DTU Aqua
National Institute of Aquatic Resources

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DTU Aqua Report no. 394-2021

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Preface

This report is the final deliverable from DTU Aqua in the project drafted by the Danish Fisheries Agency about the occurrence of ghost nets in Danish waters.

The project was carried out by DTU Aqua, in collaboration with the two subcontractors in the project; P-dyk (Patrik Juhlin) who, in addition to providing professional divers for the project, has shared his in-depth knowledge about locating and retrieving ghost nets around Sweden and DFPO (Sofie Smedegaard Mathiesen) who have collected and shared information from the fishery.

This final report describes the activities in the five phases of the project, which within the project period all have been finalized by the delivery of a note approved by the steering group of the project. These notes make up Chapters 3, 4, 6 and 7 with only minor corrections or changes. Throughout the project period, a follow-up group containing changing members from the Ministry of Environment of Denmark, Ministry of Food, Agriculture and Fisheries of Denmark, Environmental Protection Agency and the Danish Fisheries Agency have contributed with input to the project.

Kgs. Lyngby, August 2021

Content

Dansk sammendrag

Baggrund for projektet

Denne rapport udgør afslutning af Fiskeristyrelsens udbud af projektet "Spøgelsesnet i danske farvande". Projektet blev finansieret gennem en bevilling fra det danske Hav- og Fiskeriudviklingsprograms del om fremme af gennemførelsen af den Integrerede Maritime Politik (IMP) i 2019.

Hovedformålet med projektet var at undersøge (og kvantificere) forekomsten af spøgelsesnet i formodede konfliktområder for spøgelsesnet i danske farvande samt at teste hypotesen om, at tilstedeværelsen af spøgelsesnet er koncentreret i særlige konfliktområder. Desuden skulle skånsomme og omkostningseffektive metoder til effektiv oprensning af spøgelsesnet afprøves og tilpasses. Resultatet af disse undersøgelser er beskrevet i indeværende rapport.

Hvad er spøgelsesnet og hvordan opstår de?

Spøgelsesnet er en samlet betegnelse for alle typer af mistede eller efterladte fiskeredskaber i hav- eller ferskvand. Betegnelsen omfatter derfor både fritids- og erhvervsfiskerredskaber som garn, ruser, trawl og tejner, men også lystfiskerudstyr som liner, blink, pirke og gummidyr.

De fleste fiskeredskaber er lavet af forskellige former for plastikmateriale og vil på sigt nedbrydes og bidrage til mikroplast i vandsøjlen og sedimentet. Spøgelsesnet anses derfor som affald, der ikke hører til i naturen.

Spøgelsesnet vil i mange tilfælde fortsætte med at fiske i en periode efter det er mistet eller efterladt. Dette utilsigtede fiskeri kaldes spøgelsesfiskeri, og omfatter både fangst af arter, som nettene er målrettet mod, men også fangst af f.eks. havfugle, havpattedyr, skaldyr eller andre fiskearter.

Spøgelsesnet kan overordnet fremkomme på 2 forskellige måder:

1. *de kan mistes utilsigtet*, enten pga. konflikter med marin trafik eller andre fiskeriaktiviteter eller de kan mistes pga. dårligt vejr, redskabsdefekter eller fordi de sidder fast i strukturer på bunden som f.eks. sten eller vrag. <u>Dette projekt og metoderne som er anvendt, fokuserer på utilsigtede tab af erhvervsfiskerredskaber forårsaget af konflikter mellem aktivt (trawl) og passivt (garn) fiskeri samt anden marin trafik.</u>

2. *de kan bevidst efterlades eller dumpes*. Sådanne områder kan ikke identificeres med de konfliktanalyser, der dannede grundlag for dette projekt. <u>Det har dog under projektperioden vist sig, at der i Limfjorden er et alvorligt problem med dette, som sandsynligvis udgør en større mængde end hvad der samlet kan findes i de identificerede konfliktområder.</u>

Rammerne for projektet

Projektet var opdelt i tre delopgaver og fem faser:

Delopgave 1. Omfang af spøgelsesnet i danske farvande.

- Fase 1:Validering af GIS-analyse og udpegning af konfliktområder til nærmere undersøgelser
- Fase 2: Feltarbejde: Kortlægning af forekomsten af spøgelsesnet i udvalgte konfliktområder
- Fase 3: Supplering af forekomst af spøgelsesnet og af konfliktområder med BITS (Baltic International Trawl Survey) og IBTS (International Bottom Trawl Survey) affaldsdata og estimering af det samlede omfang af spøgelsesnet i konfliktområder

Delopgave 2. Afprøvning og tilpasning af metoder til fjernelse af spøgelsesnet i udvalgte fokusområder

- Fase 4: Indsamling af viden om erfaring fra andre lande
- Fase 5: Feltarbejde: Forsøg med fjernelse af spøgelsesnet.

Delopgave 3. Nærværende rapport.

I forbindelse med afslutningen af hver fase er der under projektperioden udfærdiget et notat som bl.a. redegør for aktiviteter og resultater. Disse notater og deres bilag udgør hovedbestanddelen af denne rapport, en undtagelse er afsnittet omkring fremtidige anbefalinger samt resultaterne af fase 3, som kun er beskrevet i indeværende rapport.

Aktiviteter og resultater fra hver fase

Delopgave 1. Omfang af spøgelsesnet i danske farvande

Fase 1: Validering af GIS-analyse og udpegning af konfliktområder til nærmere undersøgelser

Der blev i alt udpeget 11 konfliktområder, hvoraf 6 var tilhørende i Nordsøen/Skagerrak og 5 var tilhørende i de indre danske farvande inkl. området omkring Bornholm. Kriterierne for prioritering samt til- og fravalg af områder var;

- Flere 1x1 km kvadrater med forskellige konfliktintensiteter mellem passive og aktive fiskeredskaber (Fig. 3.1.2).
- Stort passivt fiskeri i områder med megen marin trafik (Fig. 3.1.3).
- Informationer fra andre projekter omkring udenlandsk fiskeriaktivitet eller upublicerede spøgelsesnet aktiviteter.

Områder der hovedsageligt befiskes af små fartøjer <12m og fritidsfiskere (fartøjer uden VMS (Vessel Monitoring System) og ofte uden AIS (Automatisk Identifikations System)) er ikke taget i betragtning, da deres fiskeriintensitet ikke er kvantificeret i statistikker. Områder dybere end 40 meter er nedprioriteret pga. tekniske udfordringer i forbindelse med at operere med sidescan sonar og ROV på disse dybder og dermed bliver det svært at opnå den krævede kvalitet af data. Områder med et stort fiskeri med trawl er ikke inkluderet på baggrund af andre landes erfaringer. Årsagen er, at mistede net i disse områder forventes at blive fanget af trawl.

De udpegede områder i Nordsøen/Skagerrak kan ses i nedenstående tabel sammen med bundtyperne i området, hovedbegrundelsen for udpegningen og prioriteten af området. Jf. kravspecifikationerne skulle følgende to bundtyper som minimum undersøges; sand/blød bund samt sten- eller boblerev.

Område	Bundtype	Hovedbegrundelse for udpegning	Prioritet
Gule Rev	Blandet sediment Natura 2000 stenrev	Dage med overlap mellem aktive og passive redskaber, men hovedsageligt udpeget pga. kendt fiskeri med udenlandske bomtrawlere i området. Natura 2000 stenrev.	Første prioritet stenrev
Store Rev	Blandet sediment (Natura 2000 stenrev) Sand	Området med mest overlap mellem aktive og passive redskaber, både gennemsnitligt i området og i et enkelt kvadrat. Kortlagt som Natura 2000 stenrev omkranset af sandbund 3 timer fra Hirtshals.	Første prioritet stenrev og sandområde
Jammerbugten	Sand	Overlap mellem aktive og passive redskaber inkl. udenlandske bomtrawlere og marin trafik i området. Stort passivt fiskeri i område 2.	Første prioritet, lokaliseret mellem de to første prioritets stenrevsområder
Hanstholm	Sand Blandet sediment	Overlap mellem aktive og passive redskaber og halvdelen af begge underområder er påvirket af meget marin trafik. Tæt på land og Hanstholm Havn.	Anden prioritet
Hirtshals	Blandet sediment Sand	Overlap mellem aktive og passive redskaber og marin trafik i området. Inkluderer både sand og Natura 2000 stenrev. Tæt på land og Hirtshals Havn.	Anden prioritet
Jyske Vestkyst	Groft sediment Blandet sediment Sand Natura 2000 stenrev	Stort område med overlap mellem aktive og passive redskaber. Høj fiskeriintensitet med passive redskaber og moderat aktivitet med aktive redskaber. Natura 2000 stenrev.	Anden prioritet, baseret på cost efficiency

De udpegede områder i de Indre danske farvande inkl. området omkring Bornholm kan ses i nedenstående tabel sammen med bundtyperne i området, hovedbegrundelsen for udpegningen og prioriteten af området.

Område	Bundtype	Hovedbegrundelse for udpegning	Prioritet
Vest for Bornholm	Blandet sediment Sten og biogene rev Sand Mudder	Stort passivt fiskeri i området. Svenske upublicerede spøgelsesnet aktiviteter i området. Natura 2000 stenrev område.	Første prioritet pga. svenske spøgelsesnet aktiviteter, dog er område 2 og 3 meget dybe.
Langelandsbælt	Blandet sediment Sand Stenrev i Natura 2000 område	Største overlap i indre danske farvande mellem aktive og passive redskaber. Meget marin trafik, stenrev i Natura 2000 område	Første prioritet. Området dækker kravene om både stenrev og sandområder.
Store Middelgrund	Groft sediment (Natura 2000 stenrev) Blandet sediment Sand, mudder	Et af de få områder med overlap mellem passive og aktive redskaber i Kattegat og mellem passive redskaber og marin trafik. Stenrev	Anden prioritet. Ikke megen aktivitet og langt fra havne.
Øresund området	Groft sediment Sand Blandet sediment	Stort fiskeri med passive redskaber, ingen aktive redskaber men megen marin trafik. Under mange vindretninger et beskyttet område. Lavvandet område.	Anden prioritet. Stor afstand til første prioritetsområder.
Sydøst for Bornholm	Blandet sediment Sand Mudder	Dette område har sammenlignet med andre områder i de indre danske farvande et kvadrat med et meget højt antal dage med overlap mellem passive og aktive redskaber. Den store dybde i området og den blandede bund, øger potentielt risikoen for at miste net eller dele af net.	Anden prioritet Området er for dybt og langt fra en havn.

Fase 2: Feltarbejde: Kortlægning af forekomsten af spøgelsesnet i udvalgte konfliktområder
Der blev gennemført i alt 4 togter i 2020 og 2021; 3 med sidescan sonar og video, og 1 med dykkerundersøgelser på vrag.

Undersøgelserne på vrag blev gennemført i farvandet omkring Møn og der blev fundet garn eller trawl på 4 af 7 undersøgte vrag samt lystfiskerudstyr på 5 af 7. Hovedparten af nettene vurderes at være af ældre dato.

Kortlægningerne med sidescan blev for området Indre danske farvande gennemført i Langelandsbæltet og dækkede både sandområder og stenrevsområder. Der blev i alt undersøgt 31 1x1 km kvadrater. Der blev observeret 7 anomalier på sidescan billederne og disse blev undersøgt med video, men ingen af dem kunne bekræftes som værende spøgelsesnet.

I Nordsø/Skagerrak området blev 25 kvadrater (1x1 km) undersøgt i områderne Jammerbugten, Store Rev og Hirtshals. Her blev 5 anomalier undersøgt med enten video eller dræg, og 1 af disse viste sig at være et 240m langt garn med en bøje og et anker samt en fangst af 40 kg taskekrabber. Nettet var mistet for nyligt. Yderligere 1 anomali antages at være et mistet redskab, da der på dræget sad rebfibre, men det lykkedes ikke at bjærge så stort et stykke, at oprindelsen kunne identificeres.

Som en tillægsopgave blev der gennemført en sidescan undersøgelse i Limfjorden for at teste hypotesen om, at problemet er koncentreret i de områder, hvor der fiskes efter hummer. Her blev i alt 5 områder undersøgt; 3 hummerområder og 2 almindelige fiskeområder. Mere end 30 anomalier som muligvis kan være spøgelsesnet blev udpeget, hovedparten i hummer-områderne. Af disse blev 2 net visuelt bekræftet, den ene i et hummerområde og det andet i et fiskeområde.

Fase 3: Supplering af forekomst af spøgelsesnet og af konfliktområder med BITS og IBTS data og estimering af det samlede omfang af spøgelsesnet i konfliktområder
Hvis alle områder i de danske farvande blev trawlet, som under de standardiserede trawltogter (BITS/IBTS) vurderes det, at man ville fange 49×10^3 net/netstykker (med en standard afvigelse på 13×10^3), hvilket svarer til ca. 0,45 net stykker pr. km^2. Da en trawl ikke forventes at fange alle netstykker og fangbarheden er variabel afhængigt af størrelse og redskabsmateriale (Galgani et al., 1995), skal dette estimat betragtes som et underestimat af det totale antal netstykker i danske farvande. Estimatet på 49×10^3 net stykker er modelleret på baggrund af fund af spøgelsesnet under projektets togter samt data om marint affald indsamlet under de standardiserede trawltogter (IBTS/BITS). Stykkerne fra IBTS/BITS varierer i størrelse fra et par centimeter til en fangst på 350 kg net, og omfatter både garn og trawlstykker.

Stykkerne var ikke fordelt jævnt i de danske farvande, men der blev ikke fundet en signifikant korrelation mellem koncentrationen af netstykker i et område og antallet af konfliktdage mellem aktive og passive redskaber. Hverken mellem intensiteten af passivt fiskeri og netstykker eller aktivt fiskeri og netstykker. Hypotesen om at spøgelsesnet koncentreres i konfliktområder, kan derfor ikke bekræftes.

Delopgave 2. Afprøvning og tilpasning af metoder til fjernelse af spøgelsesnet i udvalgte fokusområder

Fase 4: Indsamling af viden om erfaringer fra andre lande omkring bjærgning af spøgelsesnet

Der har i landene omkring os været gennemført to større projekter om spøgelsesnet, hhv. FANTARED 2 og Marelitt Baltic. Begge projekter er kommet med en række anbefalinger, og Marelitt Baltic har udformet en række dokumenter med guidelines for, hvordan forskellige problematikker omkring spøgelsesnet bør gribes an. Helt kort kan man sige, at en succesfuld fjernelse af spøgelsesnet kræver to trin.

1. At den præcise position for spøgelsesnettet kan identificeres enten vha. sidescan sonar, video, dykkere, trækken med dræg, eller rapportering af observationer med angivelse af position.
2. Opfiskning af spøgelsesnettet enten med dræg eller med dykkere. Placeringen af nettet på bunden (f.eks. vrag eller sandbund) er afgørende for valg af metode.

Fase 5: Feltarbejde: Forsøg med fjernelse af spøgelsesnet

Der blev under projektet fjernet spøgelsesnet både med dykkere og med dræg. Begge metoder er effektive, hvis positionen på spøgelsesnettet er kendt, dog kræver en fjernelse med dræg ikke helt så præcist kendskab til position, som en fjernelse med dykkere, da der i områder uden følsomme arter som f.eks. ålegræs, kan afsøges et større område med dræg uden betragtelige uhensigtsmæssige forstyrrelser af havbunden (Sahlin & Tjensvoll, 2018).

Fjernelse af net på vrag, beskyttede rev og andre komplekse og skrøbelige strukturer skal gøres skånsomt med dykkere for ikke ødelægge strukturen, og det bør vurderes, om det evt. gør mere skade end gavn, hvis nettet f.eks. er blevet en integreret del af strukturen. Fjernelse af net skal af sikkerhedshensyn altid udføres af professionelle dykkere. Fjernelse med dræg af net der ligger på havbunden er en forholdsmæssigt billig og effektiv metode og kan principielt udføres af fartøjer i alle størrelser.

Konklusioner og perspektivering af resultater til omkringliggende lande

Spøgelsesnet forårsaget af *mistede* fiskeredskaber vurderes overordnet ikke til at være et udbredt problem i de danske farvande, og projektet har ikke fundet en signifikant højere koncentration af spøgelsesnet i de udpegede konfliktområder (hovedsageligt udpeget på baggrund af overlap mellem passivt og aktivt fiskeri). Der er fundet redskaber fra både erhvervs-, fritids- og lystfiskere. Det estimeres, at der på over 50% af de vrag, der ligger i områder hvor der er eller har været fiskeri, vil kunne findes spøgelsesnet i større eller mindre omfang, afhængigt af fiskeriintensitet og strømforhold. I tillæg er der under projektperioden identificeret et alvorligt problem i Limfjorden med, hvad der vurderes at være *bevidst efterladte* redskaber i områder med fiskeri efter hummer og taskekrabber (Christensen (2020), upublicerede resultater fra Limfjordens oprensningsprojekt App. A.22.).

Ovenstående konklusioner vil i det følgende blive uddybet og perspektiveret.

På baggrund af projektets fund af spøgelsesnet under de gennemførte togter, suppleret med affaldsdata indsamlet under årlige standardiserede trawltogter (BITS/IBTS) estimeres det, at man vil fange $49x10^3$ net eller netstykker (standardafvigelse på $12x10^3$) hvis man trawler alle områder i de danske farvande, hvilket svarer til et gennemsnit på ca. 0,45 net stykker pr. km^2.

Tallet er sandsynligvis underestimeret, da de standardiserede trawltogter som udgangspunkt gennemføres på jævn bund, hvor der ikke er strukturer til at fange og tilbageholde net og netstykker. Ydermere er fangbarheden af materialerne ikke 100% og varierer afhængigt af nettype og størrelse (Galgani et al., 1995). Dette tal er det første estimat af net og netstykker, og er ikke umiddelbart sammenligneligt med de tabsestimater og estimater af marint affald, der er lavet for de omkringliggende farvande eller andre europæiske områder. Perspektiveringen er derfor en mere bred diskussion af situationen for spøgelsesnet i danske farvande.

I FANTARED 2 rapporten fra 2003 er det estimeret, at svenske fiskere mistede 3,6 til 3,8 net per garnfartøj svarende til 0,1% af de satte redskaber. Disse tal er dog fra en periode med nedgang i torskebestanden i Østersøen og en reel kamp for fiskepladser mellem garnbåde og trawlere, så hovedårsagen til tab blev begrundet med konflikter mellem fiskerierne. Det antages derfor, at den kraftige nedgang i fiskeriflåden de seneste 25 år formentligt også har medført færre konflikter og derved en reduktion af tab af net per garnfartøj. Det skal tilføjes, at FANTARED 2 også vurderede, at svenske trawlere i samme periode årligt opfiskede en mængde af spøgelsesnet svarende til garnfiskernes tab. Dog menes en del af de opfiskede net at stamme fra andre landes flåder.

Erhvervsfiskere er forpligtet til at melde et tab af redskaber til fiskeristyrelsens Fiskeri Moniterings Center (FMC) højst 24 timer efter tabet samt registrere det i deres eLog. I perioden 2015 til 2019 har der været i alt 40 rapporteringer, hvoraf 27 var fra bundtrawlere, 10 fra snurrevod og 3 fra pelagiske trawlere og ingen rapporteringer fra garnbåde (Tabel 5.1.5). I fiskernes eLog kan de ud over tab af redskaber, også rapportere skader på redskaber. Dette er de dog ikke forpligtiget til (Tabel 5.1.5). Her har bundtrawlere ca. 100 rapporteringer om skader på redskabet pr. år. I garnfiskerier er der er dog kun en enkelt rapportering af et ødelagt/revet net fra 2015, hvilket er langt under, hvad der er fundet i Marelitt Baltic projektet. Her har 25% af de adspurgte garnfiskere svaret, at de mister net en eller under en gang om året.

Ovenstående tabstal er meget lave i forhold til f.eks. norske rapporteringer, men dette er forventeligt, da hovedparten af de norske rapporteringer om tab er fra det nordlige Norge, hvor der er meget dybe fiskeområder og hvor vejret generelt er barskt. Det er også her de gennemfører deres oprensningstogter, som er på vanddybder mellem 50 og 1000 m (Ref. #1), og dermed er under forhold, der ikke er sammenlignelige med danske farvande. Dog peger Clean Nordic Oceans netværket på, at der generelt i de nordiske lande er for lave rapporteringer om tab i forhold til de samlede fiskeriaktiviteter og typer af fiskeri. De danske rapporteringer fra garnfartøjer, både omkring skader og omkring mistede net er ydermere i kontrast til Clean Nordic Oceans konklusion omkring, at der er større risiko for at miste passive redskaber som garn, tejner eller ruser i forhold til aktive redskaber som trawl, vod og snurrevod (Langedal et al., 2020). Dette indikerer, at der i det danske garnfiskeri er en underrapportering både omkring skader på redskaber og på rapporteringerne om mistede redskaber.

Antallet af erhvervsfiskefartøjer er reduceret med ca. 60% over de sidste 25 år fra 4.830 i 1996 til 1.998 i 2020. Den største reduktion er sket i antallet af trawlere, hvor der kun er ca. 1/3 tilbage i forhold til antallet i 1996, og antallet af garnfartøjer er cirka halveret. Det er sandsynligt, at denne nedgang i antallet af fartøjer har betydet og fortsat vil betyde et fald i antallet af mistede redskaber i erhvervsfiskeriet. Marelitt Baltic projektet havde en tilsvarende konklusion suppleret med at forbedrede vejrprognoser og navigationsteknologi også har nedsat risikoen for tab (Predki et al 2019).

I Danmark har man dog de sidste par år set en stigning i antallet af nye og måske uerfarne fritidsfiskere på 13% (28.352 i 2019 & 32.686 i 2020), hvilket potentielt kan øge risikoen for tab af redskaber og derved tilsvarende øge antallet af spøgelsesnet (Ref. #4).

Projektets resultater kan ikke bekræfte hypotesen om, at spøgelsesnet samler sig i specifikke konfliktområder. Det betyder dog ikke nødvendigvis, at der i disse områder ikke sker flere tab af redskaber, men alene at der ikke er observeret signifikante ophobninger i disse områder. De VMS-data, der i nærværende analyse er anvendt til at udpege konfliktområderne, er fra perioden 2014-2018, hvilket betyder at ældre konfliktområder ikke identificeres ved denne metode, som f.eks. et område vest for Bornholm, hvor svenske undersøgelser har fundet store koncentrationer af gamle net (Tschernij, 2020). En anden årsag til at net ikke akkumuleres i konfliktområder mellem aktive og passive redskaber kan være, at trawlere, der fisker i sådanne områder, over tid fanger hele net eller stykker af de mistede redskaber.

Ovenstående oplysninger peger samlet set mod en vurdering af, at hverken forekomsten eller tilvæksten af spøgelsesnet i de danske farvande er et udbredt problem, men net og netstykker akkumuleres over tid, hvis ikke de fjernes fra havområderne, da der i forbindelse med fiskeriaktiviteter altid vil være risiko for at miste hele eller dele af et redskab pga. uheld eller defekter. Dette svarer til konklusionerne fra Marelitt Baltic projektet, hvor man anser nutidens mængde af *mistede* redskaber i fiskeriet som værende meget begrænset, og at mindre tab af hele eller dele af redskaber er uundgåeligt.

Limfjorden

Et område, der har vist sig være en undtagelse fra ovenstående konklusion, er den vestlige del af Limfjorden, hvor der i områder med et målrettet fiskeri efter hummere og taskekrabber er fundet meget store mængder af spøgelsesnet. På baggrund af den generelt lave vanddybde, de meget store mængder af spøgelsesnet samt manglende vager og ankre på de bjærgede redskaber, vurderes det, at disse redskaber hovedsageligt er *efterladt og ikke mistede*.

Områderne i Limfjorden ville ikke, selvom det havde været omfattet af analyserne i indeværende projekt, være blevet udpeget som et konfliktområde, da der ikke er konflikter mellem aktive og passive redskaber eller passive redskaber og marin trafik. Under projektet har det vist sig meget svært at tilvejebringe information om spøgelsesnetområder og områder der ikke er drevet af konflikter f.eks. historiske dumpningsområder, net på vrag, områder hvor der ofte rives eller mistes redskaber pga. bundstrukturer eller vejrforhold. Denne type af områder med efterladte redskaber vurderes til at være svære at identificere uden lokale rapporteringer og det kan ikke udelukkes, at der findes andre fjorde eller lokalområder med tilsvarende problemer.

Vrag

Der blev fundet spøgelsesnet på 4 af 7 vrag under projektets dykkerundersøgelser. Vragguiden.dk og andre kilder, der beskriver dyk på vrag blev gennemgået for registreringer af net på vrag. Disse informationer er dog ikke tilstrækkelige til en modellering af, på hvor mange vrag, der er net. Det skyldes, at når der ikke står beskrevet, at der er net, så er det ikke ensbetydende med, at der ikke findes net på vraget, men kun at det ikke er registreret. En engelsk undersøgelse fandt net på 7 af 11 undersøgte vrag (Revill & Dunlin, 2003) hvilke er samme niveau som i nærværende projekt.

