species in the bay relatively short. This is particularly true for offshore areas where commercial fisheries in the Bay of Bothnia mainly focus on herring and to a lesser extent on European whitefish, vendace and Atlantic salmon (Söderkultalahti & Rahikainen, Commercial marine fishery catch continued to decrease in 2021 https://Www.Luke.Fi/En/News/Commercial-Marine-Fishery-Catch-Continued-to-Decrease-in-2021., 2021). This has also been the case in more historical terms (Stephenson, et al., 2002). The commercial offshore fisheries in the Bay of Bothnia have not seen the same decline as elsewhere in the Baltic Sea over the past decades (Hamrén, 2021).

In conclusion, the environmental characteristics of the Laine offshore project area makes the natural diversity of fish in it relatively low. The habitat is mainly populated by euryhaline fish species that tolerate a variety of salinities while conditions are only tolerable or preferable for a small number of marine and freshwater species.

2.1.1. Fish surveys in the project area

A survey with multimesh gillnets was conducted twice at 30 locations in the Laine project area in July 2022 to shed light on the composition of species inhabiting it. This method is a commonly used tool to provide insights to ecosystem compositions in the Baltic Sea (Bergström, et al., 2016; HELCOM, 2018c). Details about the 2022 survey method are described in (Happo & Vatanen, 2022).

The survey found six species of fish in the project area: Herring, four horn sculpin, shorthorn sculpin, Eurasian ruffe, smelt and European whitefish. Herring and four horn sculpin were numerically dominant on all 30 stations (Figure 2.2), with a total of 71 % of all captured individuals being herring and 21 % being four horn sculpin.

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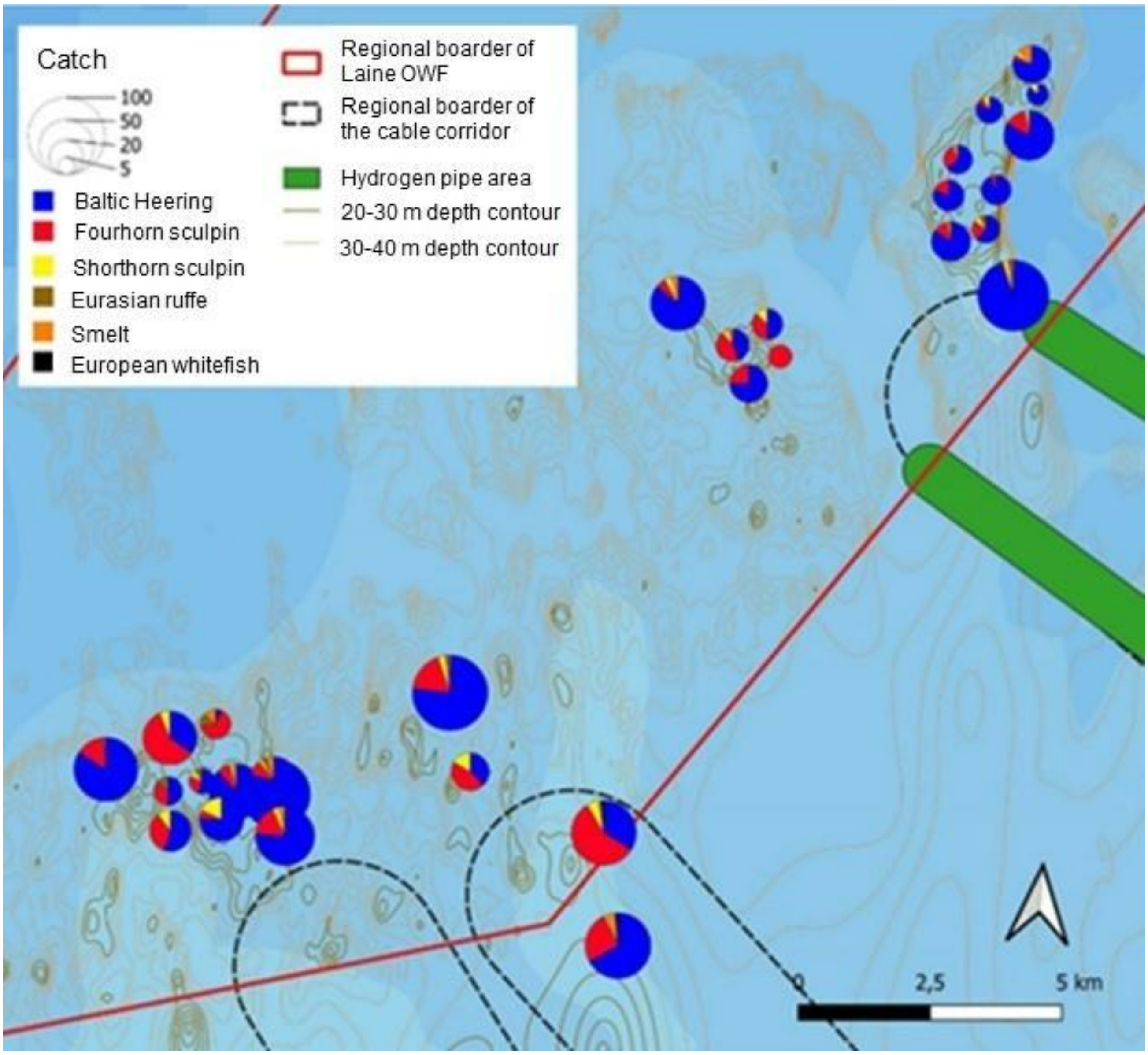

Figure 2.2: Location and catches at the 30 survey locations in the July 2022 survey. Figure modified from Happo and Vatanen (2022). See Happo and Vatanen (2022) for additional info.

Biomass of the combined catches was 47 % herring, 41 % four horn sculpin and 9 % shorthorn sculpin while smelt, ruffe and whitefish each accounted for roughly 1 % of the biomass.

The survey found no specimens of Atlantic salmon, vendace and European eel, although these fish likely utilize the area to some extent.

2.2. Main fish populations in the project area

The following chapter describes the main fish species inhabiting the Laine project area, their conservation status and the importance of the project area for them. The six species that were caught in the 2022-surveys are included. Additionally, Atlantic salmon, vendace and European eel are also included.

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2.2.1. Herring

Baltic herring are brackish water-adapted Atlantic herring with a number of reproductively isolated populations that spawn in different parts of the Baltic Sea (Jorgensen, Hansen, Bekkevold, Ruzzante, & Loeschke, 005; Lamichhaney, et al., 2012). The herring population inhabiting the Bay of Bothnia is less migratory than its neigh boring populations, and Bothnian herring individuals usually spend their entire lifecycle within the bay (Saulamo & Neuman, 2002). Herring feeds mainly on different types of zooplankton, though other food items such as fish eggs may also be consumed (Arrhenius & Hansson, 1993; Köster, 2000). Baltic herring spawn in relatively shallow waters on a variety of substrates, though soft sediment bottoms are avoided (Aneer, 1989). It is a pelagic species that is often found in offshore areas such as the Laine project area where it was also abundant during the 2022 survey (Happo & Vatanen, 2022). Herring tends to form schools and seek out deeper waters during daytime likely as a means of protection from predation as herring themselves are a preferred food item for several species of fish, birds and mammals (Nilsson, Thygesen, Lundgren, Nielsen, & Beyer, 2003). Herring is a key species in the Bay of Bothnia ecosystem.

The Bay of Bothnia-population of herring is considered healthy and assessed to be the largest population in the Baltic Sea at the moment, following a recent decline in other Baltic herring populations, mainly due to overfishing (Hamrén, 2021). The population is, however, managed with relatively scarce information about population size and recruitment. The fishing quota for Baltic herring in the Bay of Bothnia was almost doubled from the 2020 level in 2021 and 2022 as a consequence of a new ICES stock assessment method (Hamrén, 2021; Söderkultalahti & Rahikainen, Commercial marine fishery catch continued to decrease in 2021 https://Www.Luke.Fi/En/News/Commercial-Marine-Fishery-Catch-Continued-to-Decrease-in-2021., 2021). The consequences of this for the population status are still unknown.

Waters in the Laine project area are likely too deep to function as a spawning habitat for herring. Occasional spawning in the habitat cannot be ruled out entirely, though this would be of marginal extent compared to the main spawning in more shallow environments. Also, survivability of offspring from spawning in the project area would be questionable. The abundance of herring in the area in the 2022 survey suggests herring use the area as a foraging area or as a migration corridor, like other marine areas of the Bay of Bothnia. The importance of the Laine project area is therefore assessed as medium for herring.

2.2.2. Sculpins

Shorthorn sculpin and four horn sculpin are both euryhaline fish, tolerating a large spectrum of salinities despite generally living their entire life in marine or brackish waters (Fishbase, 2023a; Fishbase, 2023b; Life, 2023). Of the two species, four horn sculpin is the most tolerant towards low salinities, and there are landlocked populations of four horn sculpin in Sweden and Finland. Both species prefer cold waters and can tolerate very low temperatures due to anti-freeze proteins in their blood (Yamazaki, Nishimiya, Tsuda, Togashi, & Munehara). Both species are benthic, relatively sedentary in most of their lifecycle and feed on small fish and invertebrates (HELCOM, 2013c; HELCOM, 2013d). Spawning takes place during winter, typically in more shallow waters, and the adult individuals move back into deeper waters as water temperatures increase during spring and summer (NatureGate, 2021a; NatureGate, 2021b).

There is little commercial and recreational interest for shorthorn and four horn sculpins, and knowledge on the population sizes and dynamics of both species in the Bay of Bothnia is relatively scarce. Both species are classified as Least Concern (LC) in the Baltic by HELCOM, and there are no identified threats to the species in the Bay of Bothnia area (HELCOM, 2013c; HELCOM, 2013d).

The relatively high proportion of shorthorn sculpin in the Laine project area during the 2022-survey is surprising, as the species is reported to be more abundant further south in the Baltic Sea (Happo & Vatanen, 2022;

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HELCOM, 2013d). Shorthorn sculpins are more tolerant to higher temperatures than four horn sculpins, and the latter may have moved further out to deeper and colder waters at the time of the survey, to avoid temperatures above 10° C which was recorded at the bottom during the survey (Mattila, Halonen, & Vatanen, 2022). The project area is likely too deep to function as a spawning habitat for both species but acts as a foraging area outside the spawning season, like other marine areas. Occasional spawning in the habitat cannot be ruled out entirely, but this would be of marginal extent compared to the main spawning in more shallow environments, and the survivability of offspring from spawning in the project area is questionable. The importance of the project area is therefore assessed as medium for shorthorn and four horn sculpins.

2.2.3. Smelt

Smelt prefers cold and well-oxygenated water, and is widespread in the Bay of Bothnia, where there is no permanent halocline. The species is common in coastal waters but the most important marine smelt stocks are found in areas where water of low temperature and relatively high oxygen content persists year round, typically in the neighbourhood of large estuaries and lagoons (Shpilev, Ojaveer, & Lankov, 2005). Smelt spawns in rivers, bights, and inlets where water temperatures are higher. In the Finnish Bothnian Bay-areas, the spawning conditions for smelt are particularly favourable close to shore (CHM, 2019). Smelt diet consists of a mixture of invertebrates and fish (Taal, et al., 2014).

Smelt is a target for the commercial fisheries and smelt landings in Finland have doubled or quadrupled to record levels above 2.000 t in 2019 to 2021 compared to pre-2018 levels (Luke, 2023). There is limited knowledge about the health of the smelt stock in the Bay of Bothnia.

A total of 23 smelt were caught in the Laine project area during the 2022-survey (Mattila, Halonen, & Vatanen, 2022). Although far less abundant than e.g., herring (774 individuals caught) and sculpins (276 individuals caught), smelt still appears to use the area to some degree, most likely for foraging or as a migration corridor. The project area is not likely to be a foraging area of special importance for smelt, and spawning is unlikely to occur in the project area. The importance of the Laine project area is therefore assessed as low to medium for smelt.

2.2.4. Vendace

Vendace is a small salmonid fish that typically inhabits deep and oligotrophic lakes in Western and Northern Europe but is also found in the least saline areas of the Bay of Bothnia (López, et al., 2022). It is limited to residence in waters with salinities below 2-3 PSU. Vendace spawns from October to December in river estuaries and shallow coastal areas and is known for its strong and unpredictable stock fluctuations caused by large fluctuations in recruitment (Lehtonen, Biology and stock assessments of Coregonids by the Baltic coast of Finland. Finnish Fisheries Research., 1982). Vendace mainly feeds on zooplankton or larger prey items such as insects and fish fry. The migrations of vendace are only scarcely known in the Bay of Bothnia, but natal homing where adult individuals return to spawn in their area of origin may occur (Enderlein, 1986).

The commercial fishery for vendace is economically important in both Sweden and Finland. The fishery for vendace is practically managed as two different stocks (a Swedish and a Finnish), although the stock composition is complex and likely consists of a number of sub-populations (Bergenius, Gårdmark, Ustups, Kaljuste, & Aho, 2011; Lehtonen, Biology and stock assessments of Coregonids by the Baltic coast of Finland. Finnish Fisheries Research., 1982; Luke, 2023). The stock size has not been monitored in the Finnish waters until recently, but vendace landings have gradually increased in Finland from a low point around or below 100 t in 1980-2000 to 373 t in 2021 (Luke, 2023). The fishery mainly takes place during September and October before the spawning period.

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No vendace was caught in the 2022-survey in the Laine project area (Happo & Vatanen, 2022). The 2-3 PSU salinity limitation of vendace places the project area at the southern edge of the distribution area of the species (López, et al., 2022). Vendace may use the project area occasionally, but it is unlikely to represent an important habitat for them, neither for foraging, migration or spawning, as most of these activities would likely occur in more near-coastal areas, while spawning is limited to river estuaries or shallow coastal areas. The overall importance of the Laine project area is therefore assessed as low for vendace.

2.2.5. European whitefish

European whitefish inhabiting the brackish Baltic Sea and its freshwater tributaries is an ecologically and economically important fish, forming both sea-spawning and freshwater-resident forms (Lehtonen, Biology and stock assessments of Coregonids by the Baltic coast of Finland. Finnish Fisheries Research., 1982; Sõrmus & Turovski, 2003). Spawning takes place during autumn (Veneranta, Urho, Koho, & Hudd, 2013). The freshwater form spawns in rivers with various discharge rate (Larsson, et al., 2013), while the spawning areas of the sea-spawning form are mostly located in shallow bays with sandy, stony and/or gravely bottom (Sõrmus & Turovski, 2003). European whitefish feed mainly on zooplankton and invertebrates.

European whitefish populations are under pressure in the Baltic Sea (Veneranta, Urho, Koho, & Hudd, 2013), and Finnish commercial catches of whitefish reached a record-low of 329 t in 2021 (Luke, 2023). The decline of the species is likely linked to overfishing, eutrophication of mainly coastal areas and restricted access to spawning grounds (for the freshwater spawning form) (Verliin, Saks, Svirgsden, Vetemaa, & Saat, 2011).

Whitefish can be highly migratory and traverse large parts of the Baltic Sea during their feeding migrations (Lehtonen & Himberg, Baltic Sea migration patterns of anadromous, Coregonus lavaretus (L.) s.str. and sea-spawning European whitefich, C.l. widegreni Malmgren. , 1992). The Laine project area and similar offshore areas are thus potential foraging habitats or migration corridors for whitefish. A total of two individuals were caught in the Laine project area during the 2022-surveys, confirming that whitefish do migrate through or forage in the area to some extent, though more near-coastal environments are most likely preferred (Happo & Vatanen, 2022). Spawning occurs in freshwater or coastal environments. The importance of the Laine project area is therefore assessed as low for European whitefish.

2.2.6. Eurasian ruffe

Ruffe is common in coastal areas of the Bay of Bothnia (Appelberg, 2012; Appelberg, Holmquist, & Forsgren, 2003; Kagervall, 2008). It is a highly fecund and generally short-lived species with an adult size of roughly 20 cm (Fishbase.se., 2023). It can tolerate salinities up to 10-12 PSU and prefers soft bottom sediment or deeper waters with sand or gravel bottom. Ruffe mainly feed on benthic invertebrates in deeper, coastal areas, but migrate into shallow and warmer waters to spawn during spring (Kottelat & Freyhof, 2007; Ravinet, Syväranta, Jones, & Grey, 2010).

Ruffe is not a target species for commercial or recreational fisheries, and stock size and health of the species is scarcely known in the Bay of Bothnia.

A total of 11 ruffe were caught in the Laine project area during the 2022-survey (Mattila, Halonen, & Vatanen, 2022). Adult specimens may migrate to deeper areas offshore such as the Laine project area to some extent during summer, although most of the population likely stays closer to the coast. The project area is therefore not likely to be a foraging area of special importance for ruffe, and ruffe spawning usually occurs at shallow waters less than 3 meters deep. Ruffe migration through the areas is assessed as scarce compared to the activity in more near-coastal areas. The importance of the Laine project area is therefore assessed as low for ruffe.

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2.2.7. Atlantic salmon

Atlantic salmon spawn and start their lifecycle in freshwater but acquire most of their body weight during feeding campaigns in the open sea (Aas, Einum, Klemetsen, & Skurdal, 2011). Individuals from Baltic populations stay within the Baltic Sea and form a mixed stock within the sea until individuals return to spawn in their natal rivers (Jutila, Jokikokko, Kallio-Nyberg, Saloniemi, & Pasanen, 2003; Kallio-Nyberg & Ikonen, 1992). Salmon are pelagic and generally migrate close to the surface in the open sea, while dives to the seabed or thermocline are performed for foraging or navigational purposes (Reddin, Downton, Fleming, Hansen, & MAHON, 2011). Salmon mainly feed on fish, with herring being one of the most important prey items for the species in the Baltic Sea (Salminen, Erkamo, & Salmi, 2011). The most important foraging areas for salmon are likely found in the southern Baltic Sea (Jacobson, Gårdmark, & Huss, 2020).

Atlantic salmon populations in the Baltic Sea are under pressure, likely due to reduced access to spawning grounds in the rivers or worsening ecological conditions there (Kautsky & Kautsy, 2000). Restrictions are therefore being imposed on the recreational fishery for salmon in the Baltic Sea (Alliance, 2022). Commercial landings of salmon in Finland were 200.000 kgs in 2021, mainly from fisheries south of the Bay of Bothnia. Landings of salmon have seen a decreasing trend in Finland, though the fishery is still important due to the high market price of salmon (Söderkultalahti & Husa, 2022).

The Laine project area with its offshore location represents a possible foraging area for Atlantic salmon as they traverse the Baltic Sea. However, salmon appear to prefer feeding migrations to more southern parts of the sea (Jacobson, Gårdmark, & Huss, 2020). Salmon migrates in both near-coastal and offshore waters, and some salmon migration through the project area is therefore likely to occur. The project area is not likely to be of particular importance for salmon, although its main prey item, the herring, is present (Happo & Vatanen, 2022) and some migration through the area most likely occurs. The Laine project area is therefore assessed to be of low importance for Atlantic salmon.

2.2.8. European eel

The European eel is an iconic species that undertakes a long spawning migration from its foraging and growth habitats throughout Europe and Northern Africa to the spawning areas in the Sargasso Sea (Aarestrup, 2009). It utilizes freshwater and coastal ecosystems as growth habitats, and even adult eels that have initiated their spawning migration may spend substantial time or overwinter in the Baltic Sea (Tambets, et al., 2021; Tzeng, Wang, Wickström, & Reizenstein, 2000). Eels are generally benthic but move pelagically and close to the surface at night-time during their spawning migration (Westerberg, Lagenfelt, & Svedäng, 2007).

The European eel is critically endangered, and a large proportion of eels in the Baltic originate from stocking (ICES, 2016). European eel was once a commercially important species in large parts of Europe and migrating eels from Finland would be included in coastal fisheries on their route to the Atlantic Ocean. In Finland, eel is mostly caught in recreational fisheries or as bycatch (FishinginFinland, 2018).

The habitat use of European eel is complex and scarcely discovered in the Baltic Sea. Migrating eels may swim through the Laine project area during their migration to the spawning area, which occurs during spring and early summer in Finland. Offshore areas may, additionally, serve as overwintering habitat for eels, although this is speculative at the current level of knowledge, and overwintering most likely occurs in more near-coastal environments. Eels require relatively warm waters to grow (Sadler, 1979), and northern offshore areas such as the project area are most likely too cold to act as important growth habitats for eel. The Laine project area is therefore assessed to be of low importance for European eel.

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2.2.9. Other species

The Laine project area may be used to some degree by a number of other species including perch, pike, pike-perch, brown trout and marine species such as snake pipefish, viviparous blenny (eelpout) and sprat. These species, among several others, occur either south of the project area in more saline waters or around the coastal areas of the Bay of Bothnia from where they may move into or through the bay occasionally (Appelberg, Holmquist, & Forsgren, 2003; HELCOM, 2018d; Saulamo & Neuman, 2002). The project area is, however, not likely to constitute a necessary habitat for these species, and its importance for these species is therefore not assessed further.

2.2.10. Overall assessed importance of the project area as fish habitat

The Laine project area is species-poor and relatively scarcely used by fish. The area is unsuited or assessed as an unpreferred spawning habitat for all the species using it and it mainly constitutes a part of a larger foraging area. The project area is too far offshore, and the water temperatures are too cold compared to the warmer and more shallow coastal environments. There is a small likelihood that herring, shorthorn sculpin and four horn sculpins show occasional spawning activities in the project area, though the survivability of offspring from such spawning is questionable. Also, the extent of such spawning, if occurring at all, would be very marginal compared to the main spawning events occurring in near-coastal environments. The nearest suitable fish spawning habitats would be found closer to the shoreline, and thus several kilometres from the project area. Some migration through the project area likely occurs, mainly when herring, smelt, salmon and whitefish and perhaps eel migrate through the area. The importance of the Laine project area as spawning habitat for fish is therefore assessed as very low to low, while its importance for migrating fish is assessed as low. The importance for fish as a foraging area is assessed as low to medium, as mainly herring, smelt and sculpins use the area for foraging, which may also be the case for ruffe, salmon and whitefish.

3. Marine mammals – baseline description

This chapter contains background information on the two resident marine mammal species in the Bay of Bothnia that may occur in and around the project area for Laine OWF: grey seal and ringed seal. The Baltic proper harbour porpoise may occur sporadically in the wind farm area (Naturhistoriska riksmuseet, 2022), however the area is located outside the distribution area for the population (NAMMCO-North Atlantic Marine Mammal Commission. , 2019) and the Bothnian Bay is in general considered to be of low importance for the species (Sveegaard, et al., 2022). Harbour porpoise is therefore not considered further.

3.1. Grey seals

The grey seal (*Halichoerus grypus*) is found along the eastern and western coasts of the North Atlantic Ocean. Grey seals in Finnish waters belong to the Baltic grey seal population (*Halichoerus grypus grypus*) (HELCOM, 2018b; Olsen, Galatius, Biard, Gregersen, & Kinze, 2016). Grey seals occur in the entire Baltic Sea and are depended on coastal waters, where there is plenty of food and undisturbed haul-out sites (Galatius, 2017). They feed on a wide variety of fish and the diet varies with location, season and prey availability (HELCOM, 2013a). Grey seal haul-out sites in the Baltic Sea are shown in Figure 3.1

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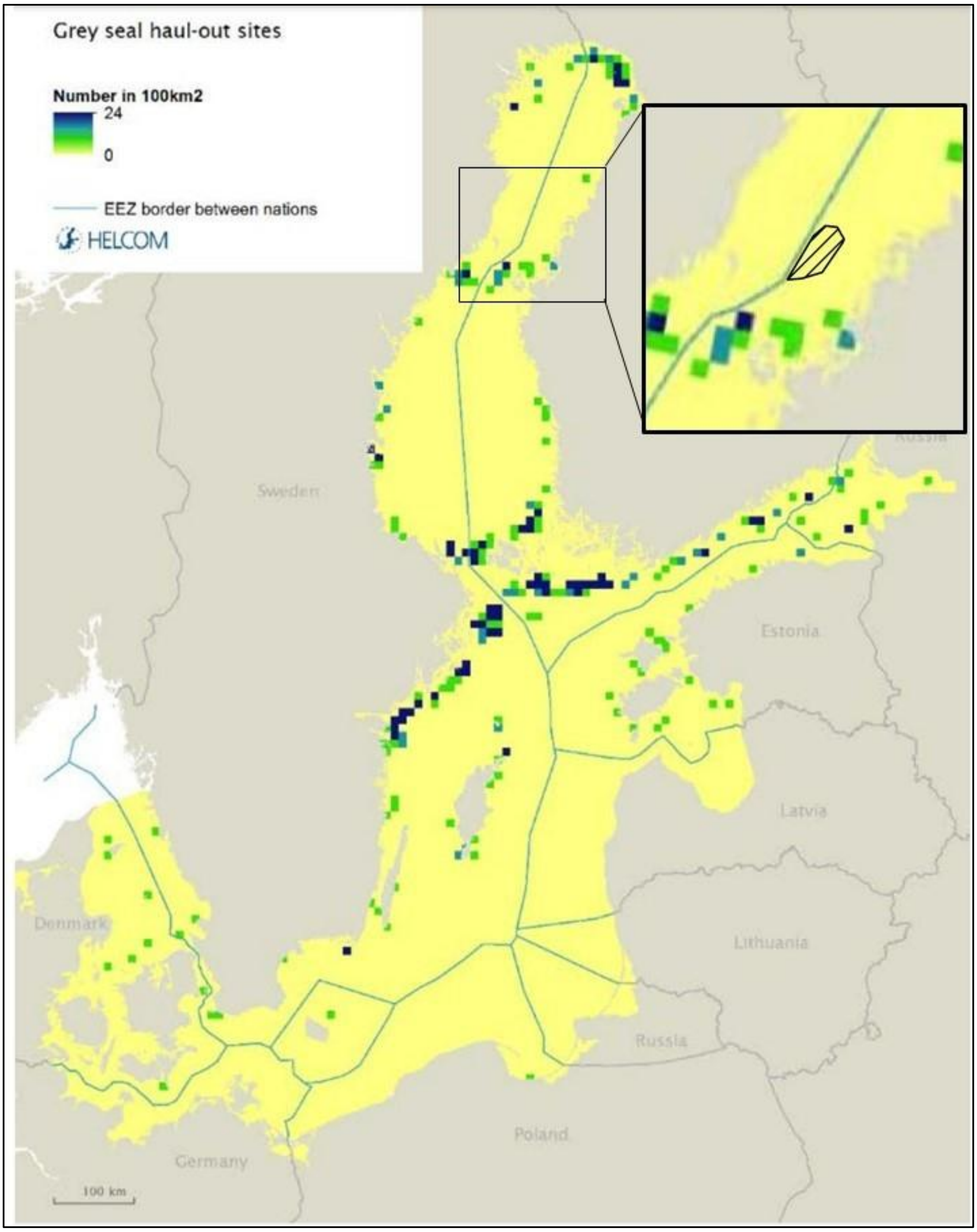

Figure 3.1: Grey seal haul-out sites in the Baltic Sea and Kattegat and the Laine OWF project area (Black lined polygon). The map includes all currently known haul-out sites. Modified from (HELCOM, 2018a).

The Baltic grey seal gives birth in February and March (Härkönen, et al., 2007). Pupping in the Baltic Sea takes place mostly on drift ice although in some areas seals also give birth on land during years of insufficient sea ice coverage (Jüssi, Härkönen, Helle, & Jüssi, 2008). The pup is born with a lanugo coat (not water-resistant), which it will moult after 2–4 weeks for a shorter adult-like coat. The pup is nursed for about 15–18 days. Grey seals also moult on ice and at the haul-out sites from April-June and spend much time on land at the haul-out sites in that

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period (HELCOM, 2013a). Grey seals usually use specific corridor areas to travel between their foraging areas offshore and their haul-out sites on land (Jones, et al., 2015). They may travel long distances and the presence of grey seals in an area does not necessarily mean that the individual depict strong site fidelity for the given area (McConnell, Lonergan, & Dietz, 2012; Galatius, 2017).

3.1.1. Grey seal conservation status

Grey seal is a protected species listed in Appendix II and Appendix V of the EU Habitats Directive and Appendix III of the Bern Convention. A limited number of grey seals are hunted under quotas in Finland (Finnish Ministry of Agriculture and Forestry, 2007) and Sweden (Havs- och Vattenmyndigheten, 2012). The actual numbers of seals that are hunted have always been far below the quota and the highest number in Finland was 632 in 2009, while in Sweden it was 132 in 2008 while (HELCOM, 2014).

The grey seal population in the Baltic Sea declined in the 1970s, with numbers as low as 3,000 individuals. The population is now recovering after a century of bounty hunting and 3 decades of low fertility rates caused by environmental pollution. Population increase is calculated from aerial counts at the important haul-out sites and the Baltic population reached a growth rate of 10–12% per annum during the early 2000s, but the growth rate has slowed to about 6% in recent years. Counted numbers fluctuate annually due to weather and other factors, however clear increasing trends in populations can be seen in all parts of the Baltic Sea. The decrease in population growth shows that the population has approached the carrying capacity in the Baltic Sea (HELCOM, 2018b). The population estimate for the Baltic Sea population is at present between 52,000-69,000 individuals (Suuronen, et al., 2023) and according to the Red list of Finnish species from 2019, the grey seal population in the Baltic Sea is classified as of least concern (LC) (Ympäristöministeriö & Suomen ympäristökeskus, 2019).

3.1.2. Importance of the Laine OWF area for grey seals

The HELCOM distribution map (Figure 3.2 shows that the Baltic grey seals use the project area for Laine OWF for both regular occurrence and reproduction. Possible reproduction in the project area will however highly be dependent on the extent of sea ice coverage. Quantitative data of the relative importance of the project area to the grey seals are not available.

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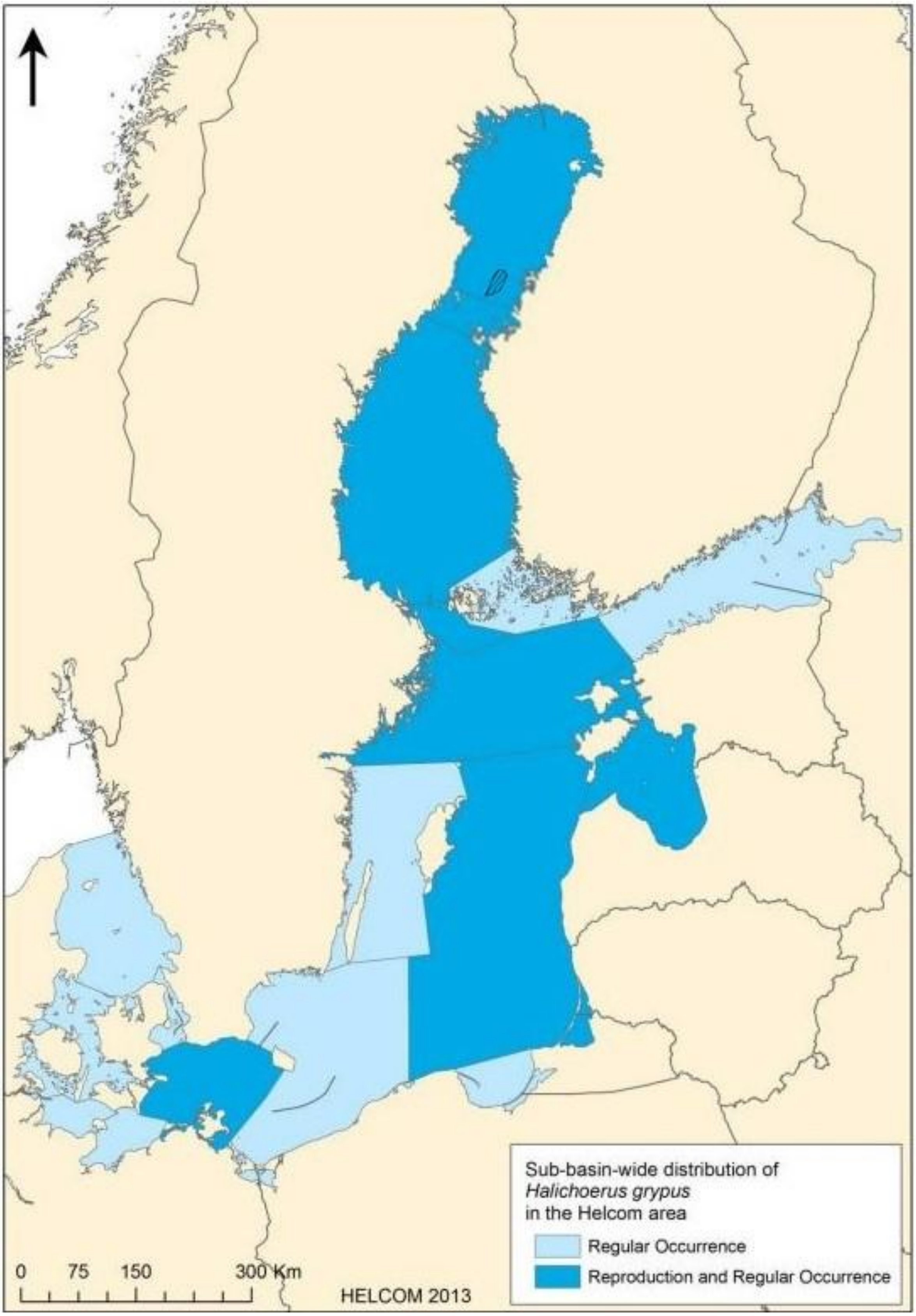

Figure 3.2: Distribution map of grey seals in the Baltic sea with the Laine project area (black lines box) modified from HELCOM (HELCOM, 2013).

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The project area for Laine OWF is found approximately 23 km north of the nearest haul-out site for grey seals at Mickelsörarna. As the project area is located relatively close to several grey seal haul-out sites, it is expected that the grey seals use the project area all year round and that the area can potentially be used as a foraging area or migration area between the haul-out sites at Mickelsörarna and the haul-sites in the northern part of the Bay of Bothnia. The area is not regarded as an important feeding area for grey seals which is supported by that the Laine project area is species-poor and relatively scarcely used by fish. The area is therefore assessed to be of low to medium importance for the Baltic grey seal.

3.2. Ringed seals

The ringed seal (*Pusa hispida*) is the most common seal in the Arctic. Ringed seals found in the project area for Laine OWF belong to the geographically isolated Baltic sub population (*Phoca hispida botnica*) (HELCOM, 2013b). Ringed seals have been surveyed during the moulting season since 1988 and the highest concentrations have always been in the central northern part of the Bay of Bothnia (HELCOM, 2018b). Around 70 % of the Baltic ringed seal population inhabits the Bay of Bothnia in the northernmost part of the Baltic Sea and the rest are found in the Gulf of Finland (5%) and Gulf of Riga (25%) (Härkönen, et al., 2014). Ringed seals feed on a wide variety of small fish and invertebrates (HELCOM, 2013).

The winter distribution of ringed seals is highly linked to the extent of sea ice that is suitable for building lairs. The highest concentrations of ringed seals are therefore found in broken consolidated ice that trap snow heaps. Females give birth to their pups in the lairs and formation of this type of ice is critical for the breeding success of this species (HELCOM, 2018a). The extent and quality of ice show considerable inter-annual variation in the Bay of Bothnia, but there has been a significant reduction in the formation of sea ice in the area since 1970s compared to historical data. Climatological modelling further predicts a decrease in sea ice formation and shorter ice-covered seasons in the future. This will likely result in the extinction of the ringed seal subpopulation in the Gulf of Riga and severely reduce the population growth rate in the Gulf of Finland and the Bay of Bothnia (Sundqvist, Harkonen, Svensson, & Harding, 2012).

Data from Baltic ringed seals tagged with satellite transmitters have provided information on distribution of ringed seals in the Bay of Bothnia. During summer, seals spend about 90 % of their time in water – feeding, travelling and resting. Data show that some ringed seals mainly stay in the basin where they were tagged (see Figure 3.3). However, the study also show that some animals move long distances of several hundreds of kilometres during the post-moulting season (Oksanen, Neimi, Ahola, & Kunnasranta, 2015).

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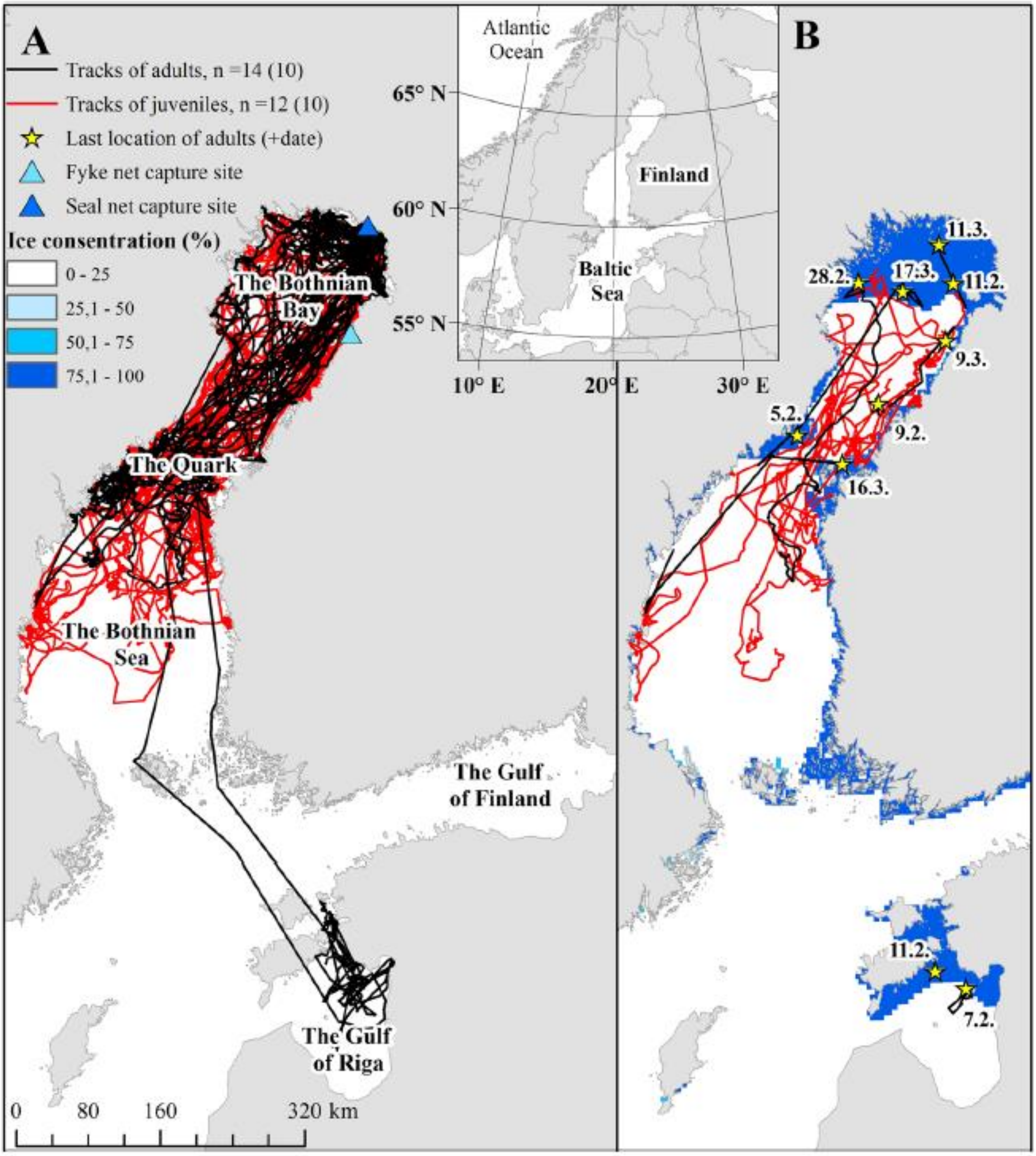

Figure 3.3: Movement of 26 ringed seals belonging to the Baltic sub population during August to May in 2011-2014. (a) movements during the whole tracking period. (b) movements during the breeding period (Oksanen, Neimi, Ahola, & Kunnasranta, 2015).

Based on the movement data from the 26 tagged ringed seals, important foraging areas for ringed seal were found. Two clusters of ringed seal foraging "hot spots" were identified, and one is found south and west of Laine OWF in the Quark and the other cluster is found north of Laine OWF in the northern part of the Bothnian Bay.

