Fra:	Kasper Storrs (STOR) <STOR@NIRAS.DK>
Sendt:	14. februar 2024 13:30
Til:	Julie Elisa Søby
Cc:	Kevin Whyte
Emne:	Ansøgning om geofysiske forundersøgelser til Verena Fiberkablet
Vedhæftede filer:	Ansøgning om geofysisk undersøgelse af VERENA fiberkabel.pdf; VERENA Subsea Fibre Optic Cable - Underwater Noise Prognosis, Geophysical survey_140224.pdf

Kære Julie

Hermed sender jeg McMahon Design & Managements ansøgning om tilladelse til geofysiske undersøgelser for Verena Fiberkablet.

Ansøgningen består af KDIs ansøgningsskema samt supplerende bilag sammenlagt i vedhæftet ansøgning. Derudover er prognosen af undervandsstøj fra de geofysiske undersøgelserne også vedhæftet separat.

Du er naturligvis meget velkommen til at kontakte mig, hvis du har spørgsmål til det fremsendte.

Vi ser frem til at høre fra dig.

Med venlig hilsen

Kasper Storrs
Konsulent

NIRAS

Ceres Allé 3
8000 Aarhus C
Denmark
www.niras.dk

M: +45 4299 5452
T: +45 8732 3232
E: stor@niras.dk

Følg os på:

Miljøministeriet
Kystdirektoratet

Ansøgning om tilladelse til anlæg på søterritoriet

Dette ansøgningsskema benyttes ved ansøgning om tilladelser til etablering, renovering og udvidelse af anlæg på søterritoriet.

Husk at læse vejledningen på side 6, før skemaet udfyldes.
Eventuelle spørgsmål til ansøgningsskema og vejledning rettes til Kystdirektoratet på tlf. 99 63 63 63 eller via e-mail kdi@kyst.dk.

Bemærk: En ansøgning kan først behandles, når alle nødvendige oplysninger foreligger.

Til Kystdirektoratets notater:

Dato for modtagelse:		*Journal nr.:*	
Projekttype:		*Sagsbehandler:*	

A. Oplysninger om ejere af den eller de matrikler, hvor anlægget opføres

Navn
Til havs - Staten

Adresse
Nordsøen, fra den danske eksklusiv økonomiske zone (EEZ) ind til det vestjyske kyst ved Henne Strand og Esbjerg.

Lokalt stednavn	Postnr.	By

Telefon nr.	Mobil nr.	E-mail

Miljøministeriet
Kystdirektoratet

B. Evt. repræsentant (entreprenør, rådgiver eller lignende)

Navn		
Kasper Storrs – NIRAS A/S (rådgiver)		

Adresse
Ceres Allé

Lokalt stednavn	Postnr.	By
	8000	Aarhus

Telefon nr.	Mobil nr.	E-mail
	4299 5452	stor@niras.dk

B. Evt. repræsentant (entreprenør, rådgiver eller lignende)

Navn
Kevin Whyte (kunden) McMahon Design & Management Limited

Adresse
15 The Seapoint Building, Clontarf Road

Lokalt stednavn	Postnr.	By
	D03 E240	Dublin (Irland)

Telefon nr.	Mobil nr.	E-mail
+353 01 853 6500		kwhyte@mdmeng.ie

B. Evt. repræsentant (entreprenør, rådgiver eller lignende)

Navn
Cian Ryan (Green Rebel – entreprenør for de geofysiske undersøgelser)

Adresse

Lokalt stednavn	Postnr.	By

Telefon nr.	Mobil nr.	E-mail
		Cian.Ryan@greenrebel.ie

Miljøministeriet
Kystdirektoratet

C. Offentliggørelse af oplysninger

Ansøger giver ved underskrift tilladelse til, at ansøgningsmaterialet må offentliggøres på Kystdirektoratets hjemmeside www.kyst.dk. I henhold til persondataloven vil personfølsomme oplysninger, eller andre oplysninger friholdt for aktindsigt, uanset denne accept ikke blive offentliggjort.

Dato	Underskrift
14/02/2024	Kasper David Pedersen Storrs

D. Anlæggets placering

Adresse
Nordsøen, fra den danske eksklusiv økonomiske zone (EEZ) ind til den vestjyske kyst ved Henne Strand og Esbjerg, se Bilag 1.

Postnr.	By	Kommune
-	-	-

Matrikel nr. og ejerlavsbetegnelse
-

E. Beskrivelse af anlægget i sin helhed

Kan evt. uddybes i bilag

Bemærk: Nødvendige bilag skal også vedlægges, se rubrik I

En fuld projektbeskrivelse, koordinater for undersøgelsesområdet, vurderinger af undersøgelsernes mulige indvirkningerne på miljøet, samt en rapport om undervandstøjmodellering er vedhæftet som bilag. Bilagene består af:

- *Ansøgning om tilladelse til geofysiske undersøgelser: Verena fiberkabel (14.02.2024)*
- *Koordinater for undersøgelsesområdet*
- *VERENA Subsea Fibre Optic Cable: underwater noise prognosis, geophysical survey (08.02.2024)*
- *Datablad over fartøjer: Glomar Vantage og Lady Kathleen*

Områdebeskrivelse
McMahon Design & Management Ltd, ønsker at udføre geofysiske undersøgelser og dermed undersøge muligheden for at etablere et fiberkabel mellem Storbritannien og Danmark. Formålet er, at levere en international strategisk, højhastigheds telekommunikationsforbindelse, som led i EUs ambition om netop at styrke EU's internationale forbindelser, herunder undersøiske telekabler.

Fiberkablet skal løbe fra North Yorkshire-kysten ved Hunmanby i England til Danmarks sydvestkyst, med to potentielle ilandføringsmuligheder undersøgt i nærværende ansøgning, (1) ved Henne Strand og (2) ved Esbjerg. Det ansøgte undersøgelsesområde strækker sig dermed fra den vestligste grænse af den danske Eksklusiv Økonomiske Zone (EEZ) i Nordsøen til de to potentielle ilandføringspunkter ind til 3 m vanddybde. Undersøgelsesområdet har et samlet areal på cirka 615 km2 og en bredde på 1 km (Figur 1). Koordinaterne for undersøgelsesområdet er vedhæftet som bilag: *Koordinater for undersøgelsesområdet*.

Figur 1. Det 1 km brede undersøgelsesområdet, hvori de ansøgte geofysiske undersøgelser planlægges. Undersøgelsesområdet strækker sig fra den danske EEZ til hhv. Henne Strand og Esbjerg via Fanø.

De geofysiske undersøgelser, som ansøges om her, gennemføres over en periode på 5 uger sammenlagt og forventes at forløbe fra maj 2024 til ultimo september 2024 inklusiv verjlig. Det forventes at der skal gennemføres geotekniske undersøgelser sammen med et fuldt UXO survey i løbet af 2026 men disse indgår ikke i nærværende ansøgning eller undersøgelse, og ansøgning om tilladelse til geotekniske undersøgelser vil blive foretaget separat og på et senere tidspunkt..

Geofysiske forundersøgelser
Tabel 1 viser en oversigt over hvilket geofysiske udstyr, som skal bruges. Det drejer sig om følgende udstyr: Multibeam ekkolod (MBES); side-scan sonar (SSS); Ultra-short baseline (USBL); sub-bottom profiler (SBP) og et magnetometer. De geofysiske undersøgelser udføres på hele strækningen fra den danske EEZ til de to ilandføringspunkter.

De geofysiske undersøgelser af havbunden har til formål, at fastslå en optimal og sikker rute for kablet inden for undersøgelsesområdet og i forbindelse med anlæg, og efterfølgende vedligeholdelse af kablet men under hensyntagen til miljømæssige og økologiske faktorer. Undersøgelserne vil facilitere beslutninger om kabelpansring og kabelnedlægning og vil identificere de nødvendige vanddybder, mulige forhindringer på havbunden, havbundens geomorfologi samt kabelrisici inden for det ansøgte undersøgelsesområde. Undersøgelser omfatter dermed indsamling af arkæologiske data for at muliggøre professionel arkæologisk fortolkning og analyse af data på et senere tidspunkt. Endvidere vil de geofysiske undersøgelser give detaljerede oplysninger om havbundssediment, stratigrafi i dybhavssedimenter og øvre sedimentlag for at understøtte kabelruten og installationsarbejdet.

Tabel 1 Udstyr som skal benyttes i forbindelse med de geofysiske undersøgelser.

Udstyrstype	***Formål***	***Frekvensområde***
Multibeam Echo Sounder (MBES)	Måling af detaljeret bathymetri	190 kHz to 400 kHz
Side Scan Sonar (SSS)	Generering af højopløselige 2D billeder af havbunden og kortlægning af objekter på havbundens overflade	230 kHz to 850 kHz
Ultra-Short Base Line (USBL)	Positionering af udstyr, som trækkes efter undersøgelsesfartøjet	19 kHz to 34 kHz
Sub-bottom Profiler (SBP) - Parametric	Profilering af de øverste geologiske lag i havbunden og belysning af potentiale og risici for nedgravning af kablet	4 to 15 kHz, 85 to 115 kHz
Magnetometer	Identificering af metalliske vragdele, potentielle UXO, rørledning, undersøiske kabler m.m.	Passiv – udsender ikke akustiske signaler

Undervandsstøj fra de geofysiske udstyre kan potentielt medføre negative påvirkninger på det marine liv (havpattedyr). Derfor er der foretaget undervandsstøjmodellering af det udstyr, som er beskrevet i Tabel 1. Undervandstøjmodelleringen er vedhæftet som bilag: *VERENA Subsea Fibre Optic Cable: underwater noise prognosis, geophysical survey*.

Det geofysiske undersøgelsers mulig påvirkninger er beskrevet i vedhæftet bilag: *Ansøgning om tilladelse til geofysiske undersøgelser.*

F. Beskrivelse af planlagte arbejdsmetoder

Kan evt. uddybes i bilag

I undersøgelsesområdet udføres de geofysiske undersøgelser i en kabelkorridor på ca. 250–400 m. Bredden af kabelkorridoren, der undersøges, afhænger af om undersøgelserne udføres i et kystnært område med vanddybder på mellem 3–15 m, eller om de udføres på dybere vand (>15 m) længere offshore. I tilfælde af, at der identificeres forhindringer på havbunden vil den undersøgte kabelkorridor kunne justeres enten mod nord eller syd, dog stadig inden for det ansøgte 1 km brede undersøgelsesområde.

Kystnært, på dybder fra 3–15 m, benyttes et mindre fartøj (Lady Kathleen) til at gennemføre undersøgelserne. Dybgangen af fartøjet er forventeligt på omtrent 1,4–1,5 m. I dette område er kabelkorridoren 250 m bred og der vil være behov for at gennemføre minimum 9 transektlinjer (på grund af den lavere dybde) for at sikre 100% overlap af SSS undersøgelsen og 20% af MBES undersøgelsen. Dette svarer til en afstand på 15-20 m mellem linjerne.

Fra dybder, som overstiger 15 m, benyttes undersøgelsesfartøjet Glomar-Vantage. Her er kabelkorridoren 400 m bred, og her vil der være behov for minimum 5 transektlinjer for at sikre 100 % overlap af SSS undersøgelsen og 20% af MBES undersøgelsen. Både den kystnære undersøgelse og offshore delen af undersøgelsen vil foregå med en sejlhastighed på omkring 4 knob.

Flere informationer vedr. overstående fartøjer er vedhæftet som bilag: *Dataplad af fartøjer: Glomar Vantage og Lady Kathleen.*

G. Uddybning

Skal der i forbindelse med anlægget foretages uddybning?

☐ Ja

☑ Nej

Hvis ja skal mængden for uddybningen angives - m³

Beskrivelse af hvordan sedimentet fra uddybningen efterfølgende tænkes behandlet:

-

Miljøministeriet
Kystdirektoratet

H. Opfyldning

Skal der i forbindelse med anlægget foretages opfyldning på søterritoriet?

☐ Ja

☑ Nej

Hvis ja skal mængden af opfyldningsmateriale angives - m³

Beskrivelse af opfyldningsmaterialets kvalitet:

-

I. Nødvendige bilag

Følgende bilag skal vedlægges:
- Søkort med indtegnet anlæg
- Matrikelkort med indtegnet anlæg
- Plan- og skitsetegning over det samlede anlæg
- Målsatte snittegninger over eventuelle moler, broer mv.
- Målfast oversigtskort med hele anlægget indtegnet
- Samtykkeerklæringer fra berørte grundejere

Evt. andet relevant materiale:

Vedhæftet dette skema er følgende bilag:
- Ansøgning om tilladelse til geofysiske undersøgelser: Verena fiberkabel (14.02.2024)
- Koordinater for undersøgelsesområdet
- VERENA Subsea Fibre Optic Cable: underwater noise prognosis, geophysical survey (08.02.2024)
- Dataplad af fartøjer: Glomar Vantage og Lady Kathleen

J. Erklæring og underskrift

Undertegnede ansøger erklærer, at oplysninger, der står i ansøgningen, er i overensstemmelse med de faktiske forhold.

Dato	Fulde navn *(benyt blokbogstaver)*	Underskrift
14-02-2024	KASPER DAVID PEDERSEN STORRS	K Storrs

Miljøministeriet
Kystdirektoratet

Ansøgningen sendes med post til:
Kystdirektoratet
Højbovej 1
Postboks 100
7620 Lemvig

Eller via e-mail: ***kdi@kyst.dk***

Vejledning til ansøgningsskema

(vedrørende ansøgning om tilladelse til anlæg på søterritoriet)

Punkt A. Oplysninger om ejere
Her anføres navn, adresse mv. på ejere af den eller de matrikler, hvor anlægget opføres på eller ud for. Er der flere ansøgere, kan det anføres i et vedlagt bilag.

Punkt B. Evt. repræsentant (entreprenør, ingeniør eller lignende)
Her anføres navn, adresse mv. på den person, der fungerer som kontaktperson (projektansvarlig) under sagens behandling, det kan for eksempel være et entreprenør- eller ingeniørfirma.

Punkt C. Offentliggørelse af oplysninger
Kystdirektoratet er forpligtiget til at orientere naboer og andre berørte parter om ansøgninger om tilladelse til anlæg på søterritoriet. Ved orienteringen sker der altid en videregivelse af de oplysninger, som er angivet i skemaet. Endvidere offentliggøres ansøgningen på Kystdirektoratets hjemmeside.

Punkt D. Anlæggets placering
Her anføres projektets adresse, dvs. dets fysiske placering. Det er vigtigt for sagens behandling, at matrikelnumre samt ejerlav angives. Disse oplysninger kan findes i ejendommens skøde eller indhentes fra kommunen eller på internettet, f.eks. på www.miljoportalen.dk.

Punkt E. Beskrivelse af anlægget
Her beskrives anlægget i sin helhed. Beskrivelsen skal bl.a. omfatte formål og baggrund for anlægget, anlæggets udformning, en beskrivelse af hvilke materialer, der anvendes til anlægget og overvejelser over anlæggets indvirkning på strømningsforhold og den nærliggende kyst.

Til anvendelse for en screening for VVM skal beskrivelsen ligeledes belyse nedenstående forhold. Anlæggets

- dimensioner
- kumulation med andre projekter
- anvendelse af naturressourcer
- affaldsproduktion, forurening og gener
- risiko for ulykker, navnlig under hensyn til de anvendte materialer og teknologier

Anlæggets betydning for den miljømæssige sårbarhed i området særligt i forhold til
- nuværende arealanvendelse
- de tilstedeværende naturressourcers relative rigdom, kvalitet og regeneringskapacitet
- det naturlige miljøs bæreevne med særlig opmærksomhed på kystområder, områder der er fredet eller omfattet af national og international natur- og miljøbeskyttelses lovgivning,tætbefolkede områder, områder der er af særlig betydning ud fra et historisk, kulturelt eller arkæologisk synspunkt

Anlæggets potentielle påvirkninger herunder
- påvirkningernes omfang (geografisk område og antal personer der berøres)
- påvirkningernes grænseoverskridende karakter
- påvirkningers grader og -kompleksitet
- påvirkningens sandsynlighed
- påvirkningens varighed, hyppighed og reversibilitet

Beskrivelsen kan eventuelt suppleres med bilag.

Punkt F. Beskrivelse af arbejdsmetoder
Her angives hvilke arbejdsmetoder, der benyttes ved opførelsen af anlægget, bl.a. hvordan og hvornår arbejdet udføres. Angivelsen af arbejdsmetoder er vigtigt for vurderingen af anlæggets påvirkning på miljøet.

Punkt G. Uddybning
Hvis der i forbindelse med anlægget foretages en uddybning, skal det angives i kubikmeter, hvor stor en mængde sediment uddybningen omfatter, og ligeledes hvad der efterfølgende skal ske med sedimentet, f.eks. om det skal bruges til kystfodring, opfyldning mv.

Punkt H. Opfyldning
Hvis der i forbindelse med projektet foretages en opfyldning, skal omfanget af opfyldningen angives i kubikmeter materiale brugt til opfyldningen. Kvaliteten af materialet til opfyldningen skal belyses, specielt mht. om det er forurenet eller uforurenet materiale, der benyttes.

Punkt I. Nødvendige bilag
Følgende bilag skal foreligge, før en ansøgning om tilladelse til anlæg på søterritoriet kan behandles:
- Søkort med anlægget indtegnet
- Matrikelkort med anlægget indtegnet. Matrikelkort kan findes på www.miljoportalen.dk. Anlæg kan f.eks. indtegnes med tusch på matrikelkortet.
- Plan- og skitsetegning over det samlede anlæg
- Målsatte snittegninger, der gør rede for anlæggets konstruktioner. På snittegningen angives f.eks. konstruktionernes højde, bredde, længde mv.
- Målfast oversigtskort med hele anlægget indtegnet
- Samtykkeerklæringer fra ejerne af alle berørte matrikler skal vedlægges, hvis anlægget strækker sig over mere end ansøger / ejers matrikel. Hvis en repræsentant for ejeren, f.eks. entreprenør- eller ingeniørfirma søger om tilladelse til anlægget på ejerens vegne, skal ansøgningen desuden vedlægges en samtykkeerklæring fra ejeren om, at han er indforstået med dennes repræsentation, samt at han er indforstået med, at anlægget opføres på hans ejendom.

Er der i forbindelse med anlægget lavet en strømningsanalyse eller lignende, er det hensigtsmæssigt at vedlægge den/dem som bilag for at belyse sagen bedst muligt.

Hvis der er spørgsmål til ansøgningsskemaet, kan Kystdirektoratet kontaktes på tlf. 99 63 63 63 eller på email: kdi@kyst.dk.

Kystdirektoratet

Ansøgning om tilladelse til geofysiske undersøgelser

Verena fiberkabel

McMahon Design & Management Ltd

Dato: 14. februar 2024

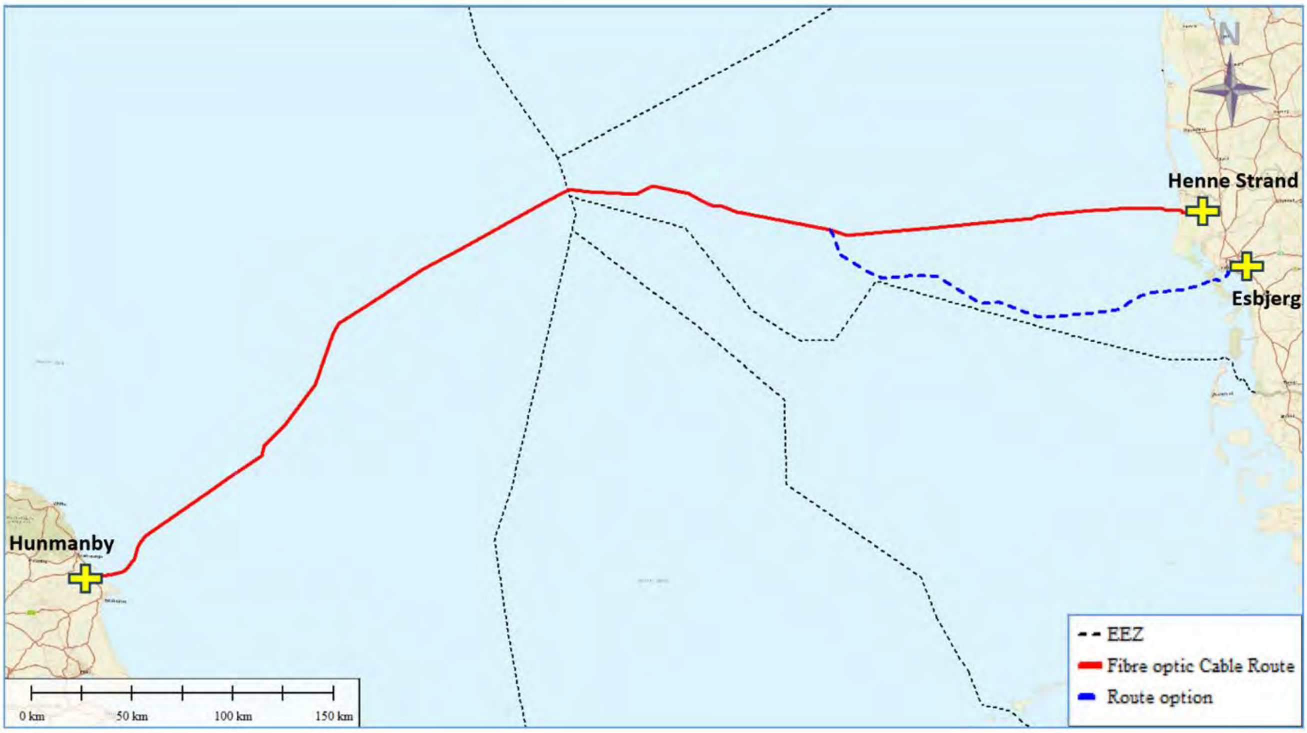
Rev.nr.	Dato	Beskrivelse	Udarbejdet af	Kontrolleret af	Godkendt af
01	29/01/24	Under revision	TEHE, MAWI		
02	14/02/24	Endelig rapport	TEHE, MAWI	VEST	STOR

Indhold

1. Indledning

McMahon Design and Management Ltd ønsker at udføre geofysiske undersøgelser og dermed undersøge muligheden for at etablere fiberkablet, Verena, mellem Storbritannien og Danmark. Formålet med Verena er at levere en international strategisk, højhastigheds telekommunikationsforbindelse som led i EUs ambition om at styrke EU's internationale forbindelser, herunder undersøiske telekabler. Når kablet er fuldt operationelt i 2027, vil fiberkablet forbedre datahastigheder og stile mod at sikre adgang af høj kvalitet til internationale telekommunikationsnetværk.

Verena-kablet skal løbe fra North Yorkshire-kysten ved Hunmanby i England til Danmarks sydvestkyst, med to potentielle ilandføringsmuligheder ved henholdsvis Henne Strand og Esbjerg (Figur 1.1).



Figur 1.1. Oversigtskort over den planlagte kabelrute for fiberkablet, Verena, mellem Storbritannien og Danmark.

Det fremgår af kystbeskyttelseslovens § 16 (a) stk. 1 nr. 3, at der på søterritoriet kun må anbringes fartøjer, der agtes anvendt til andet end sejlads efter tilladelse fra miljøministeren.

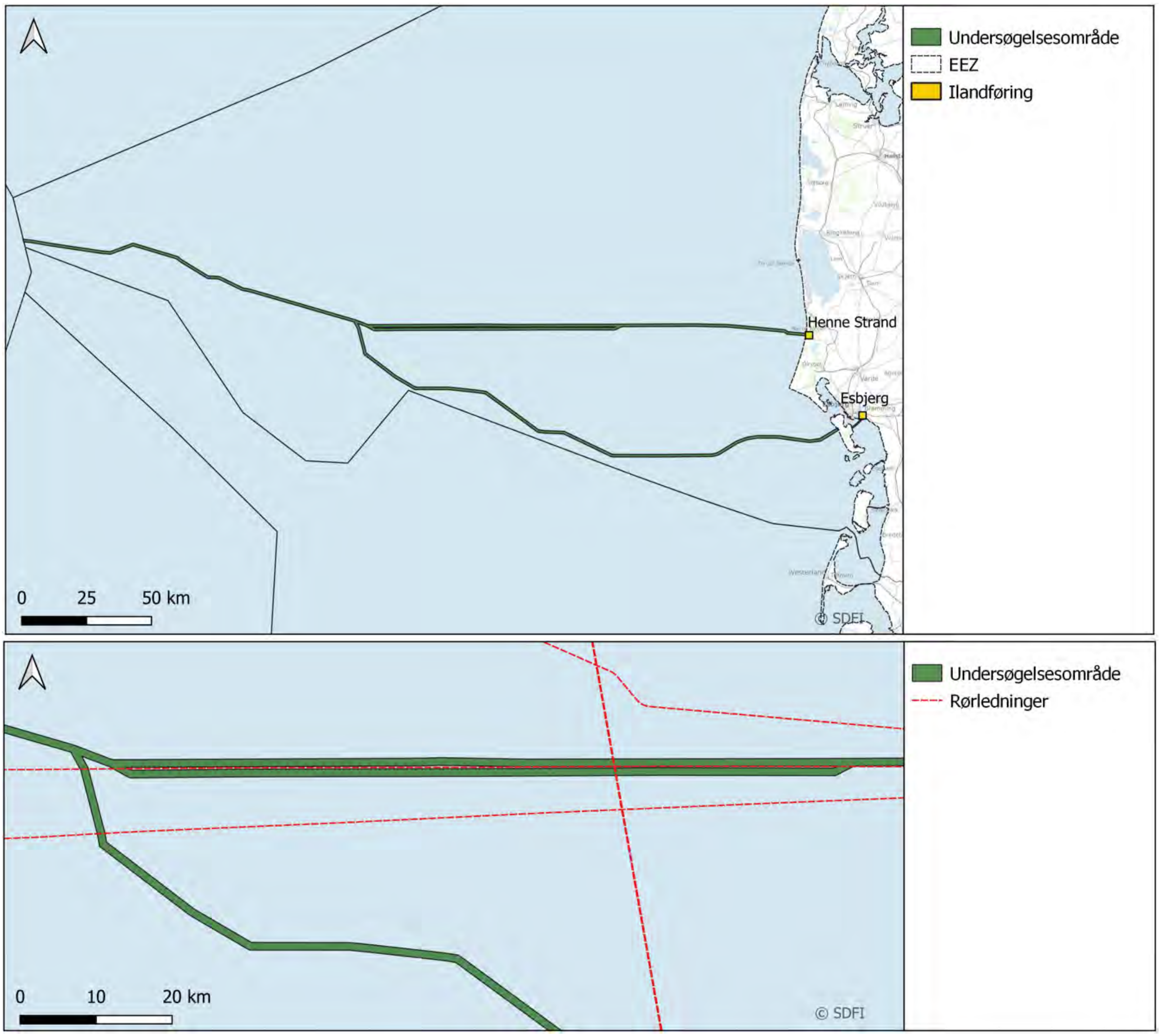
I nærværende ansøgning søges om tilladelse til at udføre geofysiske undersøgelser, som har til formål at tilvejebringe viden omkring havbunden og havbundsstrukturen i undersøgelsesområdet for fiberkablet. Den indsamlede viden skal, sammen med fremtidige geotekniske undersøgelser, i sidste ende danne grundlag for beslutningen omkring den endelige kabelrute. De geofysiske undersøgelser, som ansøges om her, forventes at forløbe fra maj 2024 til ultimo september 2024. Geotekniske undersøgelser indgår ikke i nærværende ansøgning eller undersøgelse, og ansøgningen om tilladelse til disse vil blive foretaget separat. De geotekniske undersøgelser planlægges at blive gennemført i løbet af 2026 sammen med et fuldt UXO survey og der vil i den forbindelse blive indsendt en ny ansøgning om tilladelse til at gennemføre de geotekniske undersøgelser.

2. Projektbeskrivelse

2.1. Områdebeskrivelse

Undersøgelsesområdet strækker sig fra den vestligste grænse af den danske eksklusive økonomiske zone (EEZ) i Nordsøen til de to potentielle ilandføringspunkter ved Henne Strand og Esbjerg ind til 3 m vanddybde. Undersøgelsesområdet har en samlet længde på cirka 615 km og en bredde på 1 km, dog har undersøgelsesområdet øst fra Fanø og ind til land en bredde på 250 m. Det samlede undersøgelsesområde har et areal på omkring 615 km^2 og udgør det område, inden for hvilket de ansøgte geofysiske undersøgelser vil blive fortaget (Figur 2.1). Undersøgelsesområdets præcise koordinatafgrænsning er listet i Bilag 1.

I midten af den nordlige rute deler undersøgelsesområdet sig i to (Figur 2.1). Dette skyldes, at den nordlige rute løber parallelt med Tyra East Echo TE-E gasrørledningen. Den sydlige bøjning af disse to muligheder ville kræve flere krydsningsaftaler med ejeren, og derfor undersøges begge strækninger.



Figur 2.1. Øverst: Kortet viser det 1 km brede undersøgelsesområdet, hvori de ansøgte geofysiske undersøgelser vil blive fortaget. Undersøgelsesområdet strækker sig fra den danske EEZ til hhv. Henne Strand og Esbjerg via Fanø. Nederst: I midten af den nordlige rute deler undersøgelsesområdet sig i to.

I undersøgelsesområdet udføres de geofysiske undersøgelser i en kabelkorridor på ca. 250–400 m. Bredden af kabelkorridoren der undersøges afhænger af, om undersøgelserne udføres i et kystnært område med vanddybder på mellem 3–15 m, eller om de udføres på dybere vand (>15 m) længere offshore. I tilfælde af, at der identificeres eventuelle skibsvrag eller andre forhindringer på havbunden vil det undersøgte kabelkorridor kunne justeres enten mod nord eller syd, dog stadig inden for det ansøgte 1 km brede undersøgelsesområde.

Undersøgelsesområdet består derfor af 4 delområder: nordlige offshore; nordlig kystnær; sydlig offshore; sydlig kystnær. Delområdernes bredde, omtrentlig længde og areal samt delområdets areal som en procentdel af det ansøgte undersøgelsesområde fremgår af Tabel 2.1 og Figur 2.2.

Tabel 2.1. Oversigt over undersøgelsesområdets forskellige delområder.

Undersøgelsesområdets delområder	**Vanddybde (m)**	**Bredde på kabelkorridoren (m)**	**Længde (km)**	**Areal (km²)**	**Delområdet areal som % af undersøgelsesområdet**
(1) Nordlig offshore korridor	>15	400	396	157,50	25,6
(2) Nordlig kystnær korridor	3–15	250	8,6	2,15	0,4
(3) Sydlig offshore korridor	>15	400	188,5	75,41	12,3
(4) Sydlig kystnær korridor	3–15	250	24,2	6,04	1,0
I alt			615	241,1	39,3

Figur 2.2. Afgrænsing mellem de kystnære og offshore kabelkorridorer for både den nordlige og sydlige rute. De to kystnære delområder 2 og 4 er hhv. 8,6 km og 24,2 km lange. Bemærk, at den endelige placering af det undersøgte kabelkorridor kan afvige fra den vist, dog vil den stadig være inden for undersøgelsesområdet.

2.2. De geofysiske undersøgelser

2.2.1. Formål

De geofysiske undersøgelser af havbunden har til formål, at fastslå en optimal og sikker rute for kablet i forbindelse med anlæg og efterfølgende vedligehold under hensyntagen til miljømæssige og økologiske faktorer.

Undersøgelserne vil facilitere beslutninger om kabelpansring og kabelnedlægning og vil identificere de nødvendige vanddybder, mulige forhindringer på havbunden, havbundens geomorfologi samt kabelrisici inden for det ansøgte undersøgelsesområde. Undersøgelser omfatter dermed indsamling af arkæologiske data for at muliggøre professionel arkæologisk fortolkning og analyse af data på et senere tidspunkt. Endvidere vil de geofysiske undersøgelser give detaljerede oplysninger om havbundssediment, stratigrafi i dybhavssedimenter og øvre sedimentlag for at understøtte kabelruten og installationsarbejdet.

Formålene er således:

- At indsamle opdateret, højopløselig bathymetri data langs kabelkorridorerne inden for undersøgelsesområdet;
- At indhente oplysninger om havbundssubstrat (type, tekstur, variabilitet osv.) og især at identificere eventuelle havbundsstrukturer, der kan være af betydning for planlægningen af kablet;
- At identificere eventuelle lavvandede geohazards og menneskeskabte farer (herunder men ikke begrænset til store sten, gaslommer, vrag, affald mm.);
- At bestemme stratigrafien af de øvre lag (sedimentet) af havbunden langs kabelkorridorerne og kvantificere variabiliteten og mobiliteten i de lodrette og vandrette udstrækninger af kabelkorridoren til dybder på 2-5 m;
- At identificere eventuel ueksploderet ammunition fra 2. Verdenskrig (UXO; unexploded ordnance);
- At identificere følsomme marine levesteder, som bør undgås under senere undersøgelser i forbindelse med kabelinstallation.

2.2.2. Metode

Her beskrives metoden nærmere og det udstyr, som skal benyttes i forbindelse med de geofysiske undersøgelser af kabelkorridorerne. Noget af det udstyr, som skal anvendes, udsender undervandsstøj på niveauer, der kan påvirke havpattedyr og fisk negativt. Der er derfor udført en screening af de foreslåede udstyrstyper (se Bilag 2). For udstyr, hvor det ikke umiddelbart kan udelukkes, at det udsender undervandsstøjniveauer, som kan have en negativ påvirkning på det marine liv, er der udført estimater af påvirkningsafstande, som vurderinger i afsnit 4 baseres på.

Alle arbejdsgange i forbindelse med de geofysiske undersøgelser, som benytter akustisk udstyr, vil følge gældende retningslinjer (Energistyrelsen, 2018) om at minimere risiko for skade på havpattedyr under geofysiske undersøgelser. For at minimere påvirkningen på havpattedyr vil der under de geofysiske undersøgelser således være en erfaren havpattedyrsobservatør ombord, som visuelt holder øje med tilstedeværelsen af havpattedyr. Formålet er at sikre, at ingen havpattedyr kommer inden for en specificeret afstand af undersøgelsesfartøjet forud for opstart af udstyret.

De geofysiske undersøgelser udføres på hele strækningen fra den danske EEZ til de to ilandføringspunkter svarende til en længde på ca. 615 km.

Tabel 2.2 viser en oversigt over hvilket udstyr, som skal bruges, og er beskrevet efterfølgende. Det drejer sig om følgende udstyr: Multibeam ekkolod (MBES); side-scan sonar (SSS); Ultra-short baseline (USBL); sub-bottom profiler (SBP) og et magnetometer.

De geofysiske undersøgelser udføres på hele strækningen fra den danske EEZ til de to ilandføringspunkter svarende til en længde på ca. 615 km.

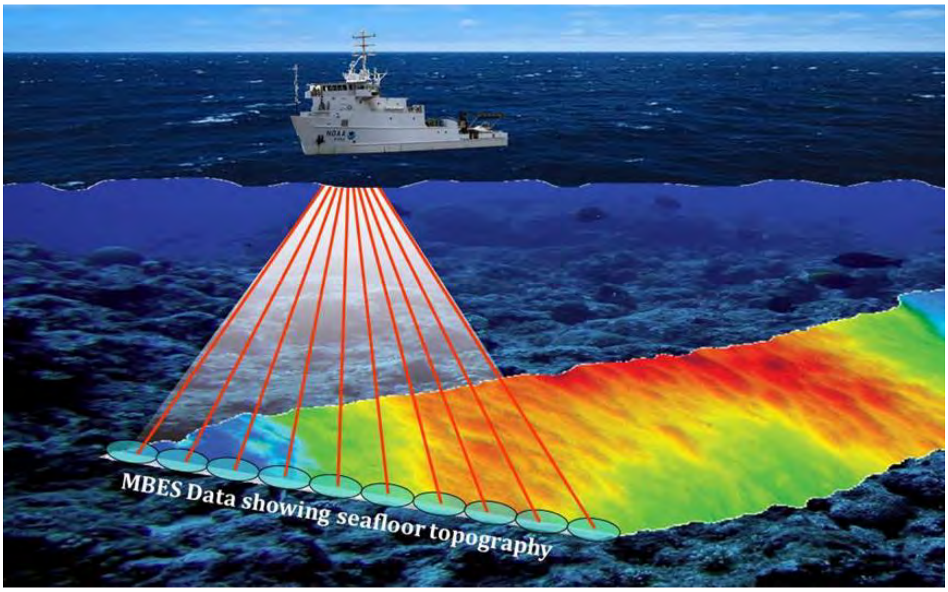
Tabel 2.2. Udstyr som skal benyttes i forbindelse med de geofysiske undersøgelser.

Udstyrstype	Formål	Frekvensområde
Multibeam Echo Sounder (MBES)	Måling af detaljeret bathymetri	190 kHz to 400 kHz
Side Scan Sonar (SSS)	Generering af højopløselige 2D billeder af havbunden og kortlægning af objekter på havbundens overflade	230 kHz to 850 kHz
Ultra-Short Base Line (USBL)	Positionering af udstyr, som trækkes efter undersøgelsesfartøjet	19 kHz to 34 kHz
Sub-bottom Profiler (SBP) - Parametric	Profilering af de øverste geologiske lag i havbunden og belysning af potentiale og risici for nedgravning af kablet	4 to 15 kHz, 85 to 115 kHz
Magnetometer	Identificering af metalliske vragdele, potentielle UXO, rørledning, undersøiske kabler m.m.	Passiv – udsender ikke akustiske signaler

2.2.2.1. Multibeam ekkolod (MBES)

Multibeam ekkolod skal bruges til at kortlægge vanddybden, havbundstopografien og objekter i vandsøjlen og vil skabe en detaljeret 3D kortlægning af bathymetrien i kabelkorridoren (Figur 2.3).

MBES er monteret på skroget af fartøjet og kortlægger ved hjælp af akustiske signaler vanddybden under fartøjet i en bredde svarende til 4–8 gange vanddybden. Der vil blive brugt en Reson Teledyne Seabat T50, som opererer ved frekvenser mellem 190 kHz–400 kHz, hvilket er udenfor det hørbare område for fisk og havpattedyr, og derfor er der ikke udført undervandsstøjmodellering for udstyret.

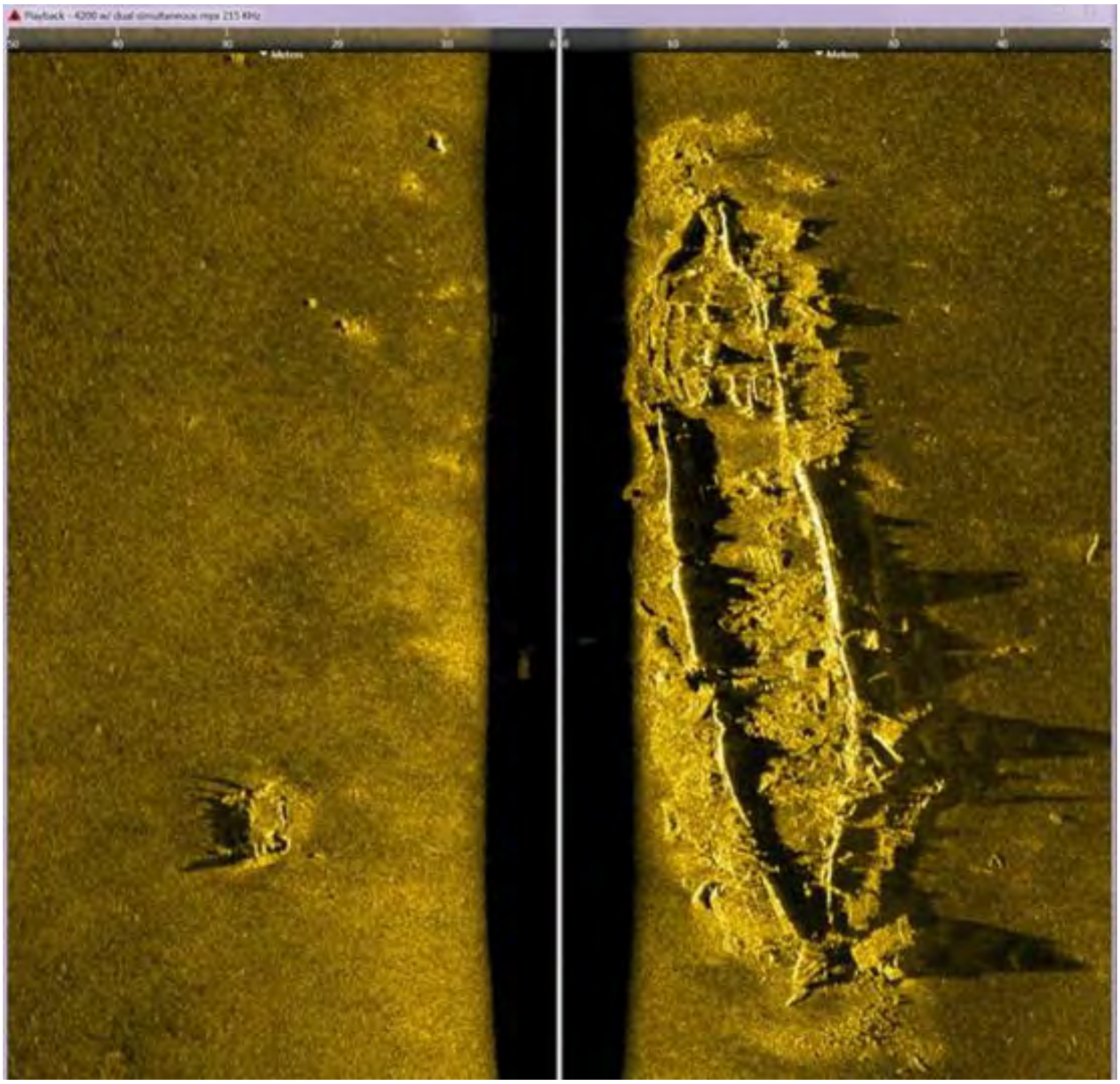


Figur 2.3. Grafisk illustration af MBES undersøgelse af havbunden (foto: fis01334, NOAA photo library)

2.2.2.2. Side-scan sonar (SSS)

Side-scan sonar genererer højopløselige 2D billeder af havbunden og skal bruges til at kortlægge havbundens overflade og eventuelle objekter, som ligger på havbunden (Figur 2.4). SSS trækkes via et kabel bag ved undersøgelsesfartøjet. Bredden på det kortlagte område vil afhænge af den frekvens, lydstyrke og andre kildekonfigurationer, som anvendes i forbindelse med undersøgelsen, men kortlægningsbredden vil typisk være ca. 50–125 m til hver side af sejllinjen. For at opnå fuld dækning og korrekt afbildning med SSS af havbunden, skal et givent område af havbunden passeres to gange i modsatte retninger med 100 % overlap. Herved sikres også, at området under sejlinjen dækkes.

Der anvendes en to-frekvent Edgetech 4205 side-scan sonar, hvor frekvensen af de anvendte akustiske signaler er mellem 230 kHz og 850 kHz. Dette er uden for det hørbare område for fisk og havpattedyr. Derfor er der ikke udført undervandsstøjmodellering for udstyret. Da SSS trækkes med kabel, benyttes en USBL (Ultra-Short Baseline) til at positionere SSS (se næste afsnit 2.2.2.3).



Figur 2.4. Billede af skibsvrag på havbunden. Data samles til hver side af sejllinjen, hvorfor der på billedet mangler data umiddelbart under undersøgelsesfartøjet. (Foto: EdgeTech).

2.2.2.3. Ultra-short Baseline (USBL)
Ultra-Short Baseline bruges til at bestemme den relative position af udstyr, som trækkes i forhold til undersøgelsesfartøjet, her SSS og magnetometer. USBLen er monteret på skroget af fartøjet. Positionering sker ved brug af lyd, hvor der typisk udsendes et akustisk signal hvert 0,5 sekund. I nærværende undersøgelse benyttes en Sonardyne Ranger 2 USBL (HPT 3000 transceiver og en omni-direktionel minitransponder (8190–3111)).

Sonardyne USBLen arbejder ved omkring 20–34 kHz. Da USBLen opererer ved frekvenser, som er hørbare for havpattedyr, er der udført en modelleringen af undervandsstøjen fra udstyret, som findes i Bilag 2.

2.2.2.4. Sub-bottom Profiler (SBP)
Sub-bottom profiler skal bruges til at lave en profil af de øverste geologiske lag i havbunden for at undersøge ændringer i sedimentet og synliggøre strukturer, som kan være begravet heri. SBP'en kan lave en profil af sedimentet ned til mange meters dybde, afhængig af hvilke geologiske lag, som sedimentet består af. Formålet med SBP-undersøgelsen i nærværende ansøgning er dog blot at undersøge de øverste geologiske lag for at belyse potentialet for nedgravning af kablet samt potentielle risici i forbindelse med installation. Der fokuseres derfor ikke på de dybe geologiske lag, som det ses i eksempelvis seismiske undersøgelser foretaget af råstofindustrien eller i forbindelse med anlæg af havvindmølleparker.

Den geologiske profil fremkommer ved at sende lyd ned i havbunden, og målingerne foretages direkte under sejllinjen. I nærværende undersøgelse benyttes en Innomar Medium 100, som opererer ved frekvenserne 85kHz–115kHz samt 4kHz til 15kHz. Da SBPen opererer ved frekvenser, som er hørbare for havpattedyr, er der udført en modelleringen af undervandsstøjen fra udstyret, som findes i Bilag 2.

2.2.2.5. Magnetometer
Der skal anvendes et magnetometer til at genkende magnetiske objekter på havbunden og i de øverste lag af havbunden. Det kan være metalliske vragdele, UXO, rørledninger, undersøiske kabler eller sten med naturlige forekomster af metal. Magnetometeret vil være af typen Geometrics G-882 og trækkes i nærværende undersøgelse efter fartøjet i tandem med SSS. Magnetometeret udsender ikke akustiske signaler, men da det trækkes efter undersøgelsesfartøjet, anvendes USBL til positionering.

En undersøgelse med magnetometer med en linjeafstand på omtrent 15–20 m forventes at kunne identificere genstande på mere end 100 kg på eller nær havbundens overflade (Geometrics, 2020) og bruges som en indledende screening af området for potentielle UXO og andre genstande.

2.2.3. Fartøjer
Kystnært, på dybder fra 3–15 m, benyttes et mindre fartøj til at gennemføre undersøgelserne (Bilag 3). Dybgangen af fartøjet er forventeligt på omtrent 1,4–1,5 m. I dette område er kabelkorridoren 250 m bred og der vil være behov for at gennemføre minimum 9 transektlinjer (på grund af den lavere dybde) for at sikre 100% overlap af SSS undersøgelsen og 20% af MBES undersøgelsen. Dette svarer til en afstand på 15-20 m mellem linjerne.

Fra dybder, som overstiger 15 m, benyttes undersøgelsesfartøjet Glomar-Vantage (Bilag 3). Her er kabelkorridoren 400 m bred, og her vil der være behov for minimum 5 transektlinjer for at sikre 100 % overlap af SSS undersøgelsen og 20% af MBES undersøgelsen. Både den kystnære undersøgelse og offshore delen af undersøgelsen vil foregå med en sejlhastighed på omkring 4 knob.

2.2.4. Tidsplan
De geofysiske undersøgelser ønskes udført inden for tidsperioden maj til ultimo september 2024. Det forventes, at de marine geofysiske undersøgelser inden for dansk farvand vil tage ca. 5 uger i alt, og at undersøgelserne vil

blive gennemført over en periode på 2 måneder, hvor der tages højde for vejrlig og andre operationelle forhold.

Tidsplanen for undersøgelserne fremgår af Tabel 2.3 og baseres på en gennemsnitlig indsamling af 100 km data pr. dag (med 24 timers drift i offshore områder og 12 timers drift i de kystnære områder). Tidsplanen tager ikke højde for den tid, hvor undersøgelsesaktiviteterne ville blive sat på pause på grund af vejret, ventetid på tidevand og strøm, eller skibets transit til havn for at få nye forsyninger.

Tabel 2.3. Estimeret tidsforbrug og tilsvarende undersøgelsesareal for de geofysiske undersøgelserne ekskl. forbehold for vejr m.m. Strækningen er i alt omtrent 615 km.

Delområde	**Undersøgelser**	**Tidsplan**
		Q2-Q3 2024
(1) Nordlig offshore korridor	*MBES, SSS, USBL, SBP, Magnetometer*	15 dage
(2) Nordlig kystnær korridor	*MBES, SSS, USBL, SBP, Magnetometer*	16 timer
(3) Sydlig offshore korridor	*MBES, SSS, USBL, SBP, Magnetometer*	9,5 dage
(4) Sydlig kystnær korridor	*MBES, SSS, USBL, SBP, Magnetometer*	35 timer

2.3. Påvirkninger fra de geofysiske undersøgelser

Undervandsstøj fra de geofysiske undersøgelser kan potentielt medføre negative påvirkninger på det marine liv (havpattedyr og fisk). I det følgende gennemgås resultaterne fra undervandsstøjmodelleringen samt de fastsatte grænseværdier samt vurderingskriterier i forhold til høreskader og adfærdspåvirkninger hos hvaler og sæler samt midlertidigt høretab og skade på fisk.

2.3.1. Tærskelværdier for havpattedyr

Intens udæmpet undervandsstøj kan medføre fysiske skader i form af midlertidig (TTS) eller permanent (PTS) høretab samt adfærdspåvirkninger hos hvaler og sæler. Tabel 2.4 viser de anvendte grænseværdier for PTS, TTS og adfærd (hvor det er relevant) for havpattedyr.

Tabel 2.4. Grænseværdier anvendt for midlertidigt og permanent høretab samt adfærdspåvirkninger for havpattedyr (NOAA, 2018, (Southall, et al., .

	PTS grænseværdi ($L_{E,CUM,24XX}$, dB re 1 μPa²s)		TTS grænseværdi ($L_{E,CUM,24XX}$, dB re 1 μPa²s)		Adfærdstærskel ($L_{p,125ms,24XX}$, dB re 1 μPa²s)
	Ikke-impulsiv støj	Impulsiv støj	Ikke-impulsiv støj	Impulsiv støj	
Marsvin	173	155	153	140	103
Vågehval	199	183	179	168	-
Hvidnæse	198	185	178	170	
Sæler	201	185	181	170	-

Hovedlinjerne i anbefalingerne er, at grænseværdien for tilladelig eksponering af havpattedyr defineres af den mindste påvirkning, der kan medføre et permanent høretab. Disse grænseværdier udregnes som kumuleret akustisk energi (eksponeret dosis, sound exposure level) over den samlede eksponering af dyret, dog begrænset til et maksimum på 24 timer. Det betyder i praksis, at dosis skal beregnes for den samlede påvirkning, et dyr udsættes for, når undersøgelsesfartøjet sejler forbi dyret. Dosis beregnes fra frekvensvægtede lydtryk, hvorved der tages højde for, at de forskellige arter ikke har lige god hørelse over hele frekvensspektret (Kyhn, et al., 2021a).

Undervandsstøj kan medføre forstyrrelse af havpattedyrenes adfærd. Adfærdsændringen kan enten være i form af bortskræmning fra et større eller mindre område omkring støjkilden, hvilket giver ophav til et midlertidigt habitattab (dyrene antages at vende tilbage til området, når støjkilden er væk) eller ophør af fødesøgning eller hvile (Bas, et al., 2017). I begge tilfælde er effekten en negativ påvirkning af dyrenes energibalance på grund af et øget energiforbrug til flugt og mindre tid til rådighed for fødesøgning. En enkeltstående, mindre påvirkning vil næppe have nogen målbar effekt på det enkelte dyr, men effekten akkumuleres over gentagne forstyrrelser, og ved en vis dosis kan påvirkningen være tilstrækkelig til, at dyrets overlevelse og/eller reproduktion påvirkes negativt. Sker dette samtidigt for et større antal individer, kan den samlede effekt have en negativ påvirkning på bestanden (lavere bærekapacitet og lavere vækstrate) (Kyhn, et al., 2021a).

En adfærdsændring må f.eks. ikke sidestilles med fortrængning, idet marsvin-populationer i danske farvande har vist høje koncentrationer selv i områder med højintensitet for skibstrafik, hvor der forventes høje støjniveauer (Sveegaard, et al., 2011).

I praksis er det imidlertid meget vanskeligt at estimere disse påvirkninger på bestandsniveau og i praksis umuligt at måle dem direkte. Vurderingen af påvirkningen af adfærd hos havpattedyr må derfor i stedet tage udgangspunkt i kvalitative kriterier (Kyhn, et al., 2021a), se Tabel 2.5.

Tabel 2.5. Kriterier for vurdering af påvirkning af adfærd hos havpattedyr (Kyhn, et al., 2021a).

Påvirkning	Kriterier/Betingelser
Ubetydelig	Antallet af påvirkede individer er ubetydeligt i forhold til populationens størrelse. Den samlede påvirkning af levested i området er ubetydelig.
Lille	Kortvarig forstyrrelse af en mindre del af det tilgængelige areal, som er uden betydning for dyrenes tidsbudget og energibalance.
Medium	Betydelig forstyrrelse af betydelige dele af det tilgængelige areal og/eller over et betydeligt tidsrum, med (midlertidigt) habitattab til følge og herved påvirkning af energibalancen for et betydeligt antal individer.
Betydelig	Svære forstyrrelser af store områder gennem længere tidsrum, med betydeligt (midlertidigt) habitattab til følge og heraf påvirkning af individers energibudget i en grad, der påvirker dyreneres overlevelses og ynglesucces.

For de øvrige arter findes ikke generaliserede reaktionstærskler, dvs. tærskler udtrykt ved et modtaget lydtryk, evt. frekvensvægtet som for marsvin. I stedet må man sammenholde konkrete målte reaktionsafstande til konkrete lydkilder og foretage en kvalitativ vurdering af, hvor sammenlignelige de empiriske data er med støj-påvirkningen fra det aktuelle måleudstyr i undersøgelsen.

2.3.2. Tærskelværdier for fisk

Undervandsstøj fra de geofysiske undersøgelser kan påvirke fisk i alle livsstadier ved at medføre fysiske skader eller hørenedsættelse eller adfærdspåvirkning. De mest sårbare arter er fisk med svømmeblærer (f.eks. sild og brisling) (Popper A. , et al., 2014). Der er ikke fastsat danske retningslinjer for tålegrænser for fisk, men det svenske Naturvårdsverket har angivet tålegrænser for død og vævsskader med død til følge for sild, torsk samt fiskeæg og fiskelarver (Andersson M. H., et al., 2016; Popper A. , et al., 2014). Popper et al. (2014) angiver en tålegrænse for midlertidig hørenedsættelse baseret på andre fiskearter, der ligesom torsk og sild har en svømmeblære. Da tålegrænsen er baseret på andre arter, skal den anvendes med en vis forsigtighed. De anvendte tærskelværdier er vist i Tabel 2.6. Der findes ikke videnskabelige studier, der understøtter adfærdstærskelværdier for fisk.

Tabel 2.6. Grænseværdier anvendt for midlertidig hørenedsættelse samt skade for fisk samt fiskeæg og larver (Andersson M. , et al., 2016a), (Popper A. , et al., 2014).

	Svømmehastighed (m/s)	TTS grænseværdi ($L_{E,CUM,24XX}$, dB re 1 μPa²s)	Skade ($L_{E,CUM,24XX}$, dB re 1 μPa²s)
Juvenil torsk	0,38	186	204
Adult torsk	0,90	186	204
Sild	1,04	186	204
Fiskeæg og larver	-	-	207

2.3.3. Resultat af undervandsstøjmodellering

Jf. projektbeskrivelsen vil de geofysiske undersøgelser foregå efter standardiserede procedurer med udstyrspakker, der typisk anvendes ved havbundsundersøgelser. Undervandsstøj fra de geofysiske undersøgelser vil potentielt kunne påvirke havpattedyr og fisk. Der er i forbindelse med nærværende ansøgning for Verena gennemført en støjmodellering for den type af udstyr, som vil blive brugt til de geofysiske undersøgelser, og som kan medføre negative påvirkninger på havpattedyr og fisk (se bilag 2). På baggrund af modelleringen er de forventede påvirkningsafstande for havpattedyr (marsvin, vågehval, hvidnæser og sæler) samt fisk beregnet. For havpattedyrene er påvirkningsafstandene angivet for midlertidig (TTS) og permanent (PTS) høretab samt adfærdspåvirkninger hos marsvin. Adfærdspåvirkning kan være i form af ophør i fødesøgning, øget svømmehastighed, flugt m.v.

De modellerede påvirkningsafstande er listet i Tabel 2.7 for havpattedyr, og er vist for de udstyrstyper, der vil blive benyttet til undersøgelsen, og som udsender støj i frekvensområdet for havpattedyrs hørelse. For både hvidnæser, vågehvaler og sæler er påvirkningsafstandene for både PTS og TTS mindre end 100 m. For marsvin er påvirkningsafstandene hhv. mindre end 100 m for PTS og op til 1650 m for TTS. Den største påvirkningsafstand i forhold til adfærdspåvirkninger hos marsvin opstår ved brug af USBL, som overskrider tærsklen for adfærdspåvirkninger hos marsvin ud til en afstand på 4,5 km fra undersøgelsesfartøjet.

Tabel 2.7. Påvirkningsafstande fra de geofysiske undersøgelser for havpattedyr. Påvirkningsafstandene er angivet som worst-case positionen. Påvirkningsafstandene er angivet for følgende udstyrstyper: Innormar Medium 100 (SBP), Sonardyne HPT 3000 (USBL unit), og Sonardyne WMT 8190 (USBL transponder) samt med alle geofysiske kilder aktive på samme tid.

	Udstyr	**Påvirkningsafstand**		
		PTS	TTS	Adfærd
Marsvin	Innomar	< 100 m	130 - 375 m	675 m
	Sonardyne HPT	< 100 m	675 – 1650 m	4,5 km
	Sonardyne WMT	< 100 m	325 – 875 m	3,6 km
	Alle kilder	< 100 m	675 – 1650 m	4,5 km
Hvidnæser	Innomar	< 100 m	< 100 m	-
	Sonardyne HPT	< 100 m	< 100 m	-
	Sonardyne WMT	< 100 m	< 100 m	-
	Alle kilder	< 100 m	< 100 m	-
Vågehvaler	Innomar	< 100 m	< 100 m	-
	Sonardyne HPT	< 100 m	< 100 m	-
	Sonardyne WMT	< 100 m	< 100 m	-
	Alle kilder	< 100 m	< 100 m	-
Sæler	Innomar	< 100 m	< 100 m	-
	Sonardyne HPT	< 100 m	< 100 m	-
	Sonardyne WMT	< 100 m	< 100 m	-
	Alle kilder	< 100 m	< 100 m	-

Der er generelt mangel på viden om adfærdspåvirkninger hos vågehvaler, hvidnæser, spættede sæler og gråsæler i forhold til undervandsstøj fra geofysiske undersøgelser. For sæler er der udført nogle få studier i forhold til adfærdspåvirkninger, når sælerne udsættes for undervandsstøj. Et enkelt studie fra 1998 undersøgte adfærdsreaktioner hos spættede sæler og gråsæler udstyret med satellitsendere, når de blev udsat for en times kontrolleret eksponering af et airgun-array (Thompson, Sjoberg, Bryant, Lovell, & Bjorge, 1998; Gordon, et al., 2003. Både spættede sæler og gråsæler svømmede væk fra arrayet, og stoppede tilsyneladende med at spise, indtil et par timer efter eksponeringen endte. En enkelt spættet sæl viste dog ikke nogen åbenlys reaktion, og blev set inden for 300 m af det aktive array. Denne ene sæls reaktion er mere lig de reaktioner man har observeret hos ringsæler i Alaska i forbindelse med et seismisk survey (Harris, Miller, & Richardson, 2001. Under konstruktionen af en havvindmøllepark i det sydøstlige England, fandt man at spættede sæler udviste undvigeadfærd i en afstand på op til 25 km fra nedramningsstedet af pælefundamenter (Russell, et al., 2016). Baseret på resultaterne har Russell et al. (2016) foreslået, at afstande for adfærdspåvirkning hos sæler er sammenlignelige med afstande for adfærdspåvirkning hos marsvin. Som et forsigtighedsprincip er det antaget, at sæler reagerer på undervandsstøj i samme afstand som marsvin. Hvilket i dette tilfælde svarer til adfærdspåvirkninger hos sæler på 4,5 km.

For fisk er påvirkningsafstandene angivet for midlertidig høretab (TTS) og skade. De modellerede påvirkningsafstande er listet i Tabel 2.8 for fisk samt fiskeæg og larver, og er vist for de udstyrstyper, der vil blive benyttet til undersøgelsen og som udsender støj i frekvensområdet for fiskenes hørelse. Der er en stor diversitet i, hvor godt de forskellige arter af fisk kan høre. Generelt gælder, at de arter af fisk, som ikke har specialiserede hørerorganer, hører i et frekvensområde, som spænder fra de dybe infralyde (<20 Hz) til nogle få 100 Hz (Sand & Karlsen, 2000). Dette gælder for alle arter uden svømmeblære, som f.eks. fladfisk, kutling og stør. Fisk som sild har en god hørelse, da en forbindelse mellem deres indre øre og den gasfyldte svømmeblære, forbedrer deres hørelse markant og gør, at de kan høre frekvenser fra infralydsområdet op til ca. 8 kHz, dog med aftagende følsomhed mod de højere frekvenser (Enger, 1967; Sand & Karlsen, 2000). Torsk har også en svømmeblære, men uden samme specialisering som sild, og kan høre fra infralydsområdet op til ca. 500 Hz (Chapman & Hawkins, 1973). Fisk uden svømmeblære eller uden en mekanisk kobling mellem det indre øre og svømmeblæren eller andre luftfyldte strukturer (som f.eks. laksefisk herunder snæbel) er mindre følsomme over for støj end sild og brisling, og det forventes derfor, at tålegrænserne for arter uden svømmeblære vil være højere (Andersson M. H., et al., 2016).

For både skade eller TTS hos fisk og fiskeæg og larver er påvirkningsafstandene mindre en 100 m og dermed meget begrænset.

Tabel 2.8. Påvirkningsafstande fra de geofysiske undersøgelser for fisk. Påvirkningsafstandene er angivet som worst-case positionen. Påvirkningsafstandene er angivet for følgende udstyrstyper: Innormar Medium 100 (SBP), Sonardyne HPT 3000 (USBL unit), og Sonardyne WMT 8190 (USBL transponder) samt med alle geofysiske kilder aktive på samme tid.

	Udstyr	**Påvirkningsafstand**	
		Skade	TTS
Torsk	Innomar	< 100 m	< 100 m
	Sonardyne HPT	< 100 m	< 100 m
	Sonardyne WMT	< 100 m	< 100 m
	Alle kilder	< 100 m	< 100 m
Sild	Innomar	< 100 m	< 100 m
	Sonardyne HPT	< 100 m	< 100 m
	Sonardyne WMT	< 100 m	< 100 m
	Alle kilder	< 100 m	< 100 m
Fiskeæg og larver	Innomar	< 100 m	-
	Sonardyne HPT	< 100 m	-
	Sonardyne WMT	< 100 m	-
	Alle kilder	< 100 m	-

2.3.4. Fysiske forstyrrelser

Fartøjernes tilstedeværelse kan medføre forstyrrelse i form af selve sejladsen forbundet med undersøgelsen, samt luftbåren lyd og undervandslyd, hvilket potentielt kan resultere i påvirkning af det marine liv.

Havpattedyrene kan påvirkes kortvarigt af undersøgelsesfartøjernes tilstedeværelse. Skibstrafik karakteriseres generelt som kontinuerlig støj og vil ikke kunne adskilles fra de omgivende støjniveauer. Undersøgelsesfartøjerne vil medføre en relativ kortvarig (omkring 27 dage) forstyrrelse, som er begrænset i tid og rum. Derudover bevæger fartøjerne sig kontinuerligt med langsom hastighed på 4 knob under undersøgelsen. Dette, kombineret med at området i forvejen er ret trafikeret, gør at den fysiske forstyrrelse fra fartøjet vurderes at ville medføre ubetydelige påvirkninger på fugle, havpattedyr og fisk.

3. Relevante miljøemner

I de følgende afsnit beskrives eksisterende forhold i og omkring undersøgelsesområdet for kabelkorridoren med særlig udgangspunkt i de internationale bestemmelser, nationale love og planer, der er gældende for området. For de enkelte miljøemner tages der stilling til, om det pågældende emne kan blive påvirket negativt af de geofysiske undersøgelser. Såfremt det konkluderes, at et givent miljøemne ikke vil blive påvirket negativt af de geofysiske undersøgelser, beskrives emnet ikke yderligere. Hvis et emne kan blive påvirket negativt af de geofysiske undersøgelser, vil påvirkningens omfang af det pågældende miljøemne blive vurderet i afsnit 4 Vurdering af undersøgelsernes mulige miljøpåvirkninger.

Beskrivelserne i nærværende afsnit ligger til grund for de efterfølgende vurderinger af miljøpåvirkninger fra undersøgelsen.

3.1. Naturforhold

Beskrivelsen af naturforhold er opdelt i henholdsvis bilag IV-arter og Natura 2000-områder. Øvrige marin biologiske forhold som bentisk flora og fauna samt fisk (ikke bilag IV) beskrives ikke nærmere, da undersøgelserne ikke vil have en direkte påvirkning af havbunden i form af skrab, boreprøver eller installationer på havbunden ligesom at undervandsstøj ikke vil påvirke det generelle fiskesamfund (afsnit 2.3.3).

3.1.1. Bilag IV-arter

Bilag IV i EU's habitatdirektiv (Rådets direktiv nr. 92/43/1992) indeholder en liste over udvalgte dyre- og plantearter, som medlemslandene er forpligtet til at beskytte generelt, både inden for og uden for Natura 2000-områderne. Disse arter betegnes bilag IV-arter. Ifølge vejledningen til habitatbekendtgørelsen (Miljøstyrelsen, 2020) gælder følgende:

- Der må ikke gives tilladelse til projekter eller vedtages planer m.v., der kan beskadige eller ødelægge yngle- eller rasteområder for de såkaldte bilag IV-dyrearter i deres naturlige udbredelsesområder, ligesom at bilag IV-dyrearter ikke må fanges, dræbes eller forstyrres forsætligt
- Ved vurderingen kan anvendes princippet om økologisk funktionalitet (en bred økologisk betragtning) af yngle- eller rasteområder.
- Der må ikke gives tilladelse til projekter eller vedtages planer, der kan ødelægge bilag IV-plantearter.
- Beskyttelsen kan kun fraviges i helt særlige tilfælde.

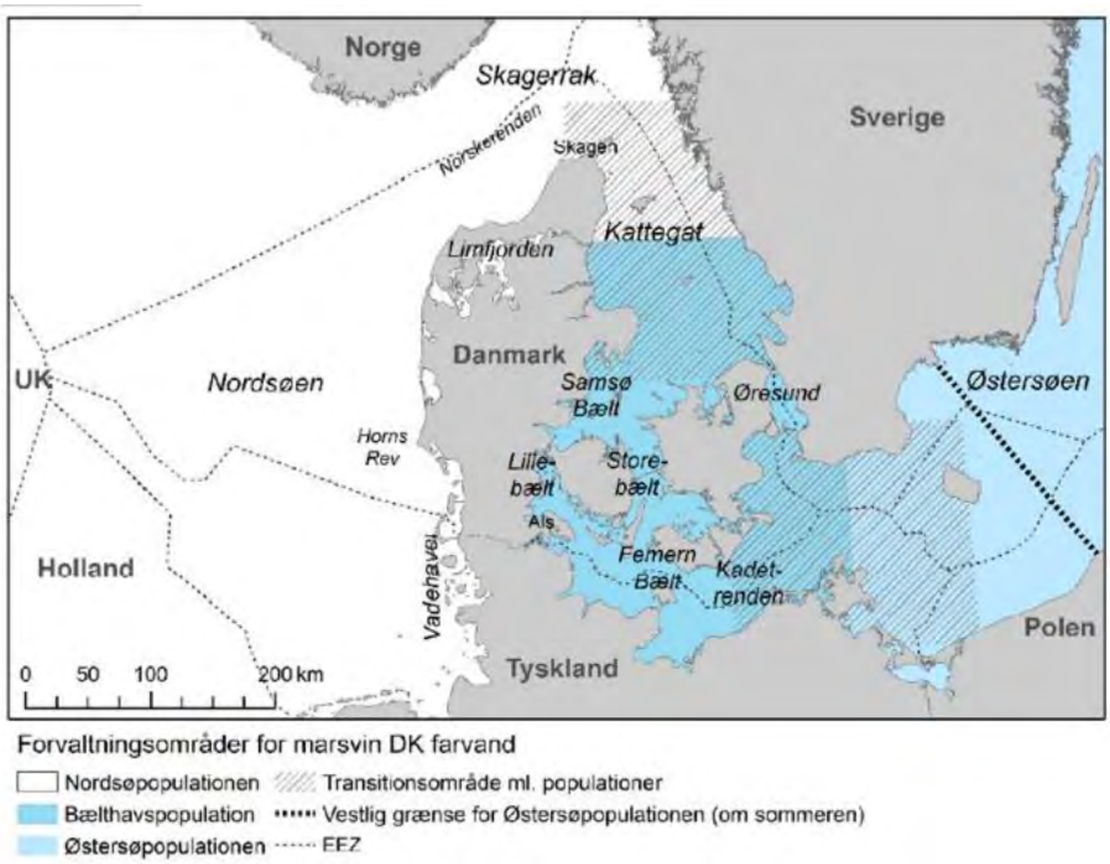
Ifølge habitatbekendtgørelsens § 10 er det ikke tilladt at gennemføre planer eller projekter, hvor der kan ske en forringelse eller ødelæggelse af et yngle- eller rasteområdes økologiske funktionalitet, og ifølge habitatdirektivets artikel 12 er det ikke tilladt forsætligt at forstyrre bilag IV-arter i deres naturlige udbredelsesområde, i særdeleshed i perioder, hvor dyrene yngler, udviser yngelpleje, overvintrer eller migrerer. Forudsætningen er, at den økologiske funktionalitet af et yngle- eller rasteområde for bilag IV-arter opretholdes på mindst samme niveau som hidtil. Med økologisk funktionalitet menes de vilkår, som et yngle- og rasteområde kan tilbyde en bestand af en art. Den økologiske funktionalitet er således medvirkende til at sikre forekomsten af yngle- og rasteområder, som arten er afhængig af.

Alle hvaler er bilag IV-arter. Flere arter af hvaler registreres i Nordsøen, men kun et fåtal forekommer regelmæssigt. Marsvin (*Phocoena phocoena*) er den mest almindelig hval, som forekommer i Danmark. Vågehvaler (*Balaenoptera* acutorostrata) og hvidnæser (*Langenorhyncus albirostris*) er også vurderet til at være en stabil del af den centrale og nordlige del af Nordsøen. De tre arter af hvaler, kan alle forekomme i undersøgelsesområdet og beskrives nedenfor. Snæblen (*Coregonus oxyrhynchus*) og den europæiske stør (*Acipenser sturio*) er de eneste danske fiskearter, som optræder på habitatdirektivets bilag IV og begge arter findes i Vadehavet. Da de kan findes i undersøgelsesområdet, beskrives arterne nedenfor.

3.1.1.1. Marsvin

Marsvin er en lille tandhval, som har sin udbredelse i hele Nordatlanten, det nordlige Stillehav og Sortehavet. Val i danske farvande er den eneste som med sikkerhed yngler i danske farvande. Yngleperioden strækker sig fra april til september men topper i juni og juli (Sonntag, Benke, Hiby, Lick, & Adelung, 1999). Det er forventeligt, at marsvin, særligt mødre og kalve, vil være følsomme for forstyrrelse i denne periode. Marsvin færdes fortrinsvis i kystnære områder, hvor de både søger føde og yngler, men arten opholder sig dog også offshore og kan i andre dele af deres udbredelsesområde findes på store dybder (Nielsen, et al., 2018; Gilles, et al., 2023).

Forvaltningsmæssigt opdeles marsvin i de danske farvande i tre populationer: Østersøpopulationen, Bælthavspopulationen og Nordsøpopulationen (Figur 3.1). Det er marsvin fra Nordsøpopulationen, som forekommer i undersøgelsesområdet.



