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Sluttrapport

Seleksjon og bifangstreduksjon i industritrålfiske

Prosjektet finansieres av FHF og Fiskeridirektoratet

Forfatter(e)

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Øyepålfiske
Sorteringsrist
Excluder**FORFATTER(E)**

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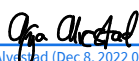
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SAMMENDRAG

Denne rapporten gir en oppsummering av alle aktivitetene som er blitt gjennomført i prosjektet. Totalt ble 6 tokt gjennomført i regi av prosjektet. I tokt 1 ble en Excluder seksjon (36mm stolpelengde) testet i tobisfiske om bord på MS «Nordsjøbas» i perioden 08.-15.04.2021. I tokt 2 ble en Excluder seksjon (36mm stolpelengde) testet på øyepålfiske om bord MS «Vikingbank» i perioden 02.-08.07.2021. I tokt 3 sammenlignet vi en større (enn dagens) rist variant mot dagens stålrister i fisket etter øyepål. Dette toktet ble gjennomført om bord på MS «Fiskebank» i perioden 10.-19.09.2021. I tokt 4 sammenlignet vi en Excluder seksjon (36mm stolpelengde) og vanlig 40mm ristseksjon i fisket etter øyepål. Forsøket foregikk om bord på MS «Fiskebank» i perioden 01.-10.10.2021. I tokt 5 ble en Excluder seksjon (28 mm stolpelengde) testet i tobisfiske om bord på MS «Bømmelfjord» i perioden 01.-10.05.2022. I tokt 6 ble en 35mm og en 40mm rist testet på øyepålfiske om bord MS «Cetus» i perioden 12.-20.10.2022.

Rapporten viser resultatene som grunnlag til diskusjoner og anbefalinger til videre arbeid i prosjektet.



Anja Alvestad (Dec 8, 2022 09:12 GMT+1)

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Historikk

VERSJON	DATO	VERSJONSBEKRIVELSE
V1	2022-11-08	Versjonen ble skrevet av Eduardo Grimaldo og Anja Alvestad.
V2	2022-11-12	Versjonen ble redigert av Jesse Brinkhof, og Shale Rosen
V3	2022-11-29	Versjonen ble redigert av andre medforfattere
V4	2022-12-06	Versjonen er kvalitetssikret av godkjent og signert av forskningsleder
V5	2022-12-08	Versjonen er godkjent og signert av forskningsleder

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BILAG/VEDLEGG

Vedlegg 1: Vitenskapelig artikkel: Brinkhof, J., Grimaldo, E., Herrmann, B., Pettersen, H. (2022). The effect of grid size on catch efficiency and by-catch in the demersal trawl fishery for Norway pout (*Trisopterus esmarkii*), Ocean & Coastal Management, Volume 229, 2022, 106333, ISSN 0964-5691, <https://doi.org/10.1016/j.ocecoaman.2022.106333>

Vedlegg 2: Vitenskapelig artikkel: Grimaldo, E., Brinkhof, J., Herrmann, B., Pettersen, H. (2022). Improved bycatch reduction in the mixed demersal trawl fishery for Norway pout (*Trisopterus esmarkii*). Estuarine, Coastal and Shelf Science. GODKJENT MANUSKRIFT.

Vedlegg 3: EU Scientific, Technical and economic committee for fisheries – 65th PLENARY REPORT (PLEN-2020-03). Section 6.2 Assessment of the potential impact on the exploitation pattern of species by-caught in the Norway Pout fishery with an alternative species selective device. Pages 63-73.

1 Bakgrunn for prosjektet

1.1 Problemstilling

Innblanding av uønsket bifangst, herunder torskefisker, makrellstørje og ulike haiarter er en økende problemstilling i trålfisket etter pelagisk fisk og industritråling. De fleste haiartene er rødlistet og bør av den grunn bli selektert skånsomt ut under tauing. Mangel på teknisk velfungerende løsninger for fortløpende utsortering og bearbeiding av hvitfisk gjør det også vanskelig å ta vare på kvaliteten. I tillegg er prosentandel for lovlig bifangst svært lav, hvilket medfører risiko for lovbrudd og økte kostnader for flåten. Innen industritråling er det først og fremst kvotebelagt fisk/stor fisk som utgjør et problem, men innblanding av verdifulle konsumfisk (makrell og sild, for eksempel) fører til et verditap når disse artene brukes til reduksjon. Kunnskap om dagens situasjon mht. bifangst blir presentert i Tabell 1.

Tabell 1. Estimert bifangst i 2014 for fire industrifiske for mel- og oljeproduksjon (Fiskeridirektoratet, 2015). Alle data i tonn. Bifangstkvantum regnet ut fra kontroller av 21 landinger stemmer ikke helt med sluttседler (siste kolonne).

Bifangst art	Tobis (57 864 tonn)	Øyepål/kolmule (27 948 tonn)	Kolmule (27 175 tonn)	Havbrisling (7 761 tonn)	Sum	Sluttседdel sum
Nordsjøsil	829		344	0	113	1 286
Makrell	246		3	0	12	261
Hestemakrell	0		664	0	0	664
Sei	0		54	< 1	0	54
Torsk	30		58	0	0	88
Hyse	0		34	0	0	34
Sum	1 105		1 157	< 1	125	2 387

Tobisfiskeri (små-masket industribunntål)

Tobis (*Ammodytidae spp.*) er en liten ålelignende fisk med en lang ryggfinne og gattfinne. I Nordsjøen deler man bestanden opp i 3 stammer. Småsil eller tobis blir maks 18 cm, havsil maks 24 cm og storsil maks 32 cm. Det er småsil som utgjør den største bestanden. Den fanges med trål i Nordsjøen, inngår i Nordsjøtrål- og industritrålfisket og brukes til produksjon av fiskeolje og fiskemel. Småsil og havsil finnes ved sand og grusbunn ned til 100 m dyp. Om våren og sommeren da fisken beiter i stimer, trives den der vannstrømmen er mellom 1-3 knop. Den spiser plankton, fiskeegg og yngel, og om natten graver den seg ned i sandbunnen. Det er i denne perioden fisket foregår. Om vinteren holder den seg mest nedgravet i sanden. Silen blir kjønnsmoden i 2-års alderen, og i den engelske kanal gyter den om høsten mens den gyter om vinteren lenger nord i Nordsjøen. Eggene fester seg til sandkornene på bunnen, og klekketiden strekker seg over flere måneder avhengig av hvor langt nede i sanden eggene ligger. Silen er en viktig næringskilde for arter som torsk, hvitting, hyse, sei, sild, makrell og ulike flatfisker. Gytebestanden av sil varierer fra år til år. Fisket etter tobis i 2019 ble gjennomført i henhold til den områdebaserte forvaltningsmodellen, og i 2020 ble det tilradd fangst av 250 000 tonn tobis. Bakgrunnen var historisk sterk rekruttering, men fremdeles er mye av biomassen eldre fisk med god mattilgang i Nordsjøen (Fiskeridirektoratet, 2019).

Øyepål- og kombinert øyepål/kolmulefiskeri (små-masket industribunntål)

Trålfisket etter øyepål (*Trisopterus esmarkii*) har foregått i mange tiår. Fisket fikk skikkelig fart på begynnelsen av 1960-tallet. Redskapet som ble benyttet under de første tiårene var først og fremst en småmasket bunntål av en type som ble kalt «Expo». Maksimum maskevidde i vinger og forpart på denne trålen var 200 millimeter, og fiskeline og headline var vanligvis på henholdsvis 60 og 50 meter. På 1980- og 1990-tallet ble kolmule også en ettertraktet art for industritrålflåten. For å kunne fange kolmule samtidig med øyepål, ble det tatt i bruk en pelagisk trål («Steintrål») som ble utstyrt med mye fløyt-kapasitet samt et lett bunn gear, og som kunne settes lett ned på bunnen. Trålen var effektiv for kolmule, men ble mindre effektiv for øyepål, spesielt på dagtid. Under gitte betingelser kan en Expo-trål fange øyepål like godt som en Steintrål som er fire-fem ganger større målt i fangstbredde (swept volume). I de siste to tiårene har fartøyene som driver trålfiske etter øyepål blitt stadig større, med ditto økte driftskostnader. For å kompensere for dette har det vært gjort forsøk med større Expo-tråler. Så langt har en imidlertid ikke oppnådd forventet «storbåteffekt» med økt fangstkvanta som følge av trål med større omkrets. For om mulig å forbedre fangsteffektiviteten til bunntåler av Expo-typen, ble det i slutten av 2016 tatt initiativ fra næringsutøvere til et prosjekt i regi av Fiskeri- og

havbruksnæringens forskningsfinansiering, FHF, hvor man kunne få belyst aspekter rundt atferd hos øyepål i fangstøyeblikket og hvordan slik kunnskap kunne benyttes til utforming av mer effektive trålfredskap for fiske etter øyepål (Isaksen, 2019).

Kolmulefiskeri (pelagisk trål)

Kolmule (*Micromesistius poutassou*) har en utbredelse som strekker seg over store deler av Nord-Atlanteren. Gyteområdet er nordvest for de britiske øyer. Totalfangsten har variert mellom 1,3 og 1,5 millioner tonn de siste årene, hvorav den norske fangsten har vært på 300–500 tusen tonn. Det meste av fangsten (også den norske) tas med pelagisk trål langs kontinentalskråningen nordvest for de britiske øyer i perioden februar til april, og det kan da tas store fangster på opptil 1000 tonn på et hal. Fisket skjer på 300–600 m dyp, og dypest tidligst i sesongen. Store fangster og krevende værforhold er utfordrende for både fartøy og redskap. Havforskningsinstituttet har, siden 2018, jobbet med FHF og næringen om problemstillinger rundt fangstkontroll i kolmulefisket. Fisket etter kolmule var MSC-sertifisert (sammen med norsk vårgytende sild), men godkjenningen utløp i 2019.

1.2 Prosjektets målsetninger

Hovedmålet med dette forsøket var å sammenligne fangstene og bifangstene av en trål med og uten Excluder montert i trålen.

Delmål:

- Teste ut teknologi som kan bidra til å redusere uønsket bifangst og dokumentere seleksjonsinnretningenes funksjonalitet og seleksjonskapasitet med målinger på art, lengde og video.
- Teste Excluder som seleksjonssystem i utvalgte pelagiske fiskerier og industritrål.
- Utvikle kunnskap om adferd som kan bidra til å finne gode seleksjonsløsninger i de viktigste kommersielle pelagiske fiskeriene og dokumentere dette med video.
- Dokumentere seleksjonsinnretningens funksjonalitet og seleksjonskapasitet med målinger og video i samarbeid med Egersund Trål.

2 Referansegruppens anbefalinger til fokus og undersøkelser

Prosjektgruppens og referansegruppens anbefalinger var å:

- Fokuserer på bifangstreduksjon i tobis- og øyepålfiskeriet i Nordsjøen.
- Teste Excluder i disse fiskeriene.
- Sammenligne Excluder og rigide sorteringsrister.
- Teste en større versjon av sorteringsristen.
- Se forskjellen i seleksjon mellom 35mm EU rist og 40mm Norskerist

3 Forsøk 1: Uttesting av en Excluder-seksjon i fisket etter tobis om bord på MS «Nordsjøbas» i perioden 08.-15.04.2021

3.1 Formål:

Kvantifisere fangst og bifangstreduksjon av en trål med og uten en Excluder-seksjon.

Deltakere på dette toktet var Eduardo Grimaldo (SINTEF Ocean), Shale Rosen (Havforskningsinstituttet) og Arvid Sæstad (Egersund Trål). Her ble det testet en Excluder med knuteløse kvadratmasker av notlin med 36 mm x 36 mm stolpelengde. Toktet foregikk uken før den kommersielle sesongen åpnet, og tobis var vanskelig å finne.

3.2 Fartøy og utstyr

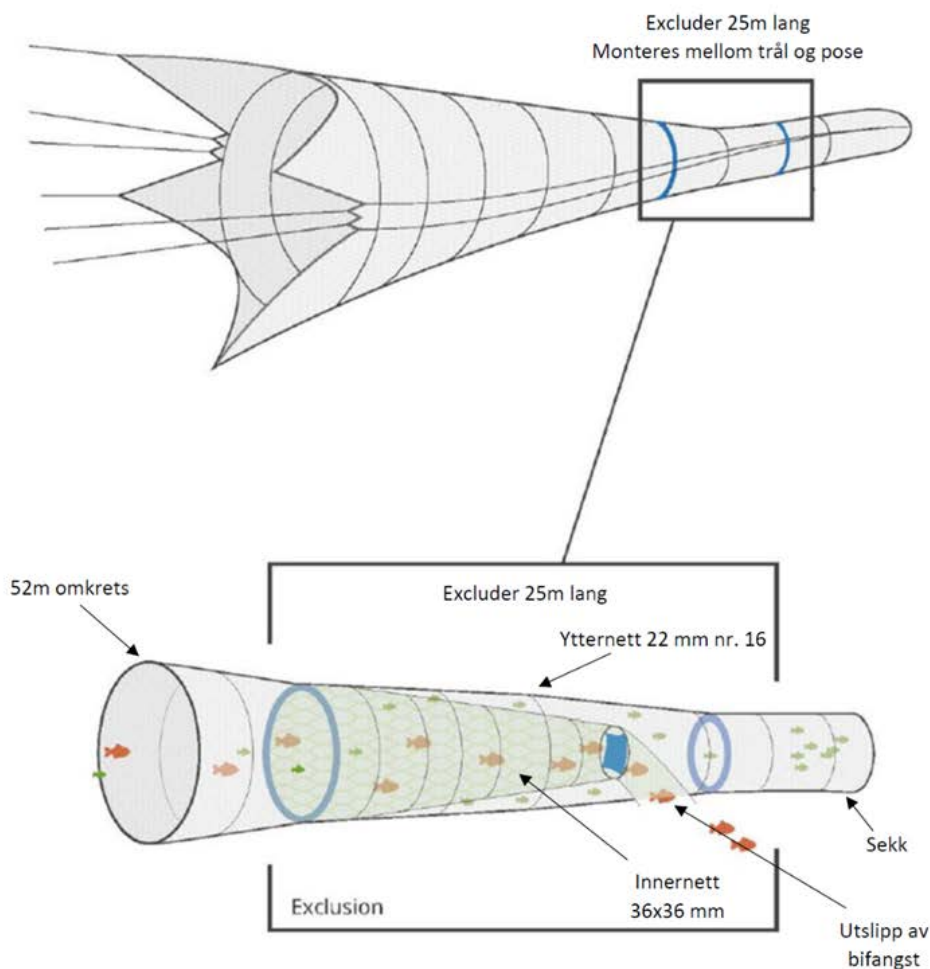
MS «Nordsjøbas» (LFJF, 70,3 m, 2055 tonn, 4474 KW) ble stilt til disposisjon for gjennomføring av toktet. Toktet ble gjennomført i perioden 08.-15. april på det kommersielle fiskefeltet i Nordsjøen. Trålen som ble brukt under forsøket var en Egersund-tobistrål (1248 m omkrets 24 m HEX; se vedlegg I) med en 82 m lang sekk med 22 mm T90 masker i de fremste 27 meterne og 5 mm masker i de bakerste 55 meterne. Under tråling ble trålens åpning målt til 40 m H x 87 m B med trålsonar.

Trålen ble rigget med 14 m², 3800 kg Thyborøn T-22vk «flipper» pelagisk tråldører (alle klaffene var lukket), 100 m sveiper (inkl. hanefot og forlengelse) og en 1500 kg kjettingklump på hver vinge. Trålen ble overvåket med en Wesmar TCS 770 trålsonar (180 kHz profilering / 110 kHz sonde), Scanmar dørsensorer for døravstand og Scanmar Tråløye plassert 35 m framfor enden av trålen. Fartøyet brukt skrogmontert Furuno FCV-1200L ekkolodd på 50 og 200 kHz, Simrad ES80 ekkolodd på 38 kHz og Furuno FSV-85 og FSV-35 fiskerisonarer på 80 og 24 kHz for å lete etter fisk.

Excluder (Figur 1) er et fleksibelt seleksjonssystem som er blitt utviklet av Green Line Fishing Gear AS i samarbeid med DTU Aqua, SINTEF Ocean and Danske Pelagisk Forening som et alternativ til seleksjonsrist i øyepålfiskeriet i Nordsjøen. Excluder presenteres som et alternativ til en tradisjonell stiv sorteringsrist som er påbudt i det småmaskede øyepåltrålfisket i Nordsjøen. Fiskeriet er et stort volumfiske og drives med store fartøy, store bunntråder og fangster på opptil 100 tonn per hal. Excluderen som ble testet i okt.-nov. 2018 var et 30 m langt nettbasert sorteringsystem, utviklet for å redusere bifangst og forbedre håndtering og sikkerhet om bord. Excluder ble testet mot et 5,8 m² standard sorteringsristsystem (med 35 mm spileavstand) i et tvillingtrålforsøk ombord den kommersielle 70 m tråleren "S364 Rockall". Resultater fra toktet er publisert i Eigaard et al. (2021).

En lignende Excluder, 25 m lang med 36 x 36 mm innernett i 6 mm Eurocross knuteløs notlin og ytternett i 22 mm diamant-notlin ble brukt under dette forsøket. Excluder ble plassert mellom trål og sekk som illustrert i Figur 1.

EXCLUDER



Figur 1: Excluder. Mindre fisk (grønne) passerer gjennom de 36 x 36 mm innernettmaskene og havner i sekken. Større fisk (røde) passerer ikke gjennom maskene i innernettet, og slippes fri.

3.3 Analyse av seleksjonsdata

Etter planen skulle seleksjonsegenskapene til Excluder testes ved bruk av «alternate haul»-metoden (Wileman 1996) og resultatene analyseres ved bruk av SELNET (Herrmann et al., 2012) og R (www.cran.com). Det ble regnet behov for minst 16 hal for å kunne få statistiske signifikante resultater, hvorav halvparten av dem skulle gjennomføres med standard trål og sekk (kontroll) og andre halvparten med seleksjonssystemet Excluder (test). Fangsten ble målt ved å ta subsamples mens fangsten ble pumpet om bord. Den totale fangsten per hal ble estimert ved å inspisere fangstindikatorer i RSW-tankene. Under pumping ble en subsample av 9 kurver fisk (~200 kg, ikke sortert etter art) tatt fra silkassen, 3 kurver hver fra begynnelsen, midten og slutten av pumpingen. Fisken ble deretter sortert etter art og lengdemålt, og resultatene fra prøvetakingsfraksjonene ble omregnet til totalfangst for videre analyser. Geometrien av seleksjonssystemet og observasjon av fiskeadferd både inne i Excluder og ved utslipp ble gjennomført med hjelp av undervannsvideoopptak (GoPro kamerasystemer med kunstig rødt lys).

3.4 Fall-through forsøk

En forstudie ble gjennomført ved hjelp av analyseprogrammet FISHSELECT (Hermann, 2008) for å anbefale de mest aktuelle maskestørrelsene for å beholde tobis mens bifangststartene blir sortert ut. FISHSELECT er en kombinasjon av verktøy, metoder og software som er utviklet for å beregne om en viss fisk kan passere gjennom en viss maske/rist. Metodikken kan beregne seleksjonsparametere for en spesifikk fiskeart og en rekke forskjellige masker ved å sammenligne de morfologiske egenskapene til fiskearten og de forskjellige maskefasongene og spileavstander som er aktuelle i nettingen/risten. Metodikken er allerede anvendt på torsk, hyse, blåkveite og uer (Herrmann et al., 2009; 2012), noe som gir et godt utgangspunkt for arbeidet som skal utføres i denne arbeidspakken.

3.5 Resultater fra toktet

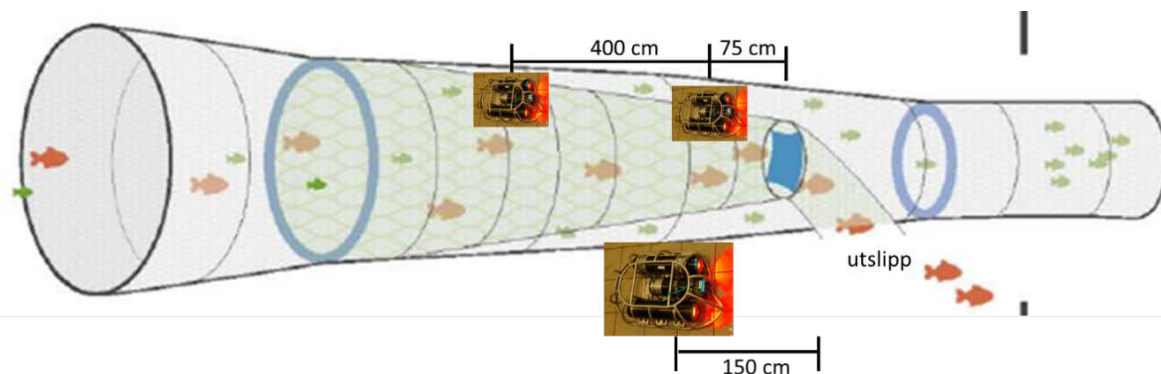
Forsøket ga ikke grunnlag til sammenligning av trål med og uten Excluder fordi bare to hal ble gjennomført, begge med Excluder på. Mesteparten av tida på tokt brukte vi på å lete etter tobis i flere kommersielle fiskefelt i Nordsjøen (Figur 2). Totalt seilte fartøyet over 1000 NM i løpet av seks dager, men så veldig lite tegn til tobis. Det dårlige fisket kan muligens skyldes toktets tidspunkt (én uke før oppstart for den kommersielle sesongen), men før i tiden har det vært fiske i mars og vanntemperaturen (7 grader) var 1 grad varmere enn ved starten på fiskesesongen i 2020.