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Observations of ringed seals during the most recent aerial counts in the Bothnian Bay from 2018, 2019 and 2020 are shown in Figure 3.4

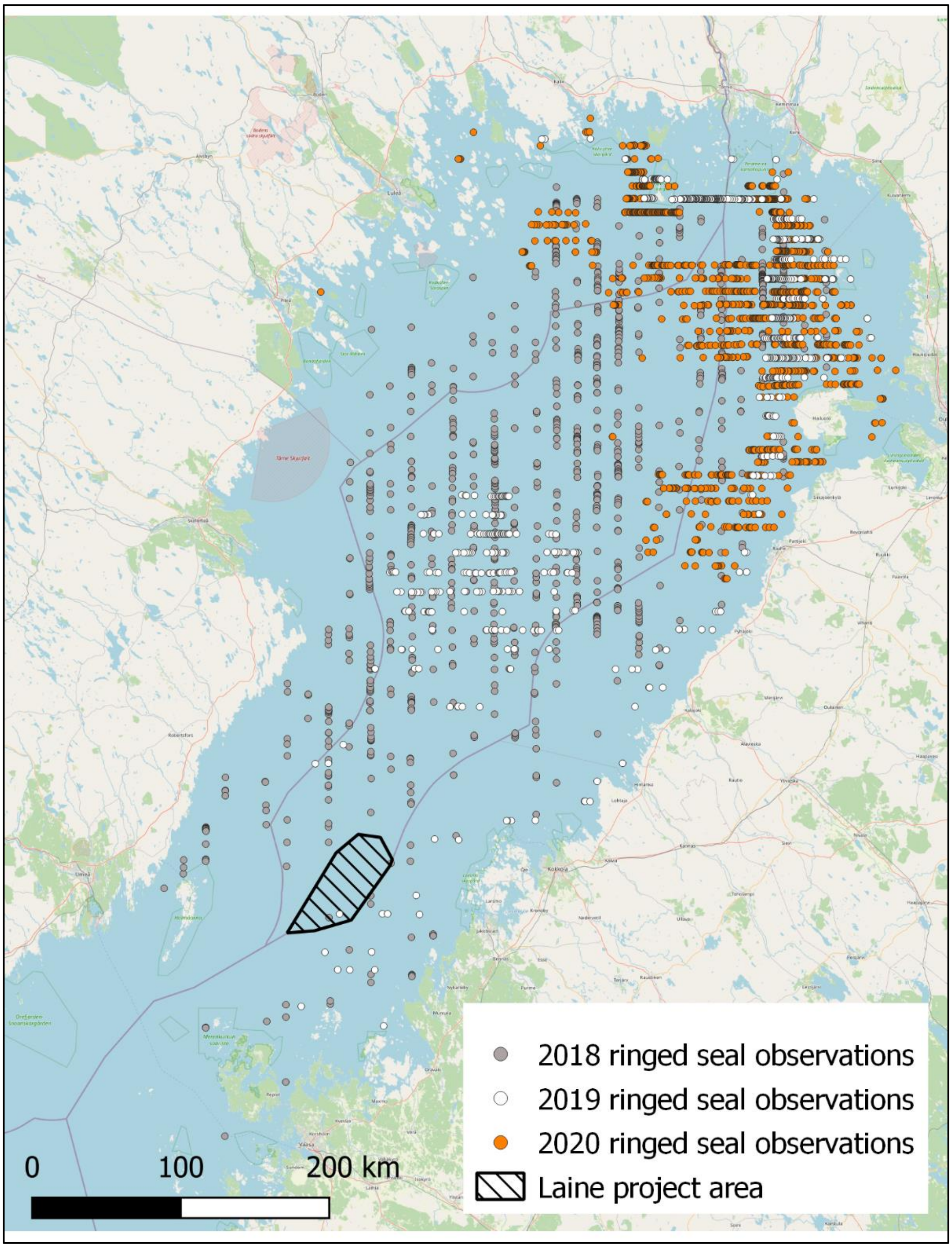

Figure 3.4: Counted ringed seals belonging to the Baltic sub population in 2018, 2019 and 2020. The aerial surveys were conducted in April for all years (modified from Havs- och vattenmyndigheten och SMHI).

As can be seen from the latest counts of ringed seals in the Bothnian Bay only few seals were seen in the Laine.

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3.2.1. Ringed seal Conservation status

Ringed seal is a protected species listed in Appendix II and V of the EU Habitats Directive and Appendix III of the Bern Convention.

Hunting and reproductive problems due to environmental pollution caused the population to collapse from approximately 200,000 to only about 5,000 individuals during the 20th century. Due to the protection of the seals and decrease in organochlorine concentrations the ringed seal population in the Bothnian Bay management unit has been increasing at a rate of 4.5% per year since 1988 and during 2003-2016 the growth rate was 5.9 % per (HELCOM, 2018b). The population size is estimated to 11,500 with an increasing trend (Härkönen, 2015). However, surveys during exceptionally mild winters in recent years, revealed that the population size most probably exceeds 20,000 animals in the Bay of Bothnia (HELCOM, 2018b).

As the population of ringed seals in the Bay of Bothnia is recovering, both Finland and Sweden have re-introduced hunting in the area, with a yearly quota to take approximately 300 ringed seals (summing both countries together) (WWF, 2017).

According to the international IUCN red list of threatened species, the ringed seal is listed as *least concern* (LC). However, according to the Red list of Finnish species from 2019, the Baltic ringed seal population is classified as *vulnerable* (VU) (Ympäristöministeriö & Suomen ympäristökeskus, 2019) and climate induced changes are foreseen to be a future challenge to ringed seals, because of their dependency of ice during the breeding season (HELCOM, 2013b).

3.2.2. Importance of the Laine OWF area for ringed seals

The HELCOM distribution map (Figure 3.5shows that the Baltic ringed seals use the project area for Laine OWF (Regular occurrence and reproduction). Breeding areas for ringed seals are tightly linked to the ice coverages, therefore breeding ringed seal may occur in the project area for Laine OWF in winters where the project area is covered with ice. The foraging of Baltic ringed seals is mostly concentrated to relatively shallow areas near the mainland and based on the movement data from the tagged ringed seals in the Bothnian Bay, the project area for Laine OWF is not considered to be an important foraging area. The project area for the Bothnian Bay is therefore assessed to be of medium importance for the Baltic ringed seal.

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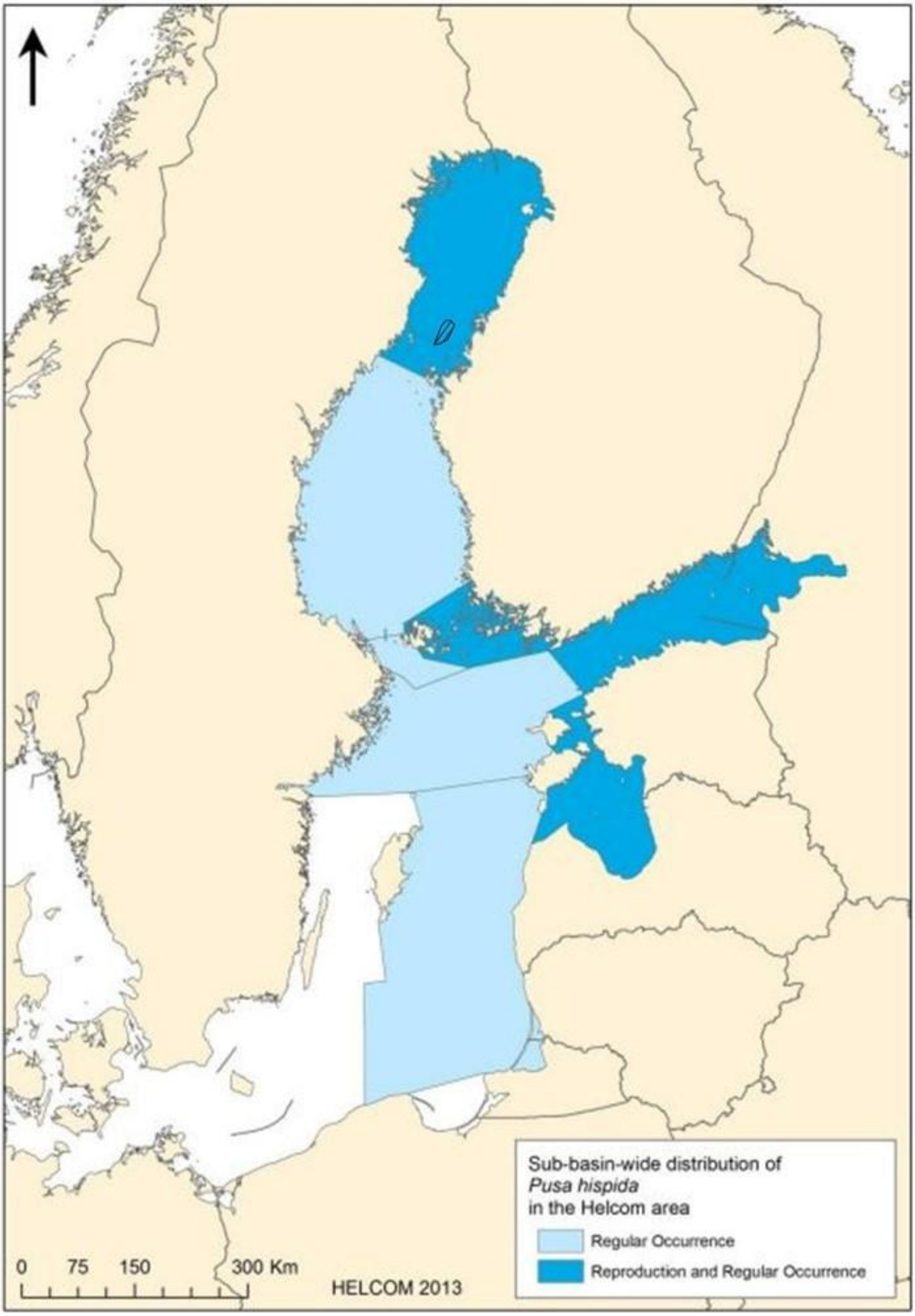

Figure 3.5: Distribution map of ringed seals in the Baltic sea with the Laine project area (black lines box) modified from HELCOM (HELCOM, 2013).

3.2.3. Existing pressures - seals

One of the main threats for seals is entanglement in fishing gear (by-catch), however it does not appear to pose a threat to the seal population (Herrmann, 2013). Fishing also has an indirect effect on pinnipeds as fishing reduces their main food source (ASCOBANS, 2012).

Seals, particularly in the Baltic Sea, are still exposed to high levels of pollutants such as lipophilic compounds including polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT) and other organic substances as well as heavy metals (Sørmo, et al., 2005). Contaminants accumulate in these animals through their prey items. DDT and PCBs especially cause reproductive problems in the Baltic Sea (Herrmann, 2013). Only little is currently known about the precise impact of pollutants on seals. Potentially, they can attack the lymphatic system, the endocrine system (e.g., the thyroid gland) and enzymes, thereby permanently damaging the animals (Sørmo, et al., 2005). Negative effects of various heavy metals on the immune system have been shown in North Sea pinnipeds (Kakuschke, Valentine-Thon, Fonfara, Kramer, & Prange, 2009).

Noise pollution from shipping, construction of offshore wind farms, and seismic surveys is a further level of pollution that may affect seals in the Baltic Sea. In addition, habitat loss due to coastal development, eutrophication and climate change that cause an increase in water temperature affect the organisms in the Baltic Sea. Particularly the Baltic ringed seal can be affected by climate changes leading to warmer winters with less ice and snow, which is crucial for the breeding success of this species (HELCOM, 2013).

4. Impact assessment - Underwater noise during construction

During construction, the most significant environmental impact on fish and marine mammals, is underwater noise from installation activities (e.g., pile driving) and shipping traffic (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006). Pile driving is assumed to have the most disturbing effect on marine animals as it can potentially cause masking of communication signals, avoidance responses, TTS (temporary) and PTS (permanent) hearing threshold shift, and in the worst-case acoustic trauma to non-auditory tissue (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006). The underwater noise from pile driving can also cause a temporary habitat loss as it may cause fish and marine mammals to be displaced from the area where pile driving is taking place as well as the surrounding area that is affected by underwater noise.

4.1. Impact thresholds for fish and seals

Guidance or threshold values for regulating underwater noise during construction of OWFs (pile driving) have been developed by several different countries and international organizations. There are different approaches in the different countries when it comes to assessing impacts from pile driving on marine mammals and fish. The project area is in the Finnish EEZ, and Finland does not have established guidelines for underwater noise from the impact of pile driving. Therefore, the used thresholds for fish and seals are defined from other countries guidelines and are explained in the following sections.

4.1.1. Applied threshold for fish

Fish eggs and fish larvae are not particularly sensitive to underwater noise and are primarily affected when underwater noise is so high that it can damage their tissue (Andersson et al., 2017).

Juvenile and adult fish have a wide range of hearing capabilities to perceive underwater noise depending on the species (Fay et al. , 1999; Sand & Karlsen, 2000). The most perceptive fish species to underwater noise are those with swim bladders linked to inner ears, which include clupeids such as the pelagic species sprat and herring

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(Popper et al., 2014). These species can hear frequencies that span from infrasound (<20 Hz) up to approximately 8 kHz, however with decreasing sensitivity with increasing frequency (Enger, 1967; Sand & Karlsen, 2000). Other species like codfish and salmons have swim bladders with less specialized internal connections with inner ears, These species are considered to be slightly less sensitivity to perceive underwater noise (Chapman & Hawkins, 1973) (Tougaard, Hermannsen, & Madsen, How loud is the underwater noise from operating offshore wind turbines? , 2020). These species can hear sound from infrasound up to 500 Hz (Chapman & Hawkins, 1973). Almost all demersal fish, such as flatfish, have poor hearing capabilities and are not particularly sensitive to underwater noise (Karlsen, 1992). These and other demersal fish species associated with seabed habitats such as gobies (Gobidae), sculpins (Cottidae), dragonet etc. have poor hearing capabilities and low sensitivity to noise. They typically hear in the range from infrasound up to a few 100 Hz (Sand & Karlsen, 2000).

Auditory threshold shift (TTS and PTS)

Specific knowledge of how different fish species react to noise (behavioural responses) is relatively limited and there is no consensus on behavioural thresholds in fish. Defining one common behavioural threshold criteria for fish is difficult and can never fit all fishes, since species vary greatly in so many ways. There are differences in their hearing capabilities and how they respond to stimuli in general (swim away, bury in the substrate, etc.) that will affect whether a sound at a given level will elicit a response or not. Moreover, responses to a signal may vary within a species, and even a single animal, depending on factors such as sex, age, size and motivation (feeding, mating, moving around a home range, etc.). Therefore, developing behavioural guidelines are far harder than developing guidelines for physiological effects.

High levels of underwater noise as well as continuous and accumulated noise (SEL_{cum}) can result in a decrease in hearing sensitivity in fish. If hearing returns to normal after a recovery time, the effect is a temporary threshold shift (TTS). Sound intensity, frequency, and duration of exposure are important factors for the degree and magnitude of hearing loss, as well as the length of the recovery time (Neo et. al., 2014) (Andersson et al., 2017). Extreme levels of noise from, for example, pile driving can be so high that they can cause permanent hearing loss (PTS) from damage to tissue and hearing organs when in the near vicinity of the activity, which can be fatal for fish, fish eggs and fish larvae (Andersson et al., 2017).

Guidelines for temporary hearing loss (TTS) in fish species with a swim bladder involved in hearing, (e.g. herrings) and fish with a swim bladder that is not involved in hearing (e.g. cod) (Popper et al., 2014) are given in Table 4.1. Cod do not occur in the project area for Laine OWF, however the threshold is used to represent other fish with no direct coupling between the swim bladder and the inner ear like salmons, smelt and whitefish, that all occur in the project aera for Laine OWF. Thresholds for tissue damage and hearing loss leading to mortality in fish, fish eggs and larvae are also given in Table 4.1. Fish species without swim bladders (primarily demersal species) including all flatfish species, are much less perceptive to noise than fish species with swim bladders (primarily pelagic) and codfish, and it can be expected that actual tolerance thresholds for demersal fish are higher than pelagic fish. However, because information of threshold values is very limited, the threshold values for the least tolerant fish species are used for all species including demersal species in this analysis.

The threshold level where fish begin to experience hearing loss depending on their hearing capabilities, begins at around 186 dB SELcum for fish least tolerant to noise (Table 4.1). Conservatively, the noise level where irreversible hearing loss and permanent injuries leading to mortality is set at 204 dB for all fish, and at 207 dB SELcum for fish larvae and eggs.

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Assessments of the noise impact on fish, larvae and eggs are all based on frequency unweighted threshold levels using the metric $L_{E,cum,24h}$, and are presented in Table 4.1. The threshold is adopted from Andersson et al. (2016) and Popper et al. (2014).

Table 4.1: Unweighted threshold criteria for fish (Andersson, et al., 2016), (Popper A. , et al., 2014).

Species	Swim speed [m/s]	Species specific unweighted thresholds (Impulsive) $L_{E,cum,24h,unweighted}$	
		TTS [dB]	Injury [dB]
Stationary fish*	0	186	204
Juvenile Cod	0.38	186	204
Adult Cod	0.9	186	204
Herring	1.04	186	204
Larvae and eggs	-	-	207

*Fish not fleeing during noise impact

4.1.2. Applied threshold for seals

As seals are adapted to life both in water and on land, their hearing ability has adapted to function in both environments. Seals produce a wide variety of communication calls both in air and in water, e.g., in connection with mating behaviour and defence of territory. There is limited knowledge of the underwater hearing abilities of grey and ringed seal. However the hearing threshold of harbour seals are generally recommended to be used as a conservative estimate of the hearing threshold for those Phocids ('true seals'), where the hearing has not yet been as thoroughly investigated (Southall, et al., 2019). Seals hear well in the frequency range from a few hundred Hz up to 50 kHz.

Based on the newest scientific literature, it is recommended that the $L_{E,cum,24h}$ and frequency weighting is used to assess TTS and PTS. Threshold levels for TTS and PTS are primarily based on a large study from the American National Oceanographic and Atmospheric Administration (NOAA), (NOAA, 2018), where species specific frequency weighting is proposed, accounting for the hearing sensitivity of each species when estimating the impact of a given noise source.

In NOAA (2018) the marine mammal species are divided into four hearing, in regard to their frequency specific hearing sensitivities: 1) Low-frequency (**LF**) cetaceans, 2) High-frequency (**HF**) cetaceans, 3) Very High-frequency (**VHF**) cetaceans, 4) and Phocid pinnipeds (**PCW**) in water. For this project, only the latter is relevant. More details about the hearing groups and their frequency sensitivities are given in the underwater noise prognosis report (NIRAS, 2023). The hearing group weighted threshold criteria for phocid pinnipeds can be seen in *Table 4.2*.

There is a general lack of quantitative information about avoidance behaviour and impact ranges of seals exposed to pile driving noise and the few existing studies point in different directions. During construction of offshore wind farms in The Wash, south-east England in 2012, harbour seals usage (abundance) was significantly reduced up to 25 km from the pile driving site during unmitigated pile driving (Russell, et al., 2016). Based on the results, Russell et al. (2016) suggested that the reaction distance for seals to unabated pile driving was comparable to that of harbour porpoises. On the other hand, Blackwell et al. (2004) studied the reaction of ringed seals to pile driving in connection with establishment of an artificial island in the arctic and saw limited reactions to the noise. As a precautionary approach, it has been assumed that seals react to underwater noise from pile driving at the same distance as harbour porpoises.

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A literature review of avoidance behaviour and onset threshold levels in Tougaard (2021), included both studies in captivity where pile driving noise was played back at greatly reduced levels, and field studies of reactions of wild porpoises to full-scale pile driving. From the review, the conclusion in Tougaard (2021) is that the behavioural avoidance threshold ranges between $L_{p,125ms} = 95 - 110$ dB re. 1 μPa, and a suitable single value of $L_{p,125ms} = 103$ dB re. 1 μPa VHF-weighted. The single value is obtained from Band et al. (2016) which includes the largest amount of empirical data. In the present report, a behavioural threshold for harbour porpoises of 103 dB $L_{p,125ms}$ VHF-weighted is therefore used, see *Table 4.2*.

Table 4.2: Species specific weighted threshold criteria for earless seals. This is a revised version of Table AE-1 in NOAA (2018) *to highlight the important species in the project area* (NOAA, 2018) *including behaviour response. "xx" indicates the weighting function.*

Species	Species specific weighted thresholds (non-impulsive)		Species specific weighted thresholds (Impulsive)		
	$L_{E,cum,24h,xx}$		$L_{E,cum,24h,xx}$		$L_{p,125ms,VHF}$
	TTS [dB]	PTS [dB]	TTS [dB]	PTS [dB]	Behaviour [dB]
Seal (PCW)	181	201	170	185	103

Thresholds listed as "non-impulsive", apply for continuous noise (e.g., ship noise) and whilst impulsive noise is expected to transition towards continuous noise over distance from the source, this transition is not expected to occur within the distances at which PTS and/or TTS can potentially occur because of these activities. For impulsive sources such as pile driving, stricter threshold levels apply as listed in *Table 4.2*. Threshold levels for continuous noise are more lenient, than those for impulsive noise, and use of the impulsive noise criteria, therefore provides conservative distance-to-threshold. The non-impulsive thresholds will not be considered further in this report.

4.2. Underwater noise from pile driving

Steel monopile foundations or jacket foundations consisting of 3-4 pin piles are some of the most common foundation designs in offshore wind farm construction due to their ease of installation in shallow to medium depths of water. The dominant method used to drive monopiles and pin piles into the seabed is by hydraulic impact piling (hammering), that causes intense underwater noise levels, characterized as being of short duration and with a steep rise in energy level (Madsen, Wahlberg, Tougaard, Lucke, & Tyack, 2006; Bellmann, et al., 2020)[1]. The intensity of the underwater noise from pile driving depends among other things on the diameter of the monopile. A larger diameter will cause a higher intensity of pile driving noise (Bellmann, et al., 2020).

To evaluate the impact of underwater noise from pile driving, a detailed underwater noise modelling has been conducted. Below, a short description of the underwater noise modelling is provided as well as the results from the modelling are presented. For a detailed description see "Laine offshore wind farm - underwater noise prognosis for construction phase" (NIRAS, 2023). A 3D acoustic model was created in dBSea 2.3.4, using detailed knowledge of bathymetry, seabed sediment composition, water column salinity, temperature and sound speed profile as well as a source model based on best available knowledge.

[1] Depending on the substrate type in the project area it can be necessary with pre-drilling before the monopile can be installed in the seabed. In this case, it is expected that the underwater noise will be significantly reduced compared to pile driving without pre-drilling, especially the cumulative underwater noise (acoustic energy). It is however, expected that the installation period will be longer as there will be breaks in the piling activity while the pre-drilling is going on.

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The underwater noise modelling used in this report builds on the recommendations from the Danish ministry of Energy (Energistyrelsen, 2022) as well as the recommendations from the National Marine Fisheries Service (NMFS) (2018) and Southall et al. (2019). In the underwater noise modelling the cumulated sound exposure level (SEL_{cum}) is modelled over an estimated period of a complete pile driving of one monopile (as it is assumed that one pile will be installed per day). Furthermore, the cumulated sound exposure level is used to estimate the distances where PTS and TTS will occur.

In the calculations it is considered that a soft start procedure will be applied. At the onset of the piling process, the piling strokes are conducted with low energy. The energy per stroke then increases gradually until full energy is applied. With increasing amount of energy, the emitted noise increases slowly, allowing the marine animals to move out of the construction site before the noise becomes physically dangerous to them. It is also included in the model that the exposed animals will flee from the noise during piling.

Underwater noise modelling has been conducted for three positions in the project area (see Figure 4.1). The positions are chosen as worst case positions where the largest underwater noise propagation is expected. The modelling was conducted for May which is worst-case regarding sound propagation (the month with highest sound propagation).

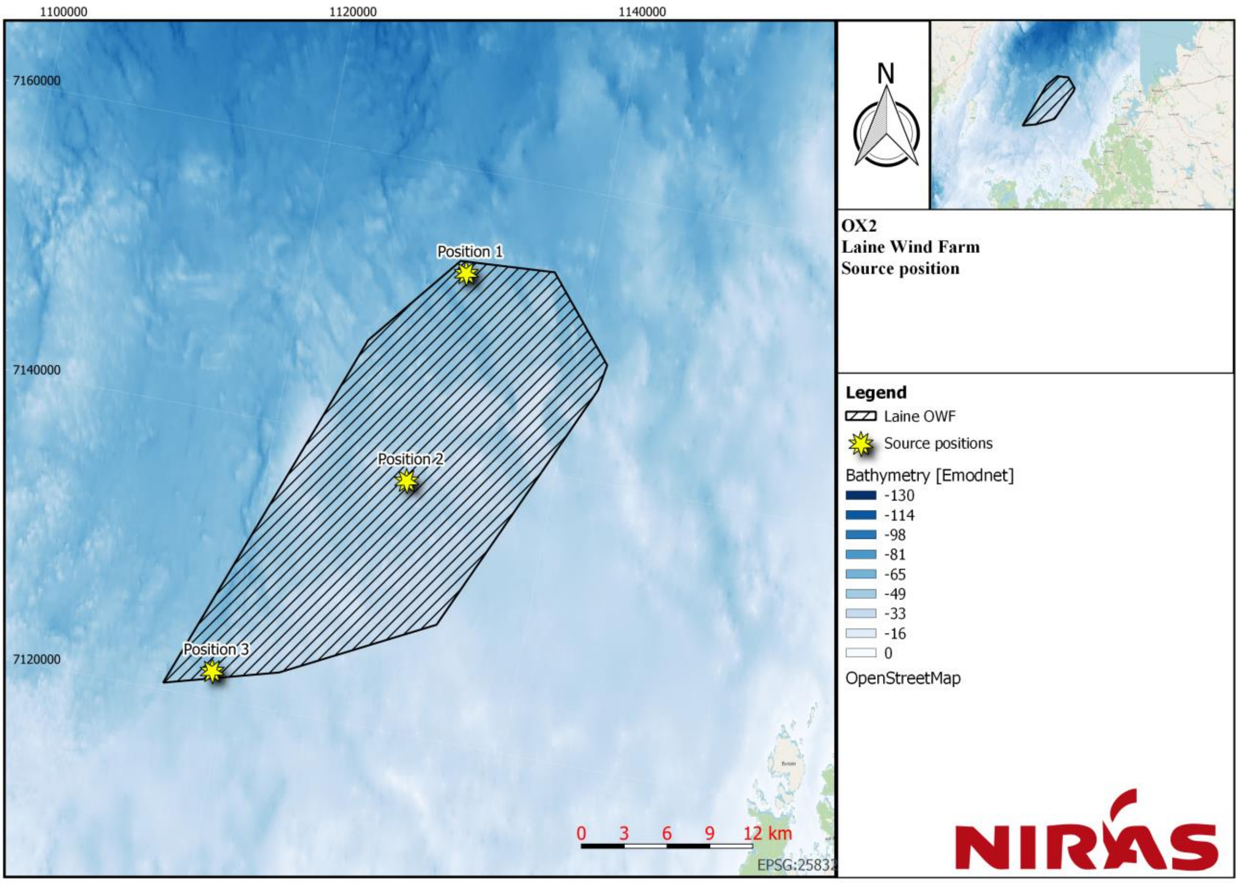

Figure 4.1: Source positions chosen for sound propagation modelling (NIRAS, 2023).

Underwater sound emission was calculated for an 18 m diameter monopile foundation as well as for a jacket foundation anchored by 4x 8 m diameter pin piles.

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The installation scenarios are based on a realistic conservative installation procedure in relation to the needed hammer energy (source level), number of strikes and time needed to complete piling and a realistic generalized soft start/ramp up phase. The technical source model parameters are provided in Table 4.3 for the monopile foundation scenario, and in Table 4.4 for the jacket foundation scenario.

The pile installation procedure for both foundation types includes a soft start, at 10% of maximum hammer energy, a ramp up phase, where the energy is gradually increased from 10% - 100%, and a conservative estimate for the full power phase of the installation with 100% hammer energy.

Table 4.3: Technical specifications and pile driving procedure for scenario 1: 18 m monopile foundation.

Technical specification for scenario 1			
Foundation type			Monopile
Impact hammer energy			6000 kJ
Pile Diameter			18 m
Total number of strikes pr. pile			10 400
Number of piles per foundation			1
Pile driving procedure			
Name	Number of strikes	% Of maximum hammer energy	Time interval between strikes [s]
Soft start	200	10	2
Ramp-up	400 1000 500 500 800 2400	10 20 40 60 80 60	1.2 1.2 1.2 1.2 1.2 1.2
Full power	4600	100	3.2

Table 4.4 Technical specifications and pile driving procedure for scenario 2: Jacket foundation with 4x 8m pin piles.

Technical specification for scenario 2			
Foundation type			Jacket
Impact hammer energy			6000 kJ
Pile Diameter			8 m
Total number of strikes pr. pile			10 400
Number of piles per foundation			4
Pile driving procedure			
Name	Number of strikes	% Of maximum hammer energy	Time interval between strikes [s]
Soft start	150	10	2
Ramp-up	700 1000 500 500 1000	10 20 40 60 80	1.2 1.2 1.2 1.2 1.2
Full power	6 550	100	2.6

For both monopile foundation, and jacket foundation, a Double Big Bubble Curtain (DBBC) mitigation effect was included. Modelling without a noise abatement system was not included as pile driving without noise mitigation measures is not considered a possible scenario. It is important to emphasize that even though a specific noise mitigation system has been applied in the underwater noise modelling (showing that is possible with the

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available mitigation solutions to provide significant mitigation of the underwater noise), installation will not be bound to the suggested mitigation system. The installation will occur in the future (in a few years) and at the moment, the technological development about mitigation systems related to pile driving is moving at a fast pace. Therefore, other mitigation solutions and/or more efficient mitigation solutions might be available at the time of installation. If other types of mitigation solutions are applied, they must be sufficiently effective to prevent the modelled impact distances from being surpassed as the impact assessment within this report is based on the modelled impact distances.

4.2.1. Pile driving results

Based on the modelling, installation of a monopile causes the longest impact ranges for fish and the following assessment on fish is based on installation of a monopile as it is considered to be the worst-case situation. (NIRAS, 2023). The results that are used for fish impact assessment are shown in Table 4.5.

Table 4.5: Resulting threshold impact distances for fish using DBBC on an 18 m monopile respectively for the worst-case month of May.

Position	**Distance-to-threshold**		
	Injury (r_{injury})		TTS (r_{TTS})
	Fish	Larvae and eggs	Fish
1	<100-975 m	525 m	6.9 – 11.5 km
2	<100-1100 m	650 m	9.4 – 17.9 km
3	<100-875 m	525 m	5.9 – 13.9 km

Based on the modelling, installation of a jacket foundation causes the longest impact ranges for seals and the following assessment on seals is based on installation of a jacket foundation as it is the worst-case situation. (NIRAS, 2023). The results that are used for seal impact assessment are shown in Table 4.6.

The acoustic modelling assumes that nearby marine mammals will move away from the underwater noise during piling and assumes a swimming speed of 1.5 m/s, which is likely a precautionary estimate for both seal species.

The underwater noise modelling further assumes that no PTS at a distance beyond 200 m may occur as described in the recommendations from the Danish ministry of Energy (Energistyrelsen, 2022). Therefore, the model includes the application of sufficient mitigation measures, in this case a double big bubble curtain (DBBC), that in addition to preventing PTS also is efficient enough to prevent TTS in seals.

Table 4.6: Resulting threshold impact distances for seals using DBBC NAS on jacked foundation with 4 x 8 pin piles for the worst-case month of May.

Position	**Distance-to-threshold**			
	PTS (r_{PTS})	TTS (r_{TTS})	Avoidance (r_{behav})	Affected area (avoidance behaviour)
	Seal	Seal	Seals	Seals
1	< 100 m	< 200 m	7.45 km	122 km^2
2	< 100 m	< 200 m	6.05 km	82 km^2

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Po-si-tion	Distance-to-threshold			
	PTS (r_{PTS})	TTS (r_{TTS})	Avoidance (r_{behav})	Affected area (avoid-ance behaviour)
	Seal	Seal	Seals	Seals
3	< 100 m	< 200 m	6.05 km	63km^2

The modelled worst-case impact ranges for behavioural avoidance responses for seals were calculated and are shown in Figure 4.2.

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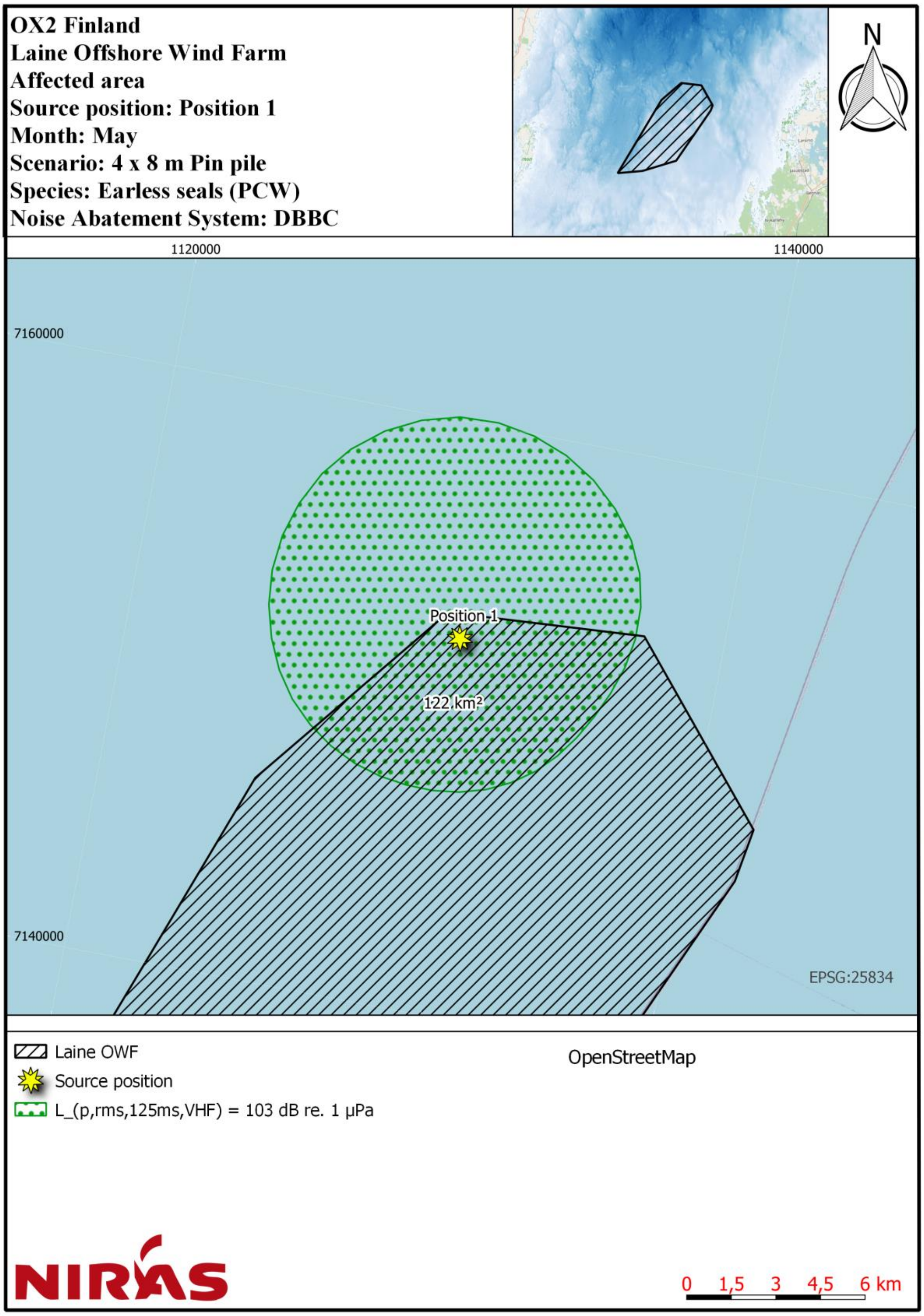

Figure 4.2: Modelled impact ranges for behavioural avoidance responses in seals (green line) in the project area for Laine. The underwater noise modelling is based on a worst-case scenario and with installation of a jacket foundation with 4x 8 m pin piles with DBBC mitigation effect.

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4.2.2. Impact assessment – fish

Although the underwater noise from pile driving is of high intensity and has the possibility of effecting fish in a relatively large geographical range, the noise will still be of relatively short duration and not continuous, and only occur during the establishment of turbine foundations. A total of 150 foundations will be installed in the project area. In theory installation of the foundations by pile driving will then last approximately 5 months (of effective work) with approximately six hours of piledriving per day, under the assumption, that one foundation is installed pr. day without any pauses (150 foundations = 150 days ~ 5 months). However, in praxis the total time for installation of one foundation will be longer and last approximately 2 days. The six hours pr day for one foundation and the 5 months for all foundations do only relate to time where piling occurs and not the other construction work related to foundation installation. The total installation time for the foundations will be longer than 5 months. Furthermore, the installation period may be longer due to for example bad weather conditions, causing days where pile driving is not possible. Still, the duration of the pile driving noise is short-term.

Results show that impact distances for PTS or injury to fish will occur within < 100 to 1100 meters of the pile driving activity, while the impact distances for TTS in fish will occur up to 5.9 - 17.9 km from the noise source depending on the fish species. For fish eggs and fish larvae, tissue damage and injury (mortality) can occur if they experience sound levels of 207 dB re 1 $\mu Pa^2 s$ SEL_{cum} and greater and modelling showed that this would occur at distances up to 650 meters from the pile driving sites.

Thus, the worst effects from the pressure of underwater noise from pile driving (PTS and injury) will be on individuals that are within close vicinity of the pile driving activity. Beyond this the majority of fish will flee from the source of pressure and return when the noise has ceased, and possibly experience temporary hearing loss that is reversible over time (Monroe, Rajadinakaran, & Smith, 2015; Smith, Kane, & Popper, 2004). Injury to fish larvae and eggs will also occur in a relatively limited area near the vicinity of the pile driving.

At present, there is very limited knowledge of the short-term and long-term consequences of PTS and TTS in fish. However, unlike the physiological damage to internal organs and in a worst-case scenario mortality, both flight behaviour and temporary hearing loss are linked to the species' specific sensitivity to frequency and sound intensity. With existing literature, it is not possible to assess whether flight behaviour or the time it takes to recover from TTS negatively affects fish communities at population level, or if the effect of the impact only revolves around the area of impact in combination with the duration of the temporary hearing loss.

In the natural environment mortality in fish larvae and eggs is very high and although there can be some loss of recruitment due to the mortality of eggs and larvae close to the source of pressure, this is considered very limited and is not expected to have any significant effect at population level. The project area is assessed to have very low to low importance as a fish spawning habitat, and fish larvae or eggs drifting into the project area are not likely to have a high natural survival due to the unsuitable (cold and deep) conditions in the area. Therefore, mortality of fish eggs and larvae caused by underwater noise from pile driving is assessed to be negligible and without consequences for fish and fish populations.

The risk of large abundances of fish experiencing either PTS or mortality is assessed as negligible because of the very short impact distances (less than 100-1100 meters) in combination with the species-poor characteristics of the Laine project area. In general, the Laine project area is relatively scarcely inhabited by fish, and the density of migratory fish such as salmon, whitefish and smelt within distance of PTS or mortality will be very low.

Close to the source of pile driving with high levels of underwater noise, but not within the range where fish will experience injury, the pressure will trigger an avoidance response causing juvenile and adult fish to flee from the pressure and possibly experience a temporary hearing loss (TTS). It is unknown if the effects from short-

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term TTS and avoidance response due to the impact of underwater noise will have consequences on survival and reproduction success of individual fish (Andersson et al., 2017). However, it could possibly affect the ability of fish to function normally which could lead to a decrease in fitness. Similarly, there are no direct field studies that address how the negative effects of pile driving noise affect a species at population level (Popper et al., 2014; Skjellerup, et al., 2015). As the Laine project area is species-poor and relatively scarcely used by fish the sensitivity is assessed to be low.