Generelt kan man sige, at et vrag danner en struktur på havbunden, som skiller sig ud fra det omkringliggende område, og at vrag ofte tiltrækker fiskearter som f.eks. torsk og derfor også alle typer af fiskere (fritids-, erhvervs- og lystfiskere) afhængigt af afstanden til kysten. Da vrag ofte har en mast, ror, eller andet der stikker ud og derved øger risikoen for at anvendte fiskeredskaber sidder fast, formodes det, at et vrag, der ligger i et område med fiskeri, har stor sandsynlighed for at have spøgelsesnet svarende til projektets fund, dvs. over 50%. De lokale fiskerintensiteter, fiskerityper (f.eks. garn, trawl, lystfiskeri), strømforhold og kompleksiteten af vraget vil være afgørende for den faktiske mængde og type af spøgelsesnet, der på et givent tidspunkt sidder på et vrag.

Bifangst

Under de gennemførte dykker- og sidescan/oprensningstogter blev der i de identificerede net kun observeret ét tilfælde af spøgelsesfiskeri. Dette var i et relativt ny-mistet krabbegarn, der blev bjærget ud for Hirtshals med 70 taskekrabber som fangst. Denne ene observation er ikke nok til at lave et estimat af den samlede fangst i spøgelsesnet, hverken på art eller mængde i de danske farvande.

Spøgelsesnet, der ruller sig sammen på havbunden, mister hurtigt evnen til effektivt at fange rundfisk, hvorimod de kan opretholde evnen til at fange fladfisk og krebsdyr, som bevæger sig langs bunden, imellem 9 måneder og et år (Kaiser et al., 1996, Revill & Dunlin, 2003). En svensk undersøgelse af torskegarn har vist, at fangsteffektiviteten faldt med ca. 80% over en tre måneders periode sammenlignet med den kommercielle fangsteffektivitet, hvorefter den stabiliserede sig på 5-6% af den oprindelige fangsteffektivitet (Tschernij & Larsson, 2003). Disse resultater stemmer godt overens med projektets fund, hvor alle spøgelsesnet blev vurderet til at være betragteligt ældre end 27 måneder og de havde ikke nogen fangster, dog undtagen det førnævnte krabbenet, som nærmest havde fisket som et aktivt sat net. Et forsøg ud for nordøstkysten af England har vist, at garn spændt ud på et vrag medførte, at nettets fiskerikapacitet blev reduceret til 18% af den oprindelige kapacitet efter 10 uger, og efter 2 år var nettet så ødelagt og degenereret, at det ikke kunne fiske mere (Revill & Dunlin, 2003).

Generelt kan man sige, at nyligt mistede garn vil fortsætte med at fange de arter, de er sat ud for at fange. Lokale forhold som f.eks. vind, strøm, fauna og bundforhold, der kan ødelægge netmasker, rulle nettet sammen eller dække nettet i biologisk materiale vil påvirke perioden et givent net effektivt kan fiske. Når den begrænsede mængde fritliggende net og net på vrag, der sandsynligvis mistes hvert år, tages i betragtning, estimeres spøgelsesfangsterne til at være af et omfang, der er ubetydelig for den samlede fiskeridødelighed, hvilket svarer til konklusionerne i Kaiser et al. (1996). Der er ikke observeret fangst af fugle og havpattedyr i de identificerede spøgelsesnet og på baggrund af dette, vurderes spøgelsesnet ikke at have konsekvenser for den samlede dødelighed af disse grupper. En undtagelse for dette skal måske findes i Limfjorden, hvor store mængder af spøgelsesnet er fundet på et antal relativt små områder med målrettet fiskeri efter hummer; over tid kan mængden her samlet set have haft en effekt på dødeligheden blandt hummer og krabber. Det kræver dog yderligere undersøgelser før der kan konkluderes på dette.

Generelle anbefalinger vedrørende spøgelsesnet i danske farvande

På baggrund af projektets konklusioner har vi følgende anbefalinger til fremtidige aktiviteter vedrørende spøgelsesnet:

- Fremtidige kortlægnings- og oprensningsaktiviteter af spøgelsesnet bør være målrettet områder/lokaliteter med begrundet mistanke om eller egentligt kendskab til forekomster af spøgelsesnet, således at processen bliver så omkostningseffektiv som muligt. Med de begrænsede mængder af net, der estimeres at kunne fanges pr. km^2 (i konfliktområderne fra 0,2 i Langeland 3 til 1,2 i Jyske Vestkyst 3) vil eftersøgningstogter med f.eks. sidescan sonar eller dræg, i områder uden begrundet mistanke om spøgelsesnet, blive meget omkostningstunge i forhold til den forventede oprydning. Det samme gør sig gældende i forhold til oprensning på vrag, hvor præcis information omkring positionen ofte er mangelfuld. Hvis der i tillæg ikke er sikker viden om, hvorvidt der forefindes spøgelsesnet på vraget, er der igen risiko for at indsatsen bliver meget omkostningstung i forhold til den opfiskede mængde.

- Til at indsamle information om forekomster af spøgelsesnet bør der oprettes en hjemmeside/app, hvor man kan rapportere fund/tab af redskaber, og hvor man derudover kan finde relevant information om spøgelsesnet. Det kan f.eks. være: Hvem kontakter man, hvis man finder et net på stranden eller i havet? Hvad gør man, hvis man mister redskaber eller ser nogen efterlade redskaber og hvad bliver der efterfølgende gjort? Flere henvendelser under projektperioden peger på et behov for dette.

- Observeres der spøgelsesnet under habitatkortlægninger, anlægsarbejde eller andre undersøgelser, bør der som minimum rapporteres om positionen, hvis der ikke er mulighed for at bjærge redskabet.

- Sidescan sonar er et nyttigt redskab ved søgning efter/identifikation af spøgelsesnet i afgrænsede områder, f.eks. i et område med flere upræcise rapporteringer om spøgelsesnet, da man på denne måde kan lokalisere positionen på spøgelsesnettet. Redskabet kan efterfølgende målrettet og omkostningseffektivt fiskes op med dræg eller dykkere, alt efter hvilken habitattype redskabet befinder sig på.

- Historiske data om fiskeriets udbredelse bør inddrages, hvis man ved fremtidige projekter søger at identificere konfliktområder fra perioder med et andet fiskerimønster og flådesammensætning, da mange af de net der findes, har vist sig at være af ældre dato (Tschernij 2020).

- Oprensningsaktiviteter på vrag bør altid udføres af professionelle dykkere, da både frigørelsen af redskabet fra vraget og hævningen af redskabet fra bunden er forbundet med risiko for dykkeren. Der bør inden en evt. oprensning på vrag foretages en række overvejelser: Er den præcises position på vraget kendt? Er der rapporteringer og evt. billeder, der kan dokumentere mængden, placeringen, fangsteffektiviteten og evt. alderen på nettene? Hvor meget er der på vraget og hvordan sidder det? Hvor dybt ligger vraget? Fiskes der fortsat på og omkring vraget? Hvis der er tale om et historisk vrag (>100 år) bør man som udgangspunkt ikke foretage en oprensning, da der er en betydelig risiko for, at strukturer på vraget enten holdes sammen af gamle spøgelsesnet eller at mindre stykker knækker af i forbindelse med at nettet hæves. Hvis der er foretaget oprensning på et givent vrag, bør fiskeri på og omkring lokaliteten forbydes fremadrettet for alle redskabstyper. Dette bør gøres for at de bjærgede og måske gamle og ødelagte net, ikke blot erstattes af nye med en større fiskerieffektivitet.

- Informationer om fritidsfiskeriets fiskerimønstre er mangelfuldt og i kombination med, at de endnu ikke har rapporteringspligt, hvis der mistes redskaber, er der begrænset kendskab til evt. konfliktområder for fritidsfiskere samt hvor de mister redskaber. En bedre registrering af fritidsfiskeriets indsats i forskellige områder samt den allerede planlagte registreringspligt for tab af fritidsfiskerredskaber, vil give en ide om, hvor der kan være forekomster af spøgelsesnet fra fritidsfiskeri og hvad der forårsager tab af net hos fritidsfiskere i Danmark.

- Limfjorden, der som udgangspunkt ikke var omfattet af dette projekt, har vist sig at have et meget alvorligt problem med spøgelsesnet, som er fokuseret på fiskepladser efter hummere og taskekrabber. En stor andel af de net, der er fundet, er af ældre dato og bliver ofte betragtet som fortidens synder, men der er også fundet et antal net af nyere dato. Der bør derfor sættes ind i dette område, således at tilvæksten af spøgelsesnet stoppes. Dette kan gøres ved stærkere regulering og kontrol, men også gennem bedre oplysning om konsekvenserne af at efterlade net f.eks. hvor meget sådanne efterladte net fortsat fisker og at de over tid nedbrydes til mikroplast, der frigives til vandmiljøet.

- For at skabe opmærksomhed og viden målrettet fiskerne i Limfjorden kan der laves lokale forsøg med at ”efterlade” forskellige redskaber (svarende til Tschernij & Larsson (2003) undersøgelser), så man kan estimere hvor mange hummere og krabber, der fanges i spøgelsesnet over tid, og hvor lang tid et redskab effektivt fisker. Forsøgene bør laves med garn, kinatejner og tejner, da det er disse redskaber, der under oprensningen har bifanget flest hummere og krabber.

- For at få mere viden om sammenhæng mellem forskellige fiskerier og tab af net kunne der laves en nærmere undersøgelse af, hvor mange skader (tab af netstykker) forskellige fiskerier har på forskellige bundtyper og over sæsonen. Disse resultater vil efterfølgende kunne relateres til estimatet af, at der kan findes $49x10^3$ netstykker i de danske farvande med et fuldt dækkende trawl survey.

Summary

Background

This report is the final delivery within the project Ghost nets in Danish waters (*Spøgelsesnet I danske farvande*) initiated by a tender from the Danish Fisheries Agency in 2019 and financed by a grant from the Danish Maritime and Fisheries Development Program to promote the implementation of the Integrated Maritime Policy (IMP).

The main purpose of the project is to investigate (and quantify) the occurrence of ghost nets in suspected conflict areas for ghost nets in Danish waters and to test the hypothesis that the occurrence of ghost nets is concentrated in specific conflict areas. In addition, methods for efficient, gentle and cost-efficient retrieval of ghost nets must be tested and adapted. The results of these studies are described in this report.

What are ghost nets and how do they arise?

Ghost nets are a collective term for all types of lost or abandoned fishing gear in the sea or in fresh water. The term therefore includes both recreational and commercial fishing gear such as gillnets, fykes, trawls and pots, but also angling equipment such as lines, lures and rubber animals.

Most fishing gear are made from different plastic materials and will in the long term, when it decomposes in the marine environment, contribute to micro plastic in the water column and the sediment. Ghost nets are therefore considered litter that, like other waste, do not belong in nature.

Ghost nets will in many cases continue to fish for some time. This unintended fishery is called ghost fishing and in addition to the targeted species the ghost nets can also catch seabirds, marine mammals, shellfish and other non-targeted fish species.

Ghost nets can generally occur in two different ways, independent of gear type

1. *They can be lost unintentionally* either due to conflicts with marine traffic or other fishing activities, or due to bad weather, gear defects or snagging on bottom structures like e.g. rocks or wrecks. <u>This project and the methods used, do focus on the unintentionally loss of commercial fishing gear caused by conflicts between active gear (trawl) and passive gear (gillnets) and other marine traffic.</u>

2. *They can be left or dumped intentionally*. Such areas cannot be identified by the conflict analysis outlined for this project. <u>However, during the project period, this have proved to be a major problem in Limfjorden, where the amounts present, probably exceeds the amounts in all the conflict areas identified.</u>

The project framework

The project was divided into three sub-tasks and five phases:

Subtask 1. Extent of ghost nets in Danish waters.

- Phase 1: Validation of GIS analysis and identification of conflict areas for further examination
- Phase 2: Fieldwork – Mapping the occurrence of ghost nets in selected conflict areas
- Phase 3: Supplementing the occurrence of ghost nets and conflict areas with BITS and IBTS data, estimating the total extent of ghost nets in conflict areas.

Subtask 2. Testing and adapting methods for removing ghost nets in selected focus areas

- Phase 4: Review of recovering methods and experiences from other countries
- Phase 5: Fieldwork – Experiments with removal of ghost nets

Subtask 3. This report.

Each phase was completed with the submission of a note which accounts for activities and results. These notes and their annexes form the main component of this report, with one exception being the section on future recommendations and the results of Phase 3, which are only described in this report.

Activities and results from each phase

Subtask 1. Extent of ghost nets in Danish waters

Phase 1: Validation of the GIS analysis and identification of conflict areas for further examination

A total of 11 conflict areas were identified, of which 6 belonged to the North Sea / Skagerrak area and 5 belonged to the inner Danish waters, incl. the area around Bornholm. The criteria for prioritizing and selecting areas were;

- Multiple 1x1 km squares with different conflict intensities between active and passive fishing gears (Fig. 3.1.2).
- Large passive fishing gear activities in areas with heavy maritime traffic (Fig. 3.1.3).
- Information from other projects on foreign fishing activities or projects on ghost nets where the maps are not yet public.

Areas mainly fished by small vessels <12m and recreational fishermen (vessels without VMS (Vessel Monitoring System) and often without AIS (Automatic Identification System)) have not been taken into account, as their fishing intensity is not quantified in statistics. Areas deeper than 40 meters are downgraded due to technical challenges in operating sidescan sonar and ROV at these depths and in achieving the required quality of data. Areas with intensive trawl fisheries are, based on experiences from other countries, not included. The reason for this, is that lost nets in these areas are expected to be caught by the trawls.

The identified areas in the North Sea / Skagerrak can be seen in the table below together with the bottom types in the area, the main reason for the selection of the area and the priority of the area. Cf. the requirements specifications, as a minimum the following two bottom types had to be examined: sand/soft bottom and stone or bubble reef. (Table 3.1.1.)

Area	Bottom type	Main reason for selection	Priority
Gule Rev	Mixed sediment Natura 2000 stone reef	Days of overlap between active and passive gears, but mainly chosen due to known foreign beam trawl activity in the area. Natura 2000 stone reef.	First priority stone reef
Store Rev	Mixed sediment (Natura 2000 stone reef) Sand	The area with most overlap between active and passive fishing gears both on average and in a single square. Mapped as a Natura 2000 stone reef surrounded by sand bottom. 3h from Hirtshals.	First priority, stone reef and sand area
Jammerbugten	Sand	Overlap between active and passive gears including foreign beam trawlers and marine traffic in the area. Large passive fishery in area 2.	First priority, on the way between the two first priority reef areas
Hanstholm	Sand Mixed sediment	Overlap between active and passive gears and half of both subareas are affected by high activity of marine traffic. Close to the shore and Hanstholm harbour.	Second priority
Hirtshals	Mixed sediment Sand	Overlap between active and passive gears and marine traffic in the area. Includes both sand and Natura 2000 stone reef area. Close to the shore and to Hirtshals harbour	Second priority
Jyske Vestkyst	Coarse sediment Mixed sediment Sand Natura 2000 stone reef	Large area with overlap between passive and active fishing gear. High fishing intensity with passive gears and moderate activities with active gears. Natura 2000 stone reef	Second priority, based on cost efficiency

The identified areas in the Inner Danish waters incl. the area around Bornholm can be seen in the table below together with the bottom types in the area, the main reason for the selection of the area and the priority of the area. (Table 3.1.2.)

Area	Bottom type	Main reason for selection	Priority
West of Bornholm	Mixed sediment Rock and biogenic reef Sand Mud	Much passive fishery in the area. Swedish (unpublished) ghost net activities in the area. Natura 2000 stone reef area.	First priority due to Swedish ghost net activities. However, area 2 and 3 are very deep.
Langelandsbælt	Mixed sediment Sand Stone reef in Natura 2000 area	Highest overlap in inner Danish waters between active and passive gears. Heavy marine traffic, stone reef in Natura 2000 area	First priority It covers the requirements for both stone reefs and sand areas
Store Middelgrund	Coarse sediment (Natura 2000 stone reef) Mixed sediment Sand, Mud	One of the few areas with overlap between passive and active gears in Kattegat. Marine traffic and passive gear. Stone reef	Second priority Not much activity and far from harbours
Øresund area	Coarse sediment Sand Mixed sediment	Large fishing activity with passive gears, no active gears but heavy marine traffic. Sheltered area under many wind directions. Shallow area.	Second priority Large distance to first priority areas.
Southeast of Bornholm	Mixed sediment Sand Mud	This area has, compared with other areas in the Inner Danish waters, a square with a high number of days with overlap between active and passive gears. The large depth and the mixed sediment potentially increase the risk of losing nets or parts of nets.	Second priority Area too deep and far from harbour

Phase 2: Fieldwork – Mapping the occurrence of ghost nets in selected conflict areas
A total of four surveys were carried out in 2020 and 2021, three surveys with sidescan sonar and video and one diving survey on wrecks.

The wreck survey was carried out in the waters around Møn, here nets or trawl were observed on 4 of 7 examined wrecks and angling equipment on 5 of the 7 wrecks examined. The majority of the nets observed on the wrecks are estimated to be old.

The sidescan survey in the Inner Danish waters area were carried out in the Langeland Belt and covered both sandy areas and stone reef areas. A total of 31 1x1 km squares were examined. 7 anomalies observed on the sidescan images were examined with video, none of these could be confirmed as ghost nets.

In the North Sea / Skagerrak area, a total of 25 squares (1x1 km) were surveyed in the areas Jammerbugten, Store Rev and Hirtshals. Here, 5 anomalies were ground truthed with video or dredge, 1 of these anomalies turned out to be a 240m long gillnet with a buoy, an anchor and a catch of 40 kilogram of brown crabs. The net was recently lost. Another anomaly is also believed to be lost gear, as rope fibres were stuck to the dredge, but it was not possible to retrieve a piece large enough to identify the origin.

As an additional task, a sidescan/video study was conducted in the Limfjord to test the hypothesis that the ghost net problem in Limfjorden is concentrated in lobster fishing areas. Here, a total of 5 areas were investigated, 3 lobster areas and 2 common fishing areas. More than 30 anomalies which may be ghost nets were identified, the majority of these were observed in the lobster areas. Of these, 2 nets were visually confirmed, one in a lobster area and the other in a fishing area.

Phase 3: Supplementing the occurrence of ghost nets and conflict areas with BITS and IBTS data, estimating the total extent of ghost nets in conflict areas
If all Danish waters were trawled by one of the International standardized trawl surveys (BITS / IBTS), it is estimated that $49x10^3$ nets/net pieces would be caught (with a standard deviation of $13x10^3$), which corresponds to approx. 0.45 nets per. km^2. This must, however, be considered an underestimate, as a trawl is not expected to catch all net pieces and the catchability will be variable depending on the size of the pieces and the gear material (Galgani et al., 1995). The estimate of $49x10^3$ nets is modelled on the basis of the project ghost net findings, as well as data on marine litter collected during the international standardized trawl surveys (IBTS / BITS). The net pieces from IBTS / BITS vary in size from a few centimetres to a catch of 350 kg nets and include both gill nets and trawl pieces.

The net pieces were not evenly distributed within the Danish waters, but no significant correlation was found between the concentration of net pieces in an area and the number of days of conflict between active (trawl) and passive gear (gillnet). Neither between the intensity of passive fishing and nets pieces nor active fishing and net pieces. The hypothesis that ghost nets are concentrated in conflict areas can therefore not be confirmed.

Subtask 2. Testing and adapting methods for removing ghost nets in selected focus areas

Phase 4: Review of recovering methods and experiences from other countries

Two major projects on ghost nets have been carried out in surrounding countries, FANTARED 2 and Marelitt Baltic. Both projects have come up with a number of recommendations, Marelitt Baltic has in addition published a number of documents with guidelines for how various ghost net problems should be addressed. In short, a successful removal of ghost nets requires two steps.

1. That the exact position of the ghost net can be identified either by sidescan sonar, video, divers, drag with drag, or reporting observations with indication of position.
2. Retrieval of the ghost net either with dredge or by divers. The location of the net on the bottom (e.g. wreck or sandy bottom) is crucial for the choice of method.

Phase 5: Fieldwork – Recovering of ghost nets

During the project, ghost nets were removed both by divers and with dredge. Both methods are effective if the position on the ghost net is known, however a removal with a dredge does not require quite as precise position knowledge as a removal with divers, since areas without a sensitive species like eel grass, can be searched by the use of a dredge, without substantial inappropriate disturbances of the seabed (Sahlin & Tjensvoll, 2018).

Prior to removal of nets on wrecks, protected reefs and other complex and fragile structures, it should be assessed whether it may do more harm than good to remove it, if the net e.g. has become an integral part of the structure. If decided to retrieve the net it must be done gently with divers, so the structure is not damaged. For safety reasons, net removal must always be carried out by professional divers. Removal of nets, lying on the seabed, with a dredge is a relatively cheap and efficient method and can in principle be performed by all sizes of vessels.

Conclusions and perspectives of results to surrounding countries

Ghost nets caused by the loss of fishing gear are generally not considered to be a widespread problem in Danish waters, and the project has not found a significantly higher concentration of ghost nets in the identified conflict areas (mainly selected due to overlap between passive and active fishing). Fishing gear from both commercial fishers, recreational fishers and anglers have been found. It is estimated that ghost nets can be found on more than 50% of the wrecks located in areas where there is or has been fishing activities. The actual number of nets will depend on the fishing intensity in the area and the current conditions. In addition, during the project period, a serious problem has been identified in the Limfjord with what is considered to be *deliberately abandoned gear* in lobster and crab fishing areas (Christensen (2020), unpublished results from the Limfjord clean-up project).

The above conclusions will be elaborated and put into perspective in the following.

Based on the project's ghost net findings, supplemented with litter data collected during the annual international standardized trawl surveys (BITS / IBTS), it is estimated that if you trawl all Danish waters you will catch $49x10^3$ net or net pieces (standard deviation of $12x10^3$), which corresponds to an average of approx. 0.45 nets per. km^2. The number is probably an underestimate, as the standardized trawl hauls generally are carried out in areas with smooth bottom, where no structures for catching and detaining nets and pieces of net are found. Furthermore, the catchability of the net materials is not 100% and varies depending on the net type and size (Galgani et al., 1995). The $49x10^3$ is the first estimate of net and net pieces and is not directly comparable with the loss estimates and estimates of marine litter made for the surrounding waters or other European areas. The perspective is therefore a broader discussion of the ghost net situation in Danish waters.

In the FANTARED 2 report from 2003, it was estimated that Swedish fishermen lost 3.6 to 3.8 nets per net vessel, corresponding to 0.1% of the fishing gear used. However, these numbers are from a period with a declining cod stock in the Baltic Sea and a real struggle for fishing grounds between gillnetters and trawlers, so the main reason for the loss was justified by conflicts between the fisheries. It is therefore assumed that the sharp decline in the fishing fleet over the past 25 years probably has led to fewer conflicts and thereby a reduction in the loss of nets per gillnet vessel. It should be added that FANTARED 2 also assessed that Swedish trawlers in the same period annually fished up ghost nets corresponding to amount of nets the gillnetters lost. However, some of the retrieved nets are believed to originate from other countries' fishing fleets.

Commercial fishermen are obliged to report loss of gear to the Danish Fisheries Agency's Fisheries Monitoring Center (FMC) no more than 24 hours after the loss and note it in their eLog. In the period 2015 to 2019, there have been a total of 40 reports, of which 27 were from bottom trawlers, 10 from purse seines and 3 from pelagic trawlers and no reports from gillnetters (Table 5.1.5). In the fishermen's eLog they can also report damage to gear, however they are not obliged to do so (Table 5.1.5). Here, bottom trawlers have approx. 100 reports of damaged gear per. year. Whereas in the gillnet fisheries, only a single report of a broken / torn net from 2015 can be found, which is far below what has been found in the Marelitt Baltic project. Here, 25% of the net fishermen surveyed answered that they lose nets once or less once a year.

The above loss figures are very low compared to e.g. Norwegian reports, but this is expected, as the majority of the Norwegian reports of losses are from northern Norway, where the fishing areas are very deep and where the weather is generally harsh. This area is also where they carry out their retrieval surveys at water depths between 50 and 1000 m (Ref. # 1), and thus under conditions not comparable to Danish waters. However, the Clean Nordic Oceans network points out that, within the Nordic countries, there seems to be too few reports of gear losses in relation to the total fishing activities and the types of fishing. The few Danish reports from gillnetters, both regarding damage to and loss of nets, are further in contrast to Clean Nordic Ocean's conclusion, that there is a greater risk of losing passive gear such as gillnets, pots or fykes compared to active gear such as trawls and seines (Langedal et al., 2020). This indicates a general underreporting within the Danish gillnet fishery both regarding voluntary reporting on damaged gear and on the required reporting of gear loss.

The number of commercial fishing vessels has been reduced by approx. 60% over the last 25 years from 4,830 in 1996 to 1,998 in 2020. The largest reduction has occurred in the number of trawlers, where there are only approx. 1/3 left, compared to the number in 1996, and the number of gillnet vessels has approximately halved. It is likely that tis decline in the number of vessels has caused and will continue to cause a decrease in the number of gear loss within commercial fishing. The Marelitt Baltic project had a similar conclusion supplemented by the fact that improved weather forecasts and navigation technology also have reduced the risk of loss (Predki et al., 2019).