Første hal ble gjennomført på dag 3 på «Engelsk Klondyke nord», en fiskebank på ca. 65 m dyp i forvaltningsområde 4b. Her var bifangst under tobisfisket høyest i fjor (2020). Ekkolodd viste litt tegn på tobis her: to lag på ekkolodd, ett nær bunn og ett på ~25 m dyp (Figur 2).



Figur 2: Ekkogrammer på Engelsk Klondyke nord, 10.04.2021 kl. 07:00 CET. Til venstre er 50 kHz og 200 kHz ekkogrammer. Til høyre er 38 kHz ekkogram.

Det ble montert 3 stk. GoPro-kameraer i Excluder (Figur 4), alle med rødt lys for å ha minst mulig påvirkning på fiskens atferd. Begge kameraene over Excluderen feilet, men kameraet montert på underpanelet 150 cm foran utslippshullet tok opp video som bekrefter utsortering av store fisk. Dessverre var avstanden for stor for å registrere mindre fisk (inkl. tobis).



Figur 3: Plassering av GoPro Hero 4-kameraer på Excluder. To kameraer ble plassert i innerrøret og ett i utslippet.

Fangsten av hal 1 bestod av 42 % tobis og 58 % bifangst av hyse, sild, hvitting, makrell og knurr (Tabell 2). Undervannsvideooptaket feilet, så vi kunne ikke å overvåke fiskeprosessen. En prøve på 198 kg ble tatt, hvorav alt ble sortert etter art og veid separat (Figur 4). Lengdemålinger ble gjennomført på alle artene.

Tabell 2. Beregning av artsfordelingen i fangsten av hal 1.

Dato	10. april
Start	11:15 (57°45.06'N / 004°13.08'E)
Slutt	14:45 (57°45.27'N / 004°11.58'E)
Fart	3,2 knop
Dybde	66-68 m
Total fangst (kg)	36 000
Tobis	42 %
Bifangst	58 %

Lengde (cm)	Tobis	Hyse	Sild	Makrell	Hvitting	Knurr
10						
11	1					
12	0					
13	2					
14	5					
15	7					
16	33	2				
17	50	7		1		
18	80	12		7		
19	77	25		59	1	
20	102	34		93	6	1
21	78	30	17	57	9	
22	32	12	86	14	30	
23	5	4	92	5	74	1
24		1	28	0	63	1
25		3	1	0	32	
26		2		1	20	
27		6			5	
28		2			5	
29		0			1	
30		1				
31		1				
32						
Antall	472	142	224	237	246	3
Kg prøver	5,7	8,3	12,9	9,2	25,0	0,9
Kg veid, men ikke lengdemålt	78,0	0,0	30,5	11,5	16,5	0,0
Kg total	83,7	8,3	43,4	20,7	41,5	0,9
Subsampling	6,8 %	100,0 %	29,7 %	44,4 %	60,2 %	100,0 %
% fordeling	42,2 %	4,2 %	21,9 %	10,4 %	20,9 %	0,5 %



Figur 4: Usortert (øverst) og sortert fangst og bifangst (nederst).

Etter flere dagers leting så vi litt registrering av tobis, og trålte på de små flekkene. Fangsten fra dette halet bestod 100 % av tobis (Tabell 3). Undervannvideoobservasjoner viste at mesteparten av tobis går gjennom kvadratmaskene og dermed havner i sekken, mens en liten andel av tobis holder seg inni røret på Excluder og blir ledet ut av trålen. Fangsten av hal 2 bestod av 100 % tobis og ingen bifangst. En prøve på 276 kg ble tatt hvorav alt ble sortert etter art. Lengdemålinger ble gjennomført på tobis.

Tabell 3. Beregning av artsfordelingen i fangsten av hal 2.

Dato	13. april
Start	17:45 (57°05.29'N / 005°11.20'E)
Slutt	18:30 (57°07.697'N / 005°12.79'E)
Fart	3,2 knop
Dybde	49 m
Total fangst	11 000 kg
Tobis	100 %
Bifangst	0 %

Lengde (cm)	Tobis	Hyse	Sild	Makrell	Hvitting	Knurr
10	4					
11	9					
12	17					
13	53					
14	76					
15	47					
16	15					
17	4					
18	4					
19	2					
20						
Antall	227	0	0	0	0	0
Kg prøver	1,4					
Kg veid	275					
Kg total	276,4					
Subsampling	0,5 %					
% fordeling	100 %					

3.6 Fall-through forsøk.

Siden bifangstraten var høy med Excluder testet under forsøket ble det utført et fall-through forsøk for å vurdere hvilken maskestørrelse er best egnet til de artene og størrelsen som ble fanget under forsøket. Her ble tobis og bifangstartene hyse, sild, hvitting og makrell fra fangsten testet med en fall-through Brett med kvadratiske åpninger fra 20 – 36 mm (Figur 5).



Figur 5: Til venstre vises fall-through plate som simulerer 10 kvadratiske maskevidder fra 20-36 mm stolpelengde. Andre bildene viser innhenting av fall-through data.

Resultatene fra fall-through forsøkene viste at 50 % sannsynlighet for at fisk blir tilbakeholdt eller selektert ut av kvadratmaskene i Excluderen (36 mm stolpelengde) er 24,4 cm for hyse, 29,8 cm for sild, 25,6 cm for hvitting og 30,4 cm for makrell (Tabell 4). Resultatene kan også hjelpe ved vurdering av bifangst med andre kvadratmaskestørrelser. For eksempel, hadde vi brukt kvadratmasker med 24 mm stolpelengde, hadde 50 % sannsynlighet for å bli tilbakeholdt vært 16,3 cm hyse, 19,4 cm sild, 18,3 cm hvitting og 20,2 cm makrell. Med andre ord, en Excluder med kvadratmasker med 24 mm stolpelengde hadde sortert ut mer enn 90 % av bifangsten av hyse, sild, hvitting og makrell som vi fikk i dette trålhalet.

Tabell 4: Estimert 50% sannsynlighet for at fisk blir tilbakeholdt eller selektert av Excluder. Stolpelengde i fet tekst (36 mm) er modellresultat for maskestørrelsen i Excluder som ble brukt under forsøket.

Maskestørrelse (stolpelengde i mm)	50 % sannsynlighet å bli tilbakeholdt (cm)			
	Hyse	Sild	hvitting	Makrell
10	6,7 (4,1-9,4)	7,3 (7,3-7,3)	9,8 (9,3-10,2)	8,4 (7,2-9,6)
11	7,4 (4,8-10,0)	8,2 (8,2-8,2)	10,4 (9,9-10,8)	9,3 (8,1-10,4)
12	8,1 (5,5-10,7)	9,0 (9,0-9,1)	11,0 (10,6-11,4)	10,1 (8,9-11,3)
13	8,8 (6,2-11,4)	9,9 (9,9-9,9)	11,6 (11,2-12,0)	10,9 (9,8-12,1)
14	9,5 (6,8-12,1)	10,8 (10,8-10,8)	12,2 (11,8-12,6)	11,8 (10,6-13,0)
15	10,1 (7,5-12,8)	11,6 (11,6-11,6)	12,8 (12,4-13,2)	12,6 (11,4-13,8)
16	10,8 (8,2-13,4)	12,5 (12,5-12,5)	13,4 (13,0-13,8)	13,5 (12,3-14,7)
17	11,5 (8,9-14,1)	13,4 (13,4-13,4)	14,0 (13,6-14,4)	14,3 (13,1-15,5)
18	12,2 (9,6-14,8)	14,2 (14,2-14,2)	14,6 (14,2-15,0)	15,2 (14,0-16,4)
19	12,9 (10,2-15,5)	15,1 (15,1-15,1)	15,2 (14,8-15,6)	16,0 (14,8-17,2)
20	13,5 (10,9-16,2)	16,0 (15,9-16,0)	15,8 (15,4-16,3)	16,9 (15,7-18,1)
21	14,2 (11,6-16,8)	16,8 (16,8-16,8)	16,4 (16,0-16,9)	17,7 (16,5-18,9)
22	14,9 (12,3-17,5)	17,7 (17,7-17,7)	17,1 (16,6-17,5)	18,6 (17,4-19,7)
23	15,6 (13,0-18,2)	18,6 (18,5-18,6)	17,7 (17,3-18,1)	19,4 (18,2-20,6)
24	16,3 (13,6-18,9)	19,4 (19,4-19,4)	18,3 (17,9-18,7)	20,2 (19,1-21,4)
25	16,9 (14,3-19,6)	20,3 (20,3-20,3)	18,9 (18,5-19,3)	21,1 (19,9-22,3)
26	17,6 (15,0-20,2)	21,1 (21,1-21,2)	19,5 (19,1-19,9)	21,9 (20,8-23,19)
27	18,3 (15,7-20,9)	22,0 (22,0-22,0)	20,1 (19,7-20,5)	22,8 (21,6-24,0)
28	19,0 (16,3-21,6)	22,9 (22,9-22,9)	20,7 (20,3-21,1)	23,6 (22,4-24,8)
29	19,7 (17,0-22,3)	23,7 (23,7-23,8)	21,3 (20,9-21,7)	24,5 (23,3-25,7)
30	20,3 (17,7-23,0)	24,6 (24,6-24,6)	21,9 (21,5-22,3)	25,3 (24,1-26,5)
31	21,0 (18,4-23,6)	25,5 (25,5-25,5)	22,5 (22,1-23,0)	26,2 (25,0-27,4)
32	21,7 (19,1-24,3)	26,3 (26,3-26,4)	23,1 (22,7-23,6)	27,0 (25,8-28,2)
33	22,4 (19,7-25,0)	27,2 (27,2-27,2)	23,8 (23,3-24,2)	27,9 (26,7-29,0)
34	23,0 (20,4-25,7)	28,1 (28,1-28,1)	24,4 (24,0-24,8)	28,7 (27,5-29,9)
35	23,7 (21,1-26,4)	28,9 (28,9-28,9)	25,0 (24,6-25,4)	29,6 (28,4-30,7)
36	24,4 (21,8-27,0)	29,8 (29,8-29,8)	25,6 (25,2-26,0)	30,4 (29,2-31,6)
37	25,1 (22,5-27,7)	30,7 (30,7-30,7)	26,2 (25,8-26,6)	31,2 (30,1-32,4)
38	25,8 (23,1-28,4)	31,5 (31,5-31,5)	26,8 (26,4-27,2)	32,1 (30,9-33,3)
39	26,4 (23,8-29,1)	32,4 (32,4-32,4)	27,4 (27,0-27,8)	32,9 (31,7-34,1)
40	27,1 (24,5-29,8)	33,3 (33,2-33,3)	28,0 (27,6-28,4)	33,8 (32,6-35,0)

3.7 Konklusjoner og videre arbeid

Forsøket ga ikke grunnlag for å sammenligne fangsten av en trål med og uten Excluder fordi bare to trålhal ble gjennomført. Mesteparten av tiden på tokt brukte vi på å lete etter tobis i flere av de kommersielle fiskefeltene i Nordsjøen. Første hal ble gjennomført på et kjent fiskefelt der vi visste det var stor risiko for innblanding av bifangst. Fangsten i dette halet bestod av 42 % tobis og 58 % bifangst av småhyse, makrell, sild, hvitting og knurr. Etter flere dagers leting så vi litt registrering av tobis og dermed trålte vi på de små flekkene. Fangsten i dette halet bestod 100 % av tobis. Undervannsvideoobservasjoner viste at mesteparten av tobis går gjennom kvadratmaskene og dermed havner i sekken, mens en liten andel av tobis holder seg inni røret og blir ledet ut av trålen. Når det gjelder bifangst, var det vanskelig å forstå hvorfor så stor mengde bifangst havnet i sekken i første hal. Undervannsvideoopptak feilet og dermed kunne vi ikke å overvåke fiskeprosessen.

4 Forsøk 2: Uttesting av en Excluder-seksjon i fisket etter øyepål om bord på MS «Vikingbank» i perioden 02.-08.07.2021

4.1 Formål

Målet med toktet var å gjøre filmopptak av Excluder på øyepålfisket i Nordsjøen.

4.2 Fartøy og utstyr

MS «Vikingbank» ble stilt til disposisjon for gjennomføring av toktet. Hermann Pettersen (Fiskeridirektoratet) deltok på toktet. Her ble det testet en Excluder med knuteløse kvadratmasker i notlin med stolpelengde 36 x 36 mm. Formålet var å filme Excluder under øyepålfisket for å se på funksjon samt tap av øyepål som slipper ut sammen med bifangststartene. Det ble samlet inn 10 fine filmopptak på et par timer hver, fra 9-11 timers trålfal. Fangsten ble også målt for å estimere andel bifangst, som var < 1 % bortsett fra større mengder kolmule i enkelte områder (kolmule er ikke ansett som et bifangstproblem siden aktuelle fartøy har kvote på begge artene og kan levere blandet fangst til fabrikkene).

Det ble gjort totalt 13 hal, hvor det i 10 av halene ble gjort vellykkede filmopptak. De 11 første halene ble gjort med en Expo 1500# trål mens de 2 siste ble gjort med en Egersund "flexitrål" ca. 7700# (lik en sperringtrål). Til hver trål brukte vi Excluder-seksjon levert av Egersund trål. Excluderen består av en innvendig traktformet seksjon av 4 paneler med 36 mm kvadratmasker som skal selektere ut fisken som skal fanges, mens større og uønsket fisk ikke skal klare å passere gjennom maskene. Disse vil bli ledet gjennom Excluderen til enden, kalt "postkassen", og så videre ut utslippshullet i underpanelet av seksjonen (se figur 1). I dette tilfellet var mållarten øyepål. Excluderen som ble brukt under dette toktet var noe mer utviklet enn på bildet under. Den hadde en ekstra presenning i midten av seksjonen for å hjelpe å presse mållarten ut av Excluderen.

4.3 Materialer og metoder

For å utføre filmopptakene ble det brukt kameraene GoPro Hero 3, 4 og 8 med dypvannshus som tåler trykk på 300-400 meter. Utstyret ble plassert inni en beskyttelsesramme av stål eller plast. Under toktet ble det prøvd ut forskjellige plasseringer på kameraene for å finne den beste plassering for gode filmopptak for å se hva som slippes ut av systemet, samt å få et inntrykk av hvordan innretningen oppførte seg under tauing.

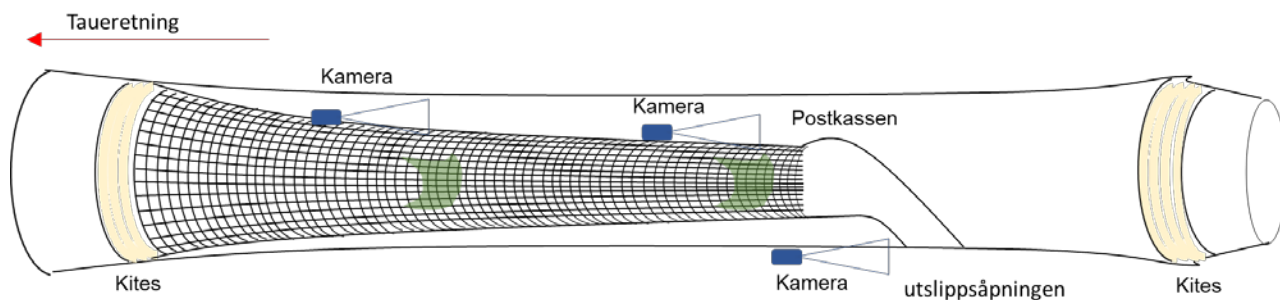
4.4 Resultater

[02/07-2021 Posisjon: N 59°26,921' Ø 003°16,603'](#)

Første hal ble satt kl. 10:00. Vi bestemte oss for å sette dette halet uten kamera for å teste om trål og vinsjer fungerte slik de skulle. Hiving kl. 21:10, posisjon: N 60°00,325' Ø 003°08,085'. Fikk fangst på ca. 7 tonn. Veldig lite innblanding av andre arter enn øyepål i fangsten (99 %). Da alt så til å fungere bra, bestemte vi oss for å sette på kamera på neste hal, hal nr. 2.

[03/07-2021 Posisjon: N 59°58,967' Ø 003°09,215'](#)

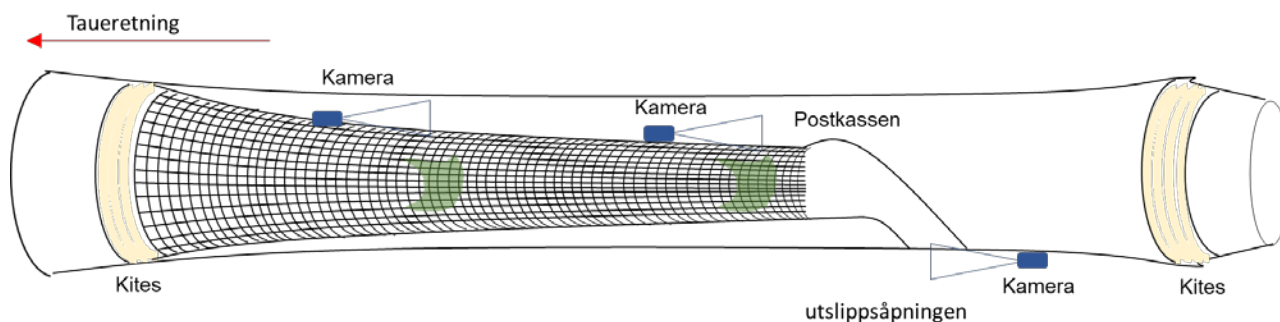
Hal 2 ble satt kl. 04:48. Det ble plassert 3 kameraer på Excluderen (Figur 6), samtlige med røde lys, da disse antas å ha minst påvirkning på fisk. Hiving hal 2 kl. 13:12, posisjon: N 59°31,864' Ø 003°14,022'. Fangst på ca. 12 tonn. Bifangst av kolmule på ca. 5 %. Babord vinge var flerret opp, så vi måtte bytte not. Kl. 16:08 hadde vi byttet not (samme type Expo) og festet på 2 kameraer, et foran "postkassen" og et foran skremmepresenningen, og skjøt av på posisjon: N 59°32,231' Ø 003°13,532'. Skipper ville ikke miste mer dagslys så fikk ikke tid til å plassere kamera på utslippshull. Etter tauingen så vi gjennom videoen, og erfaringene fra denne filmingen viste at det kunne se ut som det meste av utsorteringen skjedde i bakre del av Excluderen. Usortering skulle helst skjedd tidligere i Excluderen. Det kan også se ut fra videoene at vi mistet en del av mållarten gjennom utslippshullet.



Figur 6: Plasseringen av kameraer under hal 2.

[04/07- 2021, Posisjon: N 58°59,377` Ø 003°04,530`](#)

Kl. 03:10 hev vi hal 3. KV "Sortland" ligger på siden og skal om bord til oss for å kontrollere fangsten. Fangst ca. 10 tonn. Etter kontroll av kystvakten var resultatet 99,45 % øyepål. Resten bestod av variasjon mellom hyse, hvitting og kolmule. Så liten tvil i at Excluder kan gi rene fangster (i hvert fall i dette tilfellet). Vi så gjennom opptakene og syntes fremdeles det så ut som lite fisk ble sortert ut fremme i Excluderen, ved første presenning. Vi bestemte oss derfor for å feste kamera på innsiden av Excluderen for å se mot første presenning for å se om den fungerer til å presse ut fisk. Det ble også satt ytterligere ett kamera på oversiden av Excluderen for å se bak på "postkassen", og ett til bak utslippshullet for å se frem mot belgen (Figur 7).



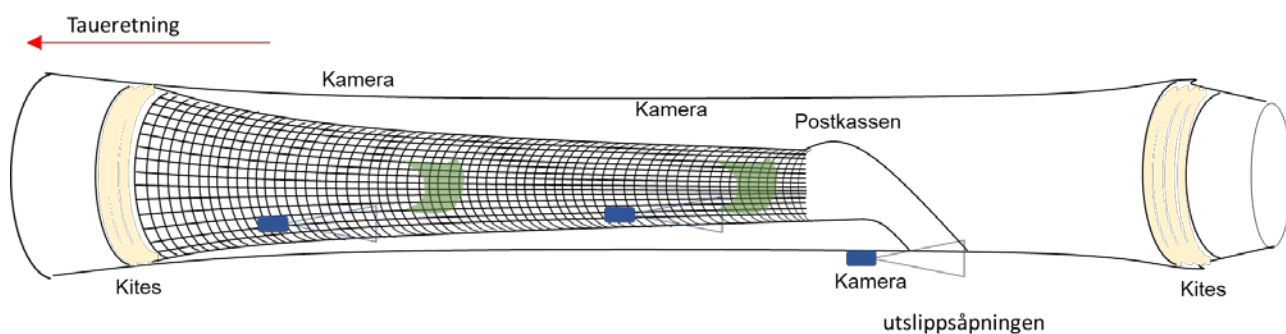
Figur 7: Plasseringen av kameraer under hal 4.