The size and extent of the impact of pile driving noise is assessed as moderate negative, because the relatively long impact distances for TTS (up to 17.9 km). Overall, the consequence of the underwater noise from pile driving in the project area for Laine OWF is assessed to be low for the fish and will not affect the fish populations short-term nor long-term (Table 4.7).

Table 4.7: Impact assessment of underwater noise from pile driving during the construction phase on fish in Laine Offshore Wind Farm area.

Impact	Sensitivity of the recipient	Size and extent of the impact	Consequence
Piledriving -fish	Low	Moderate negative	Low

4.2.3. Impact assessment - seals

Masking occurs when a sound or noise signal eliminates or reduces an animal´s ability to detect or find other sounds such as communication signals, echolocation, predator and prey signals, and environmental signals. Masking depends on the spectral and temporal characteristics of signal and noise (Erbe, et al., 2019). Sound processing in the mammalian ear happens in a series of band-pass filters (Patterson, 1974) best described as one-third-octave band filters for marine mammals (Lemonds, et al., 2011). Masking of signals can therefore occur and may occur if there is an overlap in frequency between the signal in question and the underwater noise.

Compensation mechanisms to overcome masking of communication signals have been described in several marine mammal species either increasing the amplitude of their signal (e.g. calling louder) or shifting the frequency of the signal (Holt, Noren, Veirs, Emmons, & Veirs, 2009; Parks, Johnson, Nowacek, & Tyack, 2011). Masking can also be overcome by increasing the call duration or call rate making it more probable that a signal is detected or by waiting for the noise to cease (Brumm & Slabbekoorn, 2005).

Underwater signals are particularly important in courtship and mating behaviour in seals (Van Parijs, 2003). The communication signals of seals are in the low-frequency range and masking from the pile driving noise may occur. However, harbour seals and grey seals likely mainly vocalize in the context of mating and this likely takes place close to the haul-out sites. Thus, pile driving close to a seal haul out can mask the communication signals while pile driving occurring far offshore, appears unlikely to have any significant potential to interfere with communication during mating displays (Tougaard & Michaelsen, 2018).

The modelling results show that if seals are within less than 100 meters and < 200 meters of the piledriving location, when pile driving is conducted with a noise abatement system corresponding to DBBC and with application of a soft start and ramp up phase, they may correspondingly be at risk of developing PTS and TTS. Because of the very short impact distances the risk of developing PTS or TTS in seals is more or less non-existing.

As mentioned earlier (section 4.1.2), there are only a few studies addressing the avoidance behaviour and impact ranges of seals exposed to pile driving noise and the results of these studies are ambiguous, when compared. As a precautionary approach, it has been assumed that seals react to underwater noise from pile driving

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at the same distance as harbour porpoise (within 7.45 km in the present modelling). It is expected that both ringed seals and grey seals may occur in the project area, however as the distance to the nearest haul out site for both ringed seals and grey seals is more than 20 km from the project area for Laine OWF the area is not considered to be a particularly important area for either species. This is supported by the fact that the area is fish species-poor and relatively scarcely used by fish, making the area a low-quality foraging area for seals. There may occur breeding ringed and grey seals in the project area, but they will only be present during winters with sufficient ice coverage. It is not expected that installation of foundation is possible, during periods where sea ice has formed in the project area and disturbance of breeding ringed seals will therefore not occur.

The risk of seals experiencing either PTS or TTS is assessed as negligible because of the very short impact distances (less than < 200 meters).

Behavioural responses caused by an underwater noise form pile driving can range widely from small changes in activity level to escape responses, where individuals completely avoid the area. Seal's sensitivity towards an impact on behaviour is assessed to be moderate as it is expected that the seals will avoid the impacted area to some degree. The size and extent of the impact of pile driving noise is assessed as low negative, because of the relatively short impact distances well as that the impacted area does not constitute an important foraging area for neither ringed seals nor grey seals.

A total of 150 foundations will be installed in the project area. As mentioned in section 4.2.2 on the impact assessment on fish the theoretical installation period of the foundations by pile driving will last approximately 5 months (of effective work). This is under the assumption, that one foundation is installed pr. day without any pauses and 6 hours of daily pile driving. Yet, as described, the total installation time for the foundations will be longer than 5 months. Still, the duration of the temporary habitat loss is short-term, as seals can return to the area after the foundation installation is complete.

The size and extent of the impact of pile driving noise is assessed as low negative, as it is a relatively small area of their home range that is temporarily affected, thereby causing a low likelihood of occurrence of behavioural avoidance responses despite the relatively long impact distances (7.45 km). The persistence of behavioural avoidance responses (and temporary habitat loss) is short-term for both seal species, and it is expected that the seals return to the area a few days after the installation has been completed. Overall, the consequence of the underwater noise from pile driving in the project area for Laine OWF is assessed to be low for seals and will not affect the populations short-term nor long-term (Table 4.8).

Table 4.8: Impact assessment of underwater noise from piledriving during the construction phase on seals in Laine Offshore Wind Farm area.

Impact	Sensitivity of the recipient	Size and extent of the impact	Consequence
Piledriving	Moderate	Low negative	Low

4.3. Underwater noise from ship traffic

About 75 % of the anthropogenic underwater noise is caused by ships (ICES, 2005). Ship noise is suspected to have caused an increase in the ambient ocean noise level of about 12 dB during the latter part of the 20th century (Hildebrand, 2009). During wind farm construction and operational maintenance an increase in ship traffic of both small and large vessels is expected within and near the project area for Laine OWF. The propagation of the underwater noise in the surrounding water depends on the frequency content of the underwater noise, the

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surrounding environment (e.g. temperature, salinity and depth) and factors such as operational speed, size of the ship, cargo etc. (Erbe, et al., 2019; Urick, 1983; Wisniewska, et al., 2016).

It is expected that both small and fast boats as well as larger, slower moving vessels will be used. Underwater noise from smaller boats has a noise level ranging 130-160 dB re 1 μPa@1meter (Erbe, 2013; Erbe, Liong, Koessler, uncan, & Gourlay, 2016), while the underwater noise levels from larger vessels is up to 200 dB re 1 μPa@1 meter (Erbe & Farmer, 2000; Simard, Roy, Gervaise, & Giard, 2016; Gassmann, Wiggins, & Hildebrand, 2017). Studies show that the underwater noise levels increase when the ship is maneuvered, such as when the ship goes astern, or thrusters are used to hold the ship at a certain position (Thiele, 1988). In a recent study, the underwater noise from several different types of ships was measured. The study found that the frequency content was broadband from 0.025 to 160 kHz, which is in a frequency range where it potentially may have a negative effect on fish and marine mammals (Hermannsen, Beedholm, Tougaard, & Madsen, 2014).

The project area for the wind farm is in an area with ship traffic and is located in close vicinity or overlaps with main shipping routes in the northern part of the Bay of Bothnia (Figure 4.3). The Laine project area is therefore expected already to be dominated by low-frequency ship noise. Based on data from the BIAS-project, the underwater noise level measured in the 500 Hz frequency band is assessed to be above 85 - 95 dB re 1uPa in the main part of the project area for Laine OWF (50 % of the time), especially in the winter period, where sound tends to travel further, compared to the summer period. For more details see the underwater noise report (NIRAS, 2023).

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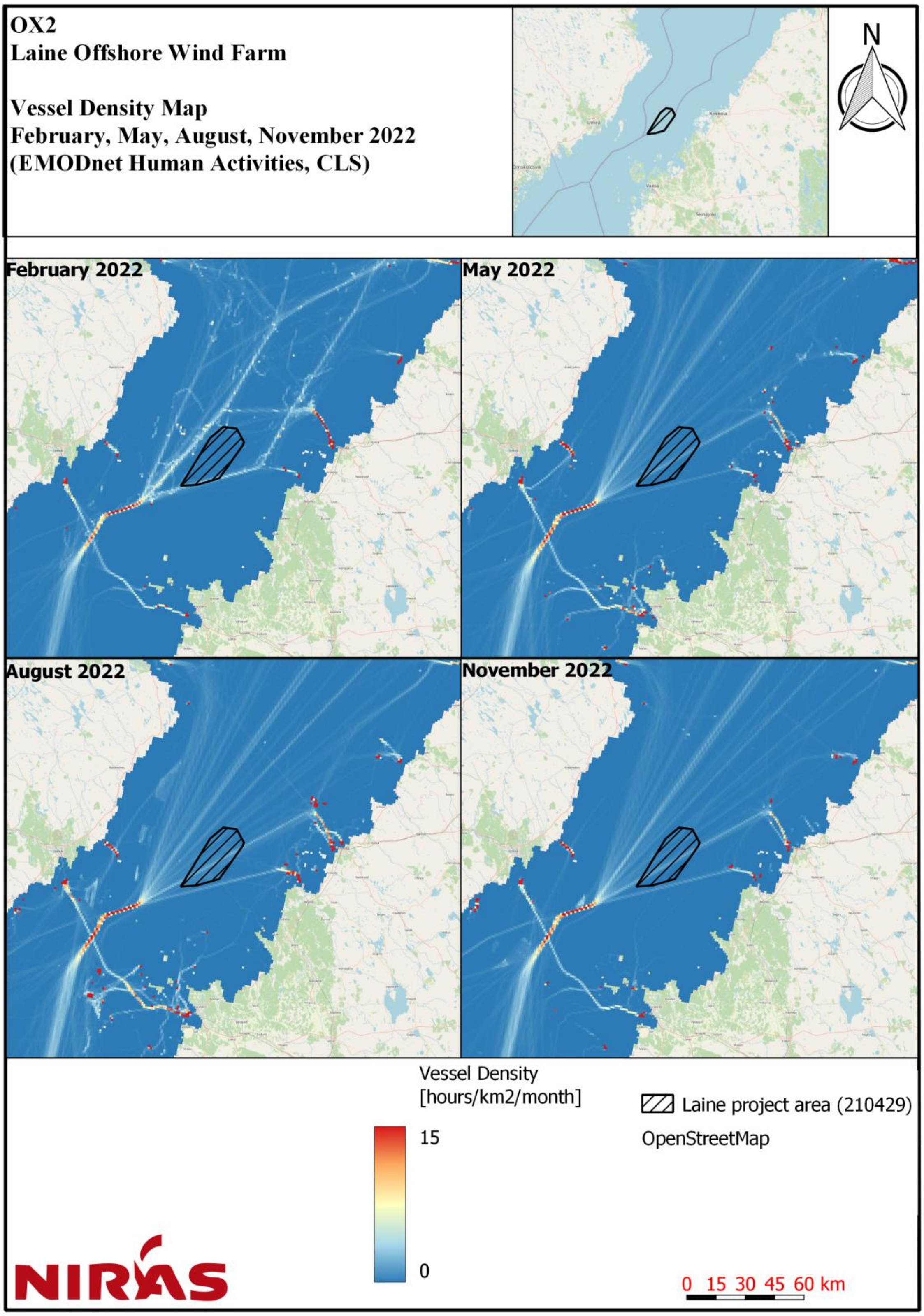

Figure 4.3: Vessel density map from 2022, from EMODnet based on AIS data from CLS.

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4.3.1. Impact assessment – fish

Demersal fish species with and without swim bladders but not specialized hearing organs, hear frequencies that span from <20 Hz to 500 Hz (Sand & Karlsen, 2000; Chapman & Hawkins, 1973), while species with specialized hear organs (hearing specialists), such as the pelagic species sprat and herring, also hear higher frequency sounds (up to 8 kHz) (Enger, 1967; Sand & Karlsen, 2000). Thus, the general frequency levels of noise where fish hear best, coincide with the frequency range of the noise produced by boats and shipping vessels.

While the general noise levels close to the underwater noise source of e.g. construction and maintenance vessels are at a level that will potentially induce a behavioural response in most fish, such as moving away from vessel (Nedwell et al., 2007), it appears that only the larger ships will create noise levels (>185 dB) that can temporarily induce hearing loss. Thus, fish can be affected by the underwater noise created by construction and maintenance vessels, but the effect of noise from vessels will for most fish only induce a fleeing response away from the vessel and in worse case for individuals very close to the source (within meters), a temporary hearing reduction/loss that will last a few weeks (Webb, Popper, & Fay, 2008).

The project area for Laine OWF borders and overlaps with main shipping routes in the Bay of Bothnia. Thus, the area is already expected to be dominated by vessel traffic creating underwater noise and fish in the area are likely to be adapted to a certain amount of underwater vessel noise. The Laine project area is species-poor and relatively scarcely used by fish and the sensitivity of both pelagic and demersal fish to underwater noise from vessel activity is low. The size and extent of the impact of ship noise is assessed as negligible as behavioural responses will occur relatively close to the ship. Overall, the consequence of the underwater noise from ship noise is assessed to be negligible for the fish and will not affect the populations short-term nor long-term (Table 4.9).

Table 4.9: Impact assessment of underwater ship noise on fish in Laine Offshore Wind Farm area.

Impact	Sensitivity of the recipient	Size and extent of the impact	Consequence
Ship noise	Low	Negligible	Negligible

4.3.2. Impact assessment - seals

The degree of negative impact caused by ship noise depends on the type and number of ships used. There is limited knowledge about how seals are affected by ship noise. As the knowledge on how ship noise affects seals is limited, there is no consensus on how impact of ship noise should be quantified (Erbe, et al., 2019). The largest impact of ship noise, however, is likely to be behavioural changes e.g., changes in their foraging pattern in the vicinity of the ships (Richardson, Greene, Malme, & Thompson, 1995; Wisniewska, et al., 2016).

Seal sensitivity towards ship noise is assessed to be low as the impact on behaviour is limited and very short term. The area is not an important foraging area for neither ringed seals nor grey seals and the avoidance response is only expected to occur in close vicinity of the ships. The size and extent of the impact from ship noise is therefore assessed as low negative. This must also be seen in the light of the fact, that the project area borders and overlaps with main shipping routes in Bay of Bothnia. The added impact of construction related ship traffic as well as ship traffic during operational maintenance will therefore be modest. Overall, the consequence of the underwater noise from ship noise in the project area for Laine OWF is assessed to be minor for the seals and will not affect the populations short-term nor long-term (Table 4.10).

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Table 4.10: Impact assessment of underwater noise from ship traffic on seals in Laine Offshore Wind Farm area.

Impact	Sensitivity of the recipient	Size and extent of the impact	Consequence
Ship Noise	Low	Low negative	Minor

5. Impact assessment - Underwater noise during operation

Underwater noise from offshore wind turbines comes primarily from two sources: mechanical vibrations in the nacelle (gearbox etc.), which are transmitted through the tower and further radiated into the surrounding water; and underwater radiated noise from the service boats in the wind farm.

5.1. Operational noise

In a review by Tougaard (2020), measurements of underwater noise from existing operational wind turbines are presented. In the review, measured underwater noise levels are evaluated as a function of wind speed and turbine size. For monopiles, the review considers measurements from 0.55 MW – 3.6 MW turbines. For other foundation types (GBF, jacket and tripod), only singular measurements are available. Since the underwater noise that is radiated during operation will depend on the radiating structure (the foundation), then the shape, material and size of the foundation will matter. The turbine technologies (direct drive vs. gear box), will also have an impact on the radiated operational underwater noise. However, the limited available operational noise data does not allow for such differences to be resolved. The trendline proposed in Tougaard (2020), not taking foundation type or size into account, is therefore considered with caution (Figure 5.1). The trend line shows a size dependency, with source level increasing by a factor of 14 dB per factor 10 in turbine nominal capacity (Tougaard, Hermannsen, & Madsen, 2020).

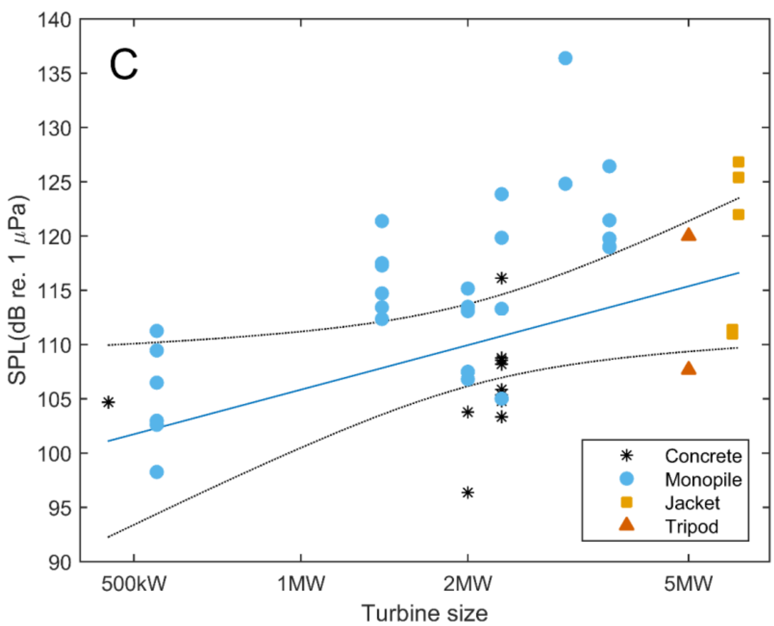

Figure 5.1: Relationship between measured broadband noise and turbine size compiled from available literature sources. Measurements have been normalized to 100 m from the turbine foundation and a wind speed of 10 m/s. From (Tougaard, Hermannsen, & Madsen, 2020).

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All measurements of turbine noise show the noise to be entirely confined to low frequencies, below a few kHz and with peak energy in the low hundreds of Hz. One spectrum of a typical mid-sized turbine is shown in Figure 5.2, where pronounced peaks are visible in the spectrum at 50, 100, 160 and 320 Hz.

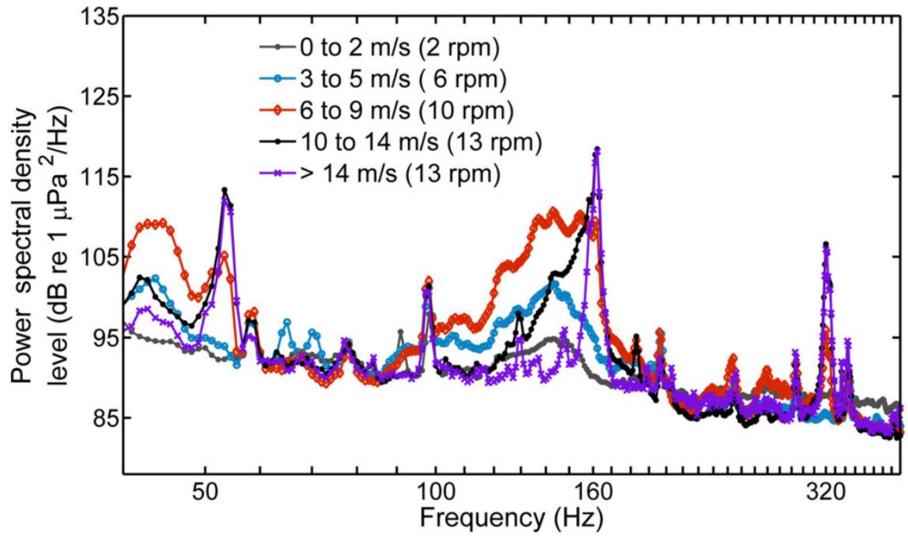

Figure 5.2: Example of frequency spectra from a medium sized turbine (3.6 MW, Gunfleet Sands) at different wind speeds. Levels are given in 10 Hz intervals. Measurements were obtained about 50 m from the turbine. Measurements from Pangerc et al. (2016).

Despite the inherent uncertainties with respect to type and size of turbines to be used in the project it is considered likely that the turbine noise will be comparable to what has been measured from other turbines. However, it should be considered with caution. Based on the data in Figure 5.1 a number of observations should be mentioned. First and foremost, significant variation in measured sound levels for individual turbine sizes on same foundation type, up to 20 dB is noticed. Second, the trendline (blue) representing the best fit of all data points, is not assessed to provide an accurate fit for any given turbine size. This presents a challenge in terms of reliably predicting source levels within the covered turbine size range in Figure 5.1 (0.4 MW – 6.15 MW), and to an even greater extent for turbine sizes outside this range. For Laine OWF, turbine sizes are expected to have a size of 15 MW – 25 MW. This would be a 5 – 7-fold increase compared to the available empirical data for monopiles. Given the uncertainties present in the empirical data, any extrapolation of such size is considered to provide a very uncertain source level prediction.

An added source of uncertainty in prediction is the type of turbine. All but one of the turbines, from which measurements are available, are types with gearbox, a main source of the radiated noise. Only one measurement is available for a turbine with a direct drive (Haliade 150, 6 MW) (Elliott, et al., 2019), which is a type increasingly being installed in new projects. The limited data suggests that noise levels from the direct drive turbine are more broadband in nature than from types with gear box.

Despite all of the above mentioned uncertainties, a calculation for TTS threshold criteria is carried out below, based on the blue trendline in Figure 5.1 as well as the scaling and frequency considerations presented in (Tougaard, Hermannsen, & Madsen, How loud is the underwater noise from operating offshore wind turbines? , 2020). It should be kept in mind, that there are significant uncertainties with the estimated impact range due to the lack of scientific data supporting such a calculation.

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For a 25 MW turbine, the sound level at 100 m, would be $SPL_{rms} = 125.4\ dB\ re\ 1\mu Pa$, based on the extrapolation of the blue trendline. The primary frequency would be ~160 Hz, with secondary frequency at 320 Hz, approximately 10 dB below the primary (Tougaard, Hermannsen, & Madsen, How loud is the underwater noise from operating offshore wind turbines? , 2020).

A conservative approach would set the unweighted 160 Hz level to $SPL_{rms} = 125.4\ dB\ re\ 1\mu Pa$ and for 320 Hz, $SPL_{rms} = 115.4\ dB\ re\ 1\mu Pa$.

Seals however are not equally good at hearing all frequencies. and taking the hearing curve for seals into consideration would lead to sound levels (as experienced by seal, from a single turbine in operation) of:

- @160Hz, 100 m distance: $SPL_{rms,PW} = 105.4\ dB\ re\ 1\mu Pa$
- @320Hz, 100 m distance: $SPL_{rms,PW} = 100.4\ dB\ re\ 1\mu Pa$
- "Broadband", 100 m distance: $SPL_{rms,PW} = 106.4\ dB\ re\ 1\mu Pa$

For seals, no behaviour threshold is currently supported by literature, and it is therefore not possible to compare the sound level at 100 m with a behavioural threshold. However calculating the cumulative noise dose for a seal located at a constant distance of 100 m from a turbine foundation within the wind farm area, over a 24 hour period, would result in cumulative sound exposure level, $SEL_{cum,24h,PCW} = 116.4 + 10 \cdot log_{10}(86400) \cong 155.4\ dB\ re.\ 1\mu Pa^2 s$. Given a threshold criteria for onset of TTS in seals for continuous noise of $SEL_{cum,24h,PW} = 183\ dB\ re.\ 1\mu Pa^2 s$, the impact over a 24 hour duration is 27.6 dB lower than the TTS onset criteria. With a 27.6 dB margin to the TTS threshold criteria, auditory injuries are unlikely to occur.

Most fish detect sound from the infrasonic frequency range (<20 Hz) up to a few hundred Hz (e.g., Salmon, dab and cod) whereas other fish species with gas-filled structures in connection with the inner ear (e.g., herring) detect sounds up to a few kHz. The main frequency hearing range for fish is therefore overlapping with the frequencies, produces by operational wind turbines (below a few hundred Hz). There are no studies defining fish behavioural response threshold for continuous noise sources, and the scientific data addressing TTS from such noise sources is very limited. The only studies providing a TTS threshold value for fish is from experiments with goldfish. Goldfish is a freshwater hearing specialist with the most sensitive hearing in any fish species. In the project area for Laine OWF, the most common fish species is herring followed by sculpins, smelt, ruffe and whitefish. All these species have a less sensitive hearing, compared to the goldfish (Popper A. , et al., 2014), and using threshold for goldfish will lead to an overestimation of the impact. Empirical data for several of the fish species without a connection between the inner ear and the gas-filled swim showed no TTS in responses to long term continuous noise exposure (Popper A. , et al., 2014). In a study by Wysocki et al. (2007), rainbow trout exposed to increased continuous noise (up to 150 dB re 1 µPa rms) for nine months in an aquaculture facility, showed no hearing loss nor any negative health effect. Therefore, it is assessed that TTS is unlikely to occur because of an operational offshore wind farm.

5.1.1. Impact assessment fish

The character and strength of the operational noise makes it probable to be heard (detectable) by sound-sensitive pelagic fish such as clupeids (sprat and herring) as well as hearing generalist at a distance of up to a few hundred meters from the source while for demersal fish with only small or no swim bladders such as sculpins (Cottidae) etc., wind turbine noise is only detected within short distances <50 meters (DFU, 2000).

Although, both pelagic and benthic species of fish can hear the underwater sounds from the mechanical components of wind turbines, there are no indications that they will show a behavioural response and flee or move out of the area. On the contrary, the presence of fish around operating turbines has been studied, at the Horns

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Rev 1 Offshore Wind Farm. Seven years after its establishment, an increased abundance of fish and more species were observed near the wind turbines than in the nearby reference area (Stenberg et.al., 2011), possibly due to good feeding and refuge possibilities around the wind farm foundations.

Potential habituation to the operational sounds produced by wind turbines is supported by studies of other offshore wind farms at Nysted OWF and Horns Rev OWF, where a large number of fish species, including dense schools of two-spotted gobies, sculpins, gold-sinny wrasses, black gobies and cod, were registered in and around the wind turbine foundations (Stenberg et.al., 2011) (Hvidt et.al., 2006). In a recent study in the Borssele 1 and 2 OWF consisting of 8 MW turbines, artificial reef structures were installed (in 2020) to create suitable habitats and feeding places for both young and adult Atlantic cod. Based on acoustic telemetry and acoustic tags, the behaviour of 45 cods were monitored. The initial analyses of the data show that cod are attracted to the reef and like to stay in its vicinity (https://phys.org/news/2023-04-cod-artificial-reef-farm.html, 2023).

Underwater operational noise is not high enough to have any effect on the early life stages (fish eggs and larvae) of fish, and thus the early life stages will not be affected by underwater noise from wind farm operations.

Both pelagic and demersal fish can probably hear the operational underwater noise from the mechanical components of wind turbines, however they do not appear to be noticeably affected. Thus, the sensitivity to underwater noise for both pelagic and benthic fish is ranked as low. Because there are no indications that suggest a difference in fish communities near working turbines in comparison to the surrounding area, the size and extent of the impact is assessed as negligible. Overall, the consequence of the operational underwater noise is assessed to be negligible for the fish and will not affect the fish populations short-term nor long-term (Table 5.1)

Table 5.1: Impact assessment of underwater noise from operation on fish in Laine Offshore Wind Farm area.

Impact	Sensitivity of the recipient	Size and extent of the impact	Consequence
Operational Noise	Low	Negligible	Negligible

5.1.2. Impact assessment – seals

It is assumed that seals will be able to hear the operational noise out to a few km under silent conditions. However, as the ambient noise is expected to be relatively high within the project area because of marine traffic, the ambient noise is expected to be the limiting factor in the low frequency range. Furthermore, seals seem to be relatively tolerant to underwater noise from wind farms in operation (Kastelein, 2011; Southall, et al., 2019). There are no studies of how ringed seals respond to operational noise from wind turbines. However a relatively recent study of harbour seals at the German OWF Alpha ventus (Russell, et al., 2014), where 11 harbour seals were tagged with GPS-transmitters., showed that four of the tagged seals entered the Alpha ventus, and two of the tagged seals foraged at the foundation structures, where they visited one turbine and stayed around the foundation for a while. They then went directly to another wind turbine foundation as shown in Figure 5.3. This results in a very structured movement pattern that shows that foundations were searched systematically for food (Russell, et al., 2014). One of the tagged harbour seals foraged at the foundations of all 12 operating wind turbines, and it clearly preferred the foundation structures over other areas inside the wind farm (see Figure 5.3).

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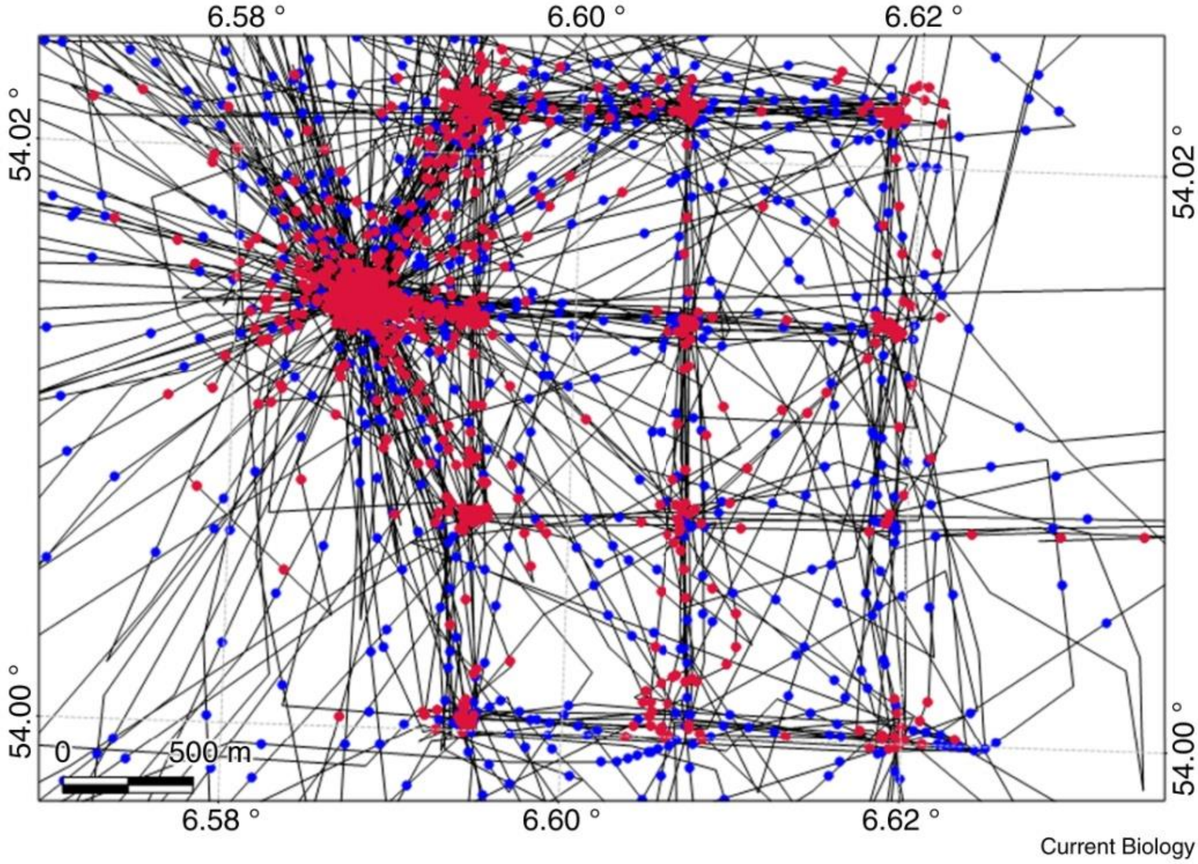

Figure 5.3: Tracks of a tagged harbour seal around the wind farm 'alpha ventus' (12 turbines) and the research platform FINO 1 (left of alpha ventus). Points show locations at 30 minute intervals; red indicates greater foraging potential (Russell, et al., 2014).

It is expected that scour protection around the foundation will be used in the establishment of the wind turbine. The new hard bottom substrate will lead to a stabilization of the seabed by helping prevent scouring from water currents and increase the physical complexity and bottom structure. Over time, it is expected that the introduced hard bottom substrates in the form of concrete, rock formations and steel will develop a hard bottom habitat and function as a so-called artificial reef. The reef will rapidly develop a succession of reef associated organisms and a reef community consisting of macroalgae species and a series of epibenthic invertebrates (bottom-dwelling invertebrates) and associated fish species depending on water depth and current conditions, and on the material from which the foundation is built, including its heterogeneity (DTU Aqua, 2013; Støttrup et al. , 2014). It is expected that an artificial reef will attract fish species associated with hard bottom and stone reefs and potentially increase the prey items for seals. Noise from wind farms could therefore potentially also serve as a kind of "dinner bell".

As with the harbour seals, grey seals were also reported to follow anthropogenic structures such as underwater cables and to forage along the cables (Russell, et al., 2014). It is therefore expected that grey seals will react to wind farms in a similar way as harbour seals.

The sensitivity of seals to underwater noise from the operating wind farm is low to negligible based on existing knowledge on seal behaviour inside offshore wind farms. The area is not an important foraging area for neither ringed seals nor grey seals. The size and extent of the impact from operational noise is assessed as negligible. This must also be seen in the light of the fact, that the project area is found adjacent and overlaps with main shipping routes in Bay of Bothnia. The added impact of underwater noise from operational of the wind farm will

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therefore be modest. Overall, the consequence of the operational underwater noise is assessed to be negligible for the seals and will not affect the populations short-term nor long-term (Table 5.1).

Table 5.2: Impact assessment of underwater noise from operation on seals in Laine Offshore Wind Farm area.

Impact	Sensitivity of the recipient	Size and extent of the impact	Consequence
Operational Noise	Low	Negligible	Negligible

6. Cumulative effects

The assessment of cumulative effects is based on the impact assessment of the project in combination with other local or regional projects or plans, which may contribute to a cumulative environmental impact. When several planned projects within the same area affect the same environmental recipients at the same time, cumulative impacts will occur. For Laine OWF, cumulative impacts from underwater noise may arise if other wind farms or projects that cause the same type of impacts are constructed at the same time. The assessment is based on projects that have obtained a construction permit as well as projects in the planning phase and simultaneous construction of the offshore wind farms.

Cumulative effects on marine mammals and fish are assumed to occur only during the construction phase, as impact during the operational phase is assessed as having a limited local impact on the marine mammals and fish (see section 5.1) and therefore cumulative impacts in the operational phase are unlikely to occur.

Spatial cumulative impacts may occur when/if noisy construction works in Laine, especially pile driving, takes place simultaneously with comparable measures in adjacent projects. In this case the individual impact zones from the individual projects may add up and thereby constitute an even larger impact zone from which marine mammals and fish cannot flee as quickly as from a single impact zone.

There is one planned offshore wind farm relatively close to the development area for Laine OWF. The planned offshore wind farm is listed in Table 6.1

Table 6.1: Project considered for cumulative assessment

Wind Farm/Developer	Country	Total planned max MW/max amount of turbines	Minimum distance to Laine OWF	Consenting phase	Expected construction year
Kappa/Njord	Sweden	1325 MW/74 turbines	1 km	EIA-report under work	2031-2033

Approximately 1 km west of Laine OWF, Njord is planning to construct Kappa offshore wind farms with a capacity of 1325 MW. Kappa is in the early planning phase and the EIA-work is ongoing at present. The construction phase of Kappa is scheduled to 2031-2033. As Laine OWF construction phase is scheduled to 2029-2031 there will be no overlap in the construction phase of the two offshore wind farms. Therefore no simultaneous pile driving will occur during construction in the two project areas. The cumulative impacts are therefore expected to be negligible for Laine OWF and Kappa OWF.

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7. Conclusion

During the construction of Laine OWF, the most significant underwater noise pressure on fish and marine mammals, is noise from installation activities (e.g., pile driving). When applying soft start/ramp-up procedure in combination with a mitigation system corresponding to the efficiency of a double big bobble curtain it is unlikely that seals will experience PTS or TTS and the risk of PTS or TTS is assessed as negligible because of the very short impact distances (< 200 meters). Seal sensitivity towards an impact on behaviour is assessed to be low as the nearest haul out site is 20 km away. Overall, the consequence of the pile driving underwater noise is assessed to be low for both ringed seals and grey seals and will not affect the populations short-term nor long-term.

The risk of fish experiencing either PTS or mortality caused by underwater noise from pile driving is assessed as negligible because of the very short impact distances (< 100 -1100 meters). Fish can experience TTS out to 17.9 km. As the Laine project area is species-poor and relatively scarcely used by fish the sensitivity is assessed to be low and the consequence of the underwater noise from pile driving in the project area for Laine OWF is assessed to be low for the fish and will not affect the fish populations short-term nor long-term.

During wind farm construction and operational maintenance an increase in ship traffic of both small and large vessels is expected within and near the project area for Laine OWF. The project area for the wind farm is located in an area that is already under the impact of ship traffic and is located in close vicinity or overlaps with main shipping routes in the northern part of the Bay of Bothnia (Figure 4.3). The Laine project area is therefore expected to be dominated by low-frequency ship noise already. Therefore, the impact from underwater noise from ship traffic is assessed to be negligible for fish and as minor for ringed and grey seal and will not affect the fish and seal populations short-term nor long-term.

During operation underwater noise from the wind turbines can occur. As mentioned above the project area for the Laine OWF is an area with expected elevated ambient noise levels because of ship noise. The operational noise from the wind farm is therefore expected to be below the ambient noise level and will only be audible close to the wind turbines. Impact from underwater noise is assessed as negligible for both fish, ringed and grey seal and will not affect the fish and seal populations short-term nor long-term.

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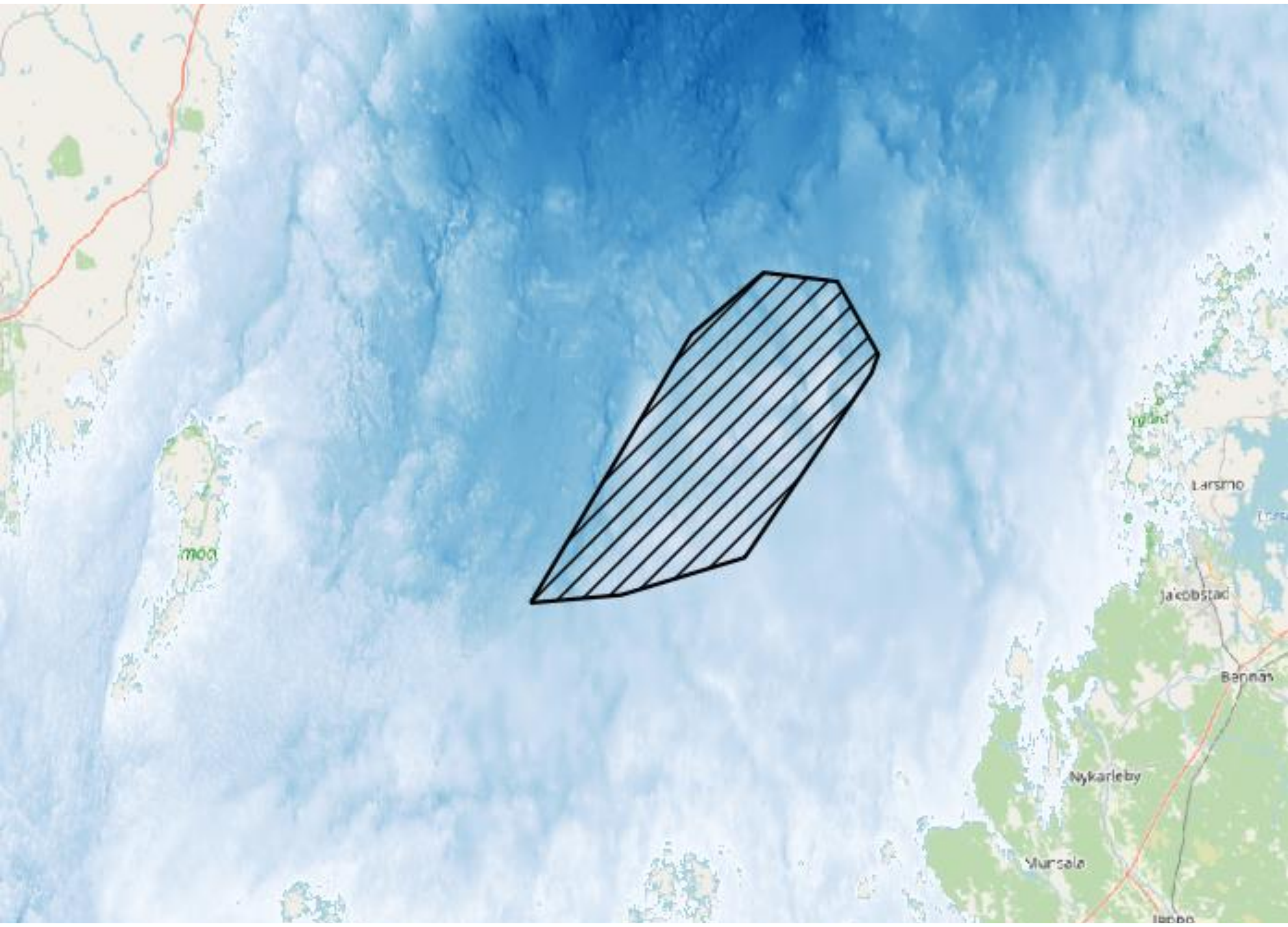

Laine offshore wind farm

Underwater noise prognosis
construction and operation

OX2

Date: 12 September 2023

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Contents

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Summary

In connection with the environmental impact assessment for Laine Offshore Wind Farm (OWF) in the Finnish part of the Gulf of Bothnia, about 30 km west of Pietarsaari and 25 km from the shoreline, NIRAS has conducted underwater sound prognosis for the construction and operation of the wind farm. A description of the ambient noise in and around the project area, is also provided. This to inform the impact assessment of marine mammals and fish of the underwater noise emission resulting from foundation installation within the OWF site.