Figur 3.1. Forvaltningszoner for de tre populationer af marsvin i danske farvande (Sveegaard, Nabe-Nielsen, & Teilmann, 2018).

Bestanden for Nordsøen (ICES, 2014) er i 2022 estimeret til 339.000 individer med en tæthed på 0,55 individer/km^2 i hele Nordsøen og bestanden vurderes at være stabil (Gilles, et al., 2023). Generelt er fordelingen og tætheden af marsvin i et givent område primært styret af fødetilgængeligheden (Sveegaard, et al., 2012), og derfor har marsvin i danske farvande en uens fordeling, hvor de samler sig i kerneområder, hvor tætheden er højere (Sveegaard, Nabe-Nielsen, & Teilmann, 2018).

Marsvin er fredet i Danmark og er omfattet af ASCOBANS, OSPAR, HELCOM, CITES, Bern-og Bonn-konventionerne, som forpligter medlemslandene, på forskellig vis, til at beskytte arten. På den danske Rødliste er bestanden af marsvin generelt vurderet som 'livskraftig' (LC), med undtagelse af Østersøbestanden, som vurderes 'kritisk truet' (CR) (Moeslund, et al., 2019). Grundet marsvins tilstedeværelse i undersøgelsesområdet og at undersøgelserne potentielt kan have påvirkning på marsvin, vurderes denne påvirkning i afsnit 4.

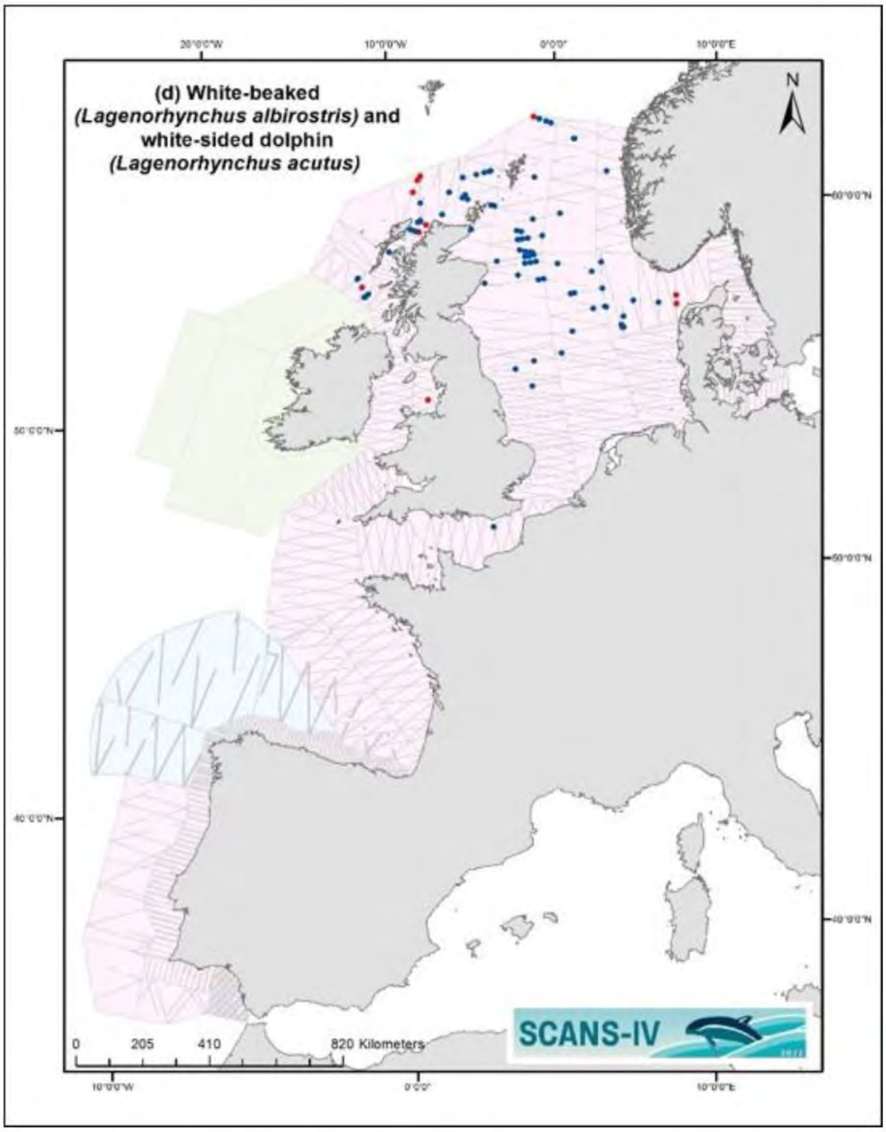
3.1.1.2. Hvidnæser

Hvidnæsen (eller hvidnæset delfin), er en mindre tandhval, som er tilknyttet de koldere tempererede og subarktiske farvande i Nordatlanten, hvor den har fire hovedudbredelsesområder, herunder Nordsøen (Galatius, A. & Kinze, A., 2018). I Nordsøen er hvidnæsen den næst talrigeste hvalrart (kun overgået af marsvin), med et bestandsestimat på cirka 46.300 individer senest optalt i 2022 (Gilles, et al., 2023).

Hvidnæser kan forekomme i hele Nordsøen, hvor deres primære udbredelse dog er i de nordlige egne (IJsseldijk, et al., 2018; Galatius, A. & Kinze, A., 2018). Observationer under SCANS-tællingerne 2022 (Gilles, et al., 2023) (men også 2005 og 2016) viser, at farvandene særligt omkring Shetlandsøerne samt den nordlige Nordsø har den største tæthed af hvidnæser (Figur 3.2). Forekomst i undersøgelsesområdet for kabelkorridoren forventes derfor at være sjælden.

Hvidnæsen parrer sig i sommerhalvåret, hvor også kalvene fødes (Galatius, A.; Jansen, O.; Kinze, C., 2013). Det er forventeligt at særligt mødre og kalve vil være følsomme for forstyrrelse i denne periode og sårbare over for forstyrrelse. Hvidnæser er fredet i Danmark samt omfattet af ASCOBANS, CITES, Bern-og Bonn-konventionerne. På både den danske Rødliste og IUCNs Rødliste er bestanden af hvidnæse vurderet som 'livskraftig' (LC) og tællinger fra 2005, 2016 og 2022 viser en stabil bestand i Nordsøen (Moeslund, et al., 2019; IUCN, 2022; Gilles, et al., 2023; Fredshavn, et al., 2019).

Støjmodelleringen af de geofysiske undersøgelser viser, at hvidnæser ikke vil blive påvirket af undervandstøj (jf. afsnit 2.3.3) og arten behandles derfor ikke yderligere.



Figur 3.2. Observationer af hvidnæser under den seneste SCANS IV-tælling i 2022 (Gilles, et al., 2023) . De blå prikker er hvidnæser, mens de røde prikker er den mindre udbredte hvidskæving (Lagenorhynchus acutus).

3.1.1.3. *Vågehval*

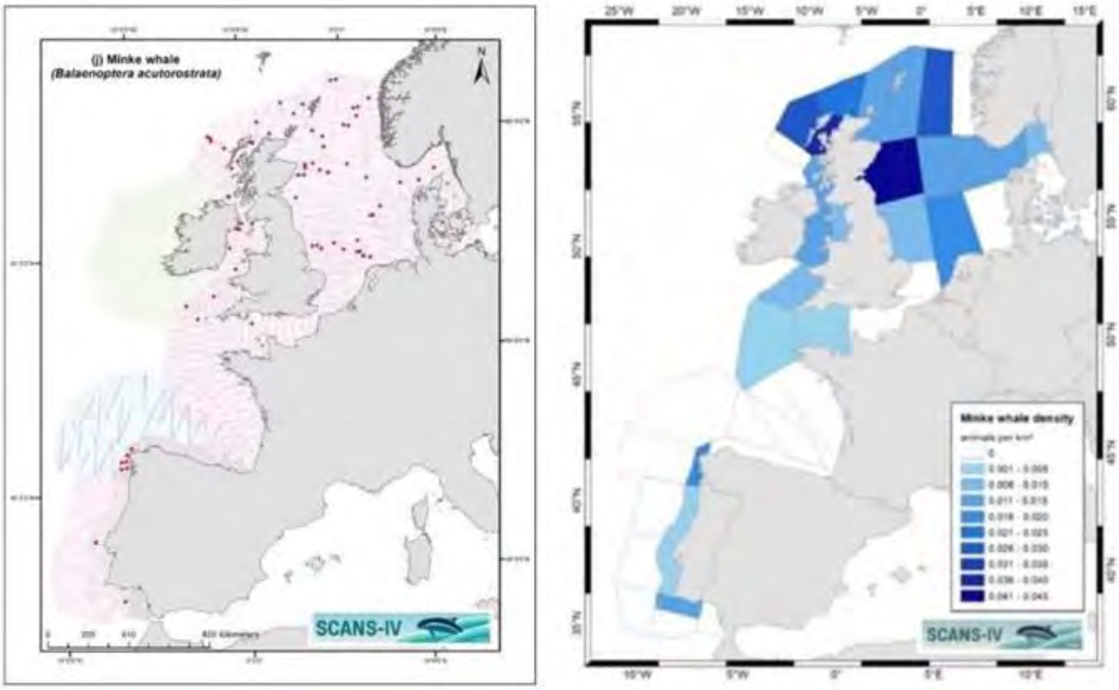
Vågehvalen er en lille og vidt udbredt bardehval, som findes i de tempererede og arktiske dele af alle oceaner, herunder i den centrale og nordlige del af Nordsøen (NAMMCO, 2021). Vågehvaler i Nordsøen er sandsynligvis en del af en større bestand af vågehvaler i Nordøst Atlanten, men der hersker usikkerhed omkring den egentlige bestandsstruktur af vågehvaler i Nordatlanten (Pastene, Goto, Taguchi, & Fujise, 2022).

Tællinger viser, at populationen af vågehvaler i Nordsøen har været stabil igennem en periode fra 1989 til den seneste tælling i 2022, hvor bestanden blev estimeret til godt 7.800 individer Gilles, et al., 2023).

Viden om årstidsvariationer i forekomsten og bestandsstørrelsen af vågehvaler i de danske farvande er mangelfuld, men data fra to individer mærket med satellitsender ved Skagen viste at de vandrede til de Kanariske øer om efteråret/vinteren (Kyhn, et al., 2021). Observationer fra boreplatforme i den centrale del af Nordsø viser, at her jævnligt registreres vågehvaler fra marts til september. Det tyder på, at tilstedeværelsen af vågehvaler i

Nordatlanten har en vis sæsonvariation, og at arten i vinterhalvåret formodentligt foretager vandringer til sydligere yngleområder (f.eks. Maio et al. (2016)), som det kendes fra andre arter af bardehvaler, og at vågehvaler altså ikke føder kalve i Nordsøen.

I Nordsøen registreres en stor andel af vågehvaler i den vestlige Nordsø og med højest tætheder ud for Skotlands østkyst (Figur 3.3). I den sydlige Nordsø er arten fåtallig (Reid, Evans, & Northridge, 2003. Området mellem Doggerbanke og Fiskebanke er tilsyneladende en yndet fødesøgningslokalitet for arten i forårsmånederne, når tobis samles for at gyde (de Boer, 2010; Worsøe, Horsten, & Hoffmann, 2002), men der er ikke kendskab til specifikke kerneområder for vågehvaler i Nordsøen. Ligeledes er der ikke viden om, hvilke perioder, vågehvaler i Nordsøen eventuelt kan være særligt følsomme for forstyrrelser.



Figur 3.3. T.v) Observationer af vågehvaler i Nordsøen i forbindelse med SCANS IV-flytællinger i 2022. samt t.h) de beregnede tætheder (Gilles, et al., 2023). Jo mørkere blå des højere tæthed.

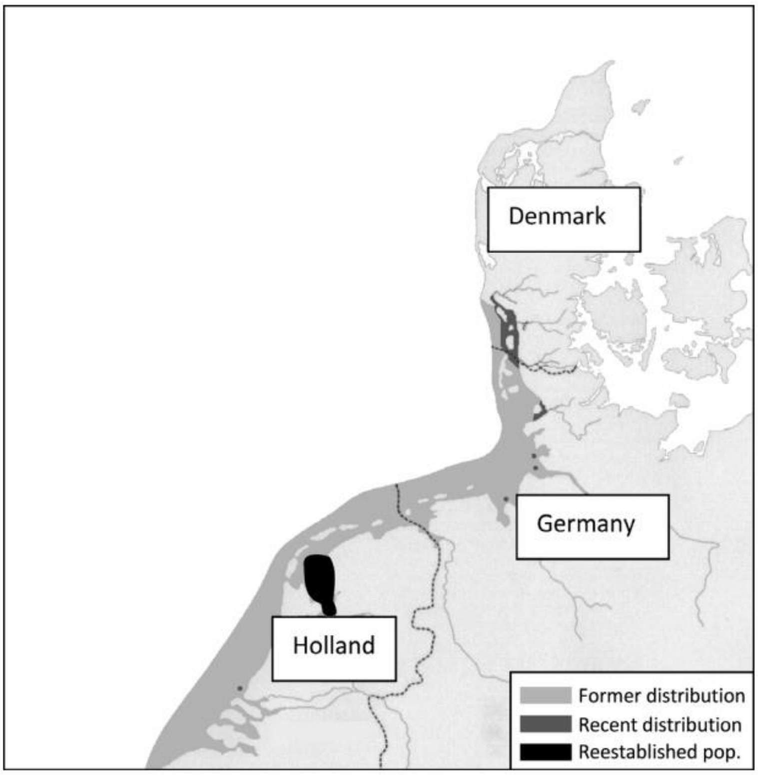
Populationen af vågehvaler i Nordsøen er vurderet som 'livskraftig' (LC) på både den danske Rødliste og IUCNs Rødliste (Moeslund, et al., 2019; Sharpe & Berggren, 2023), og bevaringsstatus for vågehvaler i dansk farvand er vurderet som gunstig (Fredshavn, et al., 2019). Vågehvaler er ligesom andre hvaler opført på habitatdirektivets bilag IV og arten er omfattet af CITES, Bern-og Bonn-konventionerne samt den Internationale Hvalfangstkommission, som beskytter storhvaler og forvalter hvalfangst.

Vågehvaler vil ikke blive påvirket af de geofysiske undersøgelser (jf. afsnit 2.3.3) og behandles derfor ikke yderligere.

3.1.1.4. Snæbel

Snæbel er en laksefisk, der lever i vandløbene fra Varde Å til Vidå. Snæblen vokser op i Vadehavet. De er gydemodne, når de er omkring 35-45 cm i længde og vandrer i November/december op i vandløbene i forbindelse med gydning (Borcherding, Pickhardt, Winter, & Becker, 2008). De er derfor helt afhængige af, at vandløbene er uden spærringer, således de ikke hindre adgang til og fra gydeområderne. Efter endt gydning vender de tilbage til havet. Bestanden af snæbel blev tidligere opretholdt ved opdræt og efterfølgende udsætninger. Den samlede bestand af snæbel er endnu meget lav, og bevaringsstatus for snæbel vurderes derfor at være stærkt ugunstig (Fredshavn, et al., 2019) og arten er vurderet som truet (*EN*) på den danske Rødliste (Moeslund, et al., 2019).

I havet forekommer snæblen primært i kystnære farvande, og i Danmark findes den i Vadehavet, ved de sydlige dele af Danmarks vestkyst og de store vandløb (Carl, Berg, & Møller, 2019; Jepsen, Deacon, & Koed, 2012), se Figur 3.4.



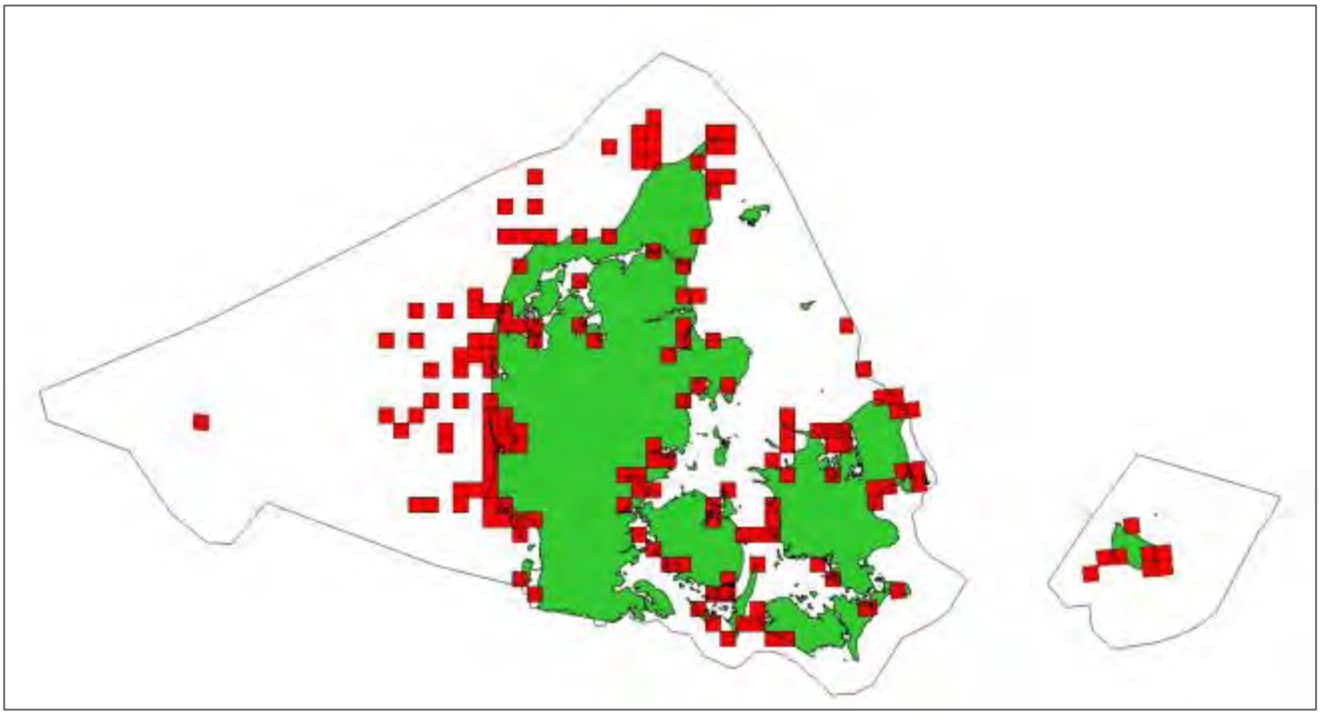
Figur 3.4. Udbredelsen af Snæbel. Lysgrå er historisk udbredelse, mørkegrå er nuværende udbredelse og sort er bestande opnået ved genudsætning (Jepsen, Deacon, & Koed, 2012).

Snæbel vil ikke blive påvirket af de geofysiske undersøgelser, da den genererede undervandsstøj er på et niveau, som ikke giver anledning til høreskade eller midlertidigt høretab (jf. afsnit 2.3.3) og behandles derfor ikke yderligere.

3.1.1.5. *Stør*

Den europæiske stør er en kystnær art, hvis fortrukne habitat til havs typisk er blødbundsområder på mindre end 50 m, hvor de lever af bentiske organismer (Møller & Carl, 2019). Arten er vurderet som kritisk truet (*CR*) på IUCNs rødliste (Gessner, Williot, Rochard, Freyhof, & Kottelat, 2022) men da viden om størens udbredelse og populationstrend er ukendt i danske farvande, er arten ikke evalueret på den danske Rødliste (Moeslund, et al., 2019). Inden for de sidste par årtier har der dog været flere registreringer langs den danske vestkyst. De registrerede individer stammer højst sandsynligt fra den tyske flod Elben, hvor en udsætningskampagne startede i 2007 og det øget antal registreringer i Nordsøen formodes at være et resultat af dette og at arten kun er til stede i dansk farvand i kraft af, at den udsættes i Tyskland. Historisk har den europæiske stør sandsynligvis aldrig været særlig talrig i dansk farvand med få dokumenterede fangster (Møller & Carl, 2019). Registreringer af europæisk stør i dansk farvand kan ses i Figur 3.5 og den kan forekomme i den kystnære del af undersøgelsesområdet.

Ligesom snæblen, yngler støren i ferskvand og trækker således op i floderne i gydeperioden. Oftest forbliver ungerne i det ferske vand til 2-4 årsalderen, hvorefter de vandrer ud i havet. Her kan de vandre langt omkring og kan således besøge danske farvande som strejfende gæst (Møller & Carl, 2019).



Figur 3.5. Registreringer af europæisk stør i danske havområder (Møller & Carl, 2019).

Stør vil ikke blive påvirket af de geofysiske undersøgelser, da den genererede undervandsstøj er på et niveau, som ikke giver anledning til høreskade eller midlertidigt høretab (jf. afsnit 2.3.3) og behandles derfor ikke yderligere.

3.1.2. Natura 2000-områder

EU har vedtaget to naturbeskyttelsesdirektiver, som pålægger EU's medlemslande at bevare arter og naturtyper:

- EU's habitatdirektiv (Rådets direktiv nr. 92/43/1992) har til formål at beskytte arter og naturtyper, der er karakteristiske, truede, sårbare eller sjældne i EU. Hvert EU-land skal udpege områder, der kan fungere som sikre levesteder for de naturtyper og arter, som er opført på habitatdirektivets bilag I og II. Disse områder betegnes habitatområder.
- EU's fuglebeskyttelsesdirektiv (Europa-Parlamentets og rådets direktiv 2009/147/EF af 30. november 2009) har til formål at beskytte levesteder og rasteområder for fugle, som er sjældne, truede eller følsomme over for ændringer af levesteder i EU. Hvert EU-land skal udpege områder for at beskytte fugle, der er omfattet af fuglebeskyttelsesdirektivet. Disse områder benævnes fuglebeskyttelsesområder.

Natura 2000 er betegnelsen for det internationale netværk af habitatområder og fuglebeskyttelsesområder i EU. For hvert Natura 2000-område er der en liste – det såkaldte udpegningsgrundlag – med naturtyper, arter og fugle, som det enkelte område er udpeget for at beskytte. Formålet med Natura 2000-netværket er at sikre gunstig bevaringsstatus for de arter og naturtyper, som er på udpegningsgrundlaget for de enkelte Natura 2000-områder.

I Danmark er habitatbekendtgørelsen (BEK nr 2091 af 12/11/2021) en væsentlig del af implementeringen af EU's habitatdirektiv og EU's fuglebeskyttelsesdirektiv, og habitatbekendtgørelsen har blandt andet til formål at udpege internationale naturbeskyttelsesområder og fastsætte regler for administrationen af disse områder.

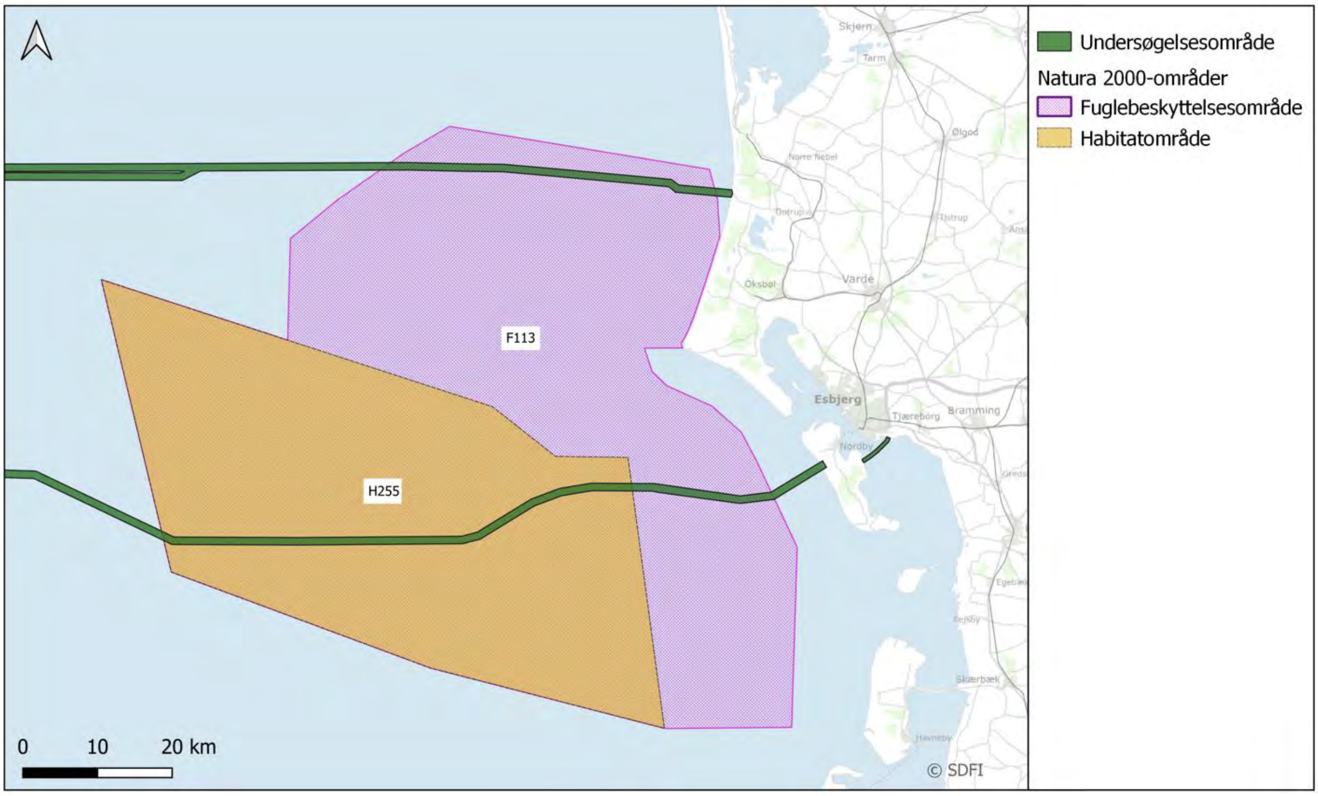
Det fremgår af § 3 i bekendtgørelse om administration af internationale naturbeskyttelsesområder samt beskyttelse af visse arter for så vidt angår kystbeskyttelsesforanstaltninger samt etablering og udvidelse af visse anlæg på søterritoriet (BEK nr. 654 af 19/05/2020), at der skal foretages en vurdering af, om projektet kan påvirke et internationalt naturbeskyttelsesområde eller visse udpegede arter væsentligt.

I forbindelse med de geofysiske undersøgelser af kabelkorridoren for Verena fiberkablet er Natura 2000-område nr. 246: 'Sydlig Nordsø' og Natura 2000-område nr. 89: 'Vadehavet' relevante, da kabelkorridoren løber igennem disse områder. Natura 2000-områderne nr. 246 og nr. 89 beskrives derfor i det følgende. På grund af afstanden til andre Natura 2000-områder, og da der udelukkende er risiko for meget lokale påvirkninger (se afsnit 2.3.3) som følge af undersøgelserne, vurderes det, at der ikke er risiko for, at undersøgelserne vil kunne påvirke andre Natura 2000-områder. Dette gælder ligeledes det tyske Natura 2000-område DE1209301: 'Sylter Auβenriff', som har en afstand på godt 9 km til undersøgelsesområdet og vil således ikke blive påvirket.

3.1.2.1. Natura 2000-område nr. 246: Sydlige Nordsø

Undersøgelsesområdet for kabelkorridoren løber igennem Natura 2000-område nr. 246: Sydlige Nordsø. Afgrænsningen af Natura 2000-område nr. 246 fremgår af Figur 3.6.

Natura 2000-område nr. 246 har ifølge Natura 2000-planen et samlet areal på ca. 247.314 ha, og er udpeget som habitatområde nr. 255 Sydlige Nordsø (H255) og fuglebeskyttelsesområde nr. 113 Sydlige Nordsø (F113) (Miljøstyrelsen, 2021). Miljøstyrelsen har i juni 2023 sendt et udkast til udvidelse af Natura 2000 område nr. 246 i høring. Udvidelsen sker på baggrund af en række faglige rapporter udarbejdet af DCE, Aarhus Universitet (Miljøstyrelsen, 2023). Det udvidede område fremgår i MiljøGIS og er opgjort til ca. 504.716 ha og udgøres stadig af F113. Der er således ikke tale om et nyt, supplerende fuglebeskyttelsesområde. Fuglebeskyttelsesområde nr. 113 omfatter en stor del af IBA (Important Bird and Biodiversity Area) 123, Østlig Tyske Bugt.



Figur 3.6. Afgrænsning af Natura 2000-område nr. 246: Sydlige Nordsø (habitatområde nr. 255 og fuglebeskyttelsesområde nr. 113) samt undersøgelsesområdet for Verena fiberkabel.

En rapport fra DCE dokumenterer, at sortand er blevet observeret i stort antal nord for det oprindelige F113 (Petersen, Nielsen, & Clausen, 2021. På baggrund af disse observationer er sortand tilføjet udpegningsgrundlaget for F113 (Miljøstyrelsen, 2023. Sortand skal derfor vurderes som værende en del af udpegelsesgrundlaget for F113, selvom arten på nuværende tidspunkt ikke er listet på udpegningsgrundlaget for Natura 2000-planen for 2022-27 (Tabel 3.1). Derudover forventes dværgmåge og sortstrubet lom at blive udtaget fra udpegningsgrundlaget (Miljøstyrelsen, 2023).

*Tabel 3.1. Udpegningsgrundlag for habitatområde nr. 255 og fuglebeskyttelsesområde nr. 113, der udgør Natura 2000-område nr. 246. Tal i parentes henviser til talkoder benyttet for naturtyper og arter fra habitatdirektivets bilag 1 og 2. * indikerer at der er tale om en prioriteret naturtype. Tabellen er baseret på udpegningsgrundlaget fra Natura 2000-planen for 2022-27 (Miljøstyrelsen Midtjylland, 2021), hvorfor sortand ikke fremgår.*

Udpegningsgrundlag for Habitatområde nr. 255		
Naturtyper:	Sandbanke (1110)	
Arter:	Gråsæl (1364)	Spættet sæl (1365)
	Marsvin (1351)	

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 113		
Fugle:	Rødstrubet lom (T)	Sortstrubet lom (T)
	Dværgmåge (T)	

Områdets eneste naturtype udgøres af sandbanke, som findes på dybt vand langt fra kysten. En påvirkning af marine habitatnaturtyper kan udelukkes, da de geofysiske undersøgelser ikke vil påvirke eller interagere fysisk med havbunden. Sandbanke er derfor ikke beskrevet nærmere i det følgende.

I forhold til fuglene på udpegningsgrundlaget, så anses den eneste forstyrrelse at være undersøgelsesfartøjets fysiske tilstedeværelse. Farvandet i og omkring undersøgelsesområdet er i forvejen stærkt trafikeret med skibsruter til og fra byerne på vestkysten og langs den jyske vestkyst (MarineTraffic, 2024). Endvidere vil undersøgelsesfartøjet sejle ved lav hastighed (4 knob) indenfor undersøgelsesområdet og i en lige linje langs kabelkorridoren og derfor vurderes undersøgelsesfartøjet og de geofysiske undersøgelser ikke at udgøre en særskilt påvirkning på fugle, som derfor heller ikke er beskrevet nærmere i det følgende.

I forhold til havpattedyrene på udpegningsgrundlaget, så er der foretaget en støjmodellering over det ansøgte udstyr (Bilag 2), som viser, at undervandsstøj fra de geofysiske undersøgelser potentielt vil kunne medføre påvirkninger på havpattedyr, hvis de befinder sig i nærheden af undersøgelsesfartøjet.

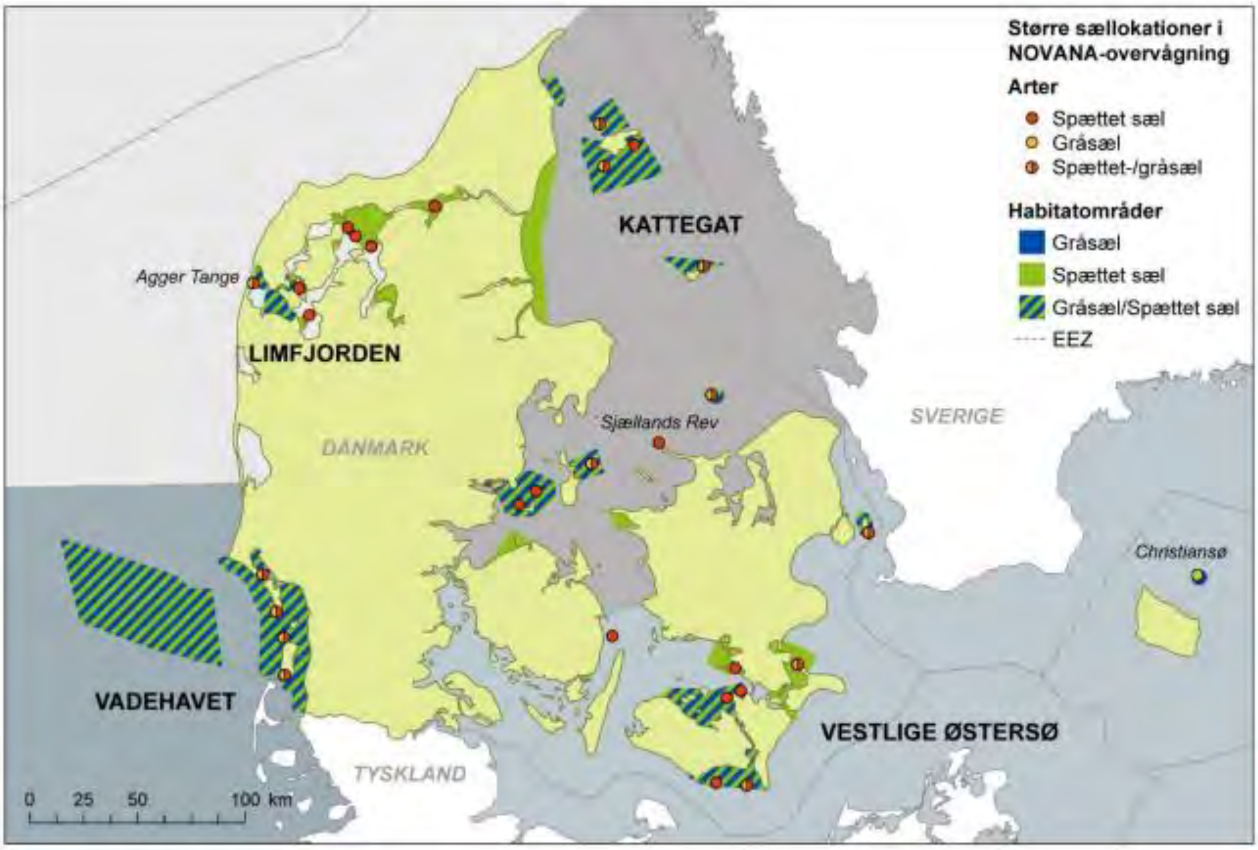
Da habitatområde nr. 255 har marsvin og sæler på udpegningsgrundlaget og da dele af de geofysiske undersøgelser vil forekomme i habitatområdet, beskrives sæler og marsvin nærmere. Sæler behandles i det følgende. Marsvin beskrives ligeledes kort i det følgende i forhold til deres brug af Natura 2000-området, men er beskrevet detaljeret i afsnit 3.1.1.1.

Spættet sæl
Spættet sæl er den mest almindelige sælart i Danmark. Den forekommer især i de kystnære farvande, hvor der er rigelig føde, og hvor der findes uforstyrrede yngle-/hvilepladser på sandbanker, rev, holme og øer.

Spættede sæler er stedfaste, hvilket betyder, at et givent individ primært benytter den samme yngle-/hvileplads år efter år. Sælerne er afhængige af at kunne komme på land hele året på disse lokaliteter for at hvile, yngle (maj/juni) og skifte pels (august) (Galatius, A., 2017; Hansen, J. W.; Høgslund (red), S., 2023). Stedfastheden har endvidere medført, at spættede sæler i Danmark fordeler sig på fire genetisk forskellige populationer i hhv. Vadehavet, centrale Limfjord, Kattegat og den vestlige Østersø (Galatius, A., 2017). Sæler, som kan ses i undersøgelsesområdet tilhører med størst sandsynlighed individer fra de nærmeste yngle- og hvilepladser i Vadehavsområdet, herunder områder i Sydlige Nordsø, men også fødesøgende individer fra den vestlige del af Limfjorden ved Nissum Bredning kan forekomme (Figur 3.7). Bestandene er senest opgjort til henholdsvis 1.700 i den danske del af Vadehavet og 400 individer i den vestlige del af Limfjorden ved Nissum Bredning.

I yngle- og fældeperioden, hvor sælerne er afhængige af at komme på land, er de forholdsvise stationære med et mindre område, som de fouragerer inden for (Dietz, Teilmann, Andersen, Rigét, & Olsen, 2013 og det er I yngle- og fældeperioden at sælerne er særligt sårbare for forstyrrelse. Udenfor ynglesæsonen kan sælerne bevæge sig over store afstande (>200 km) i forbindelse med fødesøgning (Kyhn, et al., 2021). Det forventes derfor, at sælerne forekommer i hele den kystnære del af undersøgelsesområdet.

DCE har ved habitatdirektivets artikel 17 vurdering til EU i 2019, vurderet, at spættet sæl har gunstig bevaringsstatus i Danmark (Fredshavn, et al., 2019).



Figur 3.7. Kort over habitatområder for spættet sæl og gråsæl i danske farvande. Større kolonier er vist med røde og gule cirkler

<u>*Gråsæl*</u>

Gråsælen er i løbet af de sidste 20 år genindvandret til Danmark efter at have været udryddet i landet i ca. 100 år. I Danmark lever der to bestande af gråsæler, den ene i Nordsøen med hovedudbredelse omkring Storbritannien og i det tyske og hollandske Vadehav (kaldet Nordsøbestanden), og den anden i Østersøen med hovedudbredelse omkring Stockholm, Estland og det sydlige Finland (kaldet Østersøbestanden). Det er individer fra nordsøbestanden, som kan ses i undersøgelsesområdet.

Gråsælen er ligesom spættet sæl knyttet til de kystnære farvande, hvor der er rigelig føde og uforstyrrede yngle-/og hvilepladser men i forhold til spættet sæl bevæger gråsælen over større afstande. Gråsælens yngle-/hvileområder i den danske del af Nordsøen er sammenfaldende med yngle-/hvileområder for spættet sæl og findes således også i Vadehavsområdet, herunder området for Sydlige Nordsø (Figur 3.7).

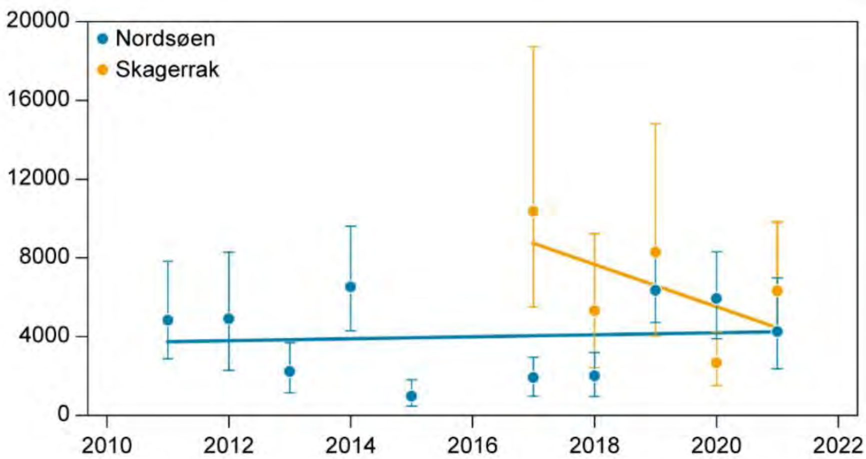
Gråsæler i Vadehavet er fåtallige. Over de sidste 5 år er bestanden af gråsæler i hele Vadehavet i gennemsnit vokset 10 % om året (Schop, et al., 2022). Gråsæler er blevet talt i den danske del af vadehavet siden 2015. I 2021 blev der talt 331 individer, mens der i 2022 blev talt 152 individer (Schop, et al., 2022; Hansen, J. W.; Høgslund (red), S., 2023). Reduktionen i observationer anses ikke som et fald i den overordnede populations-størrelse i Nordsøen, men skyldes formentlig, at de gråsæler, som ses på hvilepladserne i den danske del af vadehavet, yngler ved kolonier uden for dansk farvand. De ynglende gråsæler, som opholder sig på hvilepladserne i dansk farvand, forlader derfor sandsynligvis disse i ynglesæsonen (Schop, et al., 2022).

Siden 2003 har gråsælen dog etableret sig som ynglende art og forekommer i stigende antal i danske farvande (Fredshavn, et al., 2019). I Danmark er ynglebestanden meget lille, men der har været en fast ynglelokalitet ved Rødsand i Gedser siden 2003. Derudover er der observeret ynglende gråsæler ved Søndre Rønner og Borfelt ved Læsø, Anholt og i Vadehavet (Galatius, Dietz, Sveegaard, & Teilmann, 2019). Gråsælerne yngler i december i Nordsøen (Hansen, J. W.; Høgslund (red), S., 2023).

Arten er ligesom spættet sæl særligt sårbare for forstyrrelse i yngle- og fældeperioden. Gråsæler er sandsynligvis mere sårbar end spættet sæl, da unger af gråsæl ikke kan svømme fra fødslen (Galatius, A., 2017). I Nordsøen fælder gråsæler i marts/april

DCE har ved habitatdirektivets artikel 17 vurdering til EU i 2019, vurderet, at begge bestande af gråsæler i Danmark har stærkt ugunstig bevaringsstatus (Fredshavn, et al., 2019).

<u>*Marsvin*</u>
Eksisterende forhold for marsvin i Nordsøen er beskrevet nærmere i afsnit 3.1.1.1. Natura 2000-område 246: Sydlig Nordsø er et udpeget kerneområde for marsvin. Tætheden af marsvin i området er højere (0,80 individer/km^2 i 2021) i forhold til resten af Nordsøen generelt (0,55 individer/ km^2 i 2022) og har ligget stabilt igennem de senere år (Figur 3.8). Området har en uændret stor betydning for arten hele året rundt (Miljøstyrelsen, 2021).



Figur 3.8. Den blå linje viser antal marsvin estimeret i optællingsområderne i Nordsøen (NOVANA overvågning af Sydlige Nordsø og Vadehavet) i perioden 2011-2021. Den gule linje er Skagerrak, som er irrelevant ift. Nærværende ansøgning (Hansen, J. W.; Høgslund (red), S., 2023).

I 2021 blev bestanden i optællingsområdet, som også dækker de kystnære områder udenfor Natura 2000-område 246, estimeret til 4.250 individer (Hansen, J. W.; Høgslund (red), S., 2023). Under tællingerne, som ligger i ynglesæsonen observeres både voksne og kalve. Kigger man på NOVANA observationer igennem de seneste 3 år, har den gennemsnitlige kalveratio ligget på godt 5 % (Tabel 3.2), hvilket er noget lavere end den kalve ratio på 10-17%, som er registreret i farvandene omkring den tyske ø Sylt, som også er et udpeget yngleområdefor arten (Gilles, Scheidat, & Siebert, 2009; Gilles, Adler, Kaschner, Scheidat, & Siebert, 2011; Gilles, et al., 2016; Sonntag, Benke, Hiby, Lick, & Adelung, 1999).

Tabel 3.2. Antallet af observationer af voksne og kalve og den estimerede tæthed af marsvin i området under NOVANA tællinger i Nordsøen (Hansen & Høgslund (red), 2021a; Hansen & Høgslund (red), 2021b; Hansen, J. W.; Høgslund (red), S., 2023).

År	**Antal observationer**		**Tæthed (marsvin/km^2) (95 % konfidensinterval)**
	Voksne	Kalve	
2019	109	5	1,19 (0,88-1,58)
2020	147	7	1,11 (0,73-1,55)
2021	106	7	0,80 (0,44-1,31)

Trusler

Af den reviderede basisanalyse for Natura 2000-plan 2022-27 (Miljøstyrelsen, 2021) fremgår det, at truslerne mod havpattedyr i området primært udgøres af fiskeri. Således kan garnfiskeri og fiskeri med bundgarn (andre redskaber) bifange og dermed påvirke havpattedyr i området negativt. Pelagisk trawl og notfiskeri udgør en mindre trussel mod havpattedyr.

Målsætninger

De overordnede mål for marsvin og sæler på udpegningsgrundlaget er (Miljøstyrelsen, 2023):

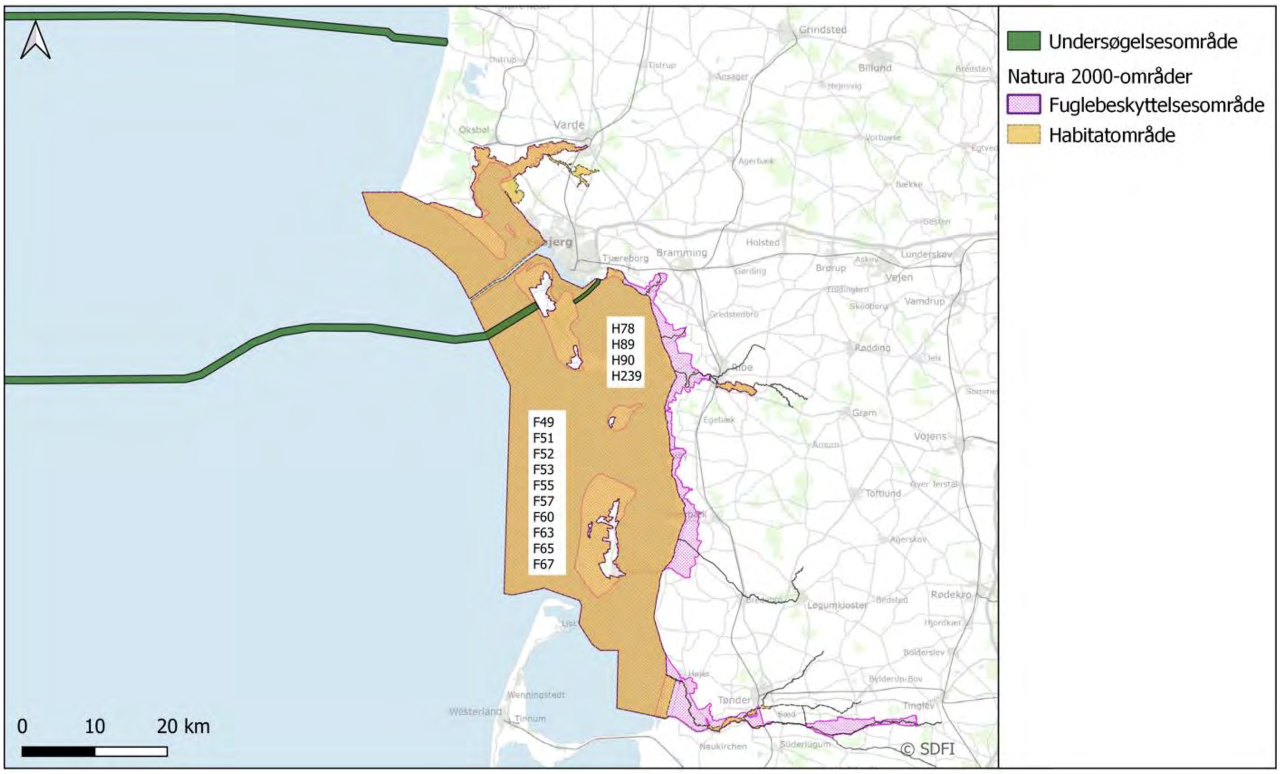
- at arterne skal bidrage til at opnå gunstig bevaringsstatus på biogeografisk niveau.

Konkrete målsætninger er:

- at forekomsten af marsvin og sæler skal være stabil eller i fremgang, såfremt naturgivne forhold giver mulighed for det.
- at bidrage til at opnå gunstig bevaringsstatus på biogeografisk niveau, ligesom at tilstanden af levestederne for marsvin og sæler (vurderet i form af forekomst og udbredelse) og det samlede areal skal være stabilt eller i fremgang.

3.1.2.2. Natura 2000-område nr. 89: Vadehavet

Undersøgelsesområdet for kabelkorridoren løber igennem Natura 2000-område nr. 89: Vadehavet. Afgrænsningen af Natura 2000-område nr. 89 fremgår af (Figur 3.9).



Figur 3.9. Afgrænsning af Natura 2000-område nr. 89: Vadehavet (habitatområde nr. 78, 86, 90 og 239 samt fuglebeskyttelsesområde nr. 49, 51, 52, 53, 55, 57, 60, 63, 65 og 67) i forhold til undersøgelsesområdet for Verena fiberkabel.

Natura 2000-området har ifølge Natura 2000-planen et samlet areal på ca. 149.869 ha, hvoraf de 112.678 ha er hav. Området består af flere habitatområder (H) og en lang række fuglebeskyttelsesområder (F), som listes nedenfor. De relevante områder for undersøgelsen er fremhævet med fed skrift og beskrives nærmere efterfølgende.

Habitatområderne:

- **H78 Vadehavet med Ribe Å, Tved Å og Varde Å vest for Varde**
- H86 Brede Å
- H90 Vidå med tilløb, Rudbøl sø og Magisterkogen
- H239 Alslev Ådal.

Fuglebeskyttelsesområderne:

- F49 Engarealer ved Ho Bugt,
- F51 Ribe Holme og enge med Kongeåens udløb,
- F52 Mandø,
- F53 Fanø,
- F55 Skallingen og Langli,
- F57 Vadehavet,
- F60 Vidåen, Tøndermarsken og Saltvandssøen,
- F63 Sønder Ådal,
- F65 Rømø
- F67 Ballum Enge, Husum Enge og Kamper Strandenge (Miljøstyrelsen, 2021).

Udpegningsgrundlaget for Natura 2000-område nr. 89 fremgår af Tabel 3.3 (habitatområder) og Tabel 3.4 (fuglebeskyttelsesområder).

Området er udpeget for at beskytte en lang række af forskellige naturhabitattyper, hvoraf mange er terrestriske. En påvirkning af både de terrestriske og marine habitatnaturtyper kan udelukkes, da de geofysiske undersøgelser ikke vil påvirke eller interagere fysisk med havbunden. Naturhabitattyperne er derfor ikke beskrevet nærmere i det følgende.

Den eneste potentielle forstyrrelse af fugle vurderes at være undersøgelsesfartøjets fysiske tilstedeværelse. Farvandet i og omkring undersøgelsesområdet er i forvejen stærkt trafikeret med skibsruter til og fra byerne på vestkysten og langs den jyske vestkyst (MarineTraffic, 2024). Derudover, vil fartøjet sejle ved lav hastighed (4 knob) indenfor undersøgelsesområdet og i en lige linje langs kabelkorridoren og derfor vurderes undersøgelsesfartøjet og de geofysiske undersøgelser ikke at udgøre en særskilt påvirkning på fugle, som derfor heller ikke er beskrevet nærmere i det følgende.

Havpattedyr og fisk, som er på udpegningsgrundlaget, kan potentielt blive påvirket af undervandsstøj. Derfor er der foretaget en støjmodellering over det ansøgte udstyr (Bilag 2) og beregninger af undervandsstøj er gennemført i henhold til Energistyrelsens guidelines (Energistyrelsen, 2022). Modelleringen viser, at undervandsstøj fra de geofysiske undersøgelser potentielt vil kunne medføre påvirkninger på havpattedyr, hvis de befinder sig i nærheden af undersøgelsesfartøjet. Undervandsstøjen, som udstyret genererer er derimod ikke på et niveau, som vil forårsage hverken skader, midlertidigt høretab eller adfærdspåvirkninger på fisk. Fisk er derfor ikke beskrevet yderligere, hvorimod, havpattedyr vurderes i afsnit 4.3.

Da habitatområde nr. 78 har marsvin, spættet sæl og gråsæler på udpegningsgrundlaget og da dele af de geofysiske undersøgelser vil forekomme i habitatområdet beskrives sæler og marsvins brug af habitatområde 78 meget kort i det følgende, da sæler i Nordsøen generelt er beskrevet i afsnit 3.1.2.1 og marsvin i Nordsøen generelt beskrevet i afsnit 3.1.1.1.

*Tabel 3.3. Udpegningsgrundlag for habitatområde nr. 78, nr. 86, nr. 90 og nr. 239 i Natura 2000-område nr. 89. Tal i parentes henviser til talkoder benyttet for naturtyper og arter fra habitatdirektivets bilag 1 og 2. * indikerer at der er tale om en prioriteret naturtype.*

Udpegningsgrundlag for Habitatområde nr. 78		
Naturtyper:	Sandbanke (1110)	Flodmunding (1130)
	Vadeflade (1140)	Lagune* (1150)
	Bugt (1160)	Rev (1170)
	Strandvold med flerårige planter (1220)	Kystklint/klippe (1230)
	Enårig strandengsvegetation (1310)	Vadegræssamfund (1320)
	Strandeng (1330)	Forklit (2110)
	Hvid klit (2120)	Grå/grøn klit* (2130)
	Klithede* (2140)	Havtornklit (2160)
	Gråriskit (2170)	Skovklit (2180)
	Klitlavning (2190)	Visse-indlandsklit (2310)
	Græs-indlandsklit (2330)	Søbred med småurter (3130)
	Kransnålalge-sø (3140)	Næringsrig sø (3150)
	Brunvandet sø (3160)	Vandløb (3260)
	Våd hede (4010)	Tør hede (4030)
	Kalkoverdrev* (6210)	Surt overdrev* (6230)
	Tidvis våd eng (6410)	Urtebræmme (6430)
	Hængesæk (7140)	Tørvelavning (7150)
	Rigkær (7230)	Bøg på mor (9110)
	Stilkege-krat (9190)	Skovbevokset tørvemose* (91D0)
	Elle- og askeskov* (91E0)	
Arter:	Grøn køllequldsmed (1037)	Bæklampret (1096)
	Flodlampret (1099)	Havlampret (1095)
	Laks (1106)	Snæbel* (1113)
	Stavsild (1103)	Odder (1355)
	Gråsæl (1364)	Spættet sæl (1365)
	Marsvin (1351)	

Udpegningsgrundlag for Habitatområde nr. 86		
Naturtyper:	Vandløb (3260)	
Arter:	Bæklampret (1096)	Flodlampret (1099)
	Snæbel* (1113)	Odder (1355)

Udpegningsgrundlag for Habitatområde nr. 90		
Naturtyper:	Næringsrig sø (3150)	Vandløb (3260)
	Rigkær (7230)	
Arter:	Bæklampret (1096)	Flodlampret (1099)
	Havlampret (1095)	Snæbel* (1113)
	Dyndsmerling (1145)	Odder (1355)

Udpegningsgrundlag for Habitatområde nr. 239		
Naturtyper:	Visse-indlandsklit (2310)	Revling-indlandsklit (2320)
	Søbred med småurter (3130)	Næringsrig sø (3150)
	Brunvandet sø (3160)	Vandløb (3260)
	Våd hede (4010)	Tør hede (4030)
	Surt overdrev* (6230)	Tidvis våd eng (6410)
	Urtebræmme (6430)	Hængesæk (7140)
	Kildevæld* (7220)	Rigkær (7230)
	Elle- og askeskov* (91E0)	
Arter:	Bæklampret (1096)	Flodlampret (1099)
	Havlampret (1095)	Laks (1106)
	Snæbel* (1113)	Odder (1355)

Tabel 3.4. Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 49, nr. 51, nr. 52, nr. 53, nr. 55, nr. 57, nr. 60, nr. 63, nr. 65 og nr. 67 i Natura 2000-område nr. 89. (Y) er ynglefugle og (T) er trækfugle.

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 49		
Fugle:	Spidsand (T)	Hedehøg (Y)
	Engsnarre (Y)	Klyde (T)
	Blåhals (Y)	

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 51		
Fugle:	Rørdrum (Y)	Hvid stork (Y)
	Skestork (T)	Pibesvane (T)
	Blisgås (T)	Kortnæbbet gås (T)
	Bramgås (T)	Rørhøg (Y)
	Hedehøg (Y)	Engsnarre (Y)
	Plettet rørvagtel (Y)	Klyde (Y)
	Hjejle (T)	Pomeransfugl (T)
	Brushane (Y)	Sorthovedet måge (Y)
	Fjordterne (Y)	Mosehornugle (Y)
	Blåhals (Y)	

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 52		
Fugle:	Rørdrum (Y)	Bramgås (T)
	Mørkbuget knortegås (T)	Rørhøg (Y)
	Vandrefalk (T)	Klyde (Y)
	Brushane (Y)	Stor kobbersneppe (Y)
	Sandterne (Y)	Fjordterne (Y)
	Havterne (Y)	Mosehornugle (Y)
	Blåhals (Y)	

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 53		
Fugle:	Rørdrum (Y)	Lysbuget knortegås (T)
	Rørhøg (Y)	Vandrefalk (T)
	Klyde (Y)	Strandskade (T)
	Hvidbrystet præstekrave (Y)	Strandhjejle (T)
	Islandsk ryle (T)	Sandløber (T)
	Almindelig ryle (TY)	Dværgterne (Y)
	Splitterne (T)	Sandterne (Y)
	Havterne (Y)	Natravn (Y)
	Blåhals (Y)	

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 55		
Fugle:	Skestork (Y)	Kortnæbbet gås (T)
	Mørkbuget knortegås (T)	Spidsand (T)
	Pibeand (T)	Strandskade (T)
	Sorthovedet måge (Y)	Dværgterne (Y)
	Splitterne (TY)	Sandterne (Y)
	Fjordterne (Y)	Havterne (Y)
	Mosehornugle (Y)	

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 57		
Fugle:	Pibesvane (T)	Sangsvane (T)
	Grågås (T)	Blisgås (T)
	Kortnæbbet gås (T)	Bramgås (T)
	Mørkbuget knortegås (T)	Lysbuget knortegås (T)
	Gravand (T)	Gråand (T)
	Spidsand (T)	Skeand (T)

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 57 (Fortsat)		
Fugle:	Pibeand (T)	Krikand (T)
	Edderfugl (T)	Sortand (T)
	Havørn (T)	Blå kærhøg (T)
	Vandrefalk (T)	Klyde (TY)
	Strandskade (T)	Hvidbrystet præstekrave (TY)
	Hjejle (T)	Strandhjejle (T)
	Islandsk ryle (T)	Sandløber (T)
	Almindelig ryle (T)	Rødben (T)
	Sortklire (T)	Hvidklire (T)
	Lille Kobbersneppe (T)	Stor regnspove (T)
	Storspove (T)	Dværgmåge (T)
	Dværgterne (Y)	Splitterne (TY)
	Sandterne (Y)	Fjordterne (Y)
	Havterne (Y)	Mosehornugle (Y)
	Blåhals (Y)	

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 60		
Fugle:	Rørdrum (Y)	Hvid stork (Y)
	Pibesvane (T)	Sangsvane (T)
	Grågås (T)	Blisgås (T)
	Kortnæbbet gås (T)	Bramgås (T)
	Gravand (T)	Knarand (T)
	Spidsand (T)	Skeand (T)
	Pibeand (T)	Krikand (T)
	Havørn (T)	Rørhøg (Y)
	Hedehøg (Y)	Engsnarre (Y)
	Plettet rørvagtel (Y)	Klyde (TY)
	Hvidbrystet præstekrave (TY)	Hjejle (T)
	Strandhjejle (T)	Islandsk ryle (T)
	Almindelig ryle (T)	Brushane (Y)
	Rødben (T)	Sortklire (T)
	Hvidklire (T)	Stor kobbersneppe (Y)
	Lille Kobbersneppe (T)	Storspove (T)
	Fjordterne (Y)	Sortterne (Y)
	Mosehornugle (Y)	Blåhals (Y)

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 63		
Fugle:	Rørdrum (Y)	Rørhøg (Y)
	Hedehøg (Y)	Engsnarre (Y)
	Sortterne (Y)	Mosehornugle (Y)
	Rødrygget tornskade (Y)	

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 65		
Fugle:	Rørdrum (Y)	Mørkbuget knortegås (T)
	Gravand (T)	Rørhøg (Y)
	Hedehøg (Y)	Plettet rørvagtel (Y)
	Klyde (Y)	Hvidbrystet præstekrave (Y)
	Hjejle (T)	Islandsk ryle (T)
	Sandløber (T)	Almindelig ryle (TY)

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 65 (Fortsat)		
Fugle:	Brushane (Y)	Lille Kobbersneppe (T)
	Dværgterne (Y)	Splitterne (Y)
	Sandterne (Y)	Fjordterne (Y)
	Havterne (Y)	Mosehornugle (Y)
	Natravn (Y)	Blåhals (Y)

Udpegningsgrundlag for Fuglebeskyttelsesområde nr. 67		
Fugle:	Rørdrum (Y)	Sangsvane (T)
	Blisgås (T)	Kortnæbbet gås (T)
	Bramgås (T)	Rørhøg (Y)
	Hedehøg (Y)	Engsnarre (Y)
	Hjejle (T)	Brushane (Y)
	Fjordterne (Y)	Mosehornugle (Y)
	Blåhals (Y)	

Spættet sæl og gråsæl

I habitatområde 78 findes større sælkolonier på både Fanø og Rømø (Figur 3.7), som deles af spættet sæl og gråsæl. De nærmeste kolonier på ilandføringspunktet til undersøgelsesområdet for den sydlige kabelkorridor, som moniteres årligt, ligger 6 til 10 km væk. Arten er beskrevet yderligere i afsnit 3.1.2.1.

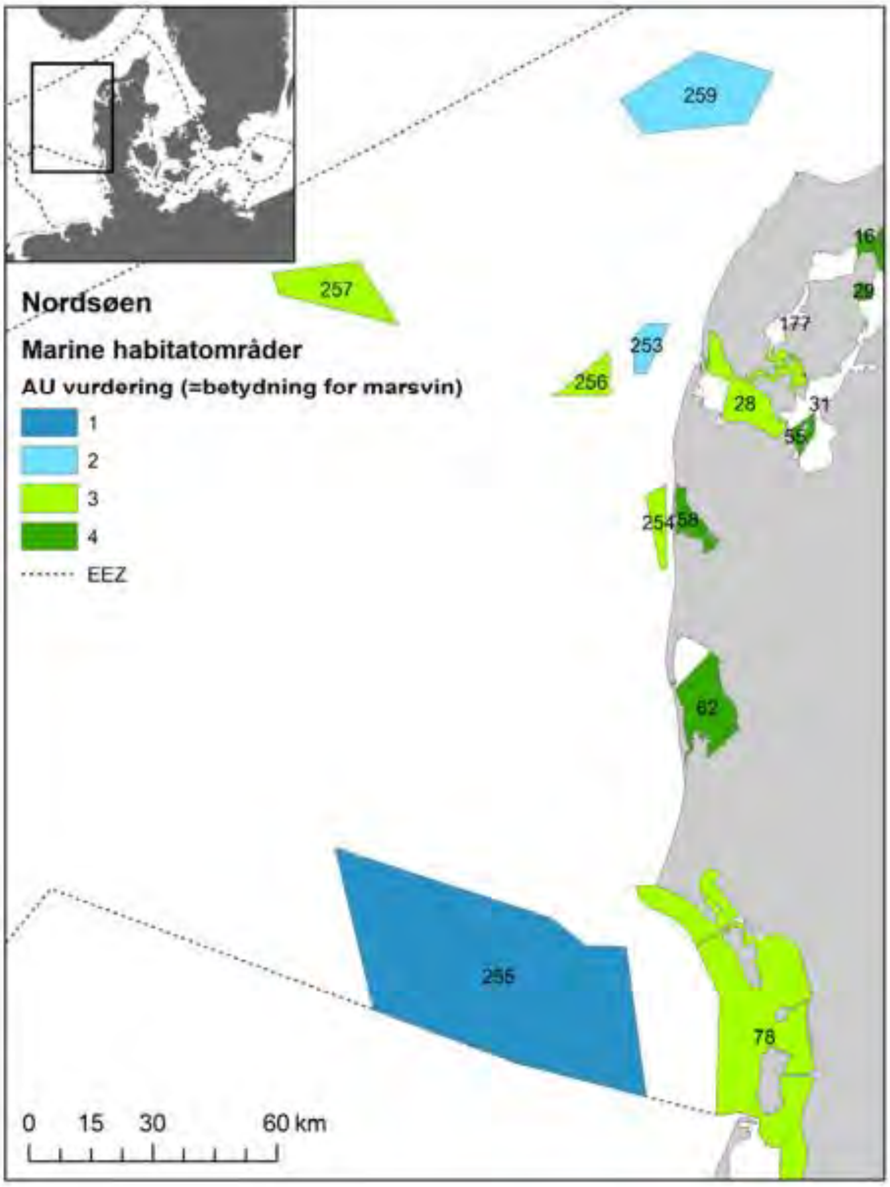
Marsvin

Der er en relativt stor forekomst af marsvin i den sydlige del af Nordsøen, men den største tæthed af marsvin er ca. 50-100 km fra kysten og med en aftagende tæthed nærmere kysten. Sveegaard (2018) angiver at habitat-område nr. 78 har en lav tæthed af marsvin både sommer og vinter og vurderer, at området ikke er af væsentlig betydning for marsvinepopulationen i Nordsøen generelt (Figur 3.10).

Trusler

Af den reviderede basisanalyse for Natura 2000-plan 2022-27 (Miljøstyrelsen, 2021) fremgår det, at truslerne mod sæler i Vadehavet primært udgøres af menneskelige aktiviteter i form af kajaksejlads, skibstrafik (herunder fiskeri) og sælsafari til sælernes hvilepladser. Presset fra forstyrrelser på sælernes yngle-, hvile- og fældepladser er vokset med væksten i sælbestanden. Topografiske ændringer i Vadehavsdybene betyder endvidere, at sælerne er begyndt at benytte nye liggepladser, der ikke er omfattet af færdselsbestemmelserne.

Yderligere trusler udgøres af fiskeri. Således kan garnfiskeri og fiskeri med bundgarn (andre redskaber) bifange og dermed påvirke havpattedyr i området negativt. Pelagisk trawl og notfiskeri udgør en mindre trussel mod havpattedyr.



Figur 3.10. Kort over danske marine habitatområder i Nordsøen med habitatnumre og Sveegaard et al. (2018) vurdering af områdets betydning for marsvin er indikeret fra 1-4, hvor 1 har højest betydning.

<u>*Målsætninger*</u>
De overordnede mål for marsvin og sæler på udpegningsgrundlaget er (Miljøstyrelsen, 2023):

- At arterne skal bidrage til at opnå gunstig bevaringsstatus på biogeografisk niveau.
- At Vadehavet fastholdes som et af landets vigtigste yngle- og rasteområder for havpattedyr, fugle og fisk knyttet til kystområder med bl.a. tidevandspåvirkede strandenge og lavvandede havområder.
- At gråsælen og dens levesteder, prioriteres højt og beskyttelsen styrkes, da arten har stærkt ugunstig bevaringsstatus.
- At områdets økologiske integritet sikres i form af gode spredningsmuligheder og etableringsmuligheder for arterne.

Konkrete målsætninger er:

- At forekomsten af marsvin og sæler, uanset om de er kortlagt, skal være stabil eller i fremgang, såfremt naturgivne forhold giver mulighed for det.

3.2. Vandområdeplaner

Vandområdeplanerne er et centralt element i gennemførelsen af EU's vandrammedirektiv. I direktivet hedder det, at alle EU-landenes vandområder: Vandløb, søer, den kystnære del af havet og grundvand skal have "god tilstand" i 2027. De danske vandområdeplaner indeholder således "opskriften" på, hvordan Danmark vil nå målsætningen i vandrammedirektivet. Den økologiske tilstand for de kystnære farvande vurderes på baggrund af flere kvalitetselementer, herunder de biologiske kvalitetselementer: Fytoplankton, bentiske invertebrater og rodfæstede bundplanter, samt nationalt specifikke stoffer, og støtteparametrene lysforhold og iltforhold, og andre understøttende hydromorfologiske- og fysisk-kemiske parametre.

Undersøgelsesområdet er beliggende i hovedvandopland Nissum Fjord (nordlig rute) og hovedvandopland Vadehavet (sydlig rute) i vandområdedistrikt Jylland og Fyn. Den nordlige kabelkorridor løber igennem Vandområde nr. 133 Vesterhavet, nord samt Vandområde nr. 218 Vesterhavet, 12 sm. Den sydlige kabelkorridor strækker sig ind i Vandområde nr. 119 Vesterhavet, syd, Vandområde nr. 121 Grådyb samt Vandområde nr. 218 Vesterhavet, 12 sm. Miljømål og tilstand for de nævnte vandområder er listet i nedenstående Tabel 3.5. Den økologiske tilstand gælder kun ud til 1 sm. Den kemiske tilstand dækker ud til 12 sm.

Tabel 3.5 Oversigt over vandområder i undersøgelsesområdet og deres økologiske og kemiske tilstand samt eventuel årsag til manglende målopfyldelse (Miljøstyrelsen, Vandplandata.dk, 2024).

Vandområde nr.	Miljømål	Tilstand	Manglende målopfyldelse (Kvalitetselement)
133 Vesterhavet, Nord	God økologisk tilstand	Moderat økologisk tilstand	Fytoplankton (moderat)
133 Vesterhavet, Nord	God kemisk tilstand	Ikke-god kemisk tilstand	Kviksølv (biota) BDE (biota) octylphenoleri (sediment)
2018 Vesterhavet, 12 sm	God økologisk tilstand	Ikke relevant	
2018 Vesterhavet, 12 sm	God kemisk tilstand	Ikke-god kemisk tilstand	Kviksølv (biota) Nonylphenoler (sediment) BDE (biota)
119 Vesterhavet, syd	God økologisk tilstand	Ringe økologisk tilstand	Fytoplankton (moderat)
119 Vesterhavet, syd	God kemisk tilstand	Ikke-god kemisk tilstand	Kviksølv (biota) Nonylphenoler (sediment)
121 Grådyb	God økologisk tilstand	Ringe økologisk tilstand	Fytoplankton (ringe) Bentiske invertebrater (ringe) Nationalt specifikke stoffer (ikke - god økologisk tilstand)
121 Grådyb	God kemisk tilstand	Ikke-god kemisk tilstand	Bly (biota) Kviksølv (biota) Cadmium (biota)

Aktiviteter, der ville kunne medføre en påvirkning på vandområdeplaner og de deri fastsatte miljømål, er identificeret som værende fysisk påvirkning af havbunden, f.eks. sedimentspild og prøvetagning. Da der i det ansøgte undersøgelse ikke skal foretages geotekniske undersøgelser eller anden undersøgelse, som fysisk påvirker havbunden, beskrives og vurderes påvirkning af vandområdeplaner ikke nærmere.

3.3. Havstrategi

EU's havstrategidirektiv har det overordnede formål at opnå eller opretholde god miljøtilstand i alle europæiske havområder (Miljø- og fødevareministeriet, 2019). Danmarks Havstrategi er en del af den danske implementering af Havstrategidirektivet, som er udmøntet i bekendtgørelse af lov om havstrategi (LBK nr 1161 af 25/11/2019).

Havstrategien omfatter ikke havområder, der strækker sig ud til én sømil fra kysten (basislinjen), i det omfang disse områder er omfattet af Lov om miljømål m.v. for vandforekomster og internationale naturbeskyttelsesområder (LBK nr 119 af 26/01/2017) samt Lov om vandplanlægning (vandområdeplanerne) (LBK nr 126 af 26/01/2017). Vurdering af påvirkning på miljømålene for enkelte deskriptorer i Havstrategien er derfor indeholdt i vurdering af påvirkning på vandrammedirektivets målsætninger om god økologisk og kemisk tilstand.

Elementer i havstrategien som f.eks. fisk, undervandsstøj og marint affald indgår derimod ikke i vandområdeplanerne og er derfor dækket af havstrategien i hele det marine område, også inden for grænsen én sømil fra basislinjen.