Hal 4 ble satt kl. 05:30, posisjon: N 59°06,844` Ø 003°05,169`. Kl. 13:00 hiver vi på hal 4. Posisjon: N 59°28,967` Ø 003°13,890`. Fangst: 9 tonn, rent. Erfaringen fra dette halet var at det ikke er lurt å setta kamera i samme retning som taueretning, da vi ikke klarte å se noe pga partikler og støv.

Hal 5 ble satt kl. 14:10, posisjon: N 59°29,423` Ø 003°14,347`. Fikk festet kun ett kamera denne gangen, ved utslippshullet, da skipper ønsket å skyte fort av igjen. Hiver igjen kl. 23:30, posisjon: N 59°57,467` Ø 003°07,174`. Fangst ca. 9 tonn, litt mer sild som bifangst denne gang, men fortsatt veldig rent. Fikk fin video av utslippshull på hal 5. Det kan se ut til at vi mister en del øyepål sammen med bifangsten, og skipper ikke helt fornøyd med det.

[05/07-2021, posisjon: N 60°29,251` Ø 003°07,806`](#)

Hal 6 ble satt kl. 04:06, endret posisjon på kameraene. Satte på 3 kameraer. Ett plasserte vi på underpanelet inni Excluderen for å se mot første presenning, andre på underpanelet for å se mot "postkassen" på innsiden av Excluderen. Siste kamera ble plassert foran utslippshull, se figur 8. Hiver på hal 6 kl. 13:03, posisjon: N 60°00,477` Ø 003°11,142`. Fangst ca. 11 tonn. Ren fangst. Da det kan se ut til på videoopptakene at vi mister en del øyepål gjennom utslippshullet, festet vi på hal 7 et kamera med hvitt lys på utslippåpningen for å få bedre oversikt over hvilke arter som gikk ut.



Figur 8: Plasseringen av kameraer under hal 6.

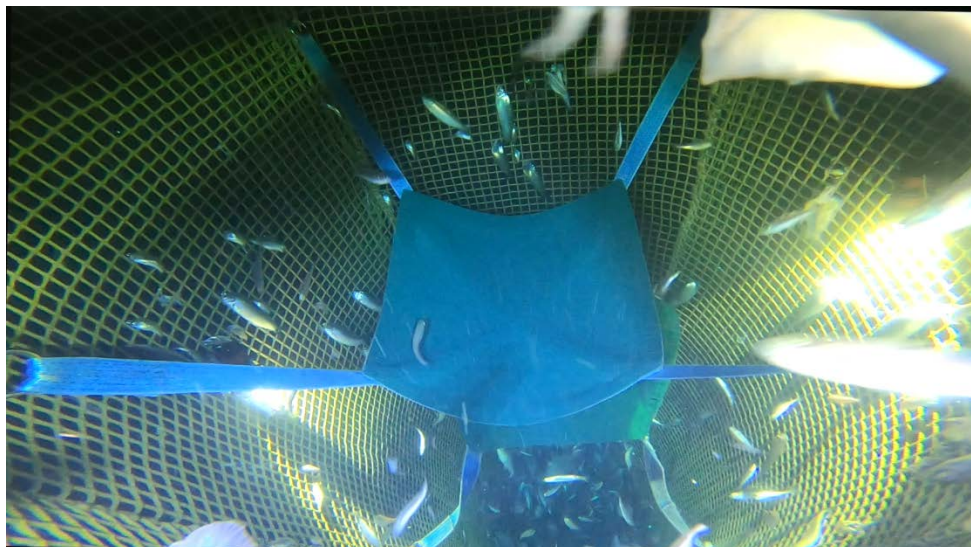
Hal 7 ble satt kl. 14:05, posisjon: N 60°00,258' Ø 003°11,065'. Kl. 22:08 hiver vi på hal 7, posisjon: N 60°25,847' Ø 003°19,543'. Fangst: 8 tonn. Tok prøve på ca. 50 kg, og bifangst på dette var ca. 2 kg kolmule og 2 stk. sild. Fra filmen fra hal 7 med hvitt lys ser det ut som det slippes svært lite øyepål ut gjennom utslippshullet. Derimot var det god utsortering på makrell, sild og sei, samt hvitting (Figur 9). Skipper var veldig fornøyd. Det er også mulig at hvitt lys har god effekt på å skremme fisken (øyepål), som kan hjelpe med å skremme den ut av Excluderen og inn i sekken. Derfor ville vi på neste hal prøve å lyse opp Excluderen på innsiden med hvite lys for å se hvilken effekt dette kunne ha på fisken. Vi festet også på en ekstra presenning noen meter bak første presenning for å se om vi klarte å presse mer av øyepålen inn i sekken.



Figur 9: Utsnitt av video fra hal 7 med hvite lys ved utslippshull. Viser forskjellige bifangstarter.

[06/07-2021, posisjon: N 59°39,414' Ø 003°10,760'](#)

Hal 8 ble satt kl. 04:30. Har ett kamera plassert på underpanelet foran første presenning på innsiden av Excluderen. Plasserte også to ekstra hvite lys for å lyse opp Excluderen (se figur 10). Kl. 14:00 hiver vi på hal 8, posisjon: N 59°07,743' Ø 003°08,092'. Fangst: ca. 11 tonn. Bifangst ca. 2 kg kolmule i en prøve på 40 kg. Lå en del sei og makrell (100-200 kg) igjen i Excluderen, dette kan være pga. hvitt lys inni Excluderen, eller at vi ikke økte farten litt før hiving, eller en kombinasjon av disse.

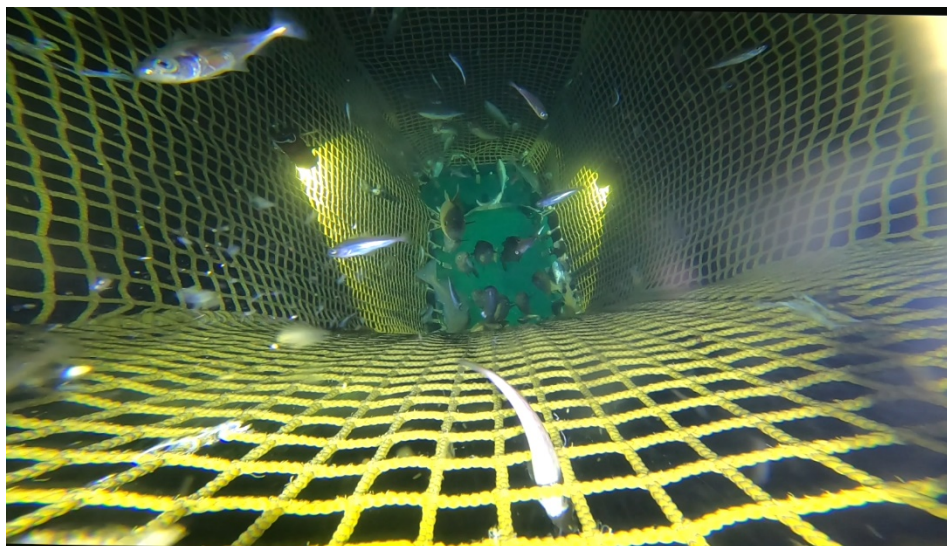


Figur 10: Utsnitt av video fra hal 8. Viser innsiden av Excluderen foran første presenning.

Hal 9 ble satt kl. 15:17, posisjon: N 59°08,876' Ø 003°00,908'. Her ble det festet kamera på utslippshull, med rødt lys. Hiver på hal 9 kl. 20:15, posisjon: N 58°57,126' Ø 003°17,989'. Fangst: ca. 7 tonn. God del innblanding av hyse i dette halet, ca. 2 kg hyse på 50 kg uttaksprøve, samt 2 strømsild og 1 kolmule. Dette kan tyde på at hvis det er mye hyseyngel i området hvor det fiskes øyepål, så kan denne være utsatt for litt økt risiko for å bli holdt tilbake sammen med øyepålen.

[07/07-2021, posisjon: N 58°01,756' Ø 004°59,021'](#)

For hal 10 byttet vi område til Egersund-banken basert på ryktet om litt bedre fiske her. Hal 10 ble satt kl. 05:00. For dette halet satte vi kamera på underpanelet i enden av Excluderen for å se nærmere på "postkassen" (Figur 11). Fra tidligere videooptak kunne det se ut som det samlet seg en del fisk i dette området, så vi ville se nærmere på det. Det ble montert opp med hvitt lys. Det ble også plassert et kamera på utslippshullet med rødt lys.



Figur 11: Utsnitt fra video hal 10. Viser innsiden bak mot enden av Excluderen, også kalt "postkassen".

Hiver på hal 10 kl. 13:00, posisjon: N 57°53,637' Ø 005°25,542'. Fangst hal 10: 14 tonn. Tok prøve på ca. 50 kg. Fant 5 kolmulere, 2 sild og 1 strømsild, så veldig ren fangst.

Hal 11 settes kl. 14:10, posisjon: N 57°54,970` Ø 005°22,627`. Satt på kamera på utslippshull (rødt lys). Dessverre sluttet kamera å filme etter 22 minutter ut i settet, så vi fikk ikke noe video. Hiver ombord hal 11 kl. 23:40, posisjon N 57°52,004` Ø 005°16,876`. Fangst: ca. 18 tonn. Mye innblanding av kolmule (30-40 %), samt 1 lysing og 2 strømsild på en prøve på 50 kg.

[08/07-2021, posisjon: N 57°57,031` Ø 005°14,992`](#)

Byttet not før hal 12 til stormasket Egersund trål. Det ble ikke festet noe kamera på trålen da vi hadde dårlig tid da skipper ville utnytte dagslyset. Skøyt av kl. 06:00. Hiver hal 12 kl. 12:15, posisjon: N 58°01,287` Ø 004°56,935`. Fangst ca. 10 tonn. Et par hyse og 2 hvitting på 50 kg prøve.

Hal 13 satt kl.13:15, posisjon: N 58°00,715` Ø 005°02,250`. Festet kamera på utslippshull, røde lys. Fangst ca. 17 tonn. Noe mer kolmule i denne fangsten, ca. 40 %, samt 1 sild og 2 strømsild på en prøve på ca. 50 kg.

4.5 Diskusjoner og konklusjoner

Toktet viser at det er mulig å bruke en slik seleksjonsinnretning på industritrålfisket etter øyepål, men det kreves fortsatt mye dokumentasjon på flere punkter.

- Må se på hvilken maskevidde som er optimal for øyepålfisket. Kanskje det er mulig å øke maskevidden, eller øke maskevidden i f.eks. underpanelet i Excluderen da det ser ut på videoene at en del øyepål faktisk søker ned/glir langs underpanelet.
- Trenger dokumentasjon på hvilken forfatning fisken som slipper ut er i etter å ha gått gjennom seleksjonsinnretningen. Fra video ser det ut som fisk som sei og makrell er i god forfatning.
- Trenger dokumentasjon på hvor mye av mållarten som selekteres ut gjennom utslippshullet. Kan se ut fra videoene (med røde lys) at det mistes en del øyepål gjennom utslippshullet.
- Trenger dokumentasjon på hvordan den fungerer med større/normale kvanta av fisk.
- Trenger dokumentasjon på hvordan den fungerer i områder med større konsentrasjoner av bifangstarter. Hva vil skje f.eks. hvis det blir tauet gjennom en større sildestim eller makrellstim?
- I områder med kolmule ser vi at fangst av kolmule øker betraktelig. Dette skal ikke være noen problem da det trekkes av kvoten til fartøyet, men hvis fartøyet ikke har mer kolmule igjen på kvoten vil nok det oppstå problemer.
- Må også dokumenteres hva som skjer hvis det fiskes i områder med bifangst av samme størrelse som øyepål, f.eks. hyseyngel. Vil bifangsten av denne øke betraktelig?

Fra dette toktet ser vi at det er godt mulig å få rene fangster av øyepål ved bruk av denne seleksjonsinnretningen. Men det trengs fortsatt utvikling på innretningen. Vi ser fra dette toktet at presenningen ikke fungerer i så stor grad som vi ønsker. Det er mulig arealet på presenningen kan økes for å få bedre «presse»-effekt, da det er rom for dette. Det er også mulig å få plass til en ekstra presenning. Selve innretning står veldig fint under tauing, med en tauetart på 3-3,5 knop. Vi så også at farten bør økes litt før hiving, med en halv knop eller mer for å presse ut resterende bifangst fra Excluderen. I enkelte hal hvor vi ikke gjorde dette kunne det samles en del bifangst igjen inni Excluderen (100-200 kg i enkelte hal). Dette viser også at det trengs videre utvikling av utslippshullet, og at det her er altfor løst. I stedet for å presse ut uønsket fangst skapes det en sone med lite vanngjennomstrømming hvor fisken blir stående da den ikke trenger å bruke særlig med krefter for å svømme. Dette kan være noe av skylden for at det er bifangst igjen hvis farten ikke økes før hiving. Vi ser fra dette toktet at Excluderen kan fungere godt på industritrålfisket etter øyepål, men det trengs fortsatt utvikling av selve innretning, samt mer dokumentasjon på hva som eksakt slippes ut, og tilstanden på det som slippes ut.

Filmene viste at mye av sorteringsprosessen skjedde bakerst i Excluder og at det mistes en del øyepål ut utslippshullet sammen med bifangstartene. Det ser ut som at bruk av hvit lys ved utslippet redusert tap av øyepål og bør undersøkes nærmere. Fisken lå lenge ved utslippet og fartøyet måtte øke hastigheten de siste 30 minuttene for å presse ut fisken slik at det ikke ble bifangstarter på til sammen estimert 100-200 kg liggende i utslippet når den kom på dekk.

5 Forsøk 3: Sammenligning av to ristvarianter i fisket etter øyepål om bord på MS «Fiskebank» i perioden 10.-19.09.2021

5.1 Formål

Målet med dette toktet var å teste en større rist (2,7 m bred x 3,6 m lang, 9,45 m²) mot vanlig rist (1,8 m bred x 3,6 m lang, 6,45 m²). Vi antar at den større risten er bedre tilpasset dagens store trålnøter ved å unngå innsnevring i ristseksjonen. Den store risten har 50% større sorteringsareal enn dagens standard rist og vil muligens gi bedre seleksjon under forhold der fangstraten er høy (Figur 12).

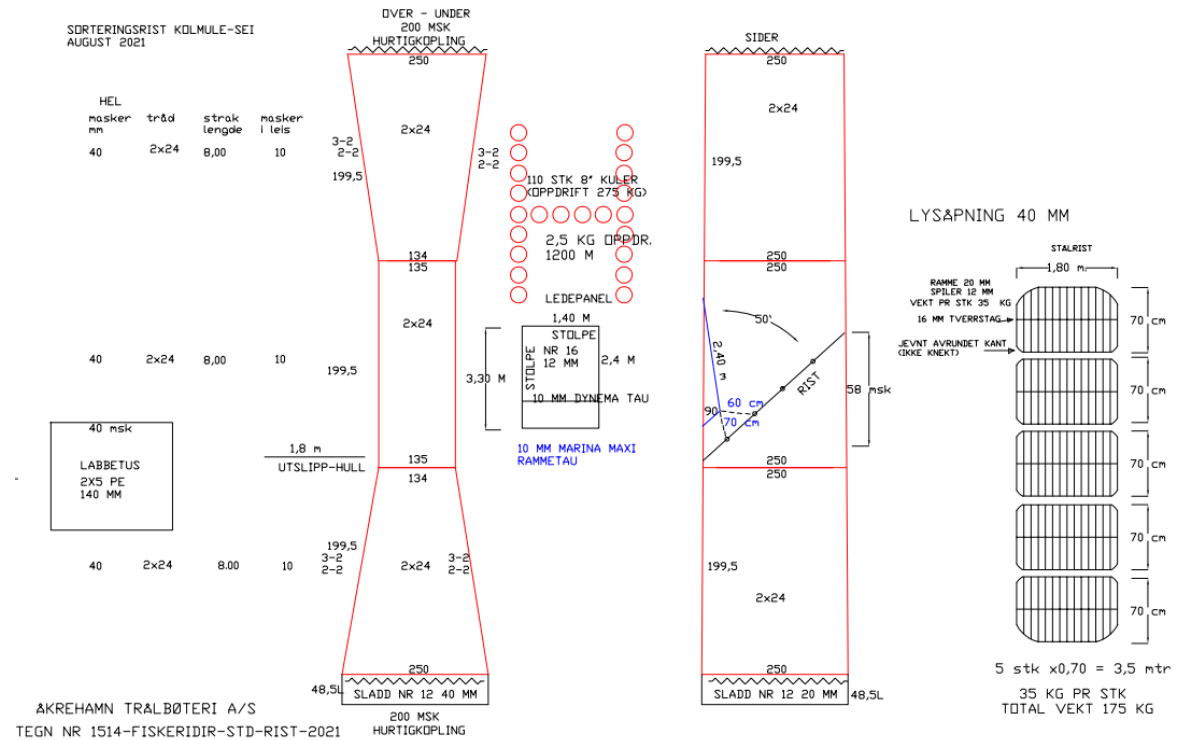


Figur 12. Bilde av den store risten som er 2,7 m bred og 3,6 m lang.

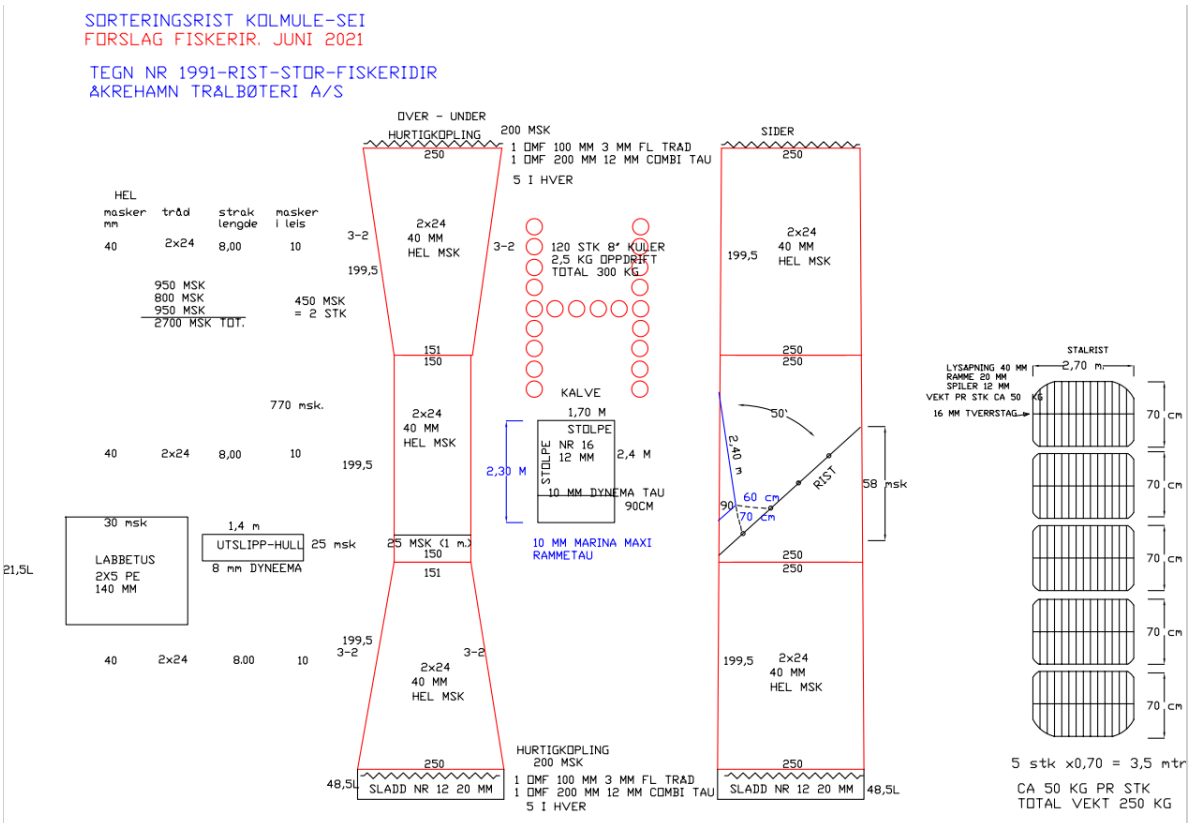
5.2 Fartøy og utstyr

Forsøket ble gjennomført om bord dobbeltråleren MS «Fiskebank» i perioden 10.-19.09.2021. Eduardo Grimaldo (SINTEF Ocean), Jesse Brinkhof (UiT) og Hermann Pettersen (Fiskeridirektoratet) deltok på toktet. To ristseksjoner ble brukt på toktet. Den ene seksjonen hadde en standard 1,8 m bred x 3,6 m lang stålrist (Figur 13), og den andre seksjonen en 2,7 m bred x 3,6 m lang rist (Figur 14). Begge ristene hadde en spileavstand på 40 mm og utslippsåpning på toppen.