Underwater sound emission was calculated for an 18 m diameter monopile foundation as well as for a jacket foundation anchored by 4 x 8 m diameter pin piles. Each foundation type was included in sound propagation calculations at three representative source positions within the Laine project area.

A 3D acoustic model was created in dBSea 2.3.4, utilizing detailed knowledge of bathymetry, seabed sediment composition, water column salinity, temperature, and sound speed profile as well as a source model based on best available knowledge. The modelling was conducted with underwater noise mitigation effect active. For both monopile foundation (scenario 1), and jacket foundation (scenario 2), a Double Big Bubble Curtain (DBBC) mitigation effect was included. Modelling without NAS was not included as pile driving without noise mitigation measures is not considered a feasible scenario. Using advanced underwater sound propagation algorithms, the sound emission from each scenario was calculated in 36 directions (10° resolution).

Distance-To-Threshold (DTT) for relevant frequency weighted species-specific threshold levels were calculated from the sound propagation models. These include safe starting distance for earless seals in order to prevent Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS), based on threshold levels in (NOAA, April 2018). Behaviour reaction distance for earless seals, were conservatively estimated based on the behaviour criteria for harbour porpoise.

DTT for TTS and injury threshold levels for Cod and Herring, as well as Injury for larvae and eggs were also calculated, see Table 1.1 and Table 1.2 for scenario 1 and scenario 2 respectively. DTT for stationary fish, represent fish that do not flee in response to noise exposure. DTT for earless seal thresholds are shown in Table 1.3 and Table 1.4 for scenario 1 and scenario 2 respectively.

Table 1.1: Resulting threshold impact distances for fish using DBBC mitigation effect on an 18 m monopile for the worst-case month of May.

Position	Distance-to-threshold (18 m monopile + DBBC mitigation effect)								
	Injury (r_{injury})					TTS (r_{TTS})			
	Stationary fish	Juvenile Cod	Adult Cod	Herring	Larvae and eggs	Stationary fish	Juvenile Cod	Adult Cod	Herring
1	975 m	< 100 m	< 100 m	< 100 m	525 m	15.2 km	11.5 km	7.8 km	6.9 km
2	1100 m	< 100 m	< 100 m	< 100 m	650 m	17.9 km	14.3 km	10.4 km	9.4 km
3	875 m	< 100 m	< 100 m	< 100 m	525 m	13.9 km	10.4 km	6.7 km	5.9 km

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Table 1.2: Resulting threshold impact distances for fish using DBBC mitigation effect on a Jacket foundation with 4x 8 m pin piles for the worst-case month of May.

Position	Distance-to-threshold (Jacket with 4x 8 m pin piles + DBBC mitigation effect)								
	Injury (r_{injury})					TTS (r_{TTS})			
	Stationary fish	Juvenile Cod	Adult Cod	Herring	Larvae and eggs	Stationary fish	Juvenile Cod	Adult Cod	Herring
1	700 m	< 100 m	< 100 m	< 100 m	400 m	10.9 km	2.1 km	< 200 m	< 200 m
2	775 m	< 100 m	< 100 m	< 100 m	475 m	13.1 km	3.5 km	250 m	< 200 m
3	625 m	< 100 m	< 100 m	< 100 m	375 m	10 km	1.8 km	< 200 m	< 200 m

Table 1.3: Resulting threshold impact distances for earless seals using DBBC mitigation effect on an 18 m monopile for the worst-case month of May.

Position	Distance-to-threshold (18 m monopile + DBBC mitigation effect)		
	PTS (r_{PTS})	TTS (r_{TTS})	Avoidance (r_{behav})
1	< 100 m	< 200 m	7.35 km
2	< 100 m	< 200 m	6 km
3	< 100 m	< 200 m	5.95 km

Table 1.4: Resulting threshold impact distances for earless seals using DBBC mitigation effect on a jacket foundation with 4x 8 m pin piles for the worst-case month of May.

Position	Distance-to-threshold (Jacket with 4x 8 m pin piles + DBBC mitigation effect)		
	PTS (r_{PTS})	TTS (r_{TTS})	Avoidance (r_{behav})
1	< 100 m	< 200 m	7.45 km
2	< 100 m	< 200 m	6.05 km
3	< 100 m	< 200 m	6.05 km

Threshold distances for PTS and TTS describe the minimum distance from the source a seal or fish must at least be, prior to onset of pile driving, in order to avoid the respective impact. It therefore does not represent a specific measurable sound level, but rather a safe starting position.

The threshold distance for behaviour, on the other hand, describes the specific distance, up to which, the behavioural response is likely to occur, when maximum hammer energy is applied to a pile strike. For pile strikes at lower than 100% hammer energy, this distance is shorter.

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List of abbreviations

Full name	Abbreviation	Symbol
Sound Exposure Level	SEL	$L_{E,p}$
Cumulative Sound Exposure Level	$SEL_{cum,24h}$	$L_{E,p,cum,24h}$
Sound Exposure Level - single impulse	SEL_{SS}	L_{E100}
Sound Pressure Level	SPL	$L_{p,rms}$
Source Level at 1 m	SL	L_S
Sound exposure source level at 1 m	ESL	$L_{S,E}$
Permanent Threshold Shift	PTS	
Temporary Threshold Shift	TTS	
National Oceanographic and Atmospheric Administration	NOAA	
Offshore Wind farm	OWF	
Noise Abatement System	NAS	
Low frequency	LF	
High frequency	HF	
Very High frequency	VHF	
Phocid Pinniped	PCW	
Big Bubble Curtain	BBC	
Double Big Bubble Curtain	DBBC	
Hydro Sound Damper	HSD	
IHC Noise Mitigation Screen	IHC-NMS	
World Ocean Atlas 2018	WOA18	
Normal modes	NM	
Parabolic Equation	PE	
Distance-To-Threshold	DTT	
Propagation loss	PL	N_{PL}
Sound Exposure Propagation loss	EPL	$N_{PL,E}$
National Marine Fisheries Service	NMFS	

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1. Introduction

This report documents the underwater sound propagation modelling in connection with the environmental impact assessment for the installation of wind turbine foundations at Laine Offshore Wind Farm (OWF).

Laine OWF site is located in the Finnish Exclusive Economic Zone (EEZ) of the Gulf of Bothnia, about 30 km west of Pietarsaari and 25 km from the shoreline. The project area is approximately 451 km^2. In Figure 1.1, the OWF area is shown along with the Finland-Sweden EEZ.

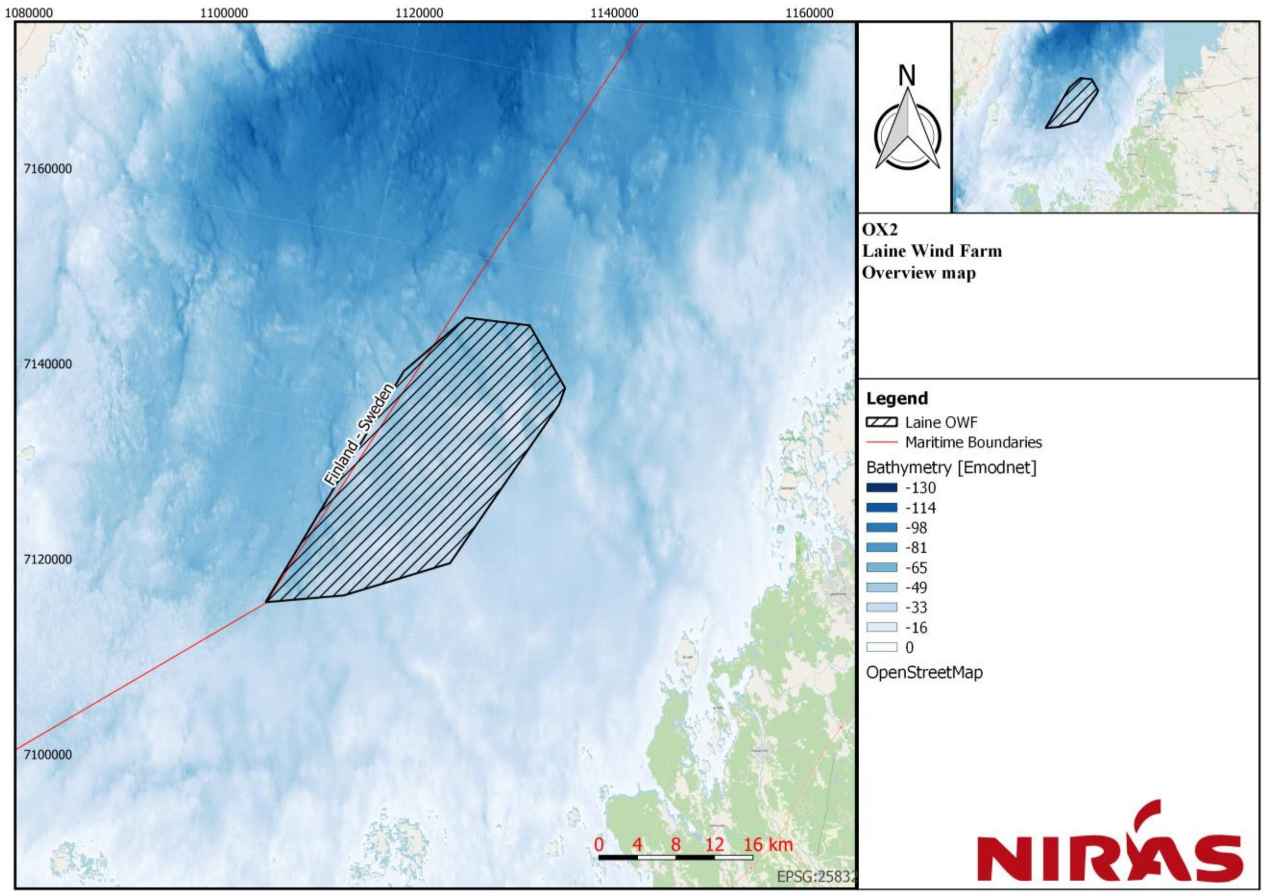

Figure 1.1: Overview of Laine offshore wind farm site (black) and surrounding area.

The project includes installation of up to 150 wind turbines within the project area. Foundation types for the turbines have not been decided, however a number of options are considered possible. Monopile foundations up to 18 m diameter, 3- or 4-legged jacket foundations with up to 8 m pin piles, or alternative foundations such as floating, gravitation or suction bucket could be used either exclusively or in combination. Sound propagation modelling is only conducted for the worst case scenario with regards to underwater noise emission. The different foundation types are evaluated in section 7.1.

The report documents impact ranges for all relevant threshold levels for the impact on earless seals and fish.

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2. Purpose

The purpose of this report is to provide a description of expected underwater noise emission from the construction of Laine OWF, to inform marine mammal and fish impact assessments. For the construction phase, the report documents sound propagation prognosis for the impact pile driving activities, and relate these to relevant marine mammal and fish specific impact threshold levels.

3. Underwater sound definitions

In the following, the reader is introduced to the acoustic metrics used throughout the report for quantifying the sound levels.

3.1. Source level

Two representations for the acoustic output of pile driving are used in this report, namely Source Level (SL), L_S, and the sound exposure source level (ESL), $L_{S,E}$.

Here, SL is defined for a continuous source as the mean-square sound pressure level at a distance of 1 m from the source with a reference value of $1\ \mu Pa \cdot m$.

ESL is used to describe a transient sound source and is defined as the time-integrated squared sound pressure level at a distance of 1 m from the source with a reference value of $1\ \mu Pa^2\ m^2\ s$.

3.2. Sound Pressure Level

In underwater noise modelling, the Sound Pressure Level (SPL), L_p, is commonly used to quantify the noise level at a specific position, and in impact assessments, is increasingly used for assessing the behavioural response of marine mammals as a result of noise emitting activities. The definition for SPL is shown in Equation 1 (Erbe, 2011):

$$L_p = 20 * \log_{10}\left(\sqrt{\left(\frac{1}{T}\right)\int_T p(t)^2}\right) \quad [\text{dB re. } 1\mu\text{Pa}] \qquad \text{Equation 1}$$

Where p is the acoustic pressure of the noise signal during the time of interest, and T is the total time. L_p is the average unweighted SPL over a measured period of time.

In order to evaluate the behavioural response of the marine mammal a time window must be specified. Often, a fixed time window of 125 ms. is used due to the integration time of the ear of mammals (Tougaard & Beedholm, 2018). The metric is then referred to as $L_{p,125ms}$ and the definition is shown in Equation 2 (Tougaard, 2021).

$$L_{p,125ms} = L_{E,p} - 10 * \log_{10}(0.125) = L_{E,p} + 9\text{ dB} \quad [\text{dB re. } 1\mu\text{Pa}]$$

Equation 2

Where $L_{E,p}$is the sound exposure level, which are explained in the next section.

3.3. Sound Exposure Level

The Sound Exposure Level (SEL) describes the total energy of a noise event (Jacobsen & Juhl, 2013). A noise event can for instance be the installation of a monopile by impact pile driving, from the start to the end, or it can be a single noise event like an explosion. The SEL is normalized to 1 second and is defined in (Martin, et al., 2019) through Equation 3.

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$$L_{E,p} = 10\log_{10}\left(\frac{1}{T_0 p_0^2}\int_0^T p^2(t)\right)\ [\text{dB re. } 1\mu Pa^2 s]$$ Equation 3

Where T_0 is 1 second, 0 is the starting time and T is end time of the noise event, p is the pressure, and p_0 is the reference sound pressure which is $1\ \mu Pa$.

The relationship between SPL in Equation 1 and SEL, in Equation 3, is given in Equation 4 (Erbe, 2011).

$$L_{E,p} = L_p + 10 * \log_{10}(T)$$

Equation 4

When SEL is used to describe the sum of noise from more than a single event/pulse, the term Cumulative SEL, $(SEL_{cum,t})$, $L_{E,cum,t}$, is used, while the SEL for a single event/pulse, is the single-strike SEL (SEL_{SS}), L_{E100}. The SEL_{SS} is calculated on the base of 100% pulse energy over the pulse duration.

Marine mammals can incur hearing loss, either temporarily or permanently as a result of exposure to high noise levels. The level of injury depends on both the intensity and duration of noise exposure, and the SEL is therefore a commonly used metric to assess the risk of hearing impairment as a result of noisy activities. (Martin, et al., 2019).

3.4. Cumulative Sound Exposure level

In the assessment of Temporary Threshold Shift (TTS), Permanent Threshold Shift (PTS) and injury caused by underwater noise on marine mammals and fish, cumulative SEL ($L_{E,cum,t}$) is used to describe the total noise dose received by the receptors as a result of an underwater noise emitting activity.

For a stationary source, such as installation of a foundation, the installation procedure, as well as the swim speed for the receptor, must be included. A method for implementing such conditions in the calculation of cumulative SEL has been proposed by (Energistyrelsen, 2022), for the Danish guidelines for pile driving activities, as given by Equation 5. Here, the duration is fixed to 24h to represent the daily cumulative SEL, $L_{E,cum,24h}$. If multiple foundations are installed in the same 24-hour window, all must be included in the calculation.

$$L_{E,cum,24h} = 10 * \log_{10}\left(\sum_{i=1}^{N}\frac{S_i}{100\%} * 10^{\left(\frac{L_{S,E} - X*\log_{10}(r_0+v_f*t_i) - A*(r_0+v_f*t_i)}{10}\right)}\right)$$ Equation 5

Where:

- S_i is the percentage of full hammer energy of the i'th strike
- N is the total number of strikes for the pile installation
- $L_{S,E}$ is the sound exposure source level at 1 m distance at 100% hammer energy.
- X and A describe the sound exposure propagation losses (EPL) for the specific project site
- r_0 is the marine mammal distance to source at the onset of piling
- v_f is the swim speed of the marine mammal directly away from the source
- t_i is the time difference between onset of piling, and the i^{th} strike.

The parameters related to the source level, hammer energy, number of strikes and time interval between each strike should be based on realistic worst-case assumptions and can be achieved through a site-specific drivability analysis. The relationship between hammer energy level and pile strike number is referred to as the hammer curve.

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The sound propagation parameters (X and A) must be determined through an advanced sound propagation model, in which all relevant site-specific environmental parameters are considered.

The calculation model presented in Equation 5, is used throughout the report for all calculations of cumulative SEL. Furthermore, the Danish approach of including all installations occurring within a 24-hour period is adopted, and $L_{E,cum,24h}$ is therefore used for the remainder of this report.

3.5. Maximum-over-depth

Sound propagation modelling is conducted in a number of directions, or radials, from source outwards. For each radial, the sound propagation loss is calculated in a range x depth grid, with spacing chosen based on local conditions. As the sound propagation loss will not be the same at all depths, a worst case approach is taken, whereby for each range step, the lowest (most conservative) sound propagation loss over all modelled depths, is used, and the rest are discarded. This concept is called Maximum-Over-Depth (MOD) and ensures a conservative approach, such that all extracted sound levels represent the highest level at any depth at each distance throughout the model area.

It should be noted, that in this way, surface plots showing underwater noise contours, will not represent a certain depth, but rather the maximum sound levels over all depths.

4. Underwater noise impact criteria

Guidance or threshold values for regulating underwater noise during construction of OWFs (pile driving) have been developed by several different countries and international organizations. There are different approaches in the different countries when it comes to assessing impacts from pile driving on marine mammals and fish. The project area is located in the Finnish EEZ, and Finland does not have established guidelines for underwater noise from impact pile driving. On the reasoning for the modelled threshold values, the reader is referred to the respective impact assessments for fish and marine mammals.

4.1. Applied threshold for fish

Unmitigated pile driving turbine foundations into the seabed can cause extreme underwater noise levels and is one of the largest potential pressures to fish in all life stages in areas where turbines will be established. Fish eggs and fish larvae are not particularly sensitive to underwater noise and are primarily affected when underwater noise is so high that it can damage their tissue (Andersson et al., 2017). Generally, the frequency range, where fish hear best, is similar to the frequencies with the largest acoustic energy emission generated by pile driving (Bellmann, 2018; Richardson, et al., 1995).

Fish have a wide range of hearing capabilities to perceive underwater noise and can be classified as hearing generalists or hearing specialists (Fay et al. , 1999) (Sand & Karlsen, 2000) depending on the species. The most perceptive fish species to underwater noise are those with swim bladders linked to inner ears, which include clupeids such as the pelagic species sprat and herring (Popper et al., 2014). These species can hear frequencies that span from infrasound (<20 Hz) up to approximately 8 kHz, however with decreasing sensitivity the higher the frequency (Enger, 1967; Sand & Karlsen, 2000). Other species with swim bladders but less specialized internal connections with inner ears, are codfish, salmons and mackerel, which can be considered hearing generalists with slightly less sensitivity to perceive underwater noise (Chapman & Hawkins, 1973) (Popper, et al., 2014). These species can hear sound from infrasound up to 500 Hz (Chapman & Hawkins, 1973). In almost all demersal fish, such as flatfish, the swim bladder degenerates after the larval stage and thus demersal fish species have poor hearing capabilities and are not particularly sensitive to underwater noise (Karlsen, 1992). These and other demersal fish species associated with seabed habitats such as gobies (Gobidae), sculpins (Cottidae), dragonet etc. are hearing generalists with poor hearing capabilities and low sensitivity to noise that typically hear in the range from infrasound up to a few 100 Hz (Sand & Karlsen, 2000).

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Auditory threshold shift (TTS and PTS)

Specific knowledge of how different fish species react to noise (behavioural responses) is relatively limited and there is no consensus on behavioural thresholds in fish. Defining one common behavioural threshold criteria for fish is difficult and can never fit all fishes, since species vary greatly in so many ways. There are differences in their hearing capabilities and how they respond to stimuli in general (swim away, bury in the substrate, etc.) that will affect whether a sound at a given level will elicit a response or not. Moreover, responses to a signal may vary within a species, and even a single animal, depending on things such as sex, age, size, and motivation (feeding, mating, moving around a home range, etc.) As a consequence, developing behavioural guidelines is far harder than developing guidelines for physiological effects especially since behavioural responses are.

High levels of underwater noise as well as continuous and accumulated noise (SEL_{cum}) can result in a decrease in hearing sensitivity in fish. If hearing returns to normal after a recovery time, the effect is a temporary threshold shift (TTS). Sound intensity, frequency, and duration of exposure are important factors for the degree and magnitude of hearing loss, as well as the length of the recovery time (Neo et. al., 2014) (Andersson et al., 2017). Extreme levels of noise from, for example, pile driving can be so high that they can cause permanent hearing loss (PTS) from damage to tissue and hearing organs when in the near vicinity of the activity, which can be fatal for fish, fish eggs and fish larvae (Andersson et al., 2017).

Guidelines for temporary hearing loss (TTS) in fish species with a swim bladder involved in hearing, called a hearing specialist (e.g. herrings) and fish with a swim bladder that is not involved in hearing, called a hearing generalist (e.g. cod) (Popper et al., 2014) are given in Table 4.1. Cod do not occur in the project area for Laine OWF, however as the threshold to represent other hearing generalist like salmons, smelt and whitefish, which occur in the project area for Laine OWF. Thresholds for tissue damage and hearing loss leading to mortality in fish, fish eggs and larvae are also given in Table 4.1. Fish species without swim bladders (primarily demersal species) including all flatfish species and other demersal species, are much less perceptive to noise than fish species with swim bladders (primarily pelagic) and codfish, and it can be expected that actual tolerance thresholds for demersal fish are higher than pelagic fish. However, because information of threshold values is very limited, the threshold values for the least tolerant fish species are used for all species including demersal species in this analysis.

Threshold levels for when fish begin to experience hearing loss depending on their hearing capabilities, begins at around 186 dB SELcum for fish least tolerant to noise (Table 4.1). Conservatively, the noise level where irreversible hearing loss and permanent injuries leading to mortality is set at 204 dB for all fish, and at 207 dB SELcum for fish larvae and eggs.

Assessment of the noise impact on fish, larvae and eggs are all based on frequency unweighted threshold levels using the metric $\mathbf{L_{E,cum,24h}}$, and are presented in Table 4.1. The threshold is adopted from (Andersson, et al., 2016) and (Popper, et al., 2014).

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Table 4.1: Unweighted threshold criteria for fish (Andersson, et al., 2016), (Popper, et al., 2014).

Species	Swim speed [m/s]	Species specific unweighted thresholds (Impulsive)	
		$L_{E,cum,24h,unweighted}$	
		TTS [dB]	Injury [dB]
Stationary fish	0	186	204
Juvenile Cod	0.38	186	204
Adult Cod	0.9	186	204
Herring	1.04	186	204
Larvae and eggs	-	-	207

4.2. Applied threshold for marine mammals

As seals are adapted to life both in water and on land, their hearing ability has adapted to function in both environments. Seals produce a wide variety of communication calls both in air and in water, e.g., in connection with mating behaviour and defence of territory. There is limited knowledge of the underwater hearing abilities of grey and ringed seal. However the hearing threshold of harbour seals are generally recommended to be used as a conservative estimate of the hearing threshold for those Phocids ('true seals'), where the hearing has not yet been as thoroughly investigated (Southall, et al., 2019). Seals hear well in the frequency range from a few hundred Hz up to 50 kHz.

Based on the newest scientific literature, it is recommended that the $L_{E,cum,24h}$ and frequency weighting is used to assess TTS and PTS. Threshold levels for TTS and PTS are primarily based on a large study from the American National Oceanographic and Atmospheric Administration (NOAA), (NOAA, 2018), where species specific frequency weighting is proposed, accounting for the hearing sensitivity of each species when estimating the impact of a given noise source.

In (NOAA, 2018) the marine mammal species, are divided into four hearing groups, revised in wording in (Southall, et al., 2019), in regard to their frequency specific hearing sensitivities: 1) Low-frequency (LF) cetaceans, 2) High-frequency (HF) cetaceans, 3) Very High-frequency (VHF) cetaceans, 4) and Phocid pinnipeds (PCW) in water. For this project, only the latter is relevant. More details about the hearing groups and their frequency sensitivities are given in section 4.4. The hearing group weighted threshold criteria can be seen in Table 4.2.

There is a general lack of quantitative information about avoidance behavior and impact ranges of seals exposed to pile driving noise and the few studies point in different directions. During construction of offshore wind farms in The Wash, south-east England in 2012, harbour seals usage (abundance) was significantly reduced up to 25 km from the pile driving site during unmitigated pile driving (Russell, et al., 2016). Based on the results, Russell et al. (2016) suggested that the reaction distance for seals to unabated pile driving was comparable to that of harbour porpoises. On the other hand, Blackwell et al. (2004) studied the reaction of ringed seals to pile driving in connection with establishment of an artificial island in the arctic and saw limited reactions to the noise. As a precautionary approach, it has been assumed that seals react to underwater noise from piledriving at the same distance as harbour porpoise.

A literature review of avoidance behaviour and onset threshold levels in (Tougaard, 2021), included both studies in captivity where pile driving noise was played back at greatly reduced levels, and field studies of reactions of wild porpoises to full-scale pile driving. From the review, the conclusion in (Tougaard, 2021) is that the behavioural avoidance threshold is in the range between $L_{p,125ms} = 95 - 110$ dB re. 1 μPa, and a suitable single value of $L_{p,125ms} = 103$ dB re. 1 μPa VHF-weighted. The single value is obtained from (Band, et al., 2016) which includes the largest

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amount of empirical data. In the present report, a behavioural threshold for harbour porpoises of 103 dB $L_{p,125ms}$ VHF-weighted is therefore used, see Table 4.2.

Table 4.2: Species specific weighted threshold criteria for earless seals. This is a revised version of Table AE-1 in (NOAA, 2018) to highlight the important species in the project area (NOAA, 2018) including behaviour response.

Species	Species specific weighted thresholds (non-impulsive)		Species specific weighted thresholds (Impulsive)		
	$L_{E,cum,24h,xx}$		$L_{E,cum,24h,xx}$		$L_{p,125ms,VHF}$
	TTS [dB]	PTS [dB]	TTS [dB]	PTS [dB]	Behaviour [dB]
Seal (PCW)	181	201	170	185	103

Thresholds listed as "non-impulsive", apply for continuous noise (e.g., ship noise) and whilst impulsive noise is expected to transition towards continuous noise over distance from the source, this transition is not expected to occur within the distances at which PTS and/or TTS can potentially occur as a result of these activities. For impulsive sources such as pile driving, stricter threshold levels apply as listed in Table 4.2. Threshold levels for continuous noise are more lenient, than those for impulsive noise, and use of the impulsive noise criteria, therefore provides conservative distance-to-threshold. The non-impulsive thresholds will not be considered further in this report.

4.3. Distance-To-Threshold

The impact criteria, as presented in section 4.1 and 4.2, rely on determining the Distance-To-Threshold (DTT), $r_{<threshold>}$, which are the distances at which the various thresholds are likely to occur.

As such, DTT for PTS (DTT_{PTS}) is symbolized as r_{PTS} and TTS (DTT_{TTS}) is symbolized as r_{TTS}, both describing the minimum distance from the source, a marine mammal must be deterred to, prior to onset of the pile driving in order to avoid the respective impact. It does therefore not represent a specific measurable sound level, but rather a starting distance.

The DTT for behaviour, r_{behav}, on the other hand, describes the specific distance, up to which a behavioural response is likely to occur.

It should be noted, that for impact pile driving, a significant portion of the installation time will not be conducted applying maximum hammer energy, however a steadily increasing amount of energy from soft start (10-15% of hammer energy) through ramp up (15%-99%) to full power (100%). Depending on the soil conditions, the hammer energy requirements through the ramp up and full power phases will vary from site to site, and even between individual pile locations within a project site.

4.4. Frequency weighting functions

As described in previous sections, the impact assessment for underwater noise includes frequency weighted threshold levels. In this section, a brief technical explanation of the frequency weighting method is given.
Humans are most sensitive to frequencies in the range of 2 kHz - 5 kHz and for frequencies outside this range, the sensitivity decreases. This frequency-dependent sensitivity correlates to a weighting function, for the human auditory system it is called A-weighting. For marine mammals, the same principle applies through the weighting function, $W(f)$, defined through Equation 6.

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

Equation 6

Where:

- **a** is describing how much the weighting function amplitude is decreasing for the lower frequencies.
- **b** is describing how much the weighting function amplitude is decreasing for the higher frequencies.
- $\mathbf{f_1}$ is the frequency at which the weighting function amplitude begins to decrease at the lower frequencies [kHz]
- $\mathbf{f_2}$ is the frequency at which the weighting function amplitude begins to decrease at the higher frequencies [kHz]
- **C** is the function gain [dB].

For an illustration of the parameters see Figure 4.1.

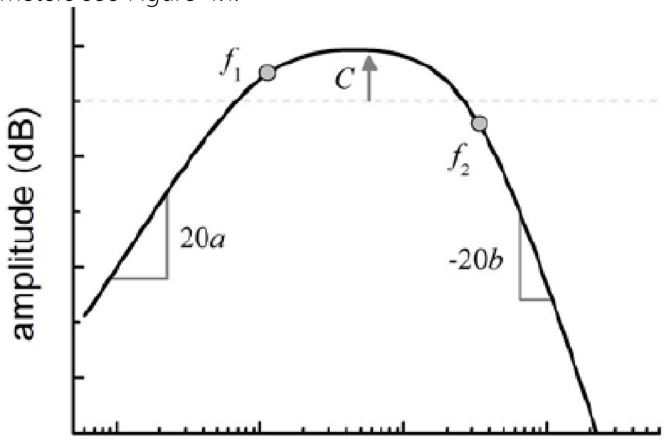

Figure 4.1: Illustration of the 5 parameters in the weighting function (NOAA, 2018).

The parameters in Equation 6 are defined for the relevant hearing groups and the values are presented in Table 4.3.

Table 4.3: Parameters for the weighting function for the relevant hearing groups (NOAA, 2018).

Hearing Group	a	b	$\mathbf{f_1}$ [kHz]	$\mathbf{f_2}$ [kHz]	C [dB]
Phocid Pinniped (PCW) (Underwater)	1.0	2	1.9	30	0.75

By inserting the values from Table 4.3 into Equation 6, the following spectra is obtained for the PCW hearing group (grey and ringed seals).

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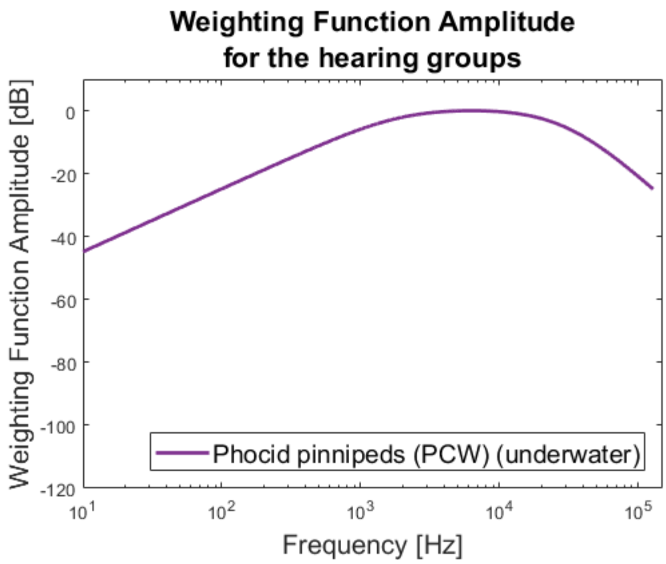

Figure 4.2: The weighting functions for the different hearing groups.

5. Ambient Underwater Noise Study

In this chapter, the ambient noise levels in the region are examined, based on available information, and the implications are discussed.

5.1. Ambient noise level

No site specific measurements of ambient noise for the Laine OWF area were conducted. For the Baltic Sea however, the ICES continuous underwater noise dataset (ICES, 2018), presents the underwater noise levels in the Baltic Sea as an average of each quarter of 2018 (Q1 – Q4). The noise maps represent a simplified modelled ambient noise level consisting of underwater noise from wind speed and vessel noise (based on AIS data). Noise levels are presented for individual 1/3 octave frequency bands as the median ambient noise level (SPL_{rms}) over all water depths for the quarter.

The noise levels are limited to three frequency bands of 63, 125 and 500 Hz. The two one-third octave band acoustic measurements centred at 63 and 125 Hz are used as international (European Union Marine Strategy Framework Directive) indicators for underwater ambient noise levels driven by shipping activity (EC Decision 2017/848, 2017). Noise maps for the project area and surroundings are shown in Figure 5.1 - Figure 5.3, for the frequency bands 63 Hz, 125 Hz and 500 Hz respectively. In addition to the 2018 data set, the data portal also features a 2014 data set (ICES, 2014) including a modelled noise map for the frequency band 2 kHz, see Figure 5.4.

The ICES maps show that the ambient noise levels are relatively invariant with season, and with frequency. Overall sound levels are below 100 dB in each frequency band and season. In Figure 5.5, the EMODnet vessel density map (EMODnet, CLS, 2022), is shown for the project area and surroundings for the months of February, May, August and November (as representative months for Q1 – Q4). By comparison, a certain correlation with shipping and noise level is observed, however due to the lack of any significant shipping lanes nearby, the noise level is more spatially distributed, rather than concentrated.

It should be noted that the ambient noise level is only modelled for four frequency bands, making it difficult to compare the impacts on marine life, especially for species with a high frequency hearing like.

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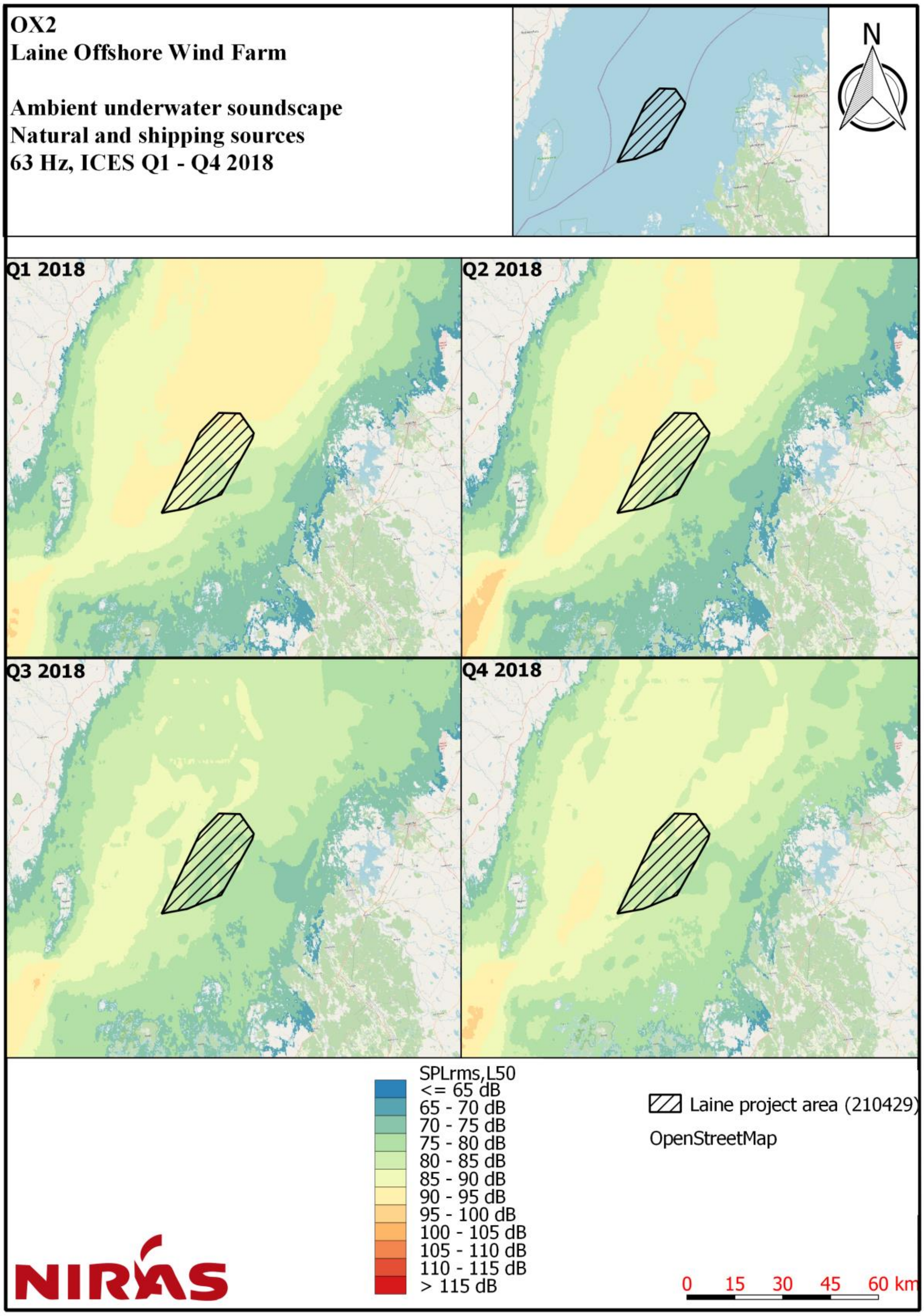

Figure 5.1: ICES soundscape map during Q1-Q4 2018, 50th percentile $SPL_{rms,63Hz}$ $[dB\ re. 1\mu Pa^2]$.

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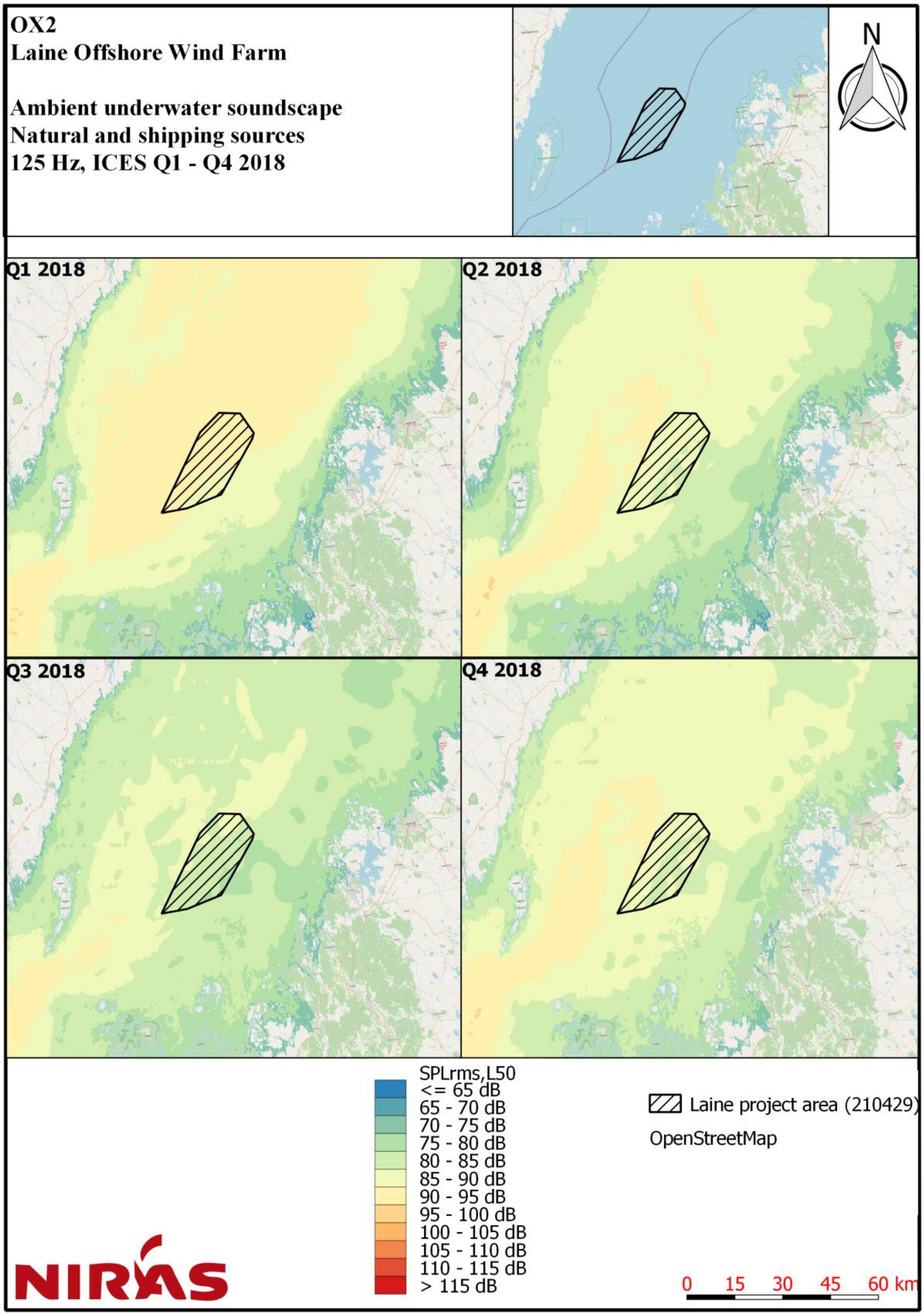

Figure 5.2: ICES soundscape map during Q1-Q4 2018, 50th percentile $SPL_{rms,125Hz}$ $[dB\ re.\ 1\mu Pa^2]$.