Til at vurdere miljøtilstanden i et havområde anvender havstrategidirektivet følgende 11 deskriptorer: Biodiversitet (D1), Ikke-hjemmehørende arter (D2), Erhvervsmæssigt udnyttede fiskebestande (D3), Havets fødenet (D4), Eutrofiering (D5), Havbundens integritet (D6), Hydrografiske ændringer (D7), Forurenende stoffer (D8), Forurenende stoffer i fisk og skaldyr til konsum (D9), Marint affald (D10) samt Undervandsstøj (D11).

Undersøgelsesområdet ligger i havområdet Nordsøen/Skagerrak (Miljø- og fødevareministeriet, 2019).Da de geofysiske undersøgelser potentielt kan påvirke havstrategiens 11 deskriptorer, vurderes eventuelle påvirkninger af de geofysiske undersøgelser på havstrategien nærmere i afsnit 4.4.

3.4. Havplan

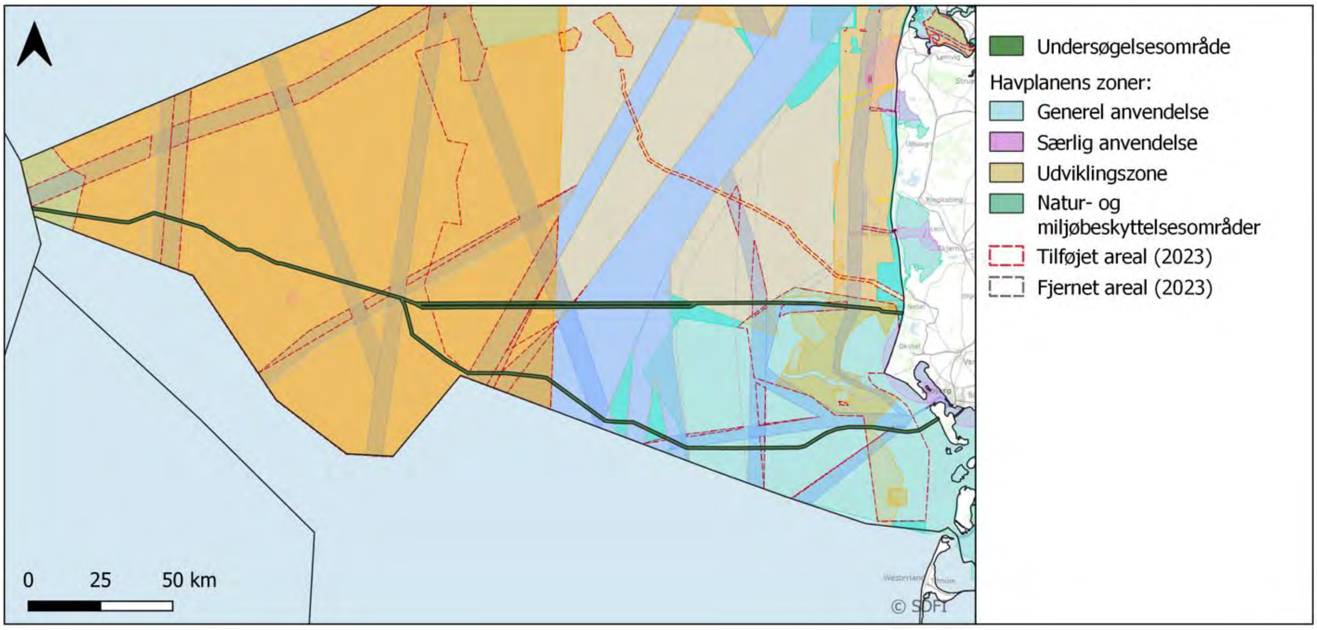
I 2014 vedtog EU et direktiv for havplanlægning (Europa-Parlamentets og rådets direktiv 2014/89/EU af 23. juli 2014). Formålet med direktivet er at skabe forudsætninger for både at udnytte og bevare marine områder og samtidig skabe muligheder for afvejninger mellem forskellige interesser for at opnå en bæredygtig fremtidig udvikling. I henhold til EU's direktiv om havplanlægning samt den nationale lov om maritim planlægning (LBK nr 400 af 06/04/2020) har Danmark udarbejdet en samlet, fysisk plan (en havplan) for det danske havareal (Søfartsstyrelsen, Havplanredegørelse, 2023). Regeringen og folketingets øvrige partier indgik en politisk aftale om Danmarks Havplan den 7. juni 2023 (Erhvervsministeriet, 2023).

Havplanen er baseret på fire principper: 1) økosystem baseret tilgang, 2) rummelighed, 3) sameksistens og 4) samspillet mellem land og hav. Disse principper understøtter havplanens formål om at fremme økonomisk vækst, udvikling af havarealer og udnyttelse af havressourcer på et bæredygtigt grundlag. Havplanen udgør derved en ramme for, hvordan forskellige aktiviteter kan sameksistere og skabe økonomisk vækst på et bæredygtigt grundlag.

Havplanen inddeler havområderne i fire zonetyper, med varierende formål for arealanvendelse : 1) udviklingszoner, 2) natur- og miljøbeskyttelsesområder, 3) særlige anvendelseszoner og 4) generelle anvendelseszoner. Herudover kan sejlads, fiskeri, turisme og rekreativ anvendelse finde sted i alle zoner medmindre anden lovgivning forhindrer det. Offentlige myndigheder har endvidere mulighed for at give tilladelse til andre aktiviteter på havet end dem, der planlægges for i de enkelte zoner, så længe tilladelserne ikke strider imod formålet med de enkelte arealudlæg (Søfartsstyrelsen, Havplanredegørelse, 2023). I Figur 3.11 ses hvilke zonetyper undersøgelsesområdet for Verena kabelkorridor overlapper med. Det strækker sig igennem tre af havplanens fire zonetyper, herunder områder for natur- og miljøbeskyttelse. Det drejer sig om natur- og miljøbeskyttelsesområder

N125 og N36 (inklusiv Natura 2000-område nr. 246), som på nuværende tidspunkt gennemgår en høringsproces i forbindelse med udpegning af nye strengt beskyttet havstrategiområder (Miljøministeriet, 2023; Miljøministeriet, 2023a). De geofysiske undersøgelser, som ansøges om i nærværende ansøgning, vurderes i forhold til havstrategien i afsnit 4.4.

De geofysiske undersøgelser i sig selv vil ikke være i uoverensstemmelse med havplanen. Havplanen beskrives derfor ikke yderligere.



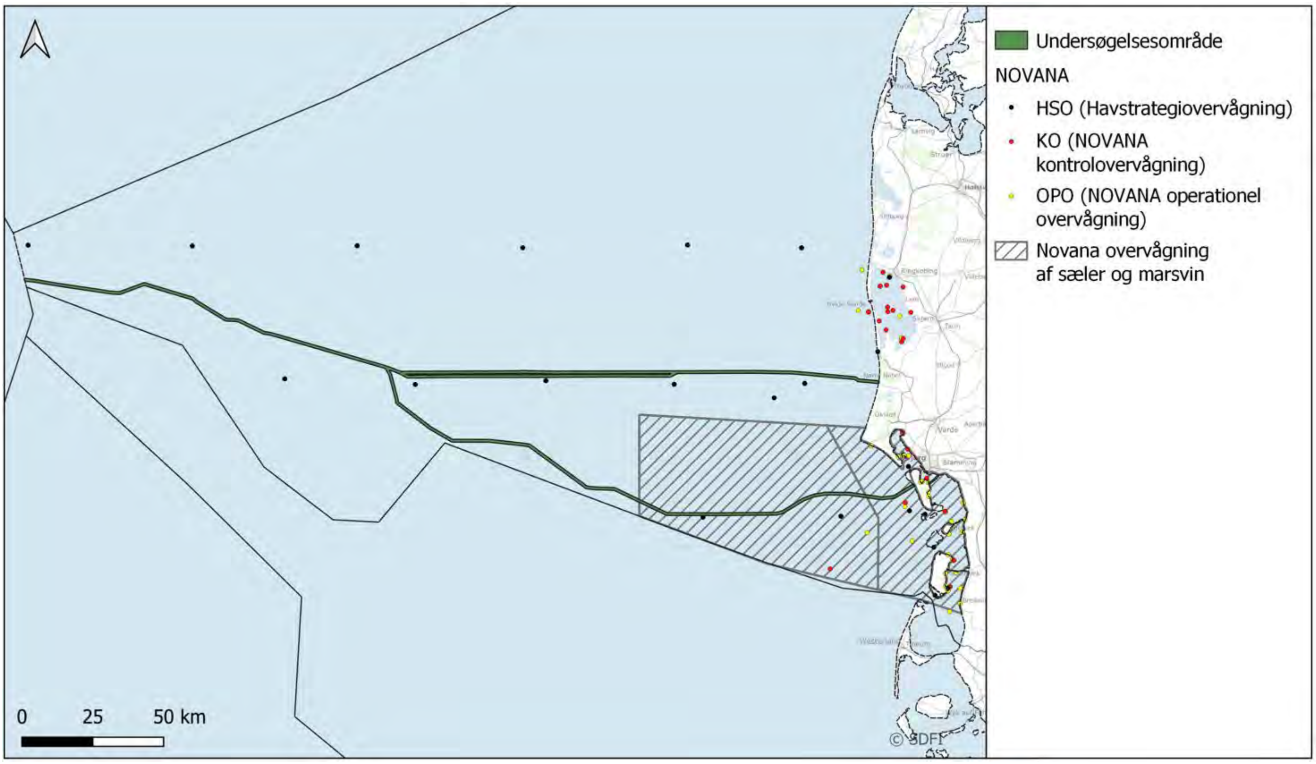
Figur 3.11. Undersøgelsesområdet for Verena kabelkorridor i forhold til Havplanens zoner (Søfartsstyrelsen, Havplan.dk, 2024)

3.5. NOVANA overvågning

Udfor den jyske vestkyst på specifikke lokaliteter udføres adskillige overvågningsprogrammer under NOVANA gennemført i henhold til vandramme-, habitat- og havstrategidirektivet (Miljøstyrelsen, 2023). På Figur 3.12 ses de planlagte overvågningsstationer for perioden 2017-2021 i og omkring undersøgelsesområdet for Verenakablet (Miljøstyrelsen, 2024). Planlagte stationer for 2022 og frem er endnu ikke tilgængelige, men det forventes, at disse ikke afviger betydeligt fra tidligere, da de er en del at et overvågningsprogram og en tidsserie, hvor data skal kunne sammenlignes fra år til år. For perioden 2017-2021 ligger der ingen prøvetagningsstationer under NOVANA inden for undersøgelsesområdet og de geofysiske undersøgelser overlapper ikke med positioner, hvor NOVANA overvågning tidligere har fundet sted. Dog løber den sydlige korridor igennem et område, hvor tællinger af sæler og marsvin under NOVANA finder sted.

Overvågningsprogrammer, som foregår omkring undersøgelsesområdet, drejer sig om registrering af havpattedyr, samt artbestemmelse af bundfauna, zoo- og fytoplankton, måling af miljøfremmede stoffer i bundflora- og fauna, fisk og sediment, næringsstofindhold i vand og sediment, makroalgeundersøgelser samt profilmålinger af ilt, temperatur og salinitet i vandsøjlen. Af de nævnte overvågningsprogrammer kan kun registreringen af havpattedyr påvirkes af de geofysiske undersøgelser af kabelkorridoren, da undersøgelserne benytter støjende udstyr. Fordi undersøgelserne ikke påvirker havbunden vil de resterende NOVANA undersøgelser ikke blive påvirket.

Såfremt de geofysiske undersøgelser koordineres med ansvarlige på Aarhus Universitet forud for den dag eller de dage, hvor havpattedyr tælles i den sydlige Nordsø, vil undervandsstøjen ligeledes ikke påvirke tællingernes udfald. Påvirkning af NOVANA beskrives derfor ikke yderligere.



Figur 3.12. Oversigt over positioner, som indgik NOVANA overvågningen i perioden 2017-2021.

3.6. Ballastvand

Ballastvand anvendes primært under transport i mange fragtskibe og kan indeholde invasive arter, som kan udgøre en trussel for havmiljøet. Skibe, som sejler med ballastvand, er pålagt at behandle ballastvandet inden det ledes ud i havet som følge af Ballastvandkonventionen fra 8. september 2017 under FNs Internationale Søfarts-organisation, IMO. Foruden ballastvand kan begroning af invasive arter på skibets yderside ligeledes udgøre en trussel for havmiljøet. Fartøjet, som benyttes i forbindelse med ansøgte tilladelse, er Glomar-Vantage (Bilag 3), som i forvejen besejler Nordsøen og de indre danske farvande, hvorfor det vurderes at risikoen for invasive arter er ubetydelig og usandsynlig. Endvidere håndteres ballastvand efter gældende regler, ligesom at IMOs retningslinjer for håndtering af begroning på skibenes undervandsskrog følges. Ballastvand vurderes derfor ikke yderligere.

3.7. Øvrige

3.7.1. Kulturarv og arkæologi

De geofysiske undersøgelser og det udstyr, som bruges, vil ikke røre havbunden og dermed ikke påvirke havbunden fysisk. Kulturlevn, som skibsvrag stenalderbopladser og sejlspærringer, hvis til stede, vil derfor ikke blive påvirket. Kulturarv og arkæologi beskrives ikke yderligere.

Som en del af undersøgelsen vil der blive indsamlet arkæologiske data, til brug for professionel arkæologisk fortolkning og analyse. Alle arkæologiske tolkninger af data vil blive udført af en kvalificeret og erfaren marine-arkæolog til at bestemme placeringen af alle kendte arkæologiske træk. Slots- og Kulturstyrelsen vil blive informeret om nye fund som fortidsminder, vrag af skibe, skibsladninger og dele af skibsvrag, jf. Bekendtgørelse af museumsloven (LBK no. 358 of 08/04/2014), og data vil indgå i beslutningen om kabelrutens endelige udformningen.

3.7.2. Fiskeri

De geofysiske undersøgelser vil ikke påvirke fiskeriet, da undervandsstøjen ikke har en påvirkning på fisk (se afsnit 2.3.3 vedrørende resultater for støjmodellering). Fiskeri beskrives ikke yderligere.

3.7.3. Påvirkning af kysten

De geofysiske undersøgelser giver ikke anledning til påvirkning af kysten og beskrives ikke yderligere.

3.7.4. Rekreative anlæg og aktiviteter

De geofysiske undersøgelser vil ikke have indvirkning på rekreative anlæg og aktiviteter og beskrives ikke yderligere.

3.7.5. Råstofområder og klappladser

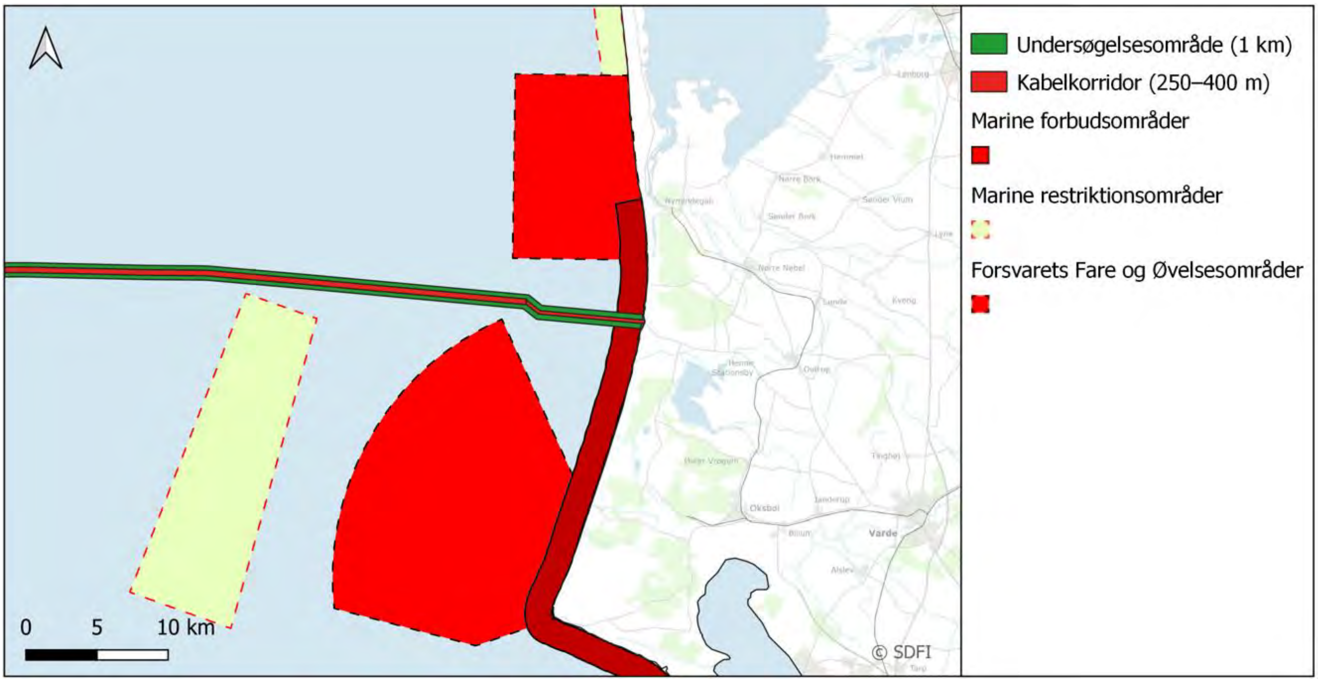
De geofysiske undersøgelser vil ikke have indvirkning på råstofområder og klappladser og beskrives ikke yderligere.

3.7.6. Sejlads

De geofysiske undersøgelser vil ikke have indvirkning på eksisterende sejlruter og beskrives ikke yderligere.

3.7.7. Forbudsområder

Den nordlige rute og ilandføringspunktet ved Henne Strand (delområde 2 i Tabel 2.1) går igennem et forbudsområde langs kysten nord for Esbjerg, jf. § 5 i Bekendtgørelse om forbud mod sejlads, ankring og fiskeri mv. i visse områder i danske farvande (BEK nr 135 af 04/03/2005). (Se Figur 3.13)



Figur 3.13. Oversigt over forbudsområdet, jf. § 5 i BEK nr 135 af 04/03/2005. Koordinaterne for segmentet af undersøgelsesområdet samt kabelkorridoren, som løber igennem forbudsområdet, fremgår af Bilag 1.

Forud for de geofysiske undersøgelser skal der ligge en dispensation fra Søfartsstyrelsen til at sejle i forbudsområdet i forbindelse med undersøgelserne, jf. § 9 stk. 3 i Bekendtgørelse om sejladssikkerhed ved entreprenørarbejder og andre aktiviteter i danske farvande (BEK nr 1351 af 29/11/2013).

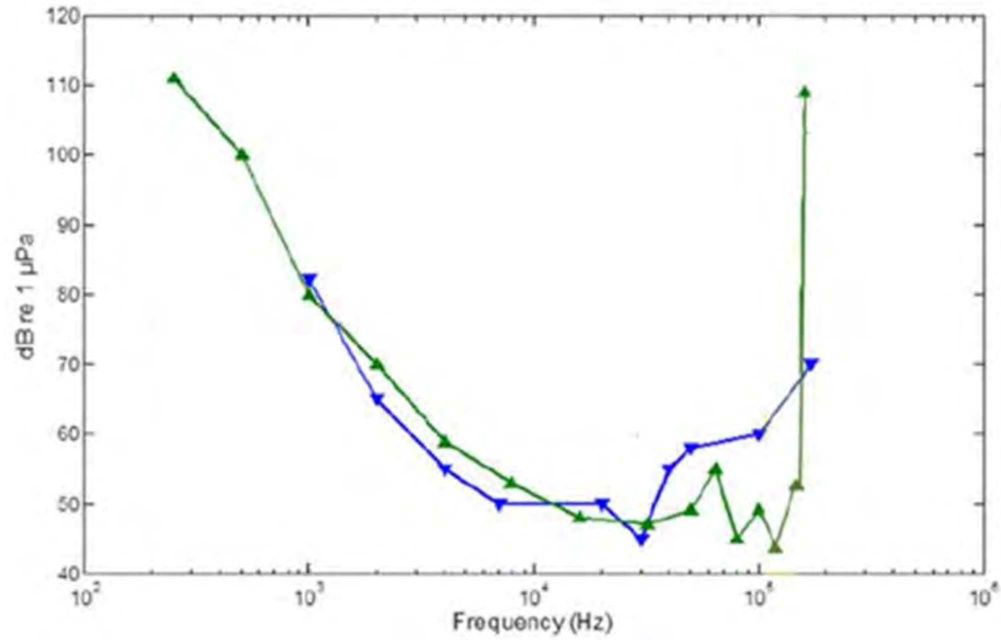
I forbindelse med denne dispensation skal der foreligge oplysninger om hvilke fartøj der skal anvendes til arbejdet i forbudsområdet (Bilag 3) samt kontaktoplysninger til disse periode for hvornår arbejdes forventes at være i gang. Søværnet skal holdes opdateret på dette. Endvidere skal koordinaterne for korridoren, der ønskes dispensation til at sejle i, angives (Bilag 1).

4. Vurdering af undersøgelsernes mulige miljøpåvirkninger

Som beskrevet i afsnit 2.3.3 kan de geofysiske undersøgelser medføre undervandsstøjniveauer, som kan påvirke primært marsvin med adfærdspåvirkninger ud til 4,5 km. Der er ikke beregnet afstande for adfærdspåvirkninger hos sæler, men det er antaget at sæler reagerer ud til samme afstand som marsvin.

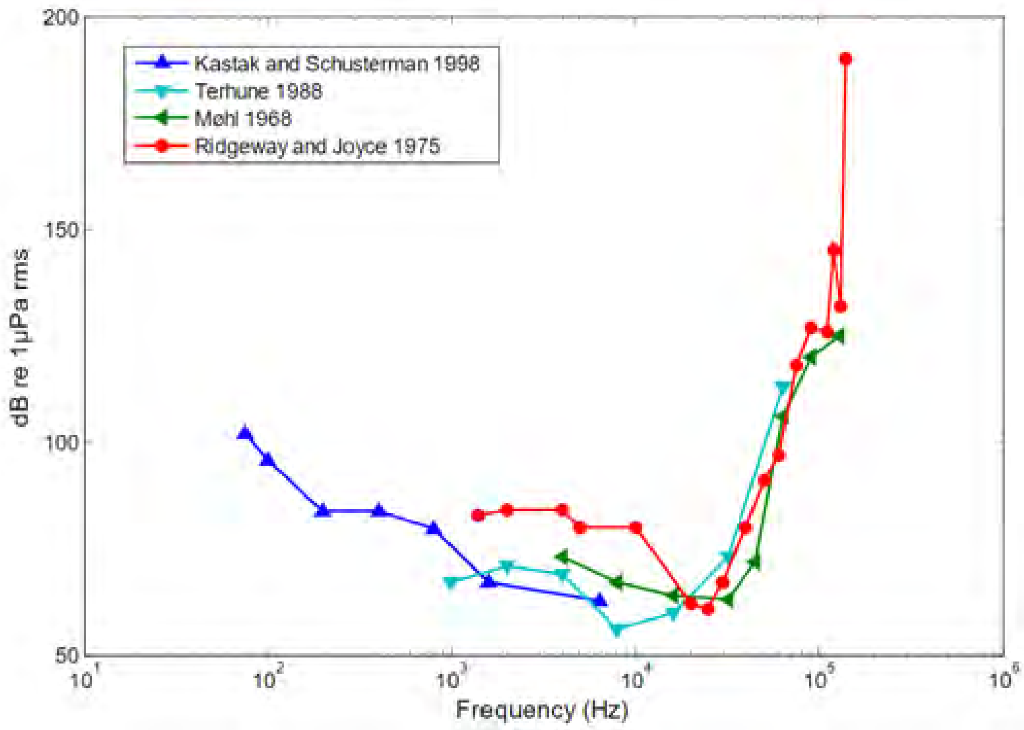
4.1. Hørelse hos marsvin og sæler

Høreevnen er livsvigtig for marsvin, fordi de er afhængige af lyd til at finde føde og kommunikere. Marsvin udsender højfrekvente lyde og lytter efter de tilbagekastede ekkoer, som de bruger til at navigere og finde byttet (Miller, 2010). Af denne grund er marsvin særligt sårbare overfor menneskeskabt støj, som kan maskere dyrenes lyde eller give høretab, særligt i det højfrekvente område. Marsvin hører godt, og deres hørekurve er vist i Figur 4.1.



Figur 4.1. Hørekurve for marsvin, som viser høreevnen med frekvensen på x-aksen og lydniveauet på y-aksen. Modificeret efter Kastelein et al. (2010 (grøn) og Andersen (1970 (blå). *Marsvin hører bedst i frekvensområdet 10-160 kHz (Tougaard & Mikaelsen, 2018).*

Sæler er tilpasset et liv både på land og i vand, hvilket gør, at deres høreevne har udviklet sig til at fungere både i luft og vand. Sæler producerer en lang række forskellige kommunikationskald både over og under vandet, f.eks. i forbindelse med parringsadfærd og hævdelse af territoriet. De er derfor afhængige af deres hørelse som led i deres livscyklus, og de kan være sårbare over for undervandstøj. Hørelsen strækker sig fra et par hundrede Hz til omtrent 60 kHz (se Figur 4.2).



Figur 4.2. Hørekurve for spættede sæler for fire forskellige individer (DHI, 2015). *Høreevnen hos gråsæl er ikke undersøgt på samme måde som for spættet sæl, men man forventer en lignende kurve, og derfor anvendes hørekurven for spættet sæl også for gråsæler.*

4.2. Vurdering af påvirkning på bilag IV-arter

For dyrearter, omfattet af bilag IV, gælder som før nævnt, at de ikke må fanges, dræbes, forstyrres forsætligt (særligt når de yngler, udviser yngelpleje eller migrerer) eller få beskadiget eller ødelagt deres yngle- eller rasteområder. Beskyttelsen af bilag IV-arterne kan normalt anses som overholdt, hvis den vedvarende økologiske funktionalitet af et yngle- eller rasteområde for bilag IV-arter opretholdes på mindst samme niveau som hidtil (Miljøstyrelsen, 2020). I dette afsnit vurderes derfor, om de geofysiske undersøgelser kan medføre væsentlige påvirkninger af bilag IV-arter, som i dette tilfælde er begrænset til marsvin.

Som beskrevet i afsnit 2.3.3, vil de geofysiske undersøgelser medføre en begrænset påvirkning på marsvin. De geofysiske undersøgelser vil ikke medføre, at marsvin omkommer. Marsvin skal befinde sig i en afstand af mindre end 100 m fra undersøgelsesfartøjet for at være i risiko for at udvikle PTS (se Tabel 2.8), når der udføres geofysiske undersøgelser. Det vurderes, som usandsynligt, at et marsvin skulle befinde sig inden for denne afstand, da det forventes, at skibsstøjen fra undersøgelsesfartøjet alene vil holde marsvin på længere afstand. Marsvin, som befinder sig indenfor 1650 m af undersøgelsesfartøjet (se Tabel 2.8) vil være i risikozonen for at udvikle TTS. For at begrænse risikoen for at marsvin udsættes for undervandsstøjniveauer, der medfører TTS, og da kabelkorridoren bl.a. går igennem et kerneområde for marsvin (se afsnit 4.3 vedr. Natura 2000 vurderinger), anbefales det, at der anvendes en soft-start/ramp op procedure under de geofysiske undersøgelser. Desuden vil der være havpattedyrsobservatører ombord på undersøgelsesfartøjet, for at begrænse påvirkningen på marsvin ligesom at gældende retningslinjer følges (Energistyrelsen, 2018). Ved brug af ovenstående afværgeforanstaltninger samt pga. de korte påvirkningsafstande for PTS og TTS vurderes det, at det er usandsynligt, at undervandsstøj fra de geofysiske undersøgelser vil medføre PTS samt en meget begrænset sandsynlighed for, at de vil medføre TTS.

De geofysiske undersøgelser kan medføre en adfærdspåvirkning på marsvin i en afstand på op til ca. 4500 m fra undersøgelsesområdet. Dette svarer til, at marsvin vil fortrænges fra et areal på ca. 64 km^2 omkring undersøgelsesfartøjet. Med en tæthed på 0,55-0,80 individer/km^2 vil dette svare til at ca. 35-51 individer af marsvin kan forventes fortrængt fra området. Undersøgelsesfartøjet bevæger sig og vil således fortrænge marsvin langs sejlruten. Det areal, som marsvinene fortrænges fra, er af begrænset udstrækning og udgør blot en meget lille del af marsvinenes fødesøgningsområde, og det vil være muligt at søge føde i nærliggende områder. Det forventes også, at marsvinene vil vende tilbage til området, når støjen ophører. Det vil derfor være et meget begrænset område af dyrenes udbredelsesområde, der kortvarigt udsættes for undervandsstøjniveauer over adfærdstærsklen. Sammenholdes estimatet med den estimerede populationsstørrelse på 339.00 marsvin, giver det et billede af, hvor stor en andel af populationen på et givent tidspunkt, som potentielt ville kunne blive adfærdspåvirket af de geofysiske undersøgelser. Det estimerede antal dyr, som påvirkes, skal dog ikke ses som det faktiske antal marsvin, der potentielt ville blive påvirket af de geofysiske undersøgelser, men derimod som en indikation af omfanget af indvirkningen på populationen.

På grund af det begrænsede område som påvirkes, samt marsvin fra Nordsø populationens store udbredelsesområde, anses den geografiske udstrækning for at være lokal, og på grund af den begrænsede undersøgelsesperiode vurderes varigheden som kortvarig. Bestandens følsomhed for adfærdspåvirkninger vurderes at være lav, da bestanden af marsvin i Nordsøen er stabil. Det forventes at marsvin forekommer i undersøgelsesområdet. Da det er en meget begrænset del af marsvins udbredelsesområde, der midlertidig støjpåvirkes, vurderes påvirkning dog på individniveau at være begrænset og uden risiko for påvirkning på populationsniveau uanset hvornår på året undersøgelserne finder sted. Den samlede påvirkning fra de geofysiske undersøgelser på Nordsøpopulationen af marsvin vurderes derfor at være begrænset og uden konsekvenser for bestandens kortsigtede eller langsigtede status. Det vurderes, at påvirkningen ikke vil forringe marsvins muligheder for at yngle i undersøgelsesområdet med succes og ikke vil påvirke deres mulighed for at færdes i eller i nærheden af undersøgelsesområdet, udover den kortvarige periode i et begrænset del af undersøgelsesområdet, hvor de geofysiske undersøgelser finder sted.

Samlet vurderes det, at påvirkningen fra undervandsstøj ikke vil have et omfang, så den vil kunne påvirke områdets økologiske funktionalitet, som yngle- og rasteområde for marsvin eller forsætligt forstyrre marsvin, når de yngler, udviser yngelpleje eller vandrer.

4.2.1.1. Kumulative indvirkninger på Bilag IV-arter

Vurderingen skal indeholde en vurdering af de geofysiske undersøgelsers kumulative virkninger sammen med andre godkendte projekter og planer.

Med kumulative effekter menes indvirkningen fra de aktuelle undersøgelser set i sammenhæng med effekten fra andre planer eller projekter, der kan have påvirkning på bilag IV-arter. Det skal således vurderes, om andre aktiviteter, projekter eller planer forstærker eller modvirker effekterne af de geofysiske undersøgelser i et sådant omfang, at påvirkningerne samlet set kan have indvirkning på bilag IV-arter.

Energinet har ansøgt om og fået tilladelse til, i 2023 og 2024, at gennemføre geofysiske og geotekniske forundersøgelser, samt marinbiologiske undersøgelser i området for Nordsø I.

Forundersøgelsesområdet for de marinbiologiske undersøgelser i Nordsø I overlapper med undersøgelsesområdet for den nordlige rute af Verena fiberkabel. Bufferzonen for de geofysiske undersøgelse i Nordsø I grænser helt op til en del af undersøgelsesområdet for den nordlige Kabelkorridor, mens forundersøgelsesområdet for de geotekniske undersøgelser overlapper ikke med den nordlige korridor. Undersøgelsesområdet for den sydlige kabelkorridor for Verena er mere end 40 km væk og overlapper ikke med undersøgelsesområdet for Nordsø I.

Det er bekræftet fra Energinet, at de geofysiske undersøgelser i Nordsø I er gennemført i 2023, og at ingen geofysiske undersøgelser skal gennemføres i området i 2024. Der vil derfor ikke forekomme undervandsstøj fra de to geofysiske undersøgelser samtidigt.

De geotekniske og marinbiologiske undersøgelser vurderes i kumulation med nærværende geofysiske undersøgelser ikke at have en negativ påvirkning på marsvin som Bilag IV-art, da de pågældende undersøgelser i Nordsø I er begrænset i tid og rum, med en lokal påvirkning og uden støjpåvirkning. Det vurderes derfor, at de geofysiske undersøgelser hverken i sig selv eller i kumulation med andre projekter eller undersøgelser, vil medføre påvirkninger af marsvin som bilag IV-arter.

4.3. Natura 2000 vurdering

Som det fremgår af afsnit 3.1.2 så passerer undersøgelsesområdet Natura 2000-område nr. 246 og nr. 89 , som begge har havpattedyr på udpegningsgrundlaget. Da undervandstøjen potentielt kan medføre adfærdspåvirkninger samt høretab hos havpattedyr, skal der gennemføres en Natura 2000-vurdering. Afhjælpende foranstaltninger kan ikke tages i betragtning i forbindelse med væsentlighedsvurderingen (Europa-Kommissionen, 2019). Det vil sige, at hvis der foreslås afhjælpende foranstaltninger, så skal disse fastlægges i en Natura 2000-konsekvensvurdering. I afsnit 4.2 er det vurderet, at der skal anvendes soft-start/ramp-up, som afværge foranstaltning, for at reducere påvirkningsgraden i form af TTS på marsvin. Dette medfører også, at der for nærliggende relevante Natura 2000-områder med havpattedyr på udpegningsgrundlaget skal gennemføres en konsekvensvurdering. I dette tilfælde betyder det, at der vil blive gennemført en konsekvensvurdering af påvirkninger på havpattedyr (spættet sæl, gråsæl og marsvin) på udpegningsgrundlaget for Natura 2000-område nr. 246, Sydlige Nordsø samt Natura 2000-område nr. 89, Vadehavet, som overlapper med undersøgelsesområdet.

4.3.1. Konsekvensvurdering Natura 2000-område nr. 246: Sydlige Nordsø

4.3.1.1. Marsvin

Som beskrevet i afsnit 2.3.3, vil de geofysiske undersøgelser medføre en begrænset påvirkning på marsvin. Marsvinet skal befinde sig i en afstand af mindre end 100 m fra undersøgelsesfartøjet for at være i risiko for at udvikle PTS (se Tabel 2.8). Sandsynligheden for, at marsvin udsættes for undervandsstøjniveauer, som medfører TTS, er ligeledes lav, da de skal befinde sig indenfor 1650 m af undersøgelsesfartøjet (se Tabel 2.8), hvilket vil blive yderligere reduceret, når der anvendes en soft start/ramp up procedure, som beskrevet i afsnit 4.2. Ved brug af afværgeforanstaltninger samt pga. de korte påvirkningsafstande for PTS og TTS vurderes det, at det er usandsynligt, at undervandsstøj fra de geofysiske undersøgelser vil medføre PTS samt en meget begrænset sandsynlighed for at den vil medføre TTS.

De geofysiske undersøgelser kan medføre en adfærdspåvirkning på marsvin i en afstand på op til ca. 4500 m fra undersøgelsesområdet. Dette svarer til, at marsvin vil fortrænges fra et areal på ca. 64 km^2 omkring undersøgelsesfartøjet. Med en tæthed på 0,80 individer/km^2 indenfor Natura 2000-område nr. 246 svarer det til at ca. 51 individer af marsvin kan forventes fortrængt fra området. Undersøgelsesfartøjet bevæger sig og vil således fortrænge marsvin langs sejlruten. Det areal, som marsvinene fortrænges fra, er af begrænset udstrækning og udgør blot en meget lille del af marsvinenes fødesøgningsområde, og det vil være muligt at søge føde i nærliggende områder. Det forventes også, at marsvinene vil vende tilbage til området, når støjen ophører. Det vil derfor være et meget begrænset område af dyrenes udbredelsesområde der kortvarigt udsættes for undervandsstøjniveauer over adfærdstærsklen. Sammenholdes estimatet med den estimerede populationsstørrelse indenfor Natura 2000 området, som er estimeret at være på 4.250 individer (Hansen, J. W.; Høgslund (red), S., 2023), giver det et billede af, hvor stor en andel af populationen, som potentielt ville kunne blive adfærdspåvirket af de geofysiske undersøgelser i forbindelse med fiber kabelkorridoren, hvilket svarer til 1,2 % af marsvinene indenfor Natura 2000 området. Det estimerede antal dyr, som påvirkes, skal dog ikke ses som det faktiske antal marsvin, der potentielt ville blive påvirket af de geofysiske undersøgelser, men derimod som en indikation af omfanget af indvirkningen på populationen. Da det er en meget begrænset del af marsvins udbredelsesområde, der midlertidig støjpåvirkes, vurderes påvirkning på individniveau at være begrænset og uden risiko for påvirkning på populationsniveau uanset hvornår på året undersøgelserne finder sted. Den samlede påvirkning fra den geofysisk undersøgelse på Nordsøpopulationen af marsvin vurderes derfor at være begrænset og uden konsekvenser for bestandens kortsigtede eller langsigtede status. Det vurderes, at påvirkningen ikke vil forringe marsvins muligheder for at yngle eller søge føde i undersøgelsesområdet med succes og ikke vil påvirke deres mulighed for at færdes i eller i nærheden af undersøgelsesområdet, udover den kortvarige periode i et begrænset del af undersøgelsesområdet, hvor de geofysiske undersøgelser finder sted.

Det vurderes, at undervandsstøj fra de geofysiske undersøgelser ikke vil medføre skadelige påvirkninger af marsvin på udpegningsgrundlaget for Natura 2000-område nr. 246 eller påvirke målsætninger for marsvin i Natura 2000-området. De geofysiske undersøgelser vil dermed ikke være til hinder for, at forekomsten af marsvin eller tilstanden af deres leve steder skal være stabil eller i fremgang eller til hinder for, at der kan bibeholdes en gunstig bevaringsstatus for marsvin i Natura 2000-område nr. 246. Vurderingen omfatter marsvin både indenfor og udenfor Natura 2000 -området.

4.3.1.2. Sæler

Sæler er betydeligt mindre følsomme overfor at få hørenedsættelse som følge af støjpåvirkning sammenlignet med marsvin (Southall, et al., . Det er usandsynligt, at undervandsstøj vil medføre PTS eller TTS hos de spættede sæler og gråsæler, da sælerne skal befinde sig indenfor mindre end 100 m af undersøgelsesfartøjet, og der vil alene kunne forekomme adfærdspåvirkninger på sæler, som opholder sig i nærheden af undersøgelsesfartøjet.

Som nævnt i afsnit 2.3.3 er der er ingen adfærdstærskel for sæler (Sveggard & Teilmann, 2018). Som et forsigtighedsprincip er det antaget, at sæler reagerer på undervandsstøj i samme afstand som marsvin, hvilket i dette tilfælde svarer til adfærdspåvirkninger hos sæler på 4,5 km. Undervandsstøjen kan derfor potentielt forårsage adfærdsreaktioner hos sæler i Natura 2000-området. Det er dog en lille del af Natura 2000-området, hvor undervandsstøjniveauet ligger over tærsklen for undvigelsesadfærd. Som beskrevet i afsnit 3.1.2.1 forventes spættet sæl at forekomme i undersøgelsesområdet, og bestandens følsomhed vurderes at være lav, da den er i gunstig bevaringsstatus. Gråsæl forventes ligeledes at forekomme regelmæssigt i undersøgelsesområdet. Populationens følsomhed over for forstyrrelser vurderes at være medium, da gråsælens bevaringsstatus er ugunstig. Den geografiske udstrækning af undersøgelsen er klassificeret som lokal med en kort varighed på få uger. Påvirkningen fra adfærdsændringer vurderes at være begrænset for både spættede sæler og gråsæler.

Da det er en meget begrænset sandsynlighed for, at sælerne udsættes for undervandsstøjniveauer, som medfører PTS og TTS, og at det er en forholdsvis lille del af Natura 2000-området, der kortvarig udsættes for undervandsstøjniveauer over adfærdstærsklen, vurderes påvirkningen på spættet sæl og gråsæl i Natura 2000-område nr. 246 at være begrænset og uden konsekvenser for Natura 2000-områdets integritet. Det vurderes, at undervandsstøj fra de geofysiske undersøgelser ikke vil medføre skadelige påvirkninger af spættet sæl og gråsæl på udpegningsgrundlaget for Natura 2000-område nr. 246 eller påvirke målsætninger for sæler i Natura 2000-området. De geofysiske undersøgelser vil dermed ikke være til hinder for, at forekomsten af sæler eller tilstanden af deres leve steder skal være stabil eller i fremgang eller til hinder for, at der kan bibeholdes en gunstig bevaringsstatus for spættet sæl samt opnås en gunstig bevaringsstatus for gråsæl i Natura 2000-område nr. 246. Vurderingen omfatter sæler både indenfor og udenfor Natura-2000 området.

4.3.1.3. *Kumulative indvirkninger på Natura 2000-område nr. 246 Sydlige Nordsø*

Vurderingen skal indeholde en vurdering af de geofysiske undersøgelsers kumulative virkninger sammen med andre godkendte projekter og planer.

Med kumulative effekter menes indvirkningen fra de aktuelle undersøgelser set i sammenhæng med effekten fra andre planer eller projekter, der kan have indvirkning på udpegningsgrundlaget for de relevante Natura 2000-områder. Det skal således vurderes, om andre aktiviteter, projekter eller planer forstærker eller modvirker effekterne af de geofysiske undersøgelser i et sådant omfang, at påvirkningerne samlet set kan have indvirkning på sammenhængen i Natura 2000-netværket eller være i konflikt med målsætninger for relevante Natura 2000-områder.

I den konkrete Natura 2000-kontekst omfatter de kumulative påvirkninger andre projekter eller undersøgelser, som medfører samme type af undervandsstøjpåvirkninger samtidig. Der er ikke kendskab til andre projekter eller undersøgelser, der gennemføres i samme tidsperiode og medfører undervandsstøjpåvirkninger, som kan påvirke udpegningsgrundlaget for Natura 2000-område nr. 246. Det vurderes derfor, at de geofysiske undersøgelser hverken i sig selv eller i kumulation med andre projekter eller undersøgelser, vil medføre påvirkninger af udpegningsgrundlaget for Natura 2000-området.

4.3.1.4. *Opsummering på Natura 2000 vurderingen for område nr. 246: Sydlige Norsdsø*

Potentielle skadelige virkninger på Natura 2000-område nr. 246: Sydlige Nordsø kan være i form af TTS, PTS og adfærdspåvirkninger på sæler og marsvin. Dog kan en skadelig virkning udelukkes hos marsvin, spættede sæler og gråsæler, da følgende afværgeforanstaltninger inkluderes i de geofysiske undersøgelser (jf. (Energistyrelsen, 2018)):

- De geofysiske undersøgelser startes med en soft-start/ramp-up periode til fuld effekt for at sikre, at marsvin og sæler ikke befandt sig inden for risikozonen for TTS og PTS.
- Havpattedyrsobservatører vil være ombord på undersøgelsesfartøjet for at sikre, at ingen havpattedyr befinder sig i umiddelbar nærhed af undersøgelsesfartøjet mens de geofysiske undersøgelser finder sted.
- Hvis de geofysiske undersøgelser afbrydes, skal de genstartes med en soft-start-procedure.

Ved anvendelse af disse afværgeforanstaltninger kan det således udelukkes, at de geofysiske undersøgelser kan medføre skadevirkninger af marsvin, spættet sæl og gråsæl på udpegningsgrundlaget for Natura 2000-område nr. 246: Sydlige Nordsø. De geofysiske undersøgelser vil dermed ikke hindre muligheden for opnåelse af gunstig bevaringsstatus for det udpegede område eller påvirke bevaringsmålsætninger, som blandt andet skal sikre, at området skal være et godt levested for arterne (marsvin, spættet sæl og gråsæl). En skadevirkning af integriteten af Natura 2000-område nr. 246 kan dermed afvises med sikkerhed.

Samlet vurderes det, at de geofysiske undersøgelser hverken i sig selv eller i kumulation med andre projekter, vil medføre skadelige påvirkninger af udpegningsgrundlaget for Natura 2000-område nr. 246: Sydlige Norsdsø.

4.3.2. Konsekvensvurdering Natura 2000-område nr. 89: Vadehavet

4.3.2.1. *Marsvin*

Som beskrevet i afsnit 2.3.3, vil de geofysiske undersøgelser medføre en begrænset påvirkning på marsvin. Det vurderes, at ved brug af afværgeforanstaltninger samt pga. de korte påvirkningsafstande for PTS og TTS er det usandsynligt, at undervandsstøj fra de geofysiske undersøgelser vil medføre PTS og der er en meget begrænset sandsynlighed for, at de vil medføre TTS. De geofysiske undersøgelser, kan medføre en adfærdspåvirkning på marsvin i en afstand på op til ca. 4500 m fra undersøgelsesområdet. Som beskrevet i afsnit 3.1.2.2 er der en relativt stor forekomst af marsvin i den sydlige del af Nordsøen. Men den størst tæthed af marsvin forekommer ca. 50–100 km fra kysten (dermed uden for Natura 2000-område nr. 89: Vadehavet) og med aftagende tæthed nærmere kysten. Natura 2000-området er vurderet at have en lav tæthed af marsvin både i vinter og sommer halvåret og dermed med en lav betydning for marsvinepopulationen i Nordsøen generelt. Da det er en meget begrænset del af marsvins udbredelsesområde, der midlertidig støjpåvirkes samt at Natura 2000-området er af lav betydning hele året rundt, vurderes påvirkning på individniveau at være begrænset og uden risiko for påvirkning på populationsniveau, uanset hvornår på året undersøgelserne finder sted. Den samlede påvirkning fra de geofysisk undersøgelser på Nordsøpopulationen af marsvin vurderes derfor at være begrænset, både for marsvin indenfor og udenfor Natura 2000-område nr. 89 og dermed uden konsekvenser for bestandens kortsigtede eller langsigtede bevaringsstatus. Det vurderes, at påvirkningen ikke vil forringe marsvins muligheder for at yngle eller søge føde i undersøgelsesområdet med succes og ikke vil påvirke deres mulighed for at færdes i eller i nærheden af undersøgelsesområdet, udover den kortvarige periode i et begrænset del af undersøgelsesområdet, hvor de geofysiske undersøgelser finder sted.

Det vurderes, at undervandsstøj fra de geofysiske undersøgelser ikke vil medføre skadelige påvirkninger af marsvin på udpegningsgrundlaget for Natura 2000-område nr. 89: Vadehavet eller påvirke målsætninger for marsvin i Natura 2000-området. De geofysiske undersøgelser vil dermed ikke være til hinder for, at forekomsten af marsvin skal være stabil eller i fremgang eller til hinder for at der kan bibeholdes en gunstig bevaringsstatus for marsvin i Natura 2000-område nr. 89. Vurderingen omfatter marsvin både indenfor og udenfor Natura-2000 området.

4.3.2.2. Sæler

Sæler er betydeligt mindre følsomme overfor at få hørenedsættelse som følge af støjpåvirkning sammenlignet med marsvin (Southall, et al., . Det er usandsynligt, at undervandsstøj vil medføre PTS eller TTS hos de spættede sæler og gråsæler, da sælerne skal befinde sig indenfor mindre end 100 m af undersøgelsesskibet, og der vil alene kunne forekomme adfærdspåvirkninger på sæler, som opholder sig i nærheden af undersøgelsesfartøjet. Inden for Natura 2000-området findes der nogle større sælkolonier på både Fanø og Rømø (Figur 3.7), som deles af spættet sæl og gråsæl. De nærmeste sælkolonier er 5–10 km fra undersøgelsesområdet. Da undersøgelserne foregår på havet i en afstand på minimum 5–10 km vil der ikke være forstyrrelser af sælerne, når de befinder sig på land. På grund af afstanden mellem undersøgelsesområdet og kolonierne, vurderes det ligeledes, at der ikke vil være påvirkning af sælerne i vandet, når de opholder sig umiddelbart tæt på kolonierne. Baseret på ovenstående samt vurderingen i afsnit 4.3.1.2 vurderes påvirkningen i form af adfærdsændringer at være begrænset for både spættede sæler og gråsæler.

Da det er en meget begrænset sandsynlighed for at sælerne udsættes for undervandsstøjniveauer, som medfører PTS og TTS og at det er en forholdsvis lille del af Natura 2000-området, der kortvarig udsættes for undervandsstøjniveauer over adfærdstærsklen, vurderes påvirkningen på spættet sæl og gråsæl i Natura 2000-område nr. 89: Vadehavet at være begrænset og uden konsekvenser for Natura 2000-områdets integritet. Det vurderes, at undervandsstøj fra de geofysiske undersøgelser ikke vil medføre skadelige påvirkninger af spættet sæl og gråsæl på udpegningsgrundlaget for Natura 2000-område nr. 89 eller påvirke målsætninger for sæler i Natura 2000-området. De geofysiske undersøgelser vil dermed ikke være til hinder for, at forekomsten af sæler skal være stabil eller i fremgang eller til hinder for, at der kan bibeholdes en gunstig bevaringsstatus for spættet sæl samt opnås en gunstig bevaringsstatus for gråsæl i Natura 2000-område nr. 89. Vurderingen omfatter sæler både inden for og uden for Natura-2000 området.

4.3.2.3. Kumulative indvirkninger på Natura 2000-område nr. 89: Vadehavet

Der er ikke kendskab til andre projekter eller undersøgelser, der gennemføres i samme tidsperiode og medfører undervandsstøjpåvirkninger, som kan påvirke udpegningsgrundlaget for Natura 2000-område nr. 89:

Vadehavet. Det vurderes derfor, at de geofysiske undersøgelser hverken i sig selv eller i kumulation med andre projekter eller undersøgelser, vil medføre påvirkninger af udpegningsgrundlaget for Natura 2000-området.

4.3.2.4. Opsummering på Natura 2000 vurderingen for område nr. 89: Vadehavet

Potentielle skadelige virkninger på Natura 2000-område nr. 89: Vadehavet kan være i form af TTS, PTS og adfærdspåvirkninger på sæler og marsvin. Dog kan en skadelig påvirkning udelukkes hos marsvin, spættede sæler og gråsæler, da følgende afværgeforanstaltninger inkluderes i de geofysiske undersøgelser (jf. (Energistyrelsen, 2018)):

- De geofysiske undersøgelser startes med en soft-start/ramp-up periode til fuld effekt for at sikre, at marsvin og sæler ikke befinder sig inden for risikozonen for TTS og PTS.
- Havpattedyrsobservatører vil være ombord på undersøgelsesfartøjet for at sikre, at ingen havpattedyr befinder sig i umiddelbar nærhed af undersøgelsesfartøjet mens de geofysiske undersøgelser finder sted.
- Hvis de geofysiske undersøgelser afbrydes, skal de genstartes med en soft-start-procedure.

Ved anvendelse af disse afværgeforanstaltninger kan det således udelukkes, at de geofysiske forundersøgelser kan medføre skadevirkninger af marsvin, spættet sæl og gråsæl på udpegningsgrundlaget for Natura 2000-område nr. 89: Vadehavet. De geofysiske undersøgelser vil dermed ikke hindre muligheden for opnåelse af gunstig bevaringsstatus for det udpegede område eller påvirke bevaringsmålsætninger, som blandt andet skal sikre, at området skal være et godt levested for arterne (marsvin, spættet sæl og gråsæl). En skadevirkning af integriteten af Natura 2000-område nr. 89 kan dermed afvises med sikkerhed.

Samlet vurderes det, at de geofysiske undersøgelser hverken i sig selv eller i kumulation med andre projekter, vil medføre skadelige påvirkninger af udpegningsgrundlaget for Natura 2000-område nr. 89.

4.4. Havstrategi

I dette afsnit vurderes de geofysiske undersøgelsers potentielle påvirkninger på miljømålene for de 11 deskriptorer for god miljøtilstand for havområdet Nordsøen/Skagerrak. De 11 deskriptorer fremgår af Tabel 4.1.

Da hver af de 11 deskriptorer kan have mange forskellige miljømål, er det kun den overordnede beskrivelse af god miljøtilstand, som indgår i tabellen. Tabellen indeholder vurderingen af de geofysiske undersøgelsers potentielle påvirkninger på deskriptorernes miljømål. Afslutningsvist er der foretaget en samlet vurdering af påvirkninger fra de geofysiske undersøgelser i forhold til Danmarks Havstrategi II. De dele af de geofysiske undersøgelser, som foregår i 1-sømil-området er allerede behandlet i afsnit 3.2 iht. lov om vandplanlægning.

Tabel 4.1. Beskrivelse og kriterier for opnåelse af god miljøtilstand baseret på Basisanalyse for Danmarks Havstrategi II (Miljø- og fødevareministeriet, 2019) samt vurdering af undersøgelsernes mulige påvirkninger af havstrategiens 11 deskriptorer.

Deskriptor	Overordnet beskrivelse af god miljøtilstand	EU-kriterier for god tilstand	Vurdering af potentielle påvirkninger
D1 Biodiversitet	Biodiversiteten opretholdes, og tætheden af arter svarer til de fremherskende forhold, og når habitattypens tilstand ikke påvirkes negativt af menneskeskabte belastninger.	God miljøtilstand for fugle, pattedyr og fisk beskrives ud fra følgende kriterier: - D1C1 (primært): Dødelighed pr. art som følge af bifangst - D1C2 (primært): Artens populationstæthed	Undervandsstøj kan potentielt påvirke biodiversiteten ved fortrængning af fisk og havpattedyr i undersøgelsesområdet, mens fugle ikke vil blive påvirket af de geofysiske undersøgelser (afsnit 3.1.2). Støjmodelleringen, som beregner påvirkningsafstande af de geofysiske undersøgelser på fisk og havpattedyr er beskrevet i afsnit 2.3.3 og Bilag 2

		- D1C3 (sekundært): Artens populationsdemografiske kendetegn - D1C4 (sekundært): Arternes udbredelsesområde - D1C5 (sekundært): Arternes habitat, tilstand og udstrækning God miljøtilstand for pelagiske habitater beskrives ud fra følgende kriterier: - D1C6 (primært): Habitattypens tilstand	og den viser, at de geofysiske undersøgelser ikke vi have en negativ påvirkning på fisk. Dertil er der lavet en Natura 2000-vurderingen i afsnit 4.3, som vurderer, at der ikke vil være en væsentlig påvirkning på udpegningsgrundlaget for omkringliggende Natura 2000-områder, ligesom at undersøgelserne ikke vil medføre påvirkninger af marine bilag IV-arter (afsnit 4.1). Af den årsag vurderes det tilsvarende, at de geofysiske undersøgelser ikke vil påvirke biodiversiteten væsentligt, og at de geofysiske undersøgelser ikke vil forsinke eller være til hinder for opnåelse af god miljøtilstand i Nordsøen/Skagerrak for D1 – Biodiversitet.
D2 Ikke-hjemmehørende arter	Indførelsen af ikke-hjemmehørende arter via menneskelige aktiviteter er minimeret og så vidt muligt reduceret til nul, og den geografiske udbredelse ikke medfører negative effekter på havets arter og naturtyper.	God miljøtilstand beskrives ud fra følgende kriterier: - D2C1 (primært): Antallet af nye ikke-hjemmehørende arter. - D2C2 (sekundært): Udbredelse og tæthed af etablerede ikke-hjemmehørende og invasive arter. - D2C3 (sekundært): Negative ændringer som følge af ikke-hjemmehørende og invasive arter.	Havstrømmene i Nordsøen giver passage for arterne og det vurderes usandsynligt, at danske eller udenlandske operatører med fartøjer fra samme/tilstødende farvande som undersøgelsesområdet, vil medføre en påvirkning ved at introducere ikke-hjemmehørende arter (afsnit 3.6). Endvidere vil fartøjerne håndtere udledning af evt. ballastvand efter gældende lovgivning og IMOs retningslinjer for håndtering af begroning på skibenes undervandsskrog følges (afsnit 3.6). Det vurderes derfor, at de geofysiske undersøgelser ikke vil forsinke eller være til hinder for opnåelse af god miljøtilstand i Nordsøen/Skagerrak for D2 – Ikke-hjemmehørende arter.
D3 Erhvervsmæssigt udnyttede fiskebestande	Populationerne af alle fiske- og skaldyrarter, der udnyttes erhvervsmæssigt, ligger indenfor sikre biologiske grænser og udviser en alders- og størrelsesfordeling, der er betegnende for en sund bestand.	God miljøtilstand beskrives ud fra følgende kriterier: - D3C1 (primært): Fiskeridødelighed (F) - D3C2 (primært): Gydebiomasse (SSB) - D3C3 (primært): Alders- og størrelsesfordeling.	Miljømål for denne deskriptor vil ikke blive påvirket af de geofysiske undersøgelser (se afsnit 2.3.3 om undervandsstøj). De geofysiske undersøgelser vil ikke forsinke eller være til hinder for opnåelse af god miljøtilstand i Nordsøen/Skagerrak for D3 – Erhvervsmæssigt udnyttede fiskebestande.
D4 Havets fødenet	Alle elementer i havets fødenet, i den udstrækning de er kendt, er til stede og forekommer med normal tæthed og diversitet og på niveauer, som er i stand til at sikre en langvarig artstæthed og opretholdelse af arternes fulde reproduktionsevne.	God miljøtilstand beskrives ud fra følgende kriterier: - D4C1 (primært): Diversiteten indenfor de enkelte trofiske niveauer. - D4C2 (primært): Balancen mellem de trofiske niveauer (biomasse eller antal individer). - D4C3 (sekundært): Størrelsesfordelingen af individer på tværs af de trofiske niveauer. - D4C4 (sekundært): Produktiviteten af de enkelte trofiske niveauer	Potentielle påvirkninger på dyr, der udgør havets fødenet, er til dels beskrevet og vurderet under deskriptor D1 og de geofysiske undersøgelser vil ikke have indvirkning på disse. Endvidere vil de geofysiske undersøgelser ikke interagere fysisk med havbunden. Det vurderes, at de geofysiske undersøgelser ikke vil påvirke havets fødenet, og at de geofysiske undersøgelser ikke vil forsinke eller være til hinder for opnåelse af god miljøtilstand i Nordsøen/Skagerrak for D4 – Havets fødenet.

D5 Eutrofiering	Menneskeskabt eutrofiering er minimeret, navnlig de negative virkninger heraf, såsom tab af biodiversitet, forringelse af økosystemet, skadelige algeopblomstringer og iltmangel på havbunden.	God miljøtilstand beskrives ud fra følgende kriterier: - D5C1 (primært): Næringsstofkoncentrationer (DIN, DIP, TN, TP) i vandsøjlen - D5C2 (primært): Klorofyl a koncentrationer i vandsøjlen - D5C3 (sekundært): Skadelige algeopblomstringer (f.eks. cyanobakterier) i vandsøjlen - D5C4 (sekundært): Vandsøjlens fotiske zone (gennemsigtighed) - D5C5 (primært): Opløst ilt nederst i vandsøjlen - D5C6 (sekundært): Opportunistiske makroalger i bentiske habitater - D5C7 (sekundært): Makrofytsamfund (flerårige alger (f.eks Fucus sp.) og ålegræs) i bentiske habitater - D5C8 (sekundært): Makrofaunasamfund i bentiske habitater.	Miljømål for denne deskriptor vil ikke blive påvirket af de geofysiske undersøgelser (se evt. afsnit 3.2 om vandområdeplaner). Det vurderes, at de geofysiske undersøgelser ikke vil forsinke eller være til hinder for opnåelse af god miljøtilstand i Nordsøen/Skagerrak for D5 – Eutrofiering.
D6 Havbundens integritet	Havbundens integritet er på et niveau, hvor økosystemernes struktur og funktioner bevares, og hvor havbundens biodiversitet er opretholdt, og udstrækning af tab og negative effekter pr. habitattype ikke overstiger kommende tærskelværdier fastsat i EU.	God miljøtilstand for tab og fysisk forstyrrelse af havbunden beskrives ud fra følgende kriterier: - D6C1 (primært): udstrækning af fysisk tab (permanent ændring) af den naturlige havbund. - D6C2 (primært): udstrækning af fysisk forstyrrelse af havbunden. - D6C3 (primært): udstrækning af hver habitattype, som påvirkes negativt af fysisk forstyrrelse. God miljøtilstand for habitattyper på havbunden beskrives ud fra følgende kriterier: - D6C4 (primært): Udstrækning og andel af tab pr. habitattype som følge af menneskeskabt påvirkning. - D6C5 (primært): Udstrækning og andel af negative effekter pr. habitattype som følge af menneskeskabt påvirkning.	Miljømål for denne deskriptor vil ikke blive påvirket af de geofysiske undersøgelser, da undersøgelserne ikke vil forstyrre havbunden fysisk eller medføre permanente ændringer eller tab af habitat. Det vurderes, at de geofysiske undersøgelser ikke vil forsinke eller være til hinder for opnåelse af god miljøtilstand i Nordsøen/Skagerrak for D6 – Havbundens integritet.
D7 Hydrografiske ændringer	Permanent ændring af de hydrografiske egenskaber påvirker ikke de marine økosystemer i negativ retning.	God miljøtilstand beskrives ud fra følgende kriterier: - D7C1 (sekundært): Hydrografiske ændringer af havbunden og vandsøjlen (herunder tidevandsområder). - D7C2 (sekundært): Bentiske overordnede habitattyper eller andre habitattyper som anvendt under deskriptor 1 og 6.	Miljømål for denne deskriptor vil ikke blive påvirket, da de geofysiske undersøgelser ikke vil give anledning til hydrografiske ændringer. Det vurderes, at de geofysiske undersøgelser ikke vil forsinke eller være til hinder for opnåelse af god miljøtilstand i Nordsøen/Skagerrak for D7 – Hydrografiske ændringer.
D8 Forurenende stoffer	Forurenende stoffer (koncentrationer og arters sundhed): Koncentrationerne af forurenende stoffer ikke	God miljøtilstand for koncentrationer og artes sundhed beskrives ud fra følgende kriterier: - D8C1 (primært): Koncentrationer af forurenende stoffer	Miljømål for denne deskriptor vil ikke blive påvirket, da de geofysiske undersøgelser ikke tilfører forurenende stoffer til det marine miljø. Det vurderes, at de geofysiske undersøgelser ikke vil forsinke eller være til hinder for opnåelse

	overskrider fastsatte tærskelværdier. Forurenende stoffer (akutte hændelser): Væsentlige akutte forureningshændelsers negative effekter på arters sundhed og habitaters tilstand er minimeret og så vidt muligt elimineret.	- D8C2 (sekundært): Arters sundhed og habitaters tilstand. God miljøtilstand for akutte hændelser beskrives ud fra følgende kriterier: - D8C3 (primært): Den rumlige udstrækning og varighed af væsentlige akutte forureningshændelser - D8C4 (sekundært): Negative effekter af væsentlige akutte forureningshændelser.	af god miljøtilstand i Nordsøen/Skagerrak for D8 – forurenende stoffer.
D9 Forurenende stoffer i fisk og skaldyr til konsum	God miljøtilstand er, når der ikke er signifikante overskridelser af gældende maksimalgrænseværdier i fødevarelovgivningen for fisk og skaldyr til konsum.	God miljøtilstand beskrives ud fra følgende kriterium: - D9C1 (primært): Koncentrationen af forurenende stoffer i fisk og skaldyr.	Miljømål for denne deskriptor vil ikke blive påvirket, da de geofysiske undersøgelser ikke tilfører forurenende stoffer til fisk og skaldyr til konsum. Det vurderes, at de geofysiske undersøgelser ikke vil forsinke eller være til hinder for opnåelse af god miljøtilstand i Nordsøen/Skagerrak for D9 – forurenende stoffer i fisk og skaldyr til konsum
D10 Marint affald	Egenskaberne ved og mængderne af affald i havet skader ikke kyst- og havmiljøet.	God miljøtilstand beskrives ud fra følgende kriterier: - D10C1 (primært): Sammensætningen, mængden og den rumlige fordeling af affald. - D10C2 (primært): Sammensætningen, mængden og den rumlige fordeling af mikroaffald. - D10C3 (sekundært): Affald og mikroaffald indtaget af havdyr. - D10C4 (sekundært): Marint affalds påvirkning af dyrelivet.	Miljømål for denne deskriptor vil ikke blive påvirket, da de geofysiske undersøgelser ikke vil medføre, at der tilføres affald til det marine miljø. Det vurderes, at de geofysiske undersøgelser ikke vil forsinke eller være til hinder for opnåelse af god miljøtilstand i Nordsøen/Skagerrak for D10 – marint affald.
D11 Undervandsstøj	Undervandsstøj befinder sig på et niveau, der ikke påvirker havmiljøet i negativ retning.	God miljøtilstand beskrives ud fra følgende kriterier: - D11C1 (primært): Menneskeskabte impulslyde i vand - D11C2 (primært): Menneskeskabt vedvarende lavfrekvent lyd i vand.	Undervandsstøj fra de geofysiske undersøgelser kan potentielt påvirke havmiljøet, herunder fisk og havpattedyr, hvor støj kan medføre maskering af dyrenes kommunikationslyde, adfærdsændringer og midlertidig eller permanent høretab. Undervandsstøjen er modelleret og beregnet i Bilag 2 og viser at, støjen fra de geofysiske undersøgelser er på et niveau, som ikke påvirker fisk. Påvirkningen fra undervandsstøj er endvidere behandlet i afsnit 4.1 (om hørelse hos marsvin og sæler). På baggrund af vurderingerne i de pågældende afsnit vurderes det tilsvarende for havstrategien, at undervandsstøjen vil befinde sig på et niveau, der ikke påvirker havmiljøet i negativ retning. Det vurderes på baggrund heraf, at de geofysiske undersøgelser ikke vil forsinke eller være til hinder for opnåelse af god miljøtilstand i Nordsøen/Skagerrak for D11 – undervandsstøj.

4.4.1. Samlet vurdering

Det vurderes samlet, at de geofysiske undersøgelser i undersøgelsesområdet for Verena fiberkablet ikke vil medføre en væsentlig påvirkning af samtlige 11 deskriptorer for god miljøtilstand for havområdet Nordsøen/Skagerrak, og således ikke vil forsinke eller være til hinder for opnåelse af god miljøtilstand i undersøgelsesområdet eller i Nordsøen generelt.

4.4.2. Kumulative effekter

Som beskrevet i afsnit 4.2.1.1, har Energinet ansøgt om og fået tilladelse til, i 2023 og 2024, at gennemføre geofysiske og geotekniske forundersøgelser, samt marinbiologiske undersøgelser i området for Nordsø. De geofysiske undersøgelser blev dog gennemført i 2023 og Energinet bekræfter, at de ikke skal gennemføre yderligere geofysiske undersøgelser i 2024. Der vil af den årsag ikke være overlappende undervandsstøj fra de to geofysiske undersøgelser. De geotekniske og marinbiologiske undersøgelser vurderes i kumulation med nærværende geofysiske undersøgelser ikke at have en negativ påvirkning på havpattedyr, da de pågældende undersøgelser i Nordsø I er begrænset i tid og rum, med en lokal påvirkning og uden støjpåvirkning.

Det vurderes derfor, at de geofysiske undersøgelser hverken i sig selv eller i kumulation med andre projekter eller undersøgelser, vil medføre påvirkninger som vil forsinke eller være til hinder for opnåelse af god miljøtilstand i undersøgelsesområdet eller Nordsøen generelt.

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VERENA
Subsea Fibre Optic Cable

Underwater noise prognosis

Geophysical survey

NIRAS A/S

Date: 8. February 2024

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1	26-01-2024	First Draft	KRHO/MAM	MAWI	STOR
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Executive Summary

McMahon Design & Management Limited is planning geophysical survey activities in relation to the planning of the "VERENA Subsea Fibre Optic Cable", located in the Danish part of the North sea. Geophysical survey activities produce underwater noise and some of the activities have the potential to disturb and harm marine fauna. NIRAS has been tasked with preparation of an underwater noise prognosis for these activities, to act as input for an impact assessment for marine mammals and fish.

The potential for underwater noise impact was evaluated for the proposed geophysical survey activities:

1. Multibeam echosounder (MBES),
2. side scan sonar (SSS),
3. sub-bottom profiler (SBP),
4. Ultra-short baseline (USBL)

The acoustic impact of activity type MBES and SSS were assessed based on available literature, while underwater sound propagation modelling was undertaken for activity type SBP, and USBL.

A 3D acoustic environmental model, based on available online data sources, as well as client input, for bathymetry, sediment, salinity, temperature and sound speed, was created in QGIS and NIRAS TRANSMIT (Matlab toolbox). Worst case hydrographic conditions, represented by historical data for the month of February, was used. Underwater sound propagation modelling was carried out in dBSea 2.4.6, for activities SBP, and USBL, using the 3D acoustic environmental model, as well as a source model derived from available literature and NIRAS experience. Sound propagation was calculated in a 25 x 0.5 m range-depth grid in 45-90 directions from each source (4 - 8° resolution). Number of directions were increased for model positions near land masses. Resulting sound propagation losses were processed in NIRAS SILENCE (Matlab toolbox) to determine impact ranges to relevant marine mammal and fish threshold criteria.

For marine mammals, threshold criteria include hearing loss (threshold shift), resulting from exposure to high noise doses, as well as instantaneous behavioural reaction resulting from a sudden change in the experienced noise level. A noise induced threshold shift is a temporary or permanent reduction in hearing sensitivity, TTS and PTS respectively, following exposure to loud noise (for example commonly experienced by humans as a temporarily reduced hearing after attending a loud concert). The level of injury depends on both the intensity and duration of noise exposure. Small amounts of TTS will disappear in a matter of minutes, extending to hours or even days for very severe TTS. At higher levels of noise exposure, the hearing threshold does not recover fully, but leaves a smaller or larger amount of PTS. An initial TTS of 40 dB or higher is generally considered to constitute a significantly increased risk of generating a PTS (NOAA, 2018). Behavioural reaction on the other hand is linked to the instantaneous change in sound level, causing a reaction, such as avoidance.

For fish, TTS threshold criteria is used alongside a physical injury threshold criteria. For larvae and eggs, only the injury criteria is considered.

Marine mammals included in the prognosis are minke whales, white-beaked dolphin, harbour porpoise (*Phocoena phocoena*) and earless seals with threshold criteria for PTS and TTS, as well as behaviour reaction. Fish species included in the prognosis are cod and herring, as well as larvae and eggs, for which relevant TTS and injury threshold criteria were included.

Impact ranges for PTS, TTS and injury describe the minimum distance from the source a marine mammal or fish must at least be, prior to onset of survey activities, in order to avoid the respective impact. It therefore does not represent a constant distance the animals must maintain, but a safe starting distance, beyond which the threshold criteria are unlikely to be exceeded. For marine mammals, fleeing behaviour is included. For fish, fleeing behaviour is also included, while larvae and eggs are considered stationary.

Impact ranges for behaviour, describes the specific distance, up to which, the behavioural threshold criteria is likely to be exceeded, when survey activities are operating at maximum intensity.

Results are presented in numeric form in Table 1.1 - Table 1.4 for marine mammals, in Table 1.5 - Table 1.6 for fish, and in Table 1.7 for larvae and eggs.

Table 1.1: Impact ranges for minke whales.

Position	**Minke whale (LF): Threshold criteria impact ranges**		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
All sources active (combined)			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For minke whale, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 1.2: Impact ranges for white-beaked dolphin.

Position	White-beaked dolphin (HF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
All sources active (combined)			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For white-beaked dolphin, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities.

Table 1.3: Impact ranges for harbour porpoise.