The number of new and perhaps inexperienced, recreational fishermen have within the last couple of years increased by 13% in Denmark (28,352 in 2019 & 32,686 in 2020), which potentially could increase the risk of gear loss and thereby the number of ghost nets (Ref. # 4).

The results of the project cannot confirm the hypothesis that ghost nets accumulate in specific conflict areas. However, this does not necessarily mean that there is not a greater loss of gear within these areas, only that no significant accumulations have been observed. The VMS (Vessel Monitoring System) data used in the present analysis to identify the conflict areas are from the period 2014-2018, which means that older conflict areas are not identified by this method, an example of this is an area west of Bornholm, where Swedish studies have found large concentrations of old gillnets (Tschernij, 2020). Another reason why ghost nets do not accumulate in conflict areas between active and passive gear, may be that trawlers fishing in these areas, over time catch entire nets or net pieces.

Overall, the information collected within the project points towards a conclusion that neither the present occurrence of ghost nets nor the unavoidable loss of fishing gear is a widespread problem within Danish waters. But net and net pieces will accumulate over time if they are not removed from the sea, as there in all fishing activities will be a risk of losing all or part of a fishing gear due to accidents or defects. This corresponds to the conclusions from the Marelitt Baltic project, where the current amount of gear loss in the fishery is considered to be very limited and that minor losses is inevitable.

The Limfjord

An area proven to be an exception to the above conclusion is the western part of the Limfjord. Here, in areas with a targeted fishery for lobsters and crabs, very large amounts of ghost nets have been found. Given the general shallow water depth, the very large amounts of ghost nets found, as well as the lack of buys and anchors on the retrieved gear, it is assumed that the majority of this gear is *abandoned and not lost*.

The areas in the Limfjord would not, even if it had been included in the analyses in the current project, have been identified as a conflict area. This is because it is not conflicts between gear types or marine traffic that causes ghost nets in this area. During the project, it has proved very difficult to provide information about ghost net areas in general and areas not driven by conflicts, e.g. historical dumping areas, ghost nets on wrecks, areas where fishing gear often are torn or lost due to bottom structures or weather conditions. Areas with deliberately abandoned gear is difficult to identify without local reports and it cannot be ruled out that there are other fjords or areas with similar problems.

Wrecks

Ghost nets were observed on 4 of 7 wrecks examined during the diving survey. Vragguiden.dk and other sources that describe diving on wrecks were reviewed for registrations of nets on wrecks. However, this information is not sufficient for modelling how many wrecks in Danish waters that contains ghost nets, because when a wreck is described and no nets are mentioned, it does not necessarily mean that there are no nets on the wreck, only that it is not registered. An

English study found nets on 7 of 11 wrecks examined (Revill & Dunlin, 2003) which are the same level as in the present study.

In general terms, a wreck forms a structure on the seabed that stands out from the surrounding area, wrecks often attract fish species such as e.g. cod and therefore also all types of fishermen (recreational, commercial and anglers) depending on the distance to the coast. Since wrecks often have a mast, rudder, or something else that protrudes and thereby increases the risk of fishing gear getting stuck, it is assumed that a wreck located in an area with fishing activity is as likely to host ghost nets as the wrecks in this study, i.e. more than 50%. The local fishing intensities, types of fishing (e.g. gillnets, trawls, angling), current conditions and the complexity of the wreck will determine the actual quantity and type of ghost nets stuck on a wreck at any given time.

Bycatch

During the completed dive survey and sidescan sonar/clean-up surveys, ghost fishing was only observed on one occasion. This was in a relatively new-lost crab gillnet, retrieved outside Hirtshals containing 70 brown crabs as a catch. This one observation is not enough to make an estimate of the total ghost catch, neither on species nor quantity in Danish waters.

Ghost nets that curl up on the seabed quickly loses the ability to efficiently catch roundfish, whereas they can maintain the ability to catch flatfish and crustaceans moving along the bottom for between 9 months and a year (Kaiser et al., 1996; Revill & Dunlin, 2003). A Swedish study of cod nets has shown that catch efficiency fell by approx. 80% over a three-month period compared to the commercial fishing efficiency, after which it stabilized at 5-6% of the original fishing efficiency (Tschernij & Larsson, 2003). These results are in line with the project findings, where all ghost nets were assessed to be considerably older than 27 months and they had no catches, except for the crab gillnet, which had almost fished as an active net. An experiment off the north-eastern coast of England has shown that gillnets stretched out on a wreck experienced that the fishing capacity of the were reduced to 18% of its original capacity after 10 weeks, and after 2 years the net was so damaged and degenerated that it could not fish anymore (Revill & Dunlin, 2003).

In general, one can say that recently lost nets will continue to catch the species they are set out to catch. Local conditions such as wind, currents, fauna and bottom conditions that can destroy net meshes, roll up the net or cover the net in biological material will affect the period a given net effectively can fish. Taking into account the limited number of newly lost nets lying on the bottom and ghost nets stuck on wrecks, ghost catches are estimated to be insignificant in relation to the total fishing mortality, which is in line with the conclusions of Kaiser et al. (1996). No catches of birds or marine mammals have been observed in the identified ghost nets and therefore, ghost nets are not considered to have consequences for the overall mortality of these groups. An exception to this may be found in the Limfjord, where large quantities of ghost nets have been found in a number of relatively small areas with a targeted fishery for lobster. Over time, the amount here, may overall have had an effect on mortality among lobsters and crabs. However, it requires further research before this can be concluded.

General recommendations regarding ghost nets in Danish waters

Based on the conclusions of the project, we have following recommendations regarding future ghost net activities:

- Future ghost net mapping and clean-up activities should be targeted areas / locations with reasonable suspicion of or actual knowledge of ghost net occurrences, so that the process becomes as cost-effective as possible.

- With the limited quantities of nets estimated per km^2 (in the conflict areas from 0.2 in Langeland 3 to 1.2 in Jyske Vestkyst 3), search expeditions with e.g. sidescan sonar or dredge, in areas without reasonable suspicion of ghost nets, becomes very costly compared to the expected clean-up potential. The same applies to cleaning activities on wrecks, where precise information about the wreck position is a key factor for cost-efficiency but often is found to be deficient or inaccurate. In addition, the presence of ghost nets on a given wreck should be known prior to a clean-up dive activity on the site, as it otherwise can be costly for no or small amounts of ghost nets retrieved.

- To collect information about occurrences of ghost nets, a website / app should be launched where finds or losses of fishing gear could be reported, and where relevant information about ghost nets could be found. It could be questions like: Who do you contact if you find a net on the beach or in the sea? What do you do if you lose gear or see someone leave gear behind and what is done afterwards? Several inquiries during the project period indicate a need for this.

- If ghost nets are observed during habitat surveys, construction work or other surveys, the position should at least be reported if it is not possible to retrieve the fishing gear.

- Sidescan sonar is a useful tool for searching / identifying ghost nets in defined areas, e.g. in an area with several imprecise reports on ghost nets, as this method can locate the exact position of the ghost net. The ghost net can then be retrieved cost-efficiently with a dredge or divers, depending on the type of habitat the gear is located on.

- Historical data on the fisheries distribution should be included, if future projects seek to identify conflict areas from periods with different fishing patterns and fleet compositions, as many of the identified ghost net have proved to be old (Tschernij, 2020).

- Clean-up activities on wrecks should always be performed by professional divers, as both the release of the ghost net from the wreck and the raising of the ghost net to the surface are associated with risk to the diver. Prior to a possible clean-up activity on a wreck a number of considerations should be made: Is the exact position of the wreck known? Are there reports and possibly images that can document the quantity, location, catch efficiency (ghost fishing) and possibly age of the ghost net? How much ghost net is on the wreck and where is it located? How deep is the location of the wreck? Is there fishing activities on and around the wreck? In the case of a historical wreck (> 100 years), cleaning should not be carried out, as there is a significant risk that structures on the wreck are either held together by old ghost nets or that smaller pieces break off when the ghost net is freed from the wreck or raised to the surface. If cleaning has been carried out on a given wreck, fishing on and around the site should be prohibited in the future for all types of gear. This should be done so that the retrieved, perhaps old and damaged nets, are not just replaced by new ones with a higher fishing efficiency.

- Information about the fishing patterns of the recreational fishery is deficient and in combination with the fact that they are not obliged to report if they lose gear, the knowledge of possible conflict areas for recreational fishermen and where they lose gear, is limited. A better registration of the distribution of the recreational fishery in different areas as well as the already planned obligation to report losses of recreational fishing gear, will give an idea of where recreational ghost nets may be present and what causes the loss.

- The Limfjord, which originally was not included in this project, has proved to have a very serious problem with ghost nets, which are focused on fishing grounds for lobsters and crabs. A large proportion of the nets found, are of older age and are often considered "the sins of the past", but a number of nets of more recent date have also been found. Efforts should therefore be made in this area to stop the increase of ghost nets. This can be done through stronger regulation and control, but also through better information about the consequences of abandoning fishing gear e.g. how much abandoned nets fish and that over time they decompose into microplastics that are released into the aquatic environment.

- To create awareness and knowledge targeted the fishermen in the Limfjord, local experiments could be made by "leaving" various gear (corresponding to Tschernij & Larsson (2003) studies), so that estimate on lobster and crab catches for abandoned gear in Limfjorden can be made. The experiments should be done with gillnets, Chinese pots and fykes, as it is these gears that have caught the most lobsters and crabs during the clean-up activity.

- In order to gain more knowledge about the connection between different fisheries and loss of nets, a closer study could be made of how much damage (loss of net pieces) different fisheries have on different bottom types and during the season. These results can subsequently be related to the estimate that 49×10^3 nets can be found in Danish waters with a comprehensive trawl survey.

1. Introduction

This report is the final delivery within the project Ghost nets in Danish waters (*Spøgelsesnet I danske farvande*) initiated by a tender from the Danish Fisheries Agency in 2019 and financed by a grant from the Danish Maritime and Fisheries Development Program to promote the implementation of the Integrated Maritime Policy (IMP).

In the requirements specifications for the project, the aim was described in the following way: The project shall build knowledge about the extent of ghost nets in Danish waters and test the hypothesis that ghost nets is concentrated in special conflict areas, where conflicts between various human activities can result in loss of nets.

The main purpose of the project is to investigate (and quantify) the occurrence of ghost nets in suspected conflict areas for ghost nets in Danish waters. In addition, methods for efficient, gentle and cost-efficient retrieval of ghost nets must be tested and adapted. These tasks address the majority of the recommendations made in the Danish ghost net study by Egekvist et al. (2017) “Ghost nets – A pilot project on derelict fishing gear”.

This final report describes the activities in the five phases of the project, which all have been finalized by the delivery of a note approved by the steering group of the project. These approved notes make up Chapters 3, 4, 6 and 7 with only minor corrections or changes. New in this final report is *Chapter 2 on conclusions and recommendations for future work* and *Chapter 5 on estimating the total extent of ghost nets in conflict areas* including a test of the conflict area hypothesis mentioned above.

1.1 Background of the project and the definition of ghost nets

During the last few decades, there has been an increasing focus on and awareness of marine litter. A special focus has been on the extent of plastic litter, its origin and the consequences of this litter on the oceans and the marine life, which in the OSPAR Maritime Area accounts for up to 90% of the items found on beaches. It has been estimated that 4.6-12.7 million tonne was added into the oceans in 2010 (Law et al. 2010; Jambeck et al. 2015; Ref. #5). Richardson et al (2019) estimate, based on reviews of 68 publications from 1975-2017, that 5.7% of all fishing nets (trawl & seine fragments and gillnets), 8.6% of all traps, and 29% of all lines, are lost around the world each year. In EU waters it is estimated that 27% (in weight) of the marine litter, equivalent to 11,000 tons annually, originates from the fishing and aquaculture industry (CWD, 2018).

Ghost nets are a general term for abandoned, lost or otherwise discarded fishing gear (ALDFG) and cover all types of fishing gear (trawl, gillnet, fyke, pot or even jigs) and it can originate from all types of fishermen: recreational, part-time and professional or anglers. Net fragments and lines can also originate from the aquaculture industry.

Most fishermen, whether recreational or professional, will at some point lose at least parts of their fishing gear and in some cases the entire trawl, a full fleet of gillnets or a fyke/pot. These losses all contribute to marine litter if they are not recovered and also, for a variable period of time, contribute to ghost fishing.

According to EU legislation, a professional fisherman is obliged to try to recover any lost fishing gear. If the gear is not retrieved within 24 hours of the loss a report should be made to the relevant Fisheries Monitoring Center (in Denmark, the Danish Fisheries Agency) stating the position, type of gear lost and what has been done to find and retrieve it. It should also be noted in the vessels' eLog (C.R. No 1224/2009, Article 48). The number of Danish reports on lost nets are very sparse compared to reports from especially Norway, where the reports are the basis for an annual retrieval survey. This has raised the questions whether Danish fishermen underreport or if the relatively shallow waters and smooth bottom types actually cause less fishing gear to be lost in Danish waters compared to e.g. Norwegian waters, and also makes it easier to retrieve the nets if lost.

Ghost nets can generally occur in two ways, they can be:

- *lost unintentionally* due to conflicts, either with other marine traffic or other fishing activities/gear, bad weather, gear defects or snagging on bottom structures like e.g. rocks or wrecks. <u>This project and the methods used focus on the unintentionally lost ghost nets created by conflicts.</u>

- *left or dumped intentionally*, which during the project period proved to be a much bigger problem in Limfjorden than in any or even all the conflict areas identified.

Ghost nets can come in all shapes and sizes, from small fragments of a net either teared or cut off from large trawl and gillnets, over traps and fykes to large gillnets linked into long chains of often more than 100m in length, and to complete trawls.

The perception of when a net or other lost fishing gear is or will become a ghost net is very variable depending on who you ask. A fisherman, professional or recreational, will in most cases **not** consider a loss of a piece from e.g. a gillnet or a trawl to be a potential ghost net or a loss that need to be reported, whereas a diver observing just a small fraction of a net hanging from a wreck, will consider this a ghost net. Angling gear is normally not considered as ghost nets even though it can ghost fish just like any other lost fishing gear, and all anglers are at some point believed to have experienced a loss of line and jigs which are accumulated at the popular angling spots.

1.2 General implications of the presence of ghost net

Overall, there are two main implications of ALDFG or ghost nets:

1. Ghost nets are litter that, like all other waste, do not belong in nature. Most fishing gear is made from different type of plastic material and will in the long term, when it decomposes in the marine environment, contribute to microplastics in the water column and the sediment.

2. Ghost nets will in many cases continue to fish for the targeted and non-targeted species for some time. This unintended fishery is called ghost fishing and in addition to the targeted species the ghost nets can also catch seabirds, marine mammals, turtles, shellfish and other fish. Whether the ALDFG are ghost fishing or not, is very much depending on the type of ghost gear, it's actual location on the bottom structure or wreck, on the age of the gear and on the coverage with biological material e.g. macrophytes, blue

mussels or with sediment. In general, gillnets, traps and pots are known to ghost fish for variable amounts of time.

In addition, ALDFG can affect the benthic environment either by mechanical wear and tear or by becoming an integrated part of the bottom substrate. If it is a floating ALDFG it can become entangled in a passing vessel's propeller or rudder, causing the loss of navigation ability. If found on wrecks it can be a hazard to recreational divers who risk getting entangled in the net (Erzini et al. 1997; Brown et al. 2005; Hong et al. 2017).

1.3 Ghost net activities and estimates from surrounding countries

A number of ghost net projects and clean-up activities have been started or completed in our surrounding countries/waters within the last two decades. In the early 2000s the EU project FANTARED 2, with participants from Norway and Sweden, gave the first indication of the extent of the ghost net problem in Scandinavian waters. Here they found that in 1998 the Swedish fleet lost about 2,750-3,000 nets corresponding to 0.1% of the nets used in a year. The recovery rate was estimated to around 10% meaning that between 2,475 and 2,700 were left at sea. Similar results were found for the Norwegian fleet where 0.1% of used nets, in total 852, were lost in the coastal fishery for cod, 665 of these were retrieved which reduced the percentage of lost nets to 0.02%. However, if only the fleets fishing in southern Norway are considered (which is assumed to be most comparable to Denmark) only 10 nets were reported lost, and all of these were recovered.

In 2011 WWF Poland published a report stating that the cod fishery within EU, lost 5,500-10,000 nets a year in the Baltic Sea in the period 2005-2008. This calculation was based on the Swedish findings in the FANTARED 2 project. In 2013 WWF Poland published a report where they assumed that the number lost in 2009 was 1,500 nets in Poland and 150 nets in Lithuania (Kasperek & Prędki, 2011; Szulc 2013).

The Marelitt Baltic project found from interviews that 91% of Polish fishermen answered that they lose nets once or less than once a year. 12 out of 70 (17%) fishermen estimated that they lose nets once a month. In Sweden, 25% answered that they lose nets once or less than once a year. In Estonia, only 5 out of 59 (8%) state that they lose gear and 18 (30%) of the fishermen answered that they newer loose gear (Table 1.3.1.). They also found regional differences in the causes of loss. In Estonia and Poland, the primary reason was seabed objects, whereas in Sweden conflicts are given as the main reason (Table 1.3.2.).

The project assumes that due to a general reduction of the fishing effort within the last decade in the Baltic the quantities of lost fishing gears have also been decreasing (Tschernij, 2019).

Table 1.3.1. From Tschernij (2019) summarizing how often Estonian, Polish and Swedish fishermen experience gear loss.

Country/region	Less than once/year	Once/year	Once/ Month	Never	Total
Polish	22	**30**	12		70
Swedish	**4**	2	-		24
Estonian	4	-	1	**18**	59

Table 1.3.2. From Tschernij (2019) summarizing the reasons for loosing nets in Estonia, Poland and Sweden.

	Estonia		Poland		Sweden		
Factors	Past	Present	Past	Present	Past	Present	Total
Seabed objects	-	**29**	**47**	**40**	21	21	158
Conflicts	-	**26**	19	27	**40**	**43**	155
Shipwrecks	-	9	24	23	16	19	91
Environment (strong current)	-	0	9	10	14	12	45
Environment (ice)	-	**23**	0	0	0	0	23
Environment (wind/waves)	-	14	0	0	0	0	14
Other reasons (theft, sabotage)	-	-	-	-	9	5	14

Clean Nordic Ocean (CNO) was a Nordic network project funded by the Nordic Council of Ministers with the aim to exchange knowledge and experience about methods and measures to reduce the effects of ghost fishing, littering of the oceans and to increase recycling from commercial and recreational fishing. The project produced a number of information videos: What is Ghost fishing? What can be done when the gear is already lost? How can you reduce the risk of losing fishing gear? How can recreational fishermen report lost fishing gear in Norway?

More local activities are e.g. an initiative from RESCUE OCEAN where local fishermen from Simrishamn have dragged for lost net in Bornholmsgattet, an area south of Sweden and east of Bornholm. In this area more than 10 km of net was retrieved and of this, 75% was estimated to be 10 years or older and the nets caught on average 4.3 fish per 100 m (mainly flounder) (Tschernij, 2020).

In Denmark, there have been some private/NGO initiatives like WWF Denmark in 2017, Gl Åbo camping in Lillebælt 2020/2021, Limfjordsrådets retrieval initiative in 2019 and now the launch of a webpage for reporting ghost nets, Levende Hav activities in Limfjorden in 2020/21 and north of Fyn in 2021. Probably more local activities have passed unnoticed. However, the Limfjord ghost net problem has been a recurring subject and this focus has resulted in a clean-up project in Limfjorden. It started in July 2021 where the fishermen’s organisations DFPO, FSKPO, DAFF & DFF collaborate with DTU Aqua in identifying ghost net areas and clean up some of the identified areas. More than 250 gillnets, china fykes, seine ropes and pots have been removed from the fjord in 26 survey days. Preliminary results can be found in Appendix A.22.

2. Conclusions and recommendations for future work

2.1 Mapping the occurrence of ghost nets

The general conclusion on the search for ghost nets in the identified conflict areas is, that these areas do not seem to hosts ghost nets in any appreciable numbers. Only 12 anomalies were considered potential ghost nets in the 56 km² searched and only two of these were considered likely to be ghost nets. This does not necessarily mean that these conflict areas are not sources of ghost nets, but that the ghost nets do not seem to accumulate in these areas (see Section 4.1.2). Another reason could be that only a fraction of the nets is discovered by the sidescan sonar. This technique for identification of lost gear is a relatively untested method in Nordic waters and the identification percentage is unknown.

Recommendations for future work includes:

- Optimizing the sidescan sonar technique, including research into how different types of fishing gear (trawls, gillnets, longlines) on different bottom types and in different weather conditions appear on the sonar images.
- Research should be initiated on whether automatic pattern recognition programs on sidescan data can be employed to detect ALDFG.

2.2 Survey of ghost nets on wrecks

Three sources of data were considered for selecting the wrecks to cover during the dive survey: divers' private data, divers' databases and the Danish Agency for Culture and Palaces' (DACP) database of wrecks in Danish waters. The DACP-database includes information on more than 9,000 wrecks; however, a large part of the wrecks has problems of one sort or another, including imprecise positions, several names for the same wreck, multiple positions for the same wreck etc. We therefore focused the selection on suggestions from divers with local knowledge to make sure that the wrecks we selected existed and could be found. Because of the limited diving days in the project, we furthermore focused on optimal utilization of the ship time when divers were on board.

The general conclusion from the wreck survey was that ghost nets are common on wrecks, as four of the seven wrecks inspected carried ghost nets and five carried angling gear. The ghost nets observed were all considered to be of older date and no fish, seabirds or marine mammals were observed caught in the ghost nets.

Recommendations for future work includes:

- Verification of the wrecks to survey should be carried out before any future surveys of wrecks.
- If extrapolation of survey data to all Danish waters are required, a general verification of the wrecks in the DACP-database should be carried out.

2.3 Estimating the total amount of ghost nets in conflict areas

Too few ghost nets were observed during the side scan sonar surveys to allow estimating the amount of ghost nets in the conflict areas. The sonar survey data were therefore supplemented with marine litter data from the IBTS/BITS trawl surveys, which covers all Danish waters except fjords. This resulted in a total estimate of around $49x10^3$ fragments of all types of fishing gear in Danish waters (that would be caught if all areas were trawled by the surveys). These fragments can vary in size from a few centimetres to a piece weighing 350 kg, which could be an entire trawl. The fragments were not distributed evenly across Danish waters, but apparently concentrate in particular areas, probably partly as a result of the prevailing ocean currents. There was no correlation found between the intensity of net fragments and three different measures of fishing activity/conflict (hours of fishing with active gear, hours of fishing with passive gear, and days with overlap between the two gear types). Thus, the hypothesis that ghost nets are concentrated in conflict areas is not supported.

2.4 Ghost fishing

During the dive surveys on wrecks and the recoveries of ghost net with drag, there was only one observation of ghost fishing. That was observed in the relatively newly lost net, recovered outside Hirtshals. This net had caught 70 brown crabs with a total weight of 40 kilogram, all alive. This one observation is not sufficient to make a sensible estimate of the extent of ghost fishing neither in species nor in numbers within Danish waters. The reason for the very low frequency of ghost fishing is probably that the majority of the retrieved nets were old and had lost the fishing ability.

Recommendations for future work includes:

- Retrieval attempts/surveys for lost nets should be conducted as soon after the loss as possible. This will reduce the number of animals caught by ghost fishing and it probably increases the chance of actually retrieving the gear.

2.5 Review of recovering methods

2.5.1 Selection of areas to cover

The general conclusion from the present project and projects like MARELITT is that although fishing effort can be used as a basis for designation of candidate areas, it cannot stand alone to predict high densities of ALDFG. Furthermore, areas with low or no fishing effort should not automatically be excluded as candidate areas, because ocean currents may transport ALDFG over long distances.

It is also clear that precise information on the position of ALDFG is invaluable in selecting the areas to cover and should include reports from all stakeholders, both on fishing gear lost and on ALDFG detected.

Recommendations for future work includes:

- Dredging cruises in the Baltic showed that most of the ALDFG were older than 5–10 years. It is therefore recommended to use also historic fishing effort data for the ALDFG density predictions.
- An app or a dedicated website where all stakeholders can report fishing gear lost and ALDFG detected should be developed. This should also include more general information *e.g.* on how to handle retrieved gear or how to prevent loss of gear.
- All professional mapping activities for *e.g.* pipelines, construction work and habitat mapping should be obliged to report any findings of ALDFG.

2.5.2 Recovery of ALDFG

The general conclusion from the field work in the present project and similar projects in other countries is that recovery of ALDFG from wrecks, stone and bubble reefs is best carried out by professional divers, who ideally should be underwater archaeologists as well. On the smoother seabed, dredging is the preferred method, but should not be used in *e.g.* ammunition deposition areas, Natura 2000 areas, eelgrass meadows or areas with located wrecks.