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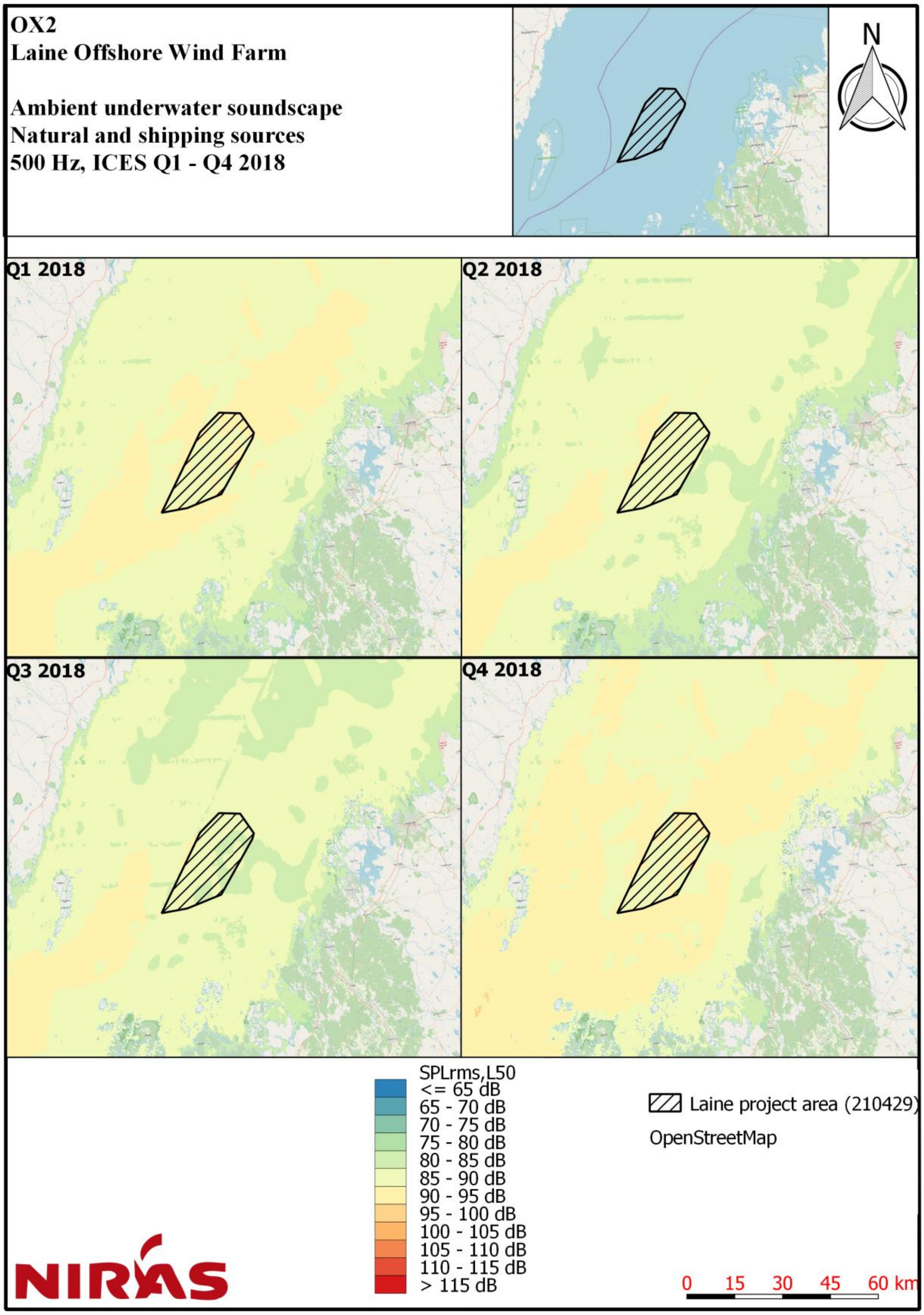

Figure 5.3: ICES soundscape map during Q1-Q4 2018, 50th percentile $SPL_{rms,500Hz}$ $[dB\ re.1\mu Pa^2]$.

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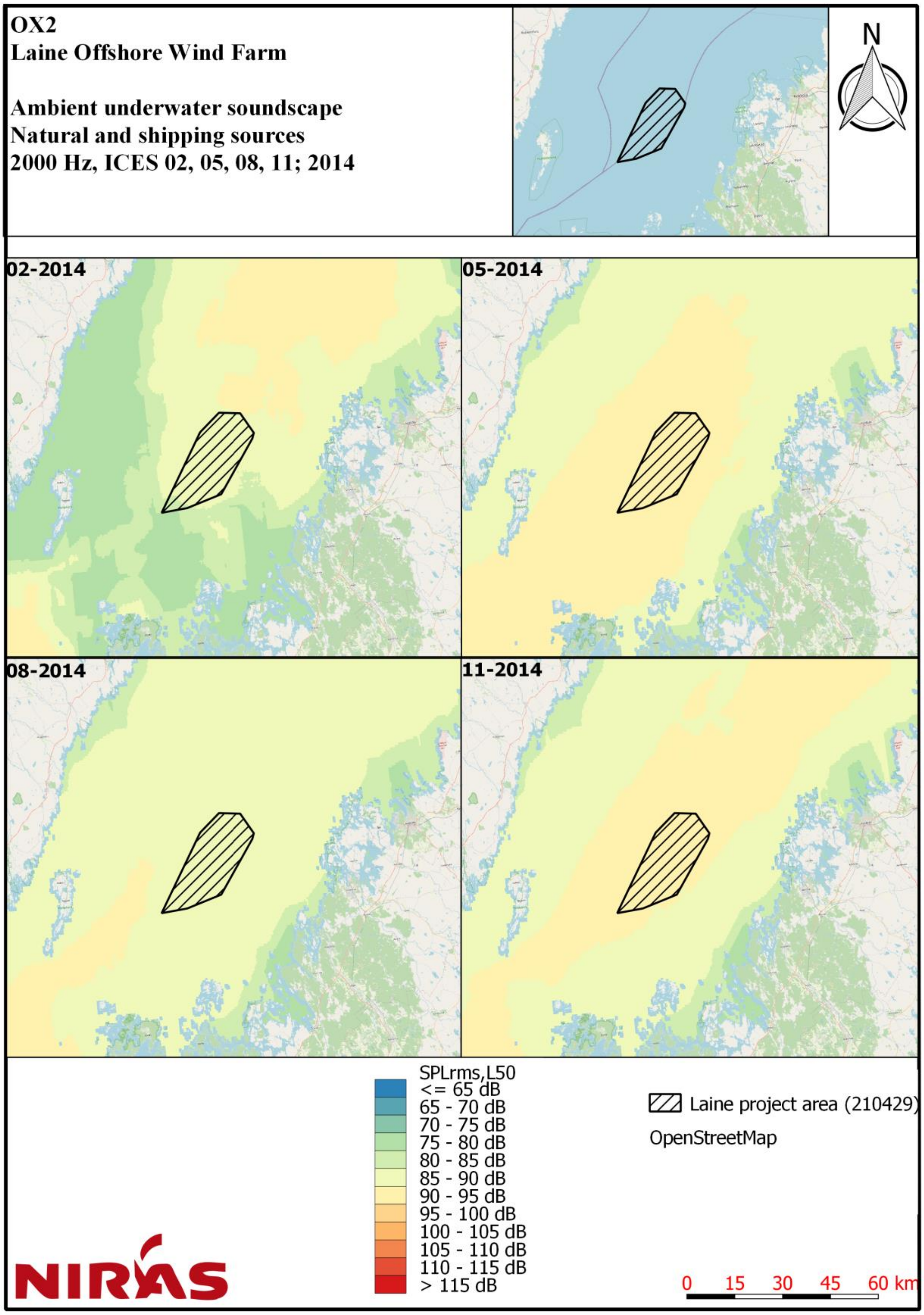

Figure 5.4: ICES soundscape map during Feb, May, Aug, Nov 2014, 50th percentile $SPL_{rms,2kHz}$ $[dB\ re.1\mu Pa^2]$.

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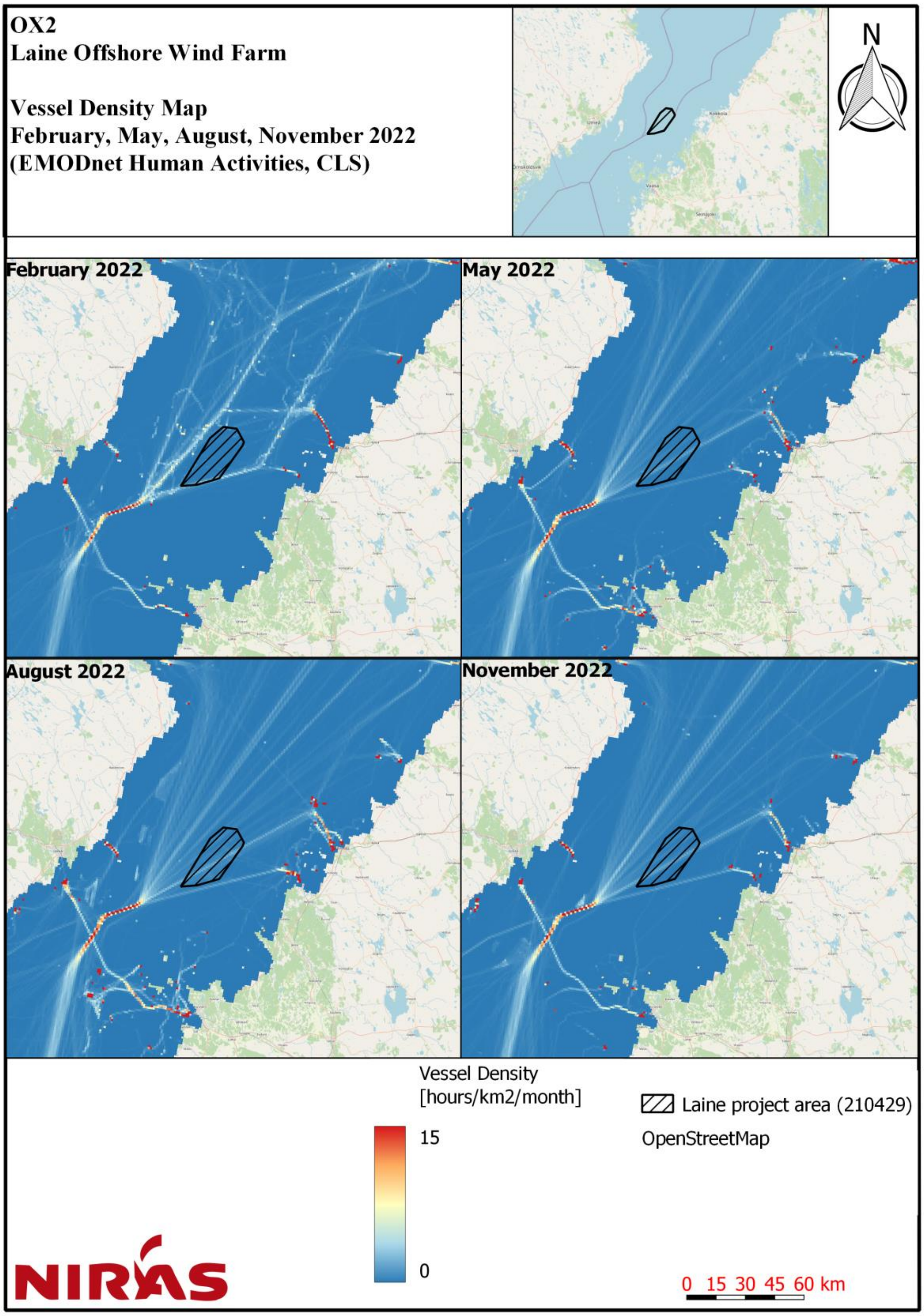

Figure 5.5: Vessel density map from 2022, from EMODnet (EMODnet, CLS, 2022) based on AIS data from CLS.

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6. Underwater sound propagation modelling background knowledge

Underwater sound propagation modelling for pile driving activities requires two parts. The first part, is a source model that approximates the actual pile driving sound emission as closely as possible, based on the project specific installation parameters. The concept of source model implementation is discussed in section 6.1 supplied with a description of underwater noise mitigation measures in section 6.2.

The second part is an underwater sound propagation model that approximates the propagation characteristics of the local (and regional) environment around the pile installation position. Such a model should include as detailed information as available for the environmental parameters of importance, most notable the bathymetry, seabed sediments, as well as salinity, temperature and sound speed profiles. The sound propagation model concepts are discussed in section 6.3. The implementation method for the environmental parameters is described in section 6.4.

6.1. Source model concept

The source model must represent the actual underwater sound source as accurately as possible, with regards to both source level, frequency content, as well as the temporal aspects of the activity. Any mitigation measures intended must also be included. These parameters are described in detail in the following sections.

6.1.1. Pile driving source level

The best available knowledge on the relationship between pile size and sound level, comes from a report on measured sound levels from pile driving activities in (Bellmann, et al., 2020), which provides a graphic summary of measured sound levels at 750 m distance as a function of pile size. This is shown in Figure 6.1. The measurements are all normalized to 750 m distance from the pile.

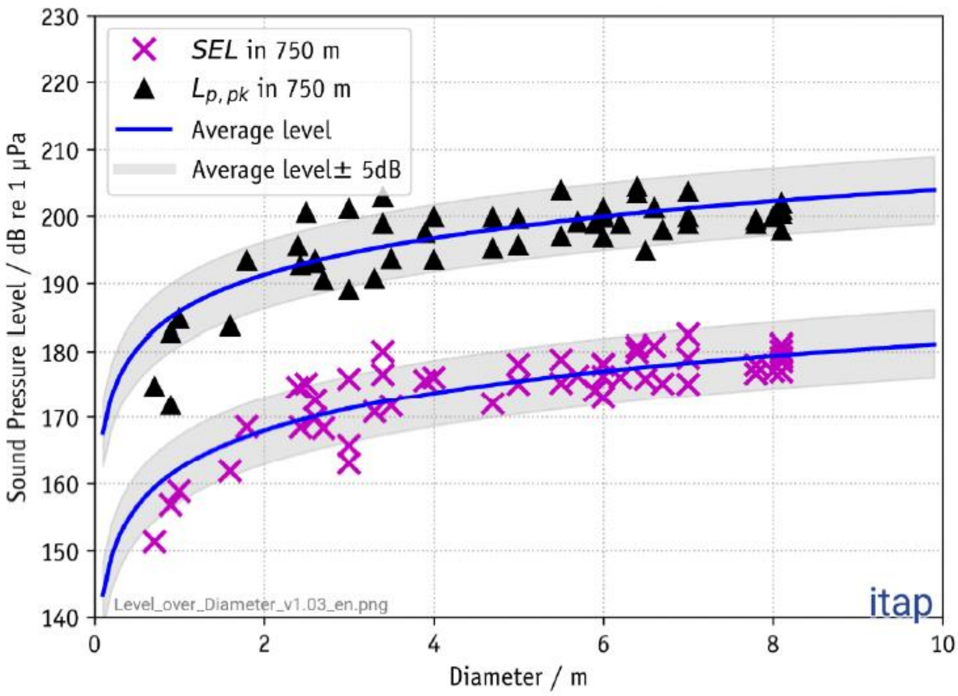

Figure 6.1: Relationship between measured SPL and SEL levels, measured at 750 m distance, and pile size (Bellmann, et al., 2020).

Examining Figure 6.1, the blue curve shows the best fit of the measurement results. For the SEL results, this relationship between pile size and measured level is approximately $\Delta\mathrm{SEL} = 20 * \log10\left(\frac{\mathrm{D2}}{\mathrm{D1}}\right)$ where D1 and D2 are the diameter of 2 piles, and ΔSEL is the dB difference in sound level between the two. This relationship shows that, when doubling the diameter, SEL increases by 6 dB.

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In order to use this data in an underwater sound propagation model, the source level at 1 m distance must be known. A common method to achieve this is through back-calculating empirical data from measurements to 1 m, whereby an equivalent source level represented as a point source is obtained. This is done, using a combination of Thiele's equation for sound propagation (Thiele, 2002), as well as NIRAS own calibration model based on several measurements at real sites. It should be noted that this approach will result in the measured sound levels at 750 m and provide accurate prognosis at further distances. It is however less accurate at distances closer to the source than 750 m as the near field is prone to significant positive and destructive interference patterns.

From Figure 6.1 it should be noted that variations in measured sound levels for a specific pile size do occur, as indicated by the spread of datapoints, around the fitted (blue) lines. This spread gives a 95%-confidence interval of ±5 dB which is indicated by the grey shaded areas. This is considered to be a result of varying site conditions and hammer efficiency applied for the individual pile installations and projects. For any project, it should therefore be considered whether the site and project specific conditions call for a more cautious source level estimate, than that of the average fitted line. In the following section, the different parameters which give rise to uncertainties regarding the source level, are examined.

6.1.1.1. Uncertainties in determining source level

In the following, several parameters influencing the actual source level for any specific installation are examined briefly.

Soil resistance

The foundation is installed by driving the piles into the seabed, which requires the predominant soil resistance has to be overcome. In general, the larger the soil resistance, the higher the blow energy required, which in turn increases the noise output (Bellmann, et al., 2020). For this reason, the harder, more compacted, and typically deeper, sediment layers require more force to be applied, thus increasing hammer energy and noise output as the piling progresses.

Water depth

The water depth, in shallow water, can also influence the noise emission. As the water depth decreases, the cut-off frequency increases, which can be seen in Figure 6.2. Frequency content of the noise source, below the cut-off frequency, has difficulty propagating through the water column, and will be attenuated at an increased rate, compared to frequency content above the cut-off (Bellmann, et al., 2020).

The cut-off frequency is dependent on, not only the water depth, but also the upper sediment type of the seabed.

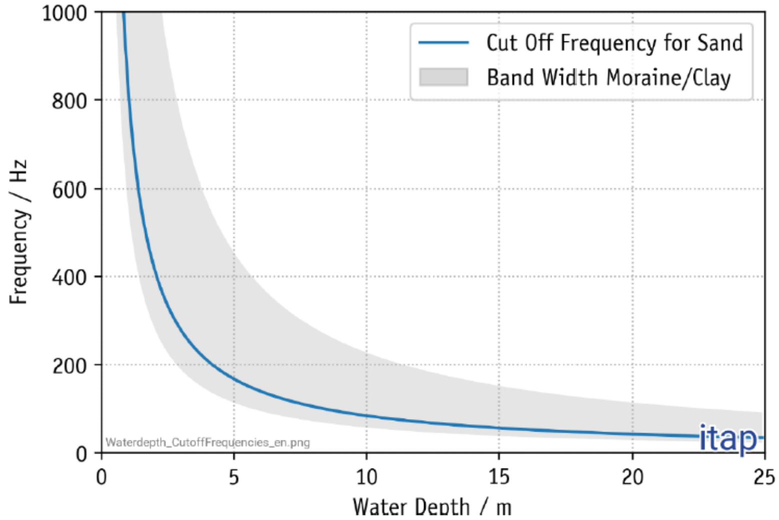

Figure 6.2: Cut off frequency and its dependency on sediment type and water depth (Bellmann, et al., 2020).

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Hammer energy

An increase in hammer energy applied to a pile, will transfer more energy into the pile and therefore also results in a higher noise emission. In Figure 6.3, which shows the SEL versus penetration depth and blow energy, it can be observed how increasing the blow energy, also increases the measured SEL.

This relationship is approximated by 2-3 dB increase in measured SEL every time the blow energy is doubled (Bellmann, et al., 2020).

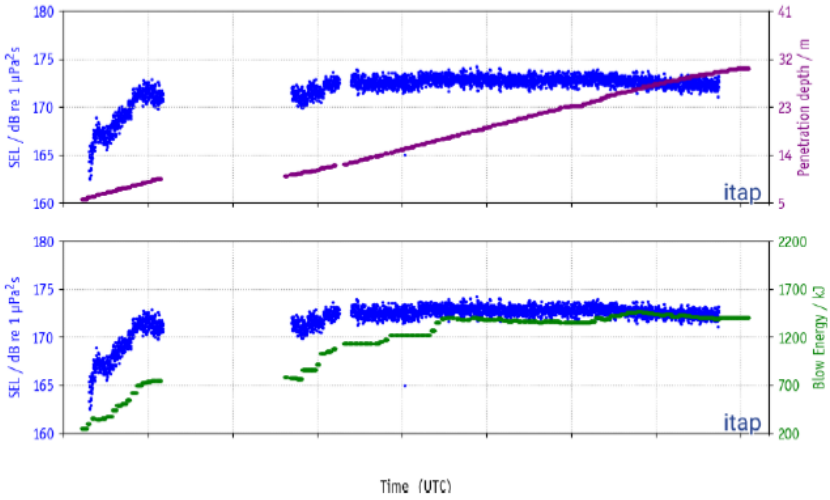

Figure 6.3: Relationship between SEL versus penetration depths and blow energy (Bellmann, et al., 2020).

Impact hammer type

Modern impact pile drivers typically consist of a large mass, or weight, suspended inside a hydraulic chamber, where the pressurized hydraulic fluid is used to push up the weight to the desired height, after which it is dropped. The impact is then transferred through an inner construction of shock absorbers and an anvil connected to the pile top. This motion transfers a large part of the applied energy to drive the pile downwards (Adegbulugbe, et al., 2019).

Using a large impact hammer with a heavy falling mass at 50-60% of its full capacity will, for acoustic reasons, lead to lower noise output compared to that from a smaller impact hammer using 100% capacity to achieve the same blow energy. While the two hammers will deliver the same energy to the pile, the maximum amplitude will be lower for the large impact hammer due to extended contact duration between hammer and pile-head. Different impact hammers can give up to several decibels difference (Bellmann, et al., 2020).

Pile length and degree of water immersion

A pile installation can be conducted through either above sea level piling, where the pile head is located above water level, or through below sea level piling, where the pile head is located below the water line. The former is typically the case for monopiles, while the latter is often the case for jacket piles (Bellmann, et al., 2020). A combination of the two is also possible, where the pile head is above water at the beginning of the pile installation and is fully submerged in the late stages of the piling.

Above water level piling automatically means that part of the pile is in contact with the entire water depth, and thus has a large radiating area. For below water level piling, this is not the case, as parts of the water column might no longer be occupied by the pile, but rather the hammer. For this reason, a higher noise emission is to be expected if the pile head is above water level (Bellmann, et al., 2020).

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6.1.2. Pile driving frequency spectrum

Due to the natural variations of measured frequency content, Figure 6.4 (grey lines), between sites, piles, water depths, hammer energy levels and other factors, it is almost guaranteed that the frequency response measured for one pile will differ from that of any other pile, even within the same project.

Since it is practically impossible to predict the exact frequency spectrum for any specific pile installation, an averaged spectrum (red line), for use in predictive modelling, is proposed by (Bellmann, et al., 2020).

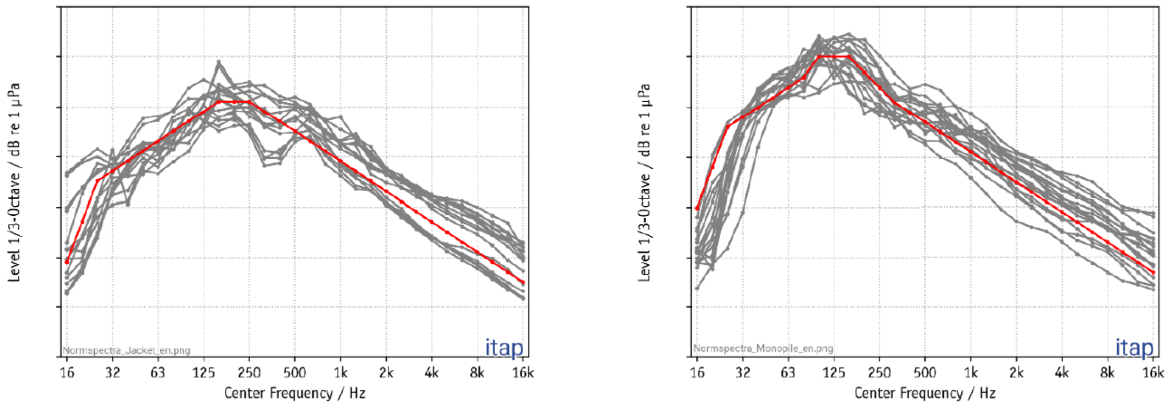

Figure 6.4: Measured pile driving frequency spectrum (grey lines) at 750m, with the averaged spectrum shown as the red line (Bellmann, et al., 2020). The spectrum ranges from 110-180 dB.

The spectrum shown to the left in Figure 6.4 is the pile driving frequency spectrum (grey lines) measured at 750 m for pin piles with diameters up to 3.5 m. The red line indicates the averaged spectrum and is proposed to be used as a theoretical model spectrum for sound propagation modelling of pin piles.

The right side of Figure 6.4 is showing the pile driving frequency spectrum (grey lines) measured at 750 m for mono-piles with diameters of minimum 6 m. The red line indicates the averaged spectrum and is proposed to be used as a theoretical model spectrum for sound propagation modelling of monopiles for the measured spectrums.

6.2. Pile driving mitigation measures

As foundation structures become larger and more knowledge come to light about marine mammal hearing, the more unlikely it is that the projects can comply with local regulation without mitigation measures.

This section provides a brief description of different Noise Abatement Systems (NAS), used as a general descriptor for measures taken that reduce the underwater noise emitted. Such systems can be either on-pile systems, actively reducing the source noise output or near-pile which reduces the noise emission after it has entered the water column.

6.2.1. Noise abatement system types

6.2.1.1. Big bubble curtains

The most frequently applied technique uses big bubble curtains (BBC). Air is pumped into a hose system positioned around the pile installation at the bottom of the sea, at a distance of 50 – 200 m. The hoses are perforated and air bubbles leak and rise towards the surface as air is pressured to the hose via compressors on a surface vessel. This forms an air curtain through the entire water column from seabed to sea surface. Due to the change in sound speed in the water-air-water bubble interface, a significant part of the outgoing noise is reflected backwards and kept near the pile, while the remaining noise energy going through the bubble curtain is greatly attenuated (Tsouvalas, 2020). Part of the noise emission from pile driving occurs through the sediment, which is then reintroduced to the water column further from the pile. It is important, that bubble curtains are not placed too close to the pile, as this would

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reduce their effectiveness on noise transmitted through the soil. By placing the bubble curtain further from the pile, it can mitigate some of this noise as it enters the water column. Bubble curtains usually surround the construction site completely leaving no gaps where noise is emitted unattenuated.

Currents can cause a drift in bubbles, but this difficulty can be overcome if the bubble curtain is installed in an oval rather than a circle. This system was used for example in Borkum West II, where a noise reduction of on average 11 dB (unweighted broadband) was achieved with the best configuration. This project tested different configurations. The success depended on three parameters: size of holes in the hosepipe (determines bubble sizes), spacing of holes (determines density of bubble curtain) and the amount of air used (air pressure). The best configuration was found to be with relatively small holes, a small spacing and using a substantial air pressure (Diederichs, et al., 2014).

The effect of bubble curtains can be increased further if a second bubble curtain is installed even further from the installation, referred to as a Double Big Bubble Curtain (DBBC). The effect is greatest if the distance between the systems is at least three times the water depth (Koschinski S et al., 2013).

6.2.1.2. Pile sleeves

A pile sleeve is an on-pile mitigation system forming a physical wall around the pile. One such system is the Noise Mitigation Screen from IHC (IHC-NMS) where a double walled steel sleeve with an air-filled cavity is positioned over the pile, thus using the impedance difference in the water-steel-air-steel-water interfaces to reduce the sound transmission. This system has been used for example at the German wind park Riffgat. Noise mitigation was assessed to be around 16-18 dB (Verfuß, 2014). Often, a pile sleeve NAS is applied in combination with a bubble curtain solution to increase the overall mitigation effect. The pile sleeve NAS however has an important limitation to consider for future installations, as the weight of the system is significant. With increasing pile sizes, the pile sleeve also increases in size, and thereby weight. It is uncertain whether this system is applicable for large future monopiles.

Cofferdams are a special type of pile sleeve. They also surround the pile, however in comparison to the IHC-NMS, the water in between the pile and the sleeve is extracted, so that the interface from pile to water becomes air-steel-water. These sleeves are deemed to reduce noise by around 20 dB, as demonstrated in Aarhus Bay (Verfuß, 2014). However, tests further offshore and in connection with the construction of wind parks have yet to be conducted (Verfuß, 2014). An inherent challenge with this solution is that it can be difficult to keep the water out of the cofferdam, as local sediment conditions can prevent a perfect water-tight seal with the seabed.

6.2.1.3. Hydro-sound-dampers

Hydro Sound Damper (HSD) systems are in many ways similar to the bubble curtain, however instead of using hoses with air, the curtain consists of fixed position air-filled balloons or foam-balls. The size, spacing and density of the foam balls or air-filled balloons then dictate the achievable noise mitigation. With the HSD system, it is possible to "tune" the NAS to work optimally at specific frequencies, thus allowing for project specific optimal solutions. For the same reason however, the system is typically less effective at other frequencies.

6.2.2. Noise abatement system effectiveness

For commercially available and proven NAS, a summary of achieved mitigation levels throughout completed installations is given in (Bellmann, et al., 2020), as shown in Figure 6.5. The listed broadband mitigation, ΔSEL represents a flat frequency spectrum, in order to compare the efficiency of the different mitigation systems on different pile installations. That is, the source level reduction achievable for a source with equal acoustic energy in all octave bands, also called pink noise. Pile driving spectra however, as described in section 6.1.2, are far from a flat octave band spectrum, and the effective noise mitigation achieved in terms of sound level measured with and without the system in use at a specific installation will therefore differ from the listed mitigation. In Figure 6.6, the broadband flat spectrum attenuation achieved with the different NAS, are instead given in 1/3 octave bands, thus showing the achieved mitigation per frequency band.

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Lastly, it is important to recognize, that development of new and improved noise mitigation systems is an ongoing process, and with every offshore wind farm installed, new knowledge and often better solutions become available.

No.	Noise Abatement System resp. combination of Noise Abatement Systems (applied air volume for the (D)BBC; water depth)	Insertion loss ΔSEL [dB] (minimum / average / maximum)	Number of foundations
1	IHC-NMS (different designs) (water depth up to 40 m)	13 ≤ 15 ≤ 17 dB IHC-NMS8000 15 ≤ 16 ≤ 17 dB	> 450 > 65
2	HSD (water depth up to 40 m)	10 ≤ 11 ≤ 12 dB	> 340
3	optimized double BBC[*1] (> 0,5 m^3/(min m), water depth ~ 40 m)	15 – 16	1
4	combination IHC-NMS + optimized BBC (> 0,3 m^3/(min m), water depth < 25 m)	17 ≤ 19 ≤ 23	> 100
5	combination IHC-NMS + optimized BBC (> 0,4 m^3/(min m), water depth ~ 40 m)	17 – 18	> 10
6	combination IHC-NMS + optimized DBBC (> 0,5 m^3/(min m), water depth ~ 40 m)	19 ≤ 21 ≤ 22	> 65
7	combination HSD + optimized BBC (> 0,4 m^3/(min m), water depth ~ 30 m)	15 ≤ 16 ≤ 20	> 30
8	combination HSD + optimized DBBC (> 0,5 m^3/(min m), water depth ~ 40 m)	18 – 19	> 30
9	GABC skirt-piles[*2] (water depth bis ~ 40 m)	~ 2 – 3	< 20
10	GABC main-piles[*3] (water depth bis ~ 30 m)	< 7	< 10
11	„noise-optimized" pile-driving procedure (additional additive, primary noise mitigation measure; chapter 5.2.2)	~ 2 - 3 dB per halving of the blow energy	

Figure 6.5: Achieved source mitigation effects at completed projects using different NAS, (Bellmann, et al., 2020).

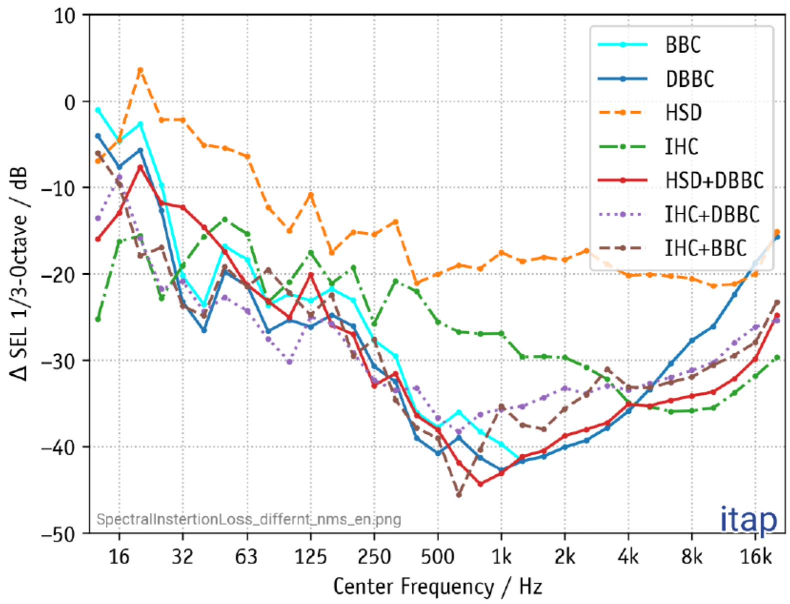

Figure 6.6: Frequency dependent noise reduction for NAS, (Bellmann, et al., 2020).

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In Figure 6.6 the mitigation effect is provided as the noise level relative to installation without any active NAS, so the more negative the value, the better the mitigation effect. In numeric form, the mitigation effect in the different frequency bands is provided in Table 6.1.

Table 6.1: Mitigation effect of different Noise Abatement Systems (NAS) (Bellmann, et al., 2020). Values are indicated by frequency band specific mitigation effects. The more negative the value, the better the mitigation effect.

Frequency	Mitigation effect of NAS [dB]		
	BBC	DBBC	HSD-DBBC
12.5	-1	-4	-10
16	-5	-8	-13
20	-3	-6	-8
25	-10	-13	-12
31.5	-20	-23	-13
40	-23	-26	-14
50	-16	-20	-17
63	-18	-21	-22
80	-23	-27	-23
100	-22	-26	-25
125	-23	-27	-20
160	-22	-25	-26
200	-23	-26	-27
250	-28	-31	-33
315	-29	-32	-32
400	-37	-39	-36
500	-38	-41	-38
630	-36	-39	-42
800	-38	-41	-44
1k	-40	-43	-43
1.2k	-42	-42	-41
1.6k	-41	-41	-41
2k	-40	-40	-39
2.5k	-39	-39	-38
3.2k	-38	-38	-37
4k	-36	-36	-35
5k	-33	-33	-35
6.3k	-30	-30	-34
8k	-28	-28	-34
10k	-27	-27	-33
12.5k	-23	-23	-32
16k	-19	-19	-30
20k	-16	-16	-25
25k	-13	-13	-20

It should be noted from Table 6.1, that the HSD-DBBC mitigation effect is less than that of the DBBC system at individual frequencies in the low and mid frequency region. This would imply, that the mitigation effect is worse for a NAS consisting of an HSD and a DBBC system, compared to a DBBC system alone.

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While the measurements would indeed indicate such an effect, it must be noted, that the representation method in (Bellmann, et al., 2020) does not represent the effect of a single fixed system used in different projects, but rather the average of a number of different systems, across different pile installations, across different project areas and current conditions. It is not clear from the report, when and where each NAS effect was measured, and it is therefore not possible to determine what would contribute to the achieved effects.

As the measurement results originate from German OWFs, it is however worth noting the measurement procedure for installations including NAS, where one pile is measured without any NAS active, one pile is measured with each individual NAS (such as BBC or IHC) and the rest of the piles are measured with all NAS active (such as IHC-NMS+DBBC). It is also worth emphasizing that the mitigation effect presented is the average of achieved mitigation, and given the continuous development of NAS technology, it is considered likely that performance would typically improve over time. Utilizing the reported average mitigation effect is therefore considered conservative. It should furthermore be expected, that entirely new and more effective NAS technologies and installation methods emerge in the coming years, however until such methods exist, it is not possible to include in a prognosis.

In summary, prediction of achievable mitigation effect for any system, based on past implementations, must be considered cautiously, and it should be expected that variations will occur between projects. The previously achieved mitigation effects can however be used more broadly to identify which type(s) of NAS is likely to be necessary for the current project, based on typical frequency specific mitigation effects.

If the purpose is to limit broadband noise output, an NAS with a high broadband mitigation effect could be a good choice. However if the purpose is to reduce the impact on a specific group of marine mammal or fish, the frequency specific mitigation effect should be considered when choosing NAS. As an example, the DBBC NAS is very effective at reducing the broadband noise level, however for species such as porpoise (VHF) and dolphin (HF), which both have high frequency hearing above 10 kHz, a combination of HSD with DBBC would provide significantly better protection. It is therefore recommended to always conduct detailed site and pile specific underwater sound emission modelling with incorporation of NAS available to the contractor, based on the project specific mitigation purpose.

6.3. Underwater sound propagation theory

This chapter provides a brief overview of underwater sound propagation theory and the software program used in the modelling, followed by a description of the inputs used for the propagation model. This includes environmental and source input parameters.

6.3.1. Underwater sound propagation basics

This section is based on (Jensen, et al., 2011) chapter 1 and chapter 3 as well as (Porter, 2011), and seeks to provide a brief introduction to sound propagation in saltwater. The interested reader is referred to (Jensen, et al., 2011) chapter 1, for a more detailed and thorough explanation of underwater sound propagation theory.

Sound levels generally decrease with increasing distance from the source, which is known as the propagation loss (PL), $\mathrm{N_{PL}}$. The PL is affected by a number of parameters making it a complex process.

The speed of sound in the sea, and thus the sound propagation, is a function of both pressure, salinity and temperature, all of which are dependent on depth and the climate above the ocean and as such are very location dependent. The theory behind the sound propagation is not the topic of this report, however it is worth mentioning one aspect of the sound speed profile importance, as stated by Snell's law, Equation 7.

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$$\frac{\cos(\theta)}{c} = \text{constant}$$

Equation 7

Where:

- θ is the ray angle [°]
- c is the speed of sound $\left[\frac{m}{s}\right]$.

This relationship implies that sound waves bend toward regions of low sound speed (Jensen, et al., 2011). The implications for sound in water are, that sound that enters a low velocity layer in the water column can get trapped there. This results in the sound being able to travel far with very low PL.