Position	Harbour porpoise (VHF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	TTS (Non-impulsive)	Behaviour
	Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	25 - 275 m	600 m
2	< 100 m	120 - 325 m	575 m
3	< 100 m	120 - 325 m	600 m
4	< 100 m	130 - 375 m	675 m
5	< 100 m	120 - 350 m	650 m
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	425 -1300 m	4.0 km
2	< 100 m	400 - 1150 m	4.1 km
3	< 100 m	400 - 1150 m	4.5 km
4	< 100 m	675 - 1650 m	4.2 km
5	< 100 m	625 - 1600 m	4.4 km
	Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel		
1	< 100 m	150 – 850 m	3.2 km
2	< 100 m	225 – 625 m	3.6 km
3	< 100 m	180 – 575 m	3.6 km
4	< 100 m	325 – 875 m	3.6 km
5	< 100 m	300 – 875 m	3.6 km
	All sources active (combined)		
1	< 100 m	425 -1300 m	4.0 km
2	< 100 m	400 - 1150 m	4.1 km
3	< 100 m	400 - 1150 m	4.5 km
4	< 100 m	675 - 1650 m	4.2 km
5	< 100 m	625 - 1600 m	4.4 km

For harbour porpoise, underwater sound propagation modelling results show impact on behaviour at up to 4.5 km distance from the survey vessel. It should be noted that this behaviour criterion is only considered valid for impulsive noise sources (Tougaard, 2021), however as no threshold criteria have been established by science for non-impulsive sources, the impulsive criterion is used as a proxy.

Results show no impact beyond 100 m range for PTS, and up to 1.6 km for TTS, for the proposed geophysical survey activities.

Table 1.4: Impact ranges for seals.

Position	Seals (PCW): Threshold criteria impact ranges		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
All sources active (combined)			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For seals, underwater sound propagation modelling results show no impact beyond 100 m range for the geo-physical survey activities.

Table 1.5: Impact ranges for Cod.

Position	**Cod: Threshold criteria impact ranges**			
	Injury		**TTS**	
	Juvenile Cod	Adult Cod	Juvenile Cod	Adult Cod
Innomar Medium 100 (SBP) – distances relative to vessel				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
All sources active (combined)				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m

For cod, both juvenile and adult, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities.

Table 1.6: Impact ranges for Herring.

Position	**Herring: Threshold criteria impact ranges**	
	Injury	**TTS**
Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
All sources active (combined)		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m

For herring, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 1.7: Impact ranges for Larvae and eggs.

Position	Larvae and eggs: Threshold criteria impact ranges
	Injury
Innomar Medium 100 (SBP) – distances relative to vessel	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
All sources active (combined)	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m

For larvae and eggs, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Miljøministeriet
Kystdirektoratet

Ansøgning om tilladelse til anlæg på søterritoriet

Dette ansøgningsskema benyttes ved ansøgning om tilladelser til etablering, renovering og udvidelse af anlæg på søterritoriet.

Husk at læse vejledningen på side 6, før skemaet udfyldes.
Eventuelle spørgsmål til ansøgningsskema og vejledning rettes til Kystdirektoratet på tlf. 99 63 63 63 eller via e-mail kdi@kyst.dk.

Bemærk: En ansøgning kan først behandles, når alle nødvendige oplysninger foreligger.

Til Kystdirektoratets notater:

Dato for modtagelse:		*Journal nr.:*	
Projekttype:		*Sagsbehandler:*	

A. Oplysninger om ejere af den eller de matrikler, hvor anlægget opføres

Navn *Til havs - Staten*		
Adresse *Nordsøen, fra den danske eksklusiv økonomiske zone (EEZ) ind til det vestjyske kyst ved Henne Strand og Esbjerg.*		
Lokalt stednavn	Postnr.	By
Telefon nr.	Mobil nr.	E-mail

Table 1.7: Impact ranges for Larvae and eggs.

Position	Larvae and eggs: Threshold criteria impact ranges
	Injury
	Innomar Medium 100 (SBP) – distances relative to vessel
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
	Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
	All sources active (combined)
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m

For larvae and eggs, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Contents

List of abbreviations

Full name	Abbreviation	Symbol
Sound Exposure Level	SEL	$L_{E,p}$
Cumulative Sound Exposure Level	$SEL_{cum,t}$	$L_{E,cum,t}$
Sound Exposure Level - single pile strike	SEL_{SS}	L_{E100}
Sound Pressure Level	SPL	L_p
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	
Low frequency	LF	
High frequency	HF	
Very High frequency	VHF	
Phocid Pinniped	PCW	
World Ocean Atlas 2023	WOA23	
Sound Exposure Propagation loss	EPL	
National Marine Fisheries Service	NMFS	
Maximum-over-depth	MOD	

1. Introduction and objectives

McMahon Design & Management Limited is planning geophysical survey activities in relation to the planning of the VERENA Subsea Fibre Optic Cable project, located in the Danish part of the North sea. NIRAS has been tasked with preparation of an underwater noise prognosis for the geophysical survey activities, as input for an environmental impact assessment for marine mammals and fish.

The report is structured as outlined below.

Chapter	Content
2	Project description
3	Definitions: A brief introduction to terms and metrics used throughout the report
4	Marine mammal and fish threshold criteria for auditory impact
5	Underwater noise prognosis for geophysical survey

2. Project description

The VERENA Subsea Fibre Optic Cable survey area covers a 1 km wide corridor between Denmark and the United Kingdom. This report only covers the geophysical investigations within the Danish part of the North Sea. In Denmark, the survey corridor reaches the coast in two different locations (Henne Strand and Esbjerg). The geophysical survey covers an area (Figure 2.1) of 613 km^2.

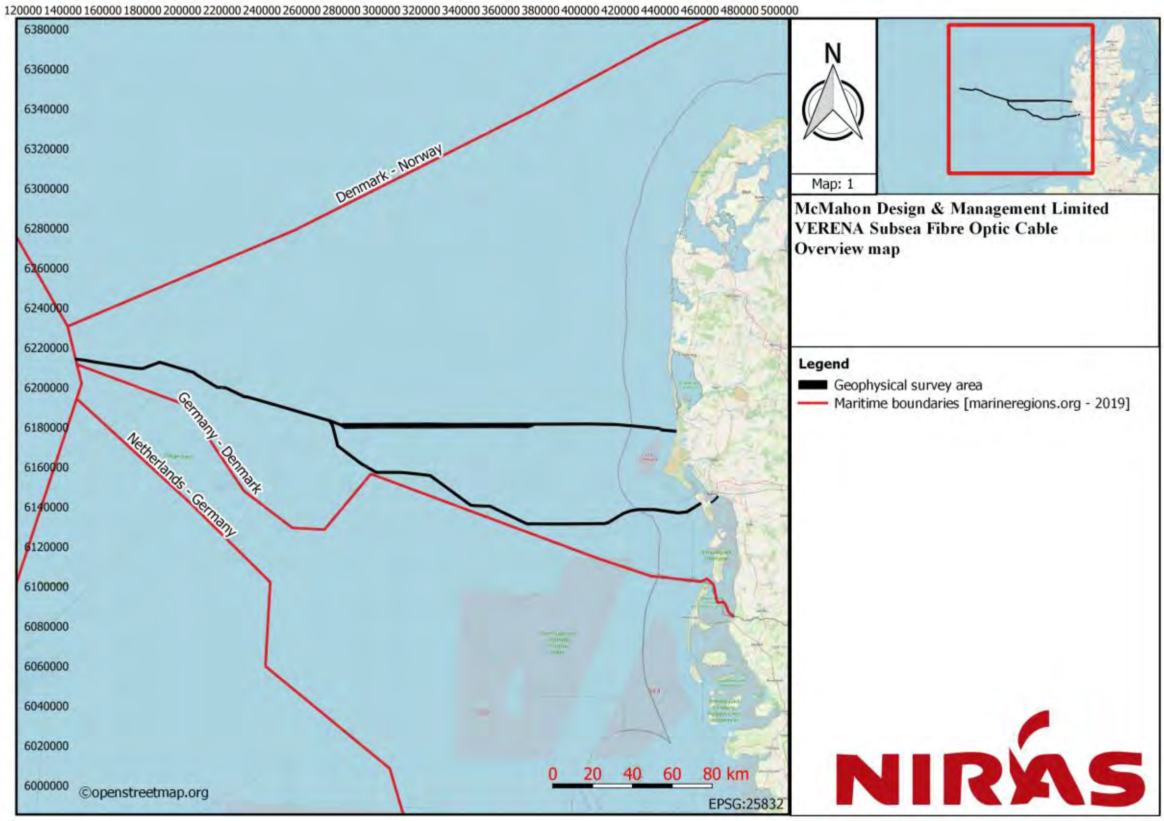

Figure 2.1: Overview of the VERENA Subsea Fibre Optic Cable geophysical survey area.

2.1. Description of Activities

Underwater noise emission is expected to occur as a result of the geophysical survey activities, where the physical properties of the seabed within the survey area are investigated.

Geophysical investigations are typically characterised by non-invasive acoustic techniques. By analysing the reflections of sound waves emitted towards the seafloor and sediment layers, the sediment layer composition, as well as pockets of natural resources, can be determined. Investigations that map the bathymetry and objects on or imbedded in the seabed, such as unexploded ordnance (UXO), are also considered part of the geophysical investigations.

3. Definitions

Acoustic metrics and relevant terms used in the report are defined in this chapter. Terminology generally follows ISO standard 18405 (DS/ISO 18405, 2017).

3.1. Sound Pressure Level

The Sound Pressure Level (SPL), $\mathrm{L_p}$, is used to describe the noise level. The definition for SPL is shown in Equation 1 (Erbe, 2011):

$$\mathrm{L_p} = 20 * \log_{10}\left(\sqrt{\left(\frac{1}{\mathrm{T}}\right)\int_0^T \mathrm{p(t)^2}}\right) \quad [\mathrm{dB\ re.\ 1\mu Pa}]$$

Equation 1

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

For ambient underwater noise and for operational underwater noise, $\mathrm{L_p}$ is the preferred metric.

In order to evaluate the behavioural response of the marine mammal a time window is needed. 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 $\mathrm{L_{p,125ms}}$ and the definition is shown in Equation 2 (Tougaard, 2021).

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

Equation 2

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

3.2. Sound Exposure Level

The Sound Exposure Level (SEL), $\mathrm{L_{E,p}}$, describes the total energy of a noise event (Jacobsen & Juhl, 2013). A noise event can for instance be the duration of an entire survey from start to end, or it can be a single noise event like an airgun pulse. The SEL is normalized to 1 second and is defined in (Martin, et al., 2019) through Equation 3.

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

Equation 3

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

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

$$L_{E,p} = L_p + 10 * \log_{10}(T) \qquad \text{Equation 4}$$

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. SEL is therefore a commonly used metric to assess the risk of hearing impairment as a result of noisy activities (Martin, et al., 2019).

3.3. Cumulative Sound Exposure level

For moving sources in combination with moving receivers, the $L_{E,cum,t}$ is calculated using the approach presented in (Tougaard, 2016). The survey vessel speed, and its direction relative to a moving receiver is used to calculate the $L_{E,cum,t}$ for a given receiver. In Equation 5, the distance between the source and receiver at the ith pulse, r_i, is given for a specific piece of survey equipment. This is based on a starting position of the marine mammal relative to the source, defined by the on-axis distance, l_0, corresponding to the transect line, and the off-axis distance, d_0, corresponding to the perpendicular distance from the transect line. Δt_i is the time in seconds between the first pulse and the ith , while v_{ship} and $v_{receiver}$ is the ship and receiver moving speed respectively, in m/s.

$$r_i = \sqrt{\left(l_0 - ((i-1)\cdot\Delta t_i)\cdot v_{ship}\right)^2 + (d_0 + ((i-1)\cdot\Delta t_i)\cdot v_{receiver})^2} \qquad \text{Equation 5}$$

By summing the pulses from the entire survey, within a 24h window, given the propagation loss for the survey area, Equation 6 gives the resulting $L_{E,cum,24h}$.

$$L_{E,cum,24h} = 10 * \log_{10}\left(\sum_{i=1}^{N} 10^{\left(\frac{L_{S,E} - X*\log_{10}(r_i) - A*(r_i)}{10}\right)}\right) \qquad \text{Equation 6}$$

Where N is the total number of pulses for that piece of survey equipment, $L_{S,E}$ is the source level at 1 m distance, X and A describe the sound exposure propagation losses (EPL), $N_{PL,E}$, for the specific project site. For surveys using multiple equipment types, the contribution from each source is first normalized into 1 sec. SEL based on firing frequency, and then added.

The parameters used in Equation 5 and Equation 6, related to the source level, firing frequency, movement speed and source direction must be based on best available knowledge. The EPL parameters (X and A) must be determined through advanced sound propagation modelling, in which all relevant site-specific environmental parameters are considered.

3.4. Source level

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

SL is defined for a continuous source as the SPL_{rms} at a distance of 1 m from the source with a reference value of $1\ \mu Pa \cdot m$. The metric is used primarily for non-impulsive source types, such as vessels.

ESL is used to describe a transient sound source and is defined as the SEL at a distance of 1 m from the source with a reference value of $1\ \mu Pa^2\ m^2\ s$. This is the standard metric used to describe the source level of impulsive noise sources.

3.5. Frequency weighting functions

In underwater noise assessments, frequency weighting is often used to more accurately reflect the underwater noise impact on specific marine mammals.

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 7 (NOAA, 2018).

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

Equation 7

Where:

- $\mathbf{a}$ is describing how much the weighting function amplitude is decreasing for the lower frequencies.
- $\mathbf{b}$ 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 3.1.

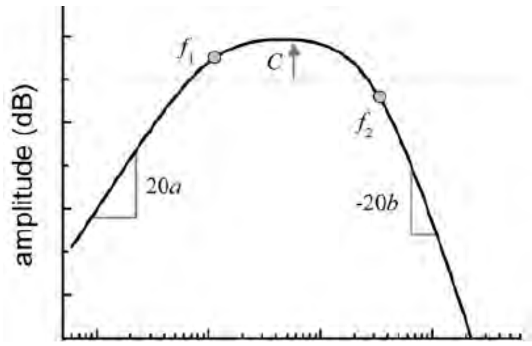

Figure 3.1: Illustration of the 5 parameters in the weighting function (NOAA, 2018).

Marine mammals are divided into four hearing groups, 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 Carnivores in Water (**PCW**) (NOAA, 2018; Southall, et al., 2019). The parameters in Equation *7* are defined for the hearing groups and the values are presented in Table 3.1.

Table 3.1: Parameters for the weighting function for the relevant hearing groups (NOAA, 2018).

Hearing Group	a	b	f_1 [kHz]	f_2 [kHz]	C [dB]
Low frequency (LF) Cetaceans	1.0	2	0.2	19	0.13
High frequency (HF) Cetaceans	1.6	2	8.8	110	1.20
Very high frequency (VHF) Cetaceans	1.8	2	12	140	1.36
Phocid Carnivores in Water (PCW)	1.0	2	1.9	30	0.75

The weighting function amplitude for the four hearing groups is achieved by inserting the values from Table 3.1 into Equation 7. The resulting spectra for the four hearing groups are shown in Figure 3.2.

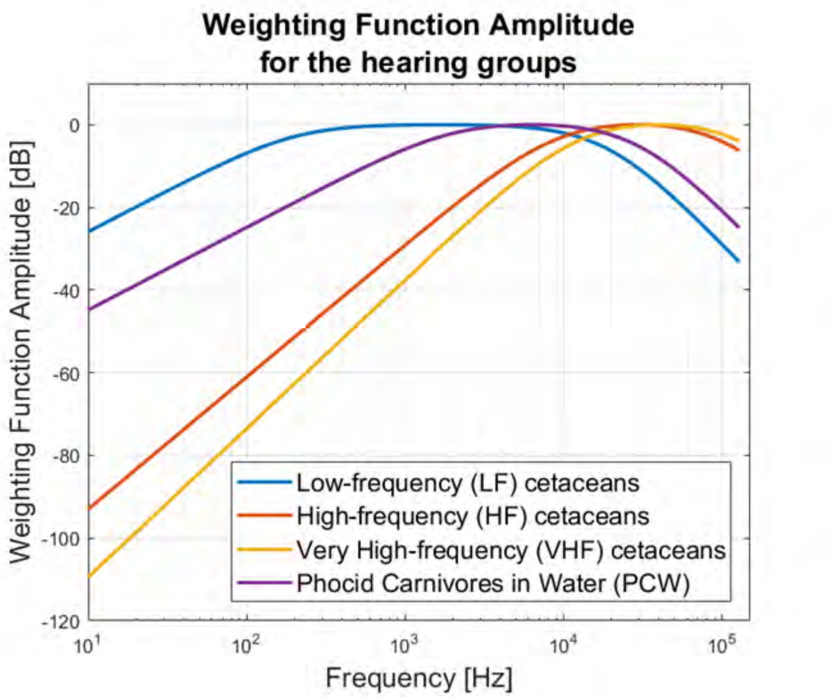

Figure 3.2: The weighting functions for the different hearing groups.

For this project, relevant species include; minke whales (classified as a Low frequency Cetaceans (LF)), white-beaked dolphin (classified as a high frequency Cetaceans (HF)), seal (classified as a Phocid Carnivores in Water (PCW)), and harbour porpoise (classified as a Very High Frequency Cetacean (VHF))]. Frequency weighting functions are not used for fish.

4. Underwater Noise Threshold Criteria

In Denmark, underwater noise from geophysical survey activities are handled by the authorities on a project-by-project basis. In order to provide a prognosis of impact, absent official threshold criteria, best available scientific knowledge from (NOAA, 2018), (Tougaard, 2021), (Energistyrelsen, 2023) is instead used in this project.

Two sets of threshold criteria are typically considered in evaluating the impact of underwater noise, based on the impulsiveness of the noise source. Following the definition of impulsive vs. non-impulsive noise sources in (NOAA, 2018), the terms are considered as follows:

- Impulsive: Sounds that are typically transient, brief (duration < 1 s), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay.
- Non-impulsive: Sounds that are broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically do not have a high peak sound pressure with rapid rise nor decay time.

For geophysical survey activities, it is not always clear if a source behaviour is impulsive or non-impulsive. While equipment types, such as airguns and explosives are unquestionably impulsive in nature, arguments can be made in both directions for other equipment types.

The impulsiveness of individual activities is reflected upon in the evaluation of each activity. For cumulative assessment, when all survey equipment is active simultaneously, it is considered likely that non-impulsive threshold criteria are more suitable than impulsive threshold criteria, which may be overly conservative. If however the combined noise emission is dominated heavily by an activity which is clearly defined as impulsive, it would however stand to reason that impulsive threshold criteria might be more appropriate.

4.1. Threshold criteria for fish

Assessment of the noise impact on fish, larvae and eggs (Table 4.1) are all based on unweighted threshold levels using the metric $\mathrm{L_{E,cum,24h}}$, defined in section 3.3. The criteria and swim speed for the different fish species are adopted from (Andersson, et al., 2016) and (Popper, et al., 2014).

Table 4.1: Threshold criteria for fish. TTS and injury criteria are unweighted (Andersson, et al., 2016), (Popper, et al., 2014).

Species	**Swim speed [m/s]**	**Threshold criteria, $L_{E,cum,24h}$ $[dB\ re.1\ \mu Pa^2 s]$**	
		TTS [dB]	**Injury [dB]**
Juvenile Cod	0.38	186	204
Adult Cod	0.90	186	204
Herring	1.04	186	204
Larvae and eggs	-	-	207

4.2. Threshold criteria for marine mammals

Based on the newest scientific literature, species specific frequency weighted $\mathrm{L_{E,cum,24h}}$ threshold values (NOAA, 2018), (Southall, et al., 2019) for TTS and PTS are used, Table 4.2. For avoidance behaviour, $\mathrm{L_{p,125ms,VHF}} = 103\ \mathrm{dB\ re.1\ \mu Pa}$ (Tougaard, 2021) is used for harbour porpoise.

Table 4.2: Threshold criteria for marine mammals. PTS and TTS criteria (NOAA, 2018), behaviour criteria (Tougaard, 2021) for hearing group classifications in (Southall, et al., 2019). "xx" notation refers to species specific weighted levels.

Species	**Swim speed [m/s]**	**Threshold criteria $L_{E,cum,24h,xx}$ $[dB\ re.1\ \mu Pa^2 s]$**				**Threshold criteria $L_{p,125ms,xx}$ $[dB\ re.1\ \mu Pa]$**
		PTS		**TTS**		**Behaviour**
		Non-impulsive	impulsive	Non-impulsive	Impulsive	
Minke whales (LF)	1,5	199	183	179	168	-
White-beaked dolphin (HF)	1,5	198	185	178	170	-
Harbour porpoise (VHF)	1.5	173 dB	155 dB	153 dB	140 dB	103 dB
Seal (PCW)	1.5	201 dB	185 dB	181 dB	170 dB	-

5. Underwater noise prognosis for geophysical survey

Geophysical survey activities have the potential to cause avoidance response, TTS, and PTS in marine mammals (Madsen, et al., 2006), as well as avoidance response, TTS and injury in fish (Popper, et al., 2014) (Andersson, et al., 2016).

Proposed survey equipment is first evaluated for its potential to have adverse effects on marine mammals or fish (section 5.1). In the evaluation of the different equipment types, the following groups of equipment are considered:

A. Equipment has insignificant underwater noise emission for marine mammals and fish:
   -> no further evaluation takes place.
B. Equipment has significant underwater noise emission but sound propagation modelling is not feasible:
   -> evaluation is based on either literature or equation based calculation.
C. Equipment has significant underwater noise emission and sound propagation modelling is feasible:
   -> evaluation is based on sound propagation modelling.

For equipment in group A or B, the impact is determined directly in the evaluation. For group C equipment, sound propagation modelling is carried out, with the following components:

- A source model, characterising the noise source, and the emission of noise into the water column (section 5.2).
- An environmental model, characterising the marine environment and its acoustic properties (section 5.3).
- A sound propagation model, through which the source and environmental model is used to determine the sound propagation (section 5.3.4).

Results are reported as impact ranges for marine mammals and fish, through numerical values of impact ranges in section 5.5.

5.1. Equipment evaluation

There is no final list of survey equipment models and operational parameters available for the survey activities, however a representative list is considered for use in the prognosis, see Table 5.1, based on experience from previous surveys, and information from the client.

Table 5.1: Geophysical survey equipment models and operational parameters. Source parameters are chosen conservatively where no information was supplied by McMahon Design & Management Limited.

Type	Equipment model	Source Level, L_s [dB re 1 µPa · m]	Primary Frequency Range (kHz)	Pulse Length	Beam Width	Sound exposure source level, $L_{S,E}$ [dB re 1 µPa$^2m^2$s]	Duty cycle over a 24 hour period
Sub-bottom profiler (SBP)	Innomar Medium 100	247 dB	1-150	0.07 – 2 ms	2°	213 dB	40 Hz
Multi-beam echosounder (MBES)	SeaBat T50-R - Standard projector (TC2181)	190 - 220 dB	190-420	0.3 - 10 ms	2° @ 200 kHz 1° @ 400 kHz	170 - 200 dB	50 Hz
Side scan sonar (SSS)	Edgetech 4205	210 dB*	230/850	-	0.63° (230 kHz) 0.30° (850 kHz)	-	-
Ultrashort Baseline (USBL)	Sonardyne - HPT 3000 USBL transceiver	194 dB	20-34	20 ms	Omni	177 dB	1 Hz
USBL transponder	Sonardyne - Wideband Mini Transponder - Type 8190-3111	187 dB	19 – 34	20 ms	Omni	170 dB	1 Hz
Magnetometer	Cesium Marine Magnetometer G-882	-	-	-	-	-	-

* Source level is assumed to be equivalent to Edgetech 4200, due to absence of model specific information

5.1.1. Parametric SBP (Innomar Medium 100)

The Innomar Medium 100 creates a very detailed profile of the uppermost part of the seabed, typically the uppermost 20 m below the seabed. It emits two high frequency pulses, called the primary frequencies, with both pulses typically in the frequency range of 100 – 120 kHz. The frequency separation between the two pulses dictate the secondary frequency, created inside the water column as the difference between the two primary frequencies: $f_{sec} = f_{pri2} - f_{pri1}$ $[Hz]$.

The source level of the Innomar Medium 100 is listed as $\mathrm{SL} = 247\ \mathrm{dB\ re.\ 1\mu Pa\ @1m}$. It is a complex sound source as the sound emission is heavily focused towards the seabed. The horizontal emission of underwater noise is therefore significantly lower than the source level would indicate, compared to the emission directly downward into the seabed.

In a sound source verification study for geophysical survey activities in the Danish North Sea (Pace, et al., 2021), acoustic measurements were carried out for the Innomar Medium 100. In the study, the sound level was recorded in the horizontal direction at distances ranging from 10s of meters to 750 m. In Figure 5.1, all measured data points in the horizontal direction are presented as the individual pulse SEL, along with a logarithmic curve

fit. The trend indicates a source level of 193 dB and a rapid decay of approximately 37 dB/decade in the horizontal direction.

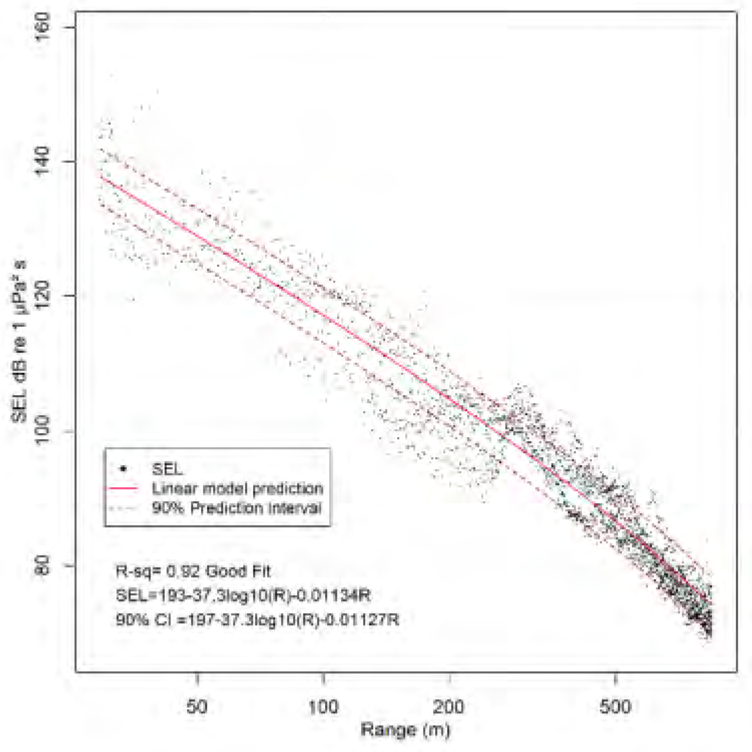

Figure 5.1: Sound Exposure Level measurements and curve fit for Innomar Medium 100, during a sound source verification study in the North Sea (Pace, et al., 2021).

The curve fit obtained from these measurements, should however be considered with a degree of caution, and should not be considered generally applicable. The environmental conditions affect the sound propagation. In order to use the measurement data in a different setting or environment, it is necessary to compensate for the environment where it was obtained, and to develop an equivalent source model that, given the same environment, performs in line with the measurements. NIRAS constructed a 3D acoustic model in dBSea, representing the actual survey environment, based on the information supplied in the report along with best available knowledge. In this model, an equivalent omnidirectional point source was designed, mimicking the measured data. The equivalent model can then be used in any other marine environment, however recognizing that the model is an approximation of the equipment behaviour, more so than an actual source model. It is therefore also recognized that this introduces an uncertainty into the sound propagation model. It is however considered the best-possible approach given the lack of an actual source model, which would require detailed source level and frequency measurements, as well as detailed frequency specific directivity measurements.

Based on the evaluation above, the Innomar Medium 100 is considered a "group C" equipment type, and will be evaluated through sound propagation modelling.

5.1.2. Ultra-Short Baseline (Sonardyne; HPT 3000 USBL transceiver and Wideband Mini Transponder - Type 8190)

The Ultra Short Baseline (USBL) system is used to determine the relative position of an underwater object, relative to a known reference point. It consists of a USBL unit mounted at a known reference point, and a transponder unit mounted on the object whose relative position is of interest. For applications such as seabed

surveys, the USBL unit would typically be mounted on the vessel. The absolute position of the vessel is registered by a GPS, thereby creating a fixed reference point for the USBL. A transponder unit is then attached to the towed equipment, such as a Side Scan Sonar (SSS), a magnetometer, ROV, etc.

It can be operated in one of two ways as outlined below, the choice between which typically relies on available equipment and project specific conditions:

A. Transponder mode (acoustic), whereby the USBL unit on the vessel emits a loud acoustic pulse acting as a "trigger". When the "trigger" pulse is registered by the transponder unit on the towed equipment, it sends out an acoustic "response" pulse. A hydrophone array on the USBL unit, records the "response" pulse and the relative distance and bearing of the transponder, relative to the vessel is registered. In this way the relative geographical position of the towed equipment is determined with very high precision.

B. Responder mode (cabled), where the "trigger" pulse is not sent acoustically through the water, but instead as an electrical impulse through a cable between the vessel and the transponder unit. On receiving the trigger pulse, the transponder unit will still emit its response pulse acoustically.

The USBL system requires a USBL unit for which the absolute geographical position must be known, and one or more transponder units mounted on equipment for which the relative position is to be determined.

From an underwater noise perspective, it is important to distinguish between the USBL unit and the transponder units. Both due to their functionality, and due to their locations. While the USBL unit is typically mounted on the vessel, the transponder units are located on the towed equipment or other objects of interest.

The Sonardyne HPT 3000 USBL transceiver USBL unit has the following source characteristics, as per supplier data sheet:

- Frequency range for the acoustic pulses: ~20 kHz – ~34 kHz,
- Source levels ranging from: $SL = 194\ dB\ re. 1\ \mu Pa$.

The frequency and source level used for any given project, depends on the environmental and project specific conditions, however standard operating frequency of 25 kHz is assumed.

It is worth noting that these systems only emit acoustic pulses in the acoustic "Transponder mode". If operated in "Responder mode", no sound is emitted, and the unit is therefore silent.

The Sonardyne - Wideband Mini Transponder - Type 8190-3111 transponder unit has the following source characteristics, as per supplier data sheet:

- Frequency range for the acoustic pulses: ~19 kHz – ~34 kHz,
- Source level: $SL = 187\ dB\ re. 1\ \mu Pa$

The frequency and source level used for any given project, depends on the environmental and project specific conditions, however standard operating frequency of 25 kHz is assumed.

Few real-world measurements of underwater noise emission from USBL systems are publicly available, and most of these include either a very limited measurement range, problems with the produced results and limited information about the used source levels and operation mode.

In 2021, a measurement was however carried out by JASCO (Pace, et al., 2021) for Energinet.dk during geotechnical survey activities of the Danish Energy Island North Sea project. For this measurement, a Kongsberg HiPaP 501 USBL unit (Vessel mounted) was used to determine the position of a towed side-scan sonar (SSS), with a "Kongsberg cNODE Micro" transponder unit. The results of these measurements are discussed in the following.

The following operational parameters were used (Pace, et al., 2021):

- The USBL unit (HiPaP 501) was operated at maximum source level,
$$SL = 191\ dB\ re. 1\ \mu Pa$$
- The Kongsberg cNODE Micro 30-180 transponder unit was operated at maximum source level,
$$SL = 170\ dB\ re. 1\ \mu Pa$$
- Pulse rate (trigger rate): 1.5 Hz
- Center frequency of both USBL and transponder units: 25 kHz
- Operational mode: "Transponder mode"

In Figure 5.2, a spectrogram of the measurements with the USBL system active is shown. The colors represent the sound pressure level (Warm = high levels, cold = low levels). The x-axis is the time stamp, and the y-axis is the frequency.

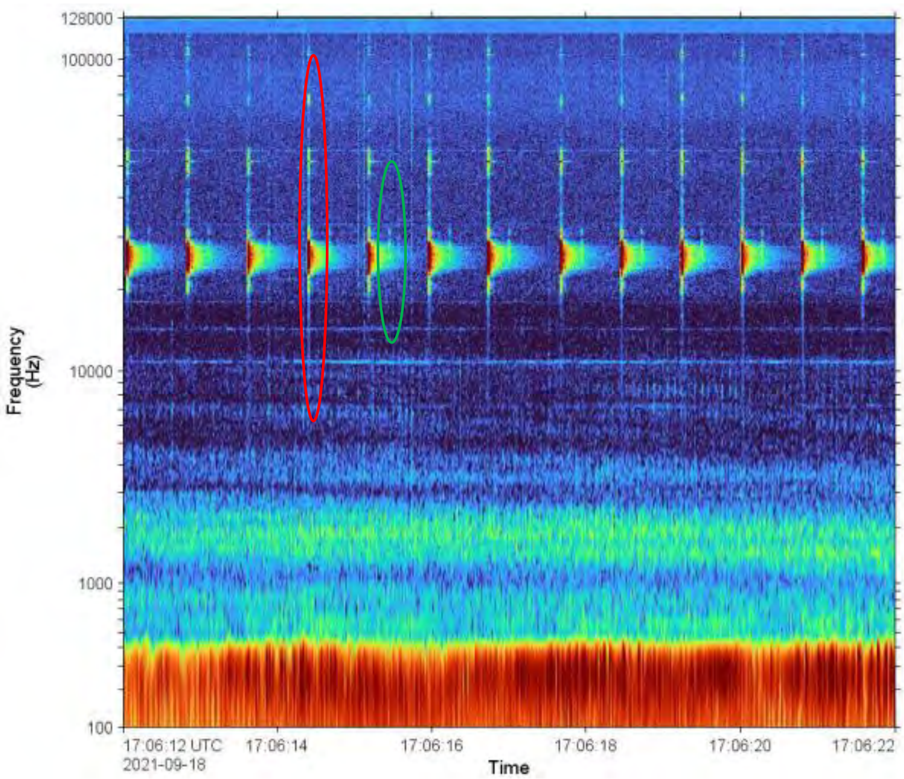

Figure 5.2: Spectrogram of measurements where SSS and USBL systems were active. Warm colours indicate high sound pressure level, and cold colours indicate low sound pressure levels as a function of frequency (Pace, et al., 2021). The red marking indicates the USBL unit pulse, while the green marking represents the transponder pulse.

From Figure 5.2, the USBL unit pulse is visible as the bright red impulses that fade into yellow to green as the sound level reduces after the pulse has stopped. The transponder pulse is less visible but can be seen as the small green lines following shortly after each of the USBL pulses.

Zooming in on a single pulse, where all the background noise is removed, is shown in Figure 5.3. Here the USBL unit pulse is clearly visible in the left half of the figure, and the transponder pulse is visible in the right-hand side where the sound level suddenly increases.

Figure 5.3: Raw data snap shot of recorded pulse at 17:06:17, where the USBL unit pulse is seen on the left hand side, and the transponder response pulse is seen on the right hand side.

As seen from Figure 5.3, the USBL unit pulse is significantly stronger than the transponder pulse.

Due to the significant difference in magnitude and short time delay between the pulses (~100 ms), only received levels for the USBL unit were reported in (Pace, et al., 2021). Curve fits for the sound level as a function of distance between source and receiver were also shown, see Figure 5.4.

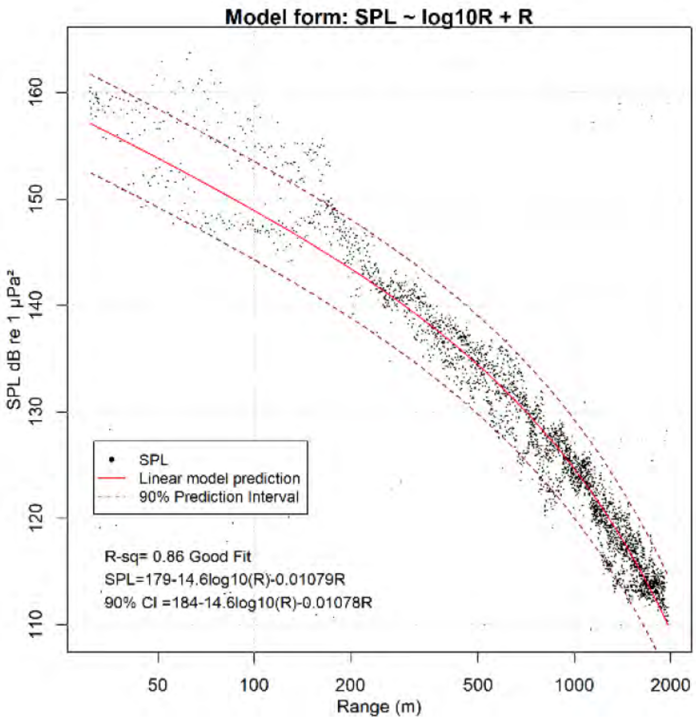

Figure 5.4: $SPL_{rms,125ms}$ as a function of measurement distance to USBL system, (Pace, et al., 2021).

From Figure 5.4, the source level for the USBL unit was back calculated to be $SL_{rms,125ms} = 179\ dB\ re. 1\ \mu Pa^2$. As previously mentioned, measured source level for the transponder was not made available. It should be noted that while the reported source level of 179 dB does not match the reported 190 dB source level set for the USBL unit, this is due to the signal duration used in the representation. Compensating for the pulse duration (20 ms)

vs. the reported levels (125 ms) gives a difference of ~8 dB. So the comparable curve fitted source level would be $SL = 187\ dB\ re. 1\ \mu Pa$ (best fit) and $SL = 192\ dB\ re. 1\ \mu Pa$ (90^{th} percentile), thus matching the reported source level of $SL = 191\ dB\ re. 1\ \mu Pa$.

The measurements were carried out in the North Sea, and can not be directly used in other waters. The equipment type is classified as "Group C", and will be evaluated through detailed sound propagation modelling.

For the sake of caution, USBL and transponder units included in this prognosis are both considered omnidirectional.

5.1.3. Multi-beam Echosounder (SeaBat T50-R)

The SeaBat T50-R MBES is a hydroacoustic device used for mapping the seafloor and collecting bathymetric data in marine environments. It employs the principles of sonar to measure the depth of the seabed and generate high-resolution bathymetric maps.

The transducer array is the primary component of the MBES. It consists of multiple individual transducers arranged in a fan-shaped or circular array. Each transducer emits a narrow beam of sound pulses in a downward direction and receives the echo reflected from the seafloor.

The frequencies emitted by the MBES are at least 200 kHz, which is outside the hearing ability of any marine mammals or fish. Coupled with the strong downward directivity, this equipment type is unlikely to have any negative auditory effect on marine mammals or fish. It is therefore considered a "Group A" equipment type, and is not considered further in this prognosis.

5.1.4. Side scan sonar (Edgetech 4205)

The Edgetech 4205 SSS is an underwater imaging system used for high-resolution imaging and mapping of the seafloor. Unlike multibeam echosounders (MBES) that primarily measure bathymetry, SSS are designed to provide detailed visual representations of the seafloor surface and its features.

The transducer array in a side scan sonar is responsible for transmitting and receiving acoustic signals. It typically consists of one or more transducers arranged in a line or an array configuration. Each transducer emits a narrow beam of sound waves perpendicular to the seafloor, covering a wide swath on either side of the sonar system.

The frequencies emitted by the SSS are typically at least 300 kHz, which is outside the hearing ability of any marine mammals or fish. While the Edgetech 4205 also comes with the option of a 100 kHz frequency, it was agreed with McMahon Design & Management Limited not to use this setting, as it coincides with the frequency range where harbour porpoise are most sensitive to sound. Coupled with the strong downward directivity, and restricting the use of frequencies below 200 kHz, this equipment type is unlikely to have any negative auditory effect on marine mammals or fish. It is therefore considered a "Group A" equipment type, and is not considered further in this prognosis.

5.1.5. Magnetometer

Marine magnetometers used in geophysical surveys for detecting buried objects such as UXOs are designed to identify variations in the magnetic field caused by the presence of ferromagnetic materials. These materials, including metallic objects like munitions, generate localized disturbances in the Earth's magnetic field, which can be detected and analyzed by the magnetometer system.

The magnetometer sensor is typically mounted on a specialized instrument platform, such as a towfish or a remotely operated vehicle (ROV). The platform is then towed at a constant altitude above the seafloor, typically a few meters, ensuring consistent proximity to the target area.

The magnetometer does not rely on acoustic output to function, and it therefore has no underwater noise emission. It is classified as a "Group A" equipment type, and is not considered further in this prognosis.

5.1.6. Noise from survey vessels

In addition to the noise from the individual activities, the survey vessel is also likely to be a source of underwater noise during the survey execution. In Pace et al. (2021), the survey vessel underwater noise emission was measured, and reporting in 1/3 octave levels at 5 different distances from the vessel, with and without marine mammal frequency weighting applied, see Figure 5.5.

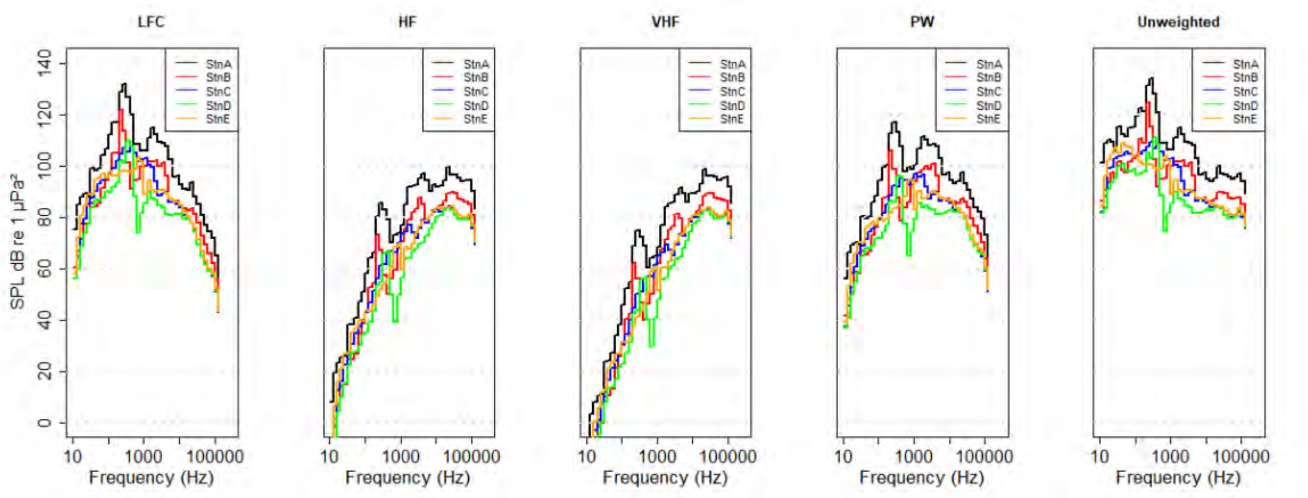

Figure 5.5: Weighted and unweighted 1/3 octave sound pressure level (SPL) measured at 5 different hydrophone distances (stnA is directly underneath the vessel path, stnB at 150 m distance, stnC at 540 m, stnD at 780 m and stnE at 2040 m). (Pace, et al., 2021).

From Figure 5.5, it is evident that noise levels are primarily low frequent, with most of the acoustic energy located below a few hundred Hz. For harbour porpoise (VHF-weighting), the measurements at station B (150 m distance) show 1/3 octave band levels below 90 dB in all bands, with broadband level below the threshold criteria for behaviour reaction, $L_{p,125ms,VHF} = 103 \text{ dB re. } 1 \text{ µPa}$.

Vessel noise is a continuous noise type, and is therefore evaluated by comparison with the non-impulsive TTS and PTS criteria. In Table 5.2, distances to PTS and TTS for each of the relevant species are provided, based on the measurement data in Figure 5.5, and assuming a 24 hour survey duration.

Table 5.2: PTS and TTS impact ranges from geophysical survey vessel noise.

Species	Swim speed [m/s]	Impact range [m]		
		PTS	TTS	Behaviour
		Non-impulsive	Non-impulsive	
Minke whales (LF)	1,5	< 10 m	< 100 m	-
White-beaked dolphin (HF)	1,5	< 10 m	< 100 m	-
Harbour porpoise (VHF)	1.5	< 10 m	< 100 m	< 150 m
Seal (PCW)	1.5	< 10 m	< 100 m	-

From this, it is evaluated that the survey vessel is categorized as "Group A", and is not evaluated any further.

5.1.7. Summary of equipment evaluation

All proposed equipment types were evaluated for their potential to emit harmful levels of underwater noise, and three groups were defined:

- Group A equipment, where underwater noise emission is evaluated to be insignificant, includes the MBES, SSS and magnetometer equipment types.
- Group B equipment, where underwater noise emission may occur at harmful levels, but where sound propagation modelling is not possible, did not apply to any proposed equipment types.
- Group C equipment, where significant underwater noise emission is likely, and sound propagation modelling should take place, included the parametric SBP and USBL.

5.2. Source model

5.2.1. Parametric SBP (Innomar Medium 100) implementation

The Innomar Medium 100 source model is based on the approach described in section 5.1.1, using an omnidirectional equivalent point source. Source characteristics are shown in Figure 5.6, as both unweighted (blue), LF (purple), HF (orange), VHF (green) and PCW (red). It is reiterated that this is an equivalent point source model from a horizontal propagation perspective, and not an accurate representation of the sound source. It is therefore only to be used as a conservative model for calculating horizontal impact ranges for marine mammals and fish.

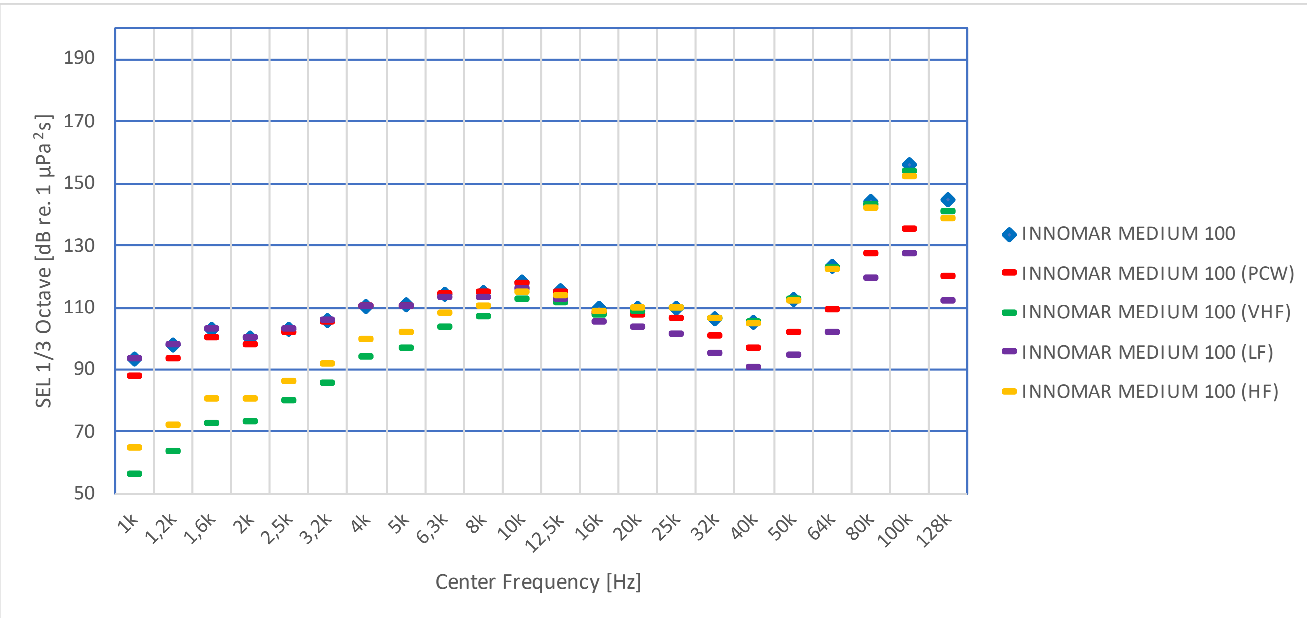

Figure 5.6: Equivalent omnidirectional point source model frequency spectrum for the Innomar Medium 100 parametric SBP. The source model is calibrated to fit measurement results from (Pace, et al., 2021).

The Innomar Medium 100 is mounted on the vessel, and is assumed operated at a 40 Hz pulse rate, while the vessel sails at 4 knots. The activity is assumed ongoing for 24 hours continuously, and it is assumed that it is not

turned off during line turns. The Innomar Medium 100 is considered a non-impulsive source type, and impact range calculation is therefore based on the non-impulsive threshold criteria.

5.2.2. USBL (Sonardyne; HPT 3000 USBL and WMT - Type 8190) implementation

The Sonardyne; HPT 3000 USBL transceiver and Wideband Mini Transponder - Type 8190 source models are based on the approach described in section 5.1.2, using an omnidirectional single-frequency point source with all energy located in the 25 kHz, 1/3 octave band. Source levels used are:

- USBL unit (Sonardyne; HPT 3000 USBL transceiver):
    - $SL = 194\ dB\ re.1\ \mu Pa$
- Transponder unit (Sonardyne; Wideband Mini Transponder - Type 8190):
    - $SL = 187\ dB\ re.1\ \mu Pa$

The USBL unit is mounted on the vessel, while the transponder unit is mounted on the tow, and both are assumed operated at a 1 Hz pulse rate, while the vessel speed is 4 knots. The activity is assumed ongoing for 24 hours continuously, and it is assumed that it is not turned off during line turns. The USBL is treated as a non-impulsive source type, due to its narrowband frequency content, pulsed characteristic and with no rapid rise nor decay.

5.2.3. Source positions

The project is in early stages of development, and final survey activities have not yet been determined. It was therefore agreed with McMahon Design & Management Limited to select a number of representative positions throughout the investigation area, so different sound propagation scenarios are covered. Areas where sound propagation most likely results in the longest impact ranges are identified, taking into account nearby marine mammal and/or fish protection areas if relevant. The source positions are listed in Table 5.3, along with coordinates, and distances to relevant areas of interest. The positions are also shown in Figure 5.7.

Table 5.3: Source positions used for sound propagation modelling of underwater noise during geotechnical and geophysical surveys.

Position ID	Easting	Northing	EPSG	Nearby areas of interest
1	456569	6139328	25832	Nat2000 area “Sydlige Nordsø”, 22 km distance Nat2000 area “Vadehavet”, overlapping City of Esbjerg, 12 km distance
2	405569	6131390	25832	Nat2000 area “Sydlige Nordsø”, overlapping
3	391896	6181635	25832	Nat2000 area “Sydlige Nordsø”, 23 km distance
4	645139	6180969	25831	-
5	567863	6200876	25831	Nat2000 area “Doggerbank”, 16 km distance

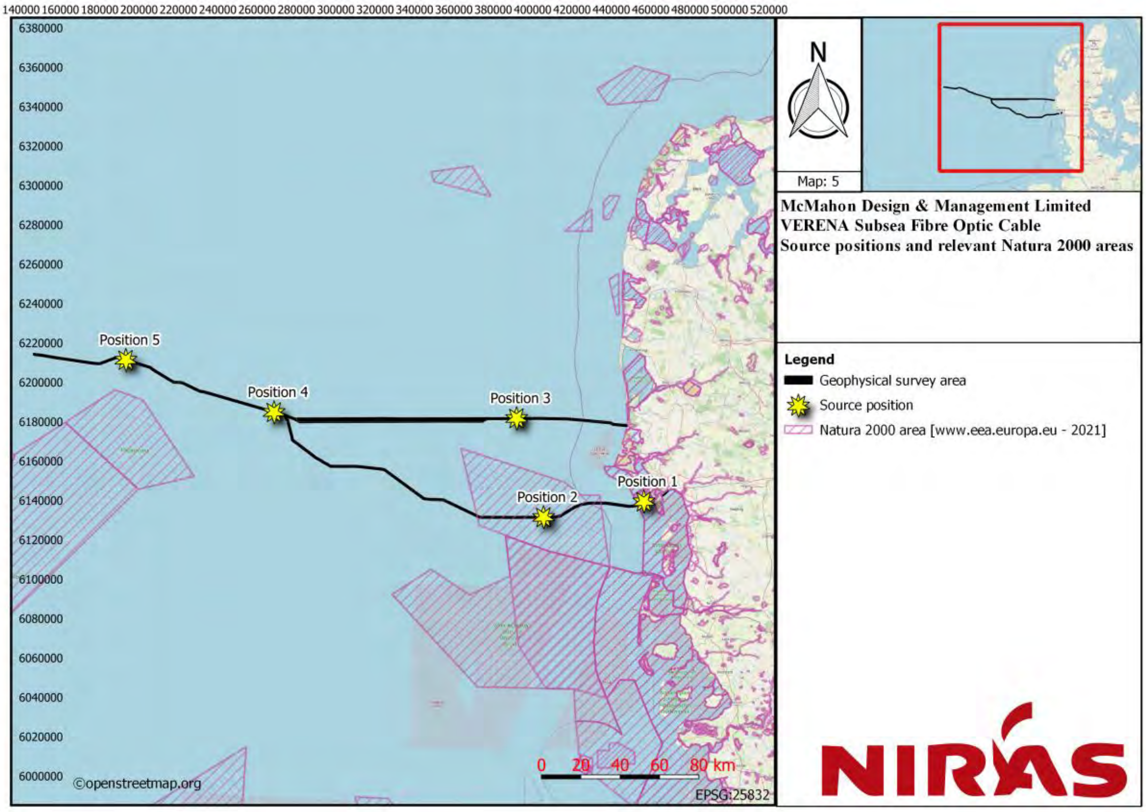

Figure 5.7: Source positions chosen for sound propagation modelling as well as nearby Natura 2000 areas.

5.3. Environmental model

Sound travels faster and farther in water than in air because water is denser and more efficient at transmitting sound waves. However, the aquatic environment is complex and heterogeneous, and sound propagation is influenced by a number of environmental parameters:

- Bathymetry,
- seabed sediments,
- temperature, salinity and sound speed,
- sea surface roughness, and
- volume attenuation.

These factors can cause sound to refract, reflect, scatter, and attenuate as the sound waves propagate through water, making it challenging to predict its behavior. These factors, and their implementation for sound propagation modelling, are described in the following sections.

5.3.1. Bathymetry

The shape and composition of the seafloor plays a critical role in the propagation of sound waves through the water. The seafloor can act as a barrier or a reflector for sound waves, depending on its composition and shape. A smooth, flat seafloor can reflect sound waves back towards the surface, whereas a rough, irregular seafloor can scatter sound waves in different directions, causing them to lose intensity and become weaker over distance.

Additionally, underwater ridges, canyons, and other geological features can act as waveguides, trapping and focusing sound waves in specific depths or regions.

Overall, bathymetry affects underwater sound propagation by influencing the speed, direction, and intensity of sound waves as they travel through the water. A detailed understanding of the bathymetry is critical for predicting and modelling the nature of underwater sound propagation in a real world scenario.

If project specific high resolution bathymetry is available, this is typically preferred over publicly available databases, which tend to be of lower resolution. Project specific bathymetry however seldomly extend beyond the project boundary. To calculate impact ranges for marine mammals and fish, it is necessary for the sound propagation model to extend 10 – 20 km beyond the project boundary. Project specific bathymetry can therefore seldomly be used alone.

For projects where no high resolution bathymetry is available, or where it is limited to the project boundary, publicly available databases, such as (EMODnet, 2021), can be used. A map of the bathymetry for Europe is shown in Figure 5.8, where darker colours indicate deeper areas, and lighter colours indicate more shallow water (EMODnet, 2021).

Figure 5.8: Bathymetry map over European waters from EMODnet, where light blue indicates shallow waters and dark blue indicates deeper waters (EMODnet, 2021).

The bathymetry for the project area and surroundings consists of information from the sources listed in Table 5.4. A visualisation of the bathymetry model for the project area and surroundings is shown in Figure 5.9.

Table 5.4: Bathymetry model data sources.

Data source	Reference
Bathymetry	(EMODnet, 2021)

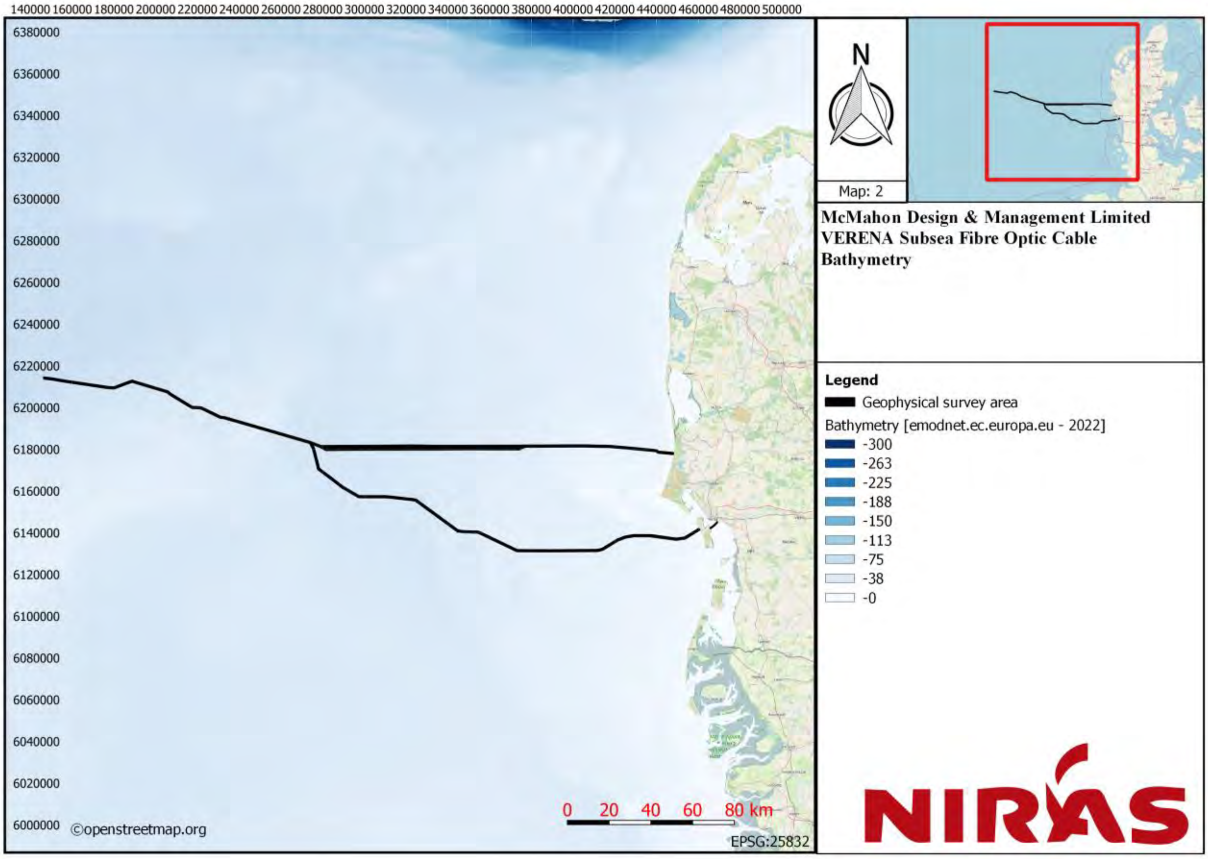

Figure 5.9: Bathymetry for the project area and surroundings, sources as listed in Table 5.4.

5.3.2. Seabed sediment

Seabed sediment layers can have a significant effect on the propagation of sound waves through the water. The acoustic properties of sediment layers are influenced by several factors, including the composition, density, porosity, and grain size distribution of the sediments. Generally, sediments with larger grain sizes and lower porosity have higher acoustic velocities and can transmit sound waves more efficiently than finer-grained and more porous sediments.

The properties of sediment layers can also affect the reflection, refraction, and attenuation of sound waves. For example, a layer of fine-grained, soft sediment can absorb and scatter sound waves, causing them to lose intensity and become weaker over distance. Conversely, a layer of hard, compacted sediment can reflect sound waves, resulting in increased sound intensity in certain areas.

The thickness of sediment layers can also play a role in underwater sound propagation. Thicker sediment layers can absorb and scatter sound waves more effectively, while shallower sediment layers can reflect and refract sound waves more strongly.

The thickness and acoustic properties of each seabed layer, from seabed to bedrock, is generally obtained through site specific literature research in combination with available site-specific survey findings.

Where site specific surveys do not reveal the top layer conditions, or where the site specific information is limited to the project boundary, publicly available databases, such as the seabed substrate map from (EMODnet, 2021) (Figure 5.10) is generally used.

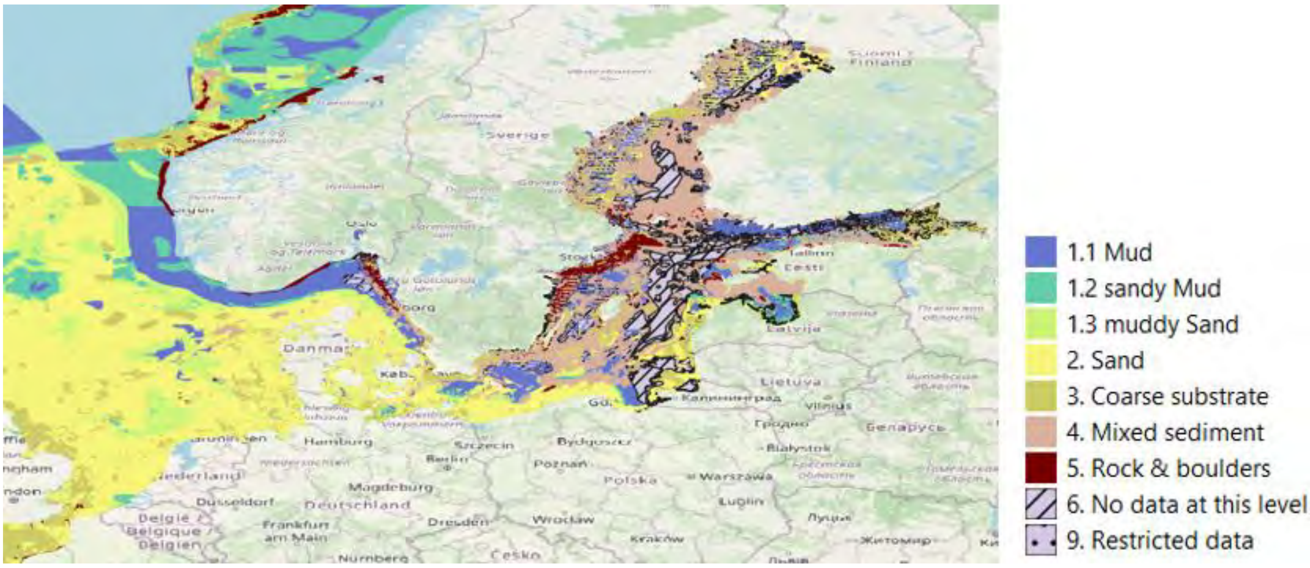

Figure 5.10: A section of the seabed substrate map, (Folk 7) (EMODnet, 2021).

From the available sediment data sources, a discretized and simplified version is created, whereby the layer thicknesses and sediment types are defined in a number of points. A high number of sediment points is necessary, when the variation in sediment types and thicknesses within the project area and surroundings increases.

For each point in the model, the sediment layer types are translated into geoacoustic parameters, in accordance with Table 5.5, utilizing information from (Jensen, et al., 2011; Hamilton, 1980).

Table 5.5: 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

The sediment model is constructed using available sources, see Table 5.6, and resulted in a 89 point sediment model, with topsoil types shown in Figure 5.11. Primary seabed surface layers in position 1, 2 and 3 are sand and coarse substrate. For position 4 and 5 the primary seabed surface layers are muddy sand. Layer thickness of the upper sediment is not well defined in the available sources and a conservative thickness of 10 m is used

throughout. Acoustic parameters for each layer are shown in Table 5.5. As it is not feasible to create an infinitely detailed sediment model, conservative layer thickness, and sediment types are used to provide a worst-case sediment model. The data source used to inform the sediment model implementation, is shown in Figure 5.12.

Table 5.6: Sediment model data sources.

Data source	Reference
Seabed substrate map	(EMODnet, 2021)
Sediment profile map	(COWI, 2020)
Acoustic parameter model for sediment types	Table 5.5

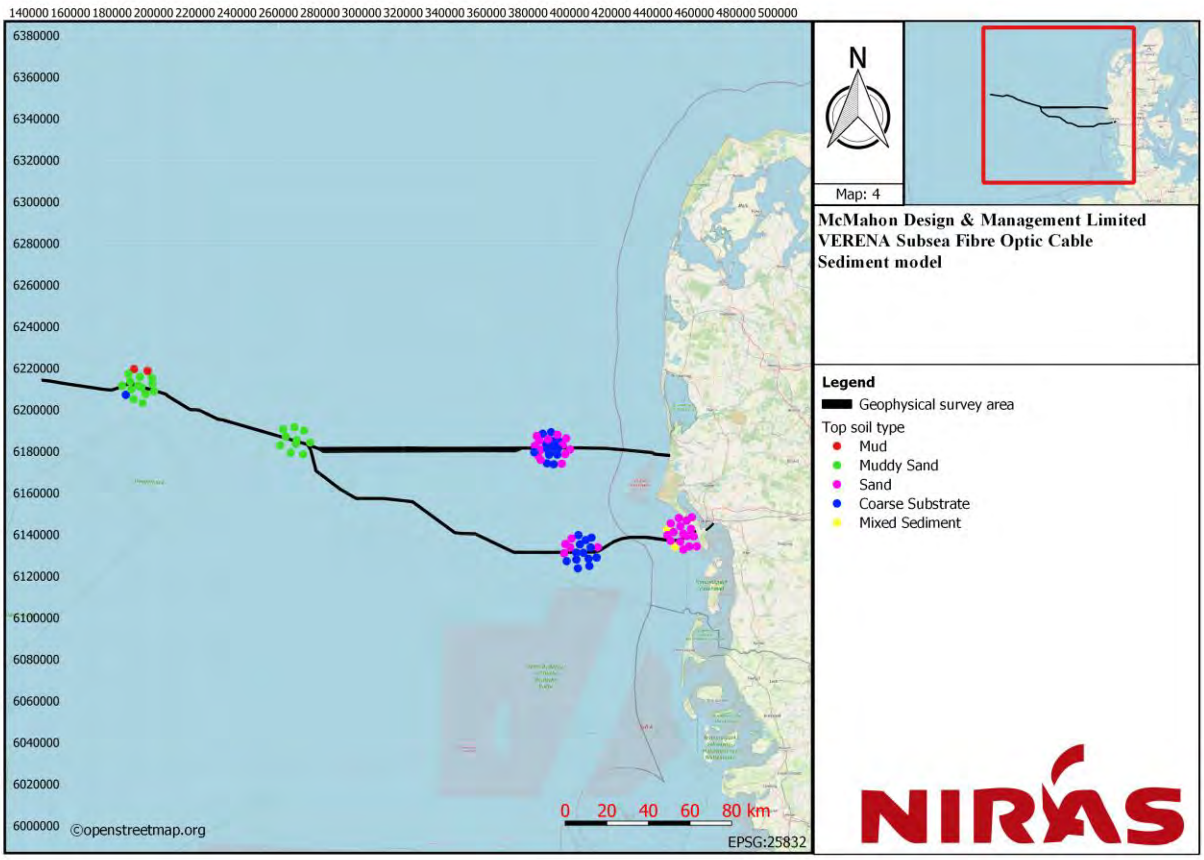

Figure 5.11: Sediment model points and topsoil layer type.

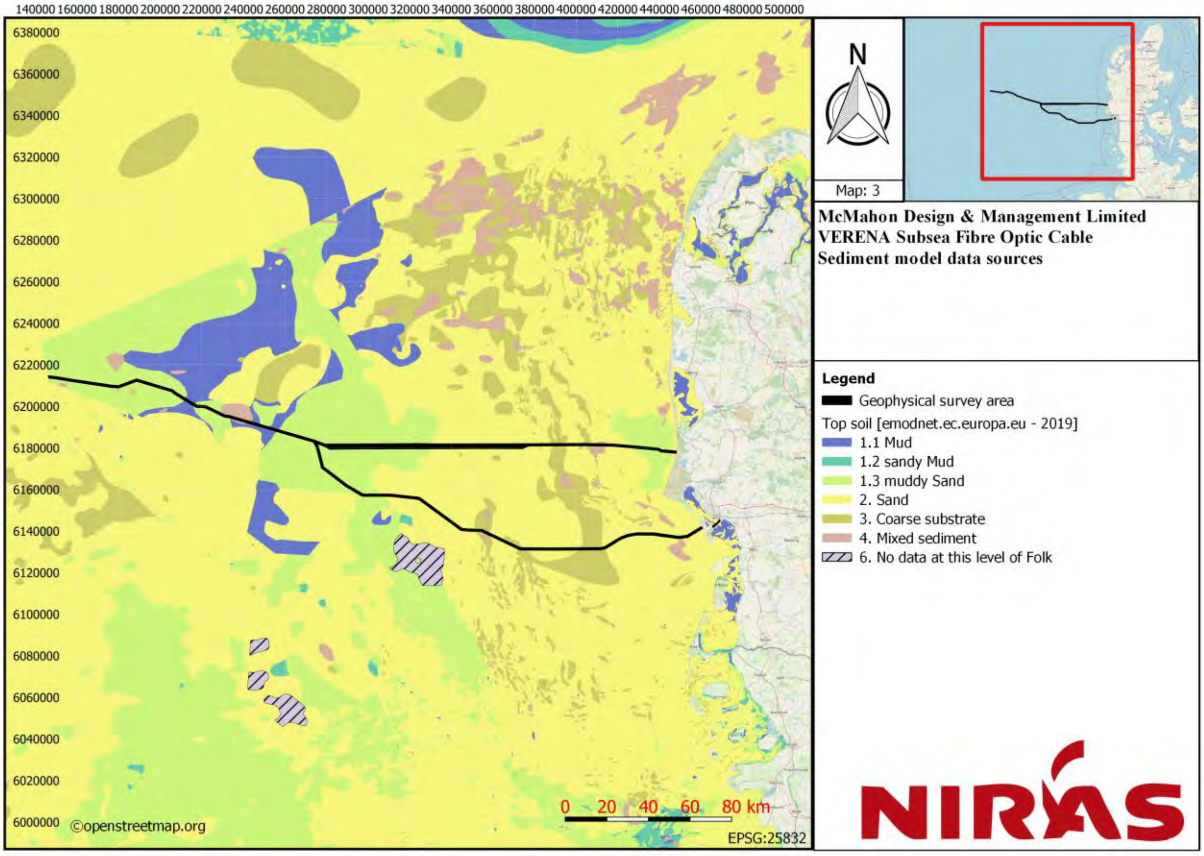

Figure 5.12: Sediment model data source, as listed in Table 5.6.

5.3.3. Temperature, salinity and sound speed profile

The combined effects of temperature and salinity on seawater density can create complex sound speed profiles in the sea, particularly in areas with strong vertical stratification or gradients in temperature and salinity. These variations in sound speed can have important implications for underwater sound propagation.

As stated by Snell's law, Equation 8, sound waves bend toward regions of low sound speed (Jensen, et al., 2011). The implications for sound in sea water are, that sound, entering a low velocity layer in the water column, can get trapped there. This results in sound travelling far with very low propagation loss.

$$\frac{\cos(\theta)}{c} = \text{constant} \qquad \text{Equation 8}$$

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

There are three main types of sound speed profiles for seawater:

1. **Uniform sound speed profile**: In a uniform sound speed profile, the speed of sound is the same at all depths. This can occur in regions of the sea where temperature and salinity are relatively constant with depth.
2. **Upward refracting sound speed profile**: When the sound speed increases with depth, it is called an upward refracting sound speed profile. Sound waves in this type of environment can be refracted upward and away from the seabed, potentially travelling over longer distances with lower absorption losses from seabed interaction.

3. **Downward refracting sound speed profile**: When the sound speed decreases with depth, it is called a downward refracting sound speed profile. Sound waves will, in this environment, be refracted downward to a higher degree and toward the seabed, potentially causing them to lose energy and travel shorter distances.

Special cases, where a low speed region is present at a depth in between sea surface and seabed can create channels where specific ranges of frequencies can get trapped and propagate without ever reaching neither seabed nor sea surface. The potential transmission range in such a channel is significantly longer than in any of the typical three sound speed profile types listed above.

While there are seasonal variations in underwater sound propagation in the Danish part of the North Sea, the overall sound speed profile is relatively stable compared to other regions. This is because the North Sea is a well-mixed medium, meaning that the water column is thoroughly mixed by currents and wind-driven turbulence. As a result, the water properties, including temperature and salinity, tend to be fairly uniform throughout the water column. This makes acoustic modelling and prediction more straightforward compared to other regions with more variable water properties.