Recommendations for future work includes:

- When dredging for ALDFG it is recommended to work with local fishermen who knows how the fishery in the area is conducted and have experience in using dredges for net retrieval.
- Retrieval of ALDFG from wrecks and sensitive habitats should be carried out by professional divers, who ideally should be underwater archaeologists as well.
- Prior to removing nets from a wreck, the cultural heritage status should always be checked and also the risk of oil leaks and other potential environmental and structural consequences associated with the removal of material.
- Before removing ALDFG, which during many years has been integrated in *e.g.* a wreck, reef or other bottom structure, it should be considered if the removal of the net will cause severe changes or damages to the structure and thereby also to the habitat for algae, mussels and other bottom-living organisms.

2.6 Prevention

The present project did not include work on prevention of ALDFG, and the following recommendations are from other projects and reviews including FAO, MARELITT and Clean Nordic Oceans (CNO).

FAO, CNO and MARELITT recommends the following in relation to prevention:

- That awareness of the consequences of ALDFG for the marine environment is increased among fishermen.
- That fishermen increase their skills in the use of fishing gear, as increased skills reduce the risk of losing fishing gear.
- That the position of fishing gear is clearly marked to reduce the risk of collisions with other users of the sea.
- That fishing gear on the seabed is better marked, as marking will increase the responsibility for reporting in the event of loss of gear. This will also increase the possibility of returning the gear to the owner and hence reuse.

2.7 General recommendations regarding handling and prevention of ghost nets in Danish waters

Based on the project conclusions, we have the following recommendations for future ghost net activities:

- With the limited quantities of nets estimated per. km^2 in the designated conflict areas (from 0.2 in Langeland 3 to 1.2 Jutland's west coast 3), dedicated sidescan sonar surveys focusing on searching for ghost nets will be very costly in relation to the expected clean-up effort. However, if reports of one or more lost nets in an area are retrieved, this method will be useful for finding the exact position, so that the gear subsequently can be retrieved cost-effectively with a dredge or divers.

- During the project period, we have received a number of inquiries from people who have either found nets on the beach or in the sea and who are looking for advice and guidance on where to report this or what to do. An easily accessible website should therefore be published where all this information can be found: Who do you contact if you find a net on the beach or in the sea? What do you do if you lose fishing gear or see someone leave fishing gear behind and what is done afterwards?

- A large part of the ghost nets that occur in Danish waters proved to be of older age, so historical data on the fishery distribution should in future projects be included to identify ghost net host areas.

- Information about the recreational fishing's fishing patterns is deficient and in combination with the fact that they do not yet have a reporting obligation if gear is lost, the knowledge of possible conflict areas for recreational fishermen and where they lose gear limited. A better registration of the recreational fishing effort in different areas, as well as the already planned obligation for recreational fishermen to register loss, will give an idea of where ghost nets from the recreational fishery might occur and what causes loss of nets in the recreational fishery in Denmark.

- Although the Limfjord initially was not part of this project, it has turned out that there is a very serious problem with ghost nets here which are focused on lobster and crab fishing grounds. A large part of the nets is of older date and are often considered the sins of the past, but a number of nets of more recent date have also been found, so it is not completely past! Efforts should therefore be made in this area to stop any increases in both conscious and unconscious ghost nets. This can be done through stronger regulation and control, but also through better information about the consequences of leaving nets and how much these nets ghost fish, e.g. through experiment with different fishing gear similar to (Tschernij & Larsson, 2003) studies so that one can estimate how many lobsters and crabs are lost this way. The experiments should be done with gill nets, china fykes and pots as these fishing gears have shown to have the highest by catch (most ghost fishing) during the clean-up.

- Investigations on how much damage different fisheries have on their gear (loss of net pieces) on different bottom types and over the season e.g. how much is lost when nets are put on and around wrecks, this can then be related to the estimate of $49x10^3$ nets in Danish waters.

During the project, a number of recommendations and proposals were received from various stakeholders. Those recommendations and proposals that are not already covered in the preceding recommendations are presented in the table in Appendix A.24 along with comments to them.

3. GIS analysis and identification of conflict areas for further examination

3.1 Note – Phase 1. Selection of areas and wrecks for ghost net surveys

This note describes the areas selected for further survey analysis using sidescan sonar and video, the underlying analysis and the criteria for selection of areas. It also gives the gross list of wrecks selected for the diving survey.

3.1.1 Selection of areas

According to the contract, a sandy/soft bottom area and a stone/bubble reef needs to be surveyed in each of the two areas North Sea/Skagerrak and Inner Danish waters including the waters around Bornholm.

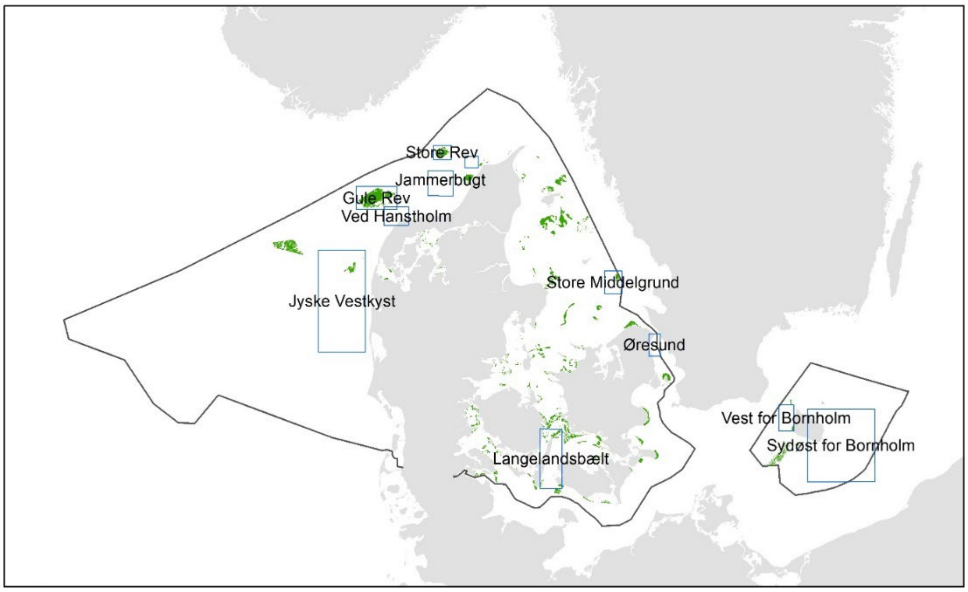

Figure 3.1.1. Map showing the 11 focus areas on the gross list. The black line illustrates the Danish EEZ, the blue lined squares illustrate the 11 focus areas, and the green areas are mapped stone reefs in Natura 2000 areas.

In total 11 areas are selected; six areas are located in the North Sea/ Skagerrak and five in the Inner Danish waters including the waters around Bornholm (Fig. 3.1.1). In each of the 11 areas, multiple smaller areas are identified as potential survey areas.

The six and five areas are gross lists for each of the two areas, as some of the selected areas are quite exposed and sensitive to bad weather; therefore, alternative areas for all wind directions are needed. The selected gross list of areas is split into first and second priority areas in order to optimize the 15 survey days available (Table 3.1.1 & 3.1.2). A detailed description of the areas is found in Appendix A.1 and description of data processing methods and data sources in Appendix A.8.

Criteria for the priority and selection of areas

The criteria for the selection of the areas are:

- Multiple 1x1 km squares with different conflict intensities between active and passive fishing gears (Fig. 3.1.2).
- Large passive fishing gear activities in areas with heavy maritime traffic (Fig. 3.1.3).
- Information from other projects on foreign fishing activities or projects on ghost nets where the maps are not yet public.
- Areas for small gillnetters <12m and recreational fishermen (ships without AIS) are not considered as their fishing intensity is not quantified in any statistics.
- Areas deeper than 40 meters are downgraded due to technical difficulties in operating the sidescan sonar and the ROV for the required quality, in deep waters.
- Areas heavily fished by active fishing gear are, based on other countries' experiences, not considered as areas where lost nets are lying for long as they are expected to be caught in the trawls.

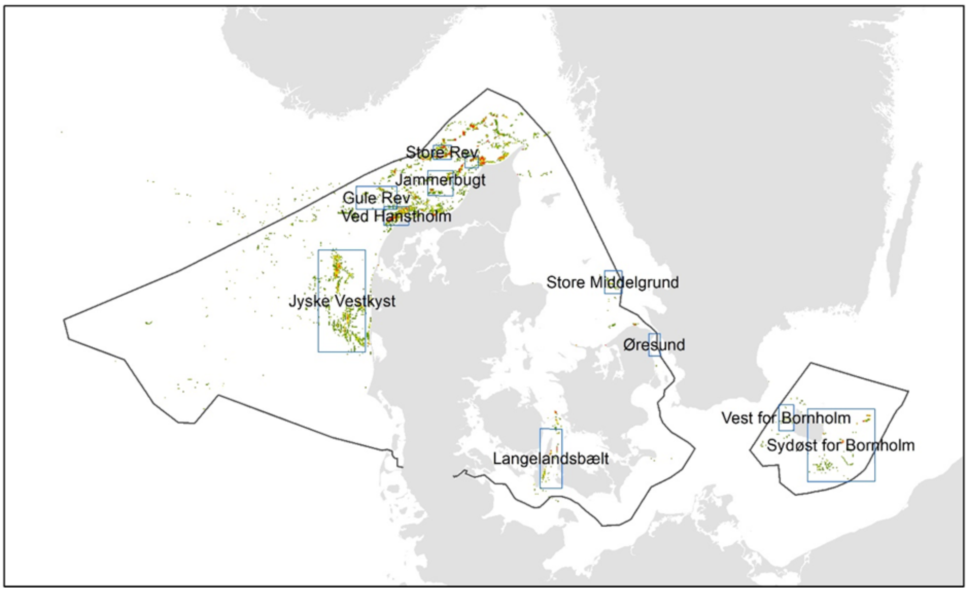

Figure 3.1.2. Map of the Danish EEZ and overlap between active and passive fishing gears 2014-2018.

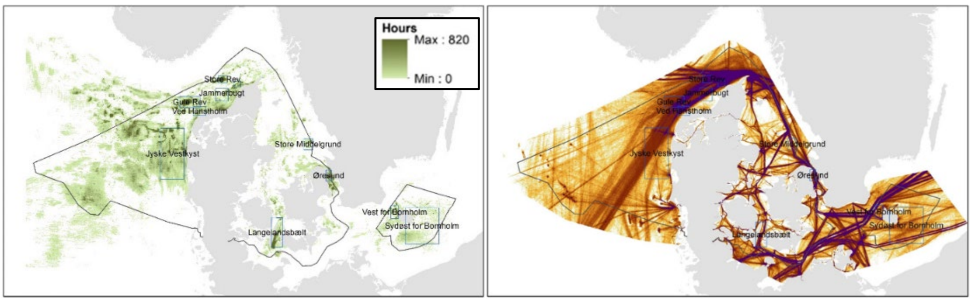

Figure 3.1.3. Left) Average fishing intensity in hours with passive gears 2009-2018. Right) AIS pings from marine traffic, all ships 2016.

Table 3.1.1. Gross list of selected areas in the North Sea/Skagerrak areas.

Area	Bottom type	Main reason for selection	Priority
Gule Rev	Mixed sediment Natura 2000 stone reef	Days of overlap between active and passive gears, but mainly chosen due to known foreign beam trawl activity in the area. Natura 2000 stone reef.	First priority stone reef
Store Rev	Mixed sediment (Natura 2000 stone reef) Sand	The area with most overlap between active and passive fishing gears both on average and in a single square. Mapped as a Natura 2000 stone reef surrounded by sand bottom. 3 hours from Hirtshals.	First priority stone reef and sand area
Jammerbugten	Sand	Overlap between active and passive gears including foreign beam trawlers and marine traffic in the area. Large passive fishery in area 2.	First priority on the way between the two first priority reef areas
Hanstholm	Sand Mixed sediment	Overlap between active and passive gears and half of both subareas are affected by high activity of marine traffic. Close to the shore and Hanstholm harbour.	Second priority
Hirtshals	Mixed sediment Sand	Overlap between active and passive gears and marine traffic in the area. Includes both sand and Natura 2000 stone reef area. Close to the shore and to Hirtshals harbour	Second priority
Jyske Vestkyst	Coarse sediment Mixed sediment Sand Natura 2000 stone reef	Large area with overlap between passive and active fishing gear. High fishing intensity with passive gears and moderate activities with active gears. Natura 2000 stone reef	Second priority, based on cost efficiency

Table 3.1.2. Gross list of selected areas in the Inner Danish waters.

Area	Bottom type	Main reason for selection	Priority
West of Bornholm	Mixed sediment Rock and biogenic reef Sand Mud	Much passive fishery in the area. Swedish (unpublished) ghost net activities in the area. Natura 2000 stone reef area.	First priority due to Swedish ghost net activities. However, area 2 and 3 are very deep.
Langelandsbælt	Mixed sediment Sand Stone reef in Natura 2000 area	Highest overlap in inner Danish waters between active and passive gears. Heavy marine traffic, stone reef in Natura 2000 area	First priority It covers the requirements for both stone reefs and sand areas
Store Middelgrund	Coarse sediment (Natura 2000 stone reef) Mixed sediment Sand, Mud	One of the few areas with overlap between passive and active gears in Kattegat. Marine traffic and passive gear. Stone reef	Second priority Not much activity and far from harbours
Øresund area	Coarse sediment Sand Mixed sediment	Large fishing activity with passive gears, no active gears but marine traffic. Sheltered area under many wind directions. Shallow area.	Second priority Large distance to first priority areas.
Southeast of Bornholm	Mixed sediment Sand Mud	This area has, compared with other areas in the Inner Danish waters, a square with a high number of days with overlap between active and passive gears. The large depth and the mixed sediment potentially increase the risk of losing nets or parts of nets.	Second priority Area too deep and far from harbour

3.1.2 Selection of wrecks for ghost net diving survey

Information on wrecks were collected from divers, divers' databases and the Danish Agency for Culture and Palaces database (Fig.3.1.4). However, only a small part of the listed wrecks is easily identified between different sources of information. There is for instance differences in names, locations or you even find multiple locations in one database, for one wreck. This makes the work with the upscaling of the gathered information difficult and connected with large uncertainties.

In the identification of wrecks for the diving survey, for inspection and clean-up, we have therefore focused the selection on suggestions from divers with local knowledge to make sure that the wrecks we select is actually present. We have also focused on optimal utilization of the ship time with divers on board, and therefore selected an overall area from Bornholm towards Langeland incl. Øresund, as the dive boat is located in Ystad, Sweden.

Criteria for the priority and deselection of wrecks

- The location of the wrecks is confirmed and pointed out by divers. This is to avoid spending valuable time at sea on locating the exact position of the wreck, and in worst case not even finding it.
- The wrecks are located in an area from Bornholm to the Langelandsbælt and includes Øresund and the area around Lolland and Falster. This limited geographical range is set to limit the time spent sailing from location to location.
- The wreck is located at depth of less than 40 meters, but preferable less than 30 m. This limit is set in order to optimize the possible diving time.
- The wrecks on the gross list are selected in a way to ensure that the wreck diving can be done in any weather conditions.
- The complexity of the wrecks is estimated based on existing images and knowledge from divers.
- The surrounding bottom type is based on divers´ knowledge and EUNIS sea maps.
- An analysis of the fishing intensity, of both active and passive gears, around the wrecks are made and the number of days with fishing activities within 100m of the wreck is considered (Fig.3.1.4).

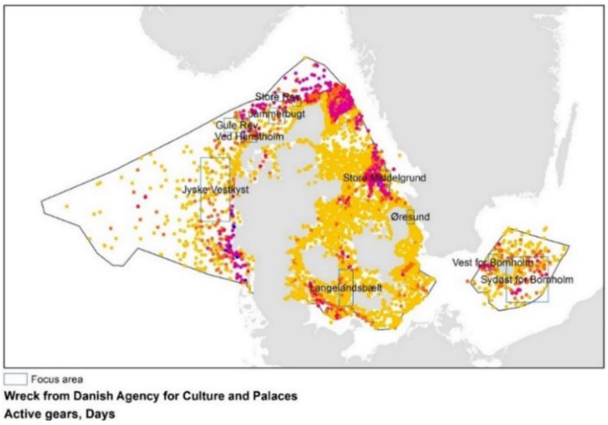

Figure 3.1.4. A fishing intensity analysis have been made for all wrecks in the Danish Agency for Culture and Palaces database. The colour indicates the days of active fishery within 100m.

4. Fieldwork – Mapping the occurrence of ghost nets in selected conflict areas

4.1 Note – Phase 2: Mapping the occurrence of ghost nets in selected conflict areas

This note describes the phase 2 fieldwork activities completed in 2020 & 2021 in the project Ghost Nets in Danish Waters. Phase 1 of the project identified a gross list of 11 conflict areas selected for future fieldwork activities: six areas in the North Sea/ Skagerrak and five in the Inner Danish waters including the waters around Bornholm. The two main criteria for selecting an area as a conflict area were overlap between active and passive fishing gear activities, and high passive fishing gear activity in areas with heavy maritime traffic (see Chapter 3 & App. A.1. for details).

This note sums up the sidescan sonar surveys and the dive survey on wrecks. It describes the methods used, the results, the challenges and solutions and the recommendations for future work. In addition, the main findings from the supplementary contract on a sidescan survey in Limfjorden is described. Details on all surveys can be found in Appendix A.2 - A.5.

The main findings from the completed surveys were:

Dive survey on wrecks (Western Baltic, ICES sub-area 24):

- Gillnets or trawls were observed on four of the seven examined wrecks.
- Angling gear was observed on five of the seven examined wrecks.
- No observations of caught or dead animals (fish, birds or mammals) in the ghost nets.
- The ghost nets observed were, based on the sediment coverage and mussel coverage, all considered to be of older date.

Sidescan sonar and video survey in a selected conflict area (Inner Danish waters):

- In the area Langelandsbæltet, 31 squares (1x1 km) were surveyed using sidescan sonar (Fig. 4.1.1).
- The survey covered both sand and stone reef areas.
- Seven anomalies were selected for video investigation.
- None of seven anomalies were identified as ghost nets.

Sidescan sonar and video survey in a selected conflict area (North Sea/Skagerrak):

- In Skagerrak, 25 squares (1x1 km) were surveyed using sidescan sonar (Fig. 4.1.1).
- The survey covered both sand and stone reef areas.
- Five anomalies were identified for ground truthing by either video or drag.
- Two of the five ground truthed anomalies were likely ghost nets.
- One of these was retrieved and proved to consist of one anchor, one buoy, 60 m blue rope, 240 m gillnet and a catch of 40 kg brown crab.

Sidescan sonar and video survey in Limfjorden (Lobster area/ fish area)

- The aim in Limfjorden was to test if the identified ghost net problem is limited to lobster fishing grounds and not fishing grounds for e.g. flatfish and other fish species.

- Contemporary fishing areas are, however, very limited and historic fishing areas were therefore selected.
- Three lobster areas and two regular fishing grounds were surveyed.
- Two nets were visually confirmed, one in a lobster area and one in the regular fishing areas.
- More than 30 potential ghost net candidate targets were identified, the majority in the lobster area.

4.1.1 Completed fieldwork

Two of the three planned surveys for the ghost net project were completed during the summer of 2020 and the last was completed in winter 2021. A supplementary 4-day survey in the Limfjord was completed in July 2021. This survey is only described in Appendix A.5. as it was completed after the deadline for the phase 2 part 2 Note and because the ghost net hotspot areas present in the Limfjord are believed predominantly to be deliberately abandoned fishing gear and not results of conflicts between passive gear and other marine activities in the area (Christensen, 2020).

The first three surveys were originally scheduled for the periods 2-8th of May (mapping using sidescan sonar and video in the inner Danish waters), 2-15th of June (eight-day diving survey) and the 6-13th of July 2020 (mapping using sidescan sonar and video in the North Sea/Skagerrak). However, due to the Covid-19 outbreak, the first sidescan survey and the dive survey had to be postponed. The dive survey was moved to the backup window in September and the sidescan survey to a window in the beginning of October, but the sidescan survey had to be cancelled again due to windy and unstable weather conditions in the planned period. Finally in January 2021, the remaining survey in the North Sea/Skagerrak could be completed.

A description of the methods used, and the results obtained during the completed surveys is given below.

Mapping survey, 7th to 14th of July 2020 – Inner Danish waters

Monday the 6th of July 2020, all the technical equipment were installed and tested on-board DTU Aqua's research vessel "Havfisken" in its home port Strandby Havn, getting ready for the survey planned for the North Sea/Skagerrak in the period 7th to 14th of July. There was, however, very strong wind from west all over Denmark and the conditions for the North Sea/Skagerrak were not forecasted to improve much within the survey period. It was therefore decided to move the survey into the Inner Danish waters and map the first priority focus area here, Langelandsbæltet (Fig. 4.1.1). In this area, shelter could be found from the strong western wind during the survey period and therefore "Havfisken" was moved to Korsør on July 7th and returned from here to Strandby on the 13th of July 2020.

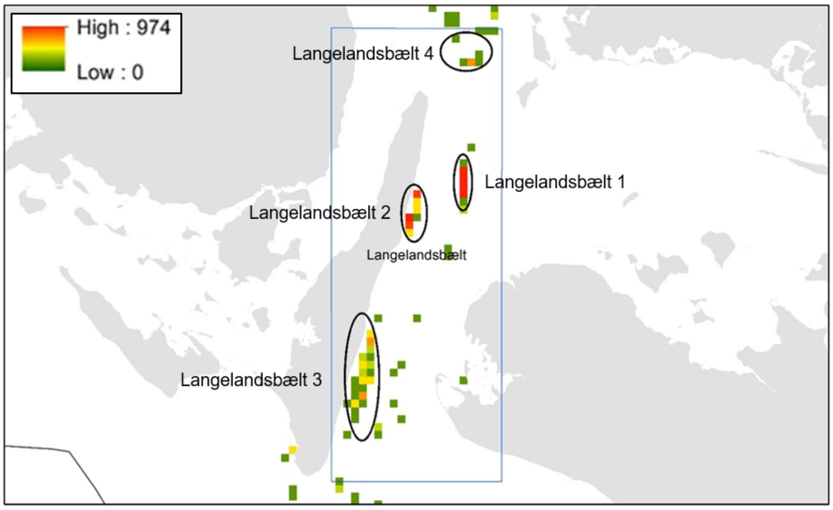

Figure 4.1.1. Map of the Langelandsbælt focus area and the four potential study areas, showing the number of days with overlap between active and passive gears from 2014-2018 in a 1x1km grid.

Results

During the eight-day survey a total of 31 1x1 km squares was surveyed using the sidescan sonar, covering both sandy bottom, mixed bottom and stone reef. Nine of the mapped squares were, however, only scanned in the three north-south going transects due to a mix of time limitation and a very shallow coastal area (the keel on “Havfisken” is 3.5 meters below the surface). All of these nine transects were located in the Langelandsbæltet 3 focus area. The sidescan sail routes can be seen for each area in Figure 4.1.2.

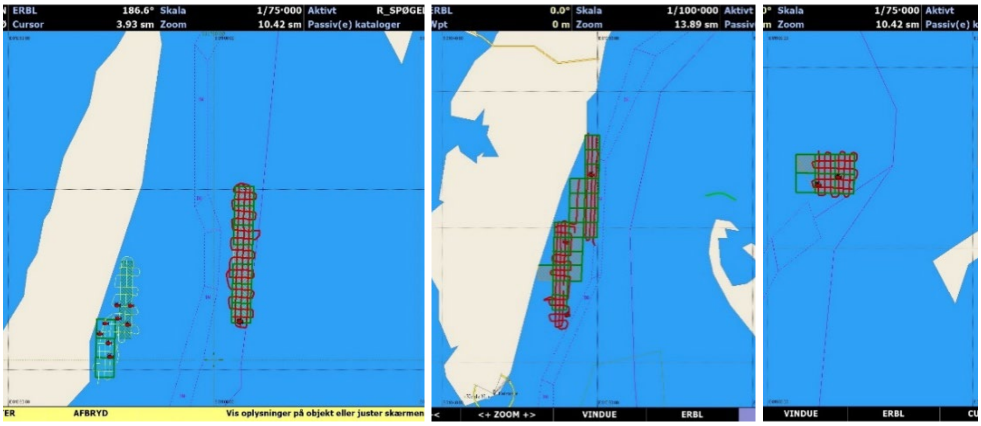

Figure 4.1.2. Sail routes for the sidescan survey in the Langelandsbælt. Left) Focus area 1 and 2, in which respectively 6 and 7 squares were covered. Middle) Focus area 3 where five squares were covered according to the plan and nine only in the north/south direction. Right) Focus area 4 with four areas covered.

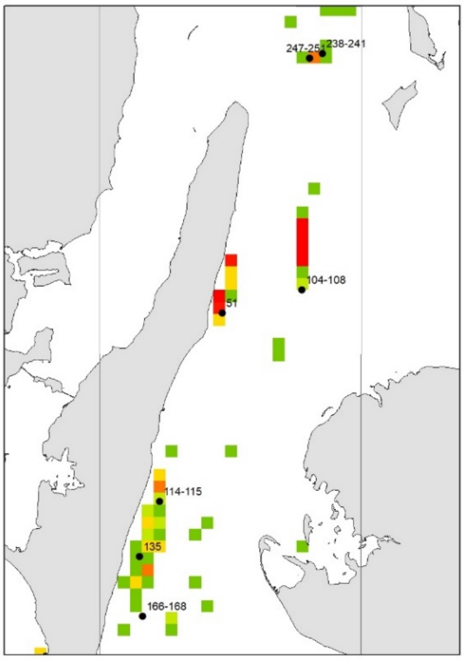

Figure 4.1.3. The locations of the seven anomalies selected for ground truthing (the numbers are the target numbers).