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Figur 13: Standard ristseksjon med rist 1,8 m x 3,6 m.



Figur 14: Ny ristseksjon med større rist 2,7 m x 3,6 m.

5.3 Forsøksoppsett, innsamling og analyse av data

Forsøket ble gjennomført i dobbeltrålkonfigurasjon med to identiske tråler med to ulike sorteringsrister: en standard sorteringsrist på den ene trålen (test) og en ny og større sorteringsrist på den andre trålen (kontroll). En prøve på ca. 300 kg (12 kørger) ble tatt fra hver trål og prøvene ble sortert etter art, lengdemålt og veid. Denne prosedyren ble gjentatt gjennom hele toktet. Det ble gjennomført undervannskameraopptak av begge ristseksjonene. Til dette brukte vi kameraet GoPro Hero 4 med rødt lys. Ingen endring ble gjort til seleksjonsinnretningene som følge av undervannsvideoopptakene. Vi brukte det statistiske analyseprogrammet SELNET (Herrmann et al., 2012) for å analysere fangstdataene og utføre en lengdeavhengig fangstsammenligning og en fangstforholdsanalyse.

5.4 Resultater fra toktet

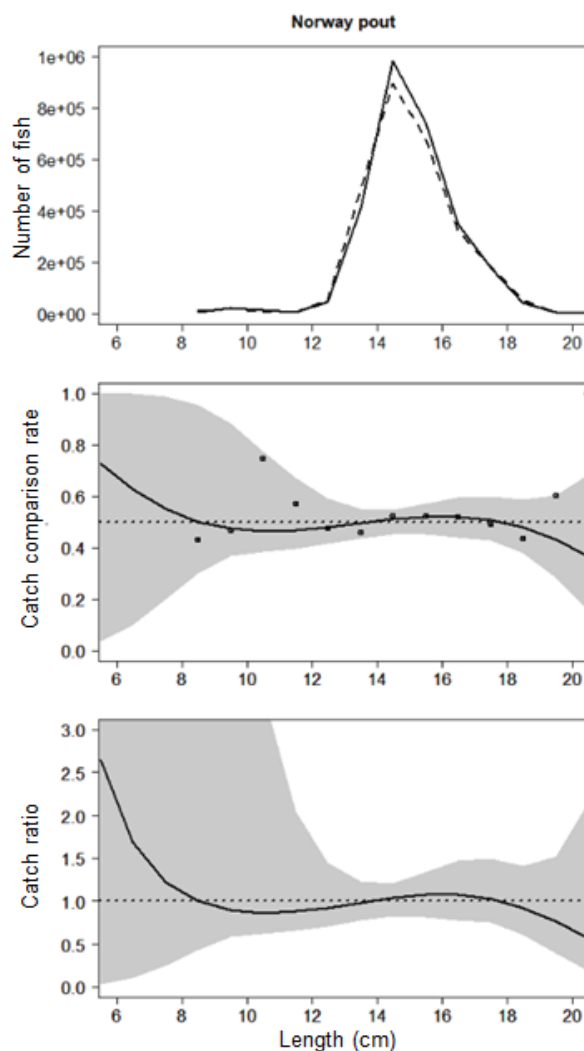
Totalt ble det gjennomført 14 hal. Det ble tatt prøver av fangsten fra 12 tolv hal til veiing og lengdemåling.

Tabell 5 viser total fangst i kg summert for de 12 halene fordelt på hver art. Resultatene viser at det var 0,2 % reduksjon i fangstmengde for øyepål ved bruk av den store risten og 11,9 % reduksjon av kolmulefangsten. Resultatene indikerer også at den store risten fanger mer hvitting, hyse og lysing. Det er dog viktig å være klar over at det ble fanget forholdsvis lite av disse tre artene og dermed kan resultatene også være en tilfeldighet.

Tabell 5. Total fangst av hver art fanget i trålen med standard rist og ny, større rist, samt endring i %.

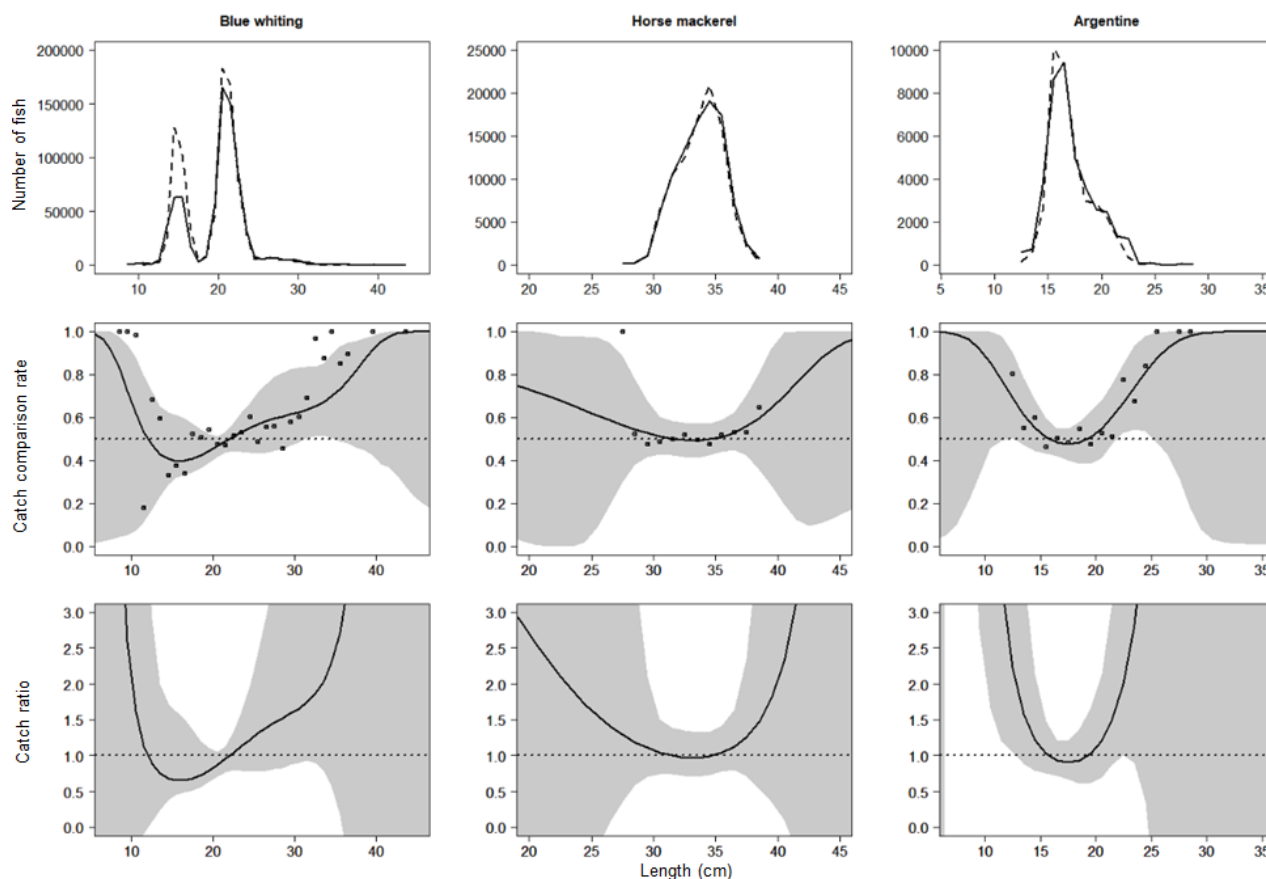
Art	Standard rist (kg)	Stor rist (kg)	Reduksjon (%)
Øyepål	70 123,9	70 273,0	0,2
Kolmule	40 979,5	36 092,4	-11,9
Makrell	53 049,5	54 308,3	2,4
Hestmakrell	29 888,5	31 617,6	5,8
Hvitting	3 503,1	4 353,6	24,3
Hyse	10 075,6	11 940,2	18,5
Torsk	320,4	219,0	-31,6
Strømsild	1 190,6	1 223,2	2,7
Lysing	879,0	1 460,6	66,2
Sild	2 989,8	2 512,1	-16,0
SUM	213 000	214 000	-0,47

Fangstsammenligning i Figur 15 viser ingen signifikant forskjell i fangstsammensetningen mellom standardristen og den store risten for øyepål (dvs. det grå området som representerer 95 % konfidensintervaller overlapper hele veien med den horisontale stiplede linjen som representerer området der begge redskapene fanger likt).



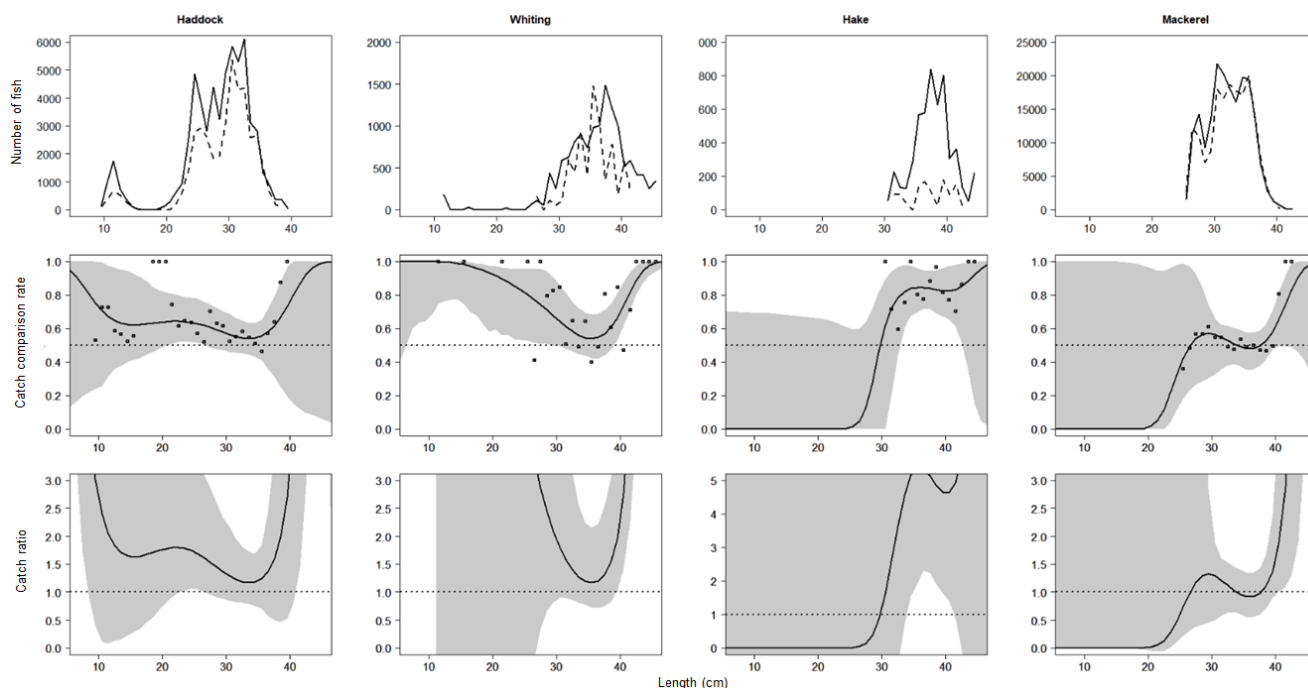
Figur 15. Fangstsammenligning og fangstforholdsanalyse for øyepål. Øverst: lengdefrekvensfordelingen til fisk fanget med redskap ved bruk av standard rist (stiplet linje) og den store risten (svart linje). Midten: den modellerte fangstsammenligningsraten (svart linje) med 95 % konfidensintervaller (grått område). Sirkler representerer de eksperimentelle punktene. Nederst: den estimerte fangstforholdskurven (svart kurve) med 95 % konfidensintervaller (grått område). De horisontale stiplede linjene ved 0,5 og 1,0 representerer punktet der begge redskapene har lik fangstrate.

Kolmule, hestemakrell og strømsild / vassild anses for å være ønskede bifangstarter i fisket etter øyepål. Resultatene fra den lengdeavhengige fangstsammenligningen mellom fisk fanget med standard rist og med større rist viste heller ingen signifikant forskjell for de tre artene (Figur 16).



Figur 16. Fangstsammenligning og fangstforholdsanalyse for kolmule (venstre), hestemakrell (midten) og vassild (høyre). Øverst: lengdefrekvensfordelingen til fisk fanget med redskap ved bruk av standard rist (stiplet linje) og den store risten (svart linje). Midten: den modellerte fangstsammenligningsraten (svart linje) med 95 % konfidensintervaller (grått område). Sirkler representerer de eksperimentelle punktene. Nederst: den estimerte fangstforholdskurven (svart kurve) med 95 % konfidensintervaller (grått område). De horisontale stiplede linjene ved 0,5 og 1,0 representerer punktet der begge redskapene har lik fangstrate.

Hyse, hvitting og lysing er arter som anses for å være uønsket bifangst i fisket etter øyepål. Makrell er en art som kan fanges som bifangst, men ettersom en får høyere pris hvis den leveres til konsum så anses den også for å være en uønsket bifangst. Resultatene fra den lengdeavhengige fangstsammenligningen mellom fisk fanget med standard rist og med større rist viste heller ingen signifikant forskjell for makrell (Figur 17). For artene hyse, hvitting og lysing viser resultatene derimot at den store risten fanget signifikant flere individer sammenlignet med standard rist (Figur 17).



Figur 17. Fangstsammenligning og fangstforholdsanalyse for (fra venstre til høyre) hyse, hvitting, lysing og makrell. Øverst: lengdefrekvensfordelingen til fisk fanget med redskap ved bruk av standard rist (stiplet linje) og den store risten (svart linje). Midten: den modellerte fangstsammenligningsraten (svart linje) med 95 % konfidensintervaller (grått område). Sirkler representerer de eksperimentelle punktene. Nederst: den estimerte fangstforholdskurven (svart kurve) med 95 % konfidensintervaller (grått område). De horisontale stiplede linjene ved 0,5 og 1,0 representerer punktet der begge redskapene har lik fangstrate.

5.5 Foreløpige konklusjoner

Foreløpige analyser viser ikke tydelig forskjell i bifangstinnblanding mellom de to ristene. Størrelsesseleksjon og fangsteffektiviteten til målarten (øyepål) var upåvirket. Det var heller ingen signifikant forskjell mellom de to ristene når det gjelder ønsket bifangstarter (kolmule, hestmakrell og strømsild/vassild). Det store risten fanget imidlertid betydelig flere uønskede bifangster (hyse, hvitting and lysing). Omtrent en tredjedel av de akkumulerte fangstene bestod av målarten, en tredjedel av ønsket bifangstartene og en tredjedel av uønskede bifangsartene, noe som viser bifangstutfordringene i dette fisket. Samtidig ble ingen av bifangstgrensene overskredet.

En annen utfordring er at den store risten er vanskelig å håndtere og fikk mye juling på vei inn i trommelen.

6 Forsøk 4: Sammenligning av en Excluder-seksjon og en vanlig ristseksjon i fisket etter øyepål om bord på MS «Fiskebank» i perioden 01.-10.10.2021

6.1 Formål

Hovedmålet for dette forsøket er å direkte sammenligne en påbudt 40 mm sorteringsrist (1,8 m x 3,6 m) vs. en Excluder med innerrør laget av kvadratmasker med 36 mm stolpelengde (Figur 18).



Figur 18: Bildet viser utsetting av dobbeltrål der vi sammenligner fangsten av en trål med en vanlig 1,8 m x 3,6 m seleksjonsrist mot fangsten av en trål med Excluder.

6.2 Fartøy og utstyr

Forsøket ble gjennomført om bord dobbeltråleren MS «Fiskebank» i perioden 01.-10.10.2021. Eduardo Grimaldo (SINTEF Ocean), Jesse Brinkhof (UiT) og Leif Grimsmo (SINTEF Ocean) deltok på toktet. Ristseksjonen som ble brukt på toktet var den samme seksjonen som ble brukt i forsøk 3, dvs. med en stålrist som var 1,8 m bred x 3,6 m lang (Figur 13). I tillegg ble det brukt en Excluder-seksjon som var 25 m lang med innernett med masker på 36 x 36 mm i 6 mm Eurocross knuteløs notlin og ytternett med diamantmasker på 22 mm i notlin.

6.3 Innsamling og analyse av data

Forsøket ble gjennomført i dobbeltrålkonfigurasjon med to identiske tråler, med en sorteringsrist på den ene trålen og en Excluder på den andre trålen. En prøve på ca. 300 kg (12 korer) ble tatt fra hver trål og prøvene ble sortert per art, lengdemålt og veid. Denne prosedyren ble gjentatt gjennom hele toktet. Det ble gjennomført undervannskameraopptak av risten, i Excluderens innerrør og ved Excluder-utslippet. Til dette ble det brukt kameraet GoPro Hero 4 med rødt lys. Ingen endring ble gjort på seleksjonsinnretningene som følge av undervannsvideoopptakene.

Vi brukte det statistiske analyseprogrammet SELNET (Herrmann et al., 2012) for å analysere fangstdataene og utføre en lengdeavhengig fangstsammenligning og en fangstforholdsanalyse (Herrmann et al., 2017).

6.4 Resultater

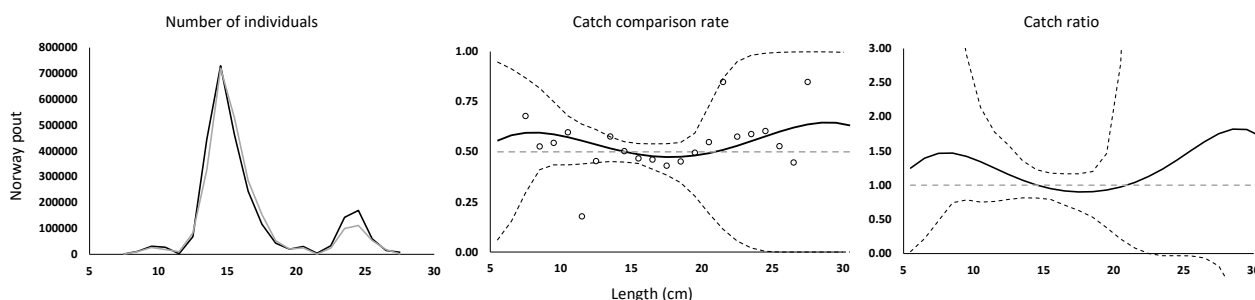
Totalt ble 12 gyldige hal gjennomført med dobbeltrål. Den samlede fangsten fra trålen med rist var 232 500 kg, mens fangsten fra trålen med Excluder var 125 100 kg. Fangsten av øyepål ble opprettholdt når Excluder ble brukt, mens fangsten av alle andre arter ble redusert. Kolmule, som er en ønsket og lovlig bifangststart, ble redusert med 27,6 %. På lik måte ble fangstene av hestmakrell også redusert med 83,6 %. Bifangst av uønskede arter som makrell og sild ble redusert med 84,5 % og 69,6 %. Bifangst av hvitfisk (f.eks. hvitting, hyse og torsk) ble redusert med over 90 % (Tabell 6).

Tabell 6: Total fangst (kg) per art fra trålen med rist og trålen med Excluder inkludert i analysen beskrevet i snitt 6.3.