When a low velocity layer occurs near the sea surface, with sound speeds increasing with depth, it is referred to, as an upward refraction. This causes the sound waves to be reflected by sea surface more than by the seabed. As the sea surface is often modelled as a calm water scenario (no waves), it causes reduced PL, and thus a minimal loss of sound energy. This scenario will always be the worst-case situation in terms of sound PL. For some sound propagation models, this can introduce an overestimation of the sound propagation, if the surface roughness is not included.

When a high velocity layer occurs near the sea surface with the sound speed decreasing with depth, it is referred to, as a downward refraction. This causes the sound waves to be angled steeper towards the seabed rather than the sea surface, and it will thus be the nature of the seabed that determines the PL. Depending on the composition of the seabed some of the sound energy will be absorbed by the seabed and some will be reflected. A seabed composed of a relatively thick layer of soft mud will absorb more of the sound energy compared to a seabed composed of hard rock, which will cause a relatively high reflection of the sound energy.

In any general scenario, the upward refraction scenario will cause the lowest sound PL and thereby the highest sound levels over distance. In waters with strong currents, the relationship between temperature and salinity is relatively constant as the water is well-mixed throughout the year.

As an example, in the Baltic Sea, an estuary-like region with melted freshwater on top, and salty sea water at the bottom, the waters are generally not well-mixed and great differences in the relation between temperature and salinity over depth can be observed. Furthermore, this relationship depends heavily on the time of year, where the winter months are usually characterized by upward refracting or iso-velocity sound speed profiles. In the opposite end of the scale, the summer months usually have downward refracting sound speed profiles. In between the two seasons, the sound speed profile gradually changes between upward and downward refracting.

Another example is the Gulf and Bay of Bothnia, where ice cover is present during winter and spring. After the thaw, in April/May a gradual shift in sound speed profile from near-iso speed and/or upward refracting in the winter, to downward refracting takes place. This is observed based on temperature and salinity readings throughout the year. The readings come from the NOAAs World Ocean Atlas database (WOA18), freely available from the "National Oceanic and Atmospheric Administration" (NOAA) at https://www.nodc.noaa.gov/OC5/woa18/, (NOAA, 2019).

The physical properties of the sea surface and the seabed further affect the sound propagation by reflecting, absorbing and scattering the sound waves. Roughness, density and sound speed are among the surface/seabed properties that define how the sound propagation is affected by the boundaries.

The sea surface state is affected mainly by the climate above the water. The bigger the waves, the rougher the sea surface, and in turn, the bigger the PL from sound waves hitting the sea surface. In calm seas, the sea surface acts as a

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very reflective interface with very low sound absorption, causing the sound to travel relatively far. In rough seas states, the sound energy will to a higher degree be reflected backwards toward the source location, and thus result in an increased PL. As previously mentioned, this is not always possible to include in sound propagation models, and the PL can therefore be under-estimated, leading to higher noise propagation than what would actually occur.

Another parameter that has influence on especially the high frequency PL over distance is the volume attenuation, defined as an absorption coefficient dependent on chemical conditions of the water column. This parameter has been approximated by Equation 8 (Jensen, et al., 2011):

$$\alpha' \cong 3.3 \times 10^{-3} + \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + 3.0 \times 10^{-4}f^2 \quad \left[\frac{\mathrm{dB}}{\mathrm{km}}\right] \qquad \text{Equation 8}$$

Where $\mathbf{f}$ is the frequency of the wave in kHz. This infers that increasing frequency leads to increased absorption.

6.3.2. Numerical sound propagation models

There are different algorithms for modelling the sound propagation in the sea, all building on different concepts of seabed interaction and sound propagation. Commonly used sound propagation models for long distance modelling tasks are Ray tracing, Normal Modes (NM), and Parabolic Equation (PE).

Ray tracing has a good accuracy when working with frequencies above 200 Hz, however in very shallow waters, the minimum frequency would be higher, as the rays need space to properly propagate. Different techniques can be applied for ray tracing to improve and counteract certain of its inherent shortcomings (Jensen, et al., 2011). Ray tracing, furthermore, is the only algorithm that inherently supports directional sources, that is, sources that do not radiate sound equally in all directions.

The normal mode algorithm makes it possible to calculate the sound field at any position between the source and receiver. Since the modes grow linearly with frequency, the algorithm is usually used for low frequencies, because at high frequencies it is hard to find all the modes which contributed to the sound field (Wang, et al., 2014).

Last is the parabolic equation method, which is usually used for low frequencies, due to increasing computational requirements with frequency squared. This method is generally not used for frequencies higher than 1 kHz. The method is however more accepting of discontinuous sound speed profiles (Wang, et al., 2014).

In Table 6.2, an overview of the application range of the different sound propagation models is shown.

Table 6.2: An overview which indicates where the different sound propagation models are most optimal (Wang, et al., 2014).

Shallow water - low frequency	Shallow water - high frequency	Deep water – low frequency	Deep water - high frequency
Ray theory	Ray theory	Ray theory	Ray theory
Normal mode	Normal mode	Normal mode	Normal mode
Parabolic equation	Parabolic equation	Parabolic equation	Parabolic equation
Green – suitable; Amber – suitable with limitations; Red – not suitable or applicable			

In most real world sound propagation scenarios, a combination of two algorithms is typically preferred to cover the entire frequency range of interest, such as normal modes for the low frequencies and ray tracing for the high frequencies. In this regard, the split between the two is typically defined as $f = \frac{8 \cdot c}{d}$ [Hz], where $\mathbf{c}$ is the speed of sound in

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[m/s] and d is the average bathymetry depth in [m]. This however assumes, that the change in bathymetry is not several orders of magnitude. If the bathymetry ranges from very shallow to very deep, it is likely that an optimal split frequency does not exist. In such cases, it might be necessary to choose between calculation range and calculation accuracy.

In sound propagation modelling using mitigation systems, the sound levels of interest usually occur up to a few tens of km from the source, and in most cases, the relevant bathymetry will either be shallow or deep, but rarely both. For sound propagation modelling using unmitigated source levels, where it is desired to prognosticate the propagation loss over tens to hundreds of km, it is however very likely that the bathymetry variation becomes problematic.

6.3.3. Underwater sound propagation modelling software

NIRAS uses the underwater noise modelling software: dBSea version 2.3.4, developed by Marshall Day Acoustics. The software uses 3D bathymetry, sediment and sound speed models as input data to build a 3D acoustic model of the environment and allows for the use of either individual sound propagation algorithms or combinations of multiple algorithms, based on the scenario and need. dBSea sound propagation results are afterwards post-processed in NIRAS' software package NiFlee, where distances to relevant thresholds are calculated and noise contour maps are created.

6.4. Environmental model

The sound propagation depends primarily on the site bathymetry, sediment and sound speed conditions. In the following, these input parameters are described in greater detail.

6.4.1. Bathymetry

dBSea incorporates range-dependent bathymetry modelling and supports raster and vector bathymetry import. Figure 6.7 shows a map of the bathymetry for Europe, where darker colours indicate deeper areas, and lighter colours indicate more shallow water. The resolution of the map is 115 x 115 meters. EMODnet has created the map using Satellite Derived Bathymetry (SDB) data products, bathymetric survey data sets, and composite digital terrain models from several sources. Where no data is available EMODnet has interpolated the bathymetry by integrating the GEBCO Digital Bathymetry (EMODnet, 2021).

6.4.2. Sediment

In dBSea, the sound interaction with the seabed is managed through specifying the thickness and acoustic properties of each seabed layer, where the uppermost layer is the most important. The thickness and acoustic properties of the layers, from seabed to bedrock, is generally obtained through literature research in combination with available site-specific survey findings.

For determining the top layer type, the seabed substrate map (Folk 7) from https://www.emodnet-geology.eu/ is generally used. This map is shown in Figure 6.8.

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Figure 6.7: Bathymetry map over European waters from EMODnet, where light blue indicates shallow waters and dark blue indicates deeper waters (EMODnet, 2021).

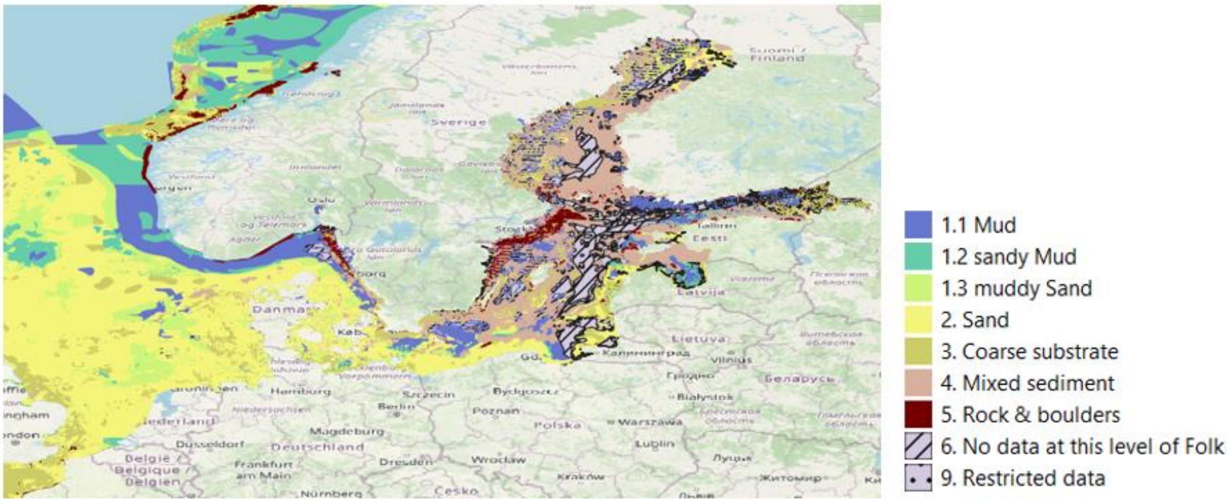

Figure 6.8: A section of the seabed substrate map, (Folk 7) (EMODnet, 2021).

6.4.3. Sound speed profile, salinity and temperature

The sound propagation also depends on the season and location dependent sound speed profile. To create an accurate sound speed profile, the temperature and salinity must be known throughout the water column for the time of year where the activities take place. As weather conditions prior to, and during installation can have an effect on the salinity and temperature profiles, early prognosis based on historical values will be connected with a degree of uncertainty.

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NIRAS uses NOAAs WOA18, freely available from the "National Oceanic and Atmospheric Administration" (NOAA) at https://www.nodc.noaa.gov/OC5/woa18/, (NOAA, 2019) which contains temperature and salinity information at multiple depths throughout the water column.

For each of the sediment model positions, the nearest available sound speed profile, as well as average temperature and salinity are extracted for the desired months.

7. Underwater noise prognosis for pile driving activities

This chapter describes the project specific details relevant to the source model and sound propagation model, as described in chapter 5. Section 7.1 describes the project specific parameters used for the source model, and section 7.2.1 describes the environmental part of the sound propagation model. Settings used for the numerical sound propagation modelling software is provided in section 7.2.

7.1. Source model

7.1.1. Foundation types

It is not yet decided which foundation types will be used for the actual installation. It may be a single foundation type, or a mix of different foundation types. For the wind turbines, foundation types could include steel monopiles up to 18 m diameter, jacket foundations with pin piles up to 8 m diameter, gravitation or suction bucket or even floating structures with anchor piles.

Gravitation and suction bucket foundations are the foundation types with the lowest underwater noise emissions, and are considered negligible from an underwater noise impact perspective. These options are therefore not considered further in this report.

Floating foundations, consisting of a floating steel frame anchored to the seabed through a number of anchor lines. Each anchor line would then be securely fastened in the seabed to one or more anchor piles. Since floating foundation types are still largely untested, little data is available on pile sizes and the number of piles to be used per anchor line, however it is expected that pile size and number of piles is inversely proportional. So the more anchor piles used per anchor line, the smaller each pile would be. It is not expected that anchor piles in any case would exceed a diameter of 8 m, and they are therefore considered to have less underwater noise emission than both jacket and monopile foundations. Floating foundations will therefore not be treated further in this report.

In summary, it is assessed that the worst-case scenarios for the construction phase will be either monopiles of 18 m diameter, or jacket foundations with 4 x 8 m pin piles. Due to differences in the frequency spectrum and number of piles for the different foundation types, both are included in sound propagation modelling. Source models for the two scenarios are described further in section 7.1.3.

The sound propagation modelling, conducted in this report assumes a single pile installation within any 24-hour period for the monopile foundation type, and 4 pin piles per 24 hours for jacket foundations.

The technical source model parameters are provided in Table 7.1 for the monopile foundation scenario, and in Table 7.2 for the jacket foundation scenario.

The pile installation procedure for both foundation types include a soft start, at 10% of maximum hammer energy, a ramp up phase, where the energy is gradually increased from 10% - 100%, and a conservative estimate for the full power phase of the installation with 100% hammer energy.

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Table 7.1: Technical specifications and pile driving procedure for scenario 1: 18 m monopile foundation.

Technical specification for scenario 1			
Foundation type			Monopile
Impact hammer energy			6000 kJ
Pile Diameter			18 m
Total number of strikes pr. pile			10 400
Number of piles per foundation			1
Pile driving procedure			
Name	Number of strikes	% of maximum hammer energy	Time interval between strikes [s]
Soft start	200	10	2
Ramp-up	400 1000 500 500 800 2400	10 20 40 60 80 60	1.2 1.2 1.2 1.2 1.2 1.2
Full power	4600	100	3.2

Table 7.2: Technical specifications and pile driving procedure for scenario 2: Jacket foundation with 4x8m pin piles.

Technical specification for scenario 2			
Foundation type			Jacket
Impact hammer energy			6000 kJ
Pile Diameter			8 m
Total number of strikes pr. pile			10 400
Number of piles per foundation			4
Pile driving procedure			
Name	Number of strikes	% of maximum hammer energy	Time interval between strikes [s]
Soft start	150	10	2
Ramp-up	700 1000 500 500 1000	10 20 40 60 80	1.2 1.2 1.2 1.2 1.2
Full power	6 550	100	2.6

7.1.2. Source positions

Sound propagation modelling for pile driving activities is conducted at the three positions shown in Figure 7.1. The source positions were chosen due to their location relative to maximum expected sound propagation. In Figure 7.2, the project area is shown in relation to the nearby Natura 2000 areas.

- Position 1 is located at the northern edge of the OWF area, at 45.5 km distance from the natura 2000 area “Holmöarna”. The water depth at the source position is 54 m, and topsoil sediments are mainly clay. This position is considered representative worst case for the maximum expected sound propagation due to the water depth.

- Position 2 is located in the middle of the OWF area, at ~30 km distance from the natura 2000 areas “Luodon saaristo”, “Uudenkaarlepyyn saaristo” and “Merenkurkun saaristo”. The water depth at the source position is 36 m,

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and topsoil sediments are mainly clay. This position is considered representative worst case in regard to the Natura 2000 areas.

- Position 3 is located at the southwest corner of the OWF area, at ~25 km distance from the natura 2000 areas "Holmöarna" and "Merenkurkun saaristo". The water depth at the source position is 55 m, and sediment conditions are a mix of silt, sand, bedrock and clay. This position is considered representative worst case in regard to the Natura 2000 areas and water depth.

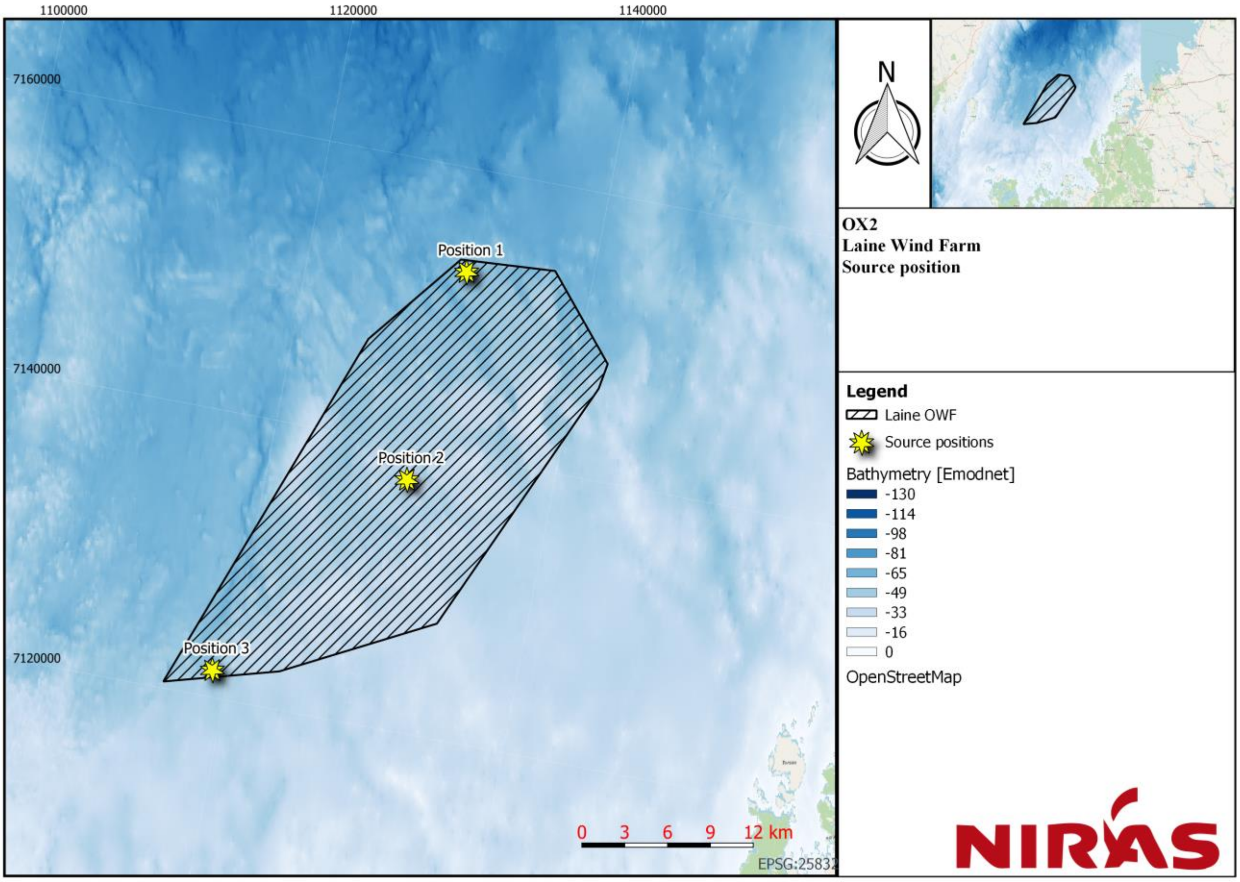

Figure 7.1: Source positions chosen for sound propagation modelling.

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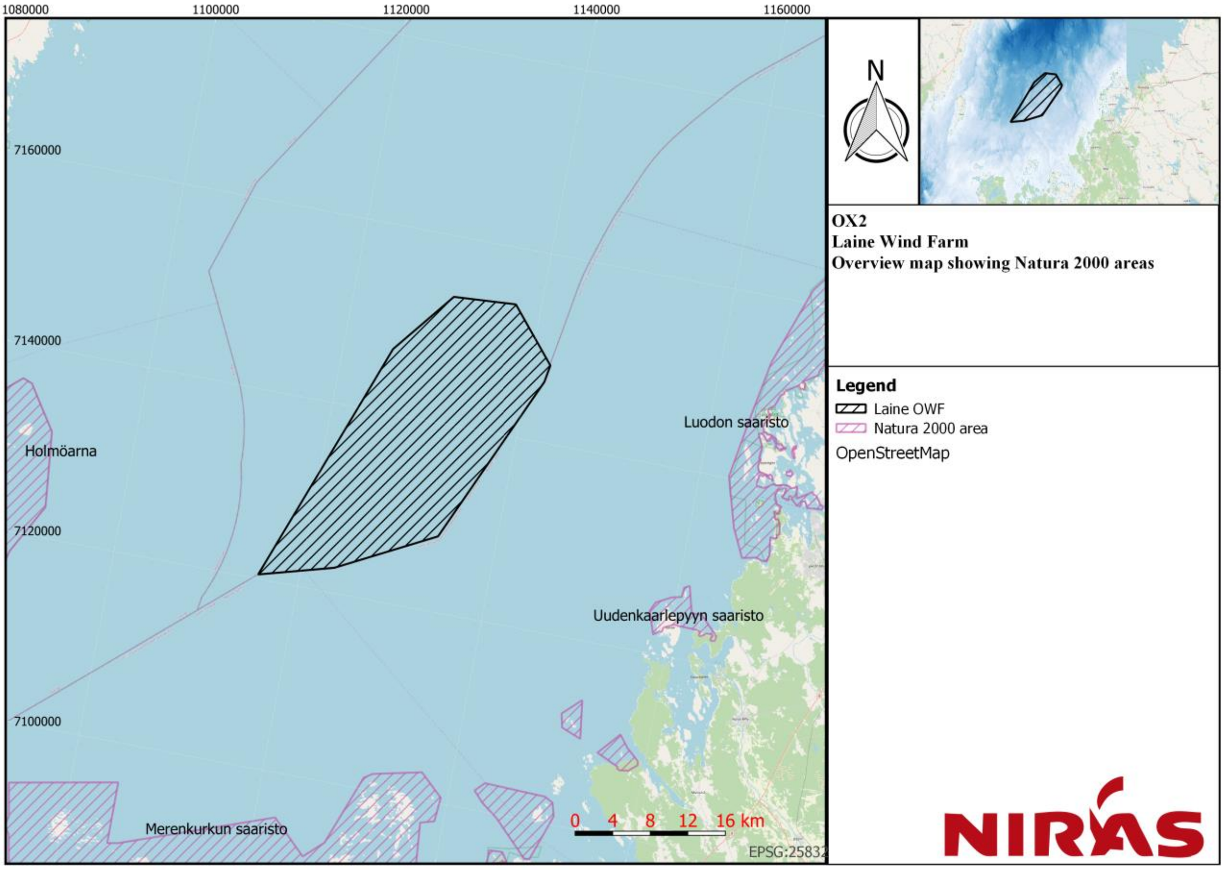

Figure 7.2: Overview of nearby Natura 2000 areas.

7.1.3. Source level and frequency spectrum

Following the methodology presented in the section 6.1, source levels and frequency spectrum for the two foundation scenarios are defined in the following subsections.

7.1.3.1. Foundation scenario 1: 18 m diameter monopile

For the monopile foundation scenario, the unmitigated and unweighted SEL at 750 m was derived to be: $\mathbf{SEL_{@750m}} = \mathbf{186.7\ dB\ re.1\ \mu Pa^2 s}$. Backcalculating this level to 1 m, results in $L_{S,E} = \mathbf{229.9\ dB\ re.1\ \mu Pa^2\ m^2\ s}$. The source level is presented in all relevant metrics, with and without frequency weighting, see Table 7.3.

Table 7.3: Broadband source level for monopile foundation scenario, with and without frequency weighting.

Frequency weighting	Source level $(\mathbf{L_{S,E}})[\mathbf{dB\ re.1\mu Pa^2m^2s}]$
Unweighted	229.9 dB
Phocid Carnivores in water (PCW)	206.4 dB

As previously mentioned, due to the unlikeliness of an unmitigated installation scenario being allowed, the source model includes the application of a noise mitigation effect. For the monopile foundation scenario, the DBBC mitigation effect presented in Table 6.1 was used. Unmitigated as well as mitigated source level in 1/3 octave bands are presented in Figure 7.3. For the mitigated scenario, source levels with applied frequency weightings are also shown.

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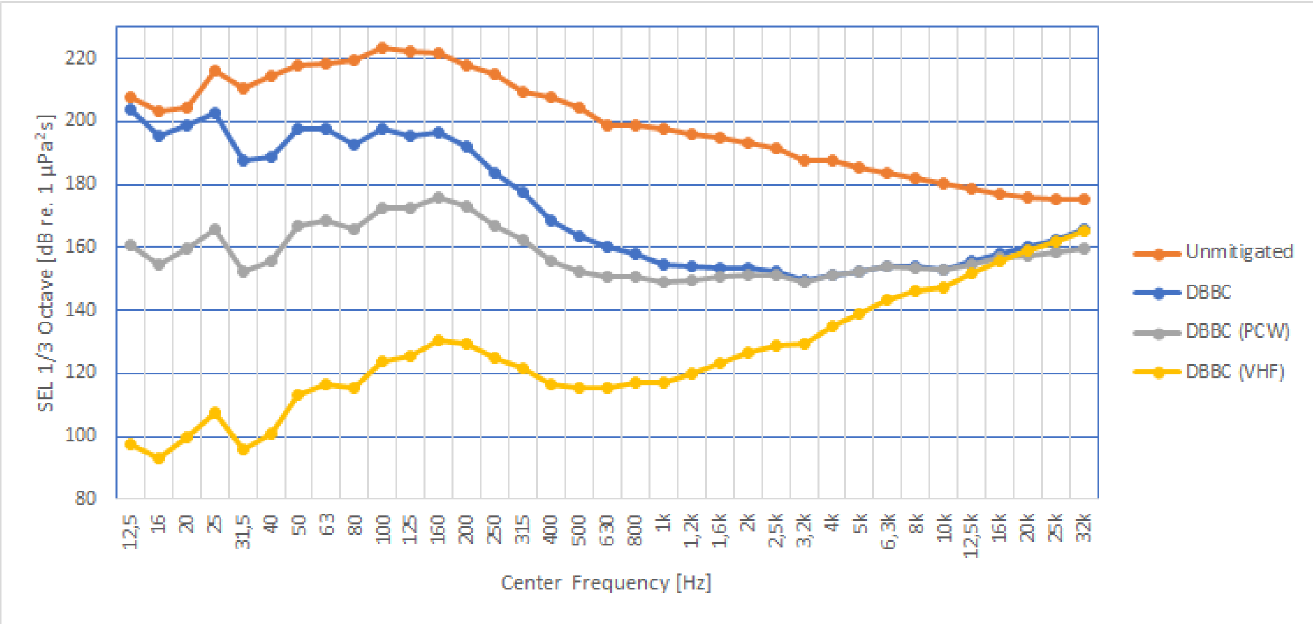

Figure 7.3: Source level in 1/3 octave bands for 18 m monopile; unmitigated as well as mitigated using DBBC equivalent mitigation effect.

7.1.3.2. Foundation scenario 2: Jacket foundation with 4x8m pin piles

For the jacket foundation scenario, the unmitigated and unweighted SEL at 750 m was derived to be: $\mathrm{SEL}_{@750\mathrm{m}} = 180.5 \ \mathrm{dB\ re.\ 1\ \mu Pa^2 s}$. Backcalculating this level to 1 m, results in $L_{S,E} = 222.4 \ \mathrm{dB\ re.\ 1\ \mu Pa^2\ m^2\ s}$. The source level is presented in all relevant metrics, with and without frequency weighting, see Figure 7.4.

Table 7.4: Broadband source level for jacket foundation scenario, with and without frequency weighting.

Frequency weighting	Source level $(\mathbf{L_{S,E}})[\mathbf{dB\ re.\ 1\mu Pa^2 m^2 s}]$
Unweighted	222.4 dB
Phocid Carnivores in water (PCW)	204.8 dB

As previously mentioned, due to the unlikeliness of an unmitigated installation scenario being allowed, the source model includes the application of a noise mitigation effect. For the monopile foundation scenario, the DBBC mitigation effect presented in Table 6.1 was used. Unmitigated as well as mitigated source level in 1/3 octave bands are presented in Figure 7.4. For the mitigated scenario, source levels with applied frequency weightings are also shown.

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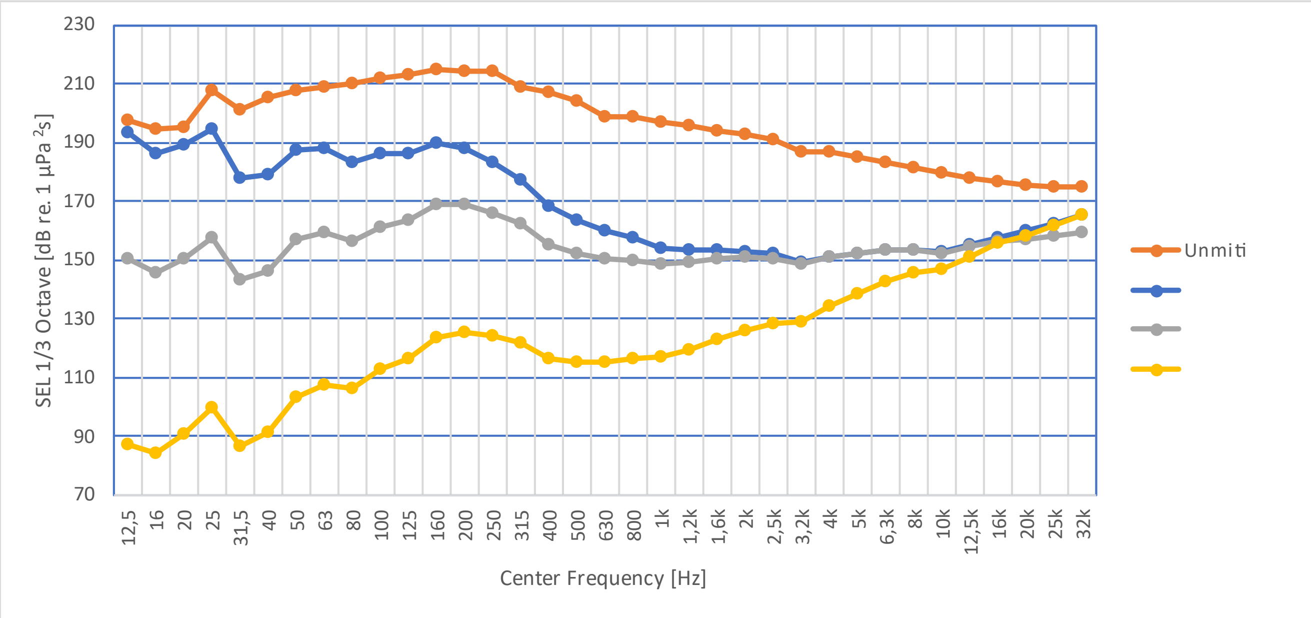

Figure 7.4: Source level in 1/3 octave bands for 8 m pin pile; unmitigated as well as mitigated using DBBC equivalent mitigation effect.

7.1.4. Installation of two foundations within a 24-hour period

If two foundations were to be installed within a 24-hour period, sound propagation and foundation type considered equal, it is assumed that the noise emission from each is similar. Differentiation between simultaneous/partially overlapping and sequential installation is important, and the consequence of each scenario is discussed in the following.

7.1.4.1. Installation of two foundations simultaneously

If the two foundations were to be installed at the same time, this would likely result in increased PTS and TTS impact distances (up to a factor 2 increase), as these thresholds are based on the time-dependent noise emission relative to the swim speed of the marine mammal.

The further apart the two foundations, the lower the difference in PTS/TTS relative to the single foundation scenario. However, with larger spacing, a trapping effect can occur, where a marine mammal would swim away from one foundation, only to get closer to the installation of the second foundation, thus not achieving a linear decrease in received SEL with time. In this scenario, it is difficult to predict what kind of cumulative sound exposure level, the marine mammal would receive over the span of the installations.

Inversely, the closer the foundations, the lower the risk of trapping, but also the closer to 2x single foundation threshold distances would be expected. One method for reducing the increase in impact distances for concurrent installations, would be to add a time-delay to the installation of the second foundation, such that the marine mammals are able to create distance between themselves and the pile installation(s), before both piling activities are active.

Another aspect of concurrent installations is that it can potentially result in increased behaviour distances if the pile strikes are synchronized. The likelihood of synchronization would however be low as the behaviour criteria is based on the noise dose within a 125 ms time window.

There is however also a secondary effect, where the noise emission from one pile installation would cause positive and destructive interference with the noise emission from the second pile installation, resulting in local variations of ±3 dB,

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and thereby potentially increasing the impact distance for behaviour significantly. Installation of two foundation simultaneously is therefore not recommended.

7.1.4.2. Installation of two foundations sequentially

If installation of two foundations is conducted sequentially, where the second pile installation is started as soon as the former is completed, the effects on underwater noise exposure become significantly less uncertain. In a closely spaced scenario, the marine mammals that would be affected by the second pile installation, would already have had significant time to vacate the underwater noise impacted area, thereby limiting the increase in impact on marine mammals. For behaviour, the impact distance would not be affected by interference patterns (which will be the case if installation of two pile installations occurs at the same time), nor would it equate the sum of impact areas for both installations, rather it would shift from one location to the next. For PTS and TTS, the impact distances would likely not increase, as the marine mammals are already far from both installation sites and therefore receiving minimal additional impact from the installation of the second installation. It is however important that the second installation is not delayed significantly in time after the completion of the first, as this would allow for marine mammals to return to the area.

Thus, it is assessed that the installation of two foundations (positioned close to each other) sequentially will not increase the impact ranges for behavioural avoidance responses nor the TTS and PTS impact ranges. A theoretical scenario where sequential installation is used with 2 piles installed per day, will prolong (double) the daily time period where pile driving is taking place, however reduce (half) the number of days with piling noise emission. Under the assumption, that installation will occur every day, the effective installation period for pile driving activities would be reduced (halved).

7.2. Underwater sound propagation model

For this project, the dBSea settings listed in Table 7.5 were used.

Table 7.5: dBSea Settings

Technical Specification		
Octave bands		1/3
Grid resolution (Range step, depth)		20 m x 0.2 m
Number of transects		36 (10°)
Sound Propagation Model Settings		
Model	Start frequency band	End frequency band
dBSeaModes (Normal Modes)	32 Hz	200 kHz
dBSeaRay (Ray tracing)	250 kHz	32 kHz

7.2.1. Environmental model

The following sections provide the input values for each of the important environmental model parameters.

7.2.1.1. Bathymetry

Figure 7.5 shows the bathymetry for the wind farm site and surroundings (extracted from the bathymetry map in section 6.4.1). In this area, the bathymetry ranges from a depth of 130 m, indicated by the darker colours, to a depth of 0 m, indicated by the lighter colours. For each source position, described in section 7.1.1, a bathymetry of around 30 km to each side is extracted and used in the calculations.

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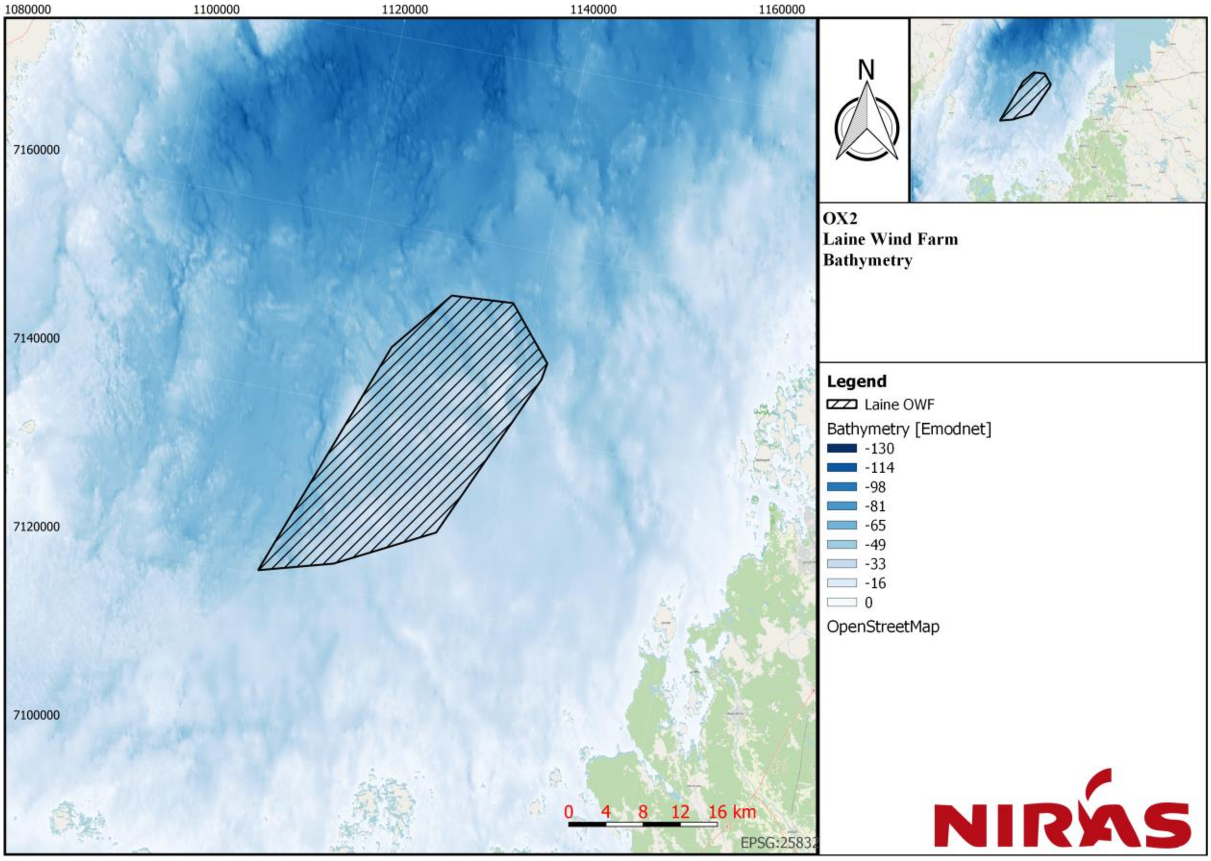

Figure 7.5: Bathymetry map for the project area and surroundings.

7.2.1.2. Sediment

The sediment model is based on the methodology described in section 6.4.2, utilizing publicly available data for seabed surface sediment types and thicknesses. For this project, no geological profiles from survey transects or other literature were found near the project site. Therefore no information on local layer depths were obtained. To calculate the worst case sound propagation it was decided to have a thin overlay of 1 m of the top sediment before reaching bedrock. The top layer (seabed) was obtained through Figure 7.6 which was provided by OX2.

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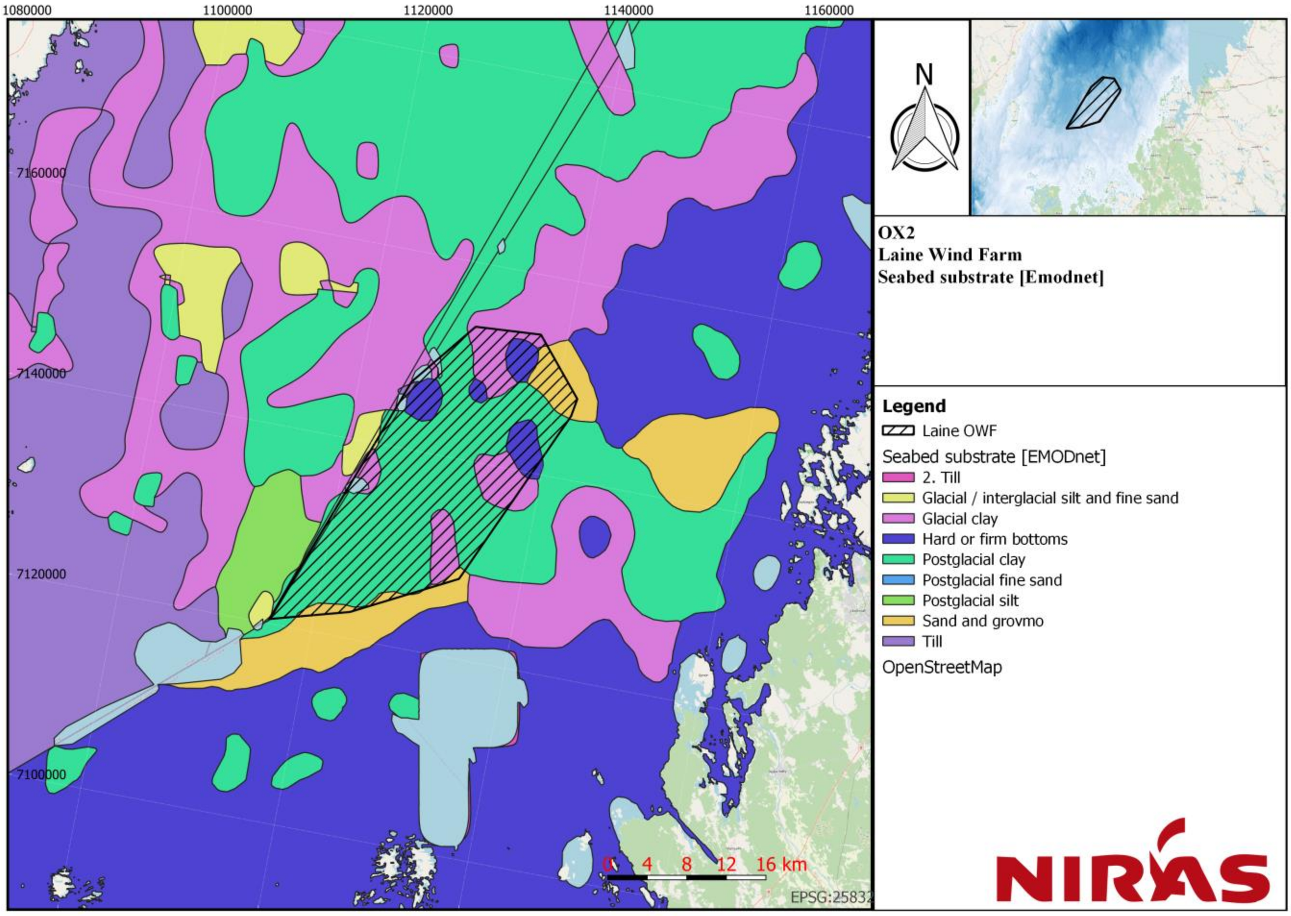

Figure 7.6: Seabed substrate from EMODnet, which was provided by OX2.