A number of anomalies were observed and saved as targets during the sidescan sonar mapping, and seven of these were selected for ground truthing. Figure 4.1.3 shows a map of the ground truthed positions. Lost fishing gear was not identified on any of the positions ground truthed. One target was identified as a cable/pipe, one as a rope or macrophyte algae and the others as natural structures like sand ribs or were not identified at all. In Table 4.1.1, the findings on the ground truthed targets are summarized.

Table 4.1.1. The findings at seven anomalies selected for ground trothing.

Target number	Reason for ground truthing	Notes	Findings
51	Test of system on believed sand ribs	Sandy bottom, OK visibility	Large sand ribs
114-115	Long structure lying on top of the hard bottom parallel to the sail direction	Hard bottom with spread out rocks, covered by tunicates, red algae and large Laminaria. OK visibility, depth around 19 meters.	The most elongated structures observed were the Laminaria; this was also the only catch of the drag
135	Sandy plain area with hard structures connected by lines	OK visibility, depth around 13 meters	No foreign obstacles were observed, and the structures are believed to be sand ribs and stones
166-168	Long elongated structure lying on a flat bottom with spread out rocks	Mainly gravel. Bad visibility, depth around 36 meters	Dark brown cable, rope or pipe identified
104-108	Long elongated structure lying on a flat bottom with spread out rocks	Mainly gravel Very bad visibility, depth around 30 meters	The object that looks like the end of tied up rope on one video, looks like macrophyte algae on the other
247-251	Long elongated structure lying on a flat bottom with many spread out rocks	Hard bottom with rocks covered by tunicates. OK visibility, depth around 15 meters	The most elongated structures observed were again Laminaria. The structures could be cracks or grooves between the rocks.
238-241	Long elongated structure lying on the bottom with spread out rocks	Hard bottom with rocks. Not so good visibility, depth around 18-20 meters	The most elongated structures observed were again Laminaria. The structures could be cracks or grooves between the rocks.

Methods used

The equipment used for this mapping survey was a portable Edgetech 4125, 600/1600 kHz sidescan sonar, with a 7 kg keel weight attached. The sonar was equipped with a Sonardyne Micro-Ranger 2 USBL system, which again was connected to a DGPS (HGNSS-3276 Atlaslink A222 GNSS Smart Antenna). For ground truthing, we used a BlueRov, a Paralenz camera, a LH-HDD camera and GoPro cameras. In addition, we used Havfiskens CTD to measure the sound velocity in every area before deploying the USBL system.

In the Edgetech Discover software for the sidescan sonar, the frequency was set to 600 kHz and the swath range to 50 m (100 m in total). The required speed was max 3 knots and the towfish (sidescan sonar) was, if possible, towed 5 m above the seabed. In some of the coastal areas, where the water was shallow < 8 m, the towfish was in the same depth as the keel of the boat resulting in shorter distance from the seabed and thereby a narrower scanning range. In addition, this very short distance from the USBL transmitter resulted in some accuracy problems. Thus, in some areas it was decided that the precision was better without the USBL system.

The focus areas for this survey were, based on the VMS conflict analysis, divided into a 1x1 km grid. The survey pattern for a square were three transects in north/south direction and two transects in east/west direction (the pattern can be turned 90° to adapt to the conditions in a given square) (Fig. 4.1.4). When an anomaly was observed, a target contact point was recorded, and if possible, more than one contact point was recorded for each anomaly to get a direction/size of the anomaly. The anomalies we focused on, and that we believed could be lost nets, trawls or fyke nets, were elongated structures lying on top of the sediment either straight or slightly twisted around other objects on the seafloor. Before leaving an area, all anomalies were evaluated and structures looking like ghost nets were selected for ground truthing.

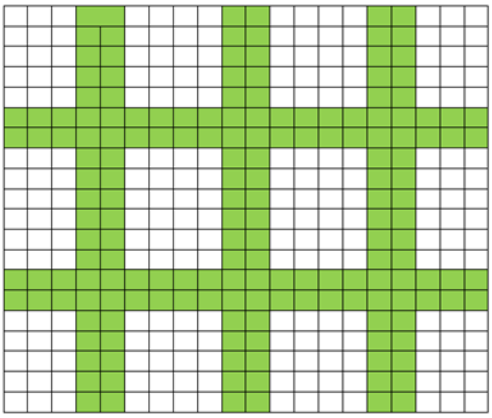

Figure 4.1.4. Schematic drawing of the survey pattern in a given 1x1 km square. The green areas illustrate the sidescan coverage using a 50 m range on each side.

For ground truthing, the first two selected targets a BlueROV2 was used with an extra Paralenz camera attached. However, due to an overheated battery, which caused the loss of a watertight lid and later a flooding of the electronics, a creative solution for the video ground truthing had to be invented. The vessel's CTD was rigged with the cabled LH-HD camera, lights and a Paralenz camera, the CTD was deployed, and the vessel then drifted across the area of interest with the CTD very close to the bottom.

Dive survey on wrecks, 31st of august to 8th of September 2020

The vessel for the dive survey, "M/S Baltic Explorer", was on 31st of August relocated from its homeport Ystad, Sweden, to Hesnæs harbour on Falster, a central harbour in the selected wreck survey area around Hesnæs/Møn (Western Baltic, ICES sub-area 24) (Fig. 4.1.5). The goal for the survey was to search a minimum of five wrecks for fishing gear and to remove nets from a minimum of three of these.

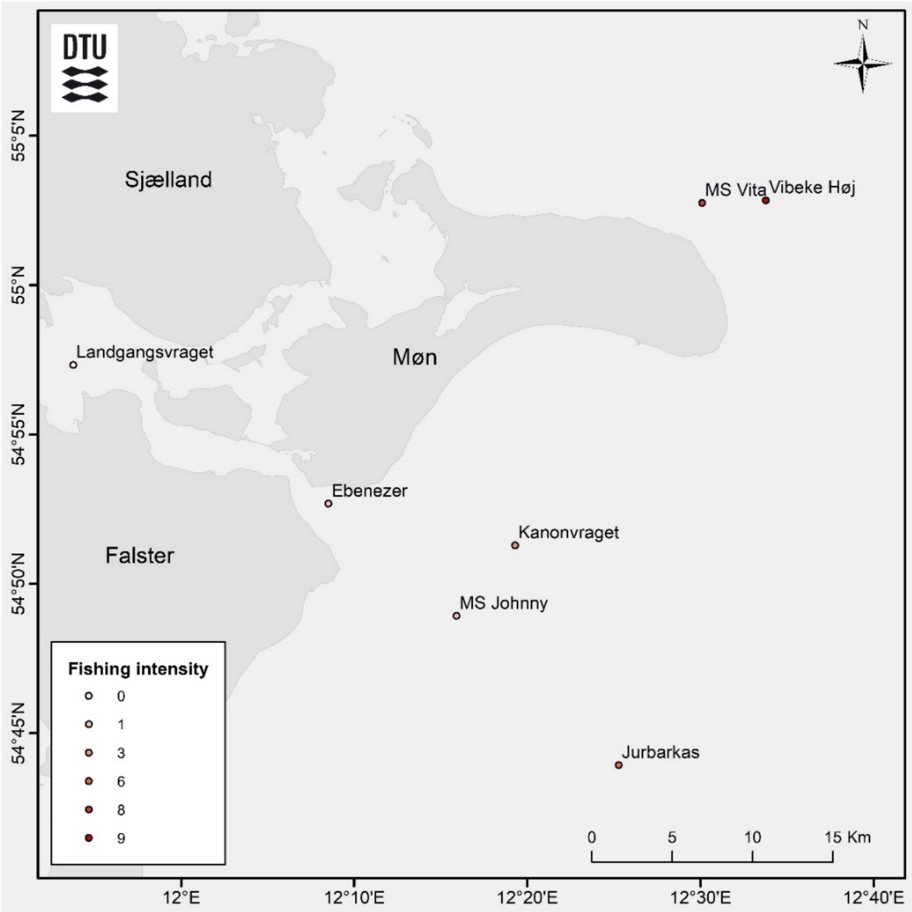

Figure 4.1.5. The seven wrecks examined during the dive survey. Fishing intensity is calculated from vessels with AIS or VMS. Fishing intensity is defined as number of times a vessel, which is considered fishing, is within 100 meters of the wreck in the period 2005-2020.

Results

During the dive survey, 13 dives were completed on seven different shipwrecks. The wrecks differed in size from the 20 m long “Ebenezer” to the 100 m long “Jurbarkas”, sunk on depths from 6 (“Ebenezer”) to 23 meters (“Vibeke Høj”). Most of the wrecks observed were lying on sandy bottom. Only “Landgangsvraget” was lying on gravel/stone (Table 4.1.2).

Gillnets or trawl were observed on four of the seven wrecks and angling gear were observed on five of the seven wrecks (Table 4.1.2). All nets were closely wrapped around parts of the wreck and the meshes and ropes were covered in silt/sediment, some were even overgrown by mussels, indicating that none of the nets were lost recently (Fig. 4.1.6). It was not possible to determine the age of the nets based on the video recordings. No observations of animals (fish, birds or mammals) caught in the ghost nets, were made during this survey.

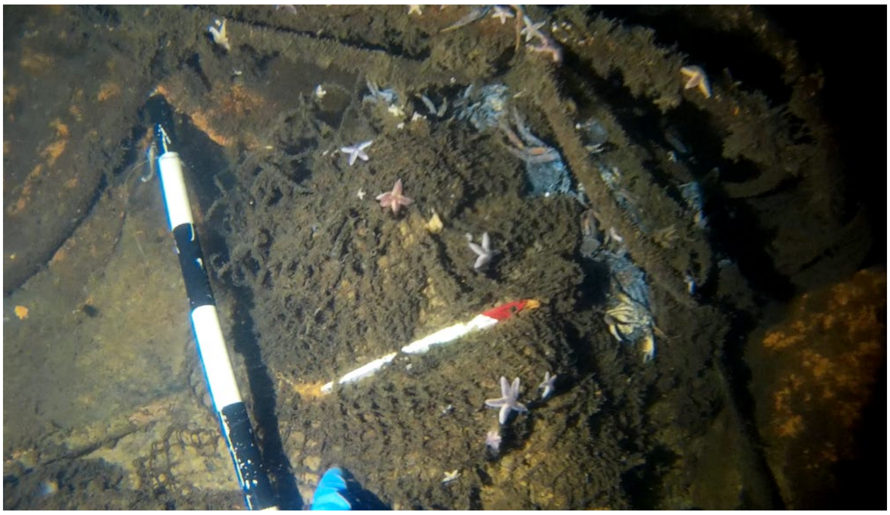

Figure 4.1.6. A net and a jig observed at M/S Johnny. On the net is starfish and dead crabs (probably dead from oxygen depletion) (Photo: DTU Aqua).

Table 4.1.2. List of the examined wrecks, their size in meters, the depth, the surrounding bottom type, the number of dives on the wreck, the fishing gear observed during the dive and additional notes.

Wreck name	Size (l,w,h)	Depth (m)	Bottom type	No dives	Fishing gear observed	Notes
M/S Johnny	22x7x3	19-22	Silty sand	2	1 gillnet 2 trawls 6-8 large jigs	Prior knowledge of ghost net on the wreck
Kanon-Vraget	40x12x2	20-22	Soft mud on hard gravel	2	1 gillnet 1 trawl 3 jigs	A historic wreck, therefore no attempts of removing net
Jurbarkas	100x26x3	16-19	Slightly silty solid sand	3	3 gillnets 9-11 jigs and lines	Big wreck, only about 1/3 of the wreck was mapped
Ebenezer	20x7x2	6-10	Fine sand	1	-	
Landgangs-vraget	38x8x4	6-10	Gravel/stone with mussels	1	two fishing lines	Strong current running
Vibeke Høj	60x6x4	17-23	Silty sand	3	1 trawl 1 jig	
M/S Vita	28x9x2	17-18	Fine sand	1	-	

Methods used

When arriving on a wreck location, the exact position, minimum and maximum depth and direction of the wreck was mapped using “Baltic Explorer’s” ship mounted sidescan sonar. Based on this, the dive team calculated the bottom time for the dive and agreed on safety stop/decompression time. The roles of the diver, rescue diver and dive leader were distributed among the divers. Those appointed as diver and rescue diver dressed up in the diving gear while the dive leader checked the air mixture and the intercom. DTU Aqua’s personnel set up the LH-video system and the station information. When everyone was ready, the diver went into the water and dived to the bottom along the anchor line. When at the bottom, the diver on some occasions moved the anchor line to a better location either closer to the wreck or at a safer position. The diver then began mapping the wreck, while communicating swimming direction, depth and all observations to the surface along the way. Due to the two-way communication system, request from the dive leader or the Aqua personnel could be put forward to the diver. This could for instance be identification of the bottom type, a panoramic view or another look at a specific item. Just before the bottom time expired, the diver returned to the anchor line and went back up along the line. After each dive, a debriefing was held between the diver and DTU Aqua personnel to ensure that all relevant information about the divers' observations was noted in the station log.

Mapping survey, 15th to 19th of January 2021 – North Sea/Skagerrak

Friday the 15th of January 2021, DTU Aqua's research vessel "Havfisken" sailed from its home port in Strandby towards Hirtshals in Skagerrak, as this area was conveniently located considering the weather conditions and sailing distance to three different focus areas in the North Sea/Skagerrak area: Store Rev, Jammerbugt and Hirtshals (Fig. 4.1.7). The following four days were spent searching for ghost net in these areas. On January the 19th Havfisken returned to Strandby one day earlier than planned, due to strong winds the following day.

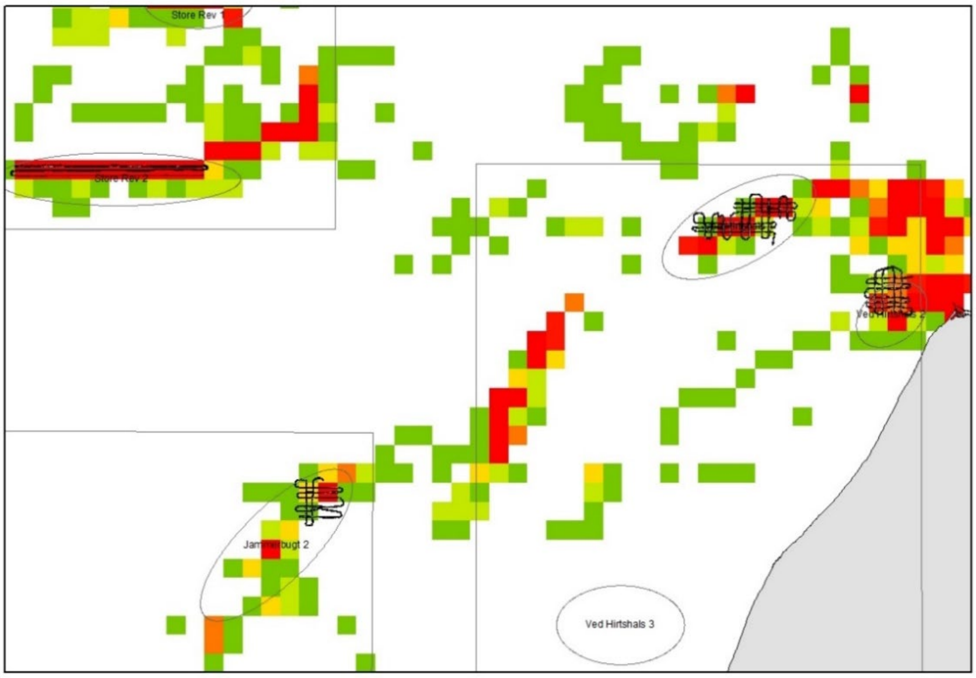

Figure 4.1.7. Map of the Skagerrak area covering the three different focus areas Store Rev, Hirtshals and Jammerbugt and their potential study areas. The coloured squares show the number of days with overlap between active and passive gears from 2014-2018 in a 1x1km grid.

Results

During the five-day survey, a total of 25 1x1 km squares were surveyed using the sidescan sonar, covering both sandy bottom, mixed bottom and stone reef. Twelve of the mapped squares were, however, only scanned in the three east-west going transects due to limited time. Ten of these transects were located in the Store Rev 2 study area and two in the Jammerbugt 2 study area. The sidescan sail routes can be seen for each area in Figure 4.1.8.

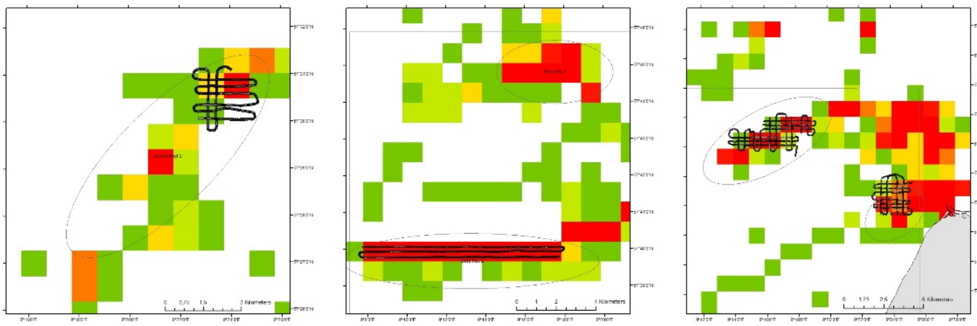

Figure 4.1.8. Sail routes for the sidescan survey in Skagerrak. Left panel: Jammerbugt 2 study area, in which four squares were covered, two of these were fully covered and two only in the east-west direction. Middle panel: Store Rev 2 study area, here 10 squares were covered, all only in the east/west direction. Right panel: Hirtshals study area 1 & 2, with seven and four squares covered, respectively.

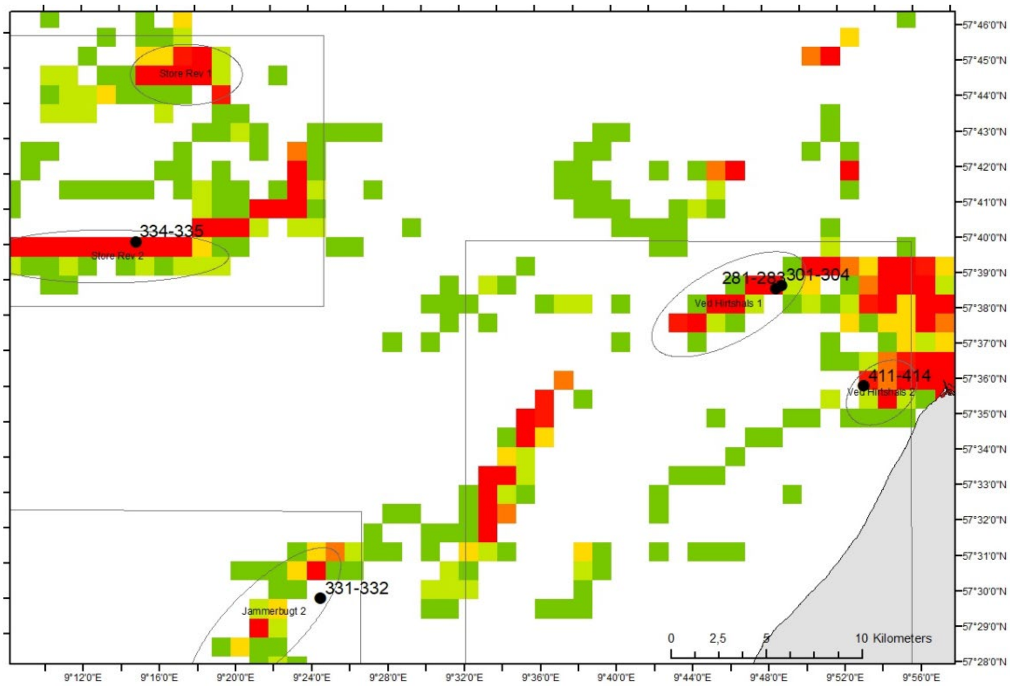

Figure 4.1.9. The locations of the five anomalies selected for ground truthing (the numbers are the target numbers).

A number of anomalies were observed and saved as targets during the sidescan sonar mapping, and five of these were selected for ground truthing. Figure 4.1.9. shows a map of the ground truthed positions. On one of the positions ground truthed, lost fishing gear was retrieved. On a second one, rope fibers were caught and on the remaining three ground truthing spots no objects could be identified as the target anomalies. In Table 4.1.3., the findings on the ground truthed targets are summarized.

Table 4.1.3. The findings at five anomalies selected for ground trothing.

Target number Area	Reason for ground truthing	Notes	Findings
334-336 Store Rev 2	A line with a strong return and a shadow was observed	Due to limited time the drag and not ROV was used A pile/bump was also observed on Havfiskens echo sounder.	A pinch of rope, stuck on the drag. Based on the strength of the material and the images from the sidescan sonar and the echo sounder it is believed to be a trawl or part of a trawl.
281-283 Hirtshals 1	Long curved structure lying on the sand	Ground truthing with ROV had to be shortened due to a defect on the ROV, It was followed up by dredging between the target positions.	A small piece of rope can be identified on the video sequence prior to the defect on the ROV. The dredging revealed 240 m of net, an anchor and a buoy that were recovered, see App. 19 for details
301-304 Hirtshals 1	A line on target 301 which could be identified into the stony area, which potentially can host ghost nets due to the many structures where it can get caught.	Ground truthing with ROV, GoPro and Paralenz.	Many boulders, stones and rocks on sand with soft corals (*Alcyonium digitatum*)
331-332 Jammerbugt 2	Long structure lying parallel to an area with stone.	Ground truthing with ROV, GoPro and Paralenz. ROV got stuck below the ship but was recovered without serious damage	Very bad visibility. Area appointed as sand area in Phase 1! Sandy area & area with many boulders, stones and rocks on sand with soft corals (*Alcyonium digitatum*)
411-414 Hirtshals 2	Long curved structure lying on the sand and up along the edge of the stone reef	Ground truthing with ROV, GoPro and Paralenz. Drag in sand area.	Bad visibility. Mainly sandy area surrounding the Natura 2000 reef area. No unnatural structures/items observed.

Methods used

The equipment used for this mapping survey was a portable Edgetech 4125, 600/1600 kHz sidescan sonar, with a 7 kg keel weight attached. The sonar was equipped with a Sonardyne Micro-Ranger 2 USBL system, which again was connected to a DGPS (HGNSS-3276 Atlaslink A222 GNSS Smart Antenna). For ground truthing, we used a BlueRov, a Paralenz camera and a GoPro camera. For measuring the sound velocity, Havfisken's SBE 19plus SeaCAT Profiler CTD was used.

In the Edgetech Discover software for the sidescan sonar, the frequency was set to 600 kHz and the swath range to 50 m (100 m in total). The required speed was max 3 knots and the towfish (sidescan sonar) was towed 5 m above the seabed. Prior to every deployment of the sidescan sonar, the pressure sensor was checked to be zero or otherwise reset to zero on deck.

The USBL system was set up and calibrated according to the recommended procedures outlined by Sonardyne in the harbour, prior to survey departure. The positional accuracy of the

USBL system relative to the ship is below 5 m for up to a 100 m distance. The AtlasLink differential GPS receiver (advertised positional accuracy of 0.5 m 95% Circular Error Probable) provided high-accuracy global position data, which is fused by the USBL software to locate the transponder in WGS84 coordinates. The transceiver alignment calibration was executed on day 1 of the cruise and every day upon arrival to the survey area or when entering a new area, a water profile was made to adjust the sound velocity for the USBL system. As an extra check, the beacon was mounted on the CTD so that the depth measurement could be checked.

The focus areas for the sidescan sonar surveys were, based on the VMS conflict analysis, divided into 1x1 km grids. The survey pattern for a square were three transects in north/south direction and two transects in east/west direction (the pattern can be turned 90° to adapt to the conditions in a given square). When an anomaly was observed, a target contact point was recorded, and if possible, more than one contact point was recorded for each anomaly to get a direction/size of the anomaly. The anomalies we focused on, and that we believed could be lost nets, trawls or fyke nets, were elongated structures lying on top of the sediment either straight or slightly twisted around other objects on the seafloor. Before leaving an area, all anomalies were evaluated and the structure most likely to be ghost nets were selected for ground truthing.

For ground truthing, a BlueROV2 with 50 m cable was used, equipped with the USBL beacon and two extra cameras (Paralenz and GoPro). However, at the target selected for ground truthing at Store Rev only the drag was used, as the ROV investigation was skipped due to a combination of limited time and a depth of around 40 m, which would make the navigation of the ROV very difficult.