Art	Trål med rist		Trål med Excluder		% reduksjon i vekt
	Total fangst	Gjennomsnitt	Total fangst	Gjennomsnitt	
Øyepål	67 032	5 586 (3 989–7 197)	66 069	5 506 (4 269–6 796)	-1.4
Kolmule	75 038	6 253 (3 335–9 924)	48 302	4 025 (2 260–6 084)	-35.6
Strømsild/vasssild	4 372	364 (42–970)	3 301	275 (32–683)	-24.5
Hestmakrell	38 125	3 177 (2 282–4 049)	272	23 (4–54)	-99.3
Sild	34 248	2 854 (1 396–4 708)	3 458	288 (123–523)	-89.9
Makrell	27 564	2 297 (672–4 277)	1 858	155 (41–282)	-93.3
Hyse	8 356	696 (310–1 127)	118	10 (3–18)	-98.6
Torsk	151	13 (0–30)	4	0 (0–1)	-97.1
Lysing	588	49 (14–95)	12	1 (0–3)	-98.0
Hvitting	7 733	644 (390–963)	51	4 (1–8)	-99.3
SUM	263 207		123 445		

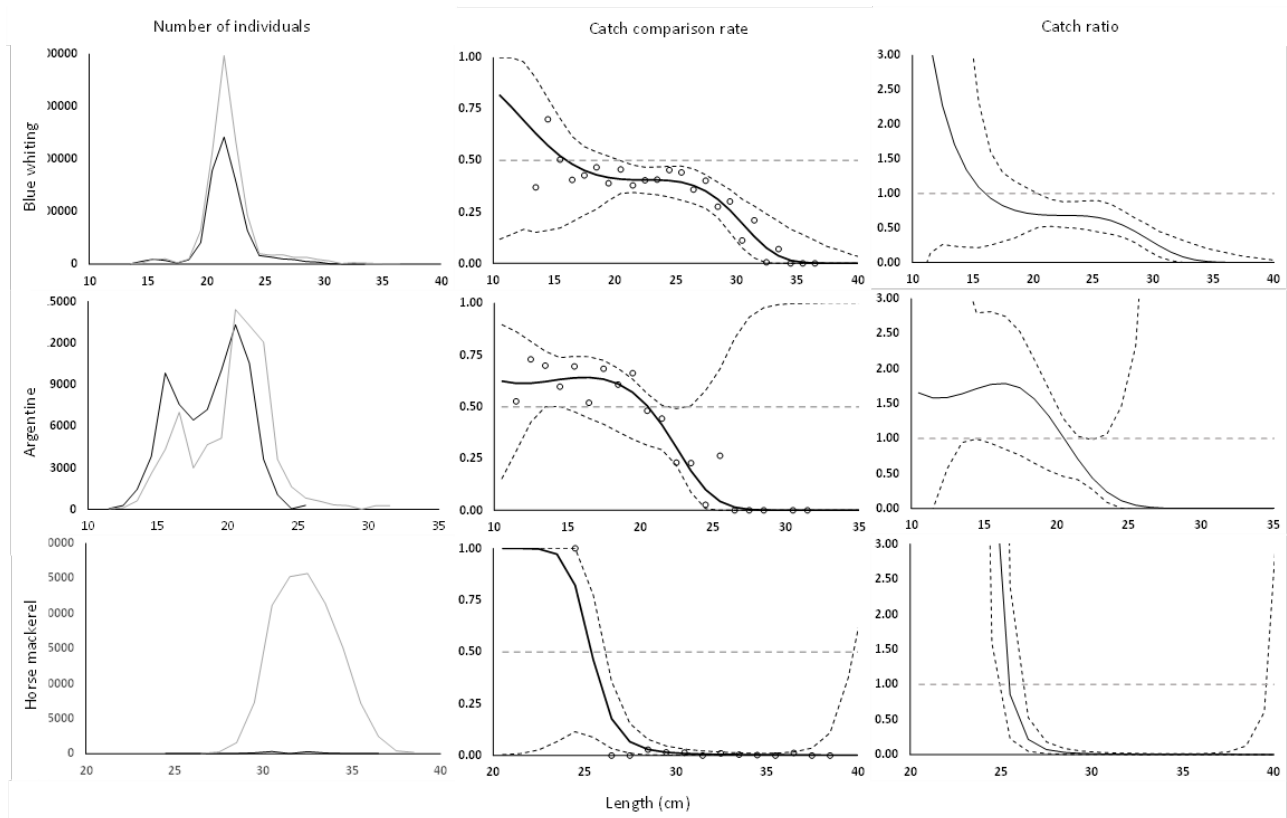
* Flatfisk og svarthå ble ikke inkludert i analysen. 605.3 kg flatfisk ble fanget med trålen med rista mens 58.1 kg ble fanget med trål med Excluder. 668.1 kg svarthå ble tatt med trålen med rist og 391.9 kg ble fanget med trålen med Excluder.

Det var ingen signifikant ($p < 0.0001$) forskjell i fangstene av øyepål. CR = 103,8 (86,7-1256) (Figur 19). Antall lengdemålt øyepål fra trålen med Excluder var 2 124 mens den fra trålene med risten var 2 177.



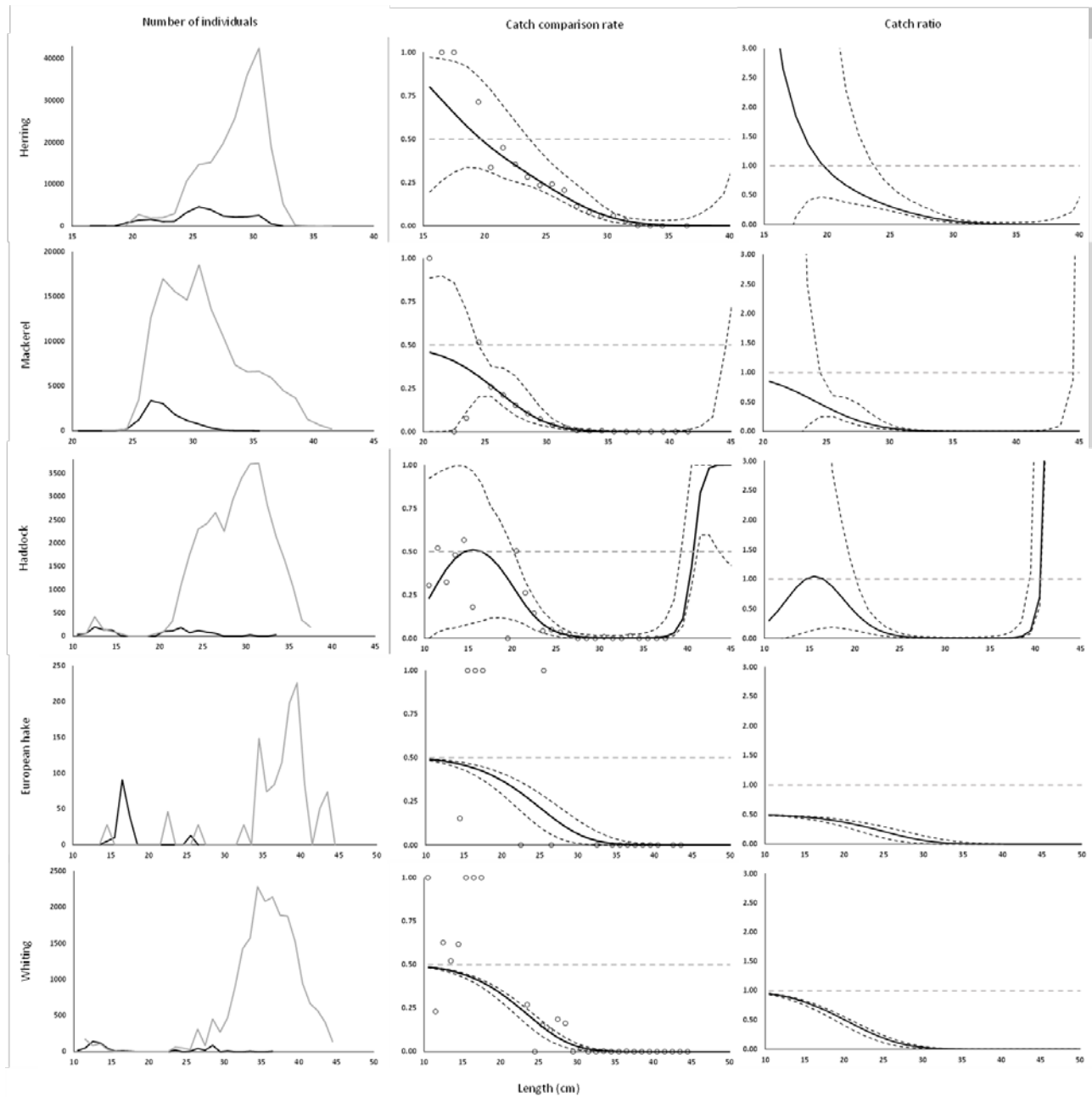
Figur 19. Fangstsammenligning og fangstforholdsanalyse for øyepål. Venstre graf: lengdefrekvensfordelingen til fisk fanget med redskap ved bruk av Excluder (svart linje) og redskap ved bruk av sorteringsrist (grå linje). Midten: den modellerte fangstsammenligningsraten (svart linje) med 95 % konfidensintervaller (svarte stiplede kurver). Sirkler representerer de eksperimentelle punktene. Høyre: den estimerte fangstforholdskurven (svart kurve) med 95 % konfidensintervaller (svarte stiplede kurver). De grå stiplede linjene ved 0,5 og 1,0 representerer punktet der begge redskapene har lik fangstrate.

Det var signifikant forskjell i fangstene av kolmule, strømsild og makrell (Figur 20).



Figur 20. Fangstsammenligning og fangstforholdsanalyse for kolmule, strømsild og hestmakrell. Venstre graf: lengdefrekvensfordelingen til fisk fanget med redskap ved bruk av Excluder (svart linje) og redskap ved bruk av sorteringsrist (grå linje). Midten: den modellerte fangstsammenligningsraten (svart linje) med 95 % konfidensintervaller (svarte stiplede kurver). Sirkler representerer den eksperimentelle hastigheten. Høyre: den estimerte fangstforholdskurven (svart kurve) med 95 % konfidensintervaller (svarte stiplede kurver). De grå stiplede linjene ved 0,5 og 1,0 representerer punktet der begge redskapene har lik fangstrate.

Det var signifikant forskjell i fangstene av kolmule, strømsild og makrell (Figur 21).



Figur 21. Fangstsammenligning og fangstforholdsanalyse for utilsiktede bifangstarter. Venstre graf: lengdefrekvensfordelingen til fisk fanget med redskap ved bruk av Excluder (svart linje) og redskap ved bruk av sorteringsrist (grå linje). Midten: den modellerte fangstsammenligningsraten (svart linje) med 95 % konfidensintervaller (svarte stiplede kurver). Sirkler representerer den eksperimentelle hastigheten. Høyre: den estimerte fangstforholdskurven (svart kurve) med 95 % konfidensintervaller (svarte stiplede kurver). De grå stiplede linjene ved 0,5 og 1,0 representerer punktet der begge redskapene har lik fangstrate.

Til tider var det mye kledning (masking) av sild i innerørret i Excluder. Dette gjorde at vi måtte fjerne mest mulig sild fra Excluderen før neste tråltrekk. Selv om kledning av sild var over nesten hele Excluder, var kanskje området foran "Postkassa" det mest utsatte (Figur 22).



Figur 22. Bilde av Excluder med masking av sild.

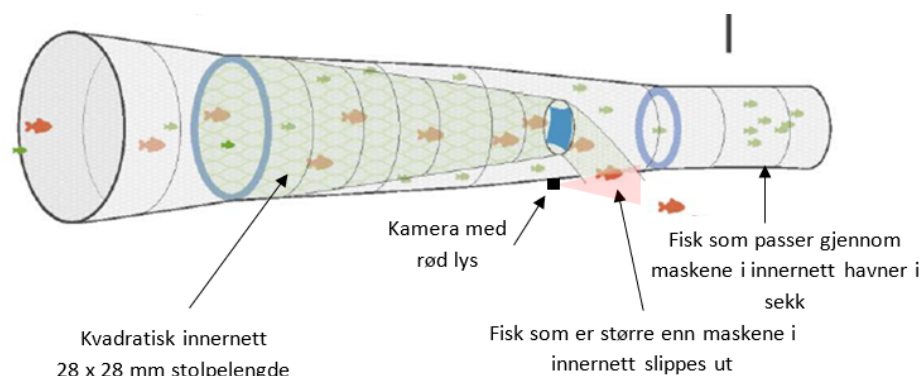
7 Forsøk 5: Analyse av videodata samlet inn under Svenske-forsøkene med en Excluder-seksjon på tobisfisket i Nordsjøen

7.1 Formål

Gjennomføre videooptak av en Excluder-seksjon under tobisfisket i norsk sone i mai 2021.

7.2 Fartøy og utstyr

Analyse av videodata fra Excluder fra MS «Odd Lundberg» under kommersielt tobisfisket i norsk sone i mai 2021 (ingen forsker om bord). Det ble brukt en Excluder-seksjon med masker med 28 mm x 28 mm stolpelengde under tobisfisket i norsk sone. Videodata ble formidlet av Egersund Trål og analysert av Shale Rosen (Havforskningsinstituttet). Tegningen av Excluder og plassering av kamera er vist i Figur 23.



Figur 23. Excluder og kamera oppsett på MS «Odd Lundberg».

Et GoPro-kamera (uten kunstig lys) ble plassert inne i kvadratmaske seksjonen. Opptak fra dette kameraet viser ren (nærmest 100 %) tobis som svømmer gjennom kvadratmaskene og havner i sekken (Figur 24). Et annet kamera (med rødt lys), som ble plassert på utslippshull, viser artene som ble sorter ut av Excluderen (Figur 25).

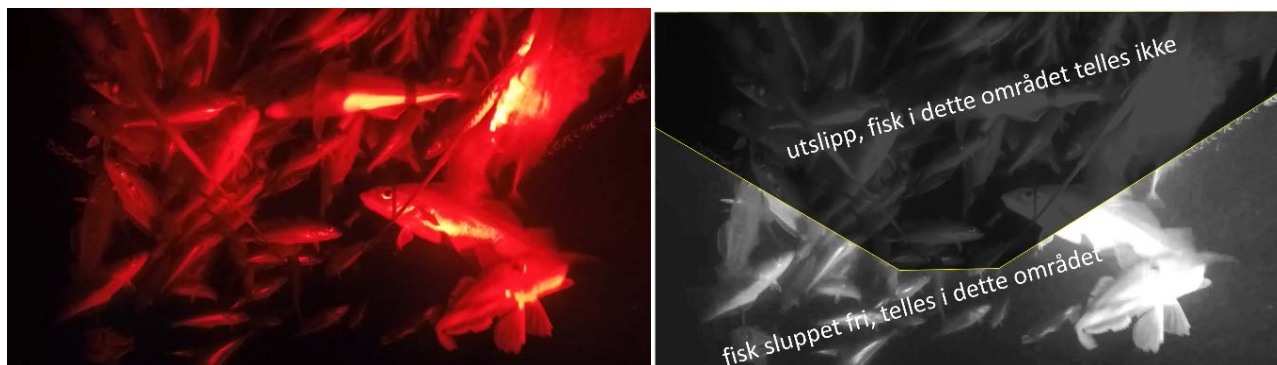


Figur 24: Bilde av tobis som går gjennom kvadratmaskene og havner bak i sekken.



Figur 25: Bilde av bifangstartene i utslippet.

Videodata i form av en 10 minutters filmsnutt fra et kamera plassert på undersiden av Excluder-seksjonen med kunstig belysning (rødt lys for å hindre at fisk skal reagere på lyset) ble analysert. Kameraet ble plassert foran utslipp og filmet bakover. Oppløsning er 1920 x 1080 piksler, bildefrekvens 30 bilder per sekund. Under analysen ble lysstyrken stilt inn +50 % og kontrast +62 % og fargene endret til gråskala. Avstand som fisken kan identifiseres og telles etter bildejusteringer er antatt ~2 m. Videoen ble spilt av på 0,25x hastighet for å kunne holde kontroll på bevegelse av hver enkelt fisk. Området over utslippet ble masket av (Figur 26) og fiskene ble talt når de svømte ut av området. Hvis en fisk svømte inn igjen ble ikke den neste fisken talt for å unngå dobbelttelling.



Figur 26. Stillbilder fra video. Bildet til venstre er uten justering. I bildet til høyre er lysstyrken stilt inn +50 %, kontrast +62 % og fargene endret til gråskala. Under analysen ble området som viser utslipp masket av og fisken talt når de gikk ut og ble sluppet fri.

Fangstdata (både tobis og bifangstartene) ble formidlet av Egersund Trål. Fangstraten var 100-200 tonn tobis i løpet av 3-5 timers tauing (minst 20, maks 67 tonn i timen). Størrelsen på tobisen lå på ca. 35-40 g og 16-20 cm lengde. Bifangst (ikke-målart som passerte gjennom maskene i Excluder og havnet i posen) var mindre makrell. Hyse og hvitting som ble sortert ut lå hovedsaklig på 70-200 g, med noen hyser på 1000 g.

Kvalitative observasjoner: Fisken ser ut til å være i ro i utslipp uten tegn på stress eller skjelltap. De virker heller ikke påvirket av de røde lysene.

Kvantitative observasjoner: Det var mulig å artsidentifisere og telle makrell, tobis, knurr og akkar. Hvitting og hyse (de vanligste artene) kunne telles, men var oftest umulig å skille mellom. For disse to artene ble begge talt sammen. Etterpå ble det analysert ett stillbilde hvert minutt (11 stillbilder til sammen) hvor det ble talt både antall fisk (kombinert hvitting + hyse) og hvilken andel som kunne identifiseres som hvitting eller hyse. I gjennomsnitt kunne 11 % av hvitting + hyse artsidentifiseres med en fordeling på 63 % hvitting og 37 % hyse (Tabell 7).

Tabell 7. Fordeling av hvitting og hyse i et systematisk utvalg av 11 stillbilder.

Tid (hh:mm)	Hvitting	Hyse	Antall fisk i bildet	% identifisert	% hvitting	% hyse
00:00	17	4	95	22 %	81 %	19 %
00:01	3	5	78	10 %	38 %	63 %
00:02	10	2	93	13 %	83 %	17 %
00:03	5	4	86	10 %	56 %	44 %
00:04	6	4	131	8 %	60 %	40 %
00:05	14	4	118	15 %	78 %	22 %
00:06	6	7	95	14 %	46 %	54 %
00:07	6	7	188	7 %	46 %	54 %
00:08	4	3	113	6 %	57 %	43 %
00:09	5	4	123	7 %	56 %	44 %
00:10	4	3	85	8 %	57 %	43 %
Totalt	80	47	1205	11 %	63 %	37 %

7.3 Resultater fra videoanalysen

Til sammen ble det talt 5 562 fisk som ble sluppet ut av Excluderen. Av disse var ca. 60 % hvitting, 35 % hyse og < 5 % tobis (Tabell 8). Andre arter (knurr, makrell og akkar) utgjorde < 1 %. Tall ble konvertert til vekt ved bruk av individvektene over. Min.-verdier for tonn/time er basert på en tobisvekt på 35 g og hvitting/hysevekt på 70 g mens maksverdier er basert på en tobisvekt på 40 g og hvitting/hysevekt på 200 g. Tap av tobis (forhold mellom fangst og kvantum som ble sluppet fri) er basert på fangstrate for tobis på 67 tonn/time (min.) og 20 tonn/time (maks).

Tabell 8. Opptelling av fisk som ble sluppet ut av Excluder, samt omregning til antall tonn per time, bifangst rate og tap av tobis. Min.- og maksverdier i tonn/time og % tap av tobis basert på min.- og maksvekt per individ. Min. bifangstrate er basert på maks tonn bifangst per time og min fangstrate (20 tonn tobis/time), maks bifangstrate er basert på min. tonn bifangst per time og maks fangstrate (67 tonn tobis/time).

Art	Antall	Fordeling		Tonn/time		Bifangstrate		% tap	
		Antall	Kg	Min.	Maks	Min.	Maks	Min.	Maks
Hvitting	3310	60 %	61-62%	1,4	4	2 %	20 %	-	-
Hyse	1944	35 %	36-37%	0,8	2	1 %	12 %	-	-
Tobis	285	5 %	1-3%	0,06	0,07	-	-	0,09 %	0,34 %
Knurr	17	0.30 %	< 1 %	-	-	-	-	-	-
Makrell	5	0.10 %	< 1 %	-	-	-	-	-	-
Akkar	1	0.00 %	< 1 %	-	-	-	-	-	-

7.4 Foreløpige konklusjoner

I dataene som ble analysert, var hvitting og hyse de vanligste artene som ble sluppet ut av Excluder, med antatt bifangstrate mellom 3 og 32 % etter vekt. Disse min.- og maksverdiene er beregnet fra fangstmengder og vekt per individ med store usikkerheter. Hvitting og hyse var ikke registrert som bifangst i trålposen, noe som indikerer at Excluder var effektiv til å sortere dem ut. Videoene indikerer at det er lite tap av tobis (< 1 %), og de fiskene som slippes ut (hvitting, hyse, tobis, knurr og makrell) ser ut til å være uskadd og viser vanlig svømmeevne.

8 Forsøk 6: Uttesting av en Excluder-seksjon i fisket etter tobis om bord på MS «Bømmelfjord» i perioden 24.04.-08.05.22

8.1 Formål

Kvantifisere fangst av tobis, tap av tobis og bifangstreduksjon i en trål med og uten en Excluder-seksjon.

8.2 Fartøy og utstyr

Forsøket ble gjennomført om bord fartøyet MS «Bømmelfjord» i perioden 24.04.-08.05.22. Eduardo Grimaldo (SINTEF Ocean) og Jesse Brinkhof (UiT) og deltok på toktet. En Excluder, 25 m lang med 30 x 30 mm innernett i 6 mm Eurocross knuteløs notlin og ytternett i 22 mm diamant-notlin ble brukt under dette forsøket. Excluderen ble plassert mellom trål og sekk som illustrert i Figur 1. En prøve på ca. 300 kg (12 korger) ble tatt fra sekken og prøven sortert etter art. Fisk ble lengdemålt og veid. Denne prosedyren ble gjentatt i hvert hal gjennom hele toktet. Det ble gjennomført undervannskameraopptak av Excluder i enkelte hal. Til dette ble det brukt GoPro Hero 4-kamera i undervannshus, utrustet med rødt lys med ekstra batteripakke. Ingen endring ble gjort til seleksjonsinnretningene som følge av undervannsvideoopptakene.