The sound speed profiles for a certain project area are calculated using Coppens equation (Coppens, 1981), based on available temperature and salinity data for the area. Data sources for the temperature and salinity profiles can be either based on empirical data, or predictive models. It is important to note, that while empirical data and predictive models can provide a historically likely scenario, they can not accurately predict the weather conditions when the project activities will occur.

For each of the sediment model points, described in section 5.3.2, the nearest available sound speed profile, as well as average temperature and salinity are extracted for the desired months. Temperature and salinity profiles for this project, were extracted from the data sources in Table 5.7, and through the NIRAS software tool "TRANSMIT", turned into sound speed profiles.

Table 5.7: Temperature, salinity and sound speed data sources.

Data source	Reference
Temperature	0.083° grid, monthly averages based on physical forecast (Copernicus, 2023)
Salinity	0.083° grid, monthly averages based on physical forecast (Copernicus, 2023)
Sound speed profile	Coppens equation (Coppens, 1981) implemented in NIRAS "TRANSMIT"

The temperature and salinity change both temporally (over the year), as well as spatially. Both the timeframe and position of the activities included in sound propagation modelling must therefore be taken into account, when evaluating which sound speed profiles should be used for any given model.

A realistic worst case approach was agreed with McMahon Design & Management Limited. The temperature, salinity and sound speed profiles for the area are therefore examined for all 12 months, to determine which month has conditions most likely to result in the furthest sound propagation.

Temperature, salinity and sound speed profiles were extracted for a radius of 10 km around each source position mentioned in section 5.2.3. From these profiles, it was assessed, that profiles with the potential for the strongest sound propagation, are those of February. Graphical representations of all profiles for position 1 are given in Figure 5.13 (temperature), Figure 5.14 (salinity), and in Figure 5.15 (sound speed). Profiles for the

remaining positions are attached in Appendix 1. The figures each show the nearest 9 data points from the temperature and salinity databases, relative to the source location. These are shown in a gridded x-y format, with the centre plot representing the data point closest to the source location. Empty plots can occur where land masses are present. The coordinates for each data point is provided above the individual plots in EPSG: 4326.

To ensure a realistic worst case approach for the prognosis, sound propagation modelling implements the profiles for February.

For each sediment model position, the spatially closest data point for average temperature and salinity, as well as sound speed profiles, were assigned to the sediment model through the NIRAS software tool "TRANSMIT", which combines sediment, temperature, salinity and sound speed data, into dBSea import files.

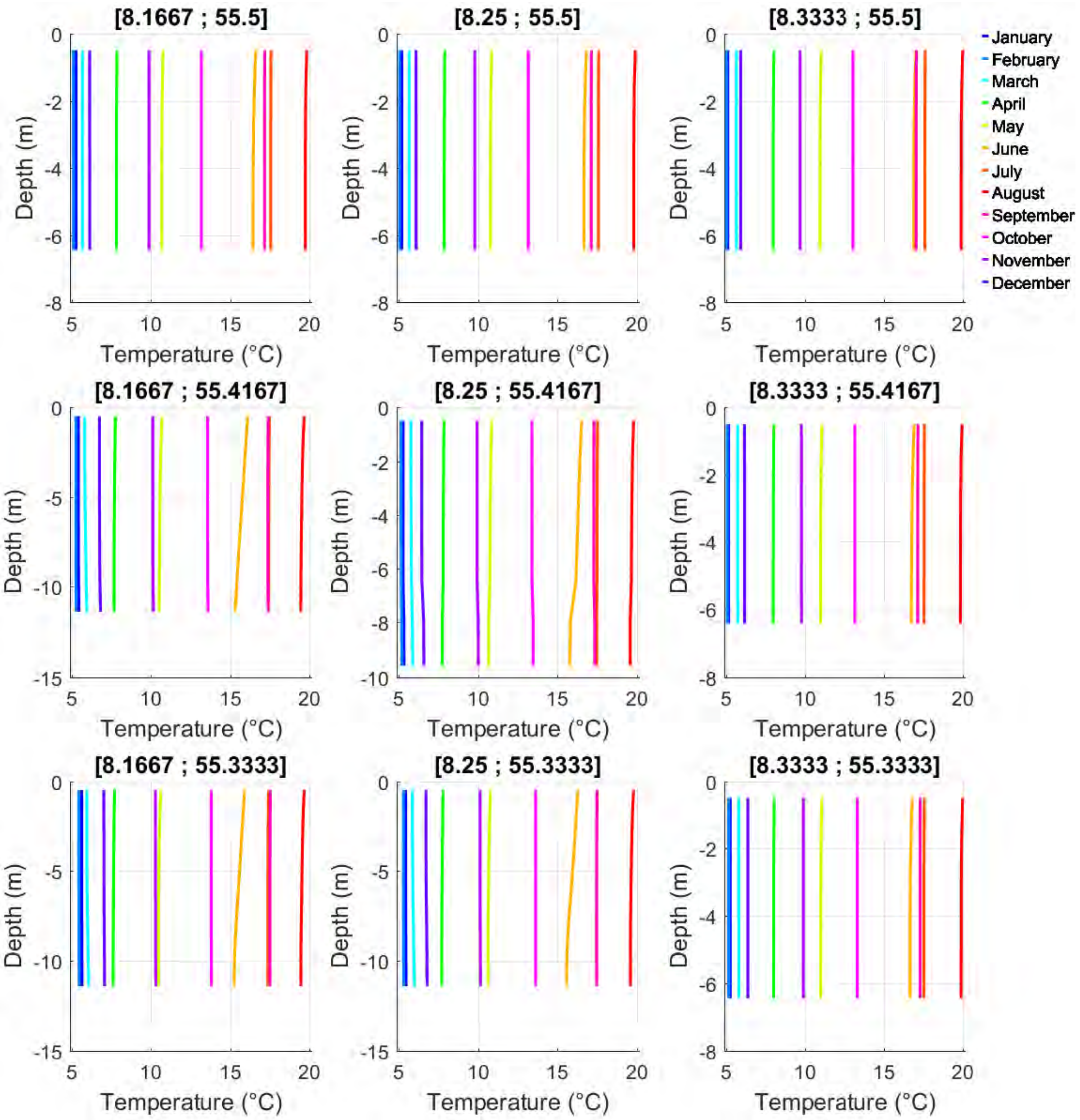

Figure 5.13: Temperature profiles for the area around source position 1 for all months. Gridded layout reflects geographical location.

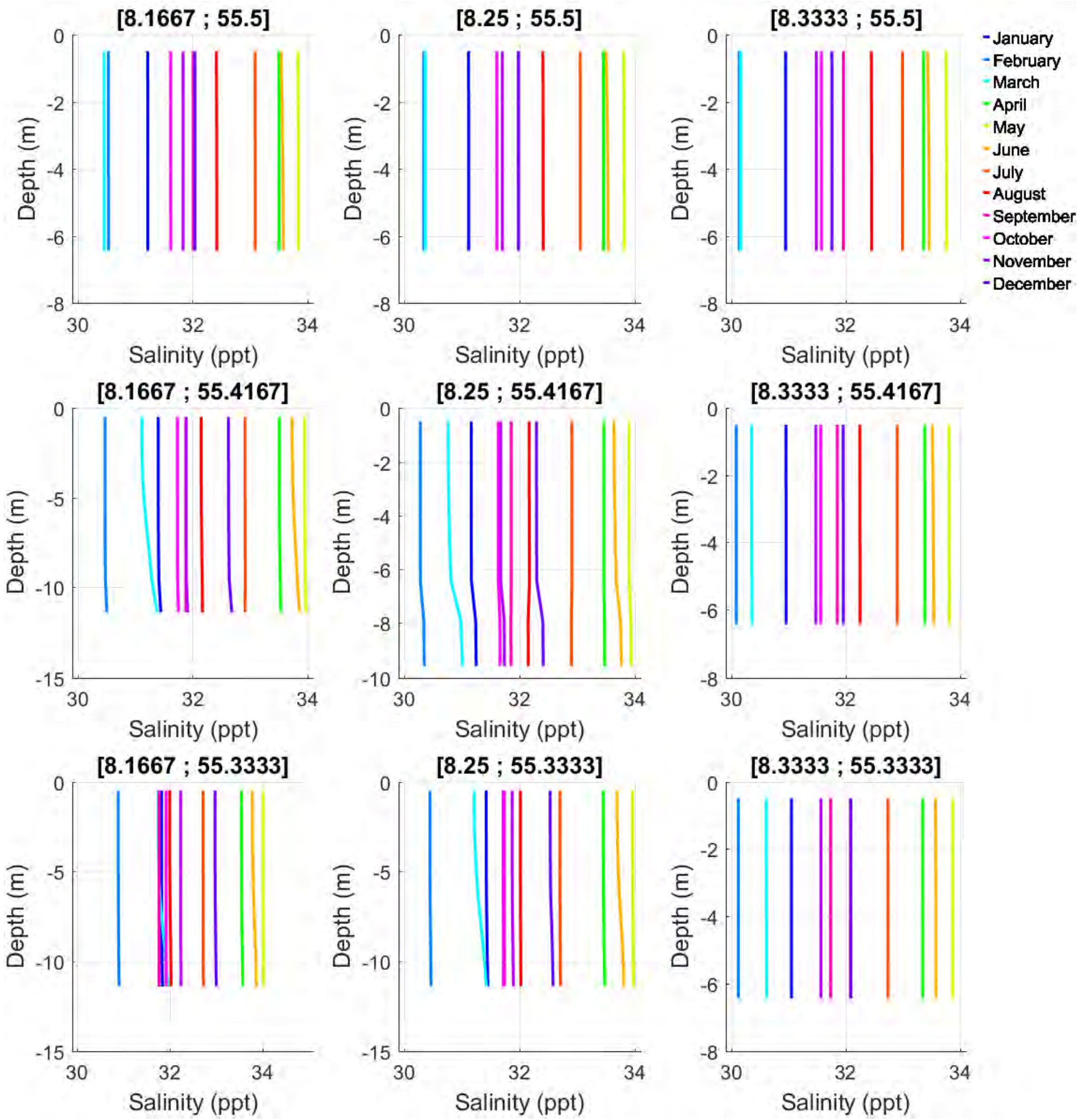

Figure 5.14: Salinity profiles for the area around source position 1 for all months. Gridded layout reflects geographical location.

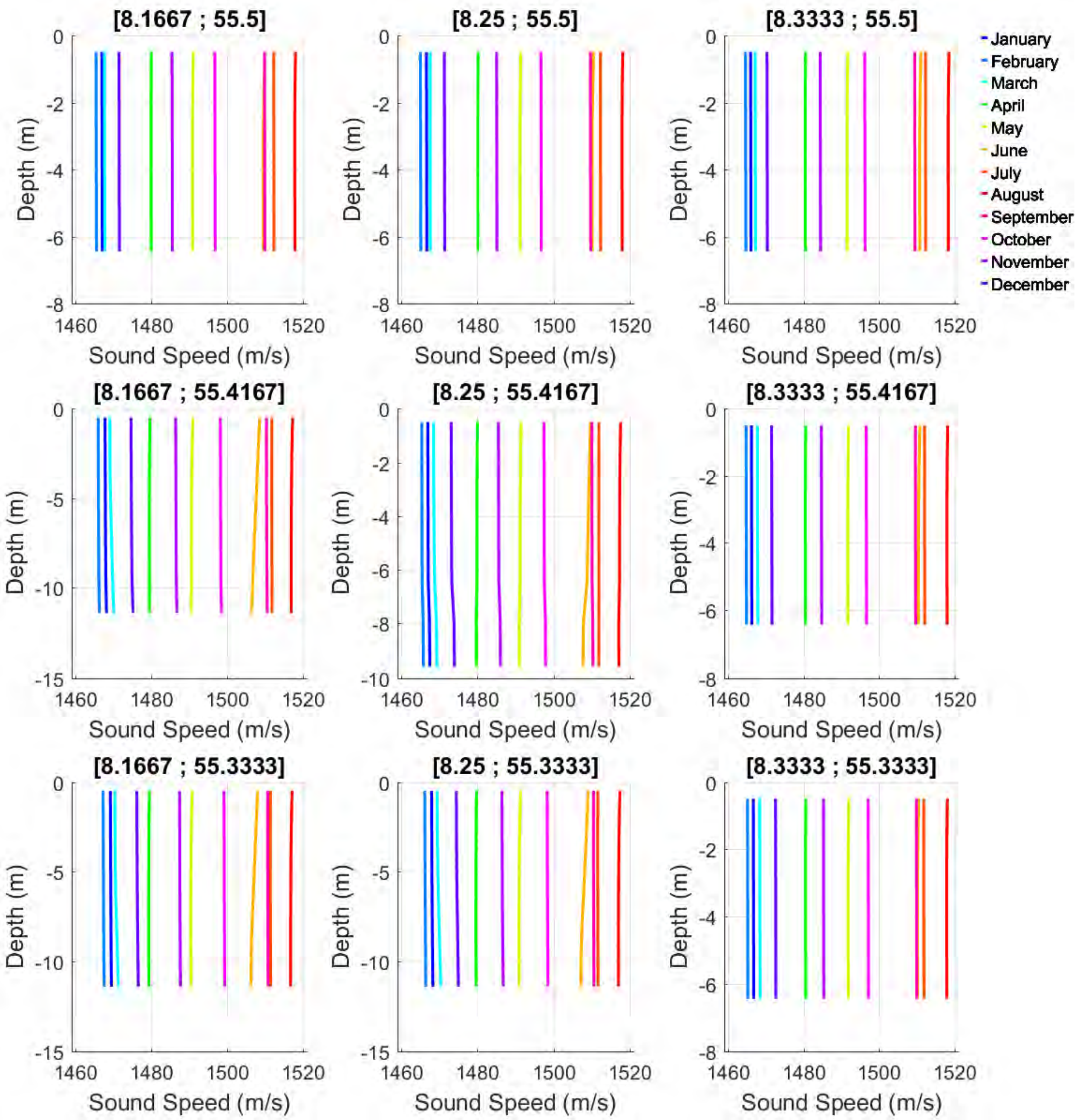

Figure 5.15: Sound speed profiles for the area around source position 1 for all months. Gridded layout reflects geographical location.

5.3.4. Sea surface roughness

Sea surface roughness, either from waves or ice cover can cause sound waves to scatter in many different directions, making it more difficult to propagate through the water. This can result in increased attenuation, backscattering and reduced range of underwater sound propagation, particularly at high frequencies.

As a precautionary approach, sound propagation modelling typically regards the sea surface as a perfect mirror (calm water), as this is also the conditions under which pile installation would be preferred. The model is therefore likely to overestimate sound propagation for any conditions where calm water is not the case.

5.3.5. Volume attenuation

Another parameter that has influence on especially the high frequency propagation loss over distance is the volume attenuation, defined as an absorption coefficient dependent on chemical conditions of the water column. This parameter has been approximated using Equation 9, from which is inferred that increasing frequency leads to increased absorption (Jensen, et al., 2011).

$$\alpha' \cong 3.3 \times 10^{-3} + \frac{0.11\mathrm{f}^2}{1+\mathrm{f}^2} + \frac{44\mathrm{f}^2}{4100+\mathrm{f}^2} + 3.0 \times 10^{-4}\mathrm{f}^2 \quad \left[\frac{\mathrm{dB}}{\mathrm{km}}\right]$$ Equation 9

Where f is the frequency of the wave in kHz.

Volume attenuation is taken into account within dBSea, which is used for sound propagation modelling.

5.4. Sound Propagation Software

Numerical models can be used to simulate and predict underwater sound propagation in sea water. These models involve a computer-based simulation that uses mathematical equations to describe the sound propagation as it travels through the sea. In this regard, environmental conditions such as temperature, salinity, sediment and bathymetry must be taken into account. Different numerical models exist to treat different environmental and source specific conditions, and the choice of numerical model should always be based on the project specific environmental parameters.

NIRAS uses the software tool dBSea, which incorporates three numerical algorithms for predicting sound propagation in complex underwater environments: dBSeaRay, dBSeaPE, and dBSeaNM.

- **dBSeaRay** is a ray-tracing algorithm that simulates the paths of individual sound rays as they travel through the sea, taking into account the effects of sea properties, such as temperature, salinity, and bathymetry, on sound propagation. This allows users to predict sound propagation in a wide range of ocean environments. Inherent limitations for this algorithm limits its use in shallow waters for very low frequencies below a few hundred Hz.
- **dBSeaPE** is a parabolic equation algorithm that solves the parabolic wave equation to simulate sound propagation in the ocean. It is particularly useful for modelling sound propagation over long distances or in areas with complex bathymetry. It however lacks computational efficiency at higher frequencies and is primarily suited for low frequencies.
- **dBSeaNM** uses the normal modes method to predict sound propagation in the ocean. This algorithm takes into account the effects of vertical variations in ocean properties, such as sound speed and density, on sound propagation. It is particularly useful for predicting sound propagation in regions with significant vertical mixing or internal waves, and is most suitable for low frequencies, up to several hundred Hz.

Depending on the local environment and source characteristics, a mix of two numerical models may provide the best result, whereby one algorithm handles the low frequencies and another handles the high frequencies.

Typically, dBSeaNM or dBSeaPE is used for low frequencies and dBSeaPE or dBSeaRay for high frequencies with a split frequency between the two algorithms, based on $f = \frac{8 \cdot c}{d}$ [Hz], where c is the speed of sound in water [m/s] and d is the average bathymetry depth [m]. For very high frequencies, dBSeaRay is typically preferred.

Output from dBSea is primarily numerical, where each modelled sound propagation radial (direction from source) is represented by the maximum-over-depth (MOD) sound level at each modelled range step. MOD, in this regard, is found by taking the maximum sound level for each range step over all modelled depths. It

therefore does not represent the sound level at a specific depth, but is a more conservative measure for the highest possible exposure at every range. An example of this concept is shown in Figure 5.16, showing the sound level (x-axis) in dB over depth (y-axis), for a specific distance and direction. On the left side, the MOD is located at 1 m depth below sea-surface and is 114.2 dB, while on the right side, in another direction from the source, MOD is located at 28 m depth and is 114.6 dB. The sound levels at all other depths are ignored in the result output.

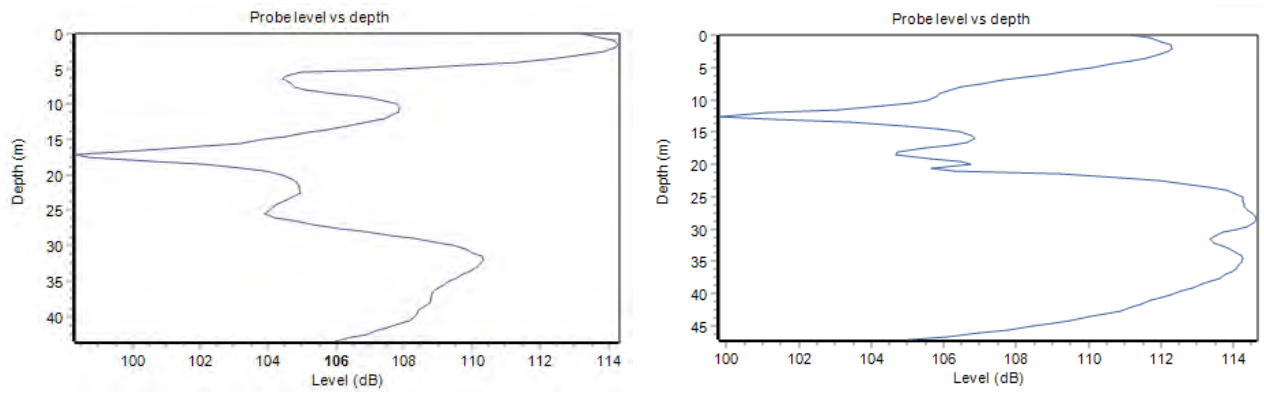

Figure 5.16: Concept of MOD, where the maximum sound level at any depth is extracted for each distance and radial interval. Example shows an MOD value of 114.2 dB (left side) at 1 m depth, and MOD value of 114.6 dB (right side) at 28 m depth.

Prognosis specific parameters for the dBSea setup is specific to the source types included, and is therefore described separately for the different source types in the prognosis.

5.4.1. Settings

The software tool dBSea was used for sound propagation modelling, with the configuration listed in Table 5.8.

Table 5.8: Sound propagation modelling tool settings for dBSea.

Parameter	Value
Software version	2.3.6
Grid (range x depth) resolution	25 m x 0.5 m
Number of radials/transects	P1: 90 (4°) P2, P3, P4, P5: 45 (8°)
Frequency solver	dBSeaRay
Frequency range	Innomar: 1 kHz – 128 kHz USBL: 25 kHz

Post-processing of the raw sound propagation results into impact ranges was done in NIRAS software tool "SILENCE", which implements Equation 6, page 16 for batch processing of different installation scenarios and threshold criteria.

5.5. Results

Sound propagation modelling was carried out in dBSea and post-processing of raw sound levels into impact ranges in NIRAS SILENCE, using the threshold criteria in chapter 4. The results are presented in the following formats:

Numerical result tables: showing the maximum range in any direction from the source to respective threshold criteria.

Distance to PTS, TTS and injury threshold criteria describe the minimum distance from the source, a marine mammal, or fish, must at least be deterred to, prior to onset of survey activities, in order to avoid the respective impact.

Distance to behavioural threshold criteria describe the range at which behavioural reactions are likely to occur when the survey operates at full intensity. During soft start, the impact ranges will be shorter.

5.5.1. Impact ranges for fish threshold criteria

For fish, all threshold criteria are based on the frequency unweighted $L_{E,cum,24h}$ [dB re. 1 μPa^{2}s]. Impact ranges are calculated for a series of different swim speeds, as discussed in section 4.1. Resulting impact ranges are provided in Table 5.9 for cod, Table 5.10 for herring and in Table 5.11 for larvae and eggs.

Table 5.9: Impact ranges for Cod.

Position	Cod: Threshold criteria impact ranges			
	Injury		**TTS**	
	Juvenile Cod	Adult Cod	Juvenile Cod	Adult Cod
Innomar Medium 100 (SBP) – distances relative to vessel				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
All sources active (combined)				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m

For cod, both juvenile and adult, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 5.10: Impact ranges for Herring.

Position	Herring: Threshold criteria impact ranges	
	Injury	**TTS**
Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
All sources active (combined)		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m

For herring, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 5.11: Impact ranges for Larvae and eggs.

Position	Larvae and eggs: Threshold criteria impact ranges
	Injury
Innomar Medium 100 (SBP) – distances relative to vessel	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
All sources active (combined)	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m

For larvae and eggs, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

5.5.2. Impact ranges for marine mammal threshold criteria

For marine mammals, PTS and TTS threshold criteria are based on the frequency weighted $\mathrm{L_{E,cum,24h,xx}}$ $[\mathrm{dB\ re.\ 1\ \mu Pa^2 s}]$, where "xx" refers to the species specific weighting function. Species specific fleeing behaviour as outlined in section 4.2 is assumed.

Threshold criteria for behaviour reaction is based on the frequency weighted $\mathrm{L_{p,125ms,xx}}$ $[\mathrm{dB\ re.\ 1\ \mu Pa}]$. Resulting impact ranges are provided in Table 5.12 for minke whale, Table 5.13 for white-beaked dolphin, Table 5.14 for harbour porpoise and in Table 5.15 for seals.

Table 5.12: Impact ranges for minke whales.

Position	**Minke whale (LF): Threshold criteria impact ranges**		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
All sources active (combined)			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For minke whale, underwater sound propagation modelling results show no impact beyond 100 m range for the geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 5.13: Impact ranges for white-beaked dolphin.

Position	White-beaked dolphin (HF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	TTS (Non-impulsive)	Behaviour
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
All sources active (combined)			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For white-beaked dolphin, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities.

Table 5.14: Impact ranges for harbour porpoise.

Position	Harbour porpoise (VHF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	TTS (Non-impulsive)	Behaviour
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	25 - 275 m	600 m
2	< 100 m	120 - 325 m	575 m
3	< 100 m	120 - 325 m	600 m
4	< 100 m	130 - 375 m	675 m
5	< 100 m	120 - 350 m	650 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	425 -1300 m	4.0 km
2	< 100 m	400 - 1150 m	4.1 km
3	< 100 m	400 - 1150 m	4.5 km
4	< 100 m	675 - 1650 m	4.2 km
5	< 100 m	625 - 1600 m	4.4 km
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	150 – 850 m	3.2 km
2	< 100 m	225 – 625 m	3.6 km
3	< 100 m	180 – 575 m	3.6 km
4	< 100 m	325 – 875 m	3.6 km
5	< 100 m	300 – 875 m	3.6 km
All sources active (combined)			
1	< 100 m	425 -1300 m	4.0 km
2	< 100 m	400 - 1150 m	4.1 km
3	< 100 m	400 - 1150 m	4.5 km
4	< 100 m	675 - 1650 m	4.2 km
5	< 100 m	625 - 1600 m	4.4 km

For harbour porpoise, underwater sound propagation modelling results show impact on the behaviour at up to 4.5 km distance from the survey. It should be noted that this behaviour criterion is only considered valid for impulsive noise sources (Tougaard, 2021), however as no threshold criteria have been established by science for non-impulsive sources, the impulsive criterion is used as a proxy.

Impact ranges for PTS were found to be less than 100 m, while results for TTS threshold criteria show up to 1600 m impact range.

Table 5.15: Impact ranges for seals.

Position	Seals (PCW): Threshold criteria impact ranges		
	PTS (Non-impulsive)	TTS (Non-impulsive)	Behaviour
	Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	All sources active (combined)		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For seals, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

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Bilag 1

Koordinater for undersøgelsesområdet

Tabel 5.1. koordinater for den 1 km brede undersøgelsesområde.

Idx	Breddegrad	Længdegrad	Idx	Breddegrad	Længdegrad
1	55° 44' 01.8118" N	5° 25' 07.6481" E	34	55° 25' 10.8739" N	8° 22' 32.4258" E
2	55° 43' 13.8051" N	5° 26' 00.4326" E	35	55° 24' 57.3236" N	8° 22' 47.9329" E
3	55° 38' 41.5916" N	5° 28' 31.9120" E	36	55° 24' 56.5656" N	8° 22' 45.8421" E
4	55° 38' 01.8652" N	5° 28' 48.0351" E	37	55° 22' 35.6667" N	8° 16' 10.9121" E
5	55° 33' 36.3216" N	5° 40' 10.8195" E	38	55° 22' 16.5619" N	8° 11' 52.1735" E
6	55° 32' 25.2142" N	5° 44' 11.7745" E	39	55° 23' 00.1129" N	8° 01' 29.0353" E
7	55° 31' 26.0040" N	5° 47' 31.9350" E	40	55° 23' 05.3666" N	8° 00' 40.8685" E
8	55° 31' 30.6743" N	5° 50' 38.8900" E	41	55° 23' 04.4119" N	7° 57' 30.2407" E
9	55° 31' 43.9219" N	5° 59' 41.1296" E	42	55° 23' 03.8809" N	7° 55' 39.7588" E
10	55° 31' 44.1735" N	5° 59' 47.8650" E	43	55° 23' 03.0862" N	7° 53' 04.1883" E
11	55° 31' 37.1401" N	6° 03' 16.3893" E	44	55° 22' 39.0879" N	7° 49' 12.4949" E
12	55° 31' 17.1172" N	6° 11' 39.3560" E	45	55° 21' 53.1094" N	7° 45' 48.3112" E
13	55° 31' 10.1019" N	6° 13' 29.4424" E	46	55° 20' 52.0624" N	7° 43' 00.3726" E
14	55° 23' 35.5883" N	6° 33' 11.3064" E	47	55° 19' 24.3686" N	7° 38' 59.6980" E
15	55° 23' 28.7957" N	6° 35' 32.3989" E	48	55° 19' 03.1225" N	7° 36' 47.1825" E
16	55° 23' 28.9360" N	6° 40' 25.7953" E	49	55° 18' 41.4746" N	7° 16' 06.7459" E
17	55° 23' 28.9368" N	6° 42' 26.5650" E	50	55° 18' 29.1407" N	7° 00' 00.3374" E
18	55° 20' 21.4314" N	6° 54' 55.2136" E	51	55° 19' 51.8492" N	6° 54' 32.3040" E
19	55° 19' 01.6437" N	7° 00' 11.6736" E	52	55° 22' 56.6021" N	6° 42' 14.6671" E
20	55° 19' 13.8001" N	7° 16' 05.2289" E	53	55° 22' 56.5998" N	6° 40' 25.8097" E
21	55° 19' 35.3336" N	7° 36' 38.5724" E	54	55° 22' 56.4577" N	6° 35' 30.0336" E
22	55° 19' 54.1985" N	7° 38' 36.2330" E	55	55° 23' 04.0788" N	6° 32' 51.6842" E
23	55° 21' 19.3153" N	7° 42' 29.8266" E	56	55° 30' 38.8549" N	6° 13' 09.1973" E
24	55° 22' 22.0365" N	7° 45' 22.3622" E	57	55° 30' 44.9099" N	6° 11' 34.1567" E
25	55° 23' 10.3293" N	7° 48' 56.8165" E	58	55° 31' 04.8715" N	6° 03' 12.7196" E
26	55° 23' 35.3953" N	7° 52' 58.8145" E	59	55° 31' 11.7753" N	5° 59' 48.0586" E
27	55° 23' 36.2158" N	7° 55' 39.2667" E	60	55° 31' 11.6311" N	5° 59' 44.1987" E
28	55° 23' 36.7467" N	7° 57' 29.7465" E	61	55° 30' 58.3700" N	5° 50' 41.3899" E
29	55° 23' 37.7970" N	8° 01' 00.3908" E	62	55° 30' 53.3144" N	5° 47' 19.1498" E
30	55° 22' 49.0555" N	8° 11' 54.4886" E	63	55° 31' 56.5380" N	5° 43' 45.4274" E
31	55° 23' 07.0621" N	8° 15' 48.0403" E	64	55° 33' 08.5557" N	5° 39' 41.3703" E
32	55° 25' 25.3100" N	8° 22' 19.3122" E	65	55° 37' 42.3199" N	5° 27' 57.3251" E
33	55° 25' 19.0270" N	8° 22' 23.0951" E	66	55° 38' 33.1130" N	5° 27' 36.6926" E

Idx	Breddegrad	Længdegrad	Idx	Breddegrad	Længdegrad
67	55° 43' 00.2578" N	5° 25' 07.9334" E	100	55° 55' 59.0964" N	3° 53' 45.1081" E
68	55° 44' 16.4034" N	5° 23' 44.6809" E	101	55° 57' 22.3167" N	3° 59' 09.6165" E
69	55° 48' 24.1395" N	4° 51' 56.8952" E	102	55° 57' 44.6452" N	4° 00' 36.9089" E
70	55° 49' 22.6278" N	4° 44' 06.4254" E	103	55° 55' 36.4560" N	4° 17' 36.6959" E
71	55° 49' 27.2982" N	4° 42' 07.0447" E	104	55° 55' 03.1025" N	4° 18' 54.2830" E
72	55° 49' 42.7609" N	4° 41' 00.8835" E	105	55° 53' 22.5691" N	4° 24' 38.0892" E
73	55° 51' 30.4897" N	4° 33' 12.7819" E	106	55° 52' 02.2209" N	4° 29' 11.8619" E
74	55° 51' 31.8185" N	4° 31' 45.3048" E	107	55° 52' 02.5505" N	4° 30' 06.7680" E
75	55° 51' 30.2219" N	4° 30' 07.9150" E	108	55° 52' 04.1646" N	4° 31' 45.2439" E
76	55° 51' 29.8014" N	4° 28' 58.0331" E	109	55° 52' 02.6444" N	4° 33' 25.2563" E
77	55° 52' 53.8978" N	4° 24' 11.4948" E	110	55° 50' 13.8658" N	4° 41' 17.7611" E
78	55° 54' 35.7133" N	4° 18' 23.2759" E	111	55° 49' 58.9238" N	4° 42' 19.0681" E
79	55° 54' 36.9027" N	4° 18' 20.5102" E	112	55° 49' 54.1525" N	4° 44' 19.2056" E
80	55° 55' 06.4790" N	4° 17' 11.7068" E	113	55° 48' 55.9677" N	4° 52' 06.8182" E
81	55° 57' 10.7357" N	4° 00' 43.2580" E	114	55° 44' 46.2552" N	5° 24' 10.3891" E
82	55° 56' 52.8994" N	3° 59' 33.5323" E	115	55° 43' 53.2297" N	5° 29' 00.7067" E
83	55° 55' 29.6965" N	3° 54' 09.0781" E	116	55° 44' 14.1514" N	5° 40' 23.4896" E
84	55° 55' 07.4962" N	3° 52' 42.7288" E	117	55° 44' 19.3302" N	5° 43' 18.0624" E
85	55° 55' 07.2580" N	3° 49' 23.2166" E	118	55° 44' 47.5637" N	5° 59' 54.5581" E
86	55° 55' 51.8571" N	3° 30' 34.0718" E	119	55° 45' 00.5199" N	6° 08' 00.7924" E
87	55° 56' 12.7719" N	3° 23' 32.4547" E	120	55° 45' 05.6664" N	6° 10' 04.3387" E
88	55° 56' 13.7188" N	3° 22' 21.9745" E	121	55° 45' 14.2717" N	6° 21' 08.5840" E
89	55° 56' 14.4837" N	3° 21' 24.4304" E	122	55° 45' 28.4617" N	6° 31' 53.7924" E
90	55° 56' 14.5149" N	3° 21' 22.0710" E	123	55° 45' 57.1960" N	6° 56' 20.1649" E
91	55° 56' 15.4091" N	3° 20' 14.0441" E	124	55° 46' 03.8051" N	7° 02' 09.5257" E
92	55° 56' 48.0467" N	3° 19' 54.6083" E	125	55° 46' 04.3381" N	7° 02' 38.3570" E
93	55° 56' 46.8391" N	3° 21' 23.4278" E	126	55° 46' 09.1388" N	7° 07' 02.7785" E
94	55° 56' 46.8079" N	3° 21' 25.7878" E	127	55° 46' 26.1235" N	7° 23' 59.7349" E
95	55° 56' 46.0429" N	3° 22' 23.3452" E	128	55° 46' 30.4512" N	7° 28' 43.9840" E
96	55° 56' 45.0711" N	3° 23' 35.6632" E	129	55° 46' 30.1373" N	7° 36' 49.9021" E
97	55° 56' 24.1087" N	3° 30' 38.2660" E	130	55° 46' 31.5202" N	7° 40' 54.8828" E
98	55° 55' 39.4982" N	3° 49' 28.2726" E	131	55° 46' 16.9282" N	7° 47' 14.6655" E
99	55° 55' 40.2702" N	3° 52' 31.8799" E	132	55° 46' 12.2827" N	7° 49' 05.8564" E

Idx	Breddegrad	Længdegrad	Idx	Breddegrad	Længdegrad
133	55° 45' 41.3836" N	8° 01' 08.9388" E	149	55° 45' 53.8017" N	7° 24' 01.3164" E
134	55° 45' 37.3715" N	8° 02' 38.2091" E	150	55° 45' 36.8209" N	7° 07' 04.5938" E
135	55° 45' 23.6292" N	8° 03' 09.6989" E	151	55° 45' 32.0213" N	7° 02' 40.2333" E
136	55° 45' 13.9842" N	8° 03' 31.7932" E	152	55° 45' 31.6218" N	7° 02' 18.6150" E
137	55° 44' 56.0747" N	8° 10' 20.8703" E	153	55° 44' 48.0547" N	6° 59' 57.8114" E
138	55° 44' 39.5242" N	8° 10' 28.4077" E	154	55° 44' 26.4400" N	6° 38' 14.9885" E
139	55° 44' 23.8073" N	8° 10' 17.1137" E	155	55° 43' 53.6282" N	6° 15' 28.9526" E
140	55° 44' 42.4862" N	8° 03' 10.2815" E	156	55° 43' 06.2382" N	5° 44' 46.1076" E
141	55° 44' 58.0584" N	8° 02' 34.6084" E	157	55° 42' 39.4796" N	5° 31' 18.7774" E
142	55° 45' 05.9063" N	8° 02' 16.6248" E	158	55° 43' 22.4714" N	5° 28' 43.0237" E
143	55° 45' 09.1483" N	8° 01' 04.4582" E	159	55° 43' 24.2211" N	5° 28' 33.0577" E
144	55° 45' 40.0376" N	7° 49' 01.6051" E	160	55° 44' 01.8118" N	5° 25' 07.6481" E
145	55° 45' 44.6764" N	7° 47' 10.5743" E			
146	55° 45' 59.1876" N	7° 40' 55.4290" E			
147	55° 45' 57.8029" N	7° 36' 50.1426" E			
148	55° 45' 58.1171" N	7° 28' 44.7372" E			

Tabel 5.2. Koordinater for segmentet af kabelkorridoren, som løber fra Fanø til Esbjerg

Idx	Breddegrad	Længdegrad
1	55° 27' 08.3112" N	8° 30' 38.4681" E
2	55° 27' 11.3734" N	8° 30' 25.3052" E
3	55° 26' 57.7303" N	8° 30' 15.4809" E
4	55° 26' 15.7521" N	8° 29' 01.4563" E
5	55° 25' 52.4421" N	8° 28' 10.5293" E
6	55° 25' 31.5248" N	8° 27' 16.8643" E
7	55° 25' 24.8572" N	8° 27' 24.9002" E
8	55° 25' 18.1895" N	8° 27' 32.9381" E
9	55° 25' 39.4575" N	8° 28' 27.5054" E
10	55° 26' 03.6976" N	8° 29' 20.4677" E
11	55° 26' 48.5860" N	8° 30' 39.6320" E
12	55° 27' 05.2485" N	8° 30' 51.6334" E
13	55° 27' 08.3112" N	8° 30' 38.4681" E

Tabel 5.3. Koordinater for segmentet af det 1 km brede undersøgelsesområde, som løber igennem forbudsområdet, jf. § 5 i (BEK nr 135 af 04/03/2005).

Idx	Breddegrad	Længdegrad
1	55° 45' 00.7638" N	8° 08' 34.6049" E
2	55° 44' 56.0747" N	8° 10' 20.8703" E
3	55° 44' 43.9511" N	8° 10' 17.4755" E
4	55° 44' 39.6843" N	8° 10' 14.5132" E
5	55° 44' 35.9019" N	8° 10' 15.8104" E
6	55° 44' 29.1422" N	8° 10' 13.8877" E
7	55° 44' 24.0396" N	8° 10' 11.8631" E
8	55° 44' 28.7961" N	8° 08' 24.0433" E
9	55° 44' 37.6983" N	8° 08' 28.7520" E
10	55° 44' 40.6524" N	8° 08' 28.8692" E
11	55° 44' 48.7179" N	8° 08' 30.0923" E
12	55° 45' 00.7638" N	8° 08' 34.6049" E

Tabel 5.4. Koordinater for segmentet af det 250 m brede kabelkorridor, som løber igennem forbudsområdet, jf. § 5 i (BEK nr 135 af 04/03/2005).

Idx	Breddegrad	Længdegrad
1	55° 44' 48.7173" N	8° 08' 30.1059" E
2	55° 44' 40.6516" N	8° 08' 28.8885" E
3	55° 44' 35.8456" N	8° 10' 15.5486" E
4	55° 44' 38.5856" N	8° 10' 14.9873" E
5	55° 44' 41.4925" N	8° 10' 15.7643" E
6	55° 44' 43.8981" N	8° 10' 17.0552" E
7	55° 44' 48.7173" N	8° 08' 30.1059" E

Bilag 2

Støjmodellering

Contents

List of abbreviations

Full name	Abbreviation	Symbol
Sound Exposure Level	SEL	$L_{E,p}$
Cumulative Sound Exposure Level	$SEL_{cum,t}$	$L_{E,cum,t}$
Sound Exposure Level - single pile strike	SEL_{SS}	L_{E100}
Sound Pressure Level	SPL	L_p
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	
Low frequency	LF	
High frequency	HF	
Very High frequency	VHF	
Phocid Pinniped	PCW	
World Ocean Atlas 2023	WOA23	
Sound Exposure Propagation loss	EPL	
National Marine Fisheries Service	NMFS	
Maximum-over-depth	MOD	

1. Introduction and objectives

McMahon Design & Management Limited is planning geophysical survey activities in relation to the planning of the VERENA Subsea Fibre Optic Cable project, located in the Danish part of the North sea. NIRAS has been tasked with preparation of an underwater noise prognosis for the geophysical survey activities, as input for an environmental impact assessment for marine mammals and fish.

The report is structured as outlined below.

Chapter	Content
2	Project description
3	Definitions: A brief introduction to terms and metrics used throughout the report
4	Marine mammal and fish threshold criteria for auditory impact
5	Underwater noise prognosis for geophysical survey

2. Project description

The VERENA Subsea Fibre Optic Cable survey area covers a 1 km wide corridor between Denmark and the United Kingdom. This report only covers the geophysical investigations within the Danish part of the North Sea. In Denmark, the survey corridor reaches the coast in two different locations (Henne Strand and Esbjerg). The geophysical survey covers an area (Figure 2.1) of 613 km^2.

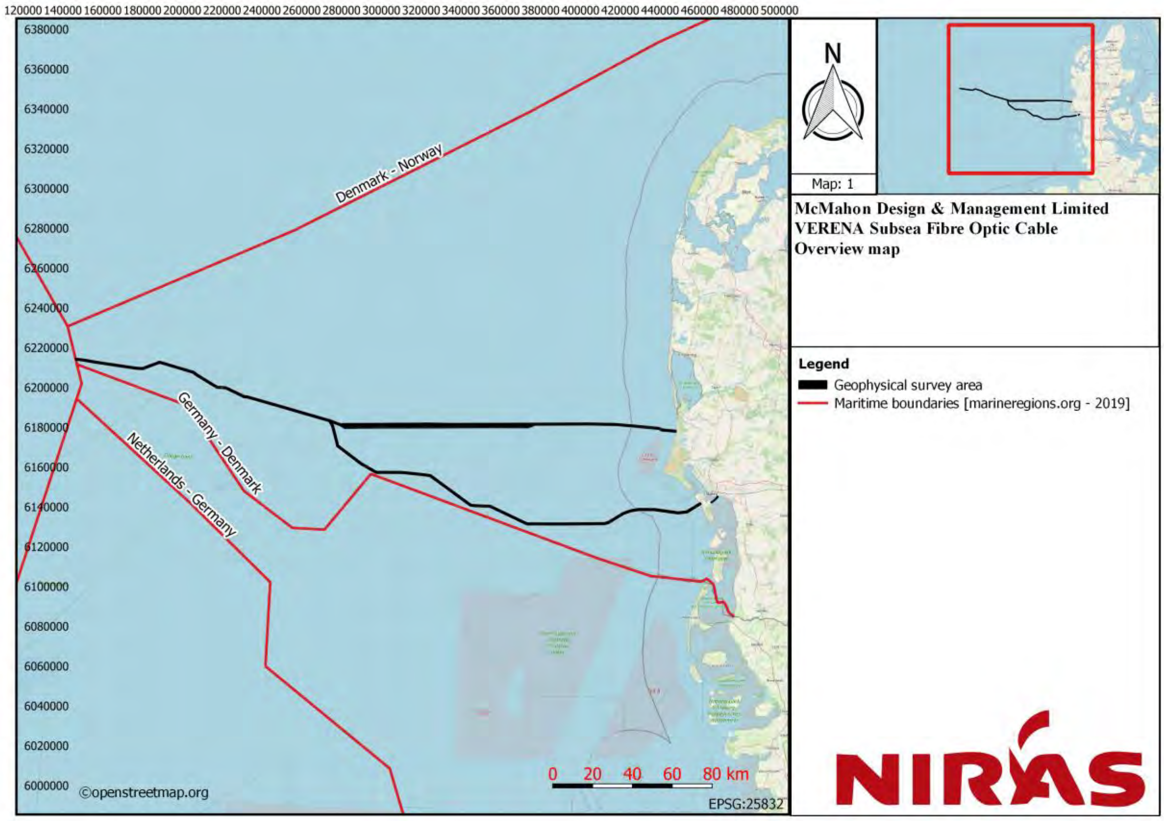

Figure 2.1: Overview of the VERENA Subsea Fibre Optic Cable geophysical survey area.

2.1. Description of Activities

Underwater noise emission is expected to occur as a result of the geophysical survey activities, where the physical properties of the seabed within the survey area are investigated.

Geophysical investigations are typically characterised by non-invasive acoustic techniques. By analysing the reflections of sound waves emitted towards the seafloor and sediment layers, the sediment layer composition, as well as pockets of natural resources, can be determined. Investigations that map the bathymetry and objects on or imbedded in the seabed, such as unexploded ordnance (UXO), are also considered part of the geophysical investigations.

3. Definitions

Acoustic metrics and relevant terms used in the report are defined in this chapter. Terminology generally follows ISO standard 18405 (DS/ISO 18405, 2017).

3.1. Sound Pressure Level

The Sound Pressure Level (SPL), L_p, is used to describe the noise level. The definition for SPL is shown in Equation 1 (Erbe, 2011):

$$L_p = 20 * \log_{10}\left(\sqrt{\left(\frac{1}{T}\right)\int_0^T p(t)^2}\right) \quad [\text{dB re. } 1\mu\text{Pa}]$$ 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.

For ambient underwater noise and for operational underwater noise, L_p is the preferred metric.

In order to evaluate the behavioural response of the marine mammal a time window is needed. 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.

3.2. Sound Exposure Level

The Sound Exposure Level (SEL), $L_{E,p}$, describes the total energy of a noise event (Jacobsen & Juhl, 2013). A noise event can for instance be the duration of an entire survey from start to end, or it can be a single noise event like an airgun pulse. The SEL is normalized to 1 second and is defined in (Martin, et al., 2019) through Equation 3.

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

The relationship between SPL, Equation 1, and SEL, Equation 3, is given by 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. SEL is therefore a commonly used metric to assess the risk of hearing impairment as a result of noisy activities (Martin, et al., 2019).

3.3. Cumulative Sound Exposure level

For moving sources in combination with moving receivers, the $L_{E,cum,t}$ is calculated using the approach presented in (Tougaard, 2016). The survey vessel speed, and its direction relative to a moving receiver is used to calculate the $L_{E,cum,t}$ for a given receiver. In Equation 5, the distance between the source and receiver at the i^{th} pulse, r_i, is given for a specific piece of survey equipment. This is based on a starting position of the marine mammal relative to the source, defined by the on-axis distance, l_0, corresponding to the transect line, and the off-axis distance, d_0, corresponding to the perpendicular distance from the transect line. Δt_i is the time in seconds between the first pulse and the i^{th} , while v_{ship} and $v_{receiver}$ is the ship and receiver moving speed respectively, in m/s.

$$r_i = \sqrt{\left(l_0 - ((i-1) \cdot \Delta t_i) \cdot v_{ship}\right)^2 + (d_0 + ((i-1) \cdot \Delta t_i) \cdot v_{receiver})^2}$$ Equation 5

By summing the pulses from the entire survey, within a 24h window, given the propagation loss for the survey area, Equation 6 gives the resulting $L_{E,cum,24h}$.

$$L_{E,cum,24h} = 10 * \log_{10}\left(\sum_{i=1}^{N} 10^{\left(\frac{L_{S,E} - X * \log_{10}(r_i) - A * (r_i)}{10}\right)}\right)$$ Equation 6

Where N is the total number of pulses for that piece of survey equipment, $L_{S,E}$ is the source level at 1 m distance, X and A describe the sound exposure propagation losses (EPL), $N_{PL,E}$, for the specific project site. For surveys using multiple equipment types, the contribution from each source is first normalized into 1 sec. SEL based on firing frequency, and then added.

The parameters used in Equation 5 and Equation 6, related to the source level, firing frequency, movement speed and source direction must be based on best available knowledge. The EPL parameters (X and A) must be determined through advanced sound propagation modelling, in which all relevant site-specific environmental parameters are considered.

3.4. Source level

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

SL is defined for a continuous source as the SPL_{rms} at a distance of 1 m from the source with a reference value of $1\ \mu Pa \cdot m$. The metric is used primarily for non-impulsive source types, such as vessels.

ESL is used to describe a transient sound source and is defined as the SEL at a distance of 1 m from the source with a reference value of 1 $\mu Pa^2\ m^2\ s$. This is the standard metric used to describe the source level of impulsive noise sources.

3.5. Frequency weighting functions

In underwater noise assessments, frequency weighting is often used to more accurately reflect the underwater noise impact on specific marine mammals.

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 7 (NOAA, 2018).

$$W(f) = C + 10 * \log_{10}\left(\frac{\left(\frac{f}{f_1}\right)^{2*a}}{\left[1+\left(\frac{f}{f_1}\right)^2\right]^a * \left[1+\left(\frac{f}{f_2}\right)^2\right]^b}\right) [dB] \qquad \text{Equation 7}$$

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 3.1.

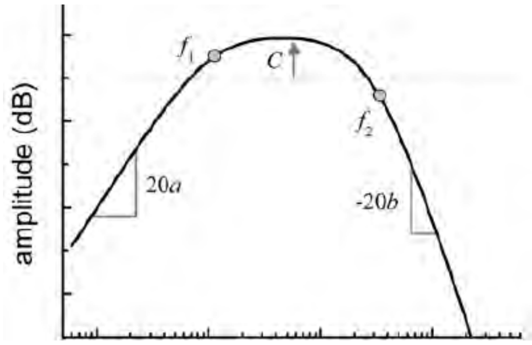

Figure 3.1: Illustration of the 5 parameters in the weighting function (NOAA, 2018).

Marine mammals are divided into four hearing groups, 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 Carnivores in Water (**PCW**) (NOAA, 2018; Southall, et al., 2019). The parameters in Equation *7* are defined for the hearing groups and the values are presented in Table 3.1.

Table 3.1: Parameters for the weighting function for the relevant hearing groups (NOAA, 2018).

Hearing Group	a	b	f_1 [kHz]	f_2 [kHz]	C [dB]
Low frequency (LF) Cetaceans	1.0	2	0.2	19	0.13
High frequency (HF) Cetaceans	1.6	2	8.8	110	1.20
Very high frequency (VHF) Cetaceans	1.8	2	12	140	1.36
Phocid Carnivores in Water (PCW)	1.0	2	1.9	30	0.75

The weighting function amplitude for the four hearing groups is achieved by inserting the values from Table 3.1 into Equation 7. The resulting spectra for the four hearing groups are shown in Figure 3.2.

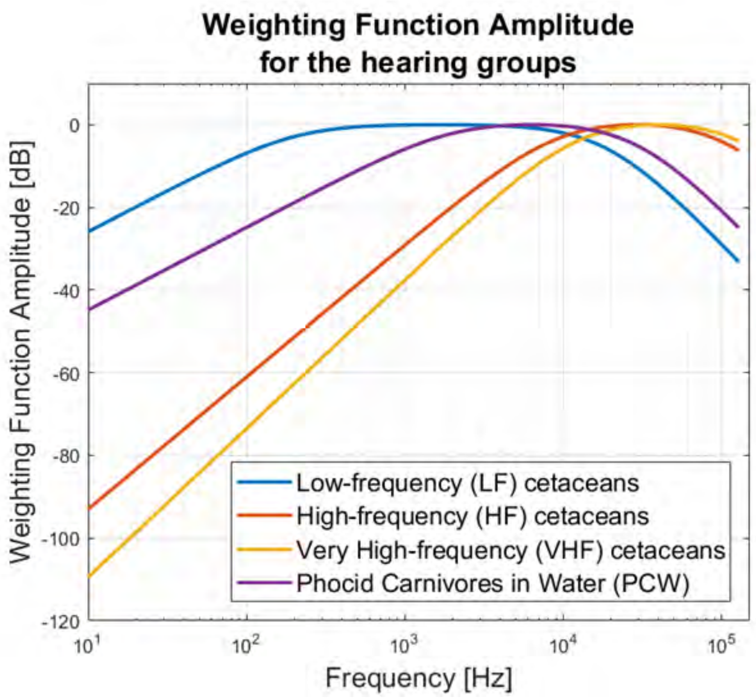

Figure 3.2: The weighting functions for the different hearing groups.

For this project, relevant species include; minke whales (classified as a Low frequency Cetaceans (LF)), white-beaked dolphin (classified as a high frequency Cetaceans (HF)), seal (classified as a Phocid Carnivores in Water (PCW)), and harbour porpoise (classified as a Very High Frequency Cetacean (VHF))]. Frequency weighting functions are not used for fish.

4. Underwater Noise Threshold Criteria

In Denmark, underwater noise from geophysical survey activities are handled by the authorities on a project-by-project basis. In order to provide a prognosis of impact, absent official threshold criteria, best available scientific knowledge from (NOAA, 2018), (Tougaard, 2021), (Energistyrelsen, 2023) is instead used in this project.

Two sets of threshold criteria are typically considered in evaluating the impact of underwater noise, based on the impulsiveness of the noise source. Following the definition of impulsive vs. non-impulsive noise sources in (NOAA, 2018), the terms are considered as follows:

- Impulsive: Sounds that are typically transient, brief (duration < 1 s), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay.
- Non-impulsive: Sounds that are broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically do not have a high peak sound pressure with rapid rise nor decay time.

For geophysical survey activities, it is not always clear if a source behaviour is impulsive or non-impulsive. While equipment types, such as airguns and explosives are unquestionably impulsive in nature, arguments can be made in both directions for other equipment types.

The impulsiveness of individual activities is reflected upon in the evaluation of each activity. For cumulative assessment, when all survey equipment is active simultaneously, it is considered likely that non-impulsive threshold criteria are more suitable than impulsive threshold criteria, which may be overly conservative. If however the combined noise emission is dominated heavily by an activity which is clearly defined as impulsive, it would however stand to reason that impulsive threshold criteria might be more appropriate.

4.1. Threshold criteria for fish

Assessment of the noise impact on fish, larvae and eggs (Table 4.1) are all based on unweighted threshold levels using the metric $\mathrm{L_{E,cum,24h}}$, defined in section 3.3. The criteria and swim speed for the different fish species are adopted from (Andersson, et al., 2016) and (Popper, et al., 2014).

Table 4.1: Threshold criteria for fish. TTS and injury criteria are unweighted (Andersson, et al., 2016), (Popper, et al., 2014).

Species	Swim speed [m/s]	Threshold criteria, $L_{E,cum,24h}$ $[dB\ re.1\ \mu Pa^2 s]$	
		TTS [dB]	Injury [dB]
Juvenile Cod	0.38	186	204
Adult Cod	0.90	186	204
Herring	1.04	186	204
Larvae and eggs	-	-	207

4.2. Threshold criteria for marine mammals

Based on the newest scientific literature, species specific frequency weighted $\mathrm{L_{E,cum,24h}}$ threshold values (NOAA, 2018), (Southall, et al., 2019) for TTS and PTS are used, Table 4.2. For avoidance behaviour, $\mathrm{L_{p,125ms,VHF}} = 103\ \mathrm{dB\ re.1\ \mu Pa}$ (Tougaard, 2021) is used for harbour porpoise.

Table 4.2: Threshold criteria for marine mammals. PTS and TTS criteria (NOAA, 2018), behaviour criteria (Tougaard, 2021) for hearing group classifications in (Southall, et al., 2019). "xx" notation refers to species specific weighted levels.

Species	Swim speed [m/s]	Threshold criteria $L_{E,cum,24h,xx}$ $[dB\ re.1\ \mu Pa^2 s]$				Threshold criteria $L_{p,125ms,xx}$ $[dB\ re.1\ \mu Pa]$
		PTS		TTS		Behaviour
		Non-impulsive	impulsive	Non-impulsive	Impulsive	
Minke whales (LF)	1,5	199	183	179	168	-
White-beaked dolphin (HF)	1,5	198	185	178	170	-
Harbour porpoise (VHF)	1.5	173 dB	155 dB	153 dB	140 dB	103 dB
Seal (PCW)	1.5	201 dB	185 dB	181 dB	170 dB	-

5. Underwater noise prognosis for geophysical survey

Geophysical survey activities have the potential to cause avoidance response, TTS, and PTS in marine mammals (Madsen, et al., 2006), as well as avoidance response, TTS and injury in fish (Popper, et al., 2014) (Andersson, et al., 2016).

Proposed survey equipment is first evaluated for its potential to have adverse effects on marine mammals or fish (section 5.1). In the evaluation of the different equipment types, the following groups of equipment are considered:

A. Equipment has insignificant underwater noise emission for marine mammals and fish:
   -> no further evaluation takes place.
B. Equipment has significant underwater noise emission but sound propagation modelling is not feasible:
   -> evaluation is based on either literature or equation based calculation.
C. Equipment has significant underwater noise emission and sound propagation modelling is feasible:
   -> evaluation is based on sound propagation modelling.

For equipment in group A or B, the impact is determined directly in the evaluation. For group C equipment, sound propagation modelling is carried out, with the following components:

- A source model, characterising the noise source, and the emission of noise into the water column (section 5.2).
- An environmental model, characterising the marine environment and its acoustic properties (section 5.3).
- A sound propagation model, through which the source and environmental model is used to determine the sound propagation (section 5.3.4).

Results are reported as impact ranges for marine mammals and fish, through numerical values of impact ranges in section 5.5.

5.1. Equipment evaluation

There is no final list of survey equipment models and operational parameters available for the survey activities, however a representative list is considered for use in the prognosis, see Table 5.1, based on experience from previous surveys, and information from the client.

Table 5.1: Geophysical survey equipment models and operational parameters. Source parameters are chosen conservatively where no information was supplied by McMahon Design & Management Limited.

Type	Equipment model	Source Level, L_s [dB re 1 µPa · m]	Primary Frequency Range (kHz)	Pulse Length	Beam Width	Sound exposure source level, $L_{S,E}$ [dB re 1 µPa$^2m^2$s]	Duty cycle over a 24 hour period
Sub-bottom profiler (SBP)	Innomar Medium 100	247 dB	1-150	0.07 – 2 ms	2°	213 dB	40 Hz
Multi-beam echosounder (MBES)	SeaBat T50-R - Standard projector (TC2181)	190 - 220 dB	190-420	0.3 - 10 ms	2° @ 200 kHz 1° @ 400 kHz	170 - 200 dB	50 Hz
Side scan sonar (SSS)	Edgetech 4205	210 dB*	230/850	-	0.63° (230 kHz) 0.30° (850 kHz)	-	-
Ultrashort Baseline (USBL)	Sonardyne - HPT 3000 USBL transceiver	194 dB	20-34	20 ms	Omni	177 dB	1 Hz
USBL transponder	Sonardyne - Wideband Mini Transponder - Type 8190-3111	187 dB	19 – 34	20 ms	Omni	170 dB	1 Hz
Magnetometer	Cesium Marine Magnetometer G-882	-	-	-	-	-	-

* Source level is assumed to be equivalent to Edgetech 4200, due to absence of model specific information

5.1.1. Parametric SBP (Innomar Medium 100)

The Innomar Medium 100 creates a very detailed profile of the uppermost part of the seabed, typically the uppermost 20 m below the seabed. It emits two high frequency pulses, called the primary frequencies, with both pulses typically in the frequency range of 100 – 120 kHz. The frequency separation between the two pulses dictate the secondary frequency, created inside the water column as the difference between the two primary frequencies: $f_{sec} = f_{pri2} - f_{pri1}$ $[Hz]$.

The source level of the Innomar Medium 100 is listed as $\mathrm{SL} = 247\ \mathrm{dB\ re.}\ 1\mu\mathrm{Pa}\ @1\mathrm{m}$. It is a complex sound source as the sound emission is heavily focused towards the seabed. The horizontal emission of underwater noise is therefore significantly lower than the source level would indicate, compared to the emission directly downward into the seabed.

In a sound source verification study for geophysical survey activities in the Danish North Sea (Pace, et al., 2021), acoustic measurements were carried out for the Innomar Medium 100. In the study, the sound level was recorded in the horizontal direction at distances ranging from 10s of meters to 750 m. In Figure 5.1, all measured data points in the horizontal direction are presented as the individual pulse SEL, along with a logarithmic curve

fit. The trend indicates a source level of 193 dB and a rapid decay of approximately 37 dB/decade in the horizontal direction.

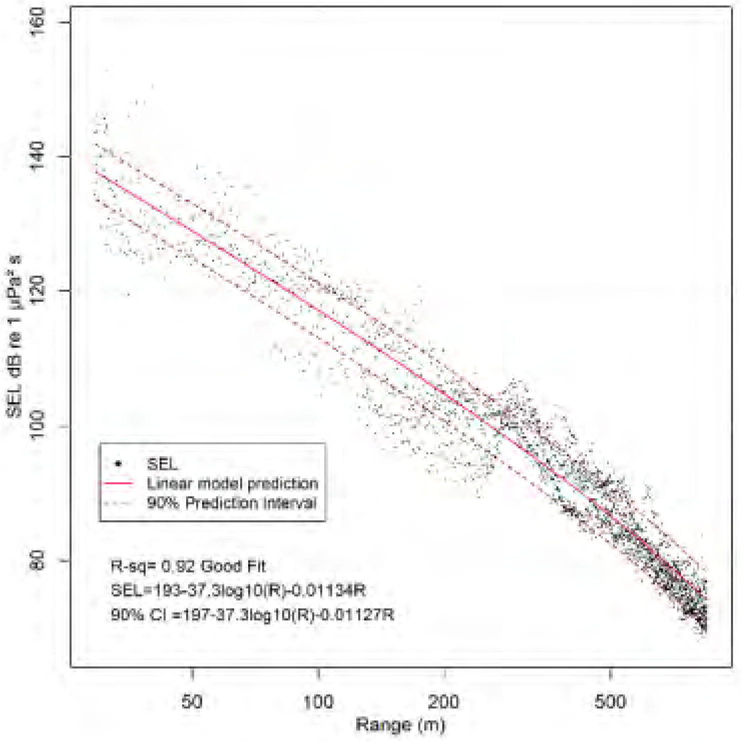

Figure 5.1: Sound Exposure Level measurements and curve fit for Innomar Medium 100, during a sound source verification study in the North Sea (Pace, et al., 2021).

The curve fit obtained from these measurements, should however be considered with a degree of caution, and should not be considered generally applicable. The environmental conditions affect the sound propagation. In order to use the measurement data in a different setting or environment, it is necessary to compensate for the environment where it was obtained, and to develop an equivalent source model that, given the same environment, performs in line with the measurements. NIRAS constructed a 3D acoustic model in dBSea, representing the actual survey environment, based on the information supplied in the report along with best available knowledge. In this model, an equivalent omnidirectional point source was designed, mimicking the measured data. The equivalent model can then be used in any other marine environment, however recognizing that the model is an approximation of the equipment behaviour, more so than an actual source model. It is therefore also recognized that this introduces an uncertainty into the sound propagation model. It is however considered the best-possible approach given the lack of an actual source model, which would require detailed source level and frequency measurements, as well as detailed frequency specific directivity measurements.

Based on the evaluation above, the Innomar Medium 100 is considered a "group C" equipment type, and will be evaluated through sound propagation modelling.

5.1.2. Ultra-Short Baseline (Sonardyne; HPT 3000 USBL transceiver and Wideband Mini Transponder - Type 8190)

The Ultra Short Baseline (USBL) system is used to determine the relative position of an underwater object, relative to a known reference point. It consists of a USBL unit mounted at a known reference point, and a transponder unit mounted on the object whose relative position is of interest. For applications such as seabed

surveys, the USBL unit would typically be mounted on the vessel. The absolute position of the vessel is registered by a GPS, thereby creating a fixed reference point for the USBL. A transponder unit is then attached to the towed equipment, such as a Side Scan Sonar (SSS), a magnetometer, ROV, etc.

It can be operated in one of two ways as outlined below, the choice between which typically relies on available equipment and project specific conditions:

A. Transponder mode (acoustic), whereby the USBL unit on the vessel emits a loud acoustic pulse acting as a "trigger". When the "trigger" pulse is registered by the transponder unit on the towed equipment, it sends out an acoustic "response" pulse. A hydrophone array on the USBL unit, records the "response" pulse and the relative distance and bearing of the transponder, relative to the vessel is registered. In this way the relative geographical position of the towed equipment is determined with very high precision.

B. Responder mode (cabled), where the "trigger" pulse is not sent acoustically through the water, but instead as an electrical impulse through a cable between the vessel and the transponder unit. On receiving the trigger pulse, the transponder unit will still emit its response pulse acoustically.

The USBL system requires a USBL unit for which the absolute geographical position must be known, and one or more transponder units mounted on equipment for which the relative position is to be determined.

From an underwater noise perspective, it is important to distinguish between the USBL unit and the transponder units. Both due to their functionality, and due to their locations. While the USBL unit is typically mounted on the vessel, the transponder units are located on the towed equipment or other objects of interest.

The Sonardyne HPT 3000 USBL transceiver USBL unit has the following source characteristics, as per supplier data sheet:

- Frequency range for the acoustic pulses: ~20 kHz – ~34 kHz,
- Source levels ranging from: $SL = 194\ dB\ re. 1\ \mu Pa$.

The frequency and source level used for any given project, depends on the environmental and project specific conditions, however standard operating frequency of 25 kHz is assumed.

It is worth noting that these systems only emit acoustic pulses in the acoustic "Transponder mode". If operated in "Responder mode", no sound is emitted, and the unit is therefore silent.

The Sonardyne - Wideband Mini Transponder - Type 8190-3111 transponder unit has the following source characteristics, as per supplier data sheet:

- Frequency range for the acoustic pulses: ~19 kHz – ~34 kHz,
- Source level: $SL = 187\ dB\ re. 1\ \mu Pa$

The frequency and source level used for any given project, depends on the environmental and project specific conditions, however standard operating frequency of 25 kHz is assumed.

Few real-world measurements of underwater noise emission from USBL systems are publicly available, and most of these include either a very limited measurement range, problems with the produced results and limited information about the used source levels and operation mode.

In 2021, a measurement was however carried out by JASCO (Pace, et al., 2021) for Energinet.dk during geotechnical survey activities of the Danish Energy Island North Sea project. For this measurement, a Kongsberg HiPaP 501 USBL unit (Vessel mounted) was used to determine the position of a towed side-scan sonar (SSS), with a “Kongsberg cNODE Micro” transponder unit. The results of these measurements are discussed in the following.

The following operational parameters were used (Pace, et al., 2021):

- The USBL unit (HiPaP 501) was operated at maximum source level,
$$SL = 191\ dB\ re.1\ \mu Pa$$
- The Kongsberg cNODE Micro 30-180 transponder unit was operated at maximum source level,
$$SL = 170\ dB\ re.1\ \mu Pa$$
- Pulse rate (trigger rate): 1.5 Hz
- Center frequency of both USBL and transponder units: 25 kHz
- Operational mode: “Transponder mode”

In Figure 5.2, a spectrogram of the measurements with the USBL system active is shown. The colors represent the sound pressure level (Warm = high levels, cold = low levels). The x-axis is the time stamp, and the y-axis is the frequency.

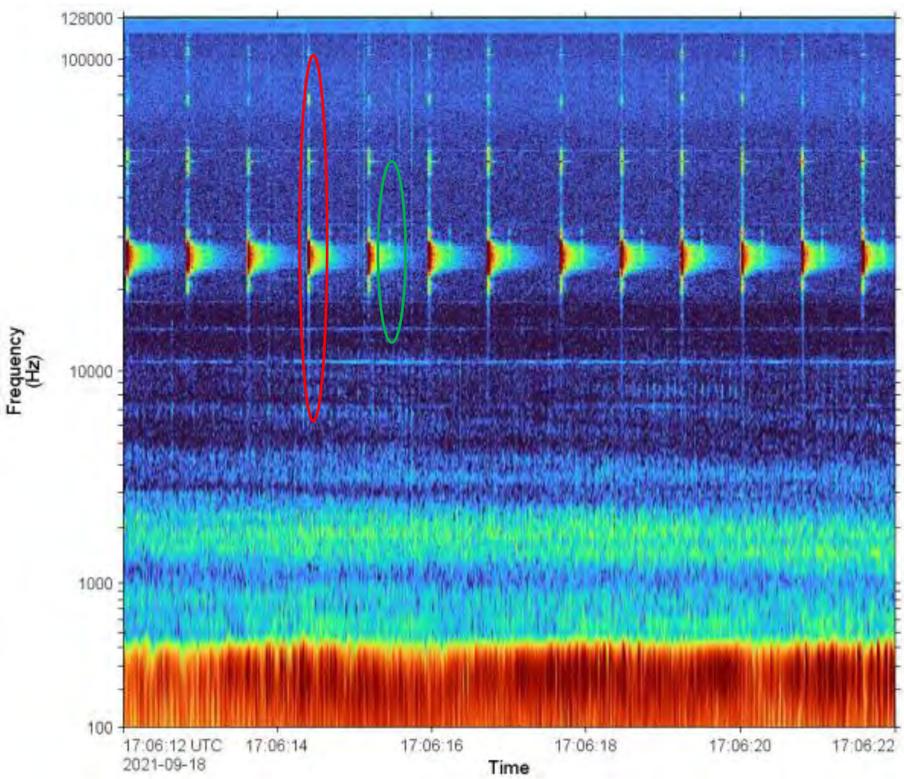

Figure 5.2: Spectrogram of measurements where SSS and USBL systems were active. Warm colours indicate high sound pressure level, and cold colours indicate low sound pressure levels as a function of frequency (Pace, et al., 2021). The red marking indicates the USBL unit pulse, while the green marking represents the transponder pulse.

From Figure 5.2, the USBL unit pulse is visible as the bright red impulses that fade into yellow to green as the sound level reduces after the pulse has stopped. The transponder pulse is less visible but can be seen as the small green lines following shortly after each of the USBL pulses.

Zooming in on a single pulse, where all the background noise is removed, is shown in Figure 5.3. Here the USBL unit pulse is clearly visible in the left half of the figure, and the transponder pulse is visible in the right-hand side where the sound level suddenly increases.

Figure 5.3: Raw data snap shot of recorded pulse at 17:06:17, where the USBL unit pulse is seen on the left hand side, and the transponder response pulse is seen on the right hand side.

As seen from Figure 5.3, the USBL unit pulse is significantly stronger than the transponder pulse.

Due to the significant difference in magnitude and short time delay between the pulses (~100 ms), only received levels for the USBL unit were reported in (Pace, et al., 2021). Curve fits for the sound level as a function of distance between source and receiver were also shown, see Figure 5.4.

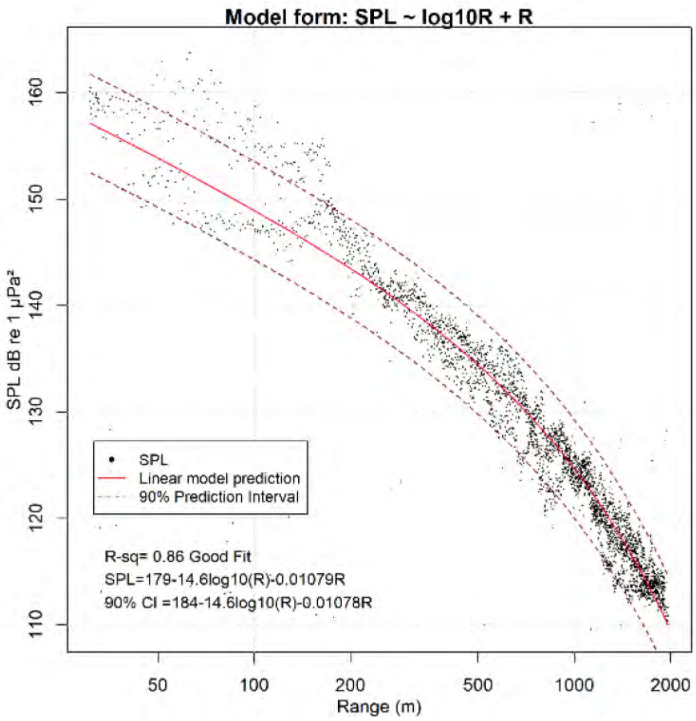

Figure 5.4: $SPL_{rms,125ms}$ as a function of measurement distance to USBL system, (Pace, et al., 2021).