4.1.2 Challenges and solutions

The fact that no ghost nets were identified during the survey in the designated conflict area in the inner Danish waters (Langelandsbæltet) and only one were retrieved in the North Sea / Skagerrak area, may be due to a number of reasons listed below:

- Sidescan sonar for identification of lost gear is a relatively untested method in Nordic waters and the identification percentage is unknown. It is therefore possible that existing ghost nets in the area cannot not identified by this method.
- Strong currents often affect this area, and this could potentially carry ghost nets away from the conflict area.
- The number of reports on lost commercial fishing gear received by the Danish Fisheries Agency is low, i.e. <20 a year are lost and many are retrieved.
- The area was selected as a conflict area between active and passive fishing gear activities, which could mean that lost gillnets on a regular basis are caught and picked up by the trawlers and in that way removed from the area.
- The lost gear drifts towards the coast and move towards the coastal shallow areas, which are not identified as conflict areas as there is neither fishing with active gear nor marine traffic.
- The hypothesis that assumes that ghost nets accumulate in areas with overlapping activities between passive and active gear/marine traffic could be rejected.

The results from the sidescan survey in Langelandsbæltet is, in relation to the conflict area hypothesis, assessed to be representative of the inner Danish waters with similar current conditions and marine activities. The fact that this survey is considered representative, is however not the same as ghost nets cannot be found in the inner Danish waters. There will always be the occasionally lost net, local unreported activities and historic conflicts, which potentially causes ghost nets and are not picked up by the type of activity-analysis and survey methods used in this project. Two examples of this are the massive findings of ghost nets in the Limfjord (Christensen, 2020), which are considered abandoned nets used in fisheries for lobster and brown crab, and the findings of old nets in a Swedish study from the Baltic Sea. In an area close to Bornholm, they retrieved 21 nets of a total length of 10 km by using the dragging method. They found that 75% of the retrieved nets were older than 10 years and 24% older than 15 years (Tschernij, 2020).

The results from the sidescan survey in Skagerrak are, in relation to the conflict area hypothesis, assessed to be representative of the North Sea/Skagerrak area with similar current conditions, bottom types and marine activities

The retrieval of only rope fibres at the anomaly target 334-336 at Store Rev 2 (North Sea / Skagerrak area), raises the question, from what kind of object they came? Based on the strength of the object and the twisted bunch of fibres, gillnet can be excluded. We therefore believe that it is likely to be a trawl severely stuck in e.g. a stone or another structure at the bottom. It would be interesting to have it checked by a diver to truly ground truth the anomaly.

The limited number of ghost net findings within the project, challenged the up-scaling method for an estimate of how many ghost nets there are in Danish waters.

Identifying ghost nets using sidescan sonar is a relatively unexplored technique in Danish and neighbouring waters and challenging with respect to which anomalies to look for in different conditions and on different bottom types. Ship time is costly, and every equipment change, e.g. from sonar to ROV, takes time so every ground truthing has to be selected carefully, if you also prioritize to cover large areas with the sidescan sonar. The solution was to register all anomalies along one or more transect. After scanning the area, the anomalies that, based on our experience were most likely to be ghost nets, were selected for ground truthing.

It was a requirement that a USBL system should be used during the sidescan survey. However, the coastal areas in Denmark are quite shallow < 10 m and the ideal distance from the towfish to the bottom is for this task 5 m. The USBL transceiver is mounted 3 m below the surface and this small angle and short distance on the signal challenge the positioning accuracy of the towfish, by either losing the GPS signal completely or showing some unrealistic “jumps” in position or depth. The solution was to bypass the USBL system and instead use the DGPS, with a cable out layback, to correct for the displacement of the towfish relative to the antenna.

Wrecks are often not located exactly at the position given in the wreck database or they even have multiple positions in the same database. This became a challenge when we had to find alternative wrecks suitable for dives in the given weather conditions. The solution for this during this specific survey was personal contact with local diving clubs and the ship-mounted sidescan sonar giving us the possibility to check that the wreck was present at the positions before sending the divers in the water.

Both mapping surveys and the dive surveys are weather sensitive. The quality of the sidescan images and the safety of the divers are challenged by winds exceeding 6-8 m/s that causes waves in unsheltered areas and especially the divers are also challenged by strong currents. In both surveys, there have been a wind challenge, which have required a change in survey area and to the survey protocol to complete the survey.

4.1.3 Recommendations for future work

An app or a central webpage where everyone can report if a ghost net is detected or lost. The information should as a minimum include date, location, type of gear and if the gear is retrieved or not. A good example on this can be seen on the Swedish site GhostGuard run by Havs- och Vatten-myndigheten (Ref. #6). All professional mapping activities for e.g. pipelines, construction work and habitat mapping should be obliged to report any net findings. This would make future recovery surveys more efficient.

The technique for identifying ghost nets on rough bottoms and in non-optimal weather conditions should be improved, in order to make future searches more cost efficient and reliable. The sidescan sonar technique should be fine-tuned for Danish conditions, and some research should be put into e.g. how do different types of net (trawl, gillnet) look on different bottom types and in different weather conditions and whether it is possible to use automatic pattern recognition programs on sidescan data to detect lost gear.

5. Supplementing the occurrence of ghost nets and conflict areas with BITS and IBTS data, estimating the total extent of ghost nets in conflict areas

The aim of this project was to investigate (and quantify) the occurrence of ghost nets in suspected conflict areas in Danish waters, caused be an overlap of active and passive fishing gear activities in time and space. In addition test the hypothesis that ghost nets are concentrated in these conflict areas.

In this Chapter, the ghost net findings within the projects sidescan sonar surveys (Chapter 4) is combined with data on marine litter collected during two bi-annual fish surveys since 2011, International Bottom Trawl Survey (IBTS) and Baltic International Trawl Surveys (BITS), and constitute basic data in the model used for estimating the number of nets in Danish waters.
The litter is split into categories, and for this analysis information on *'Fishing net' and "Plastic fishing net'* is used. In addition, an estimate on number of fishing lines is calculated and for this the categories *'Plastic fishing line (entangled)'* og *'Plastic fishing line (monofilament)* were used. Due to changing protocols for collecting litter data, the weight and size of the net catch is not always noted and can range from a few grams of net to an entire trawl. Due to this inconsistency in the data, we have only used the number of net pieces caught (for more information on the data see App. A.23).

In Chapter 5.1 the results of the upscaling and the test of the hypothesis is discussed as well as other data sources considered for use in the model. In Chapter 5.2 the technical model details for up-scaling and the statistical significance tests are described.

5.1 Estimates of the amount of ghost nets and their bycatch in Danish waters

Within this project, 56 1x1 km squares have been scanned using a sidescan sonar (Chapter 4 & App. A.3 & A.4.) and from within these squares one ghost net have been recovered, one object was thought most likely to be a ghost net as rope fibers were recovered and one could potentially be a ghost net, as a rope like structure was identified on video. In addition, 7 shipwrecks have been examined by divers, on four of these pieces of gill nets and/or trawl was observed (App. A.2.).

In order to get a spatial distribution and an estimate of the total number of ghost nets I Danish waters, these few findings were supplemented with marine litter data from the IBTS/BITS surveys which cover all Danish open water areas (not fjords). In these data 53 observations of net pieces were registered and 688 observations of line fragments in the period 2011-2020. Estimates based on both types of litter are calculated in Chapter 5.2 but only the results on net pieces are discussed later in this chapter.

A number of supplementing data sources for estimating the total number of ghost nets in conflict areas and in Danish waters in general, have been considered. Sidescan files from old mappings surveys have been downloaded from the Marta database, habitat mapping reports and archaeological reports have been screened from ghost net observation, vragguiden.dk have been scanned for notes on ghost nets and combined with Slots- og Kulturstyrelsen wreck database, the fisheries reporting of lost gear have been collected, Energinets Kabelprojektet KBH02, a Facebook group for ghost nets on wrecks, Swedish dragging survey in the Baltic. Of all these data sources only the vragguide.dk observations (wreck data) and the Swedish dragging survey in the Baltic was found suitable to supplement the basic data (findings within the project & IBTS/BITS) in the model used for estimating the number of nets in Danish waters. A description of the model can be found in Chapter 5.2. The findings of ghost net observations (including positions) not used in the model can be seen in figure 5.1.1.

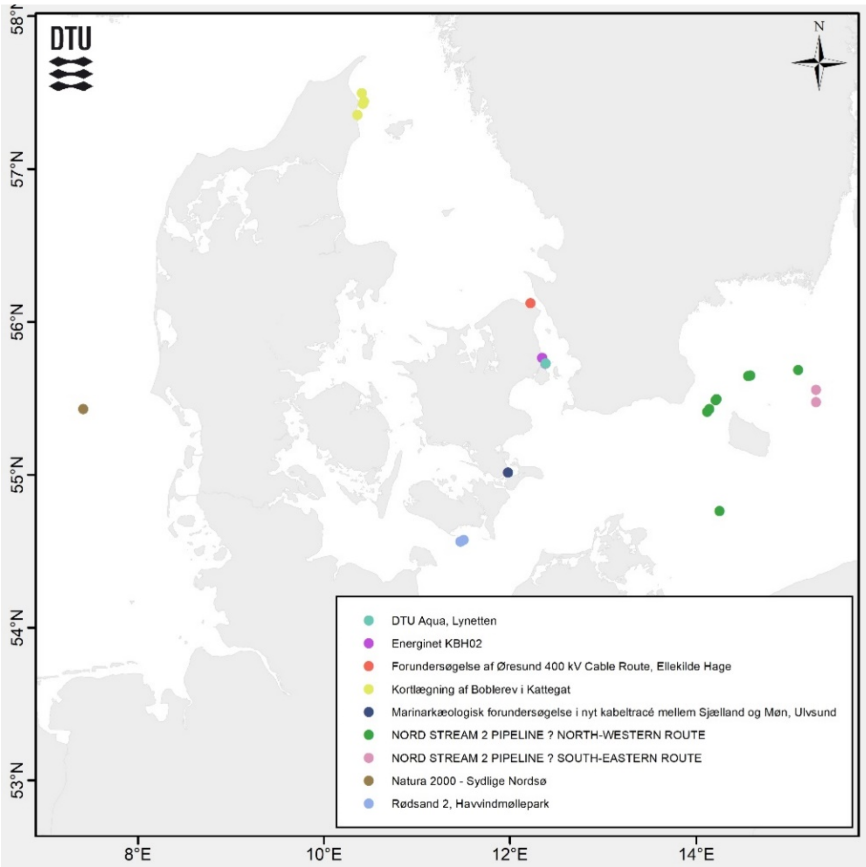

Figure 5.1.1. A number of mapping, archaeological and other reports were screened for ghost net observations, but could not be included in the model. The findings, which contained a position, are mapped here.

Table 5.1.1. Fishing gear incidents reported by Danish fishermen in Danish waters 2015-2019.

Description	2015	2016	2017	2018	2019	Total
Mesh damaged in codend	26	26	25	27	27	131
Broken gear	70	58	52	44	48	272
Lost fishing gear	11	13	6	8	2	40
Broken or teared net	64	63	64	52	59	302

5.1.1 Estimation of the number of nets in Danish waters and are more ghost nets found in conflict areas?

The two main aims of the project were to build knowledge about the extent of ghost nets in Danish waters and to test the hypothesis that ghost nets are concentrated in special areas identified as conflict areas, where various human conflicting activities could result in loss of nets.

To get an overall picture of the amount of net fragments in the Danish waters three data sources were combined. The marine litter data from the scientific surveys IBTS/BITS, which cover all Danish open water areas, the records from the shipwrecks, and the Swedish drag net survey. The estimated intensity ranges from almost 0 to about 1.3 net fragments per square km and aggregated over the entire study area that amounts to 49×10^3 net fragments (with an estimated standard error of 13×10^3 net fragments). Importantly these numbers are not the total number of net fragments expected to be in the ocean, but instead the number of net fragments expected to be found if the entire study area was surveyed by a scientific survey like IBTS/BITS. It should be taken into account that the catchability of net pieces varies depending on e.g. net-type and size and in addition the survey areas are generally on smooth bottom types which do not catch and retain net pieces (Galgani et al., 1995). The estimated spatial distribution of the net fragments can be seen in figure 5.1.2 and the details of this analysis (and the influence of the different data sources) can be found in section 5.2

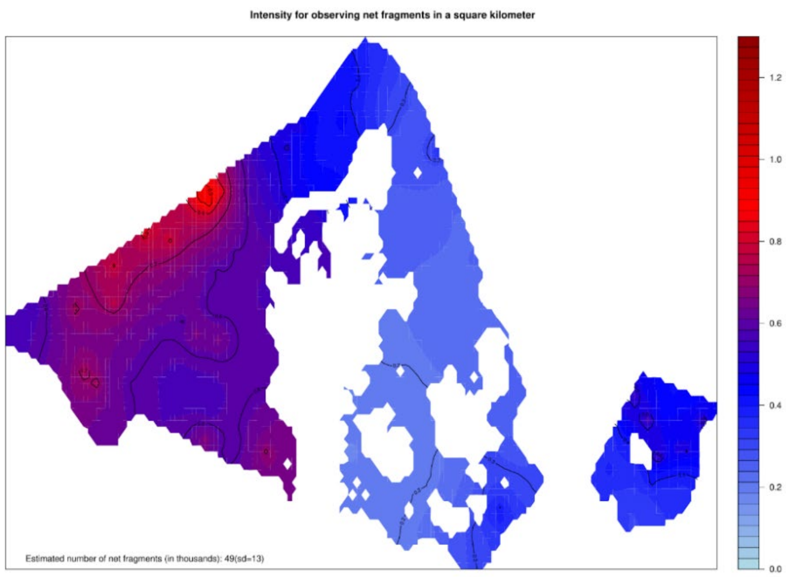

Figure 5.1.2. (Figure 5.2.9): The estimated intensity of observing net fragments per square kilometer as estimated from survey data, wreck data and the Swedish dragging survey. The sum over the entire study area (the coloured part of the map) is 49×10^3 net fragments with a standard deviation of 13×10^3 net fragments.

To investigate if the number of net fragments per square kilometer is higher in areas where more fishing is occurring three different measures were derived to describe the fishing activity. i) The amount of fishing with active fishing gear, ii) the amount of fishing with passive fishing gear, and iii) the amount of overlap between the two gear types. It was then compared if any of these measures were influencing the probability of finding net fragments. For all three fishing activity measures is was found that they did not influence the probability of finding net fragments. (The details of these statistical significance tests can be found in section 5.2).

For a number of appointed conflict areas the specific intensity (expected number of net fragments per square km) has been extracted (see table 5.1.3) and the estimated intensities show that these areas are similar to surrounding areas.

The lack of significantly higher occurrences of net fragments in conflict areas does not contradict the idea that more nets may be lost in these areas. The explanation could either be the lost nets are more quickly removed from these areas, or that currents makes the lost nets drift out of the areas and concentrates them elsewhere. In the Marelitt Baltic project, 160 fishermen from Estonia, Poland and Sweden were interviewed to identify the main causes of fishing gear loss and the four main factors in order of priority were: snagging on seabed objects, conflicts between fishing gear types or non-fishing vessels, snagging on shipwrecks and the occurrence of strong currents. However, the priority of the factors varied between the countries (Predki et al. 2019).

In areas with trawl fishery there is both a risk that lost nets are broken into smaller pieces by the trawl or trawl doors, and a chance that net/net pieces area caught in the trawl and brought to land by the fishermen. This could, in areas with a high intensity of trawl fishery probably cause a net reduction of the amount of net fragments caught in the IBTS/BITS survey. In the Marelitt Baltic project (Predki et al. 2019) the Polish part of the Baltic was divided into three areas depending on the trawl intensity and thereby the probability of ghost net occurrence: I) High density of bottom trawling – low probability of DFG occurrence. II) Low density of bottom trawling – moderate probability of DFG occurrence. III) Close to zero bottom trawling – high probability of DFG occurrence. Here they retrieved the highest number of gill net fragments in the type II areas.

Another factor that can affect the results is a change in fishing behaviour and fishing effort in different areas. Within the last two decades, there has been a large change in the fishing fleet, i.e. a heavy reduction in the number of vessel and a changing fishing pattern as a consequence of tradable fishing quotas and a shift towards fewer but larger vessels (Table 5.1.2.). Lost fishing gear will accumulate in the ocean and old losses and habits might conflict with new patterns and habits and therefore explaining why no significant differences were found between the conflict areas and non-conflict areas.

Table 5.1.2. Vessel size of the Danish fishing fleet 1996 – 2020. Data source http://fiskeristyrelsen.dk/fiskeristatistik.

Vessel size	1996	2000	2006	2010	2016	2020
Total number of vessels	773	702	457	327	255	232
Less than 10 m	18	12	13	15	14	8
10-18 m	439	388	229	174	134	123
18-40 m	288	266	181	113	79	79
More than 40 m	28	36	34	25	28	22

An estimate of the number of net fragments that could be expected to be found if each of the selected conflict areas were fully surveyed was made and ranged from 2 pieces in Øresund 1 to 98 pieces in Jyske Vestkyst 1 (Table 5.1.3.). These numbers are obviously affected by the size of the area where Øresund 1 is covering 5 km^2, Jyske Vestkyst 1 is covering 135 km^2 resulting in 0.4 net fragments in Øresund pr. km^2 and 0.7 net fragments in Jyske Vestkyst 1 pr. km^2.

Table 5.1.3. Estimated numbers (not thousands) of net fragments expected to be found if each of the predefined 30 conflict areas were fully surveyed. The coefficient of variation (cv) on these estimates ranges from 0.5 to 1. A map illustrating the table is found in Figure 5.2.11.

Area Name	Estimate of net pieces in the area	Standard deviation	Estimate of net pieces pr. km^2
Gule Rev 1	5	3	1.0
Gule Rev 2	13	7	0.9
Gule Rev 3	15	8	0.7
Jammerbugt 1	14	8	0.7
Jammerbugt 2	21	11	0.6
Jyske Vestkyst 1	98	48	0.7
Jyske Vestkyst 2	21	12	0.8
Jyske Vestkyst 3	15	8	1.2
Jyske Vestkyst 4	30	15	0.8
Langeland 1	5	4	0.4
Langeland 2	5	4	0.3
Langeland 3	12	9	0.2
Langeland 4	8	7	0.3
Øresund 1	2	2	0.4
Øresund 2	7	7	0.4
Store Middelgrund 1	9	7	0.4
Store Middelgrund 2	6	5	0.4
Store Rev 1	11	6	0.8
Store Rev 2	20	10	0.7
Sydøst for Bornholm 1	34	16	0.6
Sydøst for Bornholm 2	17	8	0.6
Sydøst for Bornholm 3	17	9	0.5
Ved Hanstholm 1	26	14	0.7
Ved Hanstholm 2	17	9	0.6
Ved Hirtshals 1	17	9	0.6
Ved Hirtshals 2	6	3	0.7
Ved Hirtshals 3	15	8	0.7
Vest for Bornholm 1	35	19	0.5
Vest for Bornholm 2	21	14	0.6
Vest for Bornholm 3	12	6	0.9

5.1.2 Ghost fishing

During the dive surveys on wrecks and the recoveries of ghost net with drag, there was only one observation of ghost fishing. That was observed in the relatively newly lost net, recovered outside Hirtshals. This net had caught 70 brown crabs with a total weight of 40 kilogram, all alive. This one observation is not enough to make a sensible estimate of the extent of ghost fishing neither in species nor in numbers within Danish waters.

The majority of the nets found within this project was more than 5 to 10 years old. The gear found on the wrecks was closely entangled in the wrecks and not hanging free with open meshes just like an active net. The other net retrieved by dredge from Øresund, was covered in *Laminaria saccharina*, blue mussels and other macrophytes/seaweed filling up the net, so the meshes' ability to fish was heavily reduced or even lost.

In general terms, newly lost gillnets will keep fishing the species the net was targeted for. Depending on its exposure to strong currents, bottom structures that will snag the meshes or free biological material that can cover the net, the ghost fishing can go on for variable amounts of time. Pots and traps are very strong constructions made for rough conditions and these will often keep fishing for years as the smell from dead individuals will lure new individuals into the trap until the hatch or the mesh breaks and the animals can escape.

Newly lost fishing gear should therefore be attempted found and salvaged as quickly as possible to reduce the amount of ghost fishing, whereas the fishing potential of old nets is very much reduced and therefore not a large ghost fishing threat. A Swedish experiment, where gillnet for cod were left as a ghost net and its catch efficiency was compared with that from the commercial fleets showed that during the first 3 months, the relative catch efficiency of the "ghost" nets was found to decrease rapidly by around 80%, and after that stabilising around 5–6% of the initial level of catch efficiency (Tschernij & Larsson, 2003). Similar results have been observed in the eastern Aegean Sea, where the effective fishing areas of monofilament and multifilament gillnets, after six months of deployment, decreased by 55 and 63%, respectively. One year after deployment, all the multifilament gillnets had completely collapsed (Ayaz et al., 2006)

Pictures of differently aged ghost nets. Left) a new ghost gillnet with brown crabs. Middle) a medium aged china fyke with lobsters (Photo: Leo Andersen). Right) an old gillnet with brown algae.

5.1.3 Perspective of the results in relation to the neighbouring countries

The estimate of $49x10^3$ net pieces in Danish waters is the first estimate of this and not comparable with the loss estimates and marine litter estimates from our neighboring or other European countries.

The fact that the hypothesis on accumulating nets in conflict areas had to be rejected does not mean that conflict areas does not cause net losses, just that the nets did not accumulate significantly in these areas. The fact that most of the surveyed areas are selected on the basis of conflict between passive and active gear between 2014 and 2018 could mean that older conflict areas are missed, like the area east of Bornholm where the Swedish dragging project found concentrations of old nets (Tschernij, 2020). The accumulation could also have been reduced if the ghost nets are caught by the trawlers.

It is likely that the number of lost nets from the professional fishermen have and will decrease with the decreasing fleet of both gillnetters and trawlers. The number of fishing vessels in Denmark have decreased almost 60% during the last 25 years from a total of 4,830 vessels in 1996 to 1,998 in 2020. The largest reduction is found among the number of trawlers which reduced close to 1/3 in number of the 1996 level, whereas the number of gillnetters has been halved (Table 5.1.4.). The Marelitt Baltic report also suggested that the amount of lost fishing gear has been reduced in later years partly due to reductions in fishing fleets and partly due to improvement of the weather forecasts and the navigation technology (Predki et al., 2019).

However, in Denmark the number of new and maybe unexperienced recreational fishermen increased by 13% from 28,352 in 2019 to 32,686 in 2020 (4), which potentially could increase the risk of gear loss.

Table 5.1.4. The number of trawlers, gillnetters and other fishing vessels in the Danish fishing fleet from 1996 to 2020. Data source: http://fiskeristyrelsen.dk/fiskeristatistik.

Type of fishing vessel	1996	2000	2006	2010	2016	2020
Trawlers	773	702	457	327	255	232
Gillnetters & hooks	1409	1184	930	873	739	686
Other	2648	2256	1749	1620	1279	1080
Total	4830	4142	3136	2820	2273	1998

The low number of fishermen reporting net losses compared to e.g. Norway is expected, as the majority of the Norwegian reports and the retrieval survey is in northern Norway with very deep fishing grounds and rough weather. However, the fishermen should also report damages to their gear and tears in mesh or codend in their eLog. The Danish reports from 2015-2019 show that the only report from a gillnetter is from 2015 where a broken or teared net was reported (Table 5.1.5). This is clearly below the findings within the Marelitt project where e.g. the 25% of the Swedish fishermen state that they lose nets once or less than once a year (Table 1.3.1, Tschernij 2019), which indicates some level of underreporting. However, we have not found any documents saying that fishermen are obliged to report teared nets or other defects, only losses.

Table 5.1.5. Fishing gear incidents reported by Danish fishermen in Danish waters 2015-2019, split into gear type groups.

Description	Gear type	2015	2016	2017	2018	2019
Mesh damaged in codend	Beam trawl	0	1	0	0	1
Mesh damaged in codend	Bottom trawl	21	20	22	19	23
Mesh damaged in codend	Pelagic trawl	5	4	3	6	3
Mesh damaged in codend	Danish seine	0	1	0	2	0
Broken gear	Beam trawl	1	0	0	0	0
Broken gear	Bottom trawl	41	39	38	34	39
Broken gear	Mussel dredge	1	0	0	0	0
Broken gear	Pelagic trawl	12	8	12	5	5
Broken gear	Danish seine	15	11	2	5	4
Lost fishing gear	Bottom trawl	8	7	3	7	2
Lost fishing gear	Pelagic trawl	0	1	1	1	0
Lost fishing gear	Danish seine	3	5	2	0	0
Broken or teared net	Beam trawl	1	0	0	0	0
Broken or teared net	Beam trawl brown shrimp	0	2	1	1	1
Broken or teared net	Bottom trawl	41	49	54	40	55
Broken or teared net	Gillnet	1	0	0	0	0
Broken or teared net	Pelagic trawl	15	2	7	6	3
Broken or teared net	Danish seine	6	10	2	5	0

5.2 Technical description of upscaling methods and results

5.2.1 Data

The main data sources which are available for quantifying occurrences of net fragments and line segments in the Danish waters are IBTS and BITS surveys (details can be found in App. 23). These surveys trawl numerous small areas and count the number of line segments and net fragments which are retained by the trawl.