8.3 Resultater fra toktet

Totalt ble 9 hal gjennomført på dette toktet. Fangstene bestod av tobis og bifangst av hyse, sild, hvitting, makrell, torsk og knurr. Totalfangsten av tobis var 1464 tonn og mengde bifangst 35 tonn. Seks av de ni halene ble gjort uten Excluder og tre hal med Excluder. Dessverre feilet undervannsvideoopptaket så det var ikke mulig å overvåke fiskeprosessen.

Trålen med Excluder var mye mindre effektiv til å fange tobis enn trålen uten Excluder. I gjennomsnitt ble tobisfangstene per hal redusert med 66.8% når trålen hadde Excluderen på. Av bifangstene var det en gjennomsnittlig reduksjon på 100% for makrell, hyse, knurr og torsk, samt en reduksjon på 99.6% for hvitting og 86.3% for sild (Tabell 9).

Tabell 9: Total fangst (kg) per art fra trålen med og uten Excluder, samt endring i %.

	Trål uten Excluder			Trål med Excluder			% reduction
	total fangst	minste-største fangst	gjennomsnitt av seks hal	total fangst	minste-største fangst	gjennomsnitt av tre hal	
tobis	1 256 454,8	(96 119.7 - 431 256.0)	209 409,1	208 316,9	(24 965 - 123 520.9)	69 439,0	66,8 %
makrell	862,5	(29.6 - 695.4)	143,8	-	0	-	100,0 %
hyse	15 438,3	(613.1 - 2 222.9)	2 573,1	-	0	-	100,0 %
hvitting	7 285,9	(266.8 - 3 167.8)	1 214,3	14,6	(0 - 14.6)	4,9	99,6 %
sild	9 755,7	(0 - 4 711.4)	1 626,0	668,5	(19.5 - 479.1)	222,8	86,3 %
knurr	1 116,7	(214.9 - 360.6)	186,1	-	0	-	100,0 %
torsk	86,0	(0 - 85.6)	14,3	-	0	-	100,0 %

8.4 Foreløpige konklusjoner

I de tre halene der Excluder var tatt i bruk ble store mengder tobis observert kledd i flere seksjonen foran Excluderen (Figur 31). Dette indikerer at tobis reagerer ved å forsøke rømme gjennom maskene i seksjonene foran Excluder. Konsekvensen av dette er store tap av tobis. Vi mistenker også at Excluderen har kapasitetsproblemer og sliter med å håndtere store tettheter av tobis, noe som igjen kan resultere i tap av fisk gjennom utslippsåpningen.



Figur 31: Kledning av tobis i seksjonen foran Excluder.

Det ble gjennomført 11 par trålhål til sammen med fangstrate på 1 til 7 tonn i timen. Av disse kunne 10 par brukes til analyse (revet trål i ett hal). Prøver på 9-12 korerger (200-300 kg) ble tatt fra hver trål under ombordspumping av fangsten. Prøven ble sortert etter art, og fiskene lengdemålt og veid. Denne prosedyren blir gjentatt for hver trål i hvert hal gjennom hele toktet. Fisk som ble sortert ut av risten ble ikke bevart (det ble ikke brukt oppsamlingspose over fiskeutslipp) og derfor ikke målt.

Undervannskameraopptak av ristseksjonene ble samlet under enkelte hal for å verifisere at ristseksjonene fungerte som tiltenkt. Vinkelsensorer ble også montert langs en spile i midterst ledd av begge rister og viste at helningsvinkel var både stabil på 44-45 grader og likt mellom ristene.

9.3 Resultater fra toktet

Tabell 10 oppsummerer resultatene fra forsøkene om bord MS «Cetus».

Tabell 10: Total fangst (kg) per art fra trålen med 40 mm rist og 35 mm rist, samt endring i %.

Art	40 mm rist	35 mm rist	% reduksjon
Breiflabb	-	1,02	100
Firetrådet tangbrosme	2,64	-	-100
Fløyfiskfamilien	11,91	2,86	-75,96
Gapeflyndre	342,84	274,05	-20,06
Glassvar	93,40	6,21	-93,35
Havmus	-	0,41	100
Hestmakrell	17 923,38	7 953,14	-55,63
Hvitting	3 349,92	1 630,98	-51,31
Hyse	5 792,56	2 051,56	-64,58
Hågjel	208,75	82,63	-60,42
Knurr	252,23	81,37	-67,74
Kolmule	157 687,53	154 586,00	-1,97
Lomre	39,83	28,94	-27,34
Lysing	42,38	-	-100
Makrell	29 440,93	12 875,33	-56,27
Sei	330,27	-	-100
Sild	773,02	580,80	-24,87
Smørflyndre	63,85	83,06	30,09
Svarthå	27,22	37,23	36,78
Sypike	6,55	9,20	40,44
Sølv torsk	25,17	60,32	139,61
Uerslekten	72,69	44,97	-38,13
Vassild / strømsild	5 417,10	4 800,49	-11,38
Øyepål	44 995,84	43 356,31	-3,64
Ålekvabbe	-	1,93	100
SUM	266 900,54	228 548,82	-14,37
SUM øyepål + kolmule + vassild / strømsild	208 100,47	202 742,80	-2,57

9.4 Foreløpige konklusjoner

Gjennomsnittlig var det 14 % reduksjon i totalfangst (alle arter) ved bruk av 35 mm rist sammenlignet med 40 mm rist, men forskjellen var ikke statistisk signifikant. Forskjellen i fangst mellom 35 mm rist og 40 mm rist for målartene øyepål, kolmule og vassild / strømsild var kun 3 %. Reduksjon var betydelig høyere for de viktigste bifangstartene med totalfangst på > 500 kg. Makrell hadde en reduksjon på 56 %; hestmakrell 56 %; hyse 65 %; hvitting 51% og sild 25 %.

Videoopptak og kledning av små øyepål rundt 35 mm rist antyder at det er større kapasitetsutfordringer med denne sammenlignet med 40 mm rist (reduert gjennomstrømning på grunn av redusert spileavstand?). Video indikerer også at 60 cm utslippshul kanskje er for liten.

10 Konklusjoner, anbefalinger og forslag til videre arbeid

Resultatene fra alle toktene kan oppsummeres slik:

- Til tider kan bifangst av hyse, makrell og hvitting være stor i tobisfisket, noe som gir store utfordringer i forhold til bifangstgrensene i dette fiskeriet. Andre ganger er fangstene av tobis ganske rene. Testing av en Excluder-seksjon med et innerrør laget av kvadratmasker med 36 mm stolpelengde så ikke ut til å være optimal for å sortere bifangsten. Disse maskene er for store for å unngå at småhyse, småsild og småmakrell (10-15 cm) går gjennom maskene og blir fanget i sekken. Fall-through forsøk indikerte at kvadrattmaskene med 28 mm stolpelengde kan være bedre egnet enn 36 mm stolpelengde til bifangstreduksjon i tobisfisket. Forsøket med en Excluder-seksjon laget av kvadrattmasker på 28 mm ga mye bedre bifangstreduksjon og rene fangster av tobis, men redusert fangster (se under).
- En Excluder-seksjon med innerrør laget med kvadratmasker med 36 mm stolpelengde fungerer ganske greit til å redusere bifangst i øyepålfisket. Fangstene av øyepål ble stort sett beholdt, mens fangstene av lovlig kolmule reduseres pga. størrelsesseleksjon. Små kolmuler tilbakeholdes mens stor kolmule blir fjernet. Kanskje burde stolpelengden i kvadratmaskene økes til 38 eller 40 mm for å beholde litt mer av kolmule og strømsild, som er lovlig å fange.
- Bruk av Excluderen kan gi fleksibilitet til fartøy som fisker med industritrål i Nordsjøen. I tilfeller der innblanding av uønskede arter (i.e., makrell, sild, hyse, hvitting, torsk og lysing) er høy, kan en Excluder-seksjon være av stor nytte ved å redusere bifangsten av disse artene betydelig.
- Den rigide sorteringsristen hadde mer problemer enn Excluder med å fjerne uønsket bifangst i industrifisket etter øyepål. Konsekvent fanget trålen med risten større prosent bifangst enn trålen med Excluder.
- Den større ristvarianten ga ikke bedre utsortering av bifangst enn standard 1,8 m bred rist. Den var i tillegg ekstra vanskelig å håndtere på dekk og så ut som at den 2,7 m brede risten ble utsatt for store krefter og at den fort kunne bli ødelagt. Vi tror ikke en større rist er veien å gå for å løse problemet med bifangst i dette fiskeriet.
- Det foreslås videre arbeid med Excluder, spesielt for å finne den riktige stolpelengden for tobis og øyepål. Det foreslås å teste en Excluder-seksjon med 38 eller 40 mm stolpelengde, og sammenligne den med en 40 mm sorteringsrist.
- Det finnes to varianter av Excluder, den ene er 15 m lengre enn den andre, og innerrør ikke er laget av kvadrattmasket lin. Har disse forskjellene noe å si for seleksjon og bifangstreduksjon?
- Bruk av Excluderen på tobisfiske kan gi store tap av fisk. Det ser ut som at Excluderen ikke har kapasitet å håndtere store mengder tobis som kommer inn i trålen. Det ble observert tap av fisk i seksjonene foran Excluderen og gjennom utslippåpningen.
- Sammenligning av 35mm EU rist mot 40mm Norskrist i fisket for øyepål viser at 35 mm rist er mye mer effektiv til å sortere ut makrell, hestmakrell, hyse, hvitting og sild med lite tap av målartene øyepål, kolmule og vassild / strømsild.
- Alle resultatene presentert i dette rapporten baserer seg på enkelt tokt og dermed er resultatene avhengige av artssammensetning i området forsøket ble gjennomført. Spatial-temporale variasjoner kan gi andre resultater. Det anbefales at datagrunnlaget styrkes ved å gjennomføre flere forsøk med rist (35mm og 40mm) og direkte sammenligning med Excluder.

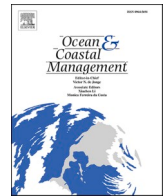
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The effect of grid size on catch efficiency and by-catch in the demersal trawl fishery for Norway pout (*Trisopterus esmarkii*)

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ABSTRACT

Norway pout (*Trisopterus esmarkii*) is caught with large trawls with small meshed codends, inevitably causing the fishery to have large by-catch issues. To reduce the amount of by-catch, a rigid sorting grid was made compulsory in 2010. However, there is still a severe by-catch issue, as well as the loss of target species because of the grid. A possible cause might be clogging of the grid, which could be solved by increasing the grid area. Therefore, this study compared the size selectivity of by-catch species and target species in a double-trawl configuration in which one trawl was equipped with a standard grid (6.30 m²), and the other trawl was equipped with a grid that had a 50% larger surface area (9.45 m²). The results demonstrated that the size selectivity and catch efficiency of the target species were unaffected; neither was there any significant difference between the two grids in terms of wanted by-catch species [blue whiting (*Micromesistius poutassou*), horse mackerel (*Trachurus trachurus*), and greater argentine (*Argentina silus*)]. However, the larger grid caught significantly more unwanted by-catch species [haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), and hake (*Merluccius merluccius*)]. Approximately one-third of the accumulated catches comprised the target species, one-third of wanted by-catch species, and one-third of unwanted by-catch species, demonstrating the by-catch challenges in this fishery. Simultaneously, none of the by-catch limits were exceeded.

1. Introduction

The fishery for Norway pout has declined substantially over the past three decades, and the total allowable catch for the North Sea, Skagerrak, and Kattegat was set to 254 038 tons for 2021 (ICES, 2020). However, even though the quotas vary from year to year because of the short life span of this species and the fluctuating stock recruitment, annual landings are usually well below the annual quota (ICES, 2020). This small gadoid species is found throughout the North Sea, all around the UK, up to Iceland and along the Norwegian coast (Lambert et al., 2009). However, because this species has no schooling behavior and lives scattered close to the seabed, sufficient catch densities are only encountered in a few areas, mostly Fladen-ground and Egersund-ground along the Norwegian trench. It is in these areas that most of the fisheries targeting Norway pout are found. The fishery is conducted both in EU and Norwegian Exclusive Economic Zone (EEZ), with different

management regulations, however, two countries Denmark and Norway account for 98% of the annual catches of Norway pout (Eigaard et al., 2021).

Given the scattered distribution of Norway pout, the trawls that are used in the fishery are commonly large opening trawls towed in a double-trawl configuration. In addition, because the species shows vertical diel migration, the vessels only fish during daylight when the species is closest to the seabed. In the Norwegian fishery the minimum legal mesh size in the codend is 16 mm, inevitably causing the fishery to have severe by-catch levels (ICES, 2017; Kvalsvik et al., 2006). Norway pout, which has no minimum landing size meaning that all sizes are targeted, is caught for reduction (i.e., extraction of fish oil and fish meal) (ICES, 2017; Eigaard et al., 2021). The fishery targeting Norway pout is a multispecies fishery with both wanted and unwanted by-catch species. All vessels that catch Norway pout also have quota for blue whiting (*Micromesistius poutassou*), which is targeted simultaneously. Nonquota

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species, such as Atlantic horse mackerel (*Trachurus trachurus*) and silvery pout (*Gadiculus argenteus*), are regarded as wanted by-catch species. Several vessels also have quota for Atlantic mackerel (*Scomber scombrus*), herring (*Clupea harengus*), and/or greater argentine (*Argentina silus*), which is allowed as by-catch up to given percentage and is drawn from the specific quota of each vessel (ICES, 2017). However, even though these can be regarded as wanted by-catch species, the vessels commonly prefer to target these species directly because this gives them a higher price when landed for human consumption. Species that are regarded as choke-species and, thus, as unwanted by-catch are haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), saithe (*Pollachius virens*), cod (*Gadus morhua*), hake (*Merluccius merluccius*), and monkfish (*Lophius piscatorius*), among others (ICES, 2017; Kvalsvik et al., 2006).

Current regulations limit the by-catch of cod, haddock, saithe, and whiting to a maximum of 20% (sum of those species by weight per haul), monkfish up to 0.5%, and herring and greater argentine up to 10% each (if the vessels have no quota for these species) (ICES, 2017). With long towing times of 8–10 h, and high catch rates up to 10 tons per hour, the amount of by-catch can be high. To reduce the fish by-catch, it has been mandatory since 2010 to apply a rigid sorting grid in the fishery, with a maximum bar spacing of 40 mm in the Norwegian EEZ and of 35 mm in the European EEZ (ICES, 2017). Although the introduction/implementation of the sorting grid has reduced the levels of by-catch of the largest fish, by-catch of juvenile fish species remains an issue (ICES, 2017; Eigaard et al., 2021). Therefore, it would be relevant to quantify

the levels of nontarget species in the total catch.

Eigaard et al. (2012) reported that the grid, in addition to releasing by-catch species, also had a length-dependent release of the target species. This was confirmed nearly a decade later by another study by Eigaard et al. (2021), documenting a loss of target species with the sorting grid system. Previous studies on rigid sorting grids documented that the size-selective properties are affected by the catch density, with high entry rates having a negative impact on size selectivity (Sistiaga et al., 2010, 2016). High entry rates can cause blockage of the grid, subsequently reducing the probability of fish contacting the grid and attempting to escape (Sistiaga et al., 2016). In the Norway pout fishery, the entry rates vary between 1 and 10 tons per hour. This means that, with such high entry rates, the grid can be saturated, subsequently reducing its selective capacity.

A common method to aid the release of by-catch species is to increase the mesh size and/or change the mesh configuration in the codend. However, considering the small size of Norway pout this would cause an even larger loss in the target species, while by-catch species larger than Norway pout would still be retained. Also, changing the mesh size and/or configuration would not affect the issue of saturation of the grid during high entry rates. One possible solution to reduce the loss of target species is increasing the size of the grid and its surface area, which could mitigate the issue of lost target species. However, an increased retention of target species could also cause an increase in unwanted by-catch species and vice versa. Therefore, this study compared the traditional sorting grid used in the Norwegian fishery for Norway pout with that of

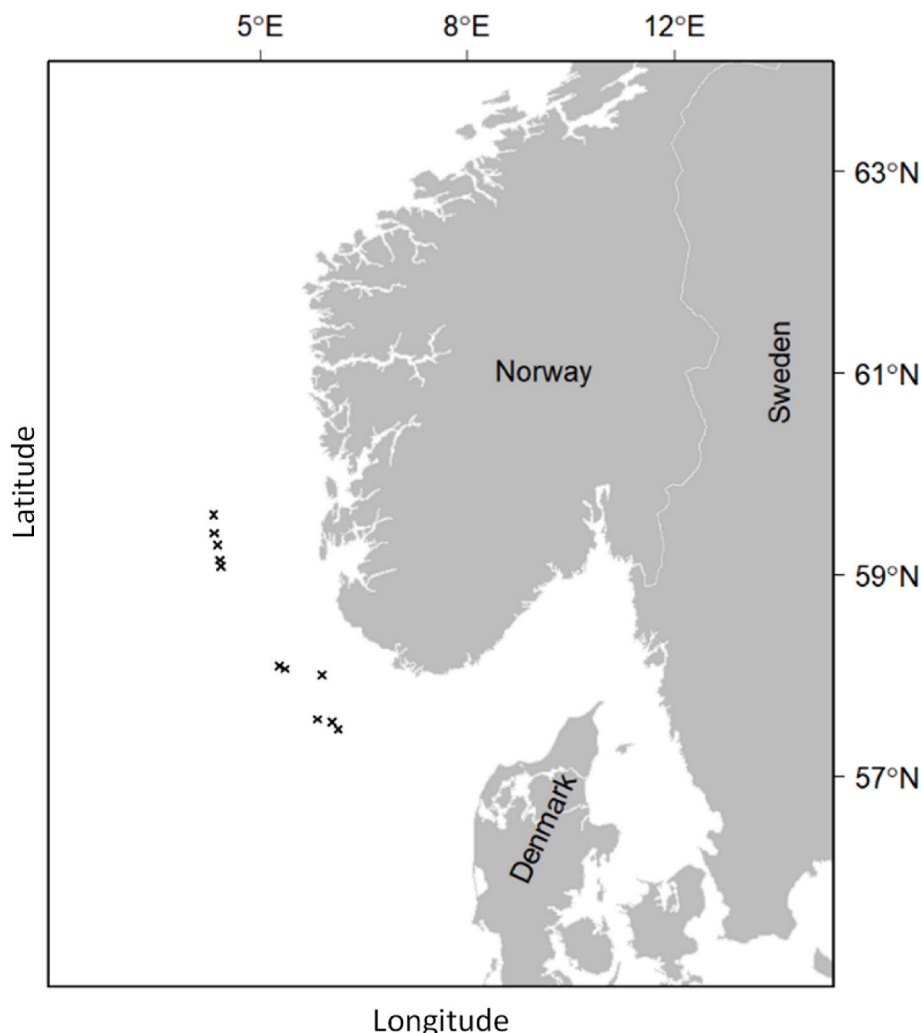


Fig. 1. Map showing the area in which the experimental trails were conducted (indicated by crosses).

an enlarged sorting grid. Specifically, the study investigated: (i) whether an enlarged sorting grid would reduce the loss of target species compared with the standard grid; (ii) whether an enlarged sorting grid would increase catches of by-catch species compared with the standard grid; and (iii) what the proportion of target and nontarget species would be in the catches caught with the standard grid and the large grid.

2. Materials and methods

2.1. Experimental trials

The cruise was conducted from 11th to September 18, 2021 onboard the 53 m-long commercial trawler *MTr Fiskebank*. The trails took place off the southwest coast of Norway (Fig. 1) on fishing grounds where Norway pout is commonly targeted.

Two identical Egersund Expo 1500 meshes trawl were used, with three 100 m-long bridles on each side. The lower bridle was equipped with a 20 cm disc in the center to avoid excessive abrasion of the sweeps. The sweeps were 30 m long followed by 25 m-long connector ropes, which were attached to the otter boards. The otter boards (Thyborøn type 22 pelagic doors) weighed 3000 kg, and were 11 m² each. The clump in the middle weighed 5500 kg. The Expo trawls had a fishing line of 67.4 m and a headline of 66.1 m. The fishing line was equipped with a 13 m-long rock hopper gear (Ø 10") in the center followed by 27.2 m-long chains on each side. The starboard trawl was equipped with a sorting grid according to the regulations. The grid had a width of 180 cm, was 350 cm long (6.30 m²), and had a bar spacing of 39.42 mm ±

1.79 mm (mean ± SD). The port trawl was equipped with the experimental grid, which had a width of 270 cm, a length of 350 cm (9.45 m²), and a bar spacing of 40.55 mm ± 0.93 mm (mean ± SD). Both grids comprised five sections that were 70 cm long, ensuring that the grid could be stored on the net drums. The grids were mounted at a 45° into four panel sections. The escape outlet was in front of the grid in the lower panel. To avoid the unwanted loss of target species, both grids had a small guiding panel in front of the escape opening in addition to bungee cords that kept the escape opening close to the grid (Fig. 2). The codends that followed the grids were both 51 m long and had a circumference of 40 m. The codend that followed the large experimental grid had a mesh size of 19.00 ± 0.65 mm (mean ± SD), whereas the codend that followed the standard grid had a mesh size of 19.23 ± 0.74 mm (mean ± SD). The trawl geometry and performance were continuously monitored using Scanmar sensors measuring the distance between the otter boards, trawl height, and catch volume. The towing speed was between 3.0 and 3.5 knots.