From Figure 5.4, the source level for the USBL unit was back calculated to be $SL_{rms,125ms} = 179\ dB\ re. 1\ \mu Pa^2$. As previously mentioned, measured source level for the transponder was not made available. It should be noted that while the reported source level of 179 dB does not match the reported 190 dB source level set for the USBL unit, this is due to the signal duration used in the representation. Compensating for the pulse duration (20 ms)

vs. the reported levels (125 ms) gives a difference of ~8 dB. So the comparable curve fitted source level would be $SL = 187\ dB\ re. 1\ \mu Pa$ (best fit) and $SL = 192\ dB\ re. 1\ \mu Pa$ (90^{th} percentile), thus matching the reported source level of $SL = 191\ dB\ re. 1\ \mu Pa$.

The measurements were carried out in the North Sea, and can not be directly used in other waters. The equipment type is classified as "Group C", and will be evaluated through detailed sound propagation modelling.

For the sake of caution, USBL and transponder units included in this prognosis are both considered omnidirectional.

5.1.3. Multi-beam Echosounder (SeaBat T50-R)

The SeaBat T50-R MBES is a hydroacoustic device used for mapping the seafloor and collecting bathymetric data in marine environments. It employs the principles of sonar to measure the depth of the seabed and generate high-resolution bathymetric maps.

The transducer array is the primary component of the MBES. It consists of multiple individual transducers arranged in a fan-shaped or circular array. Each transducer emits a narrow beam of sound pulses in a downward direction and receives the echo reflected from the seafloor.

The frequencies emitted by the MBES are at least 200 kHz, which is outside the hearing ability of any marine mammals or fish. Coupled with the strong downward directivity, this equipment type is unlikely to have any negative auditory effect on marine mammals or fish. It is therefore considered a "Group A" equipment type, and is not considered further in this prognosis.

5.1.4. Side scan sonar (Edgetech 4205)

The Edgetech 4205 SSS is an underwater imaging system used for high-resolution imaging and mapping of the seafloor. Unlike multibeam echosounders (MBES) that primarily measure bathymetry, SSS are designed to provide detailed visual representations of the seafloor surface and its features.

The transducer array in a side scan sonar is responsible for transmitting and receiving acoustic signals. It typically consists of one or more transducers arranged in a line or an array configuration. Each transducer emits a narrow beam of sound waves perpendicular to the seafloor, covering a wide swath on either side of the sonar system.

The frequencies emitted by the SSS are typically at least 300 kHz, which is outside the hearing ability of any marine mammals or fish. While the Edgetech 4205 also comes with the option of a 100 kHz frequency, it was agreed with McMahon Design & Management Limited not to use this setting, as it coincides with the frequency range where harbour porpoise are most sensitive to sound. Coupled with the strong downward directivity, and restricting the use of frequencies below 200 kHz, this equipment type is unlikely to have any negative auditory effect on marine mammals or fish. It is therefore considered a "Group A" equipment type, and is not considered further in this prognosis.

5.1.5. Magnetometer

Marine magnetometers used in geophysical surveys for detecting buried objects such as UXOs are designed to identify variations in the magnetic field caused by the presence of ferromagnetic materials. These materials, including metallic objects like munitions, generate localized disturbances in the Earth's magnetic field, which can be detected and analyzed by the magnetometer system.

The magnetometer sensor is typically mounted on a specialized instrument platform, such as a towfish or a remotely operated vehicle (ROV). The platform is then towed at a constant altitude above the seafloor, typically a few meters, ensuring consistent proximity to the target area.

The magnetometer does not rely on acoustic output to function, and it therefore has no underwater noise emission. It is classified as a "Group A" equipment type, and is not considered further in this prognosis.

5.1.6. Noise from survey vessels

In addition to the noise from the individual activities, the survey vessel is also likely to be a source of underwater noise during the survey execution. In Pace et al. (2021), the survey vessel underwater noise emission was measured, and reporting in 1/3 octave levels at 5 different distances from the vessel, with and without marine mammal frequency weighting applied, see Figure 5.5.

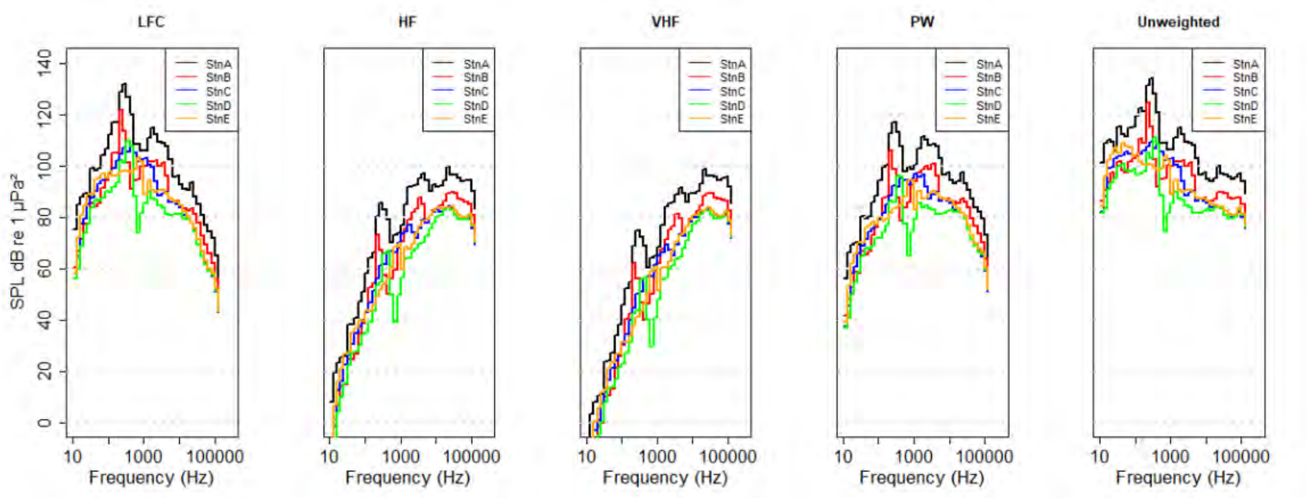

Figure 5.5: Weighted and unweighted 1/3 octave sound pressure level (SPL) measured at 5 different hydrophone distances (stnA is directly underneath the vessel path, stnB at 150 m distance, stnC at 540 m, stnD at 780 m and stnE at 2040 m). (Pace, et al., 2021).

From Figure 5.5, it is evident that noise levels are primarily low frequent, with most of the acoustic energy located below a few hundred Hz. For harbour porpoise (VHF-weighting), the measurements at station B (150 m distance) show 1/3 octave band levels below 90 dB in all bands, with broadband level below the threshold criteria for behaviour reaction, $L_{p,125ms,VHF} = 103 \text{ dB re. } 1 \text{ µPa}$.

Vessel noise is a continuous noise type, and is therefore evaluated by comparison with the non-impulsive TTS and PTS criteria. In Table 5.2, distances to PTS and TTS for each of the relevant species are provided, based on the measurement data in Figure 5.5, and assuming a 24 hour survey duration.

Table 5.2: PTS and TTS impact ranges from geophysical survey vessel noise.

Species	**Swim speed [m/s]**	**Impact range [m]**		
		PTS	**TTS**	**Behaviour**
		Non-impulsive	Non-impulsive	
Minke whales (LF)	1,5	< 10 m	< 100 m	-
White-beaked dolphin (HF)	1,5	< 10 m	< 100 m	-
Harbour porpoise (VHF)	1.5	< 10 m	< 100 m	< 150 m
Seal (PCW)	1.5	< 10 m	< 100 m	-

From this, it is evaluated that the survey vessel is categorized as "Group A", and is not evaluated any further.

5.1.7. Summary of equipment evaluation

All proposed equipment types were evaluated for their potential to emit harmful levels of underwater noise, and three groups were defined:

- Group A equipment, where underwater noise emission is evaluated to be insignificant, includes the MBES, SSS and magnetometer equipment types.
- Group B equipment, where underwater noise emission may occur at harmful levels, but where sound propagation modelling is not possible, did not apply to any proposed equipment types.
- Group C equipment, where significant underwater noise emission is likely, and sound propagation modelling should take place, included the parametric SBP and USBL.

5.2. Source model

5.2.1. Parametric SBP (Innomar Medium 100) implementation

The Innomar Medium 100 source model is based on the approach described in section 5.1.1, using an omnidirectional equivalent point source. Source characteristics are shown in Figure 5.6, as both unweighted (blue), LF (purple), HF (orange), VHF (green) and PCW (red). It is reiterated that this is an equivalent point source model from a horizontal propagation perspective, and not an accurate representation of the sound source. It is therefore only to be used as a conservative model for calculating horizontal impact ranges for marine mammals and fish.

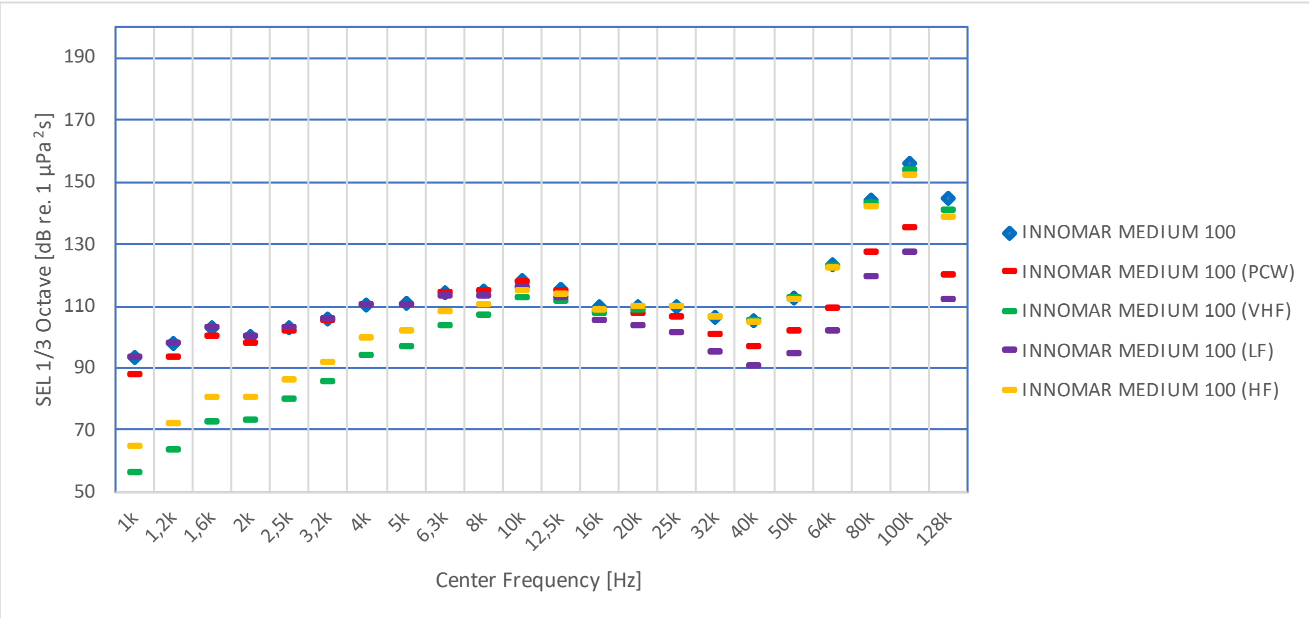

Figure 5.6: Equivalent omnidirectional point source model frequency spectrum for the Innomar Medium 100 parametric SBP. The source model is calibrated to fit measurement results from (Pace, et al., 2021).

The Innomar Medium 100 is mounted on the vessel, and is assumed operated at a 40 Hz pulse rate, while the vessel sails at 4 knots. The activity is assumed ongoing for 24 hours continuously, and it is assumed that it is not

turned off during line turns. The Innomar Medium 100 is considered a non-impulsive source type, and impact range calculation is therefore based on the non-impulsive threshold criteria.

5.2.2. USBL (Sonardyne; HPT 3000 USBL and WMT - Type 8190) implementation

The Sonardyne; HPT 3000 USBL transceiver and Wideband Mini Transponder - Type 8190 source models are based on the approach described in section 5.1.2, using an omnidirectional single-frequency point source with all energy located in the 25 kHz, 1/3 octave band. Source levels used are:

- USBL unit (Sonardyne; HPT 3000 USBL transceiver):
    - $SL = 194\, dB\, re. 1\, \mu Pa$
- Transponder unit (Sonardyne; Wideband Mini Transponder - Type 8190):
    - $SL = 187\, dB\, re. 1\, \mu Pa$

The USBL unit is mounted on the vessel, while the transponder unit is mounted on the tow, and both are assumed operated at a 1 Hz pulse rate, while the vessel speed is 4 knots. The activity is assumed ongoing for 24 hours continuously, and it is assumed that it is not turned off during line turns. The USBL is treated as a non-impulsive source type, due to its narrowband frequency content, pulsed characteristic and with no rapid rise nor decay.

5.2.3. Source positions

The project is in early stages of development, and final survey activities have not yet been determined. It was therefore agreed with McMahon Design & Management Limited to select a number of representative positions throughout the investigation area, so different sound propagation scenarios are covered. Areas where sound propagation most likely results in the longest impact ranges are identified, taking into account nearby marine mammal and/or fish protection areas if relevant. The source positions are listed in Table 5.3, along with coordinates, and distances to relevant areas of interest. The positions are also shown in Figure 5.7.

Table 5.3: Source positions used for sound propagation modelling of underwater noise during geotechnical and geophysical surveys.

Position ID	Easting	Northing	EPSG	Nearby areas of interest
1	456569	6139328	25832	Nat2000 area "Sydlige Nordsø", 22 km distance Nat2000 area "Vadehavet", overlapping City of Esbjerg, 12 km distance
2	405569	6131390	25832	Nat2000 area "Sydlige Nordsø", overlapping
3	391896	6181635	25832	Nat2000 area "Sydlige Nordsø", 23 km distance
4	645139	6180969	25831	-
5	567863	6200876	25831	Nat2000 area "Doggerbank", 16 km distance

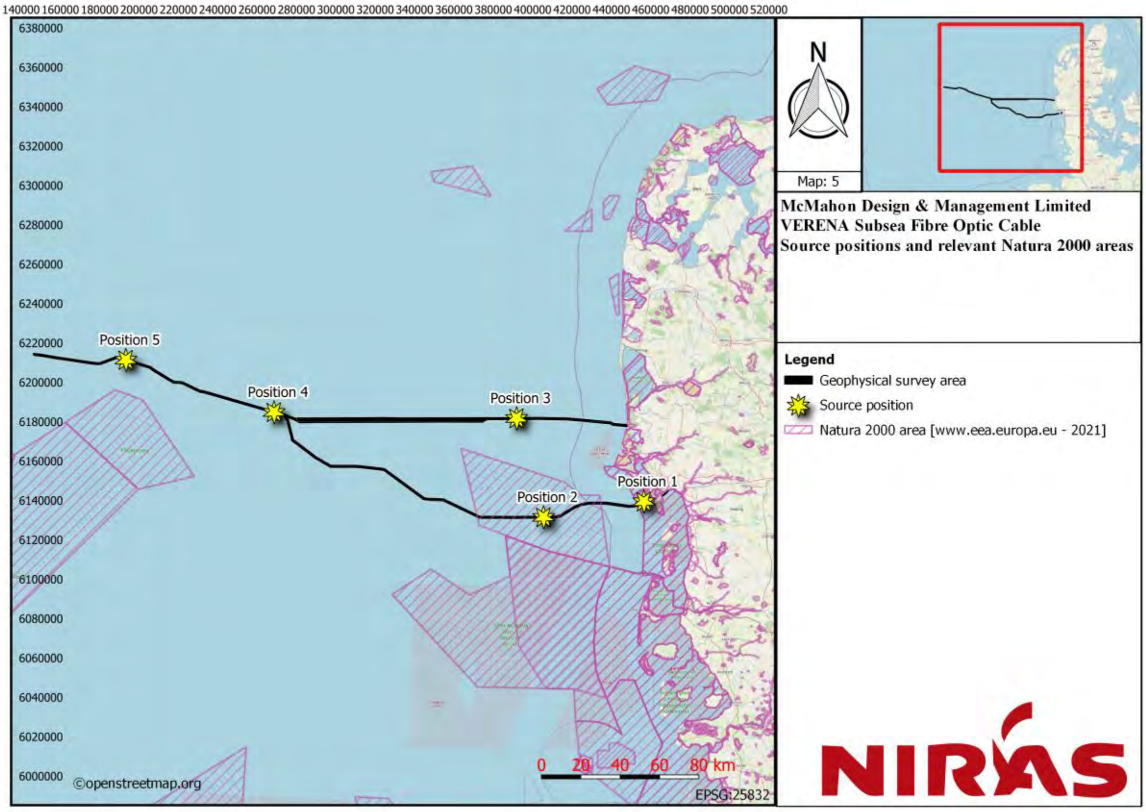

Figure 5.7: Source positions chosen for sound propagation modelling as well as nearby Natura 2000 areas.

5.3. Environmental model

Sound travels faster and farther in water than in air because water is denser and more efficient at transmitting sound waves. However, the aquatic environment is complex and heterogeneous, and sound propagation is influenced by a number of environmental parameters:

- Bathymetry,
- seabed sediments,
- temperature, salinity and sound speed,
- sea surface roughness, and
- volume attenuation.

These factors can cause sound to refract, reflect, scatter, and attenuate as the sound waves propagate through water, making it challenging to predict its behavior. These factors, and their implementation for sound propagation modelling, are described in the following sections.

5.3.1. Bathymetry

The shape and composition of the seafloor plays a critical role in the propagation of sound waves through the water. The seafloor can act as a barrier or a reflector for sound waves, depending on its composition and shape. A smooth, flat seafloor can reflect sound waves back towards the surface, whereas a rough, irregular seafloor can scatter sound waves in different directions, causing them to lose intensity and become weaker over distance.

Additionally, underwater ridges, canyons, and other geological features can act as waveguides, trapping and focusing sound waves in specific depths or regions.

Overall, bathymetry affects underwater sound propagation by influencing the speed, direction, and intensity of sound waves as they travel through the water. A detailed understanding of the bathymetry is critical for predicting and modelling the nature of underwater sound propagation in a real world scenario.

If project specific high resolution bathymetry is available, this is typically preferred over publicly available databases, which tend to be of lower resolution. Project specific bathymetry however seldomly extend beyond the project boundary. To calculate impact ranges for marine mammals and fish, it is necessary for the sound propagation model to extend 10 – 20 km beyond the project boundary. Project specific bathymetry can therefore seldomly be used alone.

For projects where no high resolution bathymetry is available, or where it is limited to the project boundary, publicly available databases, such as (EMODnet, 2021), can be used. A map of the bathymetry for Europe is shown in Figure 5.8, where darker colours indicate deeper areas, and lighter colours indicate more shallow water (EMODnet, 2021).

Figure 5.8: Bathymetry map over European waters from EMODnet, where light blue indicates shallow waters and dark blue indicates deeper waters (EMODnet, 2021).

The bathymetry for the project area and surroundings consists of information from the sources listed in Table 5.4. A visualisation of the bathymetry model for the project area and surroundings is shown in Figure 5.9.

Table 5.4: Bathymetry model data sources.

Data source	**Reference**
Bathymetry	(EMODnet, 2021)

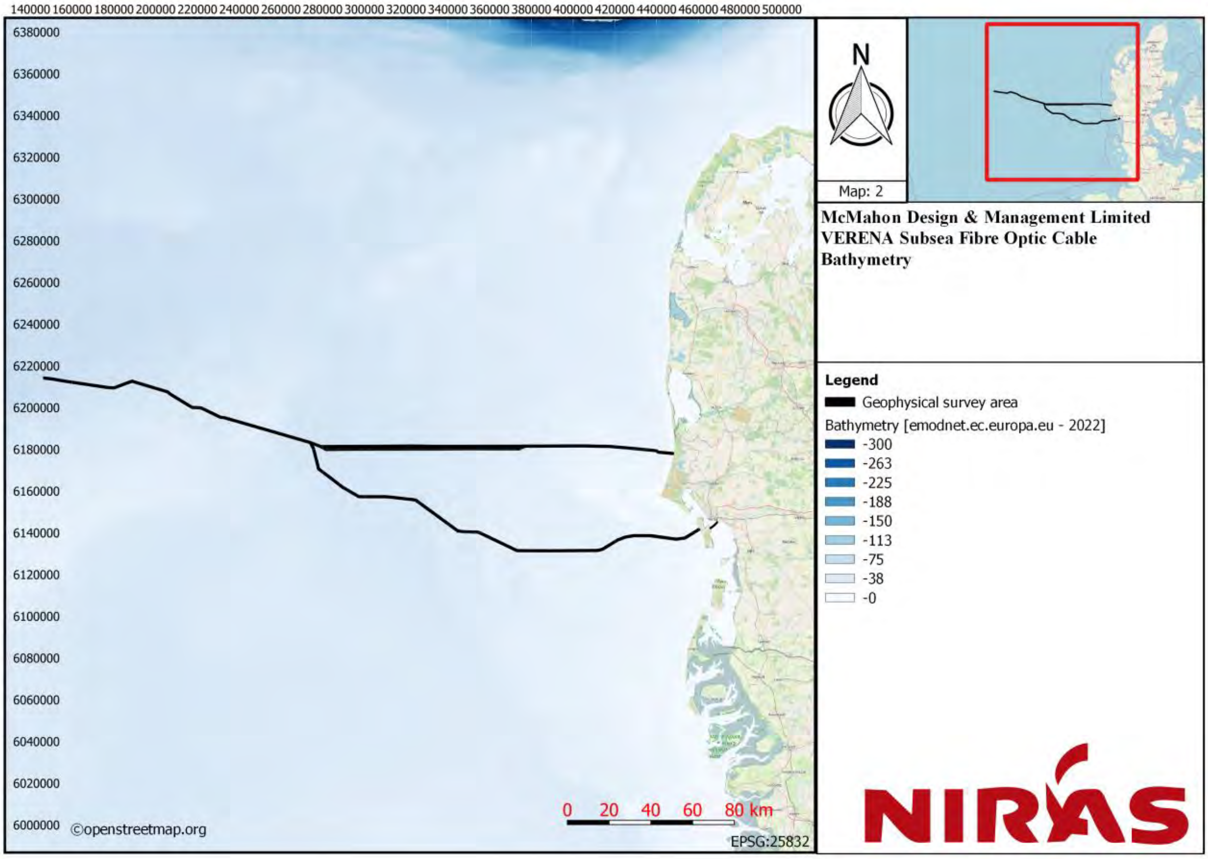

Figure 5.9: Bathymetry for the project area and surroundings, sources as listed in Table 5.4.

5.3.2. Seabed sediment

Seabed sediment layers can have a significant effect on the propagation of sound waves through the water. The acoustic properties of sediment layers are influenced by several factors, including the composition, density, porosity, and grain size distribution of the sediments. Generally, sediments with larger grain sizes and lower porosity have higher acoustic velocities and can transmit sound waves more efficiently than finer-grained and more porous sediments.

The properties of sediment layers can also affect the reflection, refraction, and attenuation of sound waves. For example, a layer of fine-grained, soft sediment can absorb and scatter sound waves, causing them to lose intensity and become weaker over distance. Conversely, a layer of hard, compacted sediment can reflect sound waves, resulting in increased sound intensity in certain areas.

The thickness of sediment layers can also play a role in underwater sound propagation. Thicker sediment layers can absorb and scatter sound waves more effectively, while shallower sediment layers can reflect and refract sound waves more strongly.

The thickness and acoustic properties of each seabed layer, from seabed to bedrock, is generally obtained through site specific literature research in combination with available site-specific survey findings.

Where site specific surveys do not reveal the top layer conditions, or where the site specific information is limited to the project boundary, publicly available databases, such as the seabed substrate map from (EMODnet, 2021) (Figure 5.10) is generally used.

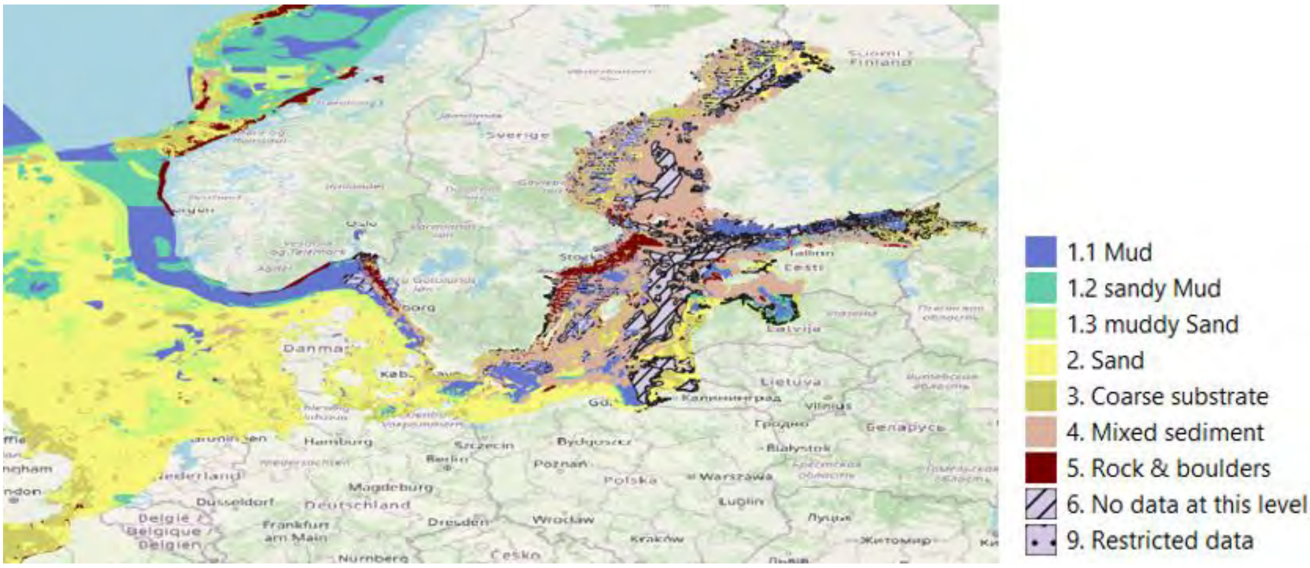

Figure 5.10: A section of the seabed substrate map, (Folk 7) (EMODnet, 2021).

From the available sediment data sources, a discretized and simplified version is created, whereby the layer thicknesses and sediment types are defined in a number of points. A high number of sediment points is necessary, when the variation in sediment types and thicknesses within the project area and surroundings increases.

For each point in the model, the sediment layer types are translated into geoacoustic parameters, in accordance with Table 5.5, utilizing information from (Jensen, et al., 2011; Hamilton, 1980).

Table 5.5: 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

The sediment model is constructed using available sources, see Table 5.6, and resulted in a 89 point sediment model, with topsoil types shown in Figure 5.11. Primary seabed surface layers in position 1, 2 and 3 are sand and coarse substrate. For position 4 and 5 the primary seabed surface layers are muddy sand. Layer thickness of the upper sediment is not well defined in the available sources and a conservative thickness of 10 m is used

throughout. Acoustic parameters for each layer are shown in Table 5.5. As it is not feasible to create an infinitely detailed sediment model, conservative layer thickness, and sediment types are used to provide a worst-case sediment model. The data source used to inform the sediment model implementation, is shown in Figure 5.12.

Table 5.6: Sediment model data sources.

Data source	Reference
Seabed substrate map	(EMODnet, 2021)
Sediment profile map	(COWI, 2020)
Acoustic parameter model for sediment types	Table 5.5

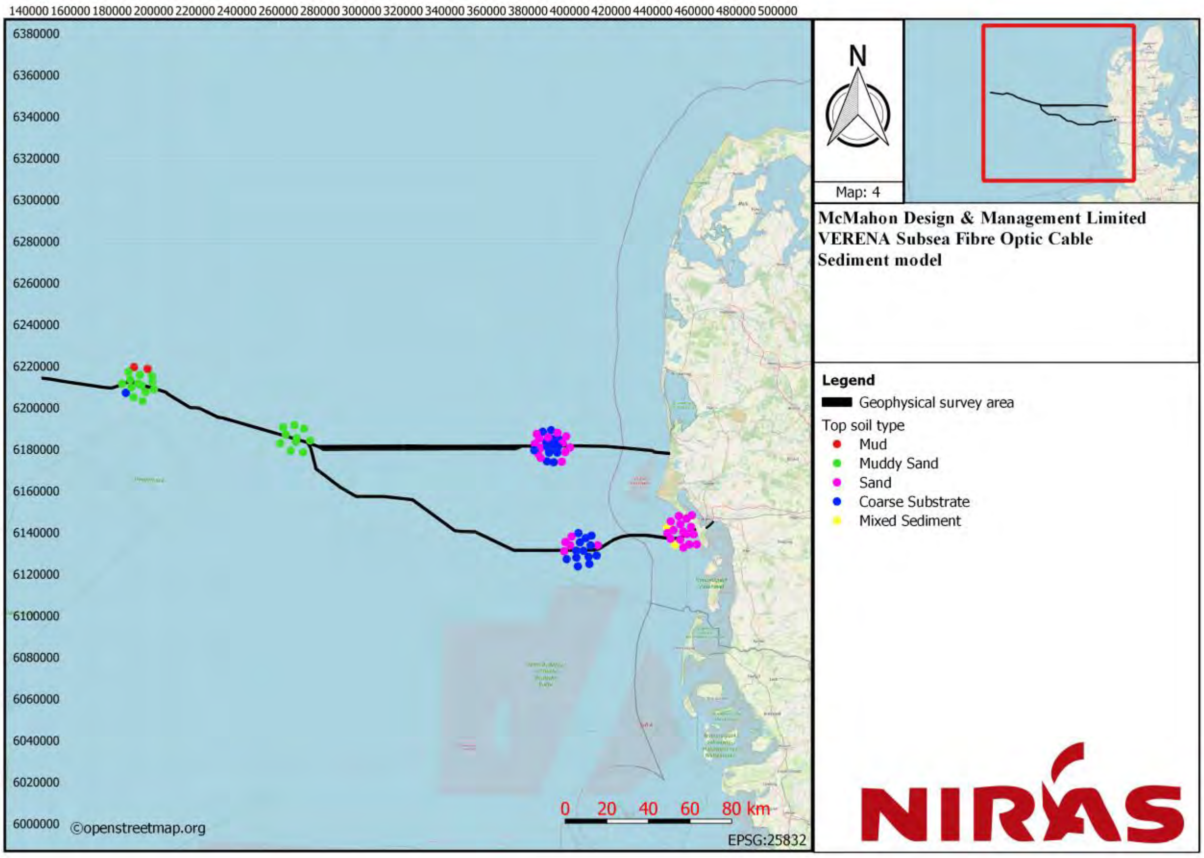

Figure 5.11: Sediment model points and topsoil layer type.

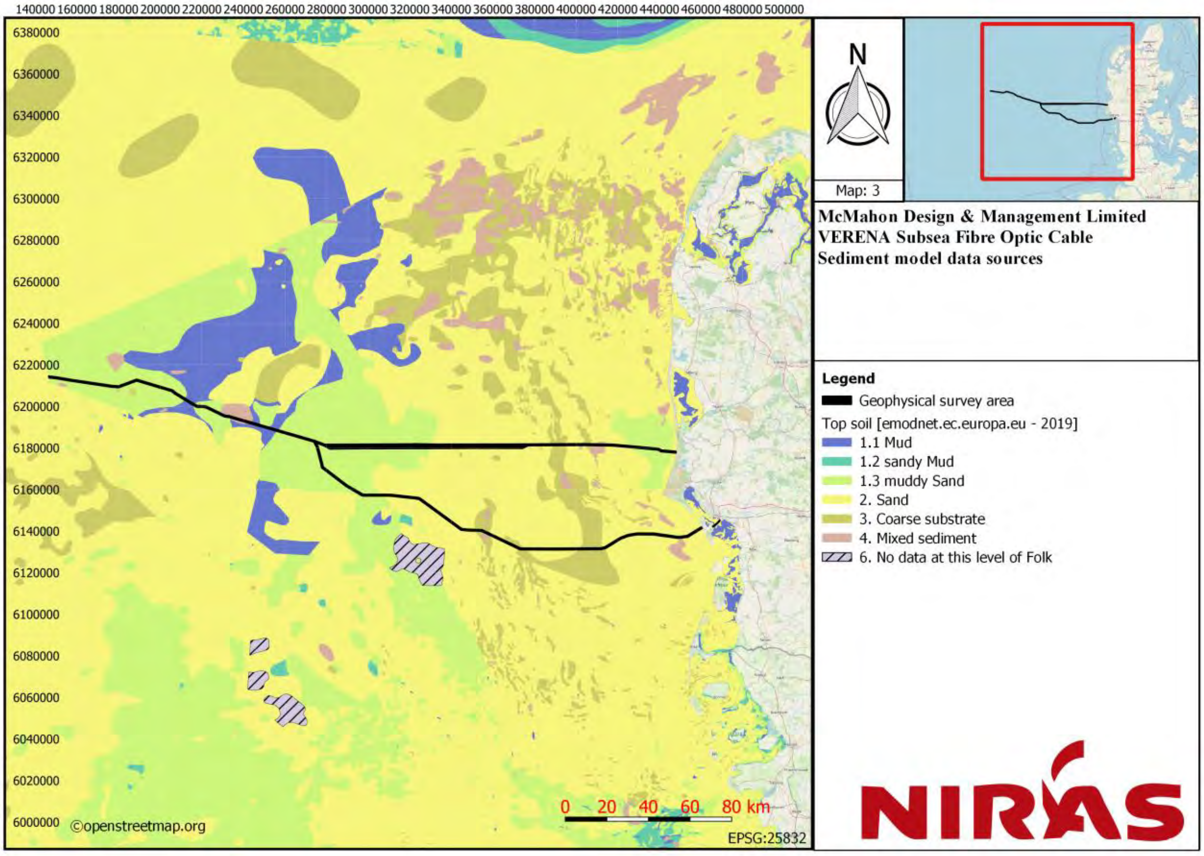

Figure 5.12: Sediment model data source, as listed in Table 5.6.

5.3.3. Temperature, salinity and sound speed profile

The combined effects of temperature and salinity on seawater density can create complex sound speed profiles in the sea, particularly in areas with strong vertical stratification or gradients in temperature and salinity. These variations in sound speed can have important implications for underwater sound propagation.

As stated by Snell's law, Equation 8, sound waves bend toward regions of low sound speed (Jensen, et al., 2011). The implications for sound in sea water are, that sound, entering a low velocity layer in the water column, can get trapped there. This results in sound travelling far with very low propagation loss.

$$\frac{\cos(\theta)}{c} = \text{constant} \qquad \text{Equation 8}$$

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

There are three main types of sound speed profiles for seawater:

1. **Uniform sound speed profile**: In a uniform sound speed profile, the speed of sound is the same at all depths. This can occur in regions of the sea where temperature and salinity are relatively constant with depth.
2. **Upward refracting sound speed profile**: When the sound speed increases with depth, it is called an upward refracting sound speed profile. Sound waves in this type of environment can be refracted up-ward and away from the seabed, potentially travelling over longer distances with lower absorption losses from seabed interaction.

3. **Downward refracting sound speed profile**: When the sound speed decreases with depth, it is called a downward refracting sound speed profile. Sound waves will, in this environment, be refracted downward to a higher degree and toward the seabed, potentially causing them to lose energy and travel shorter distances.

Special cases, where a low speed region is present at a depth in between sea surface and seabed can create channels where specific ranges of frequencies can get trapped and propagate without ever reaching neither seabed nor sea surface. The potential transmission range in such a channel is significantly longer than in any of the typical three sound speed profile types listed above.

While there are seasonal variations in underwater sound propagation in the Danish part of the North Sea, the overall sound speed profile is relatively stable compared to other regions. This is because the North Sea is a well-mixed medium, meaning that the water column is thoroughly mixed by currents and wind-driven turbulence. As a result, the water properties, including temperature and salinity, tend to be fairly uniform throughout the water column. This makes acoustic modelling and prediction more straightforward compared to other regions with more variable water properties.

The sound speed profiles for a certain project area are calculated using Coppens equation (Coppens, 1981), based on available temperature and salinity data for the area. Data sources for the temperature and salinity profiles can be either based on empirical data, or predictive models. It is important to note, that while empirical data and predictive models can provide a historically likely scenario, they can not accurately predict the weather conditions when the project activities will occur.

For each of the sediment model points, described in section 5.3.2, the nearest available sound speed profile, as well as average temperature and salinity are extracted for the desired months. Temperature and salinity profiles for this project, were extracted from the data sources in Table 5.7, and through the NIRAS software tool "TRANSMIT", turned into sound speed profiles.

Table 5.7: Temperature, salinity and sound speed data sources.

Data source	Reference
Temperature	0.083° grid, monthly averages based on physical forecast (Copernicus, 2023)
Salinity	0.083° grid, monthly averages based on physical forecast (Copernicus, 2023)
Sound speed profile	Coppens equation (Coppens, 1981) implemented in NIRAS "TRANSMIT"

The temperature and salinity change both temporally (over the year), as well as spatially. Both the timeframe and position of the activities included in sound propagation modelling must therefore be taken into account, when evaluating which sound speed profiles should be used for any given model.

A realistic worst case approach was agreed with McMahon Design & Management Limited. The temperature, salinity and sound speed profiles for the area are therefore examined for all 12 months, to determine which month has conditions most likely to result in the furthest sound propagation.

Temperature, salinity and sound speed profiles were extracted for a radius of 10 km around each source position mentioned in section 5.2.3. From these profiles, it was assessed, that profiles with the potential for the strongest sound propagation, are those of February. Graphical representations of all profiles for position 1 are given in Figure 5.13 (temperature), Figure 5.14 (salinity), and in Figure 5.15 (sound speed). Profiles for the

remaining positions are attached in Appendix 1. The figures each show the nearest 9 data points from the temperature and salinity databases, relative to the source location. These are shown in a gridded x-y format, with the centre plot representing the data point closest to the source location. Empty plots can occur where land masses are present. The coordinates for each data point is provided above the individual plots in EPSG: 4326.

To ensure a realistic worst case approach for the prognosis, sound propagation modelling implements the profiles for February.

For each sediment model position, the spatially closest data point for average temperature and salinity, as well as sound speed profiles, were assigned to the sediment model through the NIRAS software tool "TRANSMIT", which combines sediment, temperature, salinity and sound speed data, into dBSea import files.

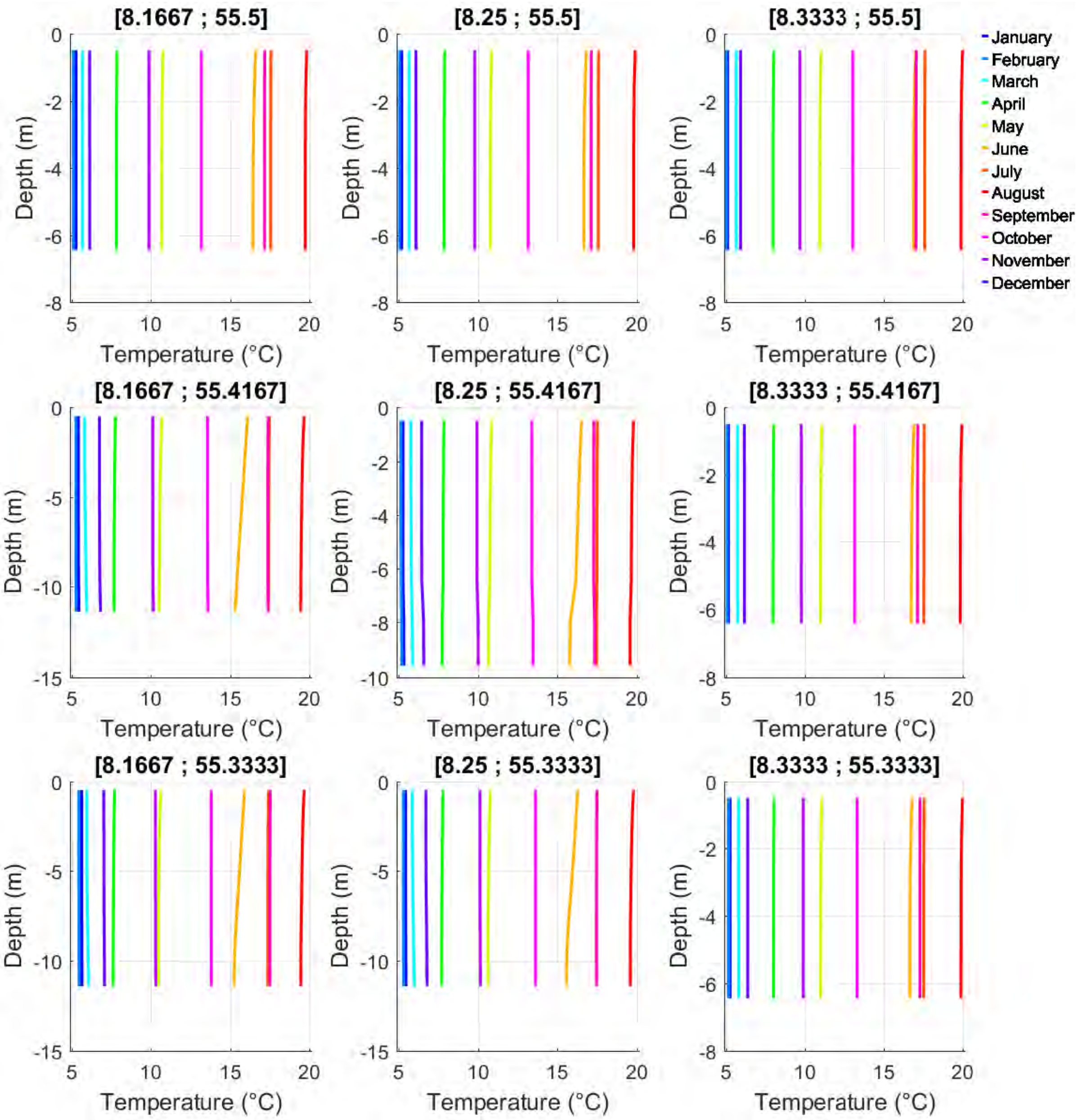

Figure 5.13: Temperature profiles for the area around source position 1 for all months. Gridded layout reflects geographical location.

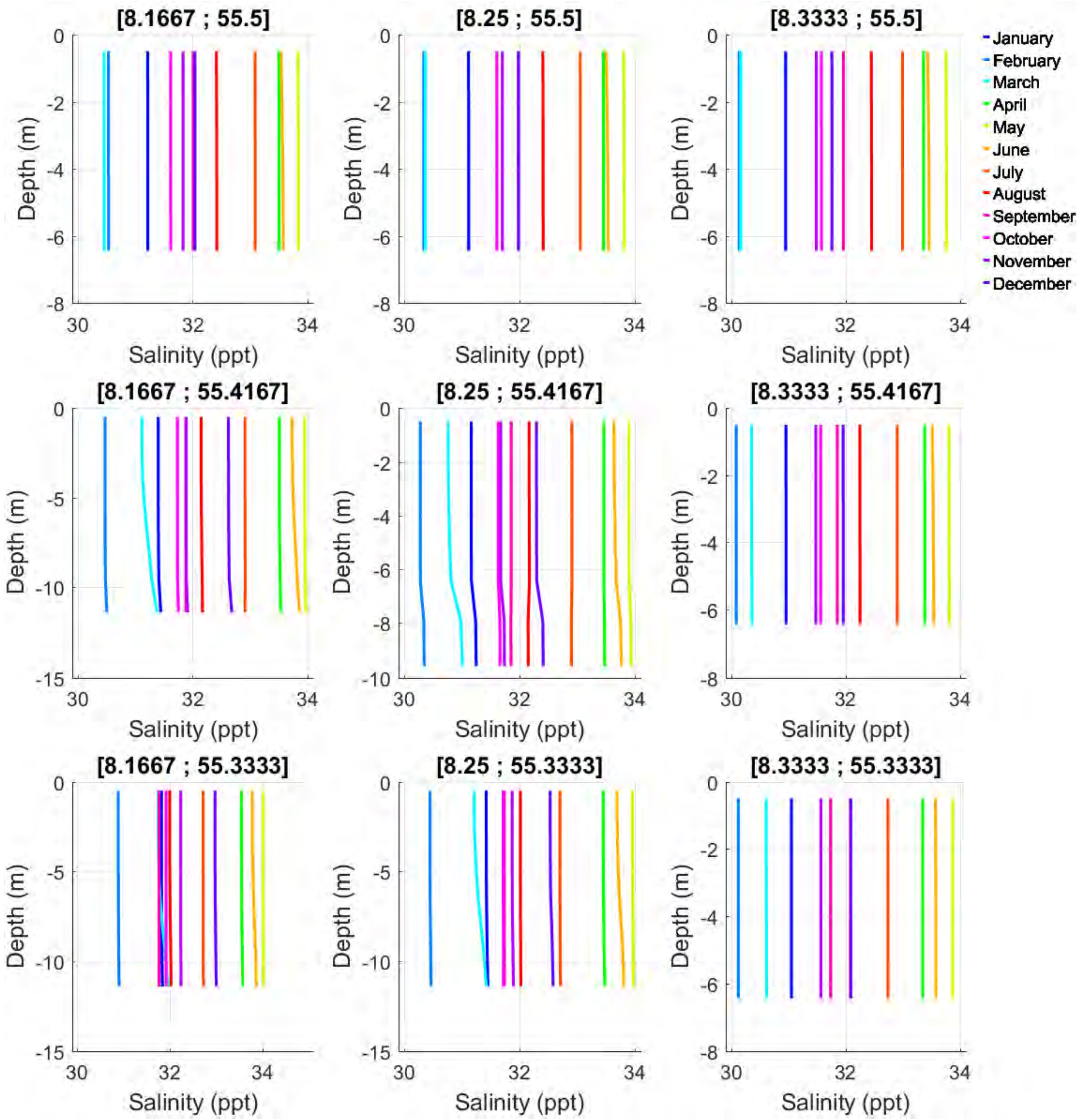

Figure 5.14: Salinity profiles for the area around source position 1 for all months. Gridded layout reflects geographical location.

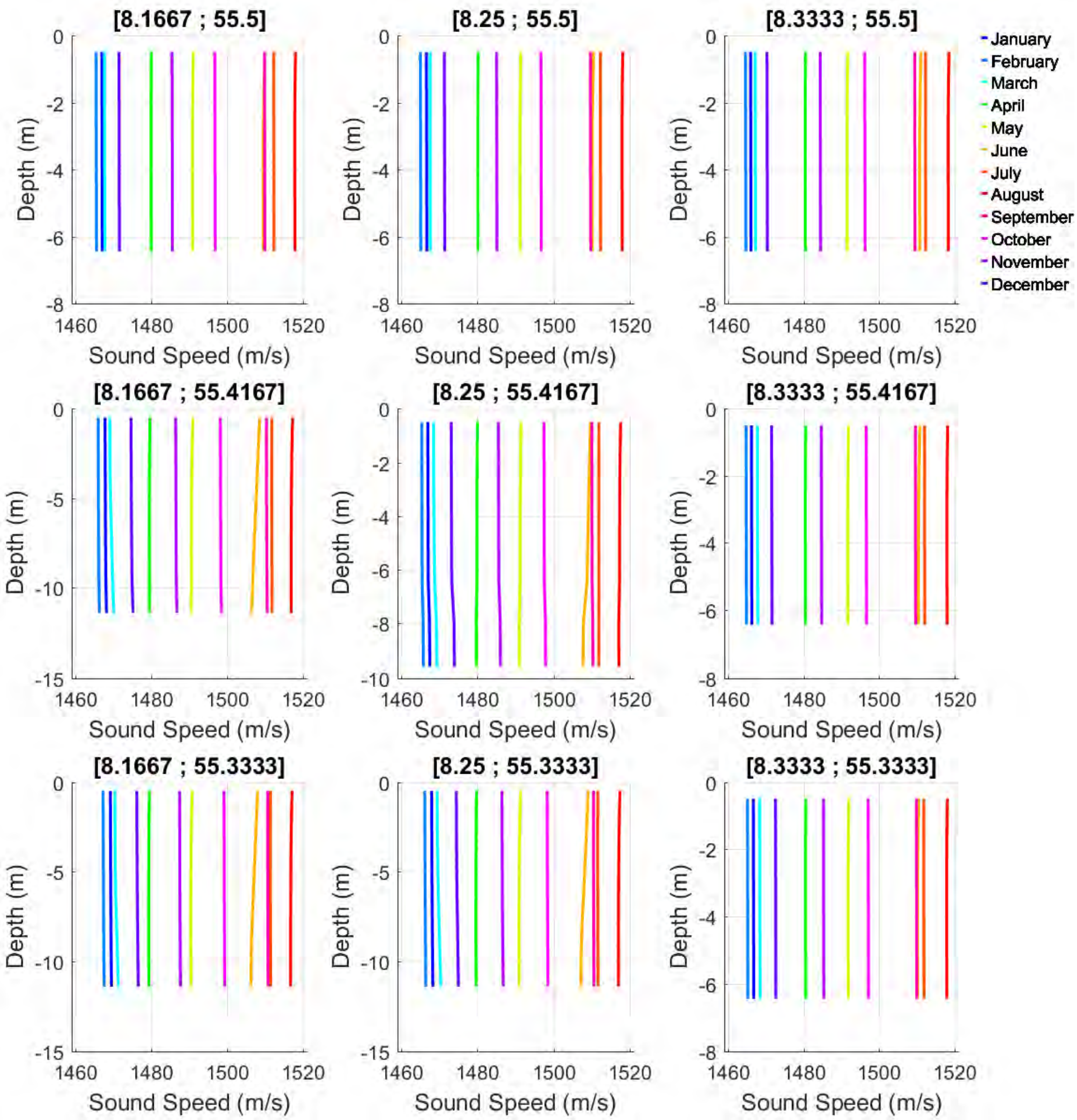

Figure 5.15: Sound speed profiles for the area around source position 1 for all months. Gridded layout reflects geographical location.

5.3.4. Sea surface roughness

Sea surface roughness, either from waves or ice cover can cause sound waves to scatter in many different directions, making it more difficult to propagate through the water. This can result in increased attenuation, backscattering and reduced range of underwater sound propagation, particularly at high frequencies.

As a precautionary approach, sound propagation modelling typically regards the sea surface as a perfect mirror (calm water), as this is also the conditions under which pile installation would be preferred. The model is therefore likely to overestimate sound propagation for any conditions where calm water is not the case.

5.3.5. Volume attenuation

Another parameter that has influence on especially the high frequency propagation loss over distance is the volume attenuation, defined as an absorption coefficient dependent on chemical conditions of the water column. This parameter has been approximated using Equation 9, from which is inferred that increasing frequency leads to increased absorption (Jensen, et al., 2011).

$$\alpha' \cong 3.3 \times 10^{-3} + \frac{0.11\mathrm{f}^2}{1+\mathrm{f}^2} + \frac{44\mathrm{f}^2}{4100+\mathrm{f}^2} + 3.0 \times 10^{-4}\mathrm{f}^2 \quad \left[\frac{\mathrm{dB}}{\mathrm{km}}\right] \qquad \text{Equation 9}$$

Where f is the frequency of the wave in kHz.

Volume attenuation is taken into account within dBSea, which is used for sound propagation modelling.

5.4. Sound Propagation Software

Numerical models can be used to simulate and predict underwater sound propagation in sea water. These models involve a computer-based simulation that uses mathematical equations to describe the sound propagation as it travels through the sea. In this regard, environmental conditions such as temperature, salinity, sediment and bathymetry must be taken into account. Different numerical models exist to treat different environmental and source specific conditions, and the choice of numerical model should always be based on the project specific environmental parameters.

NIRAS uses the software tool dBSea, which incorporates three numerical algorithms for predicting sound propagation in complex underwater environments: dBSeaRay, dBSeaPE, and dBSeaNM.

- **dBSeaRay** is a ray-tracing algorithm that simulates the paths of individual sound rays as they travel through the sea, taking into account the effects of sea properties, such as temperature, salinity, and bathymetry, on sound propagation. This allows users to predict sound propagation in a wide range of ocean environments. Inherent limitations for this algorithm limits its use in shallow waters for very low frequencies below a few hundred Hz.
- **dBSeaPE** is a parabolic equation algorithm that solves the parabolic wave equation to simulate sound propagation in the ocean. It is particularly useful for modelling sound propagation over long distances or in areas with complex bathymetry. It however lacks computational efficiency at higher frequencies and is primarily suited for low frequencies.
- **dBSeaNM** uses the normal modes method to predict sound propagation in the ocean. This algorithm takes into account the effects of vertical variations in ocean properties, such as sound speed and density, on sound propagation. It is particularly useful for predicting sound propagation in regions with significant vertical mixing or internal waves, and is most suitable for low frequencies, up to several hundred Hz.

Depending on the local environment and source characteristics, a mix of two numerical models may provide the best result, whereby one algorithm handles the low frequencies and another handles the high frequencies.

Typically, dBSeaNM or dBSeaPE is used for low frequencies and dBSeaPE or dBSeaRay for high frequencies with a split frequency between the two algorithms, based on $f = \frac{8 \cdot c}{d}$ [Hz], where c is the speed of sound in water [m/s] and d is the average bathymetry depth [m]. For very high frequencies, dBSeaRay is typically preferred.

Output from dBSea is primarily numerical, where each modelled sound propagation radial (direction from source) is represented by the maximum-over-depth (MOD) sound level at each modelled range step. MOD, in this regard, is found by taking the maximum sound level for each range step over all modelled depths. It

therefore does not represent the sound level at a specific depth, but is a more conservative measure for the highest possible exposure at every range. An example of this concept is shown in Figure 5.16, showing the sound level (x-axis) in dB over depth (y-axis), for a specific distance and direction. On the left side, the MOD is located at 1 m depth below sea-surface and is 114.2 dB, while on the right side, in another direction from the source, MOD is located at 28 m depth and is 114.6 dB. The sound levels at all other depths are ignored in the result output.

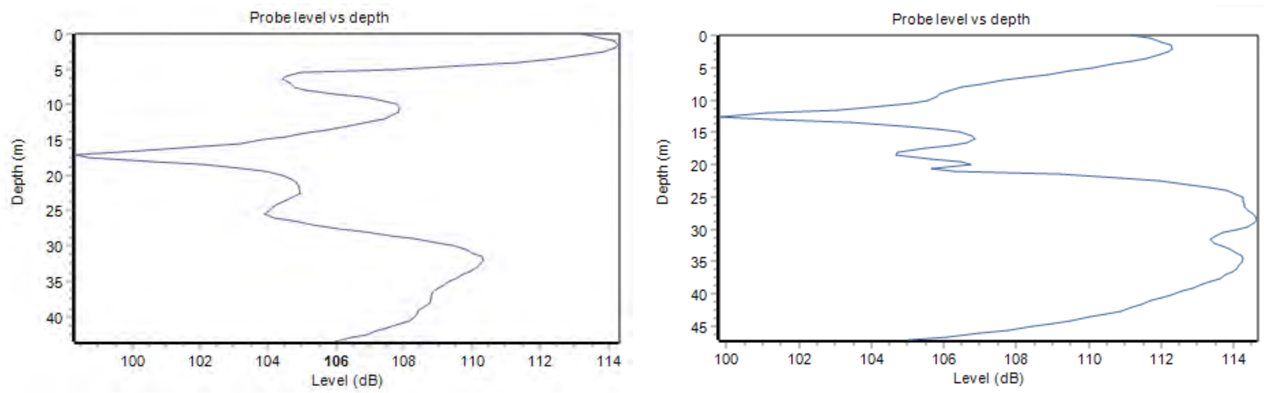

Figure 5.16: Concept of MOD, where the maximum sound level at any depth is extracted for each distance and radial interval. Example shows an MOD value of 114.2 dB (left side) at 1 m depth, and MOD value of 114.6 dB (right side) at 28 m depth.

Prognosis specific parameters for the dBSea setup is specific to the source types included, and is therefore described separately for the different source types in the prognosis.

5.4.1. Settings

The software tool dBSea was used for sound propagation modelling, with the configuration listed in Table 5.8.

Table 5.8: Sound propagation modelling tool settings for dBSea.

Parameter	Value
Software version	2.3.6
Grid (range x depth) resolution	25 m x 0.5 m
Number of radials/transects	P1: 90 (4°) P2, P3, P4, P5: 45 (8°)
Frequency solver	dBSeaRay
Frequency range	Innomar: 1 kHz – 128 kHz USBL: 25 kHz

Post-processing of the raw sound propagation results into impact ranges was done in NIRAS software tool "SILENCE", which implements Equation 6, page 16 for batch processing of different installation scenarios and threshold criteria.

5.5. Results

Sound propagation modelling was carried out in dBSea and post-processing of raw sound levels into impact ranges in NIRAS SILENCE, using the threshold criteria in chapter 4. The results are presented in the following formats:

Numerical result tables: showing the maximum range in any direction from the source to respective threshold criteria.

Distance to PTS, TTS and injury threshold criteria describe the minimum distance from the source, a marine mammal, or fish, must at least be deterred to, prior to onset of survey activities, in order to avoid the respective impact.

Distance to behavioural threshold criteria describe the range at which behavioural reactions are likely to occur when the survey operates at full intensity. During soft start, the impact ranges will be shorter.

5.5.1. Impact ranges for fish threshold criteria

For fish, all threshold criteria are based on the frequency unweighted $L_{E,cum,24h}$ [dB re. 1 $\mu Pa^2 s$]. Impact ranges are calculated for a series of different swim speeds, as discussed in section 4.1. Resulting impact ranges are provided in Table 5.9 for cod, Table 5.10 for herring and in Table 5.11 for larvae and eggs.

Table 5.9: Impact ranges for Cod.

Position	Cod: Threshold criteria impact ranges			
	Injury		TTS	
	Juvenile Cod	Adult Cod	Juvenile Cod	Adult Cod
Innomar Medium 100 (SBP) – distances relative to vessel				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
All sources active (combined)				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m

For cod, both juvenile and adult, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 5.10: Impact ranges for Herring.

Position	Herring: Threshold criteria impact ranges	
	Injury	**TTS**
	Innomar Medium 100 (SBP) – distances relative to vessel	
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel	
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
	Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object	
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
	All sources active (combined)	
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m

For herring, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 5.11: Impact ranges for Larvae and eggs.

Position	Larvae and eggs: Threshold criteria impact ranges
	Injury
Innomar Medium 100 (SBP) – distances relative to vessel	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
All sources active (combined)	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m

For larvae and eggs, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

5.5.2. Impact ranges for marine mammal threshold criteria

For marine mammals, PTS and TTS threshold criteria are based on the frequency weighted $\mathrm{L}_{\mathrm{E,cum,24h,xx}}$ [dB re. 1 μPa²s], where "xx" refers to the species specific weighting function. Species specific fleeing behaviour as outlined in section 4.2 is assumed.

Threshold criteria for behaviour reaction is based on the frequency weighted $\mathrm{L}_{\mathrm{p,125ms,xx}}$ [dB re. 1 μPa]. Resulting impact ranges are provided in Table 5.12 for minke whale, Table 5.13 for white-beaked dolphin, Table 5.14 for harbour porpoise and in Table 5.15 for seals.

Table 5.12: Impact ranges for minke whales.

Position	Minke whale (LF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
All sources active (combined)			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For minke whale, underwater sound propagation modelling results show no impact beyond 100 m range for the geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 5.13: Impact ranges for white-beaked dolphin.

Position	White-beaked dolphin (HF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
All sources active (combined)			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For white-beaked dolphin, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities.

Table 5.14: Impact ranges for harbour porpoise.

Position	Harbour porpoise (VHF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	25 - 275 m	600 m
2	< 100 m	120 - 325 m	575 m
3	< 100 m	120 - 325 m	600 m
4	< 100 m	130 - 375 m	675 m
5	< 100 m	120 - 350 m	650 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	425 -1300 m	4.0 km
2	< 100 m	400 - 1150 m	4.1 km
3	< 100 m	400 - 1150 m	4.5 km
4	< 100 m	675 - 1650 m	4.2 km
5	< 100 m	625 - 1600 m	4.4 km
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	150 – 850 m	3.2 km
2	< 100 m	225 – 625 m	3.6 km
3	< 100 m	180 – 575 m	3.6 km
4	< 100 m	325 – 875 m	3.6 km
5	< 100 m	300 – 875 m	3.6 km
All sources active (combined)			
1	< 100 m	425 -1300 m	4.0 km
2	< 100 m	400 - 1150 m	4.1 km
3	< 100 m	400 - 1150 m	4.5 km
4	< 100 m	675 - 1650 m	4.2 km
5	< 100 m	625 - 1600 m	4.4 km

For harbour porpoise, underwater sound propagation modelling results show impact on the behaviour at up to 4.5 km distance from the survey. It should be noted that this behaviour criterion is only considered valid for impulsive noise sources (Tougaard, 2021), however as no threshold criteria have been established by science for non-impulsive sources, the impulsive criterion is used as a proxy.

Impact ranges for PTS were found to be less than 100 m, while results for TTS threshold criteria show up to 1600 m impact range.

Table 5.15: Impact ranges for seals.

Position	Seals (PCW): Threshold criteria impact ranges		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
	Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	All sources active (combined)		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For seals, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

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Bilag 3

Datablad af fartøjer – Glomar Vantage og Lady Kathleen

GLOMAR // VANTAGE

SPECIFICATIONS

GENERAL

Type:	Multi Purpose Vessel
Class:	Rina
Flag:	Panama
Built / Rebuilt:	1982
Call Sign:	HO3057
IMO:	8109266
MMSI:	372867000
Port of Registry:	Panama
Class Notation:	* AUT-UMS; DIVINGSUPPORT; * DYNAPOS AM/AT

DIMENSIONS

Length:	56,27 m
Breadth:	11,50 m
Draft (Min/Max):	1,50 m / 4,00 m
Depth:	5,00 m
Gross Tonnage:	991 T

PERFORMANCE

Maximum Speed + Fuel Consumption:	7.8 Knots - 3200 L/day
Economic Speed + Fuel Consumption:	6.5 Knots/2500 L/day
DP activities:	3800 L/day- 4600 L/day - Load depending
Fuel Consumption Port:	500 L/Average per day

MACHINERY & PROPULSION

Main Engines:	2 x Stork Werkspoor DRO 216K 393 kW
Auxiliary Engines:	3 x DAF DKT 1160M 150 kW 1 x Mitsubishi S12R-MPTA 1190 kW 1 x Deutz BA 8M 816 419 kW 1 x Dongfeng Cummins 6BT5,9-G1 100 kW
Bowthruster:	Wärtsila / Lips CT 150 H
Azimuth Thruster:	Wärtsila / Lips CT 150 H

RESCUE EQUIPMENT

MOB Crane, Upper Deck:	NED-DECK Marine 04-03 E
Man Overboard Boat:	Yes

TANK CAPACITIES & DECK AREA

Total Fresh Water Tank:	58 m^3
Total Ballast Water Tank:	490 m^3
Total Fuel Tank:	202 m^3
Deck Area:	OPEN DECK-105 m^2 BELOW MEZZANINE DECK- 25 m2 Limited height MEZZANINE DECK-25 m^2 to 39 m^2 with flush hatch
Deck Strength:	5 T/m^2
Boat Landing:	No
Fresh Water Generator:	Yes

DYNAMIC POSITIONING SYSTEM

DP Class:	DP 1
Manufacturer:	Kongsberg
DGPS:	2 x Hemisphere R330 GNSS RCVR
Gyro Compass:	1 x Sperry Navigat MK2 1 x TTS Brown Meridian
Motion Sensors:	1 x Hippi 120sec. Datawell 1 x TSS DMS205
Accoustic Positioning:	1 x USBL 1 x Ranger 1 Sonardyne

DECK EQUIPMENT

Deck Crane:	Kentz EHC 10/60 SH
Safe Working Load:	10 T at 6 m
Gantry Crane Central Main Deck:	Hydrauvision B.V.
Working Load Limit:	33 T
A Frame:	P/L5
Working Load Limit:	7 T
Moonpool:	3,80 m x 3,80 m
Survey Moonpool:	500 mm Diameter

ACCOMMODATION

Total Accommodation (Berths):	29
Cabins:	19
Single Cabins:	9
Double Cabins:	10
Offices:	1
Hospital:	1
Gym:	Yes
Relaxation Room / Game Room:	Yes

RADIO & NAVIGATION EQUIPMENT

GMDSS:	A1 + A2
V-Sat:	1 x Intellian
Inmarsat:	Min: 8192/4096MIR 512/512CIR Max: 8192/4096MIR 8192/4096 - CAR 10W

Het Nieuwe Diep 34 A3 | 1781 AD Den Helder | The Netherlands | +31 223 525 030 | www.glomaroffshore.com | chartering@glomaroffshore.com

9.2 Lady Kathleen

The Lady Kathleen is a state-of-the-art 14m survey vessel that provides a stable platform for reliable, cutting edge sensor deployment. The vessel is purpose-built for hydrographic and geophysical data acquisition. She is a cutting edge survey platform with exceptional manoeuvrability both at low and high speed and can conduct nearshore work in a wide range of water depths from <3m to >100m. With top speeds of 25knots, Lady Kathleen can get to site fast and brings a fuel consumption of 10L per hour on survey operations

LADY KATHLEEN

Technical Specifications

General Vessel Information	
Builder:	Blyth Workboats
Designer:	Blyth Workboats
Launched:	2021
Length:	14 m
Beam:	5 m
Draught:	1.4 m
Flag / License:	Irish – MSO P5 30nm

General Safety Information	
Duration:	12 hour Day or Night
Safe Manning:	Master & Deckhand
Limitations:	30nm to sea
Liferaft:	1x 8man Port & Stb
Lifejackets:	8x Solas
EPIRB:	Yes
SART:	Yes

Deck Equipment	
Winch 1:	1T Hydraulic Tugger Winch
Winch 2:	STR ESW 500 – 500m Coax
Winch 3:	STR ESW 500 – 500m Coax
A Frame:	Hydraulic 1T SWL
Moonpool:	700mm x 700mm
Side Pole:	SS Duel Mount
Side Winch:	1x 1T Capstan

Navigation Equipment	
Plotter:	2x Axiom Pro RVX 16"
Auto Pilot:	Simrad AP70
AIS:	Class A
DSC VHF:	2x Icom GM600 GMDSS
DSC MF/HF:	1x Icom GM800 GMDSS
Navtex:	Yes
Internet:	4G Broadband

Propulsion & Generator	
Main Engines:	Twin Cummins QSC8.3
Gearbox:	ZF with PTO
Generator:	Fisher Panda 8KW
Max Speed:	25 knots
Cruise:	15 knots
Survey:	3.5 – 6 knots
Prop(s):	Twin 5 blade

Survey Equipment	
MBES:	Teledyne SeaBat T50-R
Processor:	Teledyne Reason T50 IDH
SV Sensor:	Reason SVP-70
SSS:	Edge Tech 4205
Magnetometer:	Geomatix G-882
Gradiometers:	2-sensor TVG Frame
Parametic SBP:	Innomar SES-2000
USBL:	GAPS M5
Navigation:	QPS QINSy 9.5.0
SV Profiler:	Valeport Swift (x2)
Attitude/Heading:	Applanix Integrated INS Teledyne Type-30 IMU
GNSS:	Applanix Integated INS Trimble AT1675-540TS (x2)

VERENA
Subsea Fibre Optic Cable

Underwater noise prognosis

Geophysical survey

NIRAS A/S

Date: 8. February 2024

Revision Log:

Rev.no.	Date	Description	Prepared by	Verified by	Approved by
1	26-01-2024	First Draft	KRHO/MAM	MAWI	STOR
2	08-02-2024	Final Version	KRHO/MAM	MAWI	STOR

Executive Summary

McMahon Design & Management Limited is planning geophysical survey activities in relation to the planning of the "VERENA Subsea Fibre Optic Cable", located in the Danish part of the North sea. Geophysical survey activities produce underwater noise and some of the activities have the potential to disturb and harm marine fauna. NIRAS has been tasked with preparation of an underwater noise prognosis for these activities, to act as input for an impact assessment for marine mammals and fish.

The potential for underwater noise impact was evaluated for the proposed geophysical survey activities:

1. Multibeam echosounder (MBES),
2. side scan sonar (SSS),
3. sub-bottom profiler (SBP),
4. Ultra-short baseline (USBL)

The acoustic impact of activity type MBES and SSS were assessed based on available literature, while underwater sound propagation modelling was undertaken for activity type SBP, and USBL.

A 3D acoustic environmental model, based on available online data sources, as well as client input, for bathymetry, sediment, salinity, temperature and sound speed, was created in QGIS and NIRAS TRANSMIT (Matlab toolbox). Worst case hydrographic conditions, represented by historical data for the month of February, was used. Underwater sound propagation modelling was carried out in dBSea 2.4.6, for activities SBP, and USBL, using the 3D acoustic environmental model, as well as a source model derived from available literature and NIRAS experience. Sound propagation was calculated in a 25 x 0.5 m range-depth grid in 45-90 directions from each source (4 - 8° resolution). Number of directions were increased for model positions near land masses. Resulting sound propagation losses were processed in NIRAS SILENCE (Matlab toolbox) to determine impact ranges to relevant marine mammal and fish threshold criteria.

For marine mammals, threshold criteria include hearing loss (threshold shift), resulting from exposure to high noise doses, as well as instantaneous behavioural reaction resulting from a sudden change in the experienced noise level. A noise induced threshold shift is a temporary or permanent reduction in hearing sensitivity, TTS and PTS respectively, following exposure to loud noise (for example commonly experienced by humans as a temporarily reduced hearing after attending a loud concert). The level of injury depends on both the intensity and duration of noise exposure. Small amounts of TTS will disappear in a matter of minutes, extending to hours or even days for very severe TTS. At higher levels of noise exposure, the hearing threshold does not recover fully, but leaves a smaller or larger amount of PTS. An initial TTS of 40 dB or higher is generally considered to constitute a significantly increased risk of generating a PTS (NOAA, 2018). Behavioural reaction on the other hand is linked to the instantaneous change in sound level, causing a reaction, such as avoidance.

For fish, TTS threshold criteria is used alongside a physical injury threshold criteria. For larvae and eggs, only the injury criteria is considered.

Marine mammals included in the prognosis are minke whales, white-beaked dolphin, harbour porpoise (*Phocoena phocoena*) and earless seals with threshold criteria for PTS and TTS, as well as behaviour reaction. Fish species included in the prognosis are cod and herring, as well as larvae and eggs, for which relevant TTS and injury threshold criteria were included.

Impact ranges for PTS, TTS and injury describe the minimum distance from the source a marine mammal or fish must at least be, prior to onset of survey activities, in order to avoid the respective impact. It therefore does not represent a constant distance the animals must maintain, but a safe starting distance, beyond which the threshold criteria are unlikely to be exceeded. For marine mammals, fleeing behaviour is included. For fish, fleeing behaviour is also included, while larvae and eggs are considered stationary.

Impact ranges for behaviour, describes the specific distance, up to which, the behavioural threshold criteria is likely to be exceeded, when survey activities are operating at maximum intensity.

Results are presented in numeric form in Table 1.1 - Table 1.4 for marine mammals, in Table 1.5 - Table 1.6 for fish, and in Table 1.7 for larvae and eggs.

Table 1.1: Impact ranges for minke whales.

Position	**Minke whale (LF): Threshold criteria impact ranges**		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
	Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	All sources active (combined)		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For minke whale, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 1.2: Impact ranges for white-beaked dolphin.

Position	**White-beaked dolphin (HF): Threshold criteria impact ranges**		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
All sources active (combined)			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For white-beaked dolphin, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities.

Table 1.3: Impact ranges for harbour porpoise.