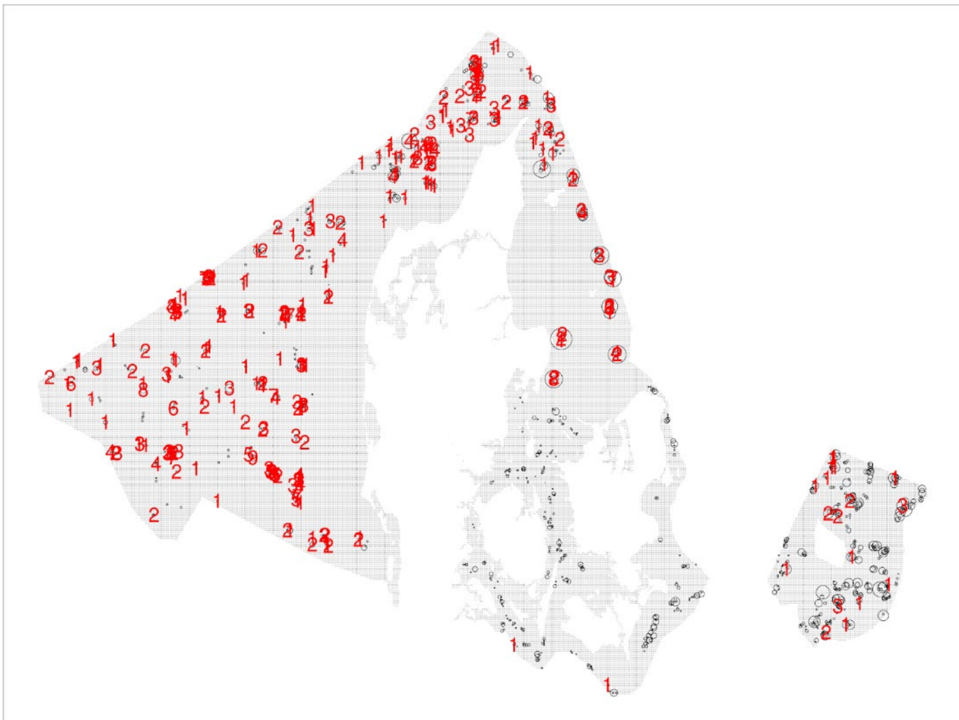

Figure 5.2.1- Line segment observations from the survey data. The shaded area is the research area (the area where we wish to quantify the number of line segments). The black circles are proportional to the area trawled and the red numbers are the number of line segments caught (if any).

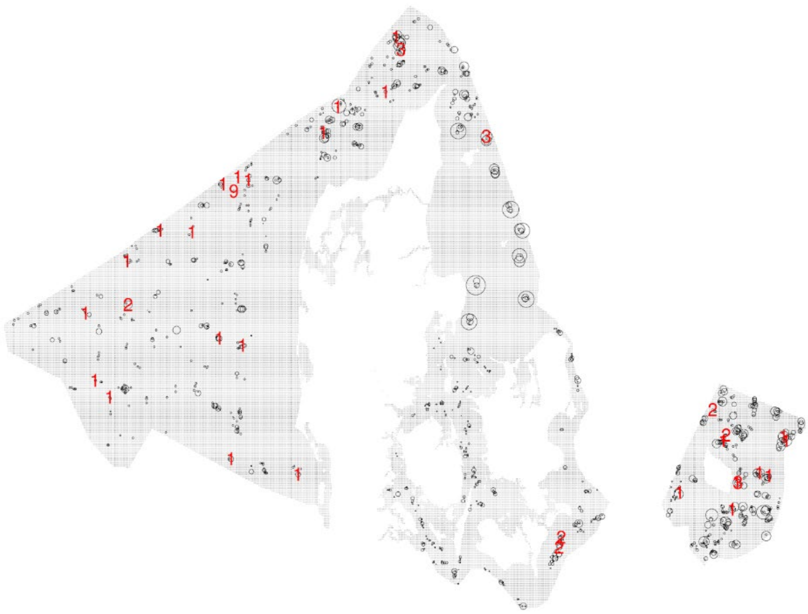

Figure 5.2.2. Net fragment observations from the survey data. The shaded area is the research area. The black circles are proportional to the area trawled and the red numbers are the number of net fragments caught (if any).

To supplement the net fragment observations, a database of shipwrecks has been monitored to see if any nets or net fragments had been reported by divers at those locations.

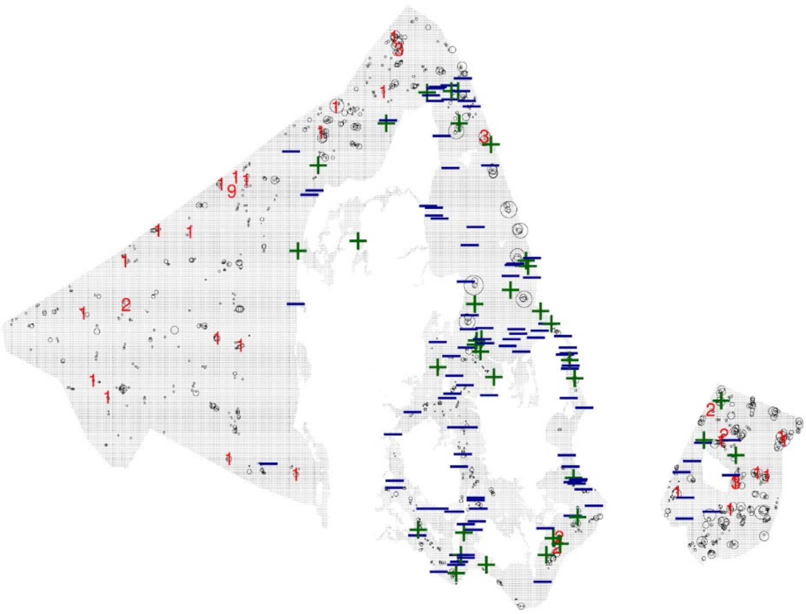

Figure 5.2.3. The additional data for the shipwrecks added to Figure 5.2.2: a blue minus symbol indicates a known shipwreck where no net fragments have been reported and a green plus symbol indicates a known shipwreck where net fragments have been reported.

Finally, near the island of Bornholm a Swedish dragging survey (Tschernij, 2020) was completed to recover nets and here it was recorded for 2x2 km areas if net or fragments were found.

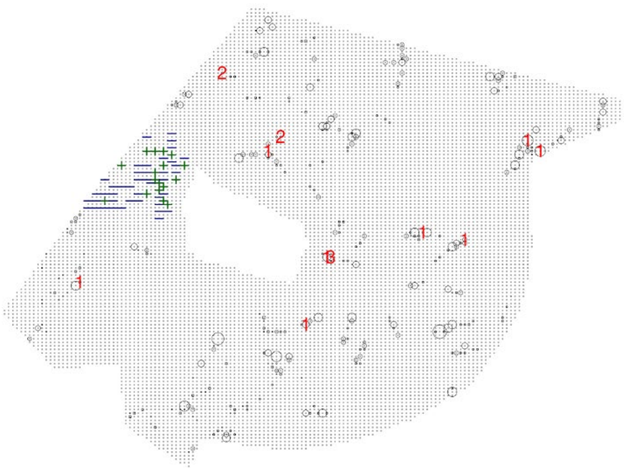

Figure 5.2.4. The additional data from the Swedish dragging survey added to part of Figure 5.2.2 (near Bornholm): a blue minus symbol indicates no net fragments found and a green plus symbol indicates that net fragments were found.

5.2.2 Analysis of line segment observations:

To derive an estimate of the total number of line segments likely to be observed if a survey scanned the entire study area (the shaded area of Figure 5.2.1) a spatial field is set up, such that the intensity can be estimated in each grid cell (*N* cells of 5x5 km are used here, but it has been validated that a 2x2 km grid gives similar estimates). The spatial intensity field is setup as a Gaussian Markov Random Field (GMRF), $(\lambda_i)_{i=1\dots N} \sim \mathcal{N}(\mu, \sigma^2 R)$ where:

$$R^{-1}_{i,i'} = \begin{cases} -1, & \text{if } i \text{ and } i' \text{ are neighbors} \\ n_i - \delta, & \text{if } i = i', \ (n_i \text{ is number of neighbors to cell } i) \\ 0, & \text{otherwise} \end{cases}$$

This field describes the log-intensity of line segment observations in each grid cell and R describes the correlation structure.

The observed number of line segments L_j in each survey haul *j*=1,...,*M* is assumed to follow a Poisson distribution with:

$$L_j \sim \text{Pois}(\exp(\lambda_{i(j)} + \log(\text{area}_j) + \alpha\text{conflict}_{i(j)}))$$

Note that the expectation depends on the intensity in the spatial field where the haul is taken, the area of the haul, and the amount of fishing gear conflicts recorded where the haul is taken.

It was tested whether the number of line segments in an area is correlated to any of the three different measures of gear activity/conflict (hours of fishing with active gear, hours of fishing with passive gear, and days with overlap between the two gear types), but none were found to be significant (Table 5.2.1).

Table 5.2.1. Significance tests for the different measures of fishing gear activity/conflict w.r.t. intensity of line segments.

Model	Test	P-value
A: $L_j \sim \text{Pois}(\exp(\lambda_{i(j)} + \log(\text{area}_j) + \alpha\text{active}_{i(j)}))$	A → D	33%
B: $L_j \sim \text{Pois}(\exp(\lambda_{i(j)} + \log(\text{area}_j) + \alpha\text{passive}_{i(j)}))$	B → D	90%
C: $L_j \sim \text{Pois}(\exp(\lambda_{i(j)} + \log(\text{area}_j) + \alpha\text{overlap}_{i(j)}))$	C → D	92%
D: $L_j \sim \text{Pois}(\exp(\lambda_{i(j)} + \log(\text{area}_j))$		

5.2.3 Results regarding line segments

The number of line segments estimated to be found if the entire study area was surveyed is estimated to be 734×10^3 with a standard deviation of 74×10^3 (Figure 5.2.5). It should be noted that this number is likely not the total number of line segments in the survey area, because it assumes that a survey haul will not capture everything in the area. The intensity appears to be highest in some areas in the North Sea and lowest in parts of the inner Danish waters (Figure 5.2.5)

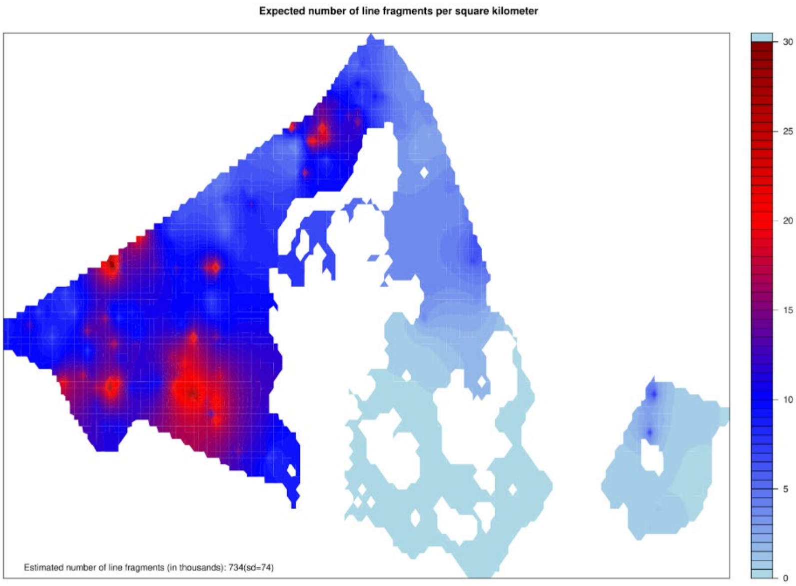

Figure 5.2.5. The estimated intensity of observing line segments per square kilometer. The sum over the entire study area (the coloured part of the map) is 734x10^3 with a standard deviation of 74x10^3.

5.2.4 Analysis of net fragment observations

Similar to the model for line segments, a spatial field is set up to derive an estimate of the total number of net fragments likely to be observed if a survey scanned the entire study area (the shaded area of Figure 5.2.2). The spatial field describes the log-intensity in each grid cell (*N* calls of 5x5 km are used here, but it has been validated that a 2x2km grid gives similar estimates). The spatial intensity field is setup as a Gaussian Markov Random Field (GMRF), $(\lambda_i)_{i=1\dots N} \sim \mathcal{N}(\mu, \sigma^2 R)$, where:

$$R^{-1}_{i,i'} = \begin{cases} -1, & \text{if } i \text{ and } i' \text{ are neighbors} \\ n_i - \delta, & \text{if } i = i', \ (n_i \text{ is number of neighbors to cell } i) \\ 0, & \text{otherwise} \end{cases}$$

Here *R* is the covariance matrix describing the correlation structure.

The observations of net fragments from the survey hauls are assumed to follow a negative binomial distribution (to account for overdispersion) with:

$$N_j \sim \text{Nbinom}(\mu_j, \phi) \ , \ \text{where } \log(\mu_j) = \lambda_{i(j)} + \log(\text{area}_j) + \alpha \text{conflict}_{i(j)}$$

The expected number of net fragments in a haul is proportional to the area covered by the haul and further depends on the intensity field in the grid cell where the haul is taken and potentially on the amount of conflict/activity in the area.

It was tested whether the number of net fragments in an area is correlated to any of the three different measures of gear activity/conflict (hours of fishing with active gear, hours of fishing with passive gear, and days with overlap between the two gear types), but none were found to be significant (Table 5.2.2).

Table 5.2.2. Significance tests for the different measures of fishing gear activity/conflict w.r.t. intensity of net fragments.

Model	Test	P-value
A: $\log(\mu_j) = \lambda_{i(j)} + \log(\text{area}_j) + \alpha\text{active}_{i(j)}$	A $\rightarrow$ D	46%
B: $\log(\mu_j) = \lambda_{i(j)} + \log(\text{area}_j) + \alpha\text{passive}_{i(j)}$	B $\rightarrow$ D	41%
C: $\log(\mu_j) = \lambda_{i(j)} + \log(\text{area}_j) + \alpha\text{overlap}_{i(j)}$	C $\rightarrow$ D	12%
D: $\log(\mu_j) = \lambda_{i(j)} + \log(\text{area}_j)$		

5.2.5 Including additional data sources

The ship-wreck observations W_s, $s=1,...,S$ (Figure 5.2.3) are binary observations indicating if net fragments have been reported by divers at a long list of S known ship-wrecks. No reporting does not necessarily indicate that no net fragments are at the wreck, but only that it has not been reported. These observations are described by a binomial distribution as:

$$W_s \sim \text{Bin}(p_s)\ ,\ \text{where}\ \text{logit}(p_s) = \beta + \delta\lambda_{i(s)}$$

The probability of net fragments being reported is related to the intensity of net fragments in the area (as a linear function at logit-scale).

Observations from the Swedish dragging survey D_k, k=1,...,K (Figure 5.2.4) are modelled in a way similar to the ship-wreck observation. For each scanned 2x2 km area it is summarized if net fragments were detected or not. The observations are described by a binomial distribution as:

$$D_k \sim \text{Bin}(q_k)\ ,\ \text{where}\ \text{logit}(q_k) = \psi + \gamma\lambda_{i(k)}$$

Notice again that the observations are predicted by the same intensity field that is used to describe the survey observations and ship-wreck data.

5.2.6 Results regarding net fragments

The results will be shown first using only the results from the survey, and then the ship-wreck observations and Swedish dragging survey observations will be added.

There are less observations of net fragments, so consequently lower intensities are estimated. The intensity varies from an expected number of net fragments observed per square kilometer of 0.1 to a little over 1. The sum over the entire study area is 49x10³. These estimates remain fairly constant whether only the survey data is used (Figure 5.2.6), or if the supplementary observations regarding shipwrecks and Swedish dragging survey are used (Figure 5.2.7 & 5.2.9).

There is a good consistency between the three different data sources (survey, shipwrecks, and Swedish dragnet), and the overall estimates are very similar (Figures 5.2.6, 5.2.7 & 5.2.9). The additional data do however give more detailed information in certain areas (Limfjorden and near Bornholm). The spatial relative differences can be seen in Figures 5.2.8 and 5.2.10.

No significance was found on the intensity of net fragments of the three different measures hours of fishing with active gear, hours of fishing with passive gear or conflict days between the gear types. It is however still possible to provide estimates of the number of net fragments expected in each of the 30 predefined conflict areas. The estimates, which are uncertain (cv ranging between 0.5 and 1), can be seen in Figure 5.2.11.

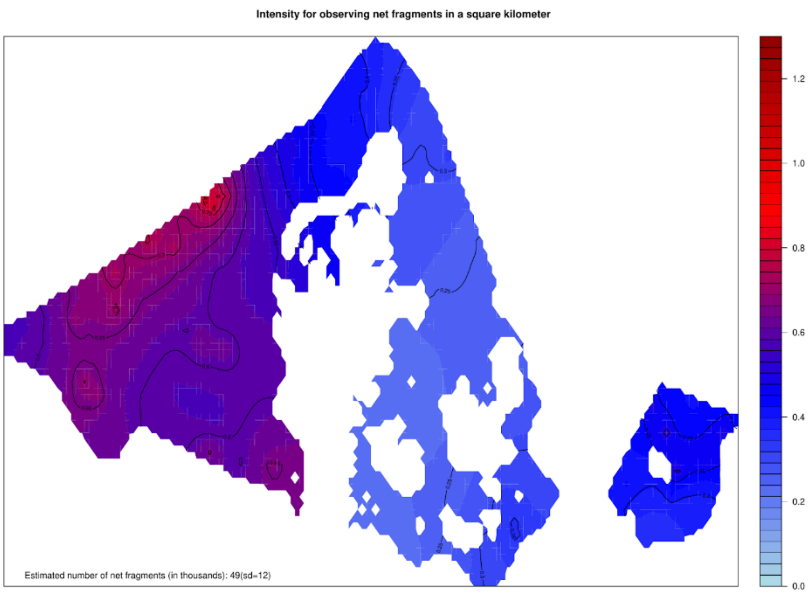

Figure 5.2.6. The estimated intensity of observing net fragments per square kilometer as estimated from survey data. The sum over the entire study area (the coloured part of the map) is 49x10³ with a standard deviation of 12x10³.

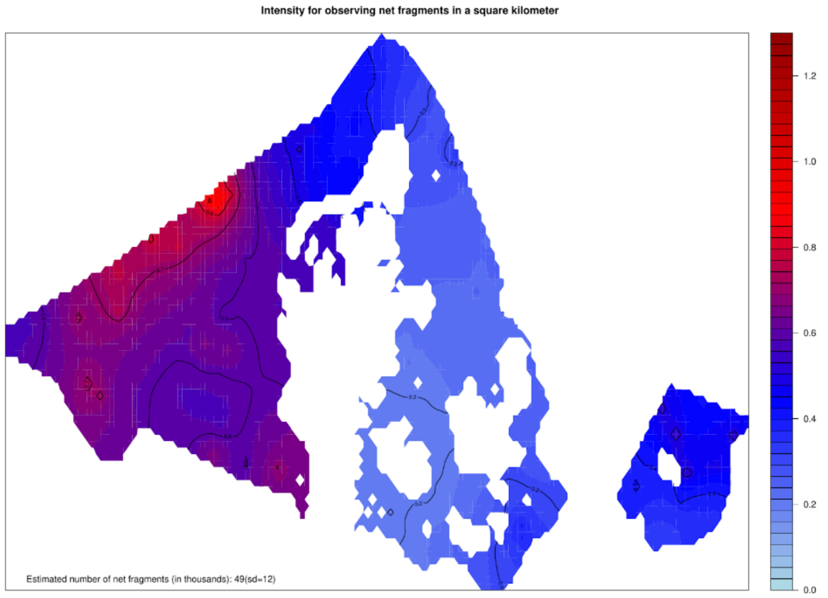

Figure 5.2.7. The estimated intensity of observing net fragments per square kilometer as estimated from survey data and ship-wreck reports. The sum over the entire study area (the coloured part of the map) is 49×10^3 with a standard deviation of 12×10^3.

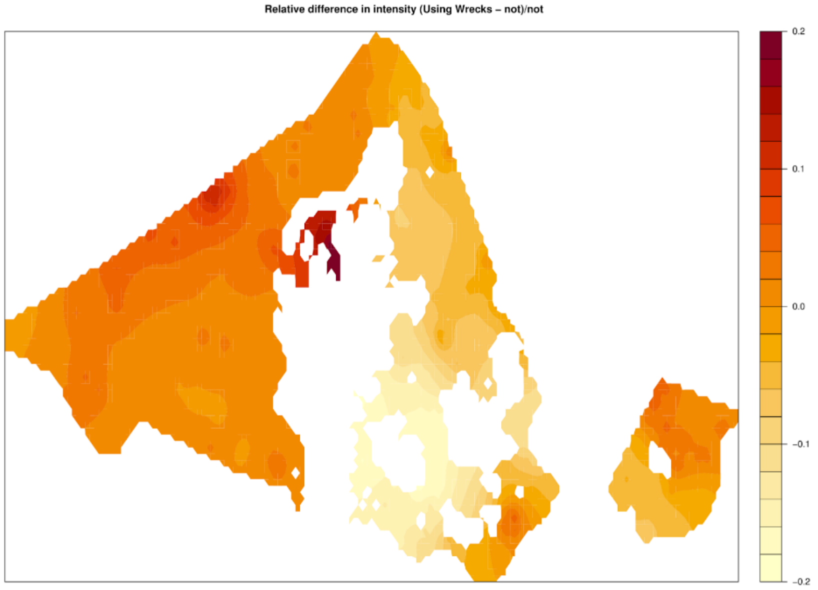

Figure 5.2.8. The relative difference in intensity estimates from using the additional observations from shipwrecks.

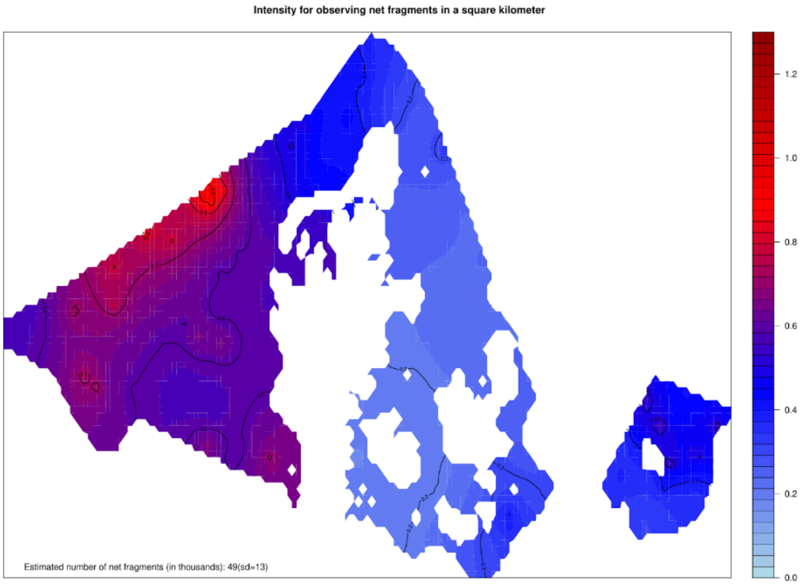

Figure 5.2.9. The estimated intensity of observing net fragments per square kilometer as estimated from survey data, ship-wreck reports and Swedish dragging survey observations. The sum over the entire study area (the colored part of the map) is 49x10³ with a standard deviation of 13x10³.

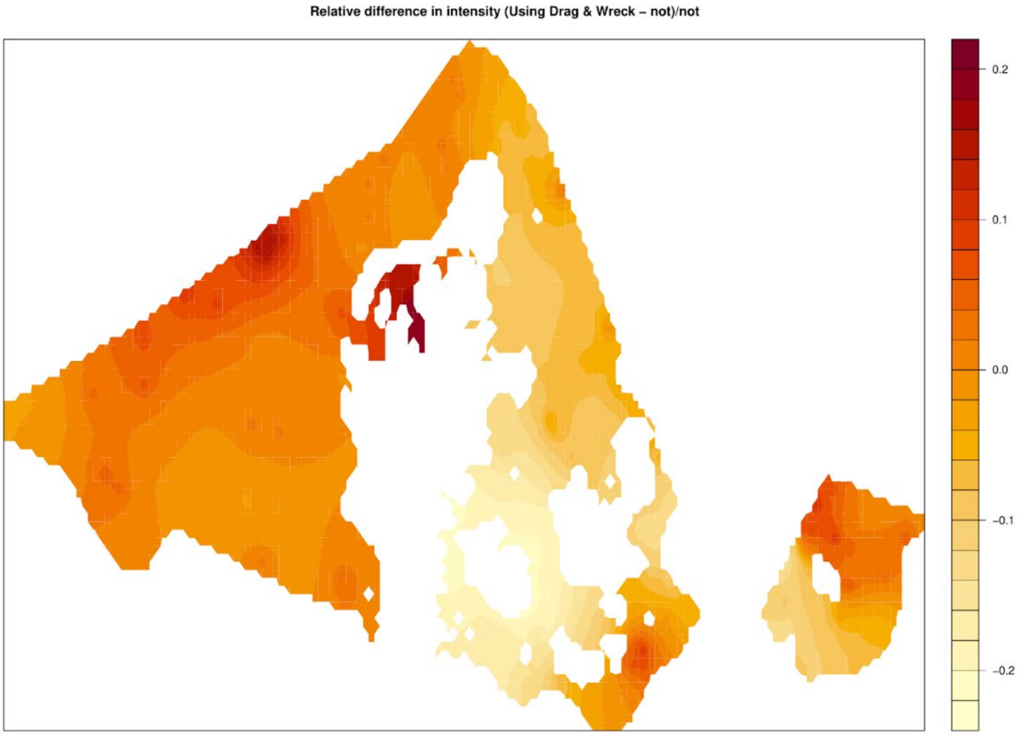

Figure 5.2.10. The relative difference in intensity estimates from using the additional observations from shipwrecks and from the Swedish dragging survey compared to using only IBTS/BITS and the projects survey observations.