2.2. Data collection

After each tow, the catch in the codend from the two trawls was pumped onboard into separate refrigerated-sea-water tanks (RSW). In total, 12 baskets of fish were sampled from each codend. To ensure a representative sample, four baskets were filled at the beginning, four in the middle, and four at the end of the onboard pumping of the catch. This resulted in ~300–350 kg of fish from each codend. Directly after pumping, the factory chief inspected each tank and estimated the catch

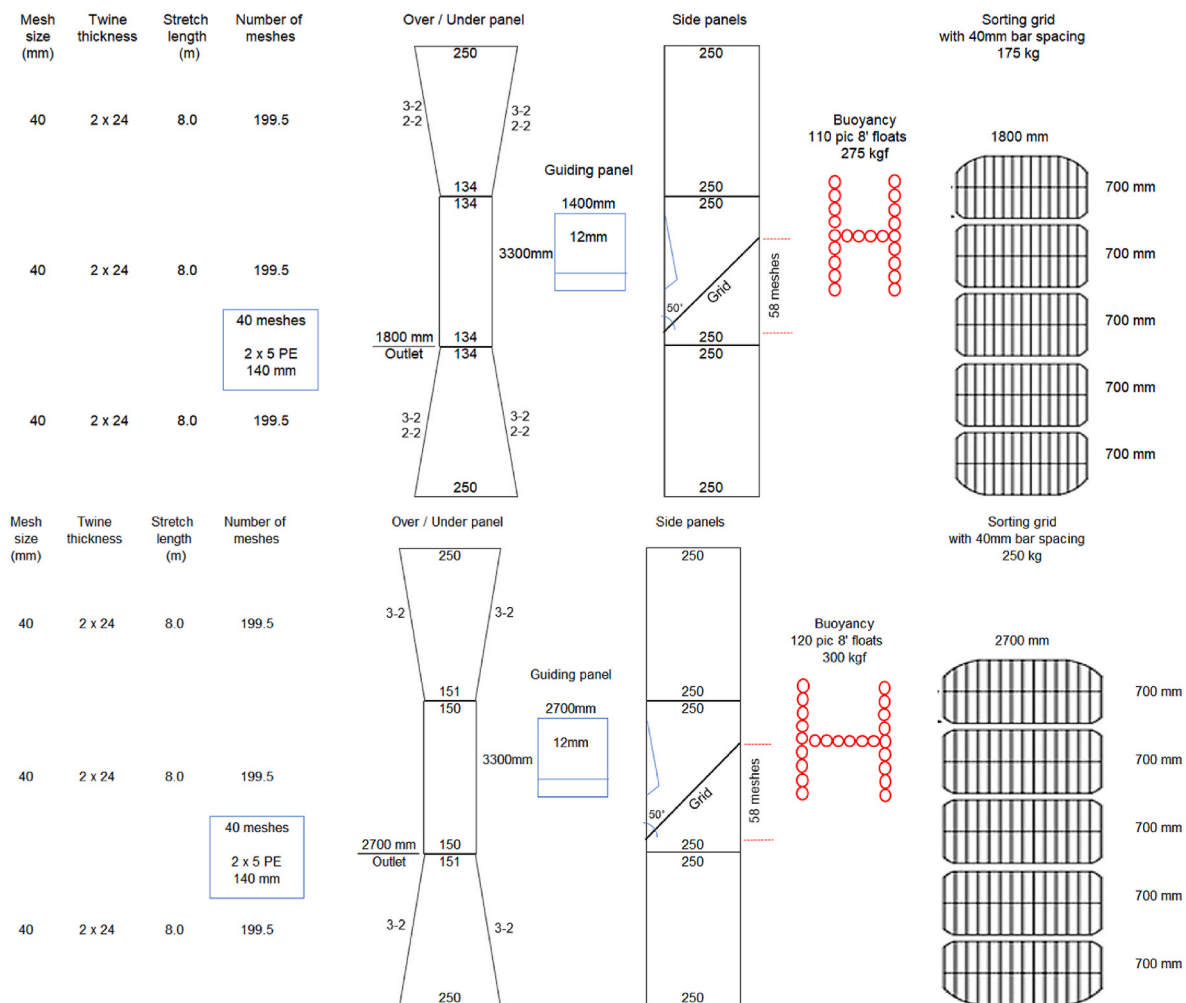


Fig. 2. Schematics of the grid sections. **Upper:** Specifications of the standard 1.8 m-wide grid. **Lower:** Specifications of the experimental 2.7 m-wide grid.

volume for each codend. The samples were sorted according to species. The weight was registered for each species and, if possible, the length of all fish was measured to the lowest centimeter. Subsamples of 10–20 kg were taken of Norway pout and blue whiting and the total weight and the subsample weight recorded. The subsampling factors were calculated by multiplying the subsample factor based on the weight from the fish measured divided by the total sample weight and the sample weight divided by the total catch weight (Table 1).

2.3. Modeling the size-dependent catch efficiency

The catch data were analyzed by modeling the size-dependent catch efficiency (Herrmann et al., 2017) using the statistical software SELNET (Herrmann et al., 2016). This method models the length-dependent catch comparison rate (CC_l) summed over hauls using Equation (1):

$$CC_l = \frac{\sum_{j=1}^m \left\{ \frac{nt_{lj}}{q_{lj}} \right\}}{\sum_{j=1}^m \left\{ \frac{nt_{lj}}{q_{lj}} + \frac{nc_{lj}}{q_{lj}} \right\}} \quad (1)$$

where nc_{lj} and nt_{lj} are the numbers of fish of each species that were measured in each length class l for the standard grid (control) and large grid (treatment) trawls in haul j. q_{lj} and q_{tj} are sampling factors quantifying the fraction, based on weight, of the catch in the codends being length-measured in the respective hauls. m is the number of hauls in which sufficient numbers of each species were caught to be included in the analysis. The functional form for the catch comparison rate CC(l, v) was obtained using maximum likelihood estimation by minimizing Equation (2):

$$- \sum_l \left\{ \sum_{j=1}^m \left\{ \frac{nt_{lj}}{q_{lj}} \times \ln(CC(l, v)) + \frac{nc_{lj}}{q_{lj}} \times \ln(1.0 - CC(l, v)) \right\} \right\} \quad (2)$$

where v is a vector of the parameters describing the catch comparison curve defined by CC(l, v). The outer summation in Equation (2) is the summation over length classes l. When the catch efficiency of the standard grid and that of the large grid trawl are similar, the expected value for the summed catch comparison rate would be 0.5 (baseline). Therefore, this baseline can be applied to judge whether there is a difference in catch efficiency between the two trawls. The experimental CC_l was modeled by the function CC(l, v) using Equation (3):

$$CC(l, v) = \frac{\exp(f(l, v_0, \dots, v_k))}{1 + \exp(f(l, v_0, \dots, v_k))} \quad (3)$$

where f is a polynomial of order k with coefficients v₀ to v_k. The values of the parameters v describing CC(l, v) were estimated by minimizing Equation (2), which was equivalent to maximizing the likelihood of the observed catch data. We considered f of up to an order of 4 with parameters v₀, v₁, v₂, v₃, and v₄. Leaving out one or more of the parameters v₀ ... v₄ led to 31 additional models also considered as potential models for the catch comparison CC(l, v). Among these models, estimations of the catch comparison rate were made using multimodel inference to obtain a combined model (Burnham and Anderson 2002). The ability of the combined model to describe the experimental data was evaluated based on the p-value. The p-value, which was calculated based on the model deviance and the degrees of freedom, should not be < 0.05 for the combined model to describe the experimental data sufficiently well, except for cases in which the data are subject to overdispersion (Wileman, 1996). Based on the estimated catch comparison function CC(l, v), we obtained the relative catch efficiency (also named catch ratio) CR(l, v) between the two trawls using Equation (4):

$$CR(l, v) = \frac{CC(l, v)}{(1 - CC(l, v))} \quad (4)$$

CR(l, v) represents the relationship between catch efficiency of the large grid and standard grid trawl. If the catch efficiency of both trawls is

Table 1 Overview of each haul showing date, time of deployment, towing time, catch weight, and subsampling factor for the standard grid (SG) and the large grid (LG).

Haul nr	1	2	3	4	5	6	7	8	9	10	11	12
Date	11.09.2021	11.09.2021	12.09.2021	13.09.2021	14.09.2021	14.09.2021	14.09.2021	15.09.2021	16.09.2021	16.09.2021	17.09.2021	17.09.2021
Time (UTC)	09:22	20:25	07:20	04:33	13:17	04:12	12:40	03:29	02:48	14:25	04:23	13:00
Depth (m)	157	149	155	153	173	168	175	161	198	165	138	-
Towing time (h:hr:mm)	8 h 15 min	8 h 12 min	10 h 35 min	6 h 23 min	5 h 2 min	6 h 55 min	5 h 58 min	5 h	8 h 56 min	5 h 35 min	6 h 55 min	4 h 50 min
Catch weight SG (kg)	32000	7000	42000	21000	17000	22000	12000	18000	13000	9000	10000	10000
Catch weight LG (kg)	30000	8000	53000	22000	18000	18000	8000	19000	12000	8000	8000	10000
Norway pout (SG)	0.0013	0.0030	0.0015	0.0020	0.0024	0.0012	0.0016	0.0025	0.0041	0.0026	0.0020	0.0040
Norway pout (LG)	0.0007	0.0040	0.0007	0.0011	0.0032	0.0016	0.0021	0.0024	0.0024	0.0031	0.0032	0.0026
Blue whiting (SG)	0.0018	0.0471	0.0044	0.0047	0.0084	0.0116	0.0101	0.0063	0.0092	0.006	0.0034	0.0034
Blue whiting (LG)	0.0023	0.0392	0.0069	0.0049	0.0087	0.0168	0.0141	0.0048	0.0022	0.0085	0.0191	0.0042
Horse mackerel (SG)	0.0111	0.0471	0.0078	0.0171	0.0187	0.0116	0.0247	0.0187	0.0239	0.0366	0.0314	0.0325
Horse mackerel (LG)	0.0121	0.0392	0.0069	0.0151	0.0177	0.0168	0.0382	0.0181	0.0263	0.0427	0.0411	0.0295
Mackerel (SG)	0.0111	0.0471	0.0078	0.0171	0.0187	0.0116	0.0247	0.0187	0.0239	-	0.0314	0.0325
Mackerel (LG)	0.0121	0.0392	0.0069	0.0151	0.0177	0.0168	0.0382	0.0181	-	-	0.0411	0.0295
Argentine (SG)	0.0111	0.0471	0.0078	0.0171	0.0187	0.0166	0.0247	0.0187	0.0239	0.0366	0.0314	0.0325
Argentine (LG)	0.0121	0.0392	0.0069	0.0151	0.0177	0.0168	0.0382	0.0181	0.0239	0.0427	0.0411	0.0295
Haddock (SG)	0.0111	0.0471	0.0078	0.0171	0.0187	0.0166	0.0247	0.0187	0.0239	0.0366	0.0314	0.0325
Haddock (LG)	0.0121	0.0392	0.0069	0.0151	0.0177	0.0168	0.0382	0.0181	0.0263	0.0427	0.0411	0.0295
Hake (SG)	0.0111	0.0471	0.0078	0.0171	0.0187	0.0166	0.0247	0.0187	0.0239	0.0366	-	0.0325
Hake (LG)	0.0121	0.0392	0.0069	0.0151	0.0177	0.0168	0.0382	0.0181	0.0263	0.0427	0.0411	0.0295
Whiting (SG)	0.0111	0.0471	0.0078	0.0171	0.0187	0.0166	0.0247	0.0187	-	0.0366	0.0314	0.0325
Whiting (LG)	0.0121	0.0392	0.0069	0.0151	0.0177	0.0168	0.0382	0.0181	-	0.0427	0.0411	0.0295

equal, then $CR(l, \nu) = 1.0$. $CR(l, \nu) = 1.5$ would mean that the large grid trawl is catching 50% more of the species with length l than the standard grid trawl. By contrast, a $CR(l, \nu)$ of 0.8 would mean that the large grid trawl is only catching 80% of the species with length l caught by the standard grid trawl.

To provide significant differences in catch efficiency between the trawls, we estimated confidence intervals (CIs) for $CC(l, \nu)$ and $CR(l, \nu)$ using a double bootstrapping method (Herrmann et al., 2017). This double bootstrapping method accounts for between-haul variability (the uncertainty in the estimation resulting from between-haul variation of catch efficiency in the trawls) as well as within-haul variability (the uncertainty about the size structure of the catch for the individual hauls, including the effect of subsampling). However, contrary to the double bootstrapping method (Herrmann et al., 2017), the outer bootstrapping loop in the current study accounting for the between-haul variation was performed paired for the large grid and standard grid trawl, taking full advantage of the experimental design with the trawls being fished in a twin-trawl setup (in parallel). By multimodel inference in each bootstrap iteration, the method also accounted for the uncertainty resulting from uncertainty in model selection. We performed 1000 bootstrap repetitions and calculated the Efron 95% (Efron 1982) confidence intervals. To identify sizes of species with significant differences in catch efficiency, we checked for length classes in which the 95% CIs for the catch ratio curve did not include 1.0. Finally, a length-integrated average value for the catch ratio was estimated directly from the experimental catch data using Equation (5):

$$CR_{average} = \frac{\sum_l \sum_{j=1}^m \left\{ \frac{n_{lj}}{q_j} \right\}}{\sum_l \sum_{j=1}^m \left\{ \frac{nc_{lj}}{qc_j} \right\}} \quad (5)$$

where the outer summation \sum_l covers the length classes in the catch during the experimental fishing period.

2.4. Species dominance

Catch dominance curves are often used to quantify information about the pattern of relative species abundances for a given sample. Here, we use catch dominance curves based on weight to quantify the dominance of the individual species in the catch. Generally, dominance curves are based on ranking of species in a sample in decreasing order of their abundance (Clarke, 1990). This implies that the species ranking could vary among stations, making it difficult to compare dominance curves among different gears. Therefore, we kept the species ranking fixed according to the species ID (Table 1).

We then estimated the catch dominance curve for each net configuration using Equation (6) (Warwick et al., 2008):

$$d_{ij} = \frac{q_{ij} \times n_{ij} \times w_{ij}}{\sum_{i=1}^K \{q_{ij} \times n_{ij} \times w_{ij}\}} \quad (6)$$

where j represents the haul and i is the species index (species rank) that was predefined. n_{ij} is the number of individuals of the species i being counted in the subsample in haul j . w_{ij} is the weight of the counted subsample of species i in haul j , whereas q_{ij} is the fraction of species i in the catch being counted in haul j . K is the total number of species considered.

To better represent species dominance patterns, we also estimated the cumulative dominance curves using Equation (7):

$$D_{ij} = \frac{\sum_{i=1}^I \{q_{ij} \times n_{ij} \times w_{ij}\}}{\sum_{i=1}^K \{q_{ij} \times n_{ij} \times w_{ij}\}} \quad \text{with } 1 \leq I \leq K \quad (7)$$

where I is the species index summed up to in the nominator.

The 95% CIs for the dominance patterns were estimated by using Equations (6) and (7) inside each of the bootstrap iterations applied to estimate the uncertainties for the catch comparison and catch ratio

curves.

3. Results

Twelve valid hauls were conducted during the cruise. The towing time varied between 4 and 10 h, with catch weights ranging from 8 to 53 tons per codend (Table 1). The towing speed was between 3.0 and 3.5 knots. The subsampling factors are presented in Table 1, whereas the number of fish measured and the total number of fish caught are presented in Table 2.

For all species, the estimated p -value was <0.05 (Table 2). However, the modeled catch comparison curve followed the main trend in the experimental data for all species (Fig. 3). Therefore, it was assumed that the low p -values obtained were a consequence of overdispersion in the experimental data that resulted from working with pooled and subsampled data with low sampling rates (Table 1). Such cases have previously led to low p -values and high dispersion (Brčić et al., 2015; Alzorric et al., 2016; Notti et al., 2016).

The size distribution curves for Norway pout (Fig. 2) show that the trawls with the two different grids caught nearly identical length classes. Furthermore, the catch comparison and catch ratio curves for Norway pout with the 95% CIs overlap the dashed horizontal line, which means that the two grids fished equally and that there was no significant difference in catch efficiency between them (Fig. 3).

Blue whiting, horse mackerel, and greater argentine are all wanted by-catch species. The size distribution curves show that the two grids had similar catch patterns, except for blue whiting, which the standard grid caught more of the smallest length classes (Fig. 4). The catch comparison curves and the catch ratio curves did not show any significant differences in the catch efficiency for these three species (Fig. 4).

Haddock, whiting, hake, and mackerel are all regarded as unwanted by-catch species. The large grid caught significant more individuals of all those species, except mackerel (Fig. 5). The catch ratio and catch comparison curves show that the large grid caught significantly more whiting between 5.6 and 28.5 cm and 39.5 and 50.5 cm in length, and hake between 33.5 and 41.5 cm (Fig. 5). In addition, the large grid caught significantly more haddock, even though the significance was less than for the two other species and for fewer length classes (between 20.5 and 26.5 cm of length) (Fig. 5).

Fig. 6 shows the accumulated catch contribution for each species caught summarized for all hauls. It includes all species presented in Figs. 3–5 and in addition herring, which was not caught in large enough numbers to conduct a length-dependent analysis. Catches with the standard grid contained nearly equal amounts of target species (Norway pout), wanted by-catch species (blue whiting, horse mackerel, and greater argentine), and unwanted by-catch species (haddock, whiting, hake, herring, and mackerel) compared with the catches caught in the trawl with the large grid (Fig. 6, Table 3). However, when looking at the percentages caught of each species, mackerel constituted most of the unwanted by-catch species, 24.63% (CI: 9.77–38.07) for the standard grid and 23.59% (CI: 8.54–43.82) for the large grid (Table 4). Of the gadoid species, haddock was caught most, but only constituted 4.64% (CI: 2.09–8.79) with the standard grid and 5.62% (CI: 2.63–11.12) with the large grid of the total catch (Table 4).

4. Discussion

Decades of research on selectivity in trawls has led to significant reductions in unwanted by-catch species and sizes in many fisheries (Kennelly and Broadhurst, 2021). However, in several trawl fisheries targeting small-sized species, unwanted by-catch of juveniles, which often are of the same size as the target species, is a persisting issue (Larsen et al., 2018; Eigaard et al., 2021). The fishery for Norway pout is one such fishery (Eigaard et al., 2012). With a minimum mesh size of 16 mm in the codend and a mandatory sorting grid with 40 mm-bar spacing, the catches can still contain large quantities of by-catch. Even

Table 2

Fit statistics showing the *p*-value, deviance, degrees of freedom (DOF), and number of fish length measured as well as the total number of fish caught for each species in the standard grid and the large grid.

Species	<i>P</i> -value	Deviance	DOF	Fish measured		Total number of fish	
				Standard grid	Large grid	Standard grid	Large grid
Norway pout	<0.0000	76.22	8	5334	5091	2 725 407	2 818 006
Blue whiting	<0.0000	291.99	26	3676	3747	846 544	733 258
Horse mackerel	0.0029	21.68	7	1663	1687	93 918	95 467
Argentine	0.0244	21.99	11	934	989	37 716	39 657
Haddock	<0.0000	103.87	24	1153	1380	41 198	58 928
Whiting	<0.0000	118.9	19	144	244	7 502	13 035
Hake	<0.0000	56.78	10	19	50	1 104	5 312
Mackerel	0.0001	40.62	13	1950	1806	176 334	191 257

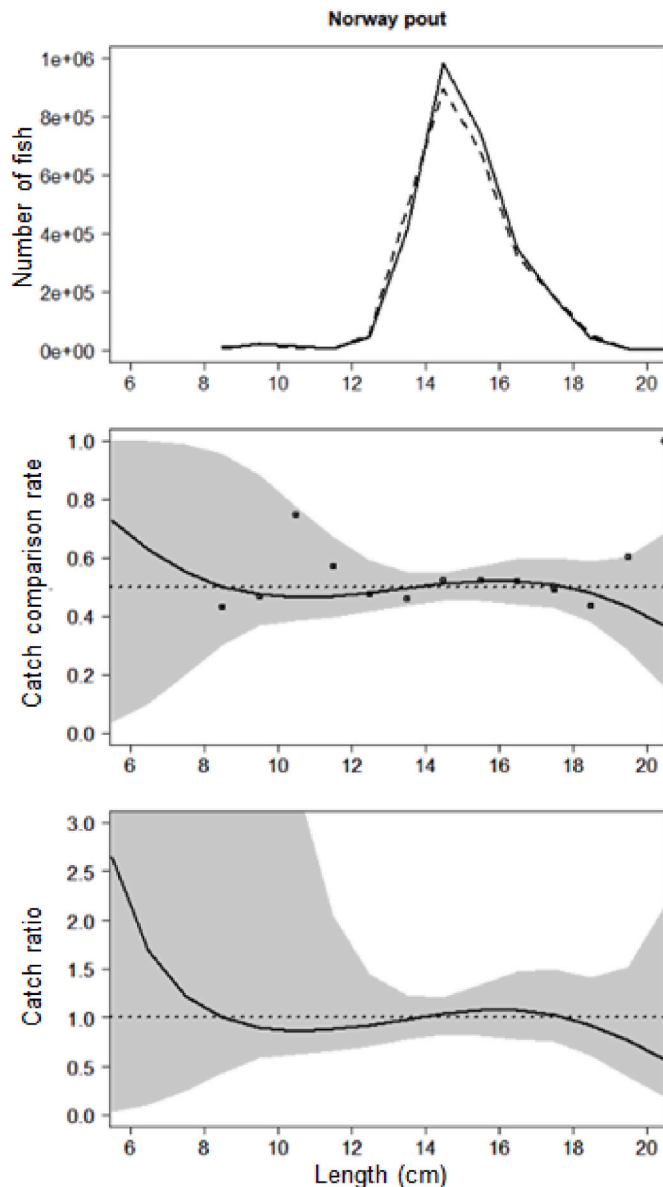


Fig. 3. Upper: Size distribution of Norway pout caught in the trawl with the large grid (solid line), and standard grid (dashed line). Middle: Catch comparison rate. Lower: Catch ratio curve. The black dots denote the experimental data point, and the gray areas denote the 95% confidence intervals. The dashed horizontal lines represent the level where the two designs caught equally.

though the introduction of the sorting grid in both the Norwegian and EU fishery has significantly reduced the catches of large gadoids, small gadoids and other unwanted by-catch species can still be caught in large quantities (Eigaard et al., 2012; ICES, 2017). Given that the catches may contain a maximum of 20% haddock, cod whiting, or hake, 10% herring, and 0.5% monkfish, large quantities of by-catch can be a problem and can be regarded as choke species.