Position	Harbour porpoise (VHF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	TTS (Non-impulsive)	Behaviour
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	25 - 275 m	600 m
2	< 100 m	120 - 325 m	575 m
3	< 100 m	120 - 325 m	600 m
4	< 100 m	130 - 375 m	675 m
5	< 100 m	120 - 350 m	650 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	425 -1300 m	4.0 km
2	< 100 m	400 - 1150 m	4.1 km
3	< 100 m	400 - 1150 m	4.5 km
4	< 100 m	675 - 1650 m	4.2 km
5	< 100 m	625 - 1600 m	4.4 km
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	150 – 850 m	3.2 km
2	< 100 m	225 – 625 m	3.6 km
3	< 100 m	180 – 575 m	3.6 km
4	< 100 m	325 – 875 m	3.6 km
5	< 100 m	300 – 875 m	3.6 km
All sources active (combined)			
1	< 100 m	425 -1300 m	4.0 km
2	< 100 m	400 - 1150 m	4.1 km
3	< 100 m	400 - 1150 m	4.5 km
4	< 100 m	675 - 1650 m	4.2 km
5	< 100 m	625 - 1600 m	4.4 km

For harbour porpoise, underwater sound propagation modelling results show impact on behaviour at up to 4.5 km distance from the survey vessel. It should be noted that this behaviour criterion is only considered valid for impulsive noise sources (Tougaard, 2021), however as no threshold criteria have been established by science for non-impulsive sources, the impulsive criterion is used as a proxy.

Results show no impact beyond 100 m range for PTS, and up to 1.6 km for TTS, for the proposed geophysical survey activities.

Table 1.4: Impact ranges for seals.

Position	Seals (PCW): Threshold criteria impact ranges		
	PTS (Non-impulsive)	TTS (Non-impulsive)	Behaviour
	Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	All sources active (combined)		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For seals, underwater sound propagation modelling results show no impact beyond 100 m range for the geo-physical survey activities.

Table 1.5: Impact ranges for Cod.

Position	**Cod: Threshold criteria impact ranges**			
	Injury		**TTS**	
	Juvenile Cod	Adult Cod	Juvenile Cod	Adult Cod
Innomar Medium 100 (SBP) – distances relative to vessel				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
All sources active (combined)				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m

For cod, both juvenile and adult, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities.

Table 1.6: Impact ranges for Herring.

Position	Herring: Threshold criteria impact ranges	
	Injury	**TTS**
	Innomar Medium 100 (SBP) – distances relative to vessel	
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel	
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
	Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object	
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
	All sources active (combined)	
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m

For herring, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 1.7: Impact ranges for Larvae and eggs.

Position	Larvae and eggs: Threshold criteria impact ranges
	Injury
Innomar Medium 100 (SBP) – distances relative to vessel	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
All sources active (combined)	
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m

For larvae and eggs, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Contents

List of abbreviations

Full name	Abbreviation	Symbol
Sound Exposure Level	SEL	$L_{E,p}$
Cumulative Sound Exposure Level	$SEL_{cum,t}$	$L_{E,cum,t}$
Sound Exposure Level - single pile strike	SEL_{SS}	L_{E100}
Sound Pressure Level	SPL	L_p
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	
Low frequency	LF	
High frequency	HF	
Very High frequency	VHF	
Phocid Pinniped	PCW	
World Ocean Atlas 2023	WOA23	
Sound Exposure Propagation loss	EPL	
National Marine Fisheries Service	NMFS	
Maximum-over-depth	MOD	

1. Introduction and objectives

McMahon Design & Management Limited is planning geophysical survey activities in relation to the planning of the VERENA Subsea Fibre Optic Cable project, located in the Danish part of the North sea. NIRAS has been tasked with preparation of an underwater noise prognosis for the geophysical survey activities, as input for an environmental impact assessment for marine mammals and fish.

The report is structured as outlined below.

Chapter	Content
2	Project description
3	Definitions: A brief introduction to terms and metrics used throughout the report
4	Marine mammal and fish threshold criteria for auditory impact
5	Underwater noise prognosis for geophysical survey

2. Project description

The VERENA Subsea Fibre Optic Cable survey area covers a 1 km wide corridor between Denmark and the United Kingdom. This report only covers the geophysical investigations within the Danish part of the North Sea. In Denmark, the survey corridor reaches the coast in two different locations (Henne Strand and Esbjerg). The geophysical survey covers an area (Figure 2.1) of 613 km^2.

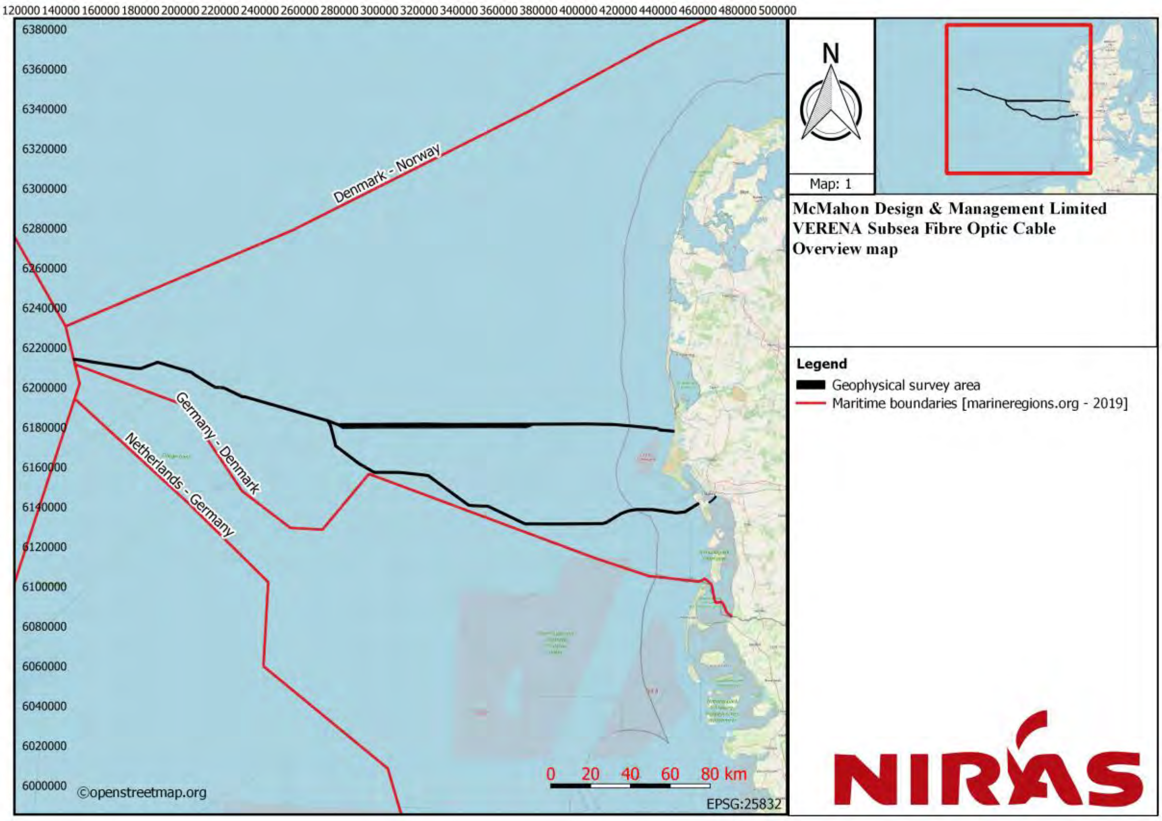

Figure 2.1: Overview of the VERENA Subsea Fibre Optic Cable geophysical survey area.

2.1. Description of Activities

Underwater noise emission is expected to occur as a result of the geophysical survey activities, where the physical properties of the seabed within the survey area are investigated.

Geophysical investigations are typically characterised by non-invasive acoustic techniques. By analysing the reflections of sound waves emitted towards the seafloor and sediment layers, the sediment layer composition, as well as pockets of natural resources, can be determined. Investigations that map the bathymetry and objects on or imbedded in the seabed, such as unexploded ordnance (UXO), are also considered part of the geophysical investigations.

3. Definitions

Acoustic metrics and relevant terms used in the report are defined in this chapter. Terminology generally follows ISO standard 18405 (DS/ISO 18405, 2017).

3.1. Sound Pressure Level

The Sound Pressure Level (SPL), L_p, is used to describe the noise level. The definition for SPL is shown in Equation 1 (Erbe, 2011):

$$L_p = 20 * \log_{10}\left(\sqrt{\left(\frac{1}{T}\right)\int_0^T p(t)^2}\right) \quad [\mathrm{dB\ re.\ 1\mu Pa}]$$

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.

For ambient underwater noise and for operational underwater noise, L_p is the preferred metric.

In order to evaluate the behavioural response of the marine mammal a time window is needed. 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).

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

Equation 2

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

3.2. Sound Exposure Level

The Sound Exposure Level (SEL), $L_{E,p}$, describes the total energy of a noise event (Jacobsen & Juhl, 2013). A noise event can for instance be the duration of an entire survey from start to end, or it can be a single noise event like an airgun pulse. The SEL is normalized to 1 second and is defined in (Martin, et al., 2019) through Equation 3.

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

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 μPa.

The relationship between SPL, Equation 1, and SEL, Equation 3, is given by 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. SEL is therefore a commonly used metric to assess the risk of hearing impairment as a result of noisy activities (Martin, et al., 2019).

3.3. Cumulative Sound Exposure level

For moving sources in combination with moving receivers, the $L_{E,cum,t}$ is calculated using the approach presented in (Tougaard, 2016). The survey vessel speed, and its direction relative to a moving receiver is used to calculate the $L_{E,cum,t}$ for a given receiver. In Equation 5, the distance between the source and receiver at the i^{th} pulse, r_i, is given for a specific piece of survey equipment. This is based on a starting position of the marine mammal relative to the source, defined by the on-axis distance, l_0, corresponding to the transect line, and the off-axis distance, d_0, corresponding to the perpendicular distance from the transect line. Δt_i is the time in seconds between the first pulse and the i^{th} , while v_{ship} and $v_{receiver}$ is the ship and receiver moving speed respectively, in m/s.

$$r_i = \sqrt{\left(l_0 - ((i-1) \cdot \Delta t_i) \cdot v_{ship}\right)^2 + (d_0 + ((i-1) \cdot \Delta t_i) \cdot v_{receiver})^2}$$ Equation 5

By summing the pulses from the entire survey, within a 24h window, given the propagation loss for the survey area, Equation 6 gives the resulting $L_{E,cum,24h}$.

$$L_{E,cum,24h} = 10 * \log_{10}\left(\sum_{i=1}^{N} 10^{\left(\frac{L_{S,E} - X*\log_{10}(r_i) - A*(r_i)}{10}\right)}\right)$$ Equation 6

Where N is the total number of pulses for that piece of survey equipment, $L_{S,E}$ is the source level at 1 m distance, X and A describe the sound exposure propagation losses (EPL), $N_{PL,E}$, for the specific project site. For surveys using multiple equipment types, the contribution from each source is first normalized into 1 sec. SEL based on firing frequency, and then added.

The parameters used in Equation 5 and Equation 6, related to the source level, firing frequency, movement speed and source direction must be based on best available knowledge. The EPL parameters (X and A) must be determined through advanced sound propagation modelling, in which all relevant site-specific environmental parameters are considered.

3.4. Source level

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

SL is defined for a continuous source as the SPL_{rms} at a distance of 1 m from the source with a reference value of $1\ \mu Pa \cdot m$. The metric is used primarily for non-impulsive source types, such as vessels.

ESL is used to describe a transient sound source and is defined as the SEL at a distance of 1 m from the source with a reference value of $1\ \mu Pa^2\ m^2\ s$. This is the standard metric used to describe the source level of impulsive noise sources.

3.5. Frequency weighting functions

In underwater noise assessments, frequency weighting is often used to more accurately reflect the underwater noise impact on specific marine mammals.

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 7 (NOAA, 2018).

$$W(f) = C + 10 * \log_{10}\left(\frac{\left(\frac{f}{f_1}\right)^{2*a}}{\left[1+\left(\frac{f}{f_1}\right)^2\right]^a * \left[1+\left(\frac{f}{f_2}\right)^2\right]^b}\right)\ [dB] \qquad \text{Equation 7}$$

Where:

- $\mathbf{a}$ is describing how much the weighting function amplitude is decreasing for the lower frequencies.
- $\mathbf{b}$ 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]
- $\mathbf{C}$ is the function gain [dB].

For an illustration of the parameters see Figure 3.1.

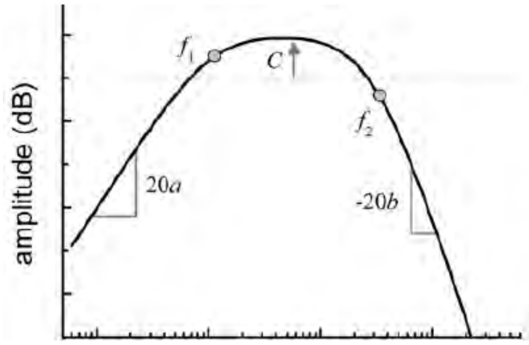

Figure 3.1: Illustration of the 5 parameters in the weighting function (NOAA, 2018).

Marine mammals are divided into four hearing groups, 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 Carnivores in Water (**PCW**) (NOAA, 2018; Southall, et al., 2019). The parameters in Equation *7* are defined for the hearing groups and the values are presented in Table 3.1.

Table 3.1: Parameters for the weighting function for the relevant hearing groups (NOAA, 2018).

Hearing Group	a	b	f_1 [kHz]	f_2 [kHz]	C [dB]
Low frequency (LF) Cetaceans	1.0	2	0.2	19	0.13
High frequency (HF) Cetaceans	1.6	2	8.8	110	1.20
Very high frequency (VHF) Cetaceans	1.8	2	12	140	1.36
Phocid Carnivores in Water (PCW)	1.0	2	1.9	30	0.75

The weighting function amplitude for the four hearing groups is achieved by inserting the values from Table 3.1 into Equation 7. The resulting spectra for the four hearing groups are shown in Figure 3.2.

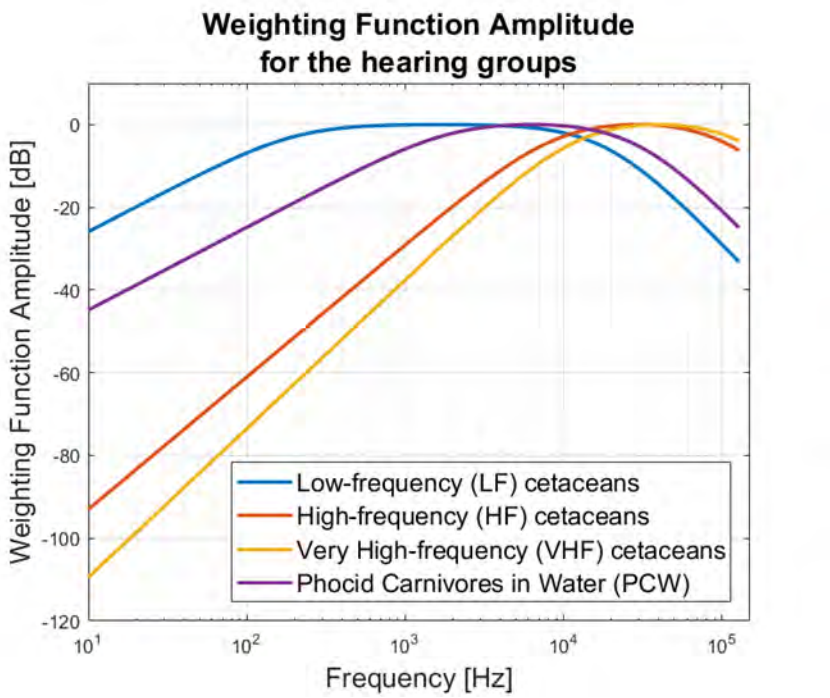

Figure 3.2: The weighting functions for the different hearing groups.

For this project, relevant species include; minke whales (classified as a Low frequency Cetaceans (LF)), white-beaked dolphin (classified as a high frequency Cetaceans (HF)), seal (classified as a Phocid Carnivores in Water (PCW)), and harbour porpoise (classified as a Very High Frequency Cetacean (VHF))]. Frequency weighting functions are not used for fish.

4. Underwater Noise Threshold Criteria

In Denmark, underwater noise from geophysical survey activities are handled by the authorities on a project-by-project basis. In order to provide a prognosis of impact, absent official threshold criteria, best available scientific knowledge from (NOAA, 2018), (Tougaard, 2021), (Energistyrelsen, 2023) is instead used in this project.

Two sets of threshold criteria are typically considered in evaluating the impact of underwater noise, based on the impulsiveness of the noise source. Following the definition of impulsive vs. non-impulsive noise sources in (NOAA, 2018), the terms are considered as follows:

- Impulsive: Sounds that are typically transient, brief (duration < 1 s), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay.
- Non-impulsive: Sounds that are broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically do not have a high peak sound pressure with rapid rise nor decay time.

For geophysical survey activities, it is not always clear if a source behaviour is impulsive or non-impulsive. While equipment types, such as airguns and explosives are unquestionably impulsive in nature, arguments can be made in both directions for other equipment types.

The impulsiveness of individual activities is reflected upon in the evaluation of each activity. For cumulative assessment, when all survey equipment is active simultaneously, it is considered likely that non-impulsive threshold criteria are more suitable than impulsive threshold criteria, which may be overly conservative. If however the combined noise emission is dominated heavily by an activity which is clearly defined as impulsive, it would however stand to reason that impulsive threshold criteria might be more appropriate.

4.1. Threshold criteria for fish

Assessment of the noise impact on fish, larvae and eggs (Table 4.1) are all based on unweighted threshold levels using the metric $L_{E,cum,24h}$, defined in section 3.3. The criteria and swim speed for the different fish species are adopted from (Andersson, et al., 2016) and (Popper, et al., 2014).

Table 4.1: Threshold criteria for fish. TTS and injury criteria are unweighted (Andersson, et al., 2016), (Popper, et al., 2014).

Species	**Swim speed [m/s]**	**Threshold criteria, $L_{E,cum,24h}$ [$dB\ re.1\ \mu Pa^2 s$]**	
		TTS [dB]	**Injury [dB]**
Juvenile Cod	0.38	186	204
Adult Cod	0.90	186	204
Herring	1.04	186	204
Larvae and eggs	-	-	207

4.2. Threshold criteria for marine mammals

Based on the newest scientific literature, species specific frequency weighted $L_{E,cum,24h}$ threshold values (NOAA, 2018), (Southall, et al., 2019) for TTS and PTS are used, Table 4.2. For avoidance behaviour, $L_{p,125ms,VHF} = 103\ dB\ re.1\ \mu Pa$ (Tougaard, 2021) is used for harbour porpoise.

Table 4.2: Threshold criteria for marine mammals. PTS and TTS criteria (NOAA, 2018), behaviour criteria (Tougaard, 2021) for hearing group classifications in (Southall, et al., 2019). "xx" notation refers to species specific weighted levels.

Species	**Swim speed [m/s]**	**Threshold criteria $L_{E,cum,24h,xx}$ [$dB\ re.1\ \mu Pa^2 s$]**				**Threshold criteria $L_{p,125ms,xx}$ [$dB\ re.1\ \mu Pa$]**
		PTS		**TTS**		**Behaviour**
		Non-impulsive	impulsive	Non-impulsive	Impulsive	
Minke whales (LF)	1,5	199	183	179	168	-
White-beaked dolphin (HF)	1,5	198	185	178	170	-
Harbour porpoise (VHF)	1.5	173 dB	155 dB	153 dB	140 dB	103 dB
Seal (PCW)	1.5	201 dB	185 dB	181 dB	170 dB	-

5. Underwater noise prognosis for geophysical survey

Geophysical survey activities have the potential to cause avoidance response, TTS, and PTS in marine mammals (Madsen, et al., 2006), as well as avoidance response, TTS and injury in fish (Popper, et al., 2014) (Andersson, et al., 2016).

Proposed survey equipment is first evaluated for its potential to have adverse effects on marine mammals or fish (section 5.1). In the evaluation of the different equipment types, the following groups of equipment are considered:

A. Equipment has insignificant underwater noise emission for marine mammals and fish:
   -> no further evaluation takes place.
B. Equipment has significant underwater noise emission but sound propagation modelling is not feasible:
   -> evaluation is based on either literature or equation based calculation.
C. Equipment has significant underwater noise emission and sound propagation modelling is feasible:
   -> evaluation is based on sound propagation modelling.

For equipment in group A or B, the impact is determined directly in the evaluation. For group C equipment, sound propagation modelling is carried out, with the following components:

- A source model, characterising the noise source, and the emission of noise into the water column (section 5.2).
- An environmental model, characterising the marine environment and its acoustic properties (section 5.3).
- A sound propagation model, through which the source and environmental model is used to determine the sound propagation (section 5.3.4).

Results are reported as impact ranges for marine mammals and fish, through numerical values of impact ranges in section 5.5.

5.1. Equipment evaluation

There is no final list of survey equipment models and operational parameters available for the survey activities, however a representative list is considered for use in the prognosis, see Table 5.1, based on experience from previous surveys, and information from the client.

Table 5.1: Geophysical survey equipment models and operational parameters. Source parameters are chosen conservatively where no information was supplied by McMahon Design & Management Limited.

Type	Equipment model	Source Level, L_s [dB re 1 µPa · m]	Primary Frequency Range (kHz)	Pulse Length	Beam Width	Sound exposure source level, $L_{S,E}$ [dB re 1 µPa$^2m^2$s]	Duty cycle over a 24 hour period
Sub-bottom profiler (SBP)	Innomar Medium 100	247 dB	1-150	0.07 – 2 ms	2°	213 dB	40 Hz
Multi-beam echosounder (MBES)	SeaBat T50-R - Standard projector (TC2181)	190 - 220 dB	190-420	0.3 - 10 ms	2° @ 200 kHz 1° @ 400 kHz	170 - 200 dB	50 Hz
Side scan sonar (SSS)	Edgetech 4205	210 dB*	230/850	-	0.63° (230 kHz) 0.30° (850 kHz)	-	-
Ultrashort Baseline (USBL)	Sonardyne - HPT 3000 USBL transceiver	194 dB	20-34	20 ms	Omni	177 dB	1 Hz
USBL transponder	Sonardyne - Wideband Mini Transponder - Type 8190-3111	187 dB	19 – 34	20 ms	Omni	170 dB	1 Hz
Magnetometer	Cesium Marine Magnetometer G-882	-	-	-	-	-	-

* Source level is assumed to be equivalent to Edgetech 4200, due to absence of model specific information

5.1.1. Parametric SBP (Innomar Medium 100)

The Innomar Medium 100 creates a very detailed profile of the uppermost part of the seabed, typically the uppermost 20 m below the seabed. It emits two high frequency pulses, called the primary frequencies, with both pulses typically in the frequency range of 100 – 120 kHz. The frequency separation between the two pulses dictate the secondary frequency, created inside the water column as the difference between the two primary frequencies: $f_{sec} = f_{pri2} - f_{pri1}$ $[Hz]$.

The source level of the Innomar Medium 100 is listed as $\mathrm{SL} = 247\ \mathrm{dB\ re.1\mu Pa\ @1m}$. It is a complex sound source as the sound emission is heavily focused towards the seabed. The horizontal emission of underwater noise is therefore significantly lower than the source level would indicate, compared to the emission directly downward into the seabed.

In a sound source verification study for geophysical survey activities in the Danish North Sea (Pace, et al., 2021), acoustic measurements were carried out for the Innomar Medium 100. In the study, the sound level was recorded in the horizontal direction at distances ranging from 10s of meters to 750 m. In Figure 5.1, all measured data points in the horizontal direction are presented as the individual pulse SEL, along with a logarithmic curve

fit. The trend indicates a source level of 193 dB and a rapid decay of approximately 37 dB/decade in the horizontal direction.

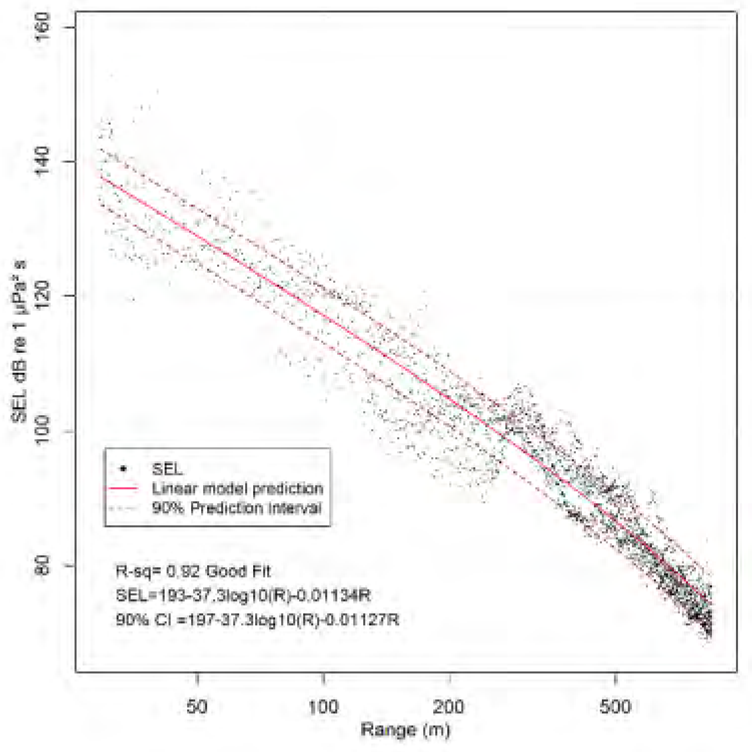

Figure 5.1: Sound Exposure Level measurements and curve fit for Innomar Medium 100, during a sound source verification study in the North Sea (Pace, et al., 2021).

The curve fit obtained from these measurements, should however be considered with a degree of caution, and should not be considered generally applicable. The environmental conditions affect the sound propagation. In order to use the measurement data in a different setting or environment, it is necessary to compensate for the environment where it was obtained, and to develop an equivalent source model that, given the same environment, performs in line with the measurements. NIRAS constructed a 3D acoustic model in dBSea, representing the actual survey environment, based on the information supplied in the report along with best available knowledge. In this model, an equivalent omnidirectional point source was designed, mimicking the measured data. The equivalent model can then be used in any other marine environment, however recognizing that the model is an approximation of the equipment behaviour, more so than an actual source model. It is therefore also recognized that this introduces an uncertainty into the sound propagation model. It is however considered the best-possible approach given the lack of an actual source model, which would require detailed source level and frequency measurements, as well as detailed frequency specific directivity measurements.

Based on the evaluation above, the Innomar Medium 100 is considered a "group C" equipment type, and will be evaluated through sound propagation modelling.

5.1.2. Ultra-Short Baseline (Sonardyne; HPT 3000 USBL transceiver and Wideband Mini Transponder - Type 8190)

The Ultra Short Baseline (USBL) system is used to determine the relative position of an underwater object, relative to a known reference point. It consists of a USBL unit mounted at a known reference point, and a transponder unit mounted on the object whose relative position is of interest. For applications such as seabed

surveys, the USBL unit would typically be mounted on the vessel. The absolute position of the vessel is registered by a GPS, thereby creating a fixed reference point for the USBL. A transponder unit is then attached to the towed equipment, such as a Side Scan Sonar (SSS), a magnetometer, ROV, etc.

It can be operated in one of two ways as outlined below, the choice between which typically relies on available equipment and project specific conditions:

A. Transponder mode (acoustic), whereby the USBL unit on the vessel emits a loud acoustic pulse acting as a "trigger". When the "trigger" pulse is registered by the transponder unit on the towed equipment, it sends out an acoustic "response" pulse. A hydrophone array on the USBL unit, records the "response" pulse and the relative distance and bearing of the transponder, relative to the vessel is registered. In this way the relative geographical position of the towed equipment is determined with very high precision.

B. Responder mode (cabled), where the "trigger" pulse is not sent acoustically through the water, but instead as an electrical impulse through a cable between the vessel and the transponder unit. On receiving the trigger pulse, the transponder unit will still emit its response pulse acoustically.

The USBL system requires a USBL unit for which the absolute geographical position must be known, and one or more transponder units mounted on equipment for which the relative position is to be determined.

From an underwater noise perspective, it is important to distinguish between the USBL unit and the transponder units. Both due to their functionality, and due to their locations. While the USBL unit is typically mounted on the vessel, the transponder units are located on the towed equipment or other objects of interest.

The Sonardyne HPT 3000 USBL transceiver USBL unit has the following source characteristics, as per supplier data sheet:

- Frequency range for the acoustic pulses: ~20 kHz – ~34 kHz,
- Source levels ranging from: $SL = 194\ dB\ re.1\ \mu Pa$.

The frequency and source level used for any given project, depends on the environmental and project specific conditions, however standard operating frequency of 25 kHz is assumed.

It is worth noting that these systems only emit acoustic pulses in the acoustic "Transponder mode". If operated in "Responder mode", no sound is emitted, and the unit is therefore silent.

The Sonardyne - Wideband Mini Transponder - Type 8190-3111 transponder unit has the following source characteristics, as per supplier data sheet:

- Frequency range for the acoustic pulses: ~19 kHz – ~34 kHz,
- Source level: $SL = 187\ dB\ re.1\ \mu Pa$

The frequency and source level used for any given project, depends on the environmental and project specific conditions, however standard operating frequency of 25 kHz is assumed.

Few real-world measurements of underwater noise emission from USBL systems are publicly available, and most of these include either a very limited measurement range, problems with the produced results and limited information about the used source levels and operation mode.

In 2021, a measurement was however carried out by JASCO (Pace, et al., 2021) for Energinet.dk during geotechnical survey activities of the Danish Energy Island North Sea project. For this measurement, a Kongsberg HiPaP 501 USBL unit (Vessel mounted) was used to determine the position of a towed side-scan sonar (SSS), with a "Kongsberg cNODE Micro" transponder unit. The results of these measurements are discussed in the following.

The following operational parameters were used (Pace, et al., 2021):

- The USBL unit (HiPaP 501) was operated at maximum source level,
$$SL = 191\ dB\ re. 1\ \mu Pa$$
- The Kongsberg cNODE Micro 30-180 transponder unit was operated at maximum source level,
$$SL = 170\ dB\ re. 1\ \mu Pa$$
- Pulse rate (trigger rate): 1.5 Hz
- Center frequency of both USBL and transponder units: 25 kHz
- Operational mode: "Transponder mode"

In Figure 5.2, a spectrogram of the measurements with the USBL system active is shown. The colors represent the sound pressure level (Warm = high levels, cold = low levels). The x-axis is the time stamp, and the y-axis is the frequency.

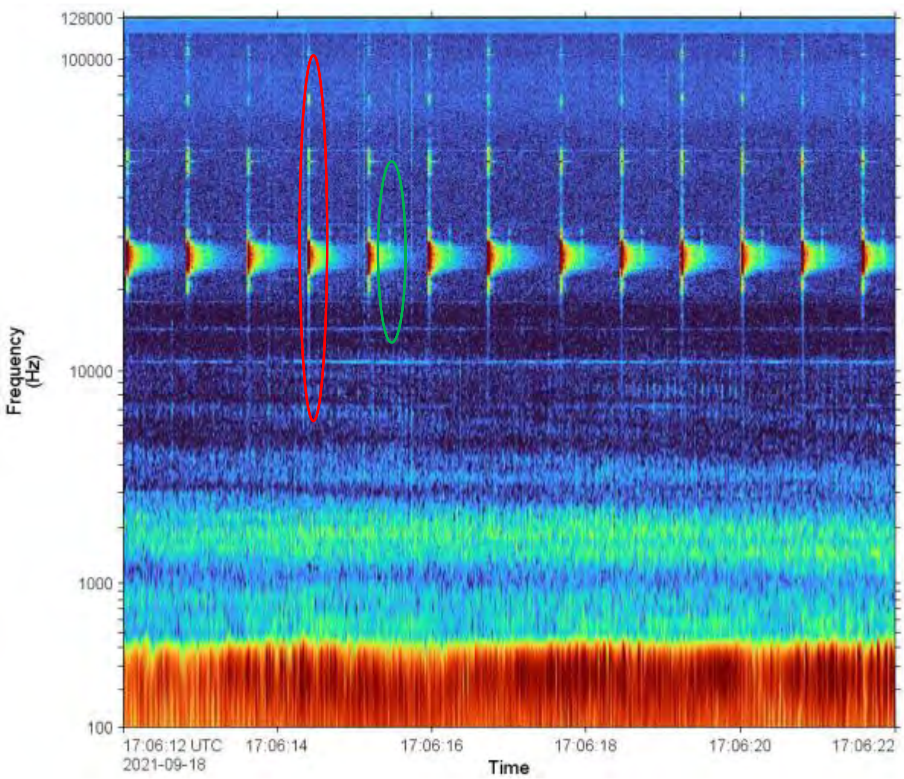

Figure 5.2: Spectrogram of measurements where SSS and USBL systems were active. Warm colours indicate high sound pressure level, and cold colours indicate low sound pressure levels as a function of frequency (Pace, et al., 2021). The red marking indicates the USBL unit pulse, while the green marking represents the transponder pulse.

From Figure 5.2, the USBL unit pulse is visible as the bright red impulses that fade into yellow to green as the sound level reduces after the pulse has stopped. The transponder pulse is less visible but can be seen as the small green lines following shortly after each of the USBL pulses.

Zooming in on a single pulse, where all the background noise is removed, is shown in Figure 5.3. Here the USBL unit pulse is clearly visible in the left half of the figure, and the transponder pulse is visible in the right-hand side where the sound level suddenly increases.

Figure 5.3: Raw data snap shot of recorded pulse at 17:06:17, where the USBL unit pulse is seen on the left hand side, and the transponder response pulse is seen on the right hand side.

As seen from Figure 5.3, the USBL unit pulse is significantly stronger than the transponder pulse.

Due to the significant difference in magnitude and short time delay between the pulses (~100 ms), only received levels for the USBL unit were reported in (Pace, et al., 2021). Curve fits for the sound level as a function of distance between source and receiver were also shown, see Figure 5.4.

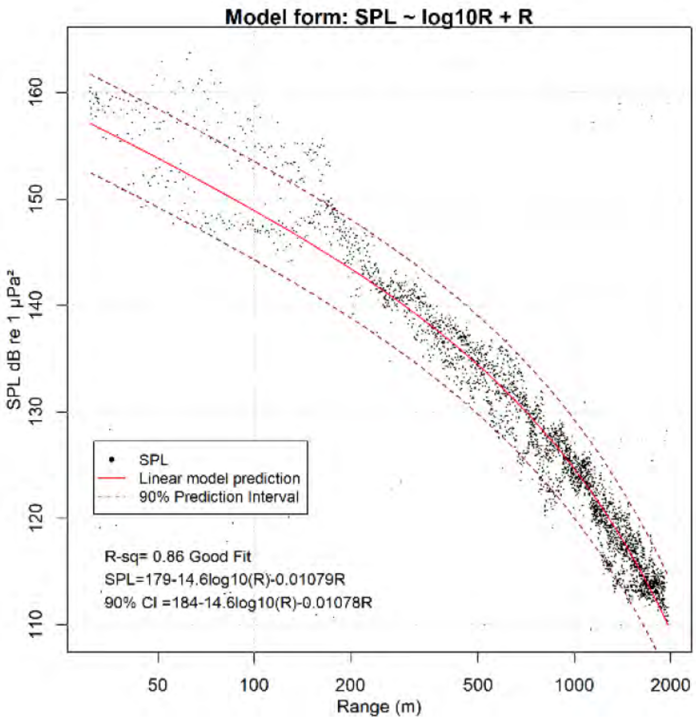

Figure 5.4: $SPL_{rms,125ms}$ as a function of measurement distance to USBL system, (Pace, et al., 2021).

From Figure 5.4, the source level for the USBL unit was back calculated to be $SL_{rms,125ms} = 179\ dB\ re.1\ \mu Pa^2$. As previously mentioned, measured source level for the transponder was not made available. It should be noted that while the reported source level of 179 dB does not match the reported 190 dB source level set for the USBL unit, this is due to the signal duration used in the representation. Compensating for the pulse duration (20 ms)

vs. the reported levels (125 ms) gives a difference of ~8 dB. So the comparable curve fitted source level would be $SL = 187\ dB\ re. 1\ \mu Pa$ (best fit) and $SL = 192\ dB\ re. 1\ \mu Pa$ (90^{th} percentile), thus matching the reported source level of $SL = 191\ dB\ re. 1\ \mu Pa$.

The measurements were carried out in the North Sea, and can not be directly used in other waters. The equipment type is classified as "Group C", and will be evaluated through detailed sound propagation modelling.

For the sake of caution, USBL and transponder units included in this prognosis are both considered omnidirectional.

5.1.3. Multi-beam Echosounder (SeaBat T50-R)

The SeaBat T50-R MBES is a hydroacoustic device used for mapping the seafloor and collecting bathymetric data in marine environments. It employs the principles of sonar to measure the depth of the seabed and generate high-resolution bathymetric maps.

The transducer array is the primary component of the MBES. It consists of multiple individual transducers arranged in a fan-shaped or circular array. Each transducer emits a narrow beam of sound pulses in a downward direction and receives the echo reflected from the seafloor.

The frequencies emitted by the MBES are at least 200 kHz, which is outside the hearing ability of any marine mammals or fish. Coupled with the strong downward directivity, this equipment type is unlikely to have any negative auditory effect on marine mammals or fish. It is therefore considered a "Group A" equipment type, and is not considered further in this prognosis.

5.1.4. Side scan sonar (Edgetech 4205)

The Edgetech 4205 SSS is an underwater imaging system used for high-resolution imaging and mapping of the seafloor. Unlike multibeam echosounders (MBES) that primarily measure bathymetry, SSS are designed to provide detailed visual representations of the seafloor surface and its features.

The transducer array in a side scan sonar is responsible for transmitting and receiving acoustic signals. It typically consists of one or more transducers arranged in a line or an array configuration. Each transducer emits a narrow beam of sound waves perpendicular to the seafloor, covering a wide swath on either side of the sonar system.

The frequencies emitted by the SSS are typically at least 300 kHz, which is outside the hearing ability of any marine mammals or fish. While the Edgetech 4205 also comes with the option of a 100 kHz frequency, it was agreed with McMahon Design & Management Limited not to use this setting, as it coincides with the frequency range where harbour porpoise are most sensitive to sound. Coupled with the strong downward directivity, and restricting the use of frequencies below 200 kHz, this equipment type is unlikely to have any negative auditory effect on marine mammals or fish. It is therefore considered a "Group A" equipment type, and is not considered further in this prognosis.

5.1.5. Magnetometer

Marine magnetometers used in geophysical surveys for detecting buried objects such as UXOs are designed to identify variations in the magnetic field caused by the presence of ferromagnetic materials. These materials, including metallic objects like munitions, generate localized disturbances in the Earth's magnetic field, which can be detected and analyzed by the magnetometer system.

The magnetometer sensor is typically mounted on a specialized instrument platform, such as a towfish or a remotely operated vehicle (ROV). The platform is then towed at a constant altitude above the seafloor, typically a few meters, ensuring consistent proximity to the target area.

The magnetometer does not rely on acoustic output to function, and it therefore has no underwater noise emission. It is classified as a "Group A" equipment type, and is not considered further in this prognosis.

5.1.6. Noise from survey vessels

In addition to the noise from the individual activities, the survey vessel is also likely to be a source of underwater noise during the survey execution. In Pace et al. (2021), the survey vessel underwater noise emission was measured, and reporting in 1/3 octave levels at 5 different distances from the vessel, with and without marine mammal frequency weighting applied, see Figure 5.5.

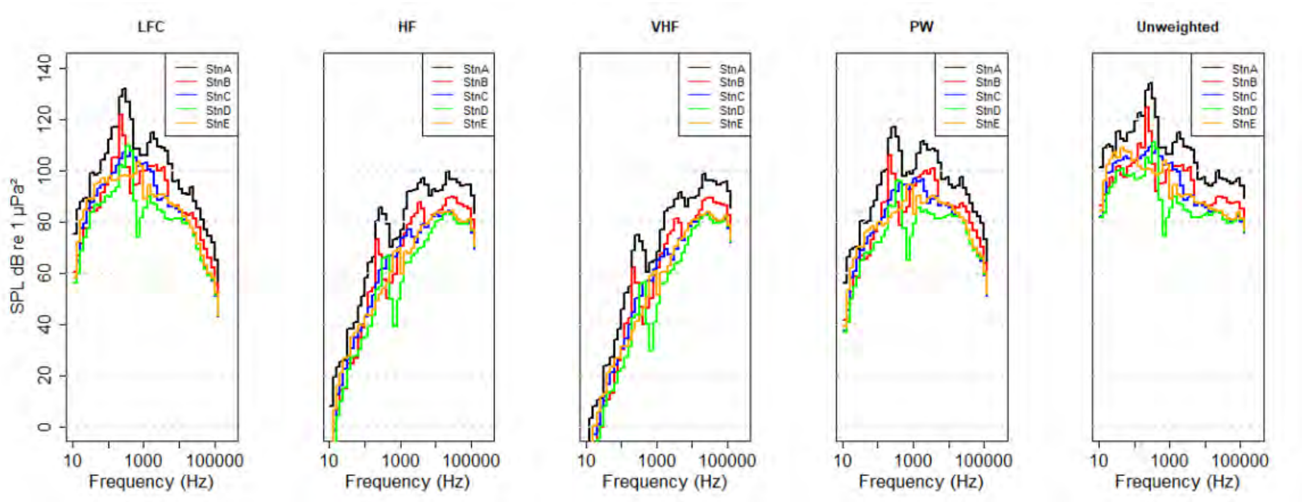

Figure 5.5: Weighted and unweighted 1/3 octave sound pressure level (SPL) measured at 5 different hydrophone distances (stnA is directly underneath the vessel path, stnB at 150 m distance, stnC at 540 m, stnD at 780 m and stnE at 2040 m). (Pace, et al., 2021).

From Figure 5.5, it is evident that noise levels are primarily low frequent, with most of the acoustic energy located below a few hundred Hz. For harbour porpoise (VHF-weighting), the measurements at station B (150 m distance) show 1/3 octave band levels below 90 dB in all bands, with broadband level below the threshold criteria for behaviour reaction, $\mathrm{L_{p,125ms,VHF}} = 103\ \mathrm{dB\ re.\,1\ \mu Pa}$.

Vessel noise is a continuous noise type, and is therefore evaluated by comparison with the non-impulsive TTS and PTS criteria. In Table 5.2, distances to PTS and TTS for each of the relevant species are provided, based on the measurement data in Figure 5.5, and assuming a 24 hour survey duration.

Table 5.2: PTS and TTS impact ranges from geophysical survey vessel noise.

Species	Swim speed [m/s]	Impact range [m]		
		PTS	TTS	Behaviour
		Non-impulsive	Non-impulsive	
Minke whales (LF)	1,5	< 10 m	< 100 m	-
White-beaked dolphin (HF)	1,5	< 10 m	< 100 m	-
Harbour porpoise (VHF)	1.5	< 10 m	< 100 m	< 150 m
Seal (PCW)	1.5	< 10 m	< 100 m	-

From this, it is evaluated that the survey vessel is categorized as "Group A", and is not evaluated any further.

5.1.7. Summary of equipment evaluation

All proposed equipment types were evaluated for their potential to emit harmful levels of underwater noise, and three groups were defined:

- Group A equipment, where underwater noise emission is evaluated to be insignificant, includes the MBES, SSS and magnetometer equipment types.
- Group B equipment, where underwater noise emission may occur at harmful levels, but where sound propagation modelling is not possible, did not apply to any proposed equipment types.
- Group C equipment, where significant underwater noise emission is likely, and sound propagation modelling should take place, included the parametric SBP and USBL.

5.2. Source model

5.2.1. Parametric SBP (Innomar Medium 100) implementation

The Innomar Medium 100 source model is based on the approach described in section 5.1.1, using an omnidirectional equivalent point source. Source characteristics are shown in Figure 5.6, as both unweighted (blue), LF (purple), HF (orange), VHF (green) and PCW (red). It is reiterated that this is an equivalent point source model from a horizontal propagation perspective, and not an accurate representation of the sound source. It is therefore only to be used as a conservative model for calculating horizontal impact ranges for marine mammals and fish.

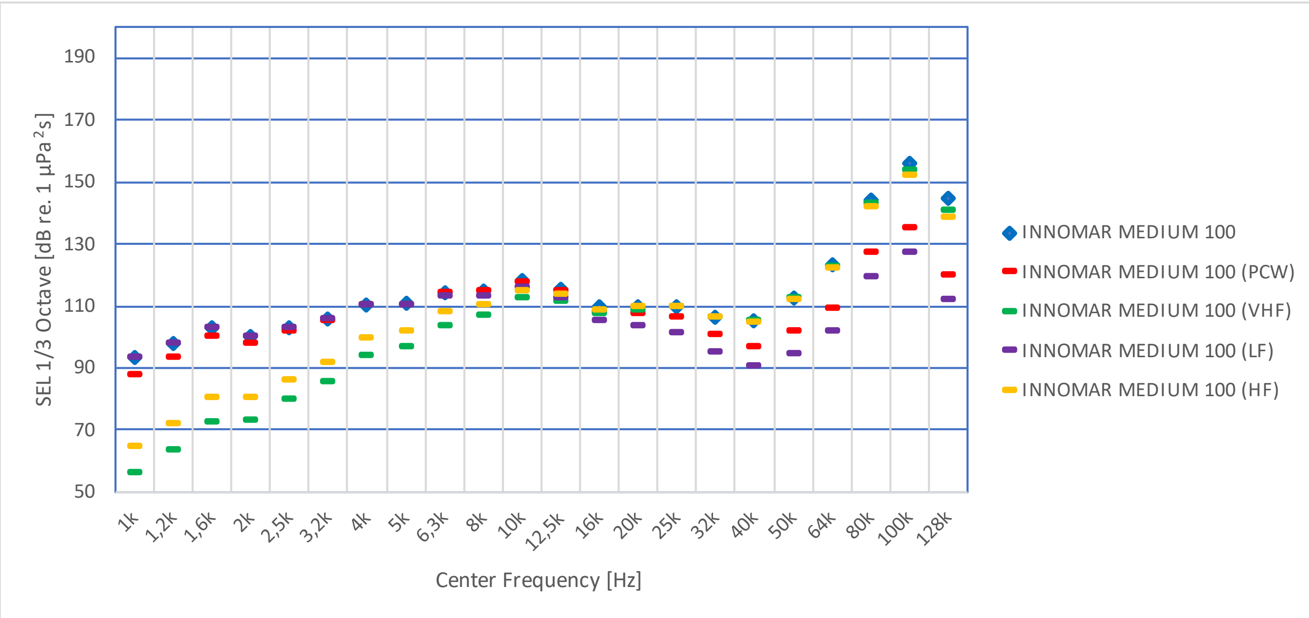

Figure 5.6: Equivalent omnidirectional point source model frequency spectrum for the Innomar Medium 100 parametric SBP. The source model is calibrated to fit measurement results from (Pace, et al., 2021).

The Innomar Medium 100 is mounted on the vessel, and is assumed operated at a 40 Hz pulse rate, while the vessel sails at 4 knots. The activity is assumed ongoing for 24 hours continuously, and it is assumed that it is not

turned off during line turns. The Innomar Medium 100 is considered a non-impulsive source type, and impact range calculation is therefore based on the non-impulsive threshold criteria.

5.2.2. USBL (Sonardyne; HPT 3000 USBL and WMT - Type 8190) implementation

The Sonardyne; HPT 3000 USBL transceiver and Wideband Mini Transponder - Type 8190 source models are based on the approach described in section 5.1.2, using an omnidirectional single-frequency point source with all energy located in the 25 kHz, 1/3 octave band. Source levels used are:

- USBL unit (Sonardyne; HPT 3000 USBL transceiver):
  - $SL = 194\, dB\, re. 1\, \mu Pa$
- Transponder unit (Sonardyne; Wideband Mini Transponder - Type 8190):
  - $SL = 187\, dB\, re. 1\, \mu Pa$

The USBL unit is mounted on the vessel, while the transponder unit is mounted on the tow, and both are assumed operated at a 1 Hz pulse rate, while the vessel speed is 4 knots. The activity is assumed ongoing for 24 hours continuously, and it is assumed that it is not turned off during line turns. The USBL is treated as a non-impulsive source type, due to its narrowband frequency content, pulsed characteristic and with no rapid rise nor decay.

5.2.3. Source positions

The project is in early stages of development, and final survey activities have not yet been determined. It was therefore agreed with McMahon Design & Management Limited to select a number of representative positions throughout the investigation area, so different sound propagation scenarios are covered. Areas where sound propagation most likely results in the longest impact ranges are identified, taking into account nearby marine mammal and/or fish protection areas if relevant. The source positions are listed in Table 5.3, along with coordinates, and distances to relevant areas of interest. The positions are also shown in Figure 5.7.

Table 5.3: Source positions used for sound propagation modelling of underwater noise during geotechnical and geophysical surveys.

Position ID	Easting	Northing	EPSG	Nearby areas of interest
1	456569	6139328	25832	Nat2000 area "Sydlige Nordsø", 22 km distance Nat2000 area "Vadehavet", overlapping City of Esbjerg, 12 km distance
2	405569	6131390	25832	Nat2000 area "Sydlige Nordsø", overlapping
3	391896	6181635	25832	Nat2000 area "Sydlige Nordsø", 23 km distance
4	645139	6180969	25831	-
5	567863	6200876	25831	Nat2000 area "Doggerbank", 16 km distance

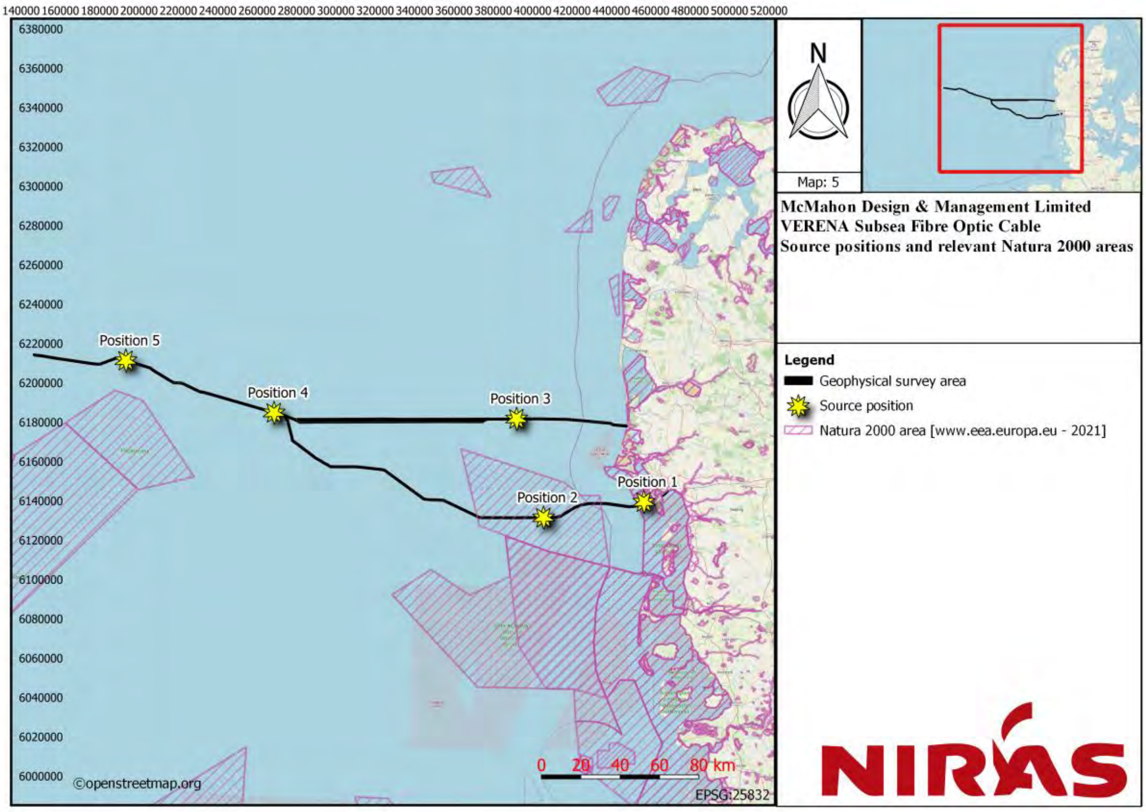

Figure 5.7: Source positions chosen for sound propagation modelling as well as nearby Natura 2000 areas.

5.3. Environmental model

Sound travels faster and farther in water than in air because water is denser and more efficient at transmitting sound waves. However, the aquatic environment is complex and heterogeneous, and sound propagation is influenced by a number of environmental parameters:

- Bathymetry,
- seabed sediments,
- temperature, salinity and sound speed,
- sea surface roughness, and
- volume attenuation.

These factors can cause sound to refract, reflect, scatter, and attenuate as the sound waves propagate through water, making it challenging to predict its behavior. These factors, and their implementation for sound propagation modelling, are described in the following sections.

5.3.1. Bathymetry

The shape and composition of the seafloor plays a critical role in the propagation of sound waves through the water. The seafloor can act as a barrier or a reflector for sound waves, depending on its composition and shape. A smooth, flat seafloor can reflect sound waves back towards the surface, whereas a rough, irregular seafloor can scatter sound waves in different directions, causing them to lose intensity and become weaker over distance.

Additionally, underwater ridges, canyons, and other geological features can act as waveguides, trapping and focusing sound waves in specific depths or regions.

Overall, bathymetry affects underwater sound propagation by influencing the speed, direction, and intensity of sound waves as they travel through the water. A detailed understanding of the bathymetry is critical for predicting and modelling the nature of underwater sound propagation in a real world scenario.

If project specific high resolution bathymetry is available, this is typically preferred over publicly available databases, which tend to be of lower resolution. Project specific bathymetry however seldomly extend beyond the project boundary. To calculate impact ranges for marine mammals and fish, it is necessary for the sound propagation model to extend 10 – 20 km beyond the project boundary. Project specific bathymetry can therefore seldomly be used alone.

For projects where no high resolution bathymetry is available, or where it is limited to the project boundary, publicly available databases, such as (EMODnet, 2021), can be used. A map of the bathymetry for Europe is shown in Figure 5.8, where darker colours indicate deeper areas, and lighter colours indicate more shallow water (EMODnet, 2021).

Figure 5.8: Bathymetry map over European waters from EMODnet, where light blue indicates shallow waters and dark blue indicates deeper waters (EMODnet, 2021).

The bathymetry for the project area and surroundings consists of information from the sources listed in Table 5.4. A visualisation of the bathymetry model for the project area and surroundings is shown in Figure 5.9.

Table 5.4: Bathymetry model data sources.

Data source	Reference
Bathymetry	(EMODnet, 2021)

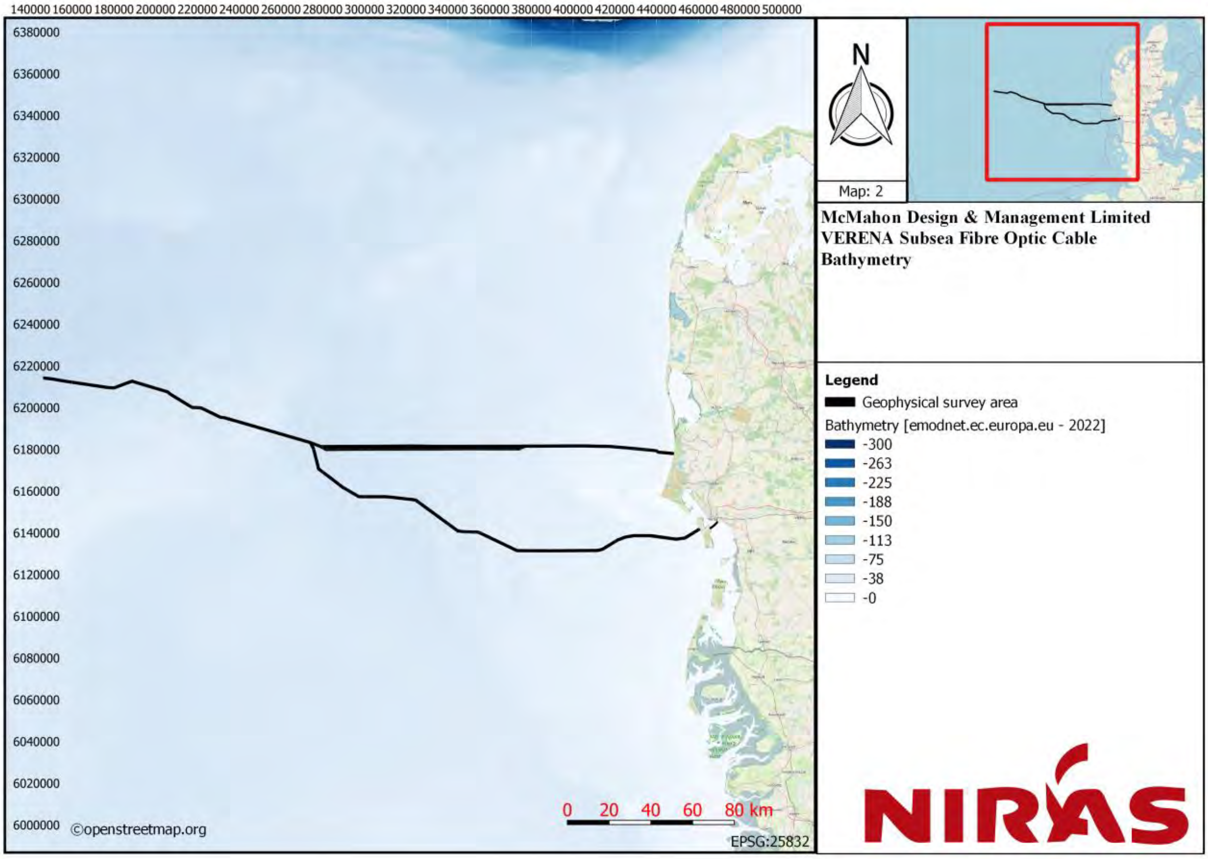

Figure 5.9: Bathymetry for the project area and surroundings, sources as listed in Table 5.4.

5.3.2. Seabed sediment

Seabed sediment layers can have a significant effect on the propagation of sound waves through the water. The acoustic properties of sediment layers are influenced by several factors, including the composition, density, porosity, and grain size distribution of the sediments. Generally, sediments with larger grain sizes and lower porosity have higher acoustic velocities and can transmit sound waves more efficiently than finer-grained and more porous sediments.

The properties of sediment layers can also affect the reflection, refraction, and attenuation of sound waves. For example, a layer of fine-grained, soft sediment can absorb and scatter sound waves, causing them to lose intensity and become weaker over distance. Conversely, a layer of hard, compacted sediment can reflect sound waves, resulting in increased sound intensity in certain areas.

The thickness of sediment layers can also play a role in underwater sound propagation. Thicker sediment layers can absorb and scatter sound waves more effectively, while shallower sediment layers can reflect and refract sound waves more strongly.

The thickness and acoustic properties of each seabed layer, from seabed to bedrock, is generally obtained through site specific literature research in combination with available site-specific survey findings.

Where site specific surveys do not reveal the top layer conditions, or where the site specific information is limited to the project boundary, publicly available databases, such as the seabed substrate map from (EMODnet, 2021) (Figure 5.10) is generally used.

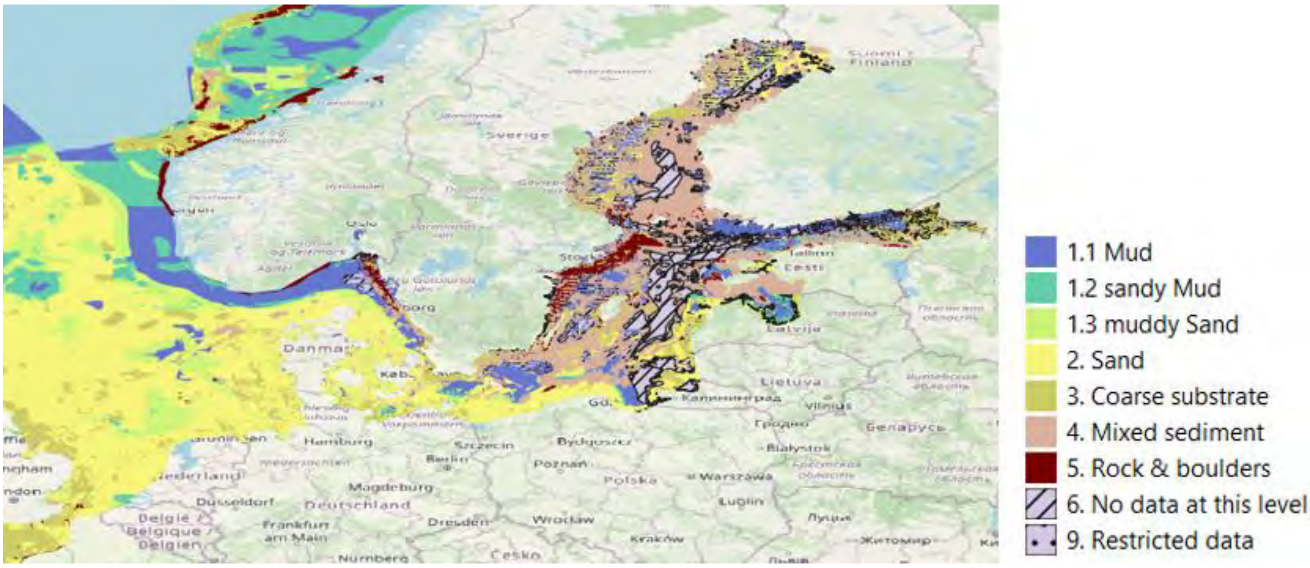

Figure 5.10: A section of the seabed substrate map, (Folk 7) (EMODnet, 2021).

From the available sediment data sources, a discretized and simplified version is created, whereby the layer thicknesses and sediment types are defined in a number of points. A high number of sediment points is necessary, when the variation in sediment types and thicknesses within the project area and surroundings increases.

For each point in the model, the sediment layer types are translated into geoacoustic parameters, in accordance with Table 5.5, utilizing information from (Jensen, et al., 2011; Hamilton, 1980).

Table 5.5: 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

The sediment model is constructed using available sources, see Table 5.6, and resulted in a 89 point sediment model, with topsoil types shown in Figure 5.11. Primary seabed surface layers in position 1, 2 and 3 are sand and coarse substrate. For position 4 and 5 the primary seabed surface layers are muddy sand. Layer thickness of the upper sediment is not well defined in the available sources and a conservative thickness of 10 m is used

throughout. Acoustic parameters for each layer are shown in Table 5.5. As it is not feasible to create an infinitely detailed sediment model, conservative layer thickness, and sediment types are used to provide a worst-case sediment model. The data source used to inform the sediment model implementation, is shown in Figure 5.12.

Table 5.6: Sediment model data sources.

Data source	Reference
Seabed substrate map	(EMODnet, 2021)
Sediment profile map	(COWI, 2020)
Acoustic parameter model for sediment types	Table 5.5

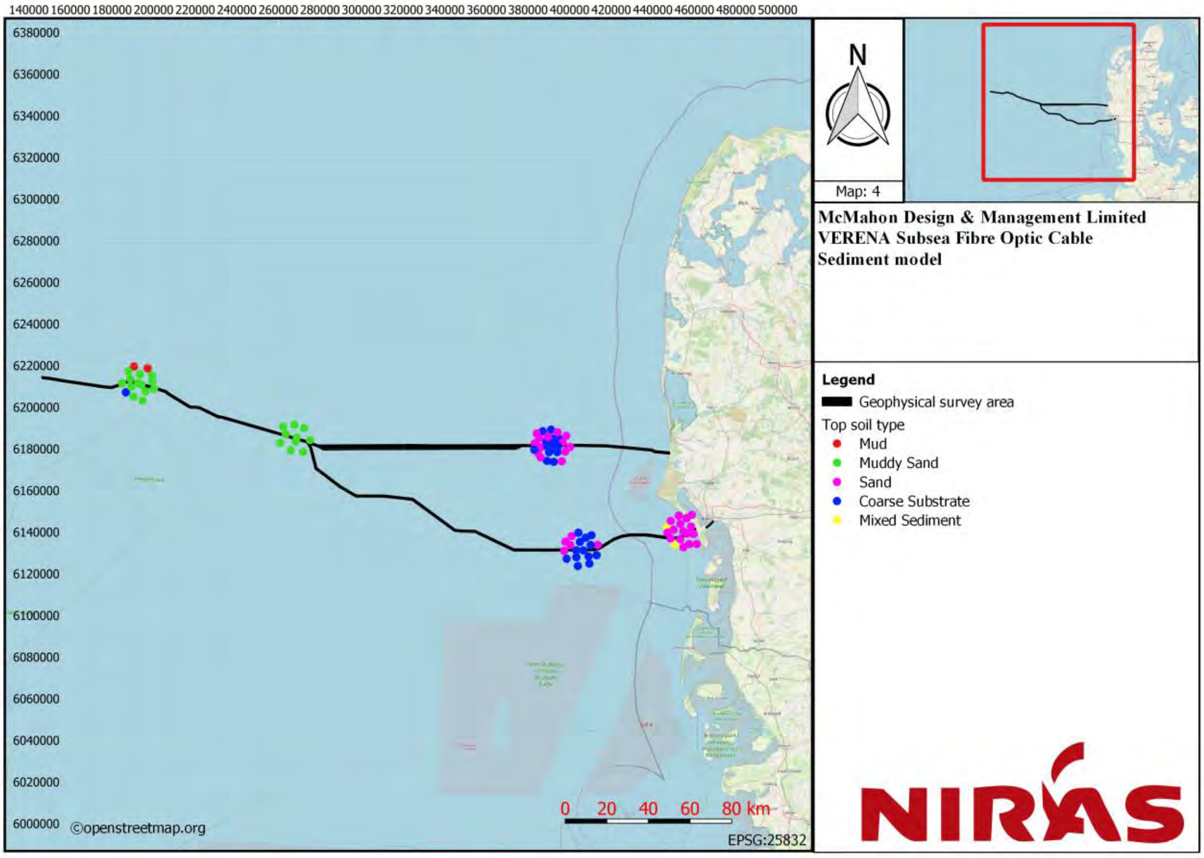

Figure 5.11: Sediment model points and topsoil layer type.

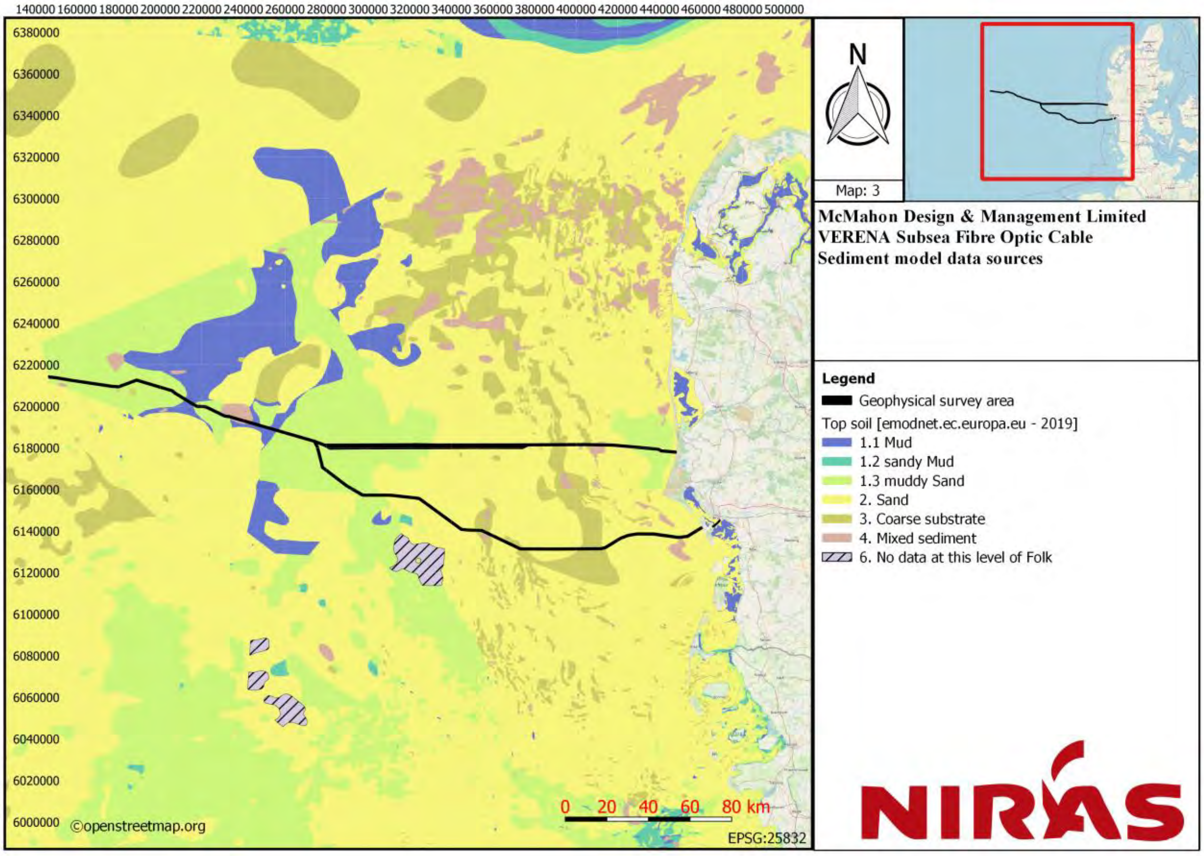

Figure 5.12: Sediment model data source, as listed in Table 5.6.

5.3.3. Temperature, salinity and sound speed profile

The combined effects of temperature and salinity on seawater density can create complex sound speed profiles in the sea, particularly in areas with strong vertical stratification or gradients in temperature and salinity. These variations in sound speed can have important implications for underwater sound propagation.

As stated by Snell's law, Equation 8, sound waves bend toward regions of low sound speed (Jensen, et al., 2011). The implications for sound in sea water are, that sound, entering a low velocity layer in the water column, can get trapped there. This results in sound travelling far with very low propagation loss.

$$\frac{\cos(\theta)}{c} = \text{constant} \qquad \text{Equation 8}$$

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

There are three main types of sound speed profiles for seawater:

1. **Uniform sound speed profile**: In a uniform sound speed profile, the speed of sound is the same at all depths. This can occur in regions of the sea where temperature and salinity are relatively constant with depth.
2. **Upward refracting sound speed profile**: When the sound speed increases with depth, it is called an upward refracting sound speed profile. Sound waves in this type of environment can be refracted up-ward and away from the seabed, potentially travelling over longer distances with lower absorption losses from seabed interaction.

3. **Downward refracting sound speed profile**: When the sound speed decreases with depth, it is called a downward refracting sound speed profile. Sound waves will, in this environment, be refracted downward to a higher degree and toward the seabed, potentially causing them to lose energy and travel shorter distances.

Special cases, where a low speed region is present at a depth in between sea surface and seabed can create channels where specific ranges of frequencies can get trapped and propagate without ever reaching neither seabed nor sea surface. The potential transmission range in such a channel is significantly longer than in any of the typical three sound speed profile types listed above.

While there are seasonal variations in underwater sound propagation in the Danish part of the North Sea, the overall sound speed profile is relatively stable compared to other regions. This is because the North Sea is a well-mixed medium, meaning that the water column is thoroughly mixed by currents and wind-driven turbulence. As a result, the water properties, including temperature and salinity, tend to be fairly uniform throughout the water column. This makes acoustic modelling and prediction more straightforward compared to other regions with more variable water properties.

The sound speed profiles for a certain project area are calculated using Coppens equation (Coppens, 1981), based on available temperature and salinity data for the area. Data sources for the temperature and salinity profiles can be either based on empirical data, or predictive models. It is important to note, that while empirical data and predictive models can provide a historically likely scenario, they can not accurately predict the weather conditions when the project activities will occur.

For each of the sediment model points, described in section 5.3.2, the nearest available sound speed profile, as well as average temperature and salinity are extracted for the desired months. Temperature and salinity profiles for this project, were extracted from the data sources in Table 5.7, and through the NIRAS software tool "TRANSMIT", turned into sound speed profiles.

Table 5.7: Temperature, salinity and sound speed data sources.

Data source	Reference
Temperature	0.083° grid, monthly averages based on physical forecast (Copernicus, 2023)
Salinity	0.083° grid, monthly averages based on physical forecast (Copernicus, 2023)
Sound speed profile	Coppens equation (Coppens, 1981) implemented in NIRAS "TRANSMIT"

The temperature and salinity change both temporally (over the year), as well as spatially. Both the timeframe and position of the activities included in sound propagation modelling must therefore be taken into account, when evaluating which sound speed profiles should be used for any given model.