From the available source, a multipoint sediment model was made for the relevant project area and surroundings. In Figure 7.7, the sediment type prevalent in the top layer of the seabed is shown to consist of mainly clay, sand and rock. The thickness of the top layer varies within the site from zero meters to tens of meters, extending to bedrock.

For each point in the model, the sediment layer types were translated into geoacoustic parameters, in accordance with Table 7.6, utilizing information from (Jensen, et al., 2011), (Hamilton, 1980).

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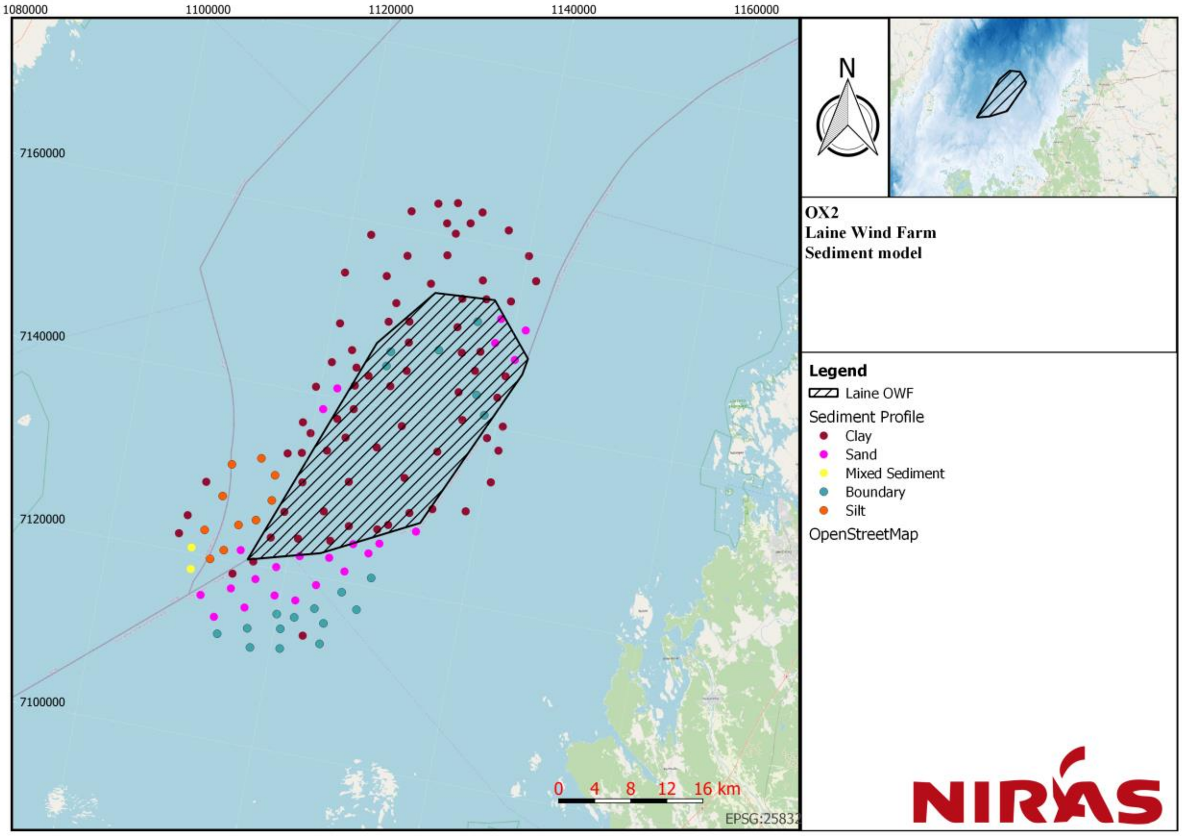

Figure 7.7: Sediment model for the project area and surroundings.

Table 7.6: Geoacoustic properties of sediment layers used in the environmental model. Sources: (Jensen, et al., 2011), (Hamilton, 1980). Note, mixed sediment is based on a mix of sand, silt and gravel. Moraine boulders is similarly a mix of primarily moraine with boulders.

Sediment	Sound Speed [m/s]	Density [kg/m^3]	Attenuation factor [dB/λ]
Clay	1500	1500	0.2
Silt	1575	1700	1.0
Mud (clay-silt)	1550	1500	1.0
Sandy mud	1600	1550	1.0
Sand	1650	1900	0.8
Muddy sand	1600	1850	0.8
Coarse substrate	1800	2000	0.6
Gravel	1800	2000	0.6
Mixed sediment	1700	1900	0.7
Moraine	1950	2100	0.4
Moraine Boulders	2200	2200	0.3
Rock and boulders	5000	2700	0.1
Chalk	2400	2000	0.2

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7.2.1.3. *Sound speed profile*

Figure 7.8 shows the extracted sound speed profiles at the available positions. Note that the gridded layout of the sound speed profiles indicates their respective position geographically.

Examining Figure 7.8, this would indicate May as the worst-case month within the proposed installation time window between May – October. Due to ice cover risks in November – April, these months are not included in the prognosis. In cooperation with OX2 it was chosen to conduct the prognosis for the worst-case conditions, being May. In Figure 7.9 the sound speed profiles for the worst-case month of May are shown.

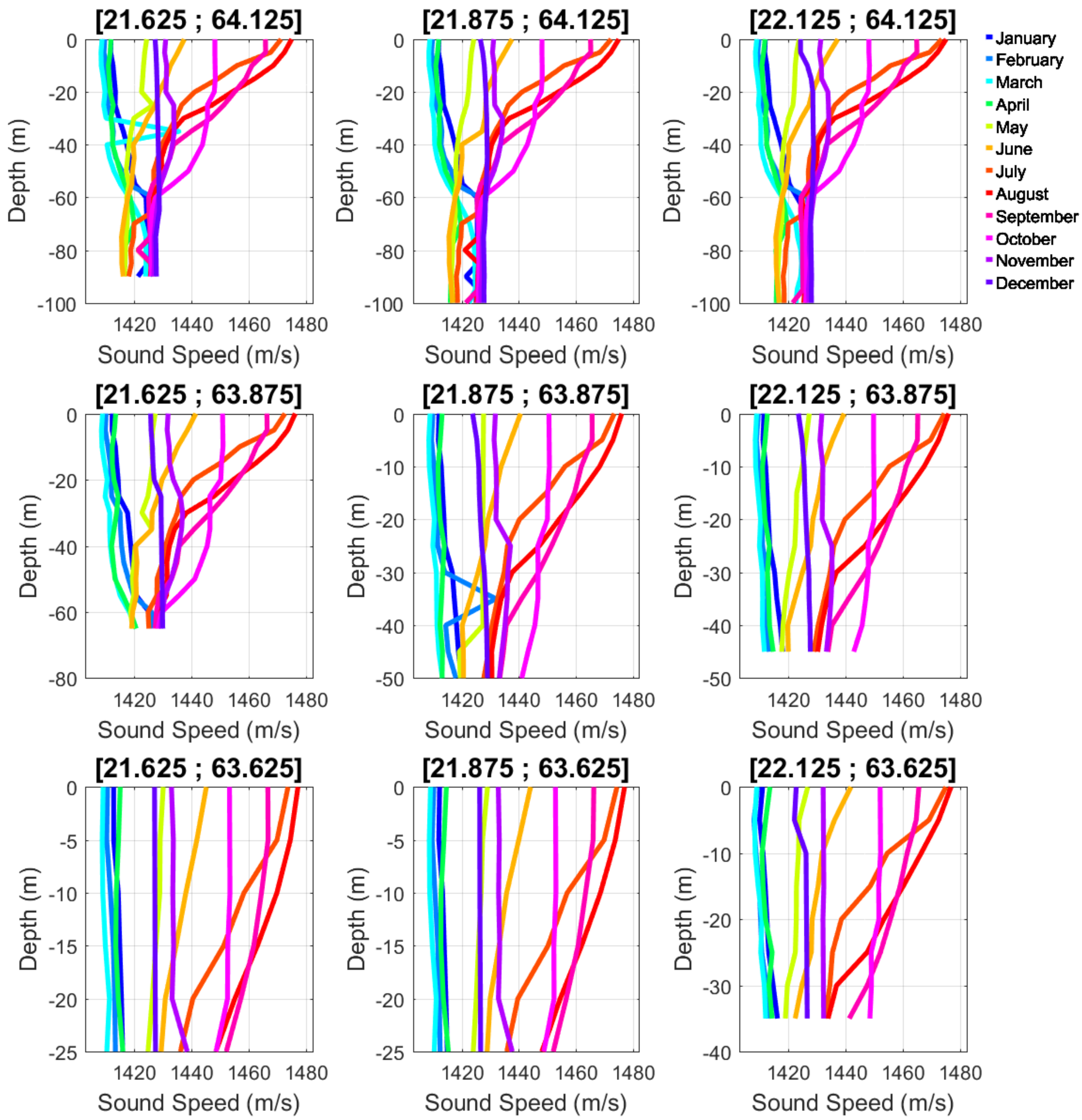

Figure 7.8: Sound speed profiles for the project area and surroundings.

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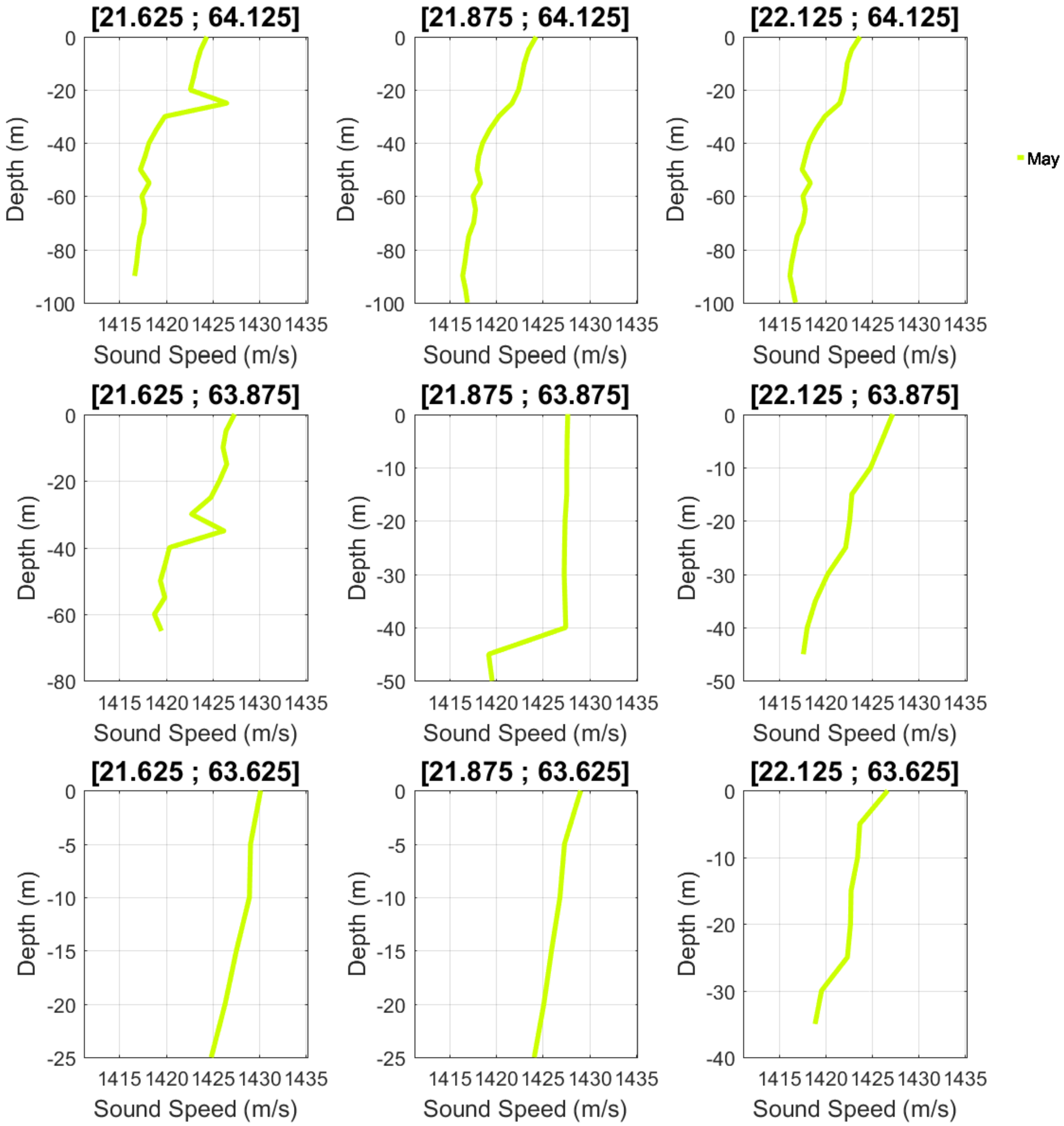

Figure 7.9: Sound speed profile for the worst-case month of May for the project area and surroundings.

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7.2.1.4. Salinity profile

Figure 7.10 shows the extracted salinity profiles at the available positions. Note that the layout of the sound speed profiles indicates their respective position geographically. Figure 7.11 shows the salinity profiles for May which was identified as the "worst case" month, according to the sound speed profiles, within the intended time frame for the activities.

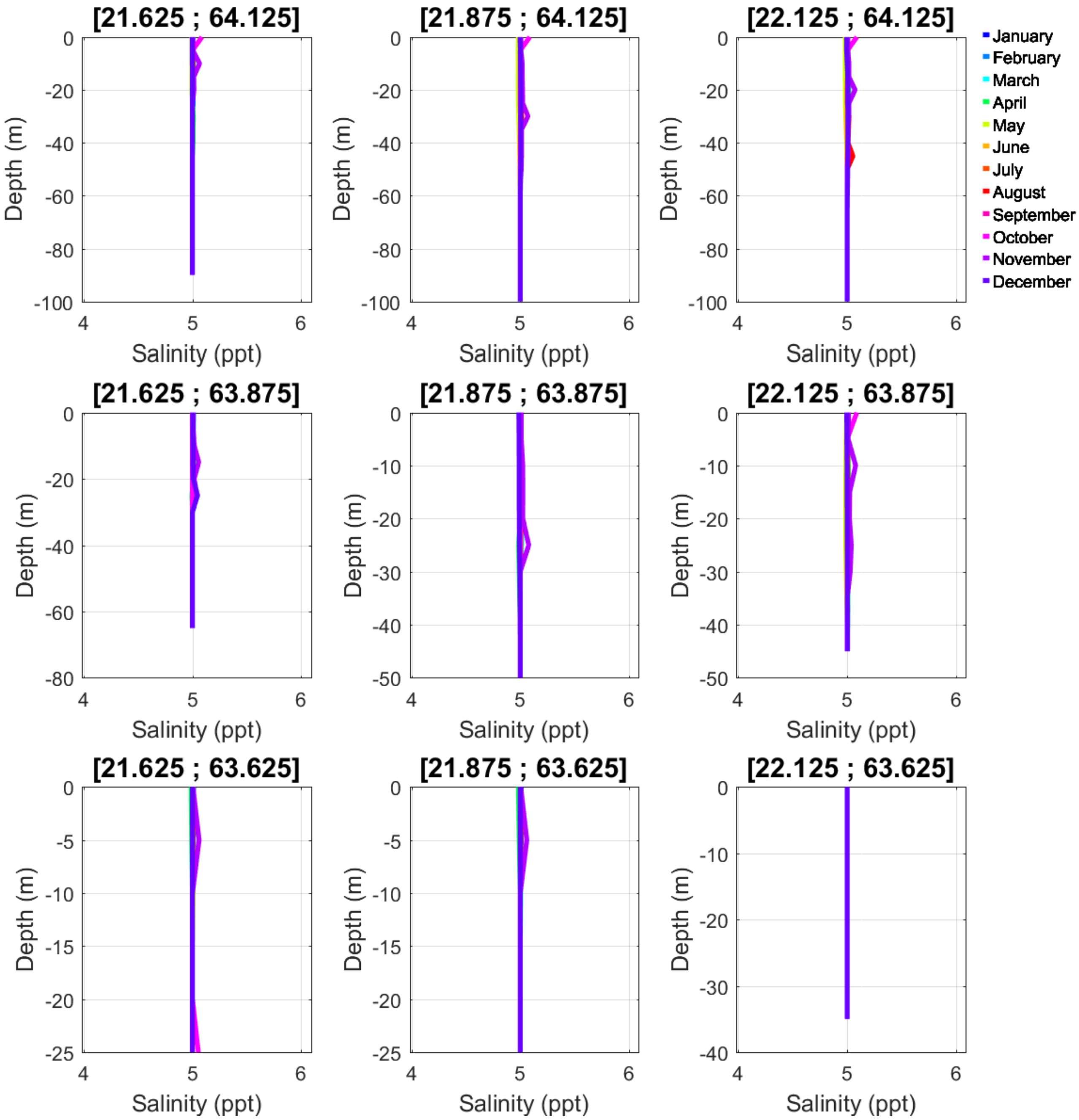

Figure 7.10: Salinity profiles for the project area and surroundings.

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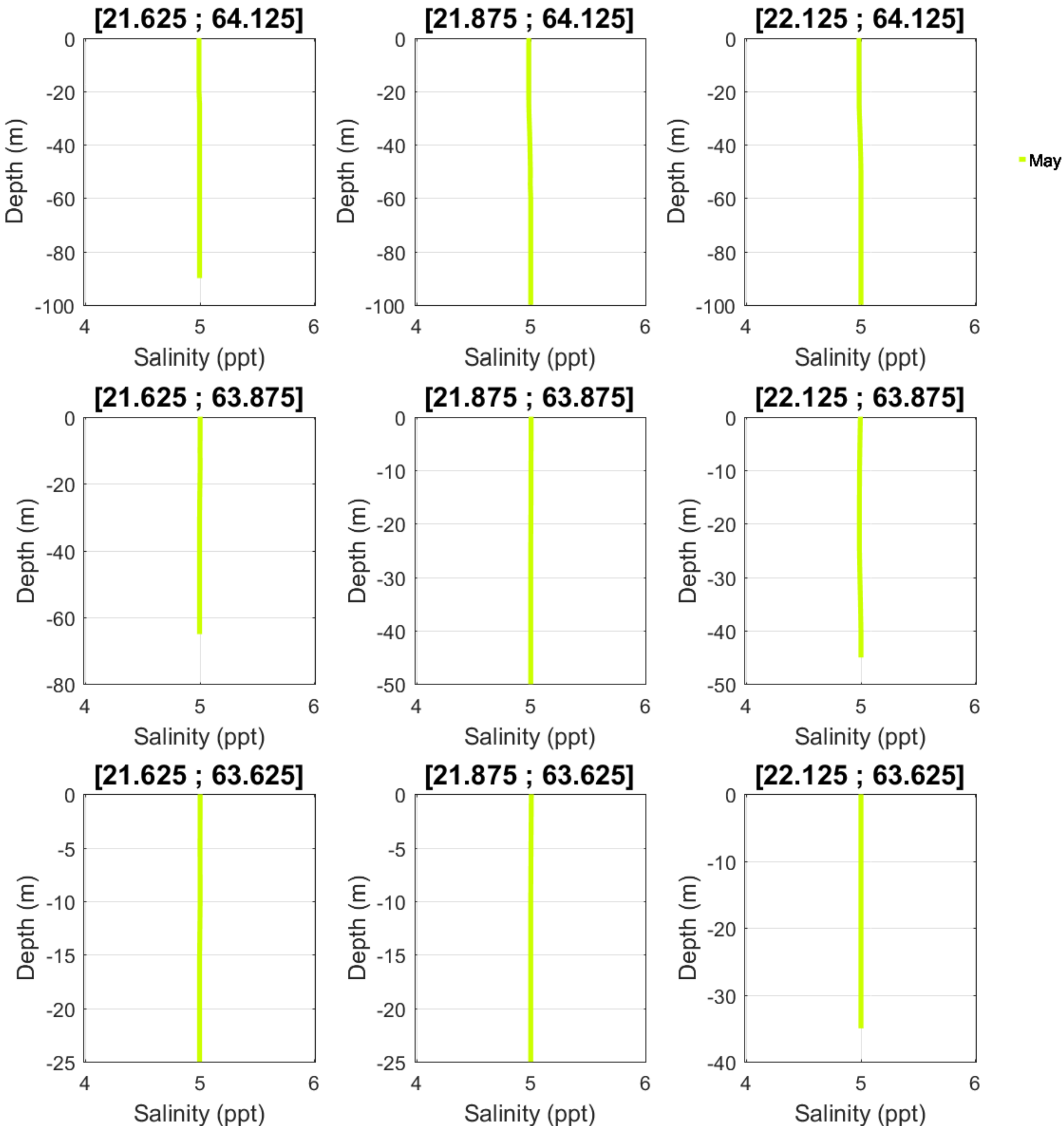

Figure 7.11: Salinity profiles for the worst-case month of May for the project area and surroundings.

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7.2.1.5. *Temperature profile*

Figure 7.12 shows the extracted temperature profiles at the available positions. Note that the layout of the sound speed profiles indicates their respective position geographically. Figure 7.13 shows the temperature profiles for May which was identified as the "worst case" month, according to the sound speed profiles, within the intended time frame for the activities.

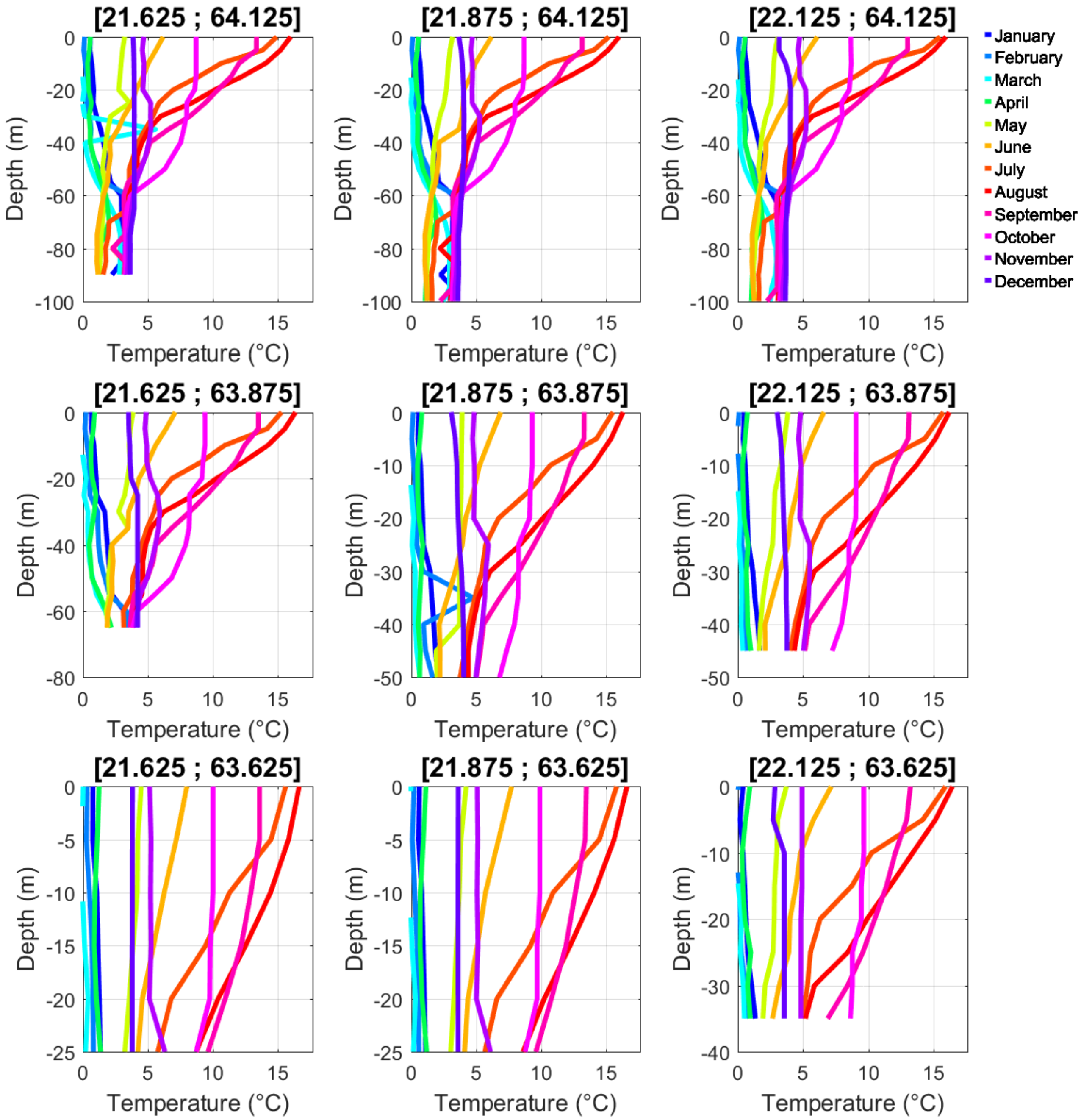

Figure 7.12: Temperature profiles for the project area and surroundings.

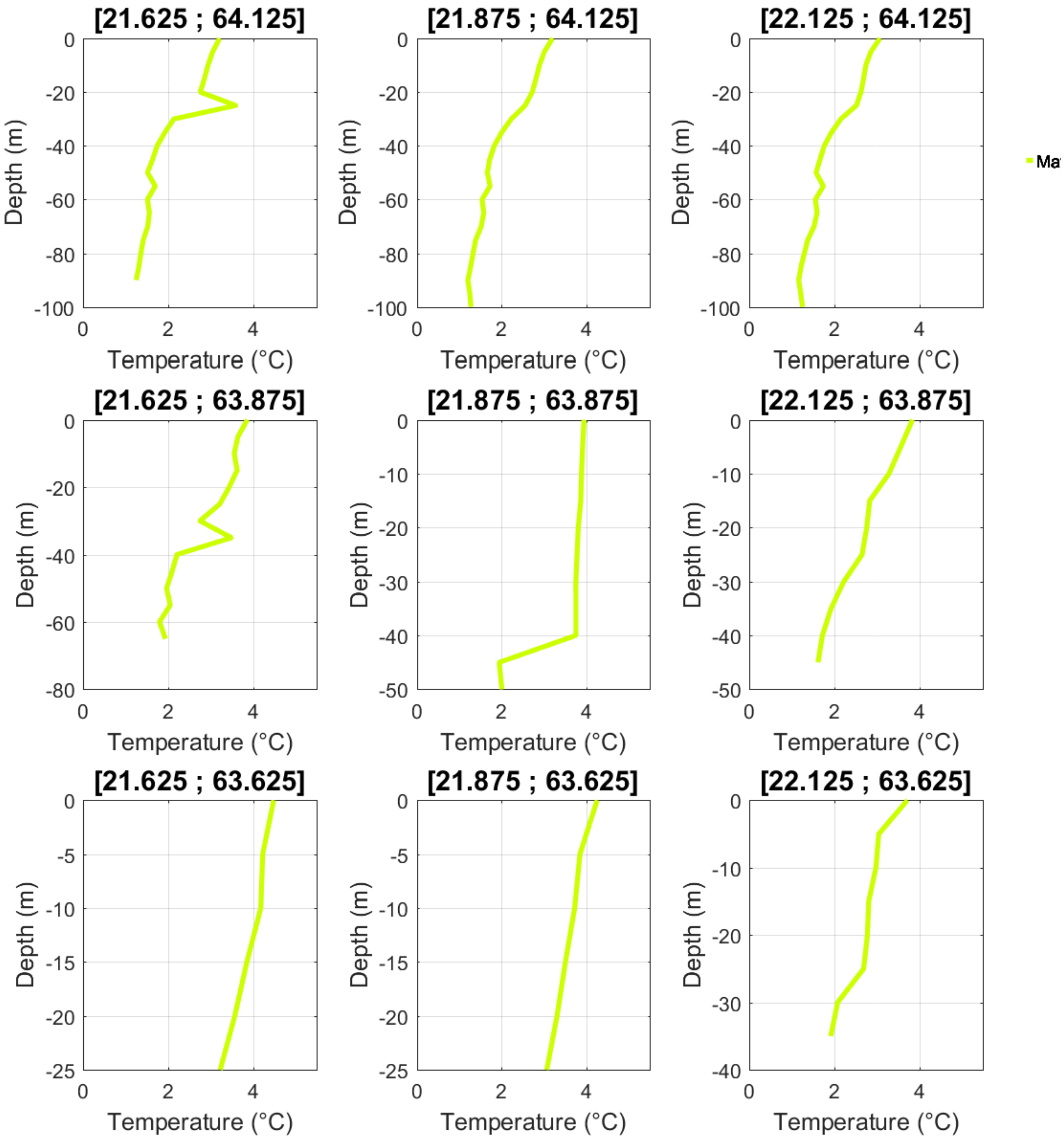

Figure 7.13: Temperature profiles for the worst-case month of May for the project area and surroundings.

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8. Pile driving underwater sound propagation results

For both the monopile and jacket foundation scenarios, impact ranges were calculated to the relevant marine mammal and fish threshold criteria.

DTT for PTS, TTS and Injury describe the minimum distance from the source, a marine mammal or fish must at least be deterred to, prior to onset of pile driving, in order to avoid the respective impact. It therefore does not represent a specific measurable sound level, but rather a safe starting distance.

The DTT for behaviour, on the other hand, describes the specific distance, up to which, the behavioural response is likely to occur, when maximum hammer energy is applied to a pile strike. It should be noted, that for pile strikes not at full hammer energy, the impact distance will be shorter.

Section 8.1 and section 8.2 shows the calculated DTT for fish and earless seals, respectively.

8.1. Mitigated threshold distances for fish

For calculating the DTT for TTS and Injury in regard to fish the cumulative 24 hour modelling was used. This is represented by the thresholds:

- $L_{E,cum,24h,unweighted} = 186\ \mathrm{dB\ re\ 1\ \mu Pa^2 s}$ for TTS,
- $L_{E,cum,24h,unweighted} = 204\ \mathrm{dB\ re\ 1\ \mu Pa^2 s}$ for injury,
- $L_{E,cum,24h,unweighted} = 207\ \mathrm{dB\ re\ 1\ \mu Pa^2 s}$. for injury in Larvae and eggs.

8.1.1. 18 m diameter monopile foundation

Table 8.1: Threshold impact distances for fish using DBBC mitigation effect on an 18 m monopile for the worst-case month of May.

Position	Distance-to-threshold (18 m monopile + DBBC mitigation effect)								
	Injury (r_{injury})					TTS (r_{TTS})			
	Stationary fish	Juvenile Cod	Adult Cod	Herring	Larvae and eggs	Stationary fish	Juvenile Cod	Adult Cod	Herring
1	975 m	< 100 m	< 100 m	< 100 m	525 m	15.2 km	11.5 km	7.8 km	6.9 km
2	1100 m	< 100 m	< 100 m	< 100 m	650 m	17.9 km	14.3 km	10.4 km	9.4 km
3	875 m	< 100 m	< 100 m	< 100 m	525 m	13.9 km	10.4 km	6.7 km	5.9 km

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8.1.2. Jacket foundation with 4x 8 m pin pile

Table 8.2: Threshold impact distances for fish using DBBC mitigation effect on a Jacket foundation with 4x 8 m pin piles for the worst-case month of May.

Position	Distance-to-threshold (Jacket with 4x 8 m pin piles + DBBC mitigation effect)								
	Injury (r_{injury})					TTS (r_{TTS})			
	Stationary fish	Juvenile Cod	Adult Cod	Herring	Larvae and eggs	Stationary fish	Juvenile Cod	Adult Cod	Herring
1	700 m	< 100 m	< 100 m	< 100 m	400 m	10.9 km	2.1 km	< 200 m	< 200 m
2	775 m	< 100 m	< 100 m	< 100 m	475 m	13.1 km	3.5 km	250 m	< 200 m
3	625 m	< 100 m	< 100 m	< 100 m	375 m	10 km	1.8 km	< 200 m	< 200 m

8.2. Mitigated threshold distances for marine mammals

For calculating the DTT for TTS and PTS in regard to earless seals the cumulative 24 hour modelling was used.

The following thresholds apply:

- $L_{E,cum,24h,PCW} = 170 \text{ dB re } 1 \text{ µPa}^2\text{s}$ for TTS,
- $L_{E,cum,24h,PCW} = 185 \text{ dB re } 1 \text{ µPa}^2\text{s}$ for PTS.
- $L_{p,rms,125ms,VHF} = 103 \text{ dB re } 1 \text{ µPa}$ for avoidance behaviour.

8.2.1. 18 m diameter monopile foundation

Table 8.3: Resulting threshold impact distances for earless seals using DBBC mitigation effect on an 18 m monopile for the worst-case month of May.

Position	Distance-to-threshold (18 m monopile + DBBC mitigation effect)		
	PTS (r_{PTS})	TTS (r_{TTS})	Avoidance (r_{behav})
1	< 100 m	< 200 m	7.35 km
2	< 100 m	< 200 m	6 km
3	< 100 m	< 200 m	5.95 km

8.2.2. Jacket foundation with 4x 8 m pin pile

Table 8.4: Resulting threshold impact distances for marine mammals using DBBC mitigation effect on a jacket foundation with 4x 8 m pin piles for the worst-case month of May.

Position	Distance-to-threshold (Jacket foundation with 4x 8 m pin piles + DBBC mitigation effect)		
	PTS (r_{PTS})	TTS (r_{TTS})	Avoidance (r_{behav})
1	< 100 m	< 200 m	7.45 km
2	< 100 m	< 200 m	6.05 km
3	< 100 m	< 200 m	6.05 km

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8.3. Mitigated area of effect for earless seal avoidance behaviour

In addition to the DTT values, the total area affected from a single pile strike at maximum hammer energy has been calculated for the earless seal behaviour threshold. See Table 8.5. It should be noted that this area effect only applies to pile strikes of maximum hammer energy. For the most part of a pile installation, hammer energy, and thereby affected area, is significantly lower.

Table 8.5: Area affected for impact threshold criteria for earless seal (behaviour) for a pile strike at maximum hammer energy for the worst case month of May.

Position	Affected area (Avoidance behaviour in earless seal) [km^2]	
	18 m monopile + DBBC	Jacket with 4x 8 m pin piles + DBBC
1	119	122
2	81	82
3	61	63

8.4. Underwater noise contour map for earless seal behaviour threshold

Underwater noise contour maps for position 1 for earless seal avoidance behaviour criteria are shown in Figure 8.1 - Figure 8.2 for each of the foundation scenarios. Affected area is also illustrated in the figures. Maps for position 2 and 3 are attached in Appendix .

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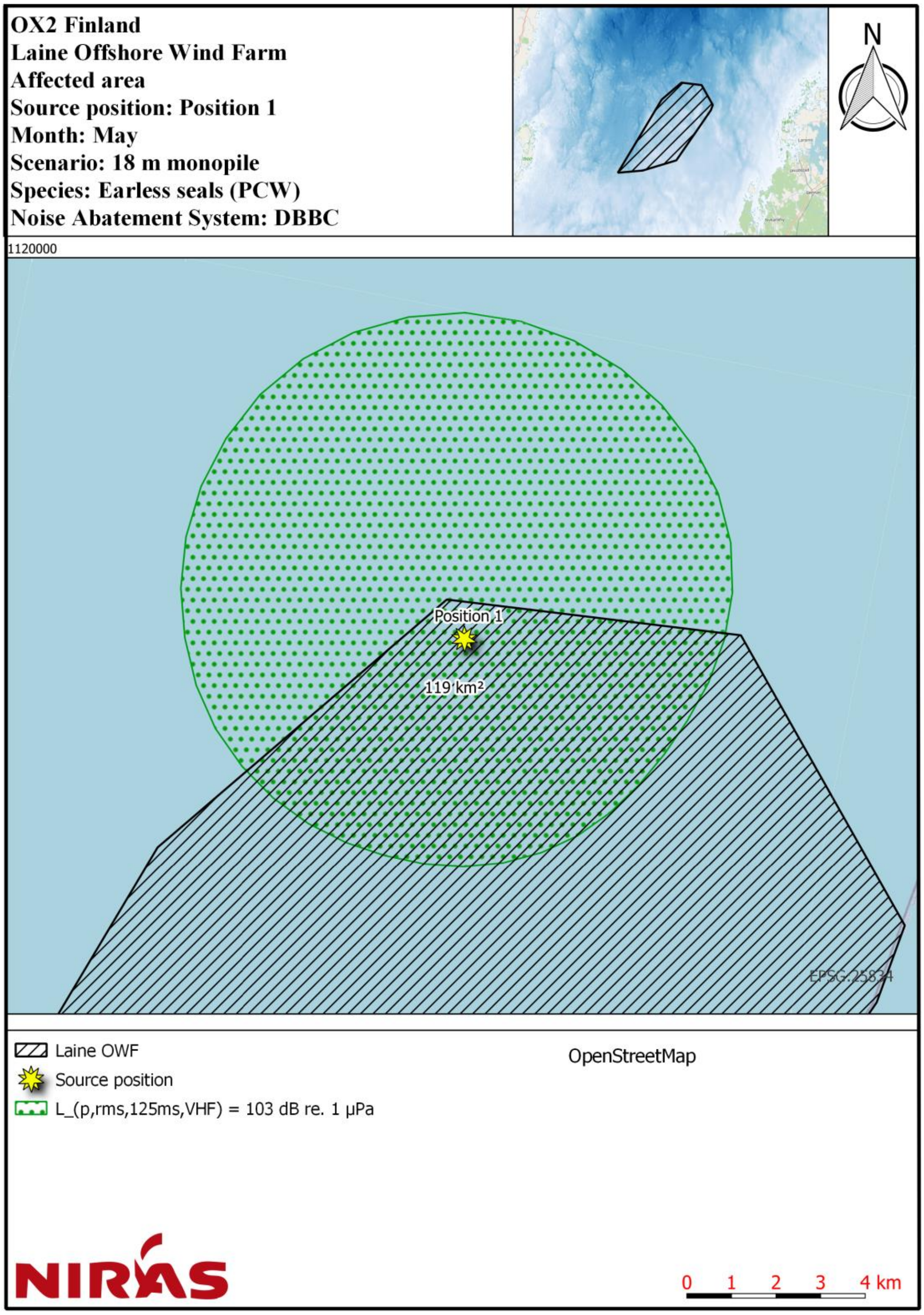

Figure 8.1: Noise contour map for position 1, showing the Distance-To-Threshold for avoidance behaviour in earless seal, for 18 m monopile with DBBC mitigation effect.