Figure 5.2.11. Estimated numbers (not thousands) of net fragments expected to be found if each of the predefined 30 conflict areas were fully surveyed. The coefficient of variation (cv) on these estimates ranges from 0.5 to 1.

6. Review of recovering methods and experiences from other countries

6.1 Note - Phase 4. Review of methods used for retrieving ghost nets in countries around Denmark

This note sums up the literature study on methods used for retrieving ghost nets (derelict fishing gear DFG) in our neighboring countries relevant for Danish conditions (Appendix A.6.) and describes the advantages and disadvantages of the various methods and their applicability in Danish waters.

Fishing gears have since the late 1950'ies (Gislason, 2013) been made from nylon and other plastic materials that degrade very slowly. DFG therefore encompass everything from recently lost gear to gear accumulated during the last 50-60 years.

During the last 20-30 years, there has been a major change in the fishery in general both by professional and recreational fishermen e.g. changing fishing patterns, new location technologies (GPS, plotters) and the rise of marine litter awareness, which all possibly affect the number and location of DFG.

Identifying the location of DFG can be challenging and resource demanding if no reports or prior knowledge on their presence is available. Overall, a successful removal of DFG requires two steps:

1. Identifying the exact location of a DFG (sidescan sonar, video and divers, dredging and reporting apps)
2. Retrieving the DFG (divers, dredging)

In the following, relevant methods that cover either one or both of the identification/retrieval steps are summarized, the advantages and disadvantages of the various methods described, and their applicability in Danish waters discussed.

It should be noted, that prior to retrieval activities, the relevant permission should be obtained from The Danish Fisheries Agency as it is illegal to remove other peoples' fishing gear and/or have fishing gear onboard your vessel that is not marked according to the regulations.

6.1.1 Methods for locating areas hosting derelict fishing gear

VMS analysis

Snagging on object on the seabed and conflicts between fishermen and other marine actives are the main causes of fishing gear loss at present as well as in the past (Predki et al. 2019). In projects in and surrounding Denmark, areas potentially hosting DFG are mainly identified by analysing VMS data from fishing activities with active and passive gear combined with knowledge from local fishermen (Predki et al. 2019, Egekvist et al. 2017). This provides valuable information on the professional fishermen's fishing patterns during the last 10 years, and based on the information the fished areas can be split into three categories with increasing potential for loss of gear:

- Bottom trawling areas
- Gill netting areas
- Mixed fishing areas

A crucial part of the Marelitt Baltic project was validation of the predicted area-specific probabilities of DFG occurrence by search and retrieval. The results clearly indicated that the actual DFG densities are caused by multiple variables. Comparing neighbour squares of contrasting seabed structures, the systematically search revealed that DFG were most often found in the square with rocky seabed compared to the one with a smooth/sandy seabed. This was confirmed by the Polish observations of accumulating DFG in areas with rocks or other seabed obstacles, where the nets are intercepted and retained. In shallow water, the retrieval rates were low, probably because strong currents and waves fragment the nets and transport the fragments away from the area or bury them in the sediment.

Fishing effort can be used as a basis for designation of candidate areas, but it cannot stand alone to predict high densities of DFG. In Poland, for example, high densities are found in areas where gillnetters and trawlers are operating simultaneously. In contrast, hot spots in Sweden were exclusively found in areas where gillnetters were operating alone. However, areas with low or no fishing effort should not automatically be excluded as candidate areas, because water currents may transport DFG over long distances to areas with complex seabed morphology or underwater obstacles.

Relevance for Danish conditions, advantages and disadvantages
VMS data from the Danish fishery is available from 2012 for vessels larger than 12 m and is a commonly used tool for fishing pattern analysis in Danish waters and used as well for selecting conflict areas within this project and a Danish pilot project from 2017 (Egekvist et al. 2017). However, the data from this limited period coincide with a period where the Danish fishery has undergone significant changes and there has been an increasing awareness of marine litter. This gives a potential bias towards areas that in recent years potentially host DFG, whereas areas relevant for the previous fishing pattern might not be noticed. This should at least partly be compensated by including information from historical sources like logbooks and old fisheries statistics. According to Predki et al. (2019), most retrieved DFG are more than 5-10 years old.

Danish waters are expected to be more similar to Polish than to Swedish waters due to the extensive rocky coastal areas surrounding Sweden. The rocky areas increase the risk of snagging and reduces the possibility for active and passive fishing activities in the same area. Gravel, sand and mixed sediment is more likely to host both fishing activities and the risk of snagging on these bottom types is less likely. Therefore, it is hypothesized that most DFG in Danish waters is found where gillnetters and trawlers are operating simultaneously.

Sidescan sonar
Sidescan sonar survey is a non-invasive method for locating DFG. This method was initiated in the Marelitt Baltic project and later with great success used by WWF Germany (Predki et al. 2019, Dederer in prep). The method is useful in areas where DFG is believed to occur, and an

accurate positioning is needed. A follow-up on observed anomalies during SSS by ground truthing using divers, video or dredging is needed to confirm whether it is a DFG or a natural structure

Relevance for Danish conditions, advantages and disadvantages
The sidescan sonar method is suitable for mapping all kinds of bottom types, but it is most suitable for locating DFG on sandy and mixed bottom areas, where the backscatter signals from the bottom is not so strong that it hides signals from more soft structures like DFG. Even nets lying on the seafloor, covered by layers of sand or mud and not easily visible for a diver or a camera, could according to the WWF Germany's experience be identified (Dederer in prep).

Sidescan sonar surveys cover large areas compared to other searching methods, as the searched corridor is up to 100 m wide and the towfish can be towed at a speed of up to 4 knots. However, all anomalies need to be ground-truthed afterwards.

Video and divers
Video and divers are mainly used for ground truthing of anomalies, or at wrecks and other complex structures unsuitable for sidescan surveys or dredging. Video can be recorded using an ROV with the ability to move around structures or as a passive drop camera towed in a cable behind a vessel.

Relevance for Danish conditions, advantages and disadvantages
Video and diving surveys could be used in small-sized, shallow areas with good visibility. The advantage of visual methodologies is the direct observation, were no additional ground truthing is needed (only recovery).

Both divers and video (possibly operated on an ROV) are limited by the visibility of the water and therefore inefficient for coverage of larger areas because of an often, narrow search area.

Divers are preferred for surveys on wrecks or reef structures as they can manoeuvre and act on observations and therefore cover less obvious areas of an obstacle. An ROV can potentially also do this, but there is a risk of the ROV getting entangled in potential nets or the obstacle itself.

Reporting Apps
Reporting Apps in Sweden and Norway are collecting information from recreational fishermen who have experienced loss of gear and on DFG observations from other stakeholders using the mainly coastal water (sport divers, sailors or anglers). The Apps also include the option to report if an already reported gear is retrieved. The Swedish homepage called GhostGuard can be found at http://www.havochvatten.se and the Norwegian app "Fritidsfiske" can be downloaded from App Store or Google Play.

WWF Germany has recently released the app "ghostdiver", where positions for anomalies found during their SSS are uploaded, so that sport divers can check a site and confirm whether it is a DFG or something else. Professional divers can then later retrieve confirmed DFG. Previously, WWF Denmark had a site on their homepage where divers could report DFG on wrecks. It is however not available here at present, only through an old link to “WWF's registreringer af spøgelsesnet i danske farvande”.

Relevance for Danish conditions, advantages and disadvantages
The Danish coastal areas are dominated by relatively shallow water and host a broad range of recreational activities where DFG occasionally are observed. At this point in time, there is no exact protocol for what you should do and who you should contact regarding such observations. An app for Danish waters would be of great value for future clean-ups as it should be possible to focus the retrieval activities at the positions reported via the apps. In addition, it would give a better overall temporal picture of the type and location of fishing gear. With this knowledge, information campaigns could be better aimed at specific groups.

Citizen-science reported data are associated with a degree of uncertainty and bias. It is of great importance that all recreational fishermen are reporting, not only the members of the fishing associations but also the occasional recreational fishermen who fish a couple of times a year.

Such apps and homepages are costly to initiate and run. Similar Danish solution should therefore await a cost and benefit analysis that includes the extent of reporting to and experience with apps in the other countries.

Update: Limfjordsrådet have after the completion of the note launched a homepage (https://www.limfjordsraadet.dk/projekter/spoegelsesnet-i-limfjorden/) where everyone can report sightings of ghost net in the Limfjord. They have in the first 3 month received around 100 reports of nets (DR, 2021).

6.1.2 Retrieval of nets
When a derelict fishing gear is located, the two methods used in northern waters for retrieval are either by dredging or by professional divers.

Divers (location and retrieval) in Germany are used for ground truthing anomalies observed in sidescan sonar surveys and retrieving DFG. This is considered a gentle retrieval method as the diver can cut and loosen the gear so the effect of the retrieval on the habitat is minimized. Therefore, divers are also generally recommended when DFG should be retrieved from wrecks, in Natura 2000 areas or on reefs (Predki et al. 2019, Dederer in prep). However, all wrecks older than 100 years are considered cultural heritage and any retrieval activities on these need a permission from “Slots- og Kulturstyrelsen”. In general, the cultural heritage status of wrecks should always be checked.

Relevance for Danish conditions, advantages and disadvantages
Diving time decreases with increasing depth. The Danish waters are generally of limited depth, which allows for long diving time and makes the use of divers suitable. The position of the targeted DFG needs however to be known quite accurately as the search area is limited by the diving time at a given depth. However, a diver has the possibility to do an active search based on the observation during the dive unlike a dredge pulled passively behind the vessel that might pass right beside the target.

The retrieval of DFG by divers can be a dangerous activity as the diver might get entangled in the netting as it floats to the surface and thus ascend too fast with the risk of diver's sickness. In areas with strong currents, recovering DFG is challenging because of the high risk of being entangled in the gear. Therefore, only professional divers should be involved in retrieval activities. *Dredging* is the method most commonly used for retrieving DFG at known positions. It is a well-known method used by the fisherman that incidentally loses his gears well as in large surveys like the annual survey undertaken by the Norwegian Directorate of Fisheries where they drag at positions for lost gear reported by the fishing industry (Ref #1). The design of the dredges used are numerous, most commonly it's an anchor pulled at slow speed across the area, but some also use devices with more hooks attached to increase the probability of entanglement. Dredges should be adapted to the depth, the bottom type and the size of the vessels at which they are used and therefore no general design is recommended.

Dredging is also used for identifying nets in areas where no exact positions for DFG are reported, but where an area is selected as a survey area for DFG. Here, stratified surveys can be made, and this method have proved to be quite efficient in the Baltic, especially Sweden has had success using this method retrieving mainly old gillnets (Predki et al. 2019; Tschernij 2020). Dredging have also been used with success in Limfjorden, Denmark where many abandoned nets were retrieved in an area popular for lobster fishery (Christensen, 2020).

Relevance for Danish conditions, advantages and disadvantages
Dredging is commonly used by fishermen at most depths. It is an efficient method as both search and retrieval can be done simultaneously. However, some areas are un-suitable for dredging. In the Marelitt Baltic project, they identified unsuitable areas to encompass ammunition deposition areas due to high risk of explosion and contamination, Natura 2000 areas due to possible negative impact on protected species and their habitats, and areas with located wrecks.

The combination of deep water, rocky bottom, rough weather conditions and the extensive use of crab traps is not relevant in the Danish fisheries. An annual dredging survey like the Norwegian one is therefore not cost effective in Danish waters.

7. Fieldwork – Recovering ghost nets

7.1 Note - Phase 5. Fieldwork: Ghost net removal trials

This note describes the phase 5 fieldwork activities on removal of ghost nets, completed in 2020 & 2021 within the project. During the project, two types of methods for removing ghost nets have been tested. Removal by divers and removal by dredging. The challenges and solutions, general advantages and disadvantages will be evaluated below as well as the cost efficiency and methods of disposal.

7.1.1 Completed fieldwork

Techniques for removal of ghost nets were tested during three surveys. Removal by divers were tested during the dive survey in September 2020 (App. A.2). Removal by dredging was tested successfully on two different types of vessels, during the sidescan and video survey with Havfisken in January 2021 (App. A.4) and on a recovery mission with DTU Aqua's small vessel Havørreden in April 2021. The two methods are in general terms described below as well as the materials recovered, more details can be found in Appendix A.7.

7.1.2 Removal of ghost nets by divers

Both gillnets, trawls and angling gear was removed by divers from three different wrecks during the dive survey. Overall, the same three steps were repeated when removing nets by divers, independently of the type of gear appointed for retrieval.

- Diver #1 documented and described the ghost net and how it was situated on the wreck, so that a plan for the cutting and release could be made and the appropriate equipment prepared.
- Diver #2 brought the appropriate equipment, usually a hydraulic cable/wire/rope cutter, an extra knife, lines and rope to tie the ghost net together and a number of lift bags. The net was cut and released from the bottom or the structure on the wreck, where it was caught.
- The net was prepared for retrieval, by tying it up and attaching the lift bags to the net. The material was then raised from the wreck to the surface by filling the lift bags with air and getting the recovered material on-board the vessel by a small crane.

Challenges and solutions

The net materials removed during the dive survey had generally been stuck on the wrecks for many years and were covered in sediments and biological material, which were released into the surrounding water during the release process. This reduced the visibility of the water and made it difficult to estimate how much of the net material was recovered and how much remained on the wrecks. An extra dive could have been made to estimate this or to remove extra material, but this was not prioritized due to the limited dive time available.

During the dive survey, it was evident that a complete ghost net clean-up on a wreck will be a very time-consuming activity if all recreational fishing gear, lines and small pieces of gillnet should be removed.

The exact position should be known when using divers for retrieval. The time used to search for uncertain ghost net or wreck positions is very expensive if you have a dive crew waiting. An exact position is not as important for retrieval by dredging. Here an approximate position is acceptable, as you will arrange a search pattern that is reasonable in relation to the size of the object you are searching for.

Before removing an old net, which during many years has been integrated in e.g. a wreck, reef or other bottom structure, it should be considered if the removal of the net will cause severe changes or damages to the structure and thereby also to the habitat for algae, mussels and other bottom-living organisms.

Prior to removing nets from a wreck, the cultural heritage status should always be checked and also the risk of oil leaks and other potential environmental and structural consequences associated with the removal of material.

General advantages and disadvantages

Ghost nets on wrecks, protected reefs and other complex and maybe fragile structures where the net can be stuck at multiple points, needs to be freed carefully to avoid damage to the structure. Dredging is therefore not a solution at these types of locations, and it have until now been done by divers. This process of freeing the net can be a time-consuming activity and initiatives with ROV's are starting up e.g. the Ghost Diving association[1] have started trials with an ROV that can cut loose and grab the nets and trials have been made on the Norwegian clean-up survey. However, use of ROV on the Norwegian survey was costly and time consuming and did not provide the expected yield and the video from the Deeptrekker ROV show that it needs much further development until it is a sensible replacement for a diver (Ref. #1, 2, 3).

Use of divers is at this point in time, therefore the only sensible method for removal of nets on complex and maybe fragile structures where the net needs to be freed to avoid damage to the structure. Recreational diving is popular activity all over the world and at first thought, it would be obvious to organize ghost net clean up campaigns for recreational divers, as this probably would engage a lot of voluntary work and reduce the cost of the clean-up activity significantly. However, removal of ghost nets from wrecks and from the seabed in general could be a dangerous activity, as the risk of e.g. "simple" entanglement of the diver is large and could have severe consequences. An entangled diver could in severe cases be lifted uncontrolled to the surface by a lifting bag and risking decompression sickness or expansion damage of the lungs. Therefore, removal of nets should only be done by professional divers,

7.1.3 Removal of ghost nets by dredging.

Two gillnets and some angler gear, stuck in one of the gillnets, was retrieved by the dredging method. The method is a traditional search method for lost gear and is in general terms described below.

When dredging for the ghost nets two different types of "x-mas tree" dredges were used, a different one on each vessel. Both were attached with a piece of chain to keep the dredge close to the bottom. The dredge was pulled at low speed (from 1 to 3 knot) with as much bottom contact as possible, in the area where a structure believed to be a net was observed. The optimal

[1] Ghost Diving is a registered charity organization and the largest international diving organization of volunteer technical divers specialized in the removal of lost (ghost) fishing gear and other marine debris since 2009.

speed was adjusted according to the water depth in the dredged area, the weight of the dredge and the length of the tow cable/rope (source, the skippers of Havørreden and Havfisken).

A crewmember had a hand or a foot on the rope/cable at which the dredge was attached, feeling for a tensioning of the rope/cable that would indicate that the dredge had caught something. The speed was then reduced and the rope/cable with the dredge was pulled in by the winch on Havfisken and by the net hauler on Havørreden, until the net was recovered. Havørreden experienced that the gill net fell of the dredge, the dredging process was then repeated in close vicinity to where it was lost, and the net was recovered in the second attempt.

Challenges and solutions

When dredging an area for ghost nets, the catch efficiency is unknown, but the main aim is to keep the bottom contact of the drag, any pulls in the rope that can cause the dredge to jump and lose bottom contact can reduce the catch efficiency. A haul perpendicular across the item is the most efficient direction as it will reduce the risk of the net falling of the dredge because there is a bigger chance that the dredge will get hold of the strong parts of a gillnet instead of just a few meshes made of thin nylon line.

If nothing is caught by the dredge, in an area known to host a ghost net it is suggested to change the haul direction in order to get a better “grip” of the net material.

An item caught by a dredge can break during the recovery process either, in the area where it is caught by the dredge or where it is stuck to the bottom by a stone or some other object. If the break is caused by a stone or another structure, there is a risk that the entire item will not be recovered as it can be difficult to see if the break is recent or the cause of the loss. If the dredge causes the break there is now two pieces of net that needs to be retrieved. The item can also fall of the dredge without breaking into two pieces. In all cases, it can be a good idea to repeat the search.

General advantages and disadvantages

Searching and retrieving object by dredging is an old, convenient and simple method for recovering lost gear at sea. The technique can be used from all kinds of vessels, from dinghy size vessels in shallow water to large vessels at water depths up to 1000 m like on the Norwegian retrieval surveys (Ref. #1).

Dredging is most suitable in smooth bottom areas like sand or mud, as the dredge is most efficient when it is pulled smoothly on the surface of the bottom or even penetrates a few centimeters. The Marelitt Baltic project (Prędki et al. 2019; Sahlin & Tjensvoll 2018) found areas unsuitable for dredging to be: 1. Ammunition deposition areas, due to the high risk of explosion and contamination. 2. Natura 2000 areas, due to possible negative impacts on protected species and their habitats. 3. Eelgrass meadows because shoots, roots and seeds, stored in the sediment can be damaged by abrasion. 4. Areas with located wrecks, due to the risk of structural damage.

7.1.4 Cost efficiency

The cost efficiency of both methods is very dependent on the prior knowledge of ghost nets in the area and there are in both cases increasing costs related to an increase in water depth.

Dredging retrievals in shallow < 10 m, coastal, smooth bottom areas can be made with a small dinghy like Havørreden, which have a net hauler and room for a bigbag for storing the retrieved nets. At larger depths, the size and weight of the dredge needs to be in-creased and thereby the required size/power of the vessel and its net hauler or winch.

The bottom time for divers is reduced significantly with increasing depth and thereby increasing the costs as more divers are needed to do the same job at a deep site com-pared to a shallow site.

In areas with high concentrations of ghost nets, the dredging method has proved to be very cost efficient. In Nissum Bredning, Limfjorden, 63 bags of ghost nets were retrieved during a 14 day, 4-6 hours a day, dredging survey (Christensen, 2020). And in an identified hot-spot area in the Baltic Sea (northwest of Bornholm) seven vessels that dredged for four days each covered an area of 276 km2 and found almost 10 km of net (Tschernij, 2020). In Predki et al. (2019), details from other more or less successful dredging surveys can be found.

When planning a ghost net clean-up in a given area, the biological/ecological “cost-efficiency” should be considered. Will the removal of a ghost net, e.g. from a wreck, a complex reef/stone structure or the sandy bottom have a smaller ecological footprint, than leaving the net? In some cases, the ghost nets have become an integrated part of the habitat and a removal could do more damage than good even with a gentle removal by divers. In other cases, even old ghost nets are found to be fishing, due either to the way they are stuck to the bottom structures or due to the habitat type that they are in. A removal of these nets, even with the dredging method, would in many cases have a smaller footprint than leaving the net.

Within this biological/ecological “cost-analysis”, the environmental condition of the given area should be checked (in relation to the Water Framework Directive and the Marine Strategy Framework Directive, including established environmental targets and the cur-rent programme of measures). Ensuring that the removal of ghost nets, does not adversely affect relevant en-vironmental parameters/factors and that the condition of the area does not worsen. Likewise, it should be ensured that the activities, and any negative effects thereof in connection with the re-moval of ghost nets does not conflict with the National Monitoring Program for the Marine Strat-egy Directive and the National Monitoring Program for Aquatic Environment and Nature (NO-VANA).

7.1.5 Method of disposal

The methods for disposal of ghost nets are at this point in time limited. In principle, nets can be recycled at companies like Plastix in Lemvig. However, ghost nets are often covered in algae, mussels and other biological material and are made from multiple types of material that needs to be separated prior to the start of a recycling process. A typical gillnet consists of a monofile or multimonofile net, mounted with floating and sinking lines, and tied to anchors and buoys with nylon rope. The person-hours required for this work is not in proportion to the amount and qual-ity of the materials for recycling. Depending on the state when recovered, floats, lead sinking lines, buoys and anchors can be separated and reused. Even recovered trawls with many kilograms of net material are at this point hard to recycle due to the impurities in and degradation of the plastic material.

The recovered nets from this project were disposed in the following ways:

- The majority of the biological material were on all occasions removed either at sea or when at the dock. This was possible due to the relatively small amounts and to the fact that we measured and categorized all the retrieved material.
- The metal recovered during the dive survey was delivered to a recycling station and the nets handed over to Fiskerikontrollen, as they had requested this.
- The net recovered outside Hirtshals was separated, the anchor and lead lines were reused by DTU Aqua, and the net material delivered to a recycling station.
- The net recovered in Øresund are at this point, kept as a ghost net sample that can be used for future demonstrations.

Clean-ups with large amounts of nets, some fitted with lead sink lines and some with large amounts of biological material attached, will probably go to landfills until efficient ways of separating and purifying the materials are developed. Potentially, all retrieved ghost nets can be dried and separated into materials for reuse and recycling. In addition, lead and other environmentally hazardous materials can be removed, so that the remaining material not suitable for reuse or recycling can go into incineration. This separation process will, in larger clean-ups however require a significant number of person-hours for detangling the material and a large area to dry up the material, which in most cases is not believed to be cost efficient. When retrieving single nets, a separation of the materials is recommended.

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Appendices

A.1. Detailed description of the selected areas, (app to chapter 3)

A.2. Dive survey, (app. to chapter 4.)

A.3. Mapping conflict areas in the Inner Danish waters (app to chapter 4)

A.4. Mapping conflict areas in the North Sea/Skagerrak area (app. to chapter 4)

A.5. Extra survey in the Limfjord (app. to chapter 4)

A.6. Methodologies for location and retrieval of derelict fishing gear – description and experience (app. to chapter 6)

A.7. Retrieval of nets (app. to chapter 7)

A.8. Data Processing methods and data sources

A.9. Dive descriptions

A.10. Dive video list

A.11. Activity log inner Danish waters

A.12. Video list, inner Danish waters

A.13. Target list, inner Danish waters

A.14. Sidescan sonar file list, inner Danish waters

A.15. Activity log, North Sea/Skagerrak

A.16. Video list, North Sea/Skagerrak

A.17. Target list, North Sea/Skagerrak

A.18. Sidescan sonar file list, North Sea/Skagerrak

A.19. Recovered materials

A.20. More detailed description of removal of nets by divers

A.21. Flyers from the industry; “Best practice”, “Gode råd” & “Vejledning”

The appendices are in a separate report:
https://www.aqua.dtu.dk/-/media/institutter/aqua/publikationer/rapporter-352-400/appendices_ghost-nets-in-danish-waters.pdf

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Technical
University
of Denmark

DTU Aqua
Kemitorvet
DK-2800 Kgs. Lyngby

www.aqua.dtu.dk