A realistic worst case approach was agreed with McMahon Design & Management Limited. The temperature, salinity and sound speed profiles for the area are therefore examined for all 12 months, to determine which month has conditions most likely to result in the furthest sound propagation.

Temperature, salinity and sound speed profiles were extracted for a radius of 10 km around each source position mentioned in section 5.2.3. From these profiles, it was assessed, that profiles with the potential for the strongest sound propagation, are those of February. Graphical representations of all profiles for position 1 are given in Figure 5.13 (temperature), Figure 5.14 (salinity), and in Figure 5.15 (sound speed). Profiles for the

remaining positions are attached in Appendix 1. The figures each show the nearest 9 data points from the temperature and salinity databases, relative to the source location. These are shown in a gridded x-y format, with the centre plot representing the data point closest to the source location. Empty plots can occur where land masses are present. The coordinates for each data point is provided above the individual plots in EPSG: 4326.

To ensure a realistic worst case approach for the prognosis, sound propagation modelling implements the profiles for February.

For each sediment model position, the spatially closest data point for average temperature and salinity, as well as sound speed profiles, were assigned to the sediment model through the NIRAS software tool "TRANSMIT", which combines sediment, temperature, salinity and sound speed data, into dBSea import files.

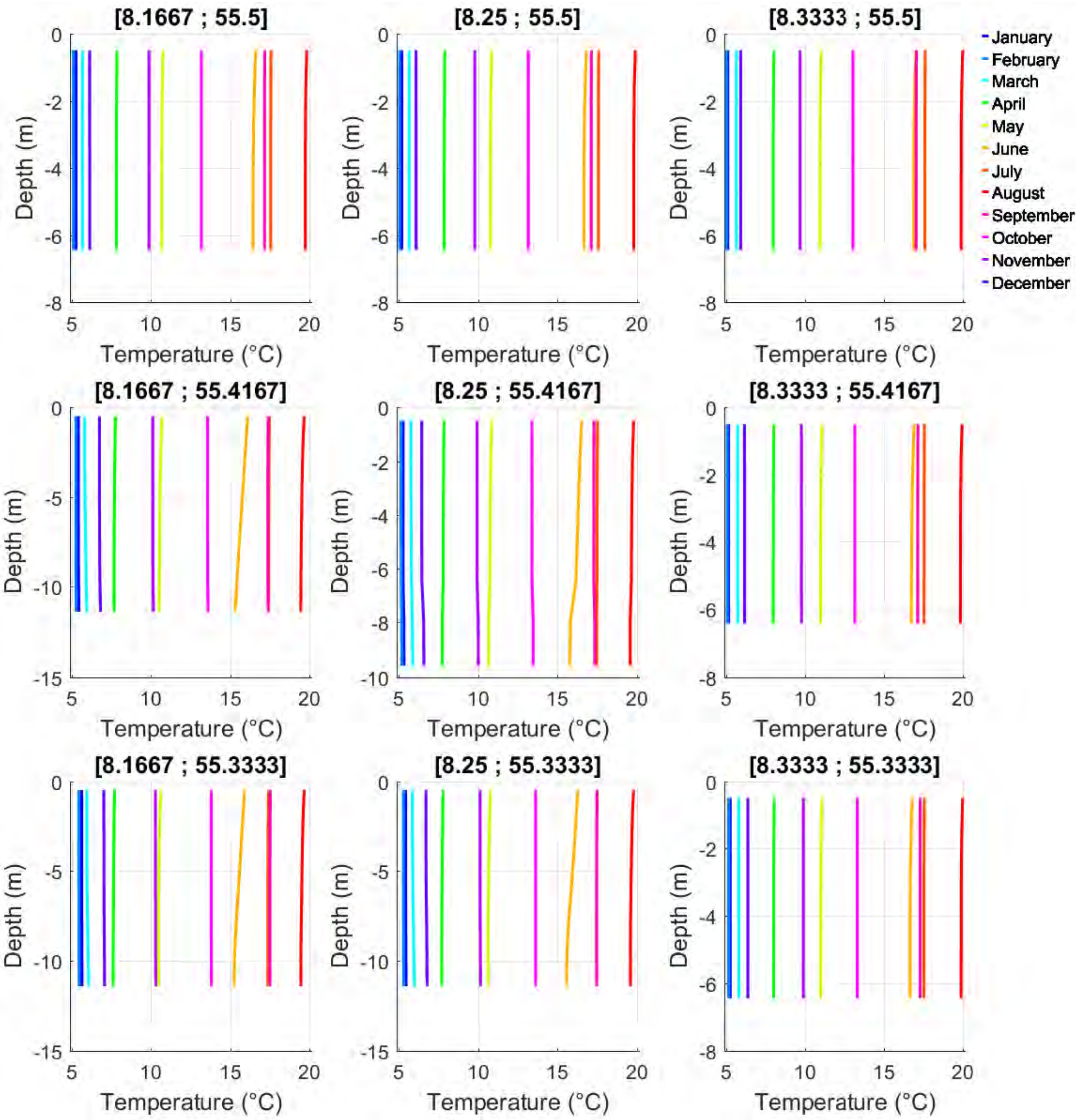

Figure 5.13: Temperature profiles for the area around source position 1 for all months. Gridded layout reflects geographical location.

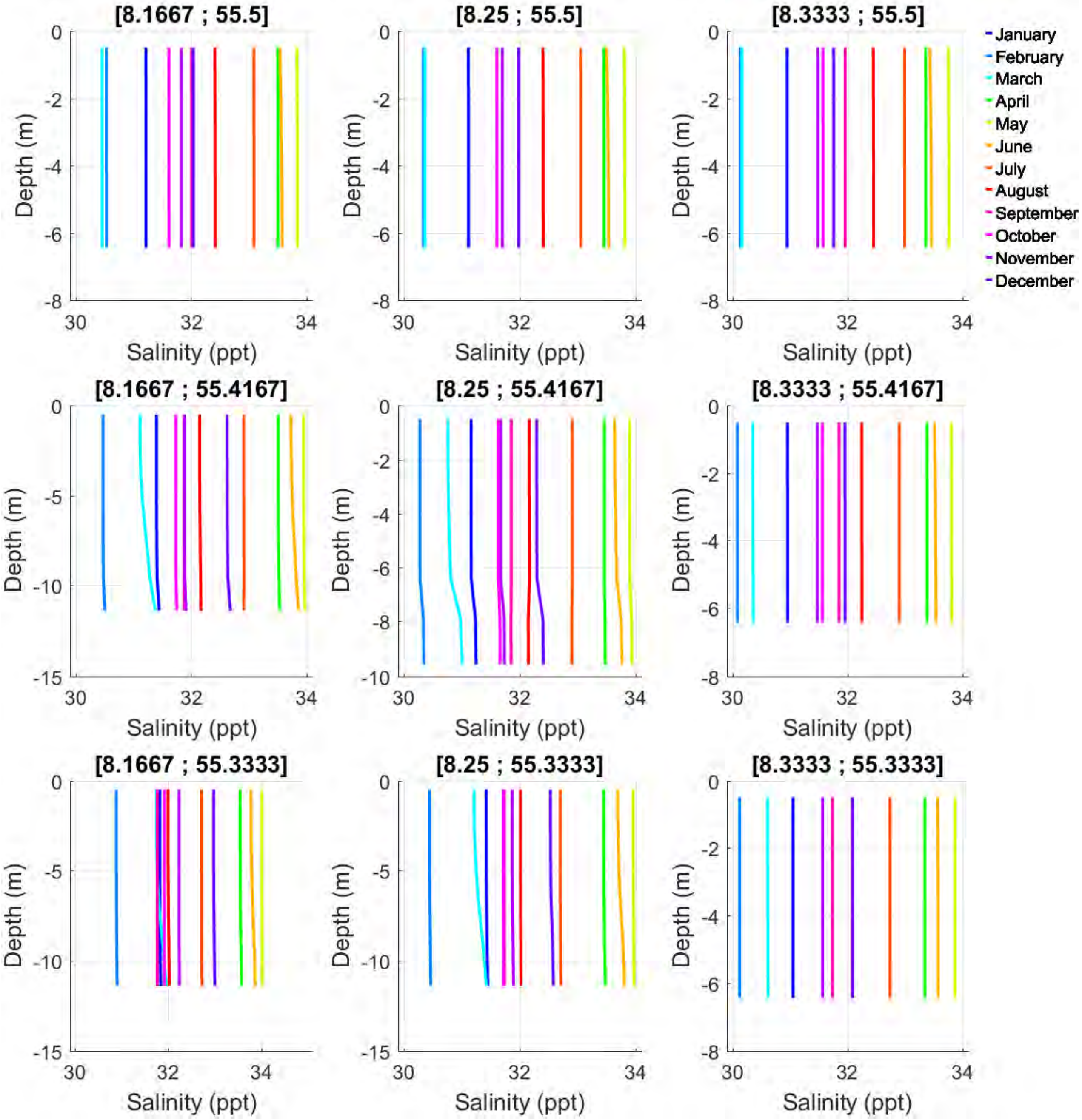

Figure 5.14: Salinity profiles for the area around source position 1 for all months. Gridded layout reflects geographical location.

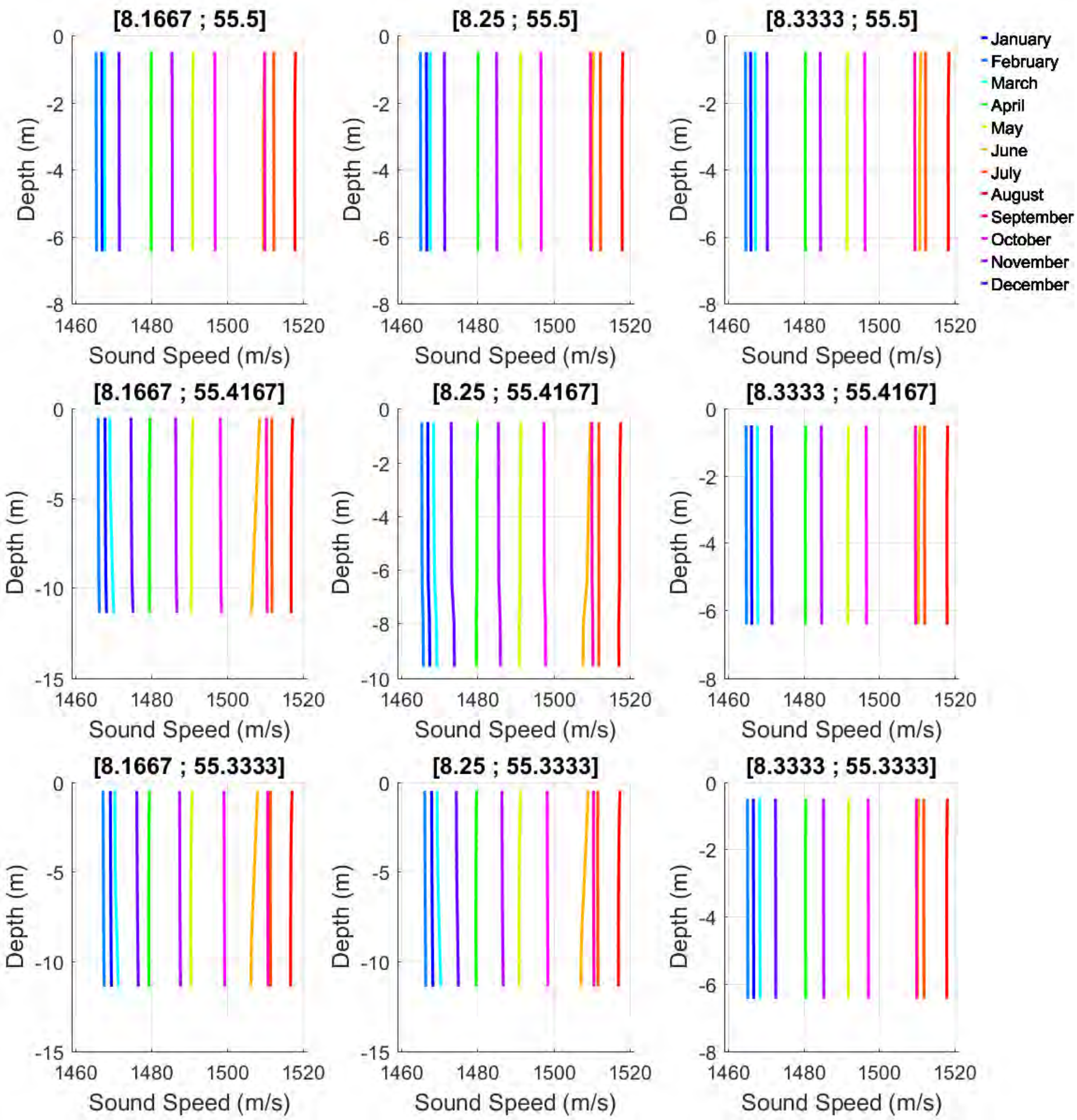

Figure 5.15: Sound speed profiles for the area around source position 1 for all months. Gridded layout reflects geographical location.

5.3.4. Sea surface roughness

Sea surface roughness, either from waves or ice cover can cause sound waves to scatter in many different directions, making it more difficult to propagate through the water. This can result in increased attenuation, backscattering and reduced range of underwater sound propagation, particularly at high frequencies.

As a precautionary approach, sound propagation modelling typically regards the sea surface as a perfect mirror (calm water), as this is also the conditions under which pile installation would be preferred. The model is therefore likely to overestimate sound propagation for any conditions where calm water is not the case.

5.3.5. Volume attenuation

Another parameter that has influence on especially the high frequency propagation loss over distance is the volume attenuation, defined as an absorption coefficient dependent on chemical conditions of the water column. This parameter has been approximated using Equation 9, from which is inferred that increasing frequency leads to increased absorption (Jensen, et al., 2011).

$$\alpha' \cong 3.3 \times 10^{-3} + \frac{0.11\mathrm{f}^2}{1+\mathrm{f}^2} + \frac{44\mathrm{f}^2}{4100+\mathrm{f}^2} + 3.0 \times 10^{-4}\mathrm{f}^2 \quad \left[\frac{\mathrm{dB}}{\mathrm{km}}\right] \qquad \text{Equation 9}$$

Where f is the frequency of the wave in kHz.

Volume attenuation is taken into account within dBSea, which is used for sound propagation modelling.

5.4. Sound Propagation Software

Numerical models can be used to simulate and predict underwater sound propagation in sea water. These models involve a computer-based simulation that uses mathematical equations to describe the sound propagation as it travels through the sea. In this regard, environmental conditions such as temperature, salinity, sediment and bathymetry must be taken into account. Different numerical models exist to treat different environmental and source specific conditions, and the choice of numerical model should always be based on the project specific environmental parameters.

NIRAS uses the software tool dBSea, which incorporates three numerical algorithms for predicting sound propagation in complex underwater environments: dBSeaRay, dBSeaPE, and dBSeaNM.

dBSeaRay is a ray-tracing algorithm that simulates the paths of individual sound rays as they travel through the sea, taking into account the effects of sea properties, such as temperature, salinity, and bathymetry, on sound propagation. This allows users to predict sound propagation in a wide range of ocean environments. Inherent limitations for this algorithm limits its use in shallow waters for very low frequencies below a few hundred Hz.

dBSeaPE is a parabolic equation algorithm that solves the parabolic wave equation to simulate sound propagation in the ocean. It is particularly useful for modelling sound propagation over long distances or in areas with complex bathymetry. It however lacks computational efficiency at higher frequencies and is primarily suited for low frequencies.

dBSeaNM uses the normal modes method to predict sound propagation in the ocean. This algorithm takes into account the effects of vertical variations in ocean properties, such as sound speed and density, on sound propagation. It is particularly useful for predicting sound propagation in regions with significant vertical mixing or internal waves, and is most suitable for low frequencies, up to several hundred Hz.

Depending on the local environment and source characteristics, a mix of two numerical models may provide the best result, whereby one algorithm handles the low frequencies and another handles the high frequencies.

Typically, dBSeaNM or dBSeaPE is used for low frequencies and dBSeaPE or dBSeaRay for high frequencies with a split frequency between the two algorithms, based on $f = \frac{8 \cdot c}{d}$ [Hz], where c is the speed of sound in water [m/s] and d is the average bathymetry depth [m]. For very high frequencies, dBSeaRay is typically preferred.

Output from dBSea is primarily numerical, where each modelled sound propagation radial (direction from source) is represented by the maximum-over-depth (MOD) sound level at each modelled range step. MOD, in this regard, is found by taking the maximum sound level for each range step over all modelled depths. It

therefore does not represent the sound level at a specific depth, but is a more conservative measure for the highest possible exposure at every range. An example of this concept is shown in Figure 5.16, showing the sound level (x-axis) in dB over depth (y-axis), for a specific distance and direction. On the left side, the MOD is located at 1 m depth below sea-surface and is 114.2 dB, while on the right side, in another direction from the source, MOD is located at 28 m depth and is 114.6 dB. The sound levels at all other depths are ignored in the result output.

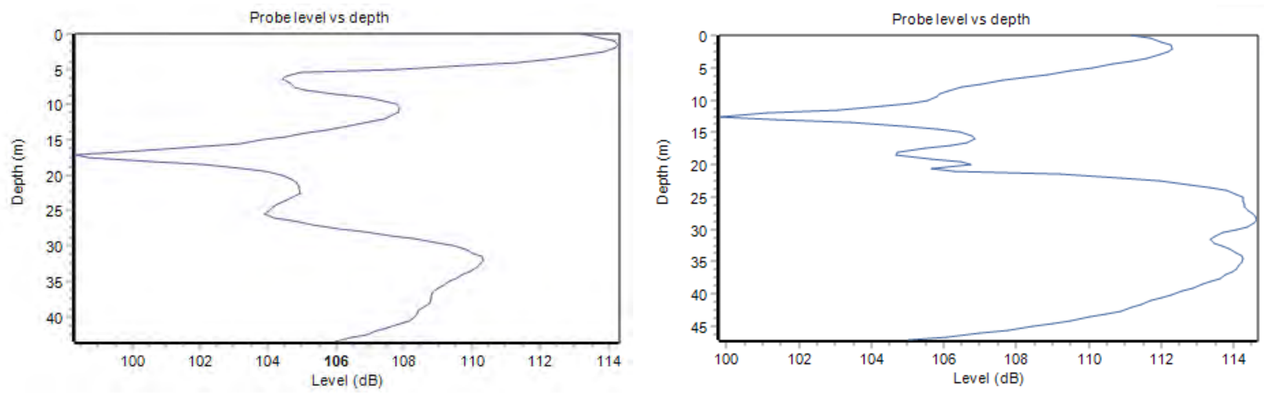

Figure 5.16: Concept of MOD, where the maximum sound level at any depth is extracted for each distance and radial interval. Example shows an MOD value of 114.2 dB (left side) at 1 m depth, and MOD value of 114.6 dB (right side) at 28 m depth.

Prognosis specific parameters for the dBSea setup is specific to the source types included, and is therefore described separately for the different source types in the prognosis.

5.4.1. Settings

The software tool dBSea was used for sound propagation modelling, with the configuration listed in Table 5.8.

Table 5.8: Sound propagation modelling tool settings for dBSea.

Parameter	Value
Software version	2.3.6
Grid (range x depth) resolution	25 m x 0.5 m
Number of radials/transects	P1: 90 (4°) P2, P3, P4, P5: 45 (8°)
Frequency solver	dBSeaRay
Frequency range	Innomar: 1 kHz – 128 kHz USBL: 25 kHz

Post-processing of the raw sound propagation results into impact ranges was done in NIRAS software tool "SILENCE", which implements Equation 6, page 16 for batch processing of different installation scenarios and threshold criteria.

5.5. Results

Sound propagation modelling was carried out in dBSea and post-processing of raw sound levels into impact ranges in NIRAS SILENCE, using the threshold criteria in chapter 4. The results are presented in the following formats:

Numerical result tables: showing the maximum range in any direction from the source to respective threshold criteria.

Distance to PTS, TTS and injury threshold criteria describe the minimum distance from the source, a marine mammal, or fish, must at least be deterred to, prior to onset of survey activities, in order to avoid the respective impact.

Distance to behavioural threshold criteria describe the range at which behavioural reactions are likely to occur when the survey operates at full intensity. During soft start, the impact ranges will be shorter.

5.5.1. Impact ranges for fish threshold criteria

For fish, all threshold criteria are based on the frequency unweighted $L_{E,cum,24h}$ [dB re. 1 μPa^{2}s]. Impact ranges are calculated for a series of different swim speeds, as discussed in section 4.1. Resulting impact ranges are provided in Table 5.9 for cod, Table 5.10 for herring and in Table 5.11 for larvae and eggs.

Table 5.9: Impact ranges for Cod.

Position	**Cod: Threshold criteria impact ranges**			
	Injury		**TTS**	
	Juvenile Cod	Adult Cod	Juvenile Cod	Adult Cod
Innomar Medium 100 (SBP) – distances relative to vessel				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m
All sources active (combined)				
1	< 100 m	< 100 m	< 100 m	< 100 m
2	< 100 m	< 100 m	< 100 m	< 100 m
3	< 100 m	< 100 m	< 100 m	< 100 m
4	< 100 m	< 100 m	< 100 m	< 100 m
5	< 100 m	< 100 m	< 100 m	< 100 m

For cod, both juvenile and adult, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 5.10: Impact ranges for Herring.

Position	**Herring: Threshold criteria impact ranges**	
	Injury	**TTS**
Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m
All sources active (combined)		
1	< 100 m	< 100 m
2	< 100 m	< 100 m
3	< 100 m	< 100 m
4	< 100 m	< 100 m
5	< 100 m	< 100 m

For herring, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 5.11: *Impact ranges for Larvae and eggs.*

Position	Larvae and eggs: Threshold criteria impact ranges
	Injury
	Innomar Medium 100 (SBP) – distances relative to vessel
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
	Sonardyne WMT 8190 (USBL transponder) – distances relative to towed object
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m
	All sources active (combined)
1	< 100 m
2	< 100 m
3	< 100 m
4	< 100 m
5	< 100 m

For larvae and eggs, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

5.5.2. Impact ranges for marine mammal threshold criteria

For marine mammals, PTS and TTS threshold criteria are based on the frequency weighted $L_{E,cum,24h,xx}$ [dB re. 1 μPa^{2}s], where "xx" refers to the species specific weighting function. Species specific fleeing behaviour as outlined in section 4.2 is assumed.

Threshold criteria for behaviour reaction is based on the frequency weighted $L_{p,125ms,xx}$ [dB re. 1 μPa]. Resulting impact ranges are provided in Table 5.12 for minke whale, Table 5.13 for white-beaked dolphin, Table 5.14 for harbour porpoise and in Table 5.15 for seals.

Table 5.12: Impact ranges for minke whales.

Position	Minke whale (LF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
	Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	All sources active (combined)		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For minke whale, underwater sound propagation modelling results show no impact beyond 100 m range for the geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

Table 5.13: Impact ranges for white-beaked dolphin.

Position	White-beaked dolphin (HF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
Innomar Medium 100 (SBP) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne HPT 3000 (USBL unit) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
All sources active (combined)			
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For white-beaked dolphin, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities.

Table 5.14: Impact ranges for harbour porpoise.

Position	Harbour porpoise (VHF): Threshold criteria impact ranges		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
	Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	25 - 275 m	600 m
2	< 100 m	120 - 325 m	575 m
3	< 100 m	120 - 325 m	600 m
4	< 100 m	130 - 375 m	675 m
5	< 100 m	120 - 350 m	650 m
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	425 -1300 m	4.0 km
2	< 100 m	400 - 1150 m	4.1 km
3	< 100 m	400 - 1150 m	4.5 km
4	< 100 m	675 - 1650 m	4.2 km
5	< 100 m	625 - 1600 m	4.4 km
	Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel		
1	< 100 m	150 – 850 m	3.2 km
2	< 100 m	225 – 625 m	3.6 km
3	< 100 m	180 – 575 m	3.6 km
4	< 100 m	325 – 875 m	3.6 km
5	< 100 m	300 – 875 m	3.6 km
	All sources active (combined)		
1	< 100 m	425 -1300 m	4.0 km
2	< 100 m	400 - 1150 m	4.1 km
3	< 100 m	400 - 1150 m	4.5 km
4	< 100 m	675 - 1650 m	4.2 km
5	< 100 m	625 - 1600 m	4.4 km

For harbour porpoise, underwater sound propagation modelling results show impact on the behaviour at up to 4.5 km distance from the survey. It should be noted that this behaviour criterion is only considered valid for impulsive noise sources (Tougaard, 2021), however as no threshold criteria have been established by science for non-impulsive sources, the impulsive criterion is used as a proxy.

Impact ranges for PTS were found to be less than 100 m, while results for TTS threshold criteria show up to 1600 m impact range.

Table 5.15: Impact ranges for seals.

Position	Seals (PCW): Threshold criteria impact ranges		
	PTS (Non-impulsive)	**TTS (Non-impulsive)**	**Behaviour**
	Innomar Medium 100 (SBP) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne HPT 3000 (USBL unit) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	Sonardyne WMT 8190 (USBL transponder) – distances relative to vessel		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-
	All sources active (combined)		
1	< 100 m	< 100 m	-
2	< 100 m	< 100 m	-
3	< 100 m	< 100 m	-
4	< 100 m	< 100 m	-
5	< 100 m	< 100 m	-

For seals, underwater sound propagation modelling results show no impact beyond 100 m range for the proposed geophysical survey activities. The survey vessel itself, producing more low frequency content than the survey equipment, is therefore likely to define the behavioural impact of the survey.

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Appendix 1

Temperature, Salinity and Sound Speed Profiles Position 2 – 5

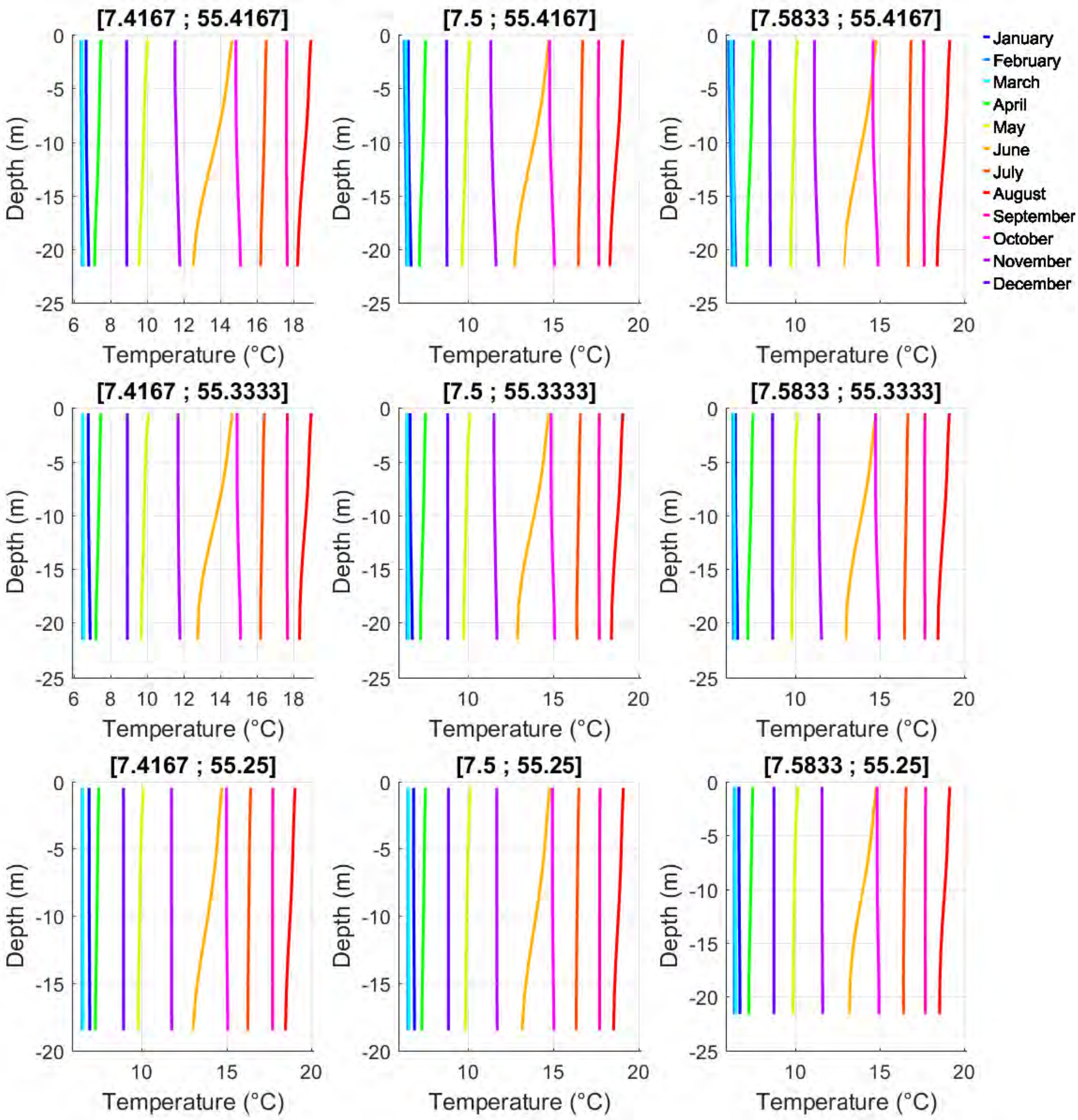

Figure 6.1: Temperature profiles for the area around source position 2 for all months. Gridded layout reflects geographical location.

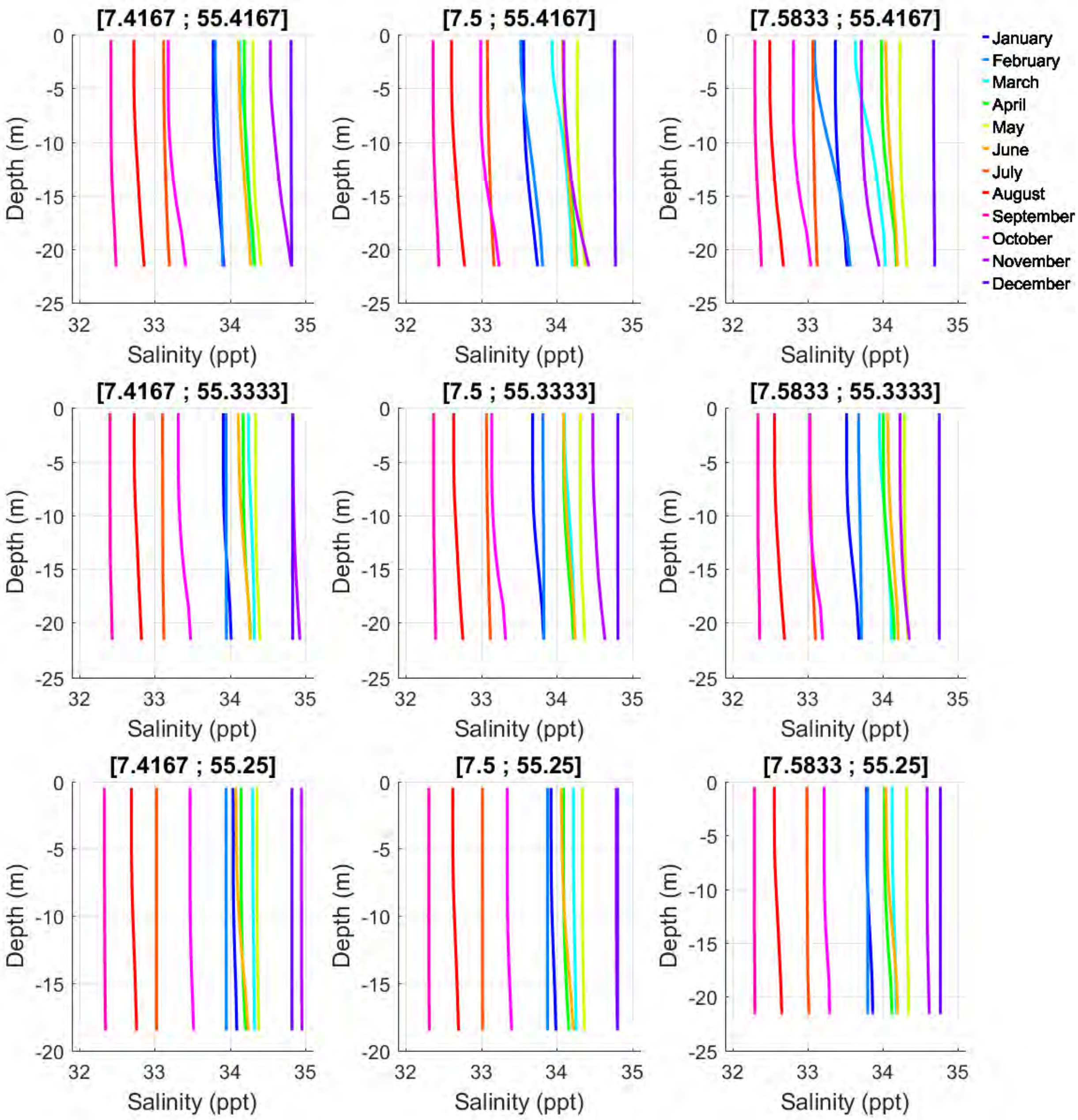

Figure 6.2: Salinity profiles for the area around source position 2 for all months. Gridded layout reflects geographical location.

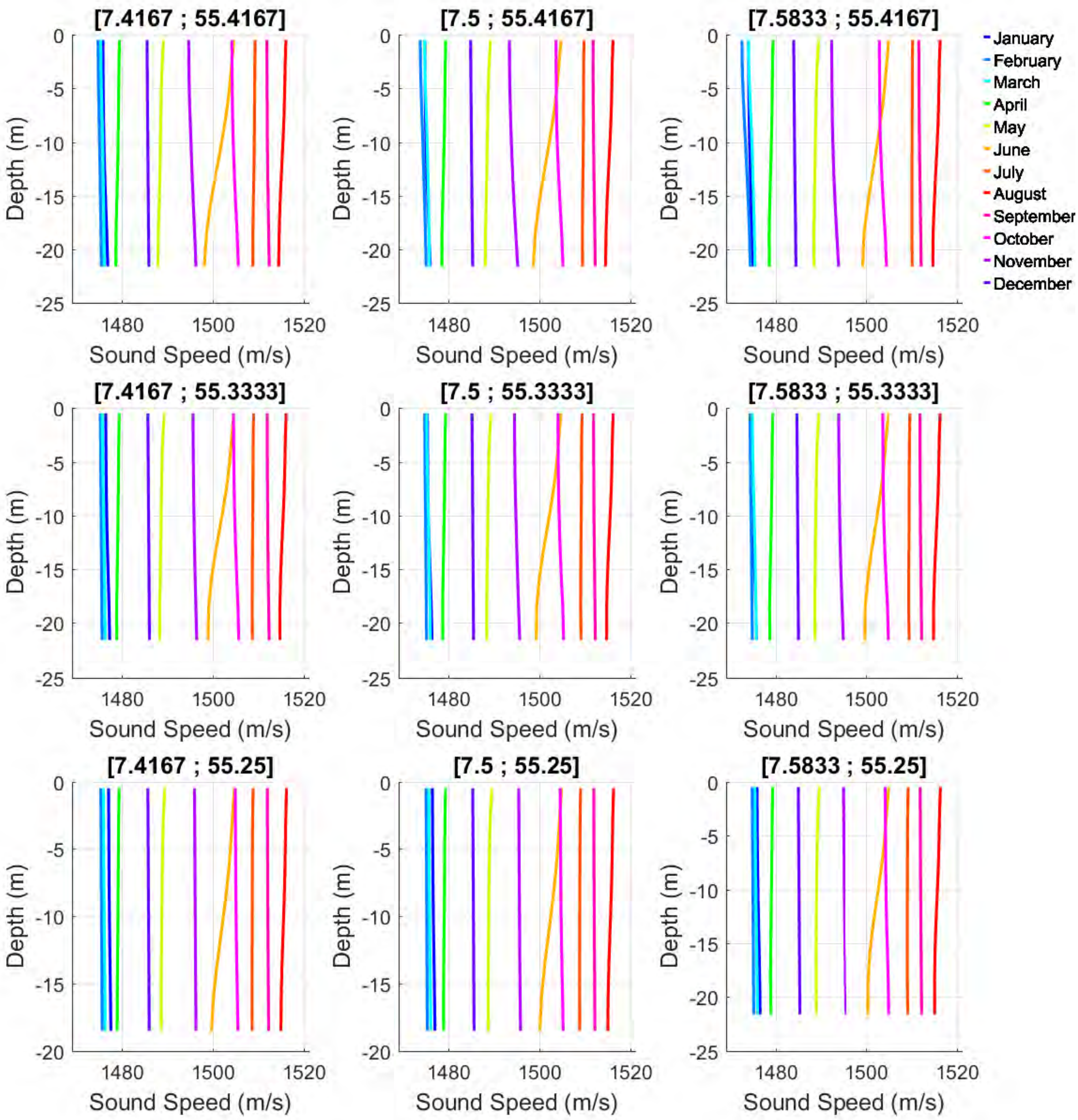

Figure 6.3: Sound speed profiles for the area around source position 2 for all months. Gridded layout reflects geographical location.

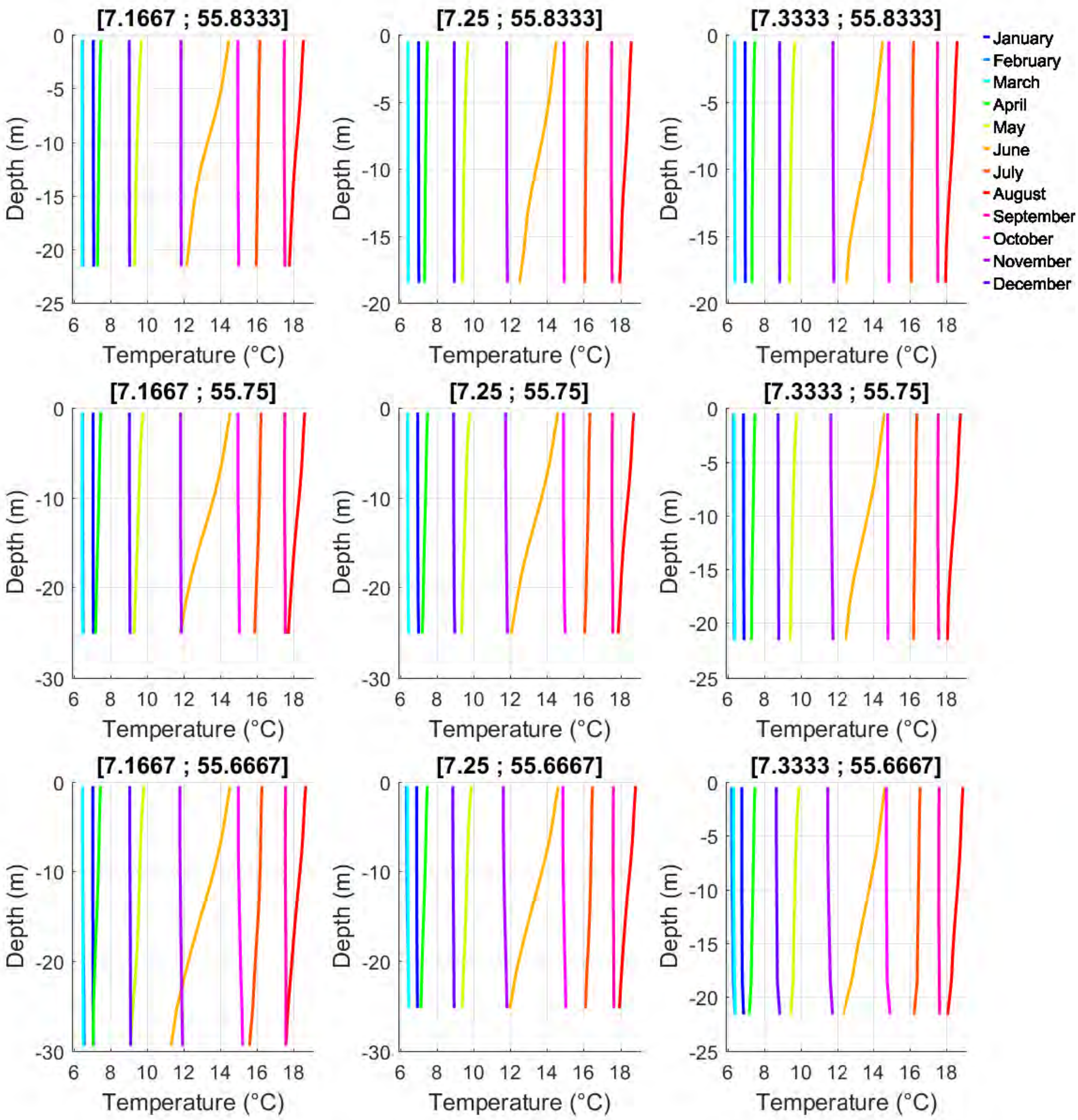

Figure 6.4: Temperature profiles for the area around source position 3 for all months. Gridded layout reflects geographical location.

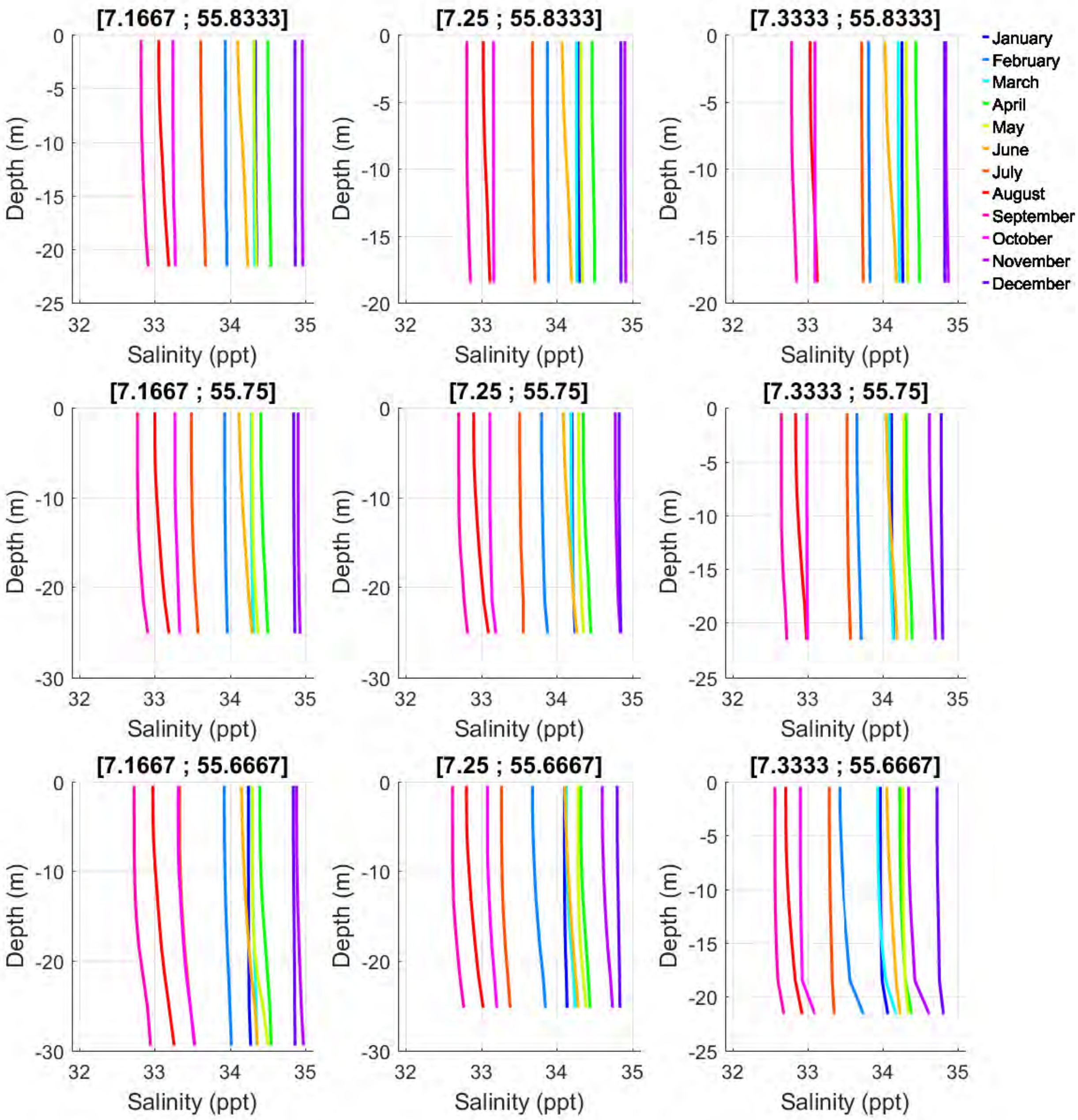

Figure 6.5: Salinity profiles for the area around source position 3 for all months. Gridded layout reflects geographical location.

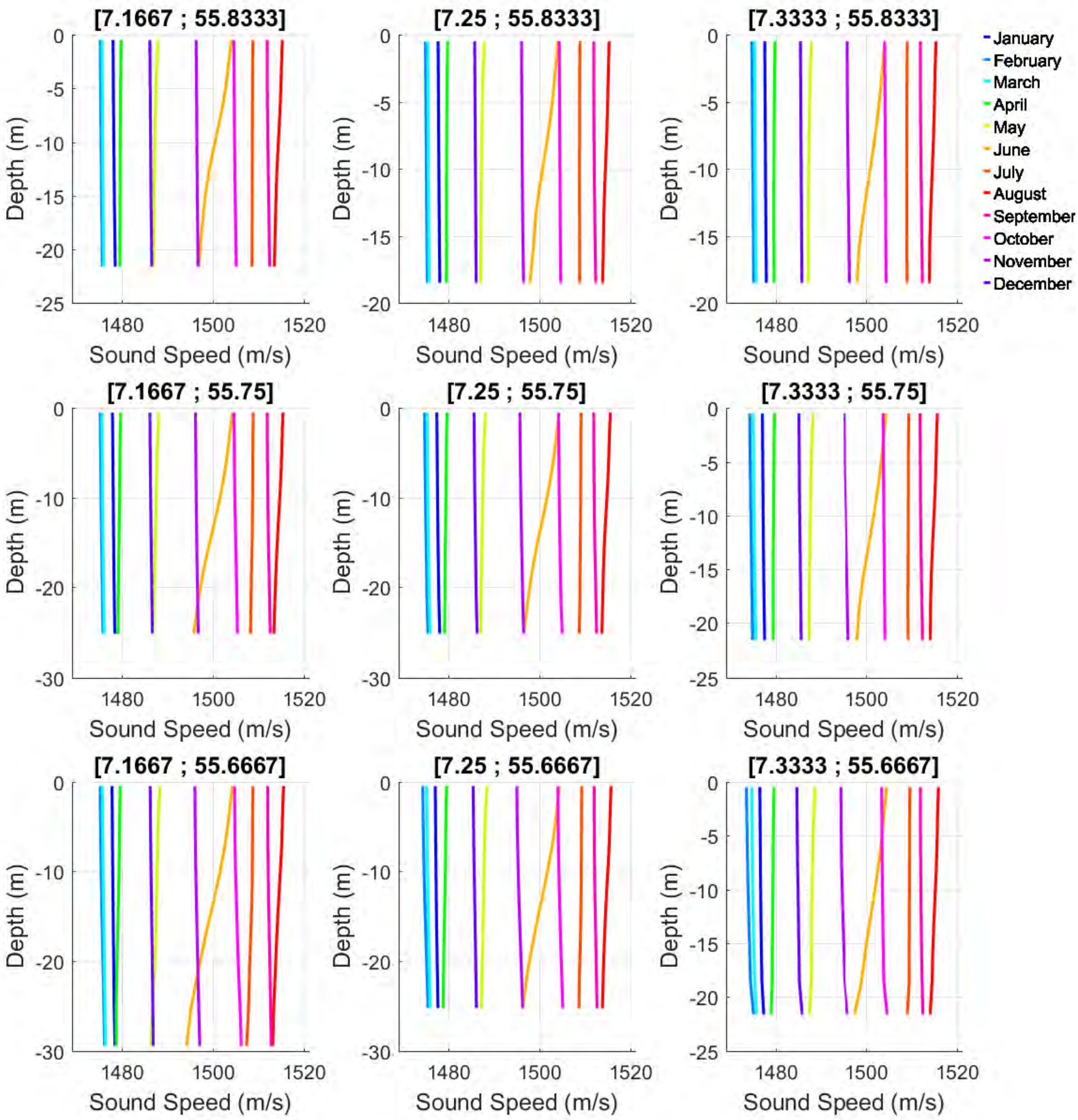

Figure 6.6: Sound speed profiles for the area around source position 3 for all months. Gridded layout reflects geographical location.

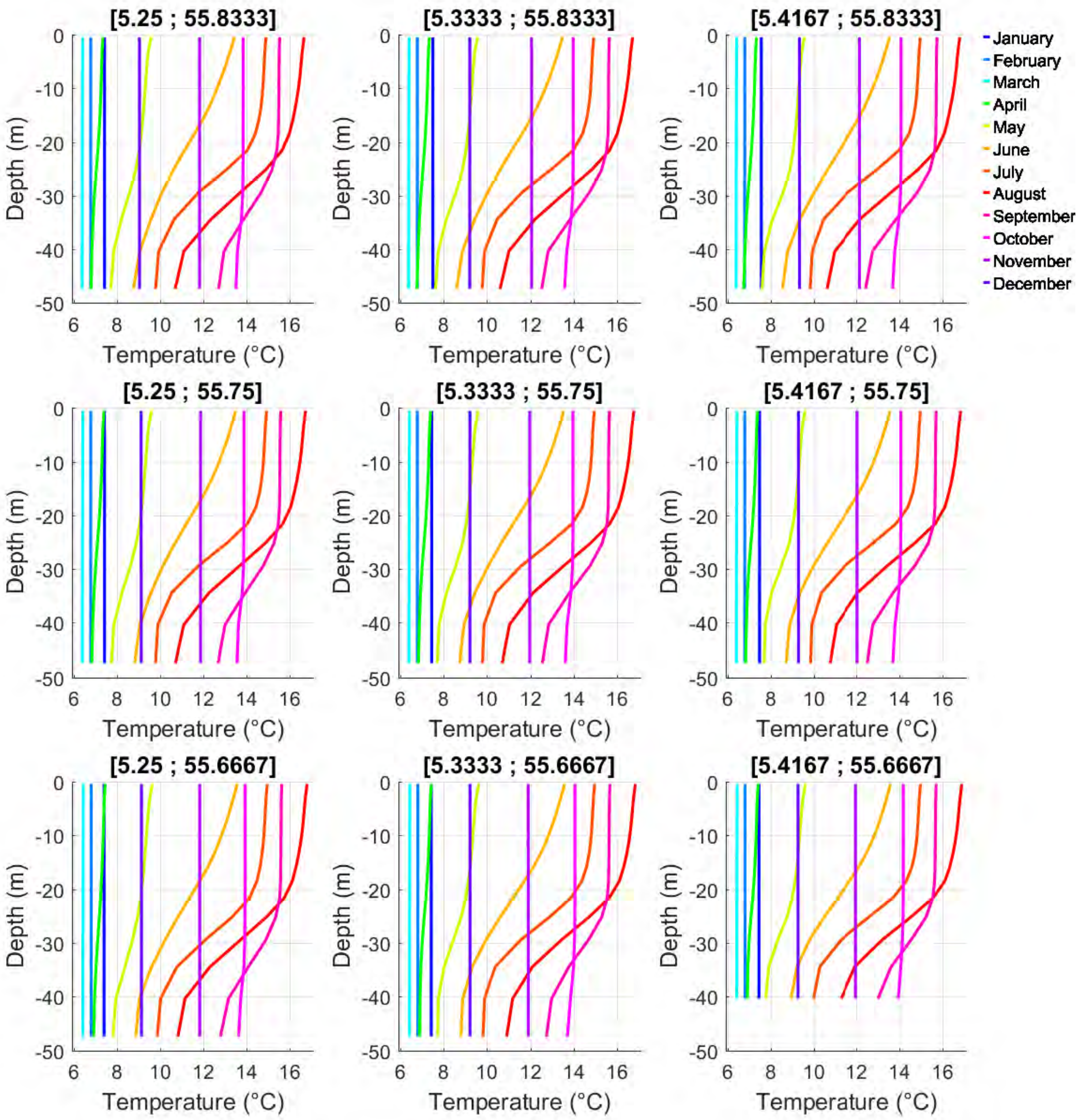

Figure 6.7: Temperature profiles for the area around source position 4 for all months. Gridded layout reflects geographical location.

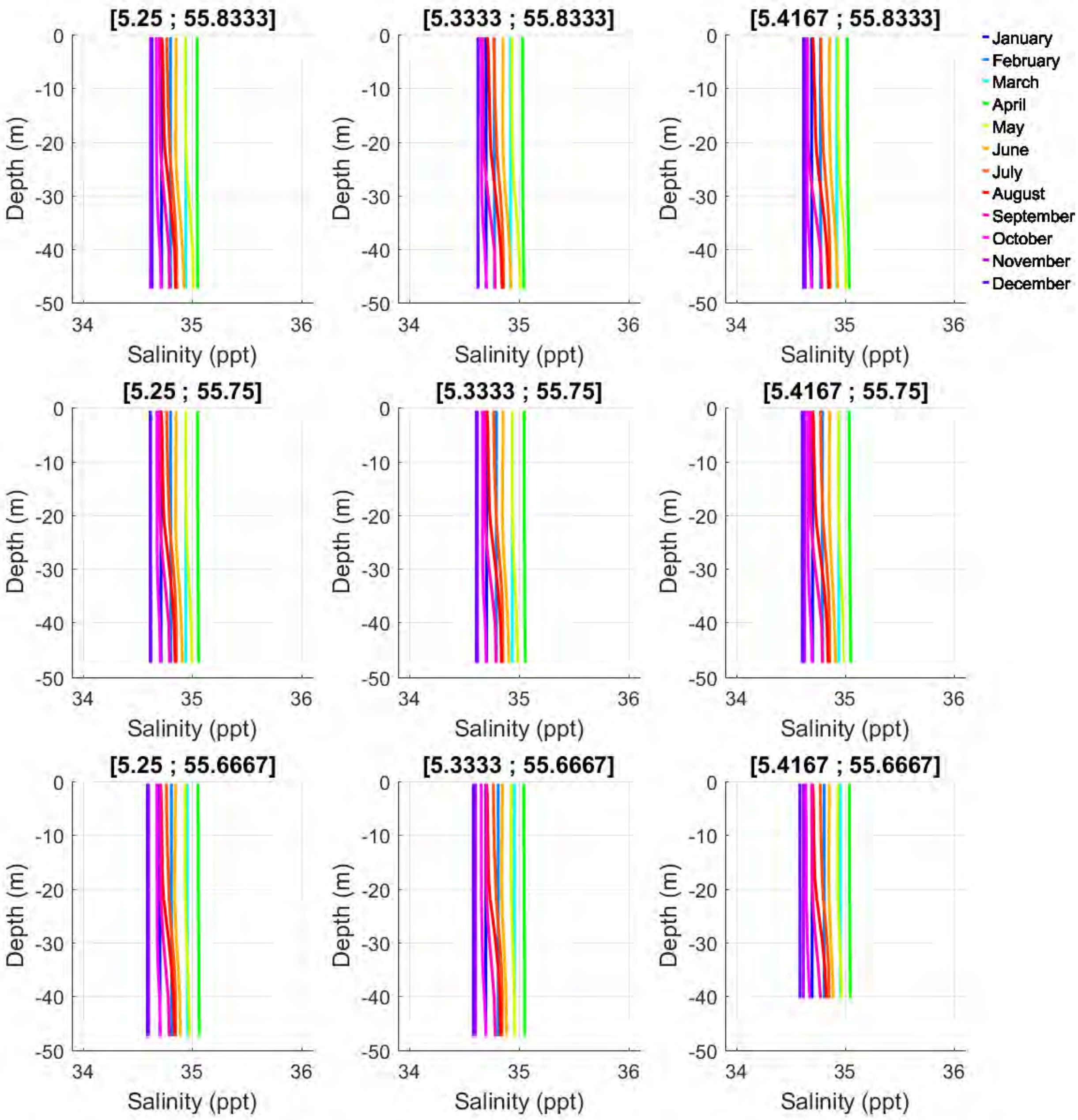

Figure 6.8: Salinity profiles for the area around source position 4 for all months. Gridded layout reflects geographical location.

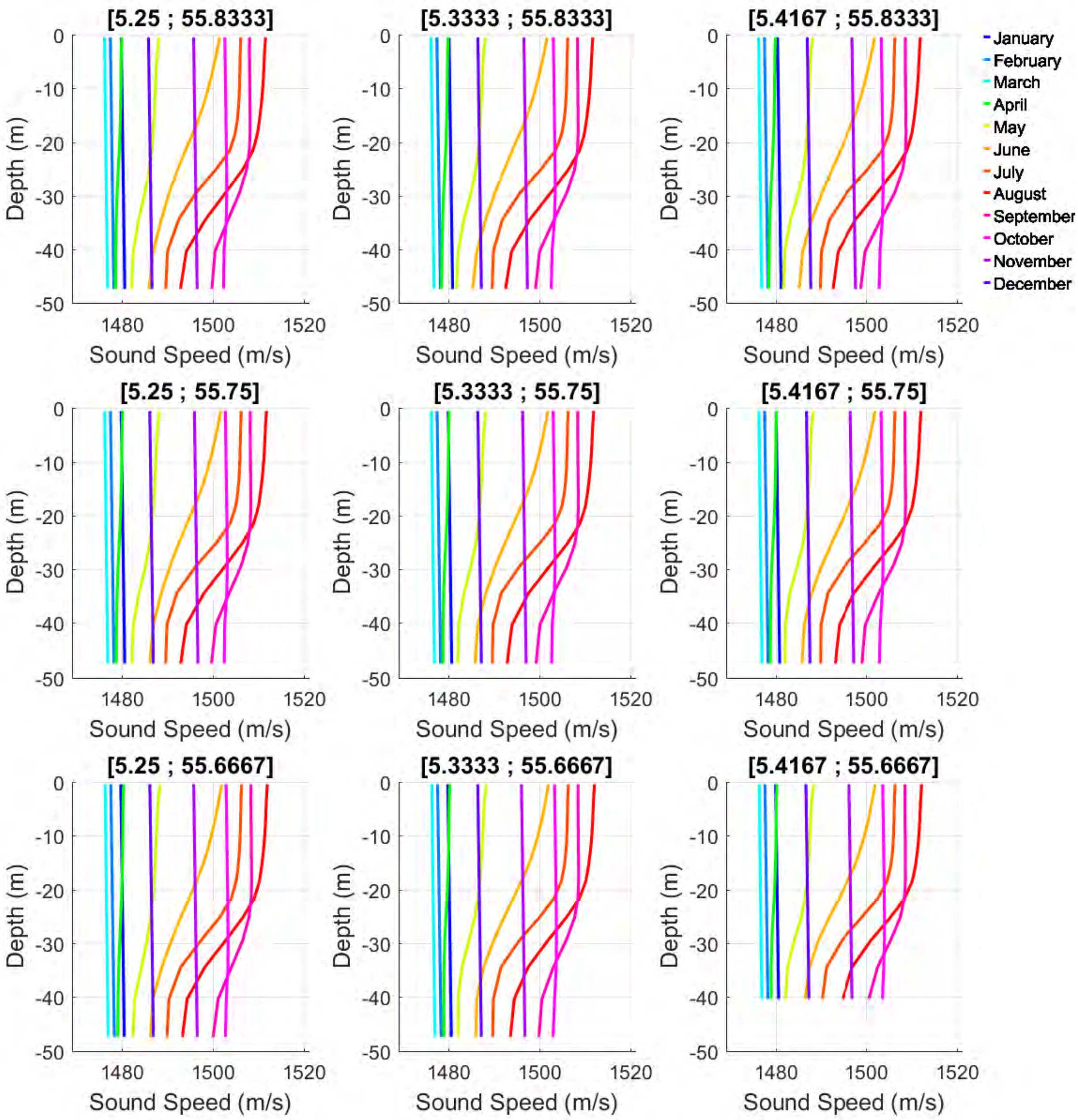

Figure 6.9: Sound speed profiles for the area around source position 4 for all months. Gridded layout reflects geographical location.

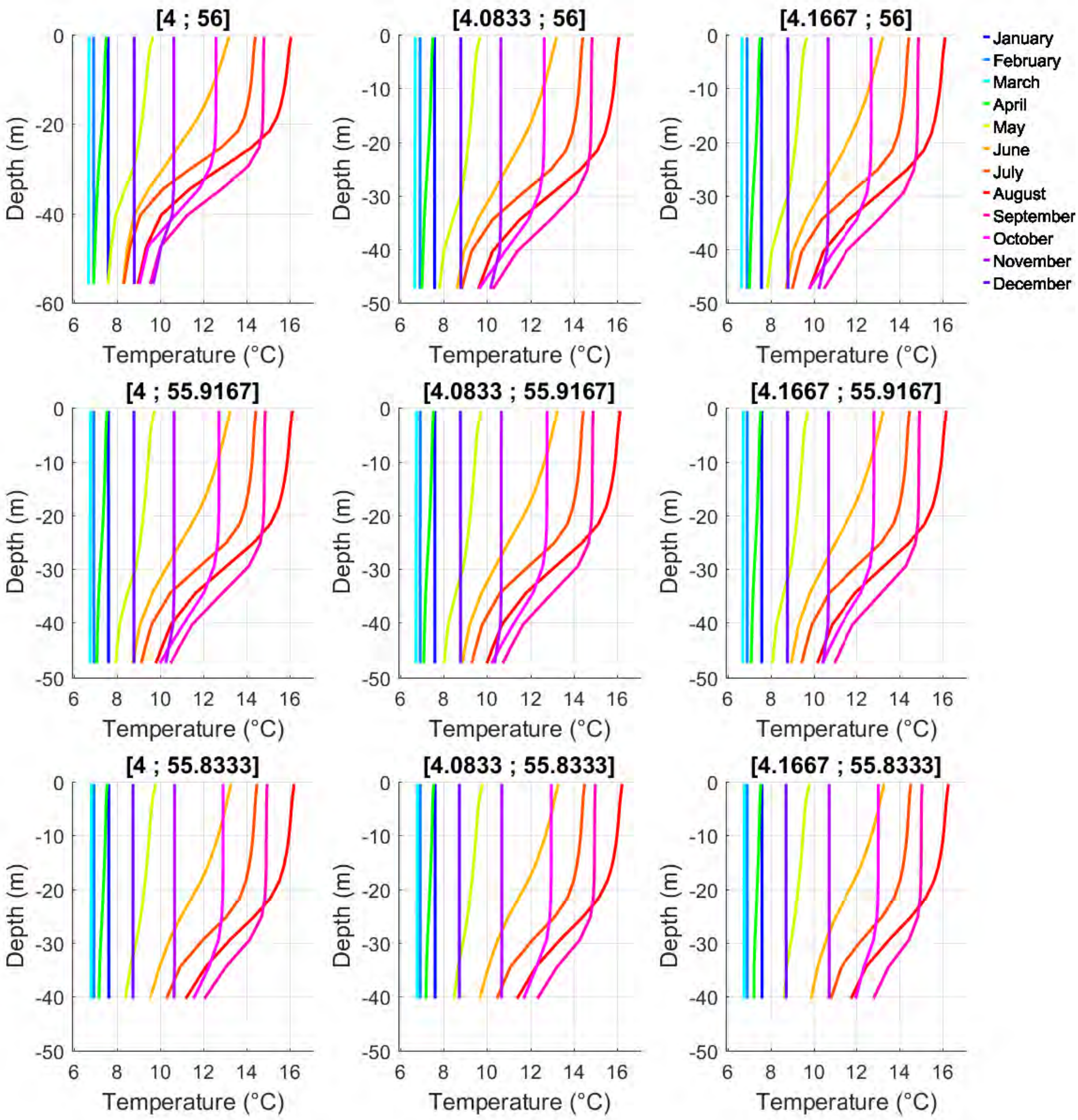

Figure 6.10: Temperature profiles for the area around source position 5 for all months. Gridded layout reflects geographical location.

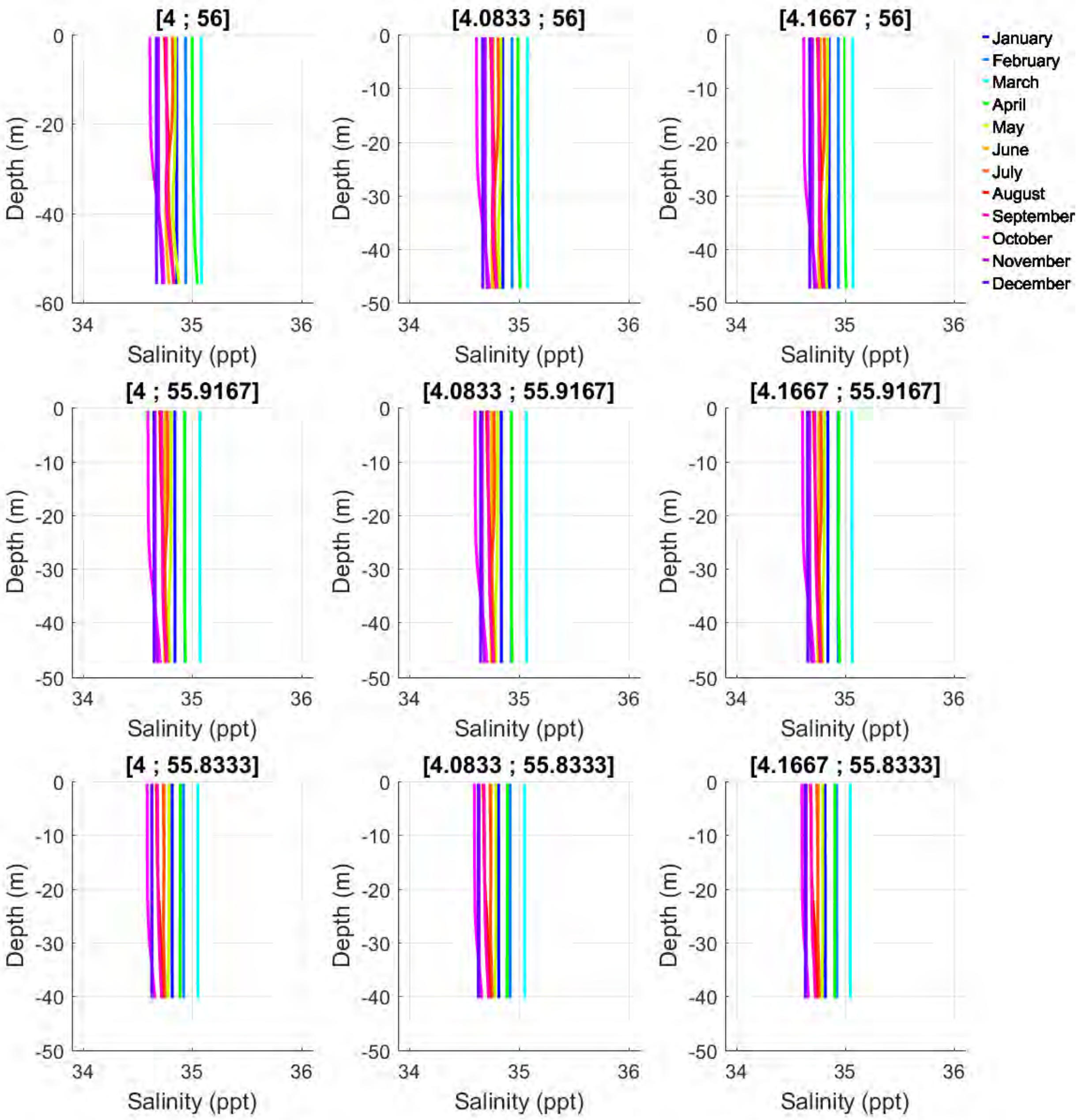

Figure 6.11: Salinity profiles for the area around source position 5 for all months. Gridded layout reflects geographical location.

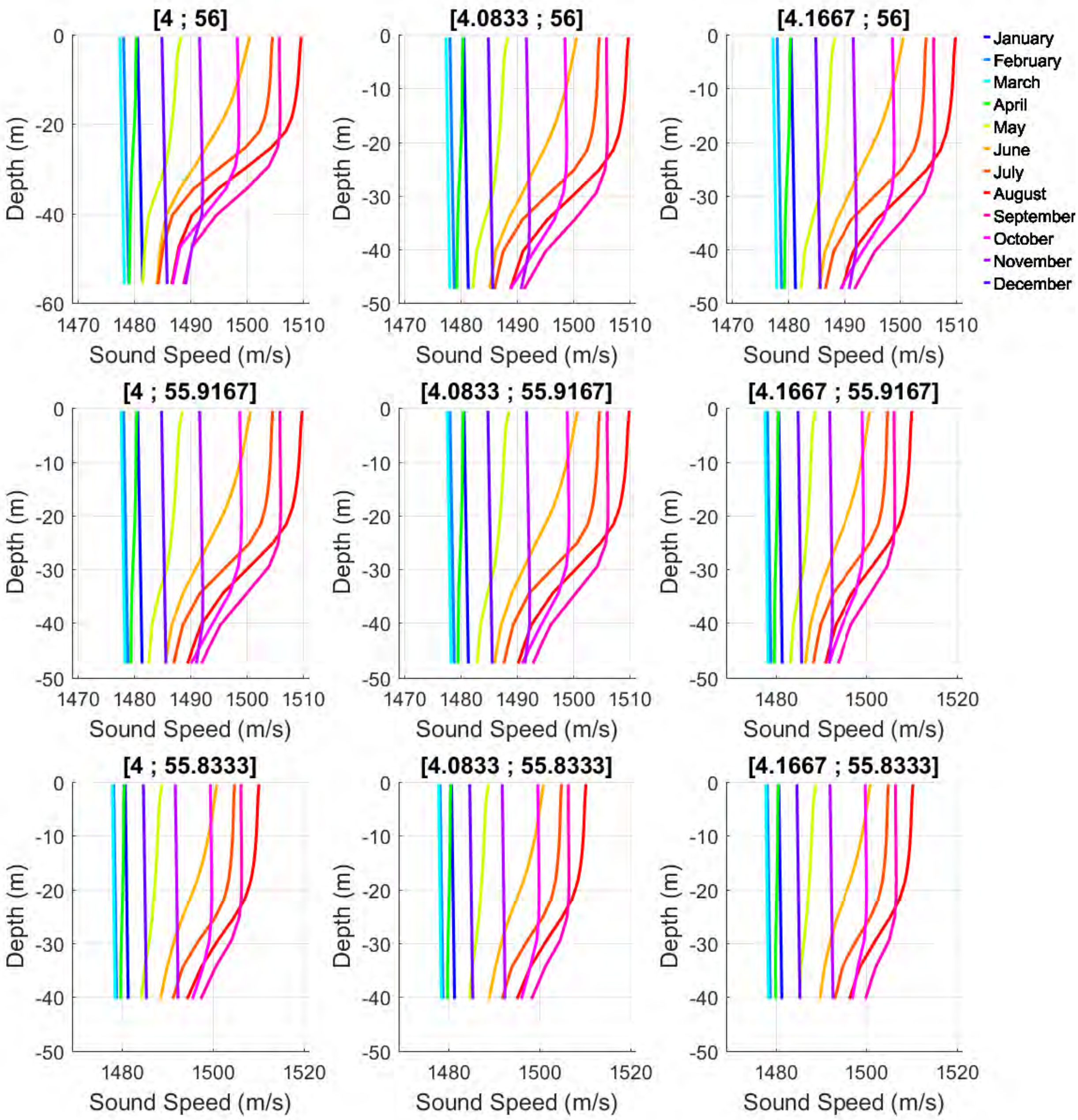

Figure 6.12: Sound speed profiles for the area around source position 5 for all months. Gridded layout reflects geographical location.