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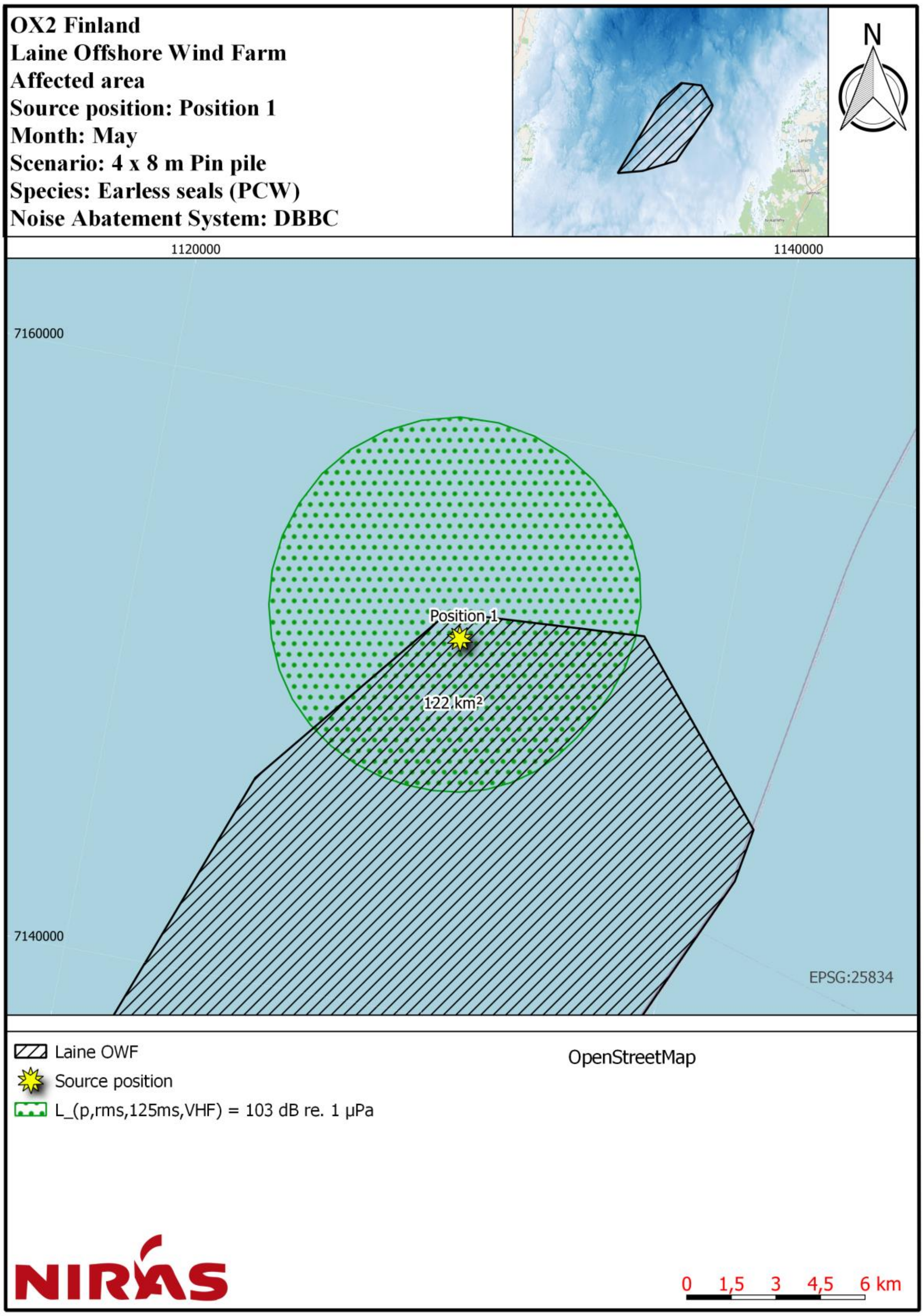

Figure 8.2: Noise contour map for position 1, showing the Distance-To-Threshold for avoidance behavior in earless seal, for jacket foundation with 4x 8 m pin piles with DBBC mitigation effect.

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9. Uncertainties for pile driving noise prognosis

In this section, a discussion of the prognosis uncertainties is provided, divided into the categories: Source characteristics, environmental parameters, and mitigation effect.

The prognosis assumes a worst case scenario of an 18 m diameter monopile, and for a jacket foundation with 4 x 8 m diameter pin piles, while the project may in reality be completed using piles of a smaller diameter. An uncertainty of absolute source level is therefore present in the model. As explained in detail in section 6.1.1.1, literature reviews of previous installations show significant variations in not only source level, but also in frequency spectrum. An unweighted uncertainty of up to ±5 dB is indicated in (Bellmann, et al., 2020), however with largest uncertainties for small pile diameters, and lower deviations from the average for larger pile sizes. Following this pattern, a ±5 dB uncertainty appears conservative for the monopile scenario, and suitable for the jacket foundation scenario. Due to the significant extrapolation with regards to the monopile diameter, it can however not be ruled out, that deviations from this might occur.

Uncertainties in the environmental parameters primarily relate to the topsoil sediment properties, and changes in the bathymetry from what is included in the model. Also the actual sound speed profile, temperature and salinity during installation will be a contributing factor. The prognosis has assumed worst-case conditions for environmental parameters, based on currently available historical information and it is therefore considered more likely than not, that the environmental conditions in the model result in a conservative prognosis. Furthermore, the sound propagation model assumes calm waters, meaning very little backscatter from the air-water interface, thus understating the losses when the sea state is higher.

Mitigation effects used in these calculations are based on a literature review by (Bellmann, et al., 2020), which is the largest publicly available collection of mitigation effectiveness of noise mitigation systems to date. It must however be noted, that mitigation effectiveness was not evaluated on a project-by-project basis, detailing the specific environmental and source conditions for each dataset, but rather with focus on the mitigation effect of different types of mitigation systems. The resulting mitigation effectiveness of such systems should therefore be considered with a degree of caution, and prone to deviations for any future application. For bubble curtain systems, differences in air pressure, hole/nozzle size, distance from pile, sediment vibration transmission properties and sea currents will also play a role in mitigation effect achievable for any given project and pile installation.

While a DBBC equivalent mitigation effect were applied in this prognosis, for monopile and jacket foundation, it should be noted, that a detailed calculation should be made for the actual mitigation solution to be used, for the actual pile installation to be performed.

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10. Underwater noise evaluation for operation phase

Underwater noise from offshore wind turbines comes primarily from two sources: mechanical vibrations in the nacelle (gearbox etc.), which are transmitted through the tower and radiated into the surrounding water; and underwater radiated noise from the service boats in the wind farm. In a review by Tougaard (2020), measurements of underwater noise from existing operational wind turbines are presented, whereby measured underwater noise levels are evaluated as a function of wind speed and turbine size. For monopiles, the review considers measurements from 0.55 MW – 3.6 MW turbines. For other foundation types (GBF, jacket and tripod), only singular measurements are available. Since the underwater noise radiated during operation will depend on the radiating structure (the foundation), its shape, material and size will matter. The turbine technologies (direct drive vs. gear box), will also have an impact on the radiated operational underwater noise. However, the limited available operational noise data does not allow for such differences to be resolved. The trendline proposed in Tougaard (2020), not taking foundation type or size into account, is therefore considered with caution (Figure 10.1). The trend line shows a size dependency, with source level increasing by a factor of 14 dB per factor 10 in turbine nominal capacity (Tougaard, et al., 2020).

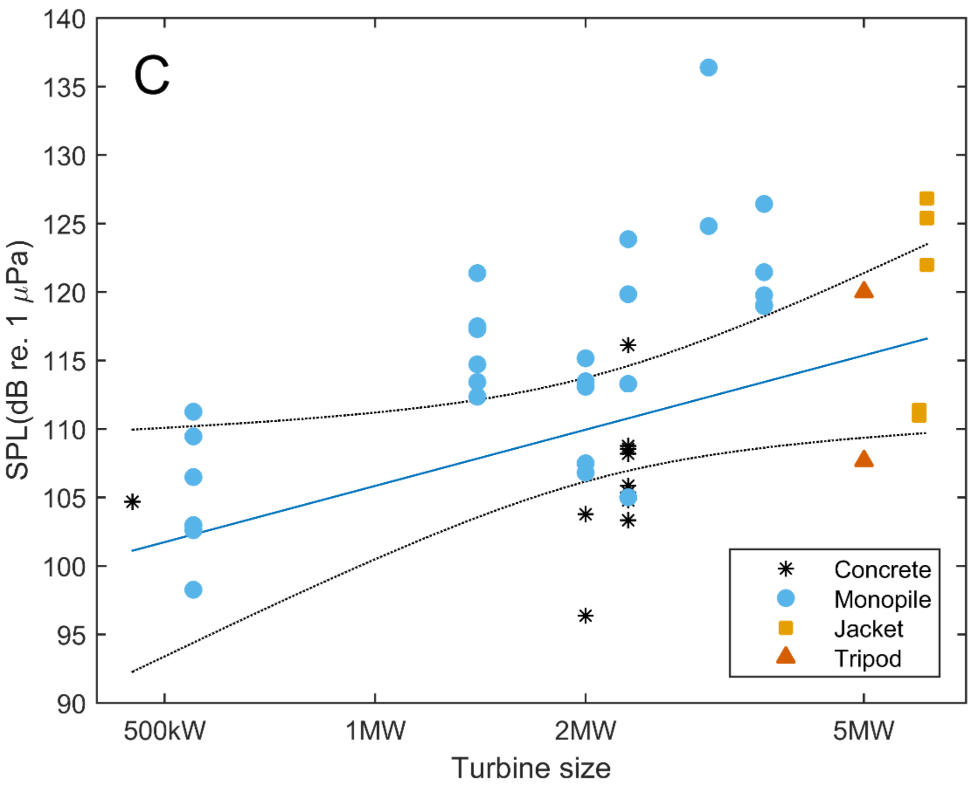

Figure 10.1: Relationship between measured broadband underwater noise and turbine size compiled from available literature sources. Measurements have been normalized to a distance of 100 m from the turbine foundation and a wind speed of 10 m/s. From (Tougaard, et al., 2020).

There is a strong dependency between wind speeds and radiated noise levels (Figure 10.2). At the lowest wind speeds, below the cut-in, there is no noise from the turbine. Above cut-in, there is a pronounced increase in the noise level with increasing wind speed, until the noise peaks when nominal capacity is reached in output from the turbine. Above this point, there is no further increase with wind speed and perhaps even a slight decrease.

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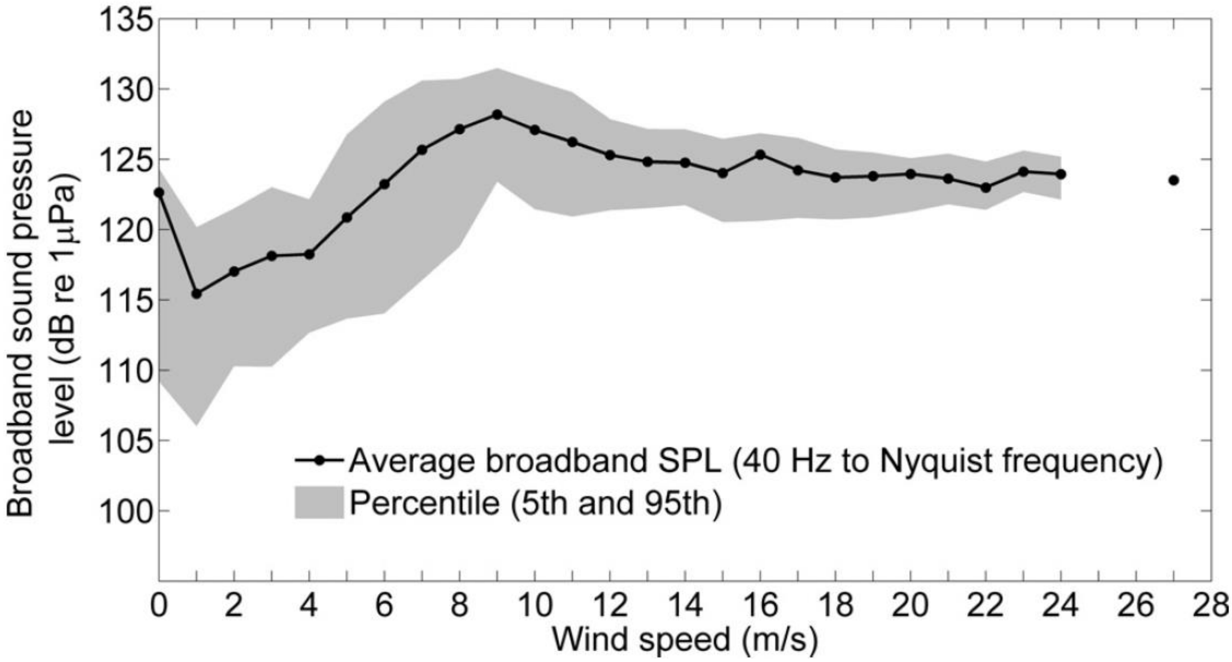

Figure 10.2: Relationship between wind speed and broadband noise level, measured about 50 m from the turbine (3.6 MW Siemens turbine at Sheringham Shoal). Maximum production of the turbine is reached at about 10 m/s, above which the production is constant. Figure from (Pangerc, et al., 2016).

All measurements of turbine underwater noise show the noise to be entirely confined to low frequencies, below a few kHz and with peak energy in the low hundreds of Hz. One spectrum of a typical mid-sized turbine is shown in Figure 10.3, where pronounced peaks are visible in the spectrum in the 160 Hz and 320 Hz, 10 Hz bands.

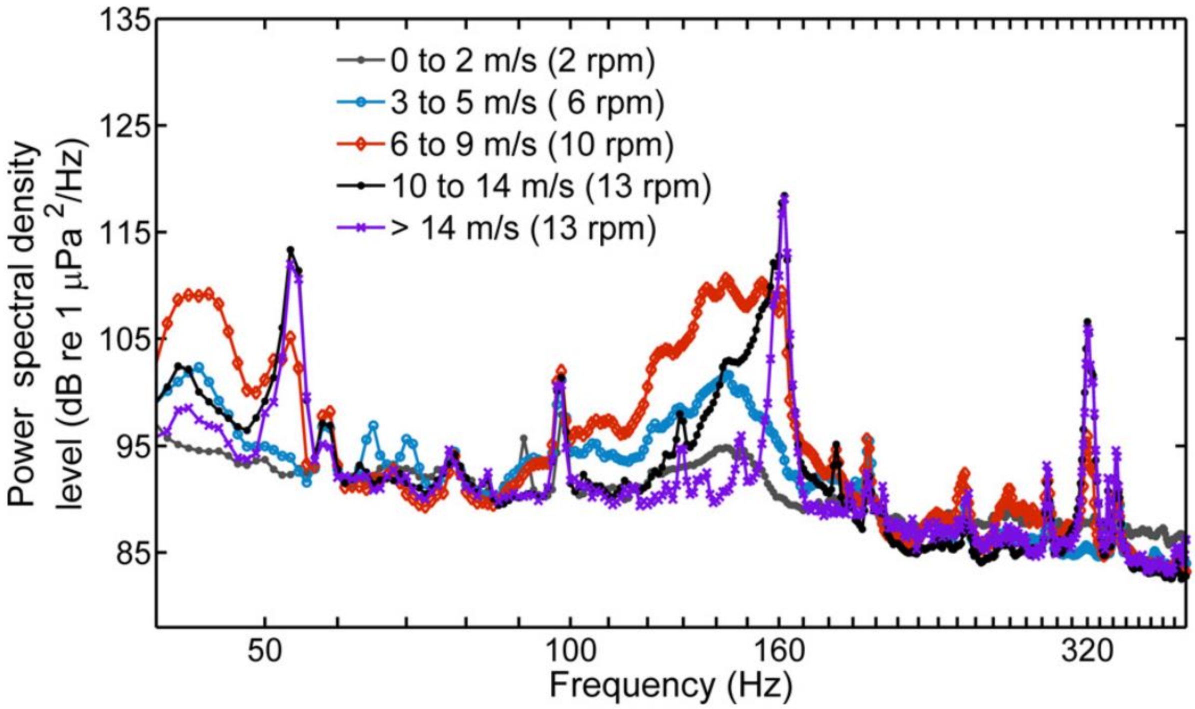

Figure 10.3: Example of frequency spectra from a medium sized turbine (3.6 MW, Gunfleet Sands) at different wind speeds. Levels are given in 10 Hz intervals. Measurements were obtained about 50 m from the turbine. Measurements from (Pangerc, et al., 2016).

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Despite the inherent uncertainties with respect to type and size of turbines to be used in the project it is considered likely that the turbine noise will be comparable to what has been measured from other turbines. However, it should be considered with caution. Based on the data in Figure 10.1, a number of observations should be mentioned. First and foremost, significant variation in measured sound levels for individual turbine sizes on same foundation type, up to 20 dB is noticed. Second, the trendline (blue) representing the best fit of all data points, is not assessed to provide an accurate fit for any given turbine size. This presents a challenge in terms of reliably predicting source levels within the covered turbine size range in Figure 10.1 (0.4 MW – 6.15 MW), and to an even greater extent for turbine sizes outside this range. For Laine OWF, turbine sizes are expected to have a size of 15 MW – 25 MW. This would represent a 5 – 7 fold increase compared to the available empirical data for monopiles. Given the uncertainties present in the empirical data, any extrapolation of such magnitude is considered to be provide a very uncertain source level prediction.

An additional source of uncertainty in prediction is the type of turbine. All but one of the turbines, from which measurements are available, are types with gearbox, a main source of the radiated noise. Only one measurement is available for a turbine with a direct drive (Haliade 150, 6 MW) (Elliott, et al., 2019), which is a type increasingly being installed in new projects. The limited data suggests that noise levels from the direct drive turbine are more broadband in nature than from types with gear box.

For comparison, in a review by Bellmann et. al (2020), a study of underwater noise emission from pile driving activities of different pile sizes was presented, see Figure 6.1. The relationship between measured sound level at 750 m and the foundation pile diameter, for piles 1 m – 8 m diameter, showed a clear trendline (blue). This was used in the pile driving prognosis to extrapolate the source level of the 18 m diameter monopile foundation, as well as interpolate it for the 8 m pin piles.

For the monopiles, this corresponded to an extrapolation factor ~2, for the available empirical data, and for the 8 m pin piles, this was covered within the available data range. Examining the lower half of the empirical data however reveals a significant variation in measured levels. Had a trendline been established for the data points spanning 0.5 – 4 m pile diameter, an extrapolation to 18 m diameter monopiles would have been connected with a significant degree of uncertainty, and would likely have indicated a steeper trendline, resulting in a higher extrapolated source level estimate for larger pile sizes.

It is assessed to be highly likely, that this is currently the case for operational underwater noise. The data set used to establish a trend, is very limited, and will potentially result in significant errors that scale in size, with the degree of extrapolation.

Despite all of the above mentioned uncertainties, a calculation for PTS, TTS and behaviour reaction threshold criteria is carried out below, based on the blue trendline in Figure 6.1 as well as the scaling and frequency considerations presented in (Tougaard, et al., 2020). It should be kept in mind, that there are significant uncertainties with the estimated impact range due to the lack of scientific data supporting such a calculation.

For a 25 MW turbine, the sound level at 100 m, would be $SPL_{rms} = 125.4\ dB\ re\ 1\mu Pa$, based on the extrapolation of the blue trendline. The primary frequency would be ~160 Hz, with secondary frequency at 320 Hz, approximately 10 dB below the primary (Tougaard, et al., 2020).

A conservative approach would set the unweighted 160 Hz level to $SPL_{rms} = 125.4\ dB\ re\ 1\mu Pa$ and for 320 Hz, $SPL_{rms} = 115.4\ dB\ re\ 1\mu Pa$.

Seals however are not equally good at hearing all frequencies. As described in further detail in section 4.4, frequency weighting functions are used to more accurately predict impact ranges for the individual species. For seal, the

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frequency weighting for Phocid Carnivores in Water (PCW) is used. In Figure 4.2, the frequency dependent correction values are listed, from which the following correction values (number of dB to be subtracted from unweighted levels) can be observed for seal.

- -20 dB at 160 Hz, and
- -15 dB at 320 Hz.

The sound levels, as experienced by seal, from a single turbine in operation would therefore amount to:

- @160Hz, 100 m distance: $SPL_{rms,PW} = 105.4\ dB\ re\ 1\mu Pa$
- @320Hz, 100 m distance: $SPL_{rms,PW} = 100.4\ dB\ re\ 1\mu Pa$
- "Broadband", 100 m distance: $SPL_{rms,PW} = 106.4\ dB\ re\ 1\mu Pa$

For seal, no behaviour threshold is currently supported by literature, and it is therefore not possible to compare the sound level at 100 m with a behavioural threshold.

Calculating the cumulative noise dose for a seal located at a constant distance of 100 m from a turbine foundation within the wind farm area, over a 24 hour period, would result in cumulative sound exposure level, $SEL_{cum,24h,PCW} = 116.4 + 10 \cdot log_{10}(86400) \cong 155.4\ dB\ re.1\mu Pa^2 s$. Given a threshold criteria for onset of TTS in seal for continuous noise of $SEL_{cum,24h,PW} = 183\ dB\ re.1\mu Pa^2 s$, the impact over a 24 hour duration is 27.6 dB lower than the TTS onset criteria. With a 27.6 dB margin to the TTS threshold criteria, auditory injures are unlikely to occur.

Most fish detect sound from the infrasonic frequency range (<20 Hz) up to a few hundred Hz (e.g. Salmon, dab and cod) whereas other fish species with gas-filled structures in connection with the inner ear (e.g. herring) detect sounds up to a few kHz. The main frequency hearing range for fish is therefore overlapping with the frequencies, produces by operational wind turbines (below a few hundred Hz). There are no studies defining fish behavioural response threshold for continuous noise sources, and the scientific data addressing TTS from such noise sources is very limited. The only studies providing a TTS threshold value for fish is from experiments with goldfish. Goldfish is a freshwater hearing specialist with the most sensitive hearing in any fish species. In the project area for Laine OWF, the most common fish species are herring followed by sculpins, smelt, ruffe and whitefish (NIRAS, 2023). All of these species have a less sensitive hearing, compared to the goldfish (Popper, et al., 2014), and using threshold for goldfish will lead to an overestimation of the impact. Empirical data for several of the fish species without a connection between the inner ear and the gas-filled swim bladder showed no TTS in responses to long term continuous noise exposure (Popper, et al., 2014). In a study by Wysocki et al. (2007), rainbow trout exposed to increased continuous noise (up to 150 dB re 1 μPa rms) for nine months in an aquaculture facility, showed no hearing loss nor any negative health effect. Therefore, it is assessed that TTS is unlikely to occur as a result of an operational offshore wind farm.

In summary, the underwater noise emission from operational wind turbines, depends on the turbine size, wind speed and whether it has a gearbox or is gearless (direct drive). While available literature indicates a correlation between turbine size and underwater noise levels, the available dataset is limited to 6.15 MW turbines, and shows significant variance in reported noise levels for the same turbine size. Extrapolation of the reported trend, to be used in assessing the underwater noise emission from future turbines of 15 - 25 MW, should therefore be used with caution.

10.1. Noise from service boats

In addition to the noise from the turbines themselves, the service boats and vessels within offshore wind farms are likely to be a source of underwater noise during the operational phase of the wind farm. However, the levels and temporal statistics of this noise source has not yet been sufficiently quantified or described. Without dedicated studies it is therefore not possible to quantify the contribution of service boats to the noise in the wind farm.
It is expected that both small and fast boats as well as larger, slower moving vessels will be used. Underwater noise from smaller boats has a noise level ranging 130-160 dB re 1 μPa@1meter (Erbe, 2013; Erbe, et al., 2016), while the

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underwater noise levels from larger vessels is up to 200 dB re 1 µPa@1 meter (Erbe & Farmer, 2000; Simard, et al., 2016; Gassmann, et al., 2017). Source levels may vary by 20-40 dB within a ship class due to variability in design, maintenance, and operation parameters such as speed (Simard, et al., 2016; Erbe, et al., 2019). Furthermore the underwater noise levels increase when the ship is maneuvered, such as when the ship goes astern, or thrusters are used to hold the ship at a certain position (Thiele, 1988). Ship noise contribute to the ambient underwater noise level from frequencies as low as 10 Hz to as high as several kHz, depending on ship size and speed (Haver, et al., 2021).

Laine OWF area is located in an area with ship traffic (Figure 5.5) and the area is therefore expected already to be dominated by low-frequency ship noise. Based on data from the BIAS-project, the underwater noise level measured in the 63 and 125 Hz frequency band (indicators of ship noise) is modelled to be in the range of 80 - 100 dB re 1uPa for both frequencies in the project area for Laine OWF (50 % of the time) (see Figure 5.1 - Figure 5.4). It is clear that underwater noise from vessels in the nearby shipping lanes, influence the OWF area.

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Appendix 1

Underwater noise maps for seal behavior threshold

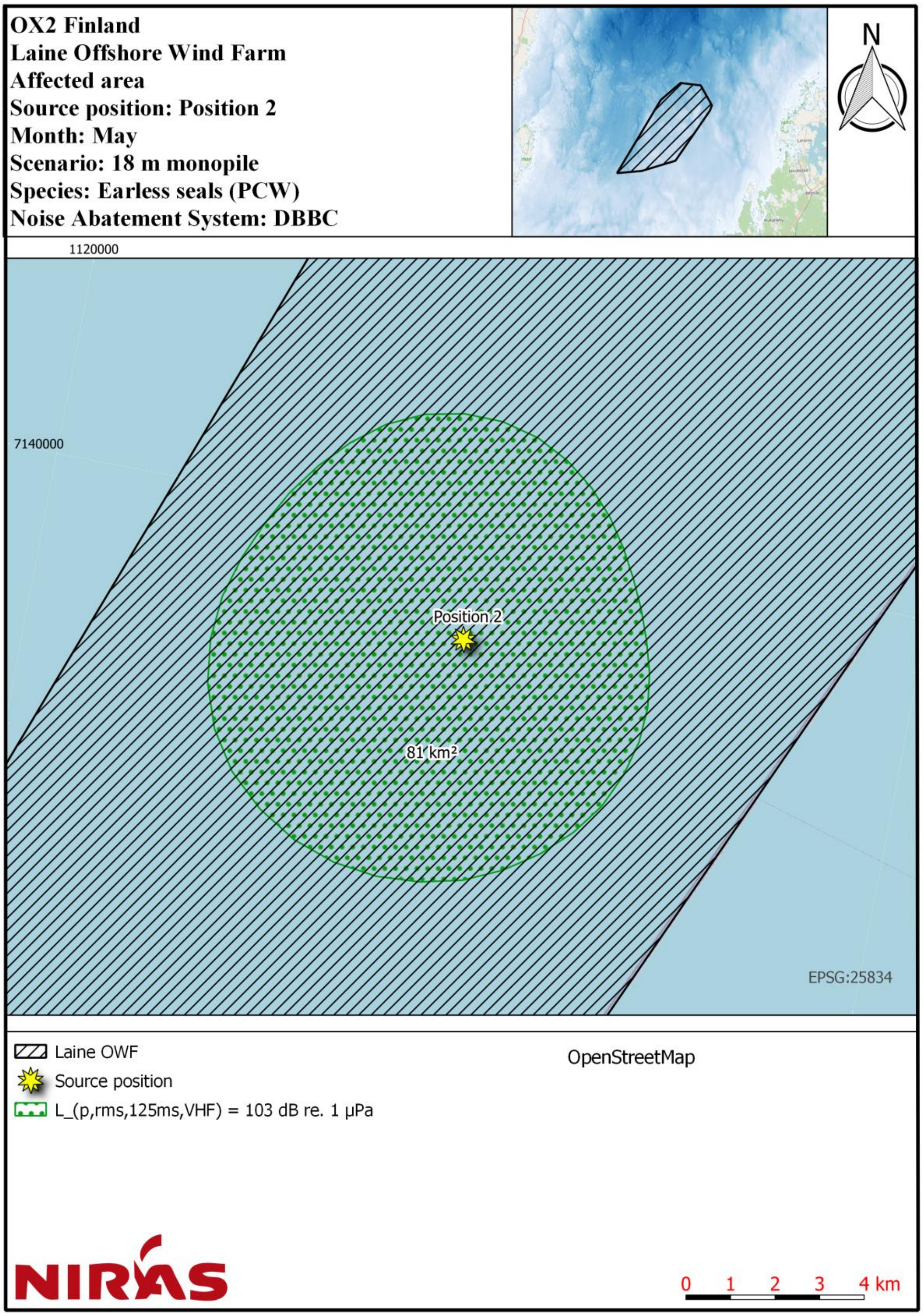

Figure 11.1: Noise contour map for position 2, showing the Distance-To-Threshold for avoidance behaviour in earless seal, for 18 m monopile with DBBC mitigation effect.

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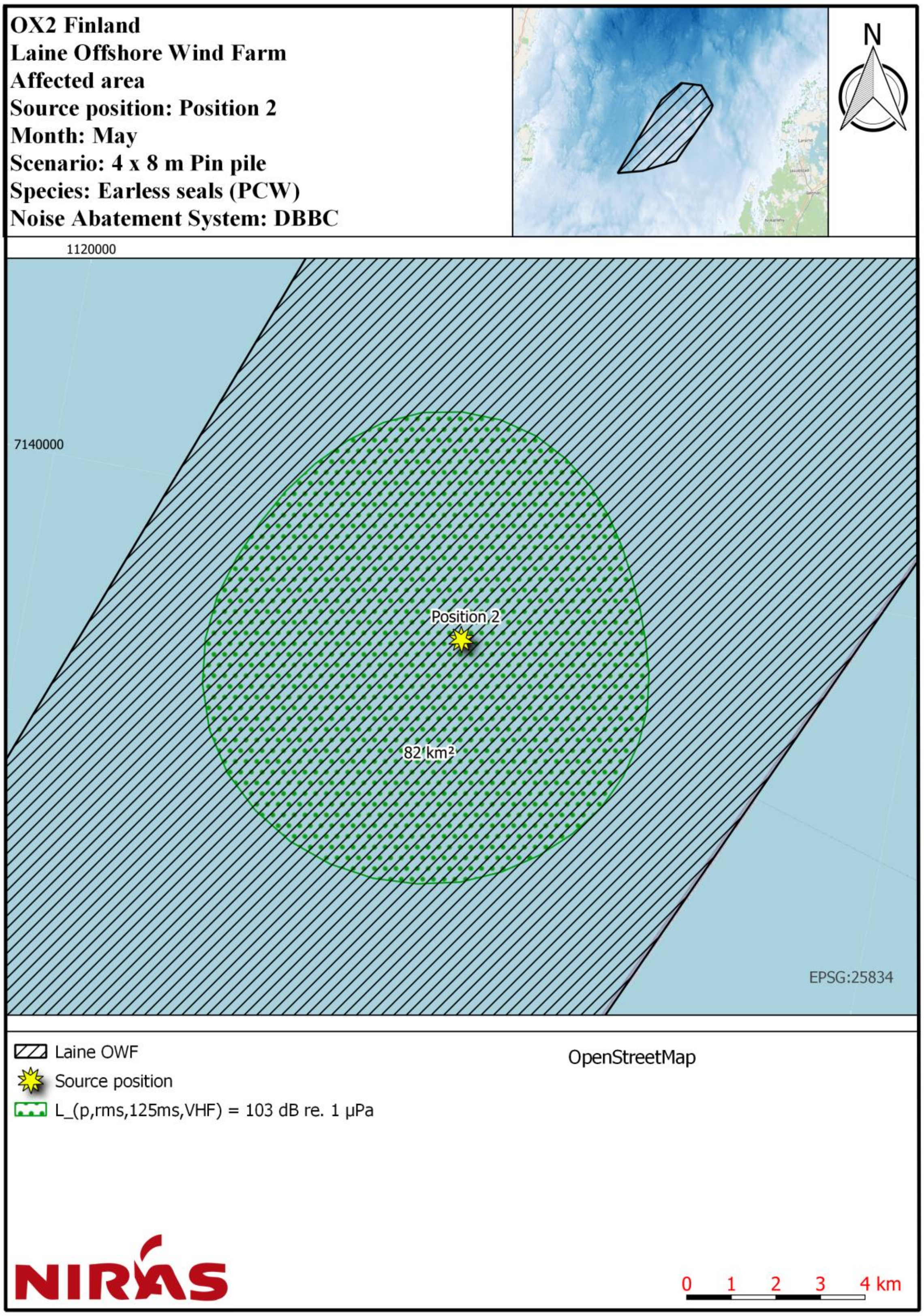

Figure 11.2: Noise contour map for position 2, showing the Distance-To-Threshold for avoidance behavior earless seal, for jacket foundation with 4x 8 m pin piles with DBBC mitigation effect.

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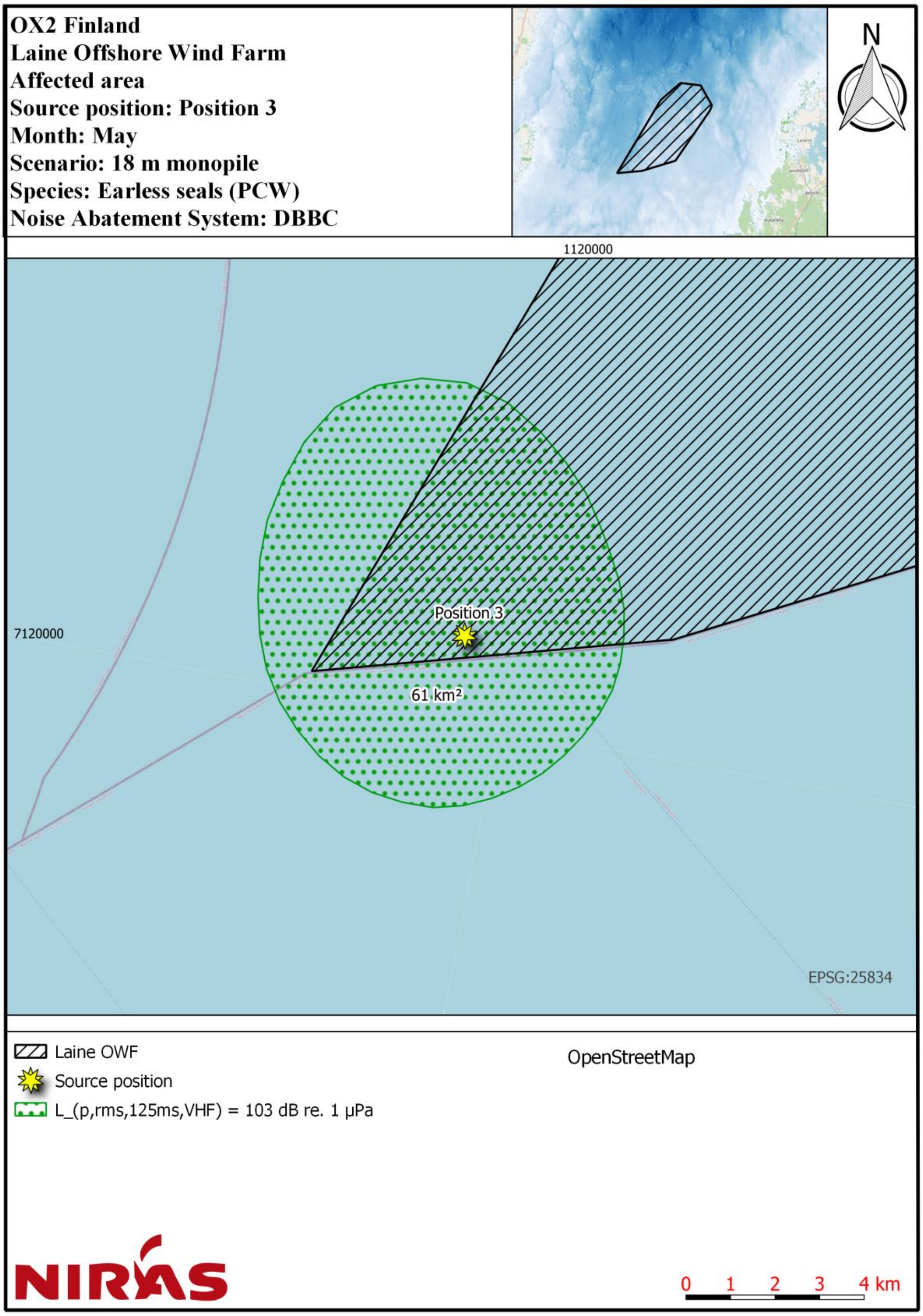

Figure 11.3: Noise contour map for position 3, showing the Distance-To-Threshold for avoidance behaviour in earless seal, for 18 m monopile with DBBC mitigation effect.

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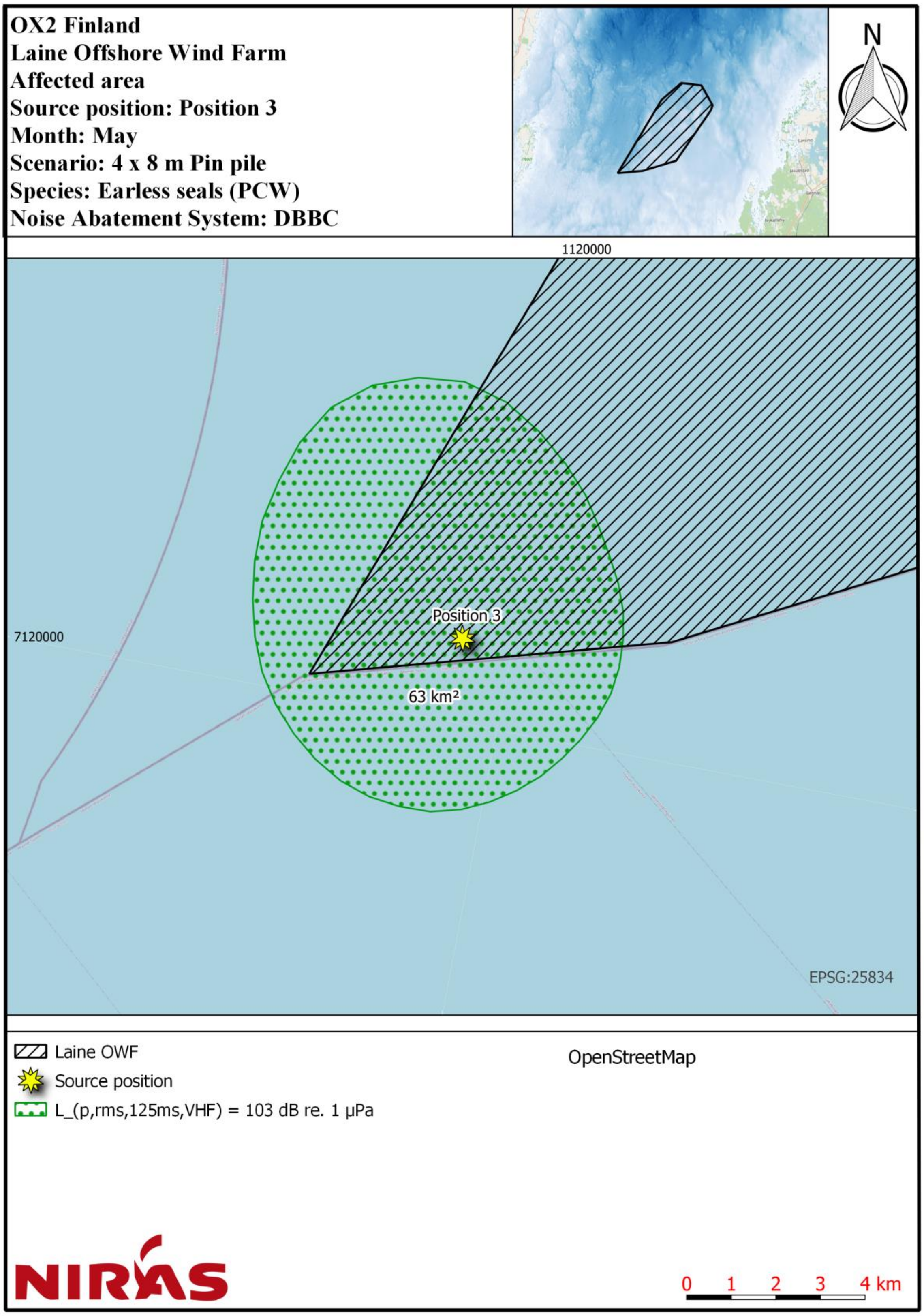

Figure 11.4: Noise contour map for position 3, showing the Distance-To-Threshold for avoidance behavior in earless seal, for jacket foundation with 4x 8 m pin piles with DBBC mitigation effect.

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