In addition, multiple studies have reported the loss of target species when applying grids (Eigaard and Holst 2004; Eigaard et al., 2012, 2021). Given that the catch rates per towing hour can be high, a possible cause of the loss of target species could be saturation and clogging of the grid, as experienced in other fisheries (Sistiaga et al., 2016). Therefore, a possible solution could be to increase the surface area of the grid. However, as the current study demonstrates, increasing the surface area of the grid with 50% had no significant effect on the size selectivity of Norway pout or on the wanted by-catch species (blue whiting, horse mackerel, and greater argentine). However, the larger grid caught significantly more of the unwanted by-catch species (haddock, whiting, and hake). Of the unwanted by-catch species, only the catch efficiency of mackerel was not significantly different between the two grids. A possible explanation for this increased retention of these gadoids species could be the increased surface area of the grid, which increases the probability of fish contacting the grid and, therefore, being retained (Sistiaga et al., 2010, 2016; Larsen et al., 2019).

A possible option to reduce the retention of unwanted by-catch species in reducing the bar spacing in the grid. The bar spacing (40 mm in Norwegian EEZ and 35 mm in EU EEZ) allows the passage of relatively large fish compared with the size of Norway pout. Reducing the bar spacing would likely reduce the by-catch more than would increasing the surface area of the grid; however, this could also negatively impact the retention of the target species as well as wanted by-catch species. The reduction of by-catch species and the loss of target species as a consequence of reducing the bar spacing in the Norway pout fishery have both been documented previously. Eigaard and Holst (2004) tested a grid with 24 mm bar spacing in combination with a square mesh panel and reported a reduction not only in haddock (37%) and (57%), but also in target species (7%). Although significant by-catch reduction was achieved in the current study, it was not possible to determine whether the 22 mm grid or the square mesh panel was responsible for the reduction of the by-catch species. Kvalsvik et al. (2006) tested three different bar spacings, 19 mm, 22 mm, and 25 mm. They reported 94.6% and 62.4% reductions in gadoids in two different trials, although the loss of target species (Norway pout and blue whiting) was 32.8% and 22%, respectively (Kvalsvik et al., 2006). In general, the smaller the bar spacing, the larger the reduction in not only unwanted by-catch species, but also target species. Other possible solutions to reduce the by-catch of unwanted species is improved information during fishing. This can possibly be achieved using cameras monitoring the fish entering the trawl (Rosen et al., 2013), or using near-real time maps showing the abundance of the target and by-catch species (Reid et al., 2019). The latter would enable the skipper to trawl in areas where the abundance of the target species is high, while the abundance of by-catch

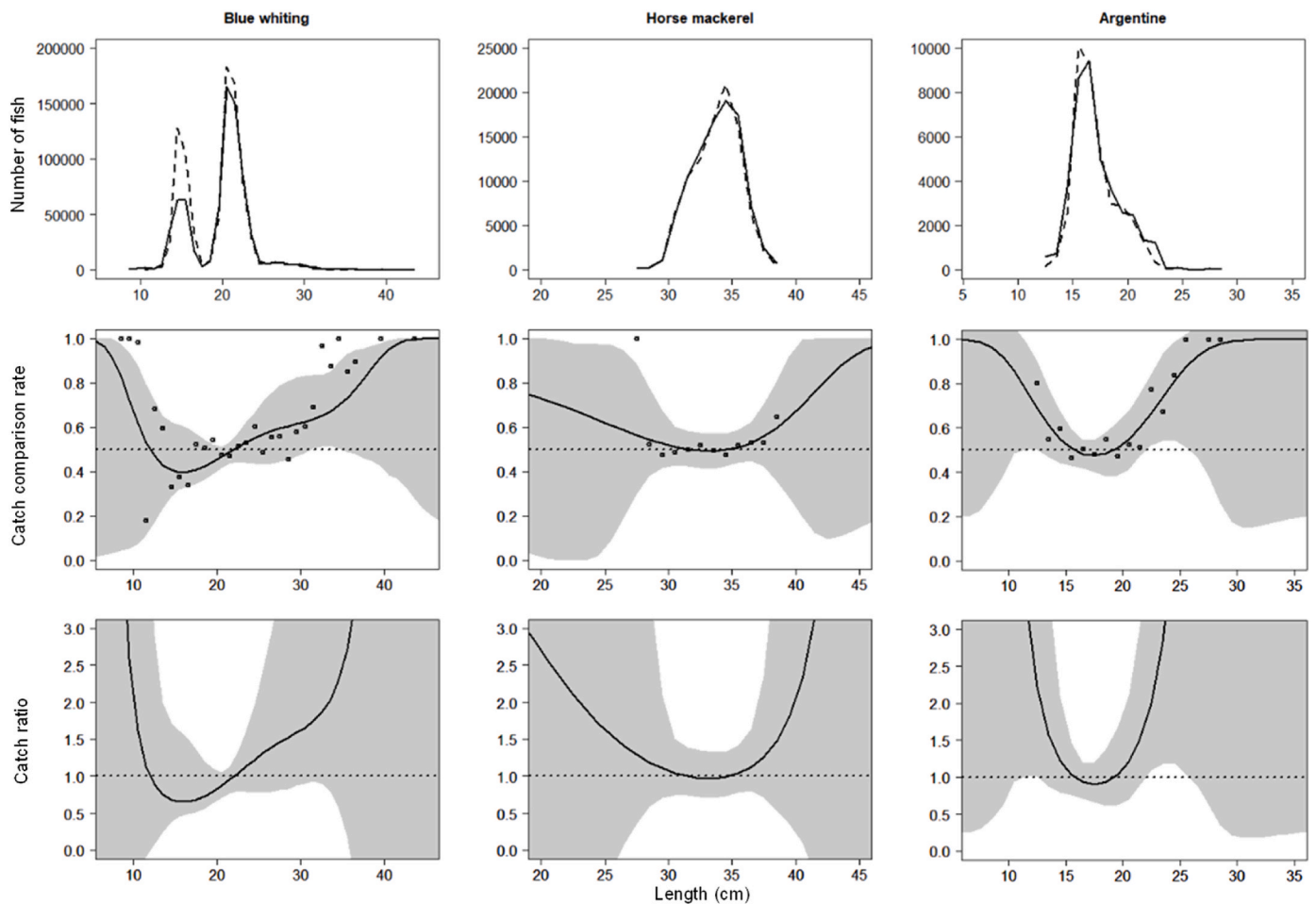


Fig. 4. **Upper:** Size distribution of wanted-by-catch species caught in the trawl with the large grid (solid line), and standard grid (dashed line). **Middle:** Catch comparison rate. **Lower:** Catch ratio curve. The black dots denote the experimental data point, and the gray areas denote the 95% confidence intervals. The dashed horizontal lines represent the level where the two designs caught equally.

species is low, and in this way improve the catch efficiency of the target species, reducing the catches of by-catch species, with a positive side effect of also reducing the time trawled, and thus reducing seabed impact, and fuel consumption.

As this study demonstrates, only approximately one-third (ca. 33%) of the catch constituted of the target species, whereas the remaining two-thirds contained wanted (ca. 33%) and unwanted (ca. 33%) by-catch species (Fig. 6, Table 3). Even though Norway pout is the target species, most of the vessels have quotas for other species, such as blue whiting and greater argentine, which can be caught simultaneously. Horse mackerel is a nonquota species and, therefore, also a wanted by-catch species. Other species, such as cod, haddock, whiting, and hake, are strictly regulated with maximum by-catch limits (as outlined above) and, therefore, are regarded as choke species (ICES, 2017). In the current study, a major part of the unwanted by-catch was mackerel, and gadoids and herring only constituted a minor part of the total catch (Table 4). Therefore, none of the by-catch limits according to the legislation were violated. Mackerel is an unwanted by-catch species in this stance because, even though many vessels have a quota for mackerel, the vessels aim to target mackerel separately because the price is much higher when delivered for human consumption. Nevertheless, in many cases, the by-catch of unwanted species, especially gadoids, can be significant and has negative consequences for the spawning stock biomass (Eigaard and Holst, 2004). This confirms the need to seek additional solutions that will significantly reduce the retention of unwanted by-catch species in this fishery.

Multiple studies have tested and demonstrated various types of

sorting grid in the Norway pout fishery, including the use of different materials, inclination angles, orientations, and bar spacings (Eigaard and Holst 2004; Kvalsvik et al., 2006; Eigaard et al., 2012; ICES, 2017). Common for all these studies, including the current study, is that the reduction in by-catch is significant but not sufficient, or the loss of target species is too high. Achieving optimal selectivity in this fishery by applying large grids is difficult, if not impossible. The even larger grid tested in this study only resulted in increased retention of gadoids. The reason for this increase is unclear, and we don't know whether it's caused by behavioral, morphological, a possible change in water flow. Eigaard et al. (2021) tested a system termed 'Excluder' in comparison with a grid with 35 mm bar spacing in the Norway pout fishery. The excluder, which is a netting-based 30 m-long 'tube' inside the trawl with a 70 mm mesh size, reduced the retention of herring to (21%), whiting (6%), mackerel (5%), American plaice (*Hippoglossoides platessoides*) (70%), witch flounder (*Glyptocephalus cynoglossus*) (15%), and lesser silver smelt (*Argentina sphyraena*) (71%), and increased the retention of Norway pout by 32%, compared to the standard grid (Eigaard et al., 2021). The increased retention of target species was possibly because the sorting area was 15 times larger than the standard grid (Eigaard et al., 2021). These promising results should be further tested, possibly reducing the mesh size even more to reduce the retention of unwanted by-catch species.

Declaration of competing interest

The authors declare that they have no known competing financial

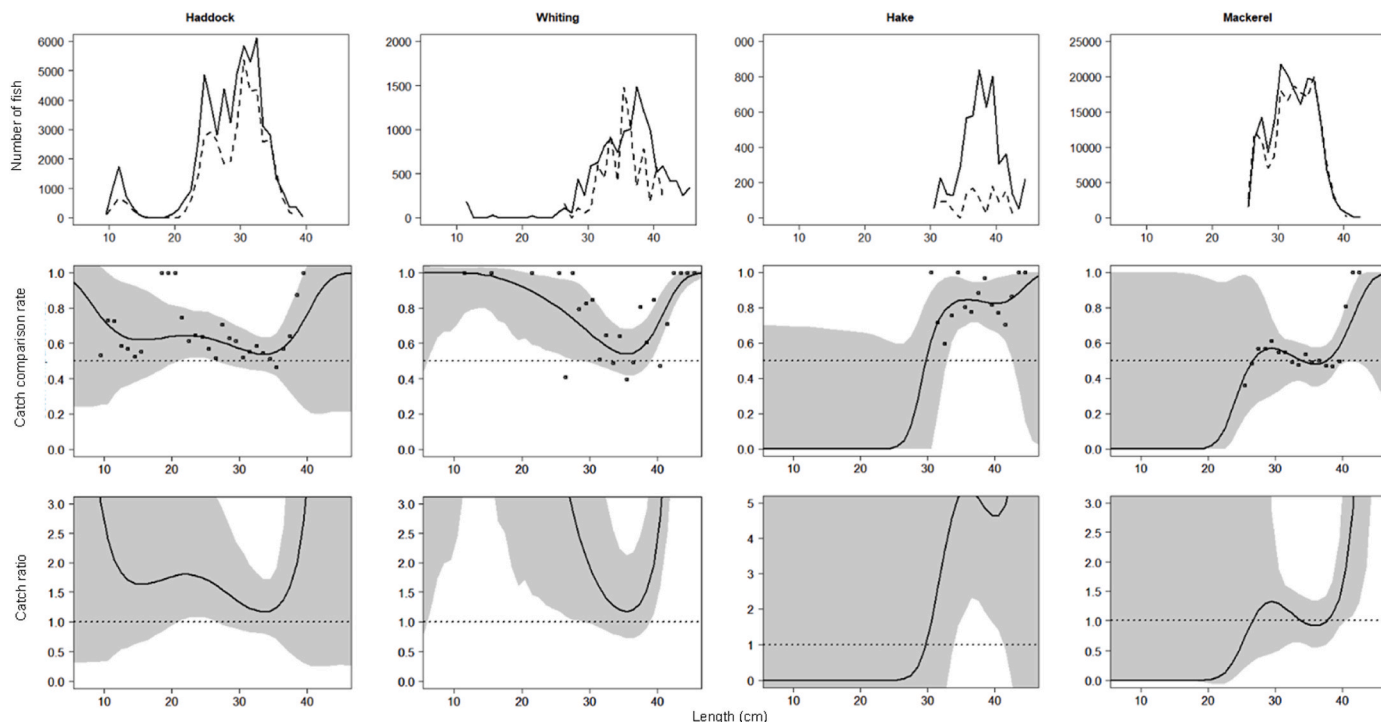


Fig. 5. Upper: Size distribution of wanted by-catch species caught in the trawl with the large grid (solid line), and standard grid (dashed line). Middle: Catch comparison rate. Lower: Catch ratio curve. The black dots denote the experimental data point, and the gray areas denote the 95% confidence intervals. The dashed horizontal lines represent the level where the two designs caught equally.

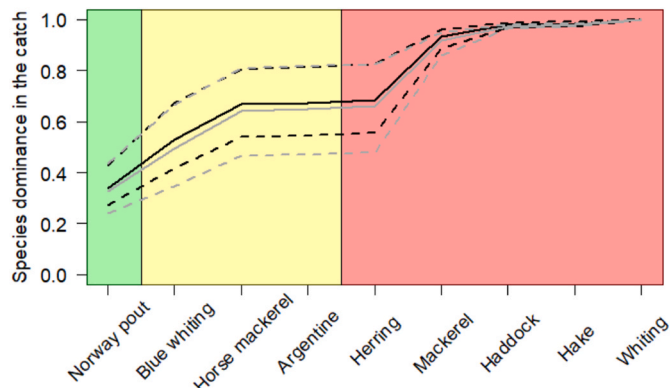


Fig. 6. Species dominance in the catch. The curves (solid lines) with 95% confidence intervals (dotted lines) represent the cumulative species dominance for the catches caught with the standard (black), and the large grid (gray). The green, yellow, and red areas represent the target species, wanted by-catch species, and unwanted by-catch species, respectively.

Table 3

Catch composition, based on all hauls, divided into target species (Norway pout), wanted by-catch species (blue whiting, horse mackerel, and greater argentine), and unwanted by-catch species (haddock, whiting, hake, herring and mackerel) (95% confidence intervals in brackets).

	Target species	Wanted by-catch species	Unwanted by-catch species
Standard grid	34.0 (27.4–42.8)	34.6 (28.2–39.6)	31.4 (44.5–17.6)
Large grid	32.3 (24.1–43.7)	33.3 (23.8–38.9)	33.9 (52.1–17.4)

Table 4

Catch percentage for each for the species caught summed for all hauls (95% confidence intervals in brackets).

Species	Standard grid	Large grid
Norway pout	33.99 (27.37–42.28)	32.74 (24.09–43.71)
Blue whiting	19.00 (10.16–31.11)	16.75 (8.11–27.14)
Horse mackerel	13.78 (8.39–21.09)	14.85 (8.48–23.42)
Argentine	0.55 (0.35–0.86)	0.58 (0.37–0.98)
Herring	1.32 (0.42–2.90)	1.16 (0.43–2.36)
Mackerel	24.63 (9.77–38.07)	23.59 (8.54–43.82)
Haddock	4.64 (2.09–8.79)	5.62 (2.63–11.12)
Hake	0.40 (0.19–0.62)	0.66 (0.35–1.05)
Whiting	1.68 (0.89–2.65)	2.05 (1.40–2.75)

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Vedlegg 2

Estuarine, Coastal and Shelf Science

Improved bycatch reduction in the mixed demersal trawl fishery for Norway pout (*Trisopterus esmarkii*) --Manuscript Draft--

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Abstract:	<p>In this study, we compared the bycatch reduction capacity of a trawl fitted with a standard rigid sorting grid with that of a trawl fitted with a newly developed, flexible system called the Excluder. We conducted the fishing trials in the Norway pout (<i>Trisopterus esmarkii</i>) small-meshed trawl fishery in the North Sea. Catch data were analysed by species and length using the catch comparison and catch ratio method. The Excluder significantly reduced the bycatch (in weight) relative to the standard grid for blue whiting (<i>Micromesistius poutassou</i>) (-35.6%), mackerel (<i>Scomber scombrus</i>) (-93.3%), horse mackerel (<i>Trachurus trachurus</i>) (-99.3%), herring (<i>Clupea harengus</i>) (-89.9%), haddock (<i>Melanogrammus aeglefinus</i>), (-98.6%), whiting (<i>Merlangius merlangus</i>) (-99.3%), cod (<i>Gadus morhua</i>) (-97.1%), European hake (<i>Merluccius merluccius</i>) (-98.0%), and greater argentine (<i>Argentina sphyraena</i>) (-24.5 %). For Norway pout there was a marginal decrease in the overall catch efficiency of -1.4%. The observed bycatch reduction efficiency is explained by the larger sorting area of the Excluder relative to the grid's area and by the differences in behaviour between Norway pout and the bycatch species. While it contributes to reduce bycatch of quota regulated species, the Excluder also can potentially affect the profitability of the fishery.</p>

Improved bycatch reduction in the mixed demersal trawl fishery for Norway pout (*Trisopterus esmarkii*)

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Abstract

In this study, we compared the bycatch reduction capacity of a trawl fitted with a standard rigid sorting grid with that of a trawl fitted with a newly developed, flexible system called the Excluder. We conducted the fishing trials in the Norway pout (*Trisopterus esmarkii*) small-meshed trawl fishery in the North Sea. Catch data were analysed by species and length using the catch comparison and catch ratio method. The Excluder significantly reduced the bycatch (in weight) relative to the standard grid for blue whiting (*Micromesistius poutassou*) (−35.6%), mackerel (*Scomber scombrus*) (−93.3%), horse mackerel (*Trachurus trachurus*) (−99.3%), herring (*Clupea harengus*) (−89.9%), haddock (*Melanogrammus aeglefinus*), (−98.6%), whiting (*Merlangius merlangus*) (−99.3%), cod (*Gadus morhua*) (−97.1%), European hake (*Merluccius merluccius*) (−98.0%), and greater argentine (*Argentina sphyraena*) (−24.5 %). For Norway pout there was a marginal decrease in the overall catch efficiency of −1.4%. The observed bycatch reduction efficiency is explained by the larger sorting area of the Excluder relative to the grid's area and by the differences in behaviour between Norway pout and the bycatch species. While it contributes to reduce bycatch of quota regulated species, the Excluder also can potentially affect the profitability of the fishery.

Keywords: Norway pout fishery, Catch efficiency, Bycatch reduction, Sorting grid, Excluder

41 1. Introduction

42

43 1.1 The resource

44 Norway pout (*Trisopterus esmarkii*) is a small, short-lived fish species in the Gadidae family that lives at
45 depths ranging from 50 to 250 m (Raitt, 1968; Sparholt et al., 2002; Lambert et al., 2009). This species is
46 widely distributed in eastern parts of the North Atlantic, but is most common in northern parts of the North
47 Sea in the area east of Shetland (Fladen Ground) and along the western edge of the Norwegian Trench.
48 Norway pout live in scattered aggregations along the seabed, usually over muddy bottom substrate.
49 Recruitment is highly variable and strongly influences both the spawning stock and total biomass.
50 Norwegian and Danish fishing fleets are responsible for most of the landings of this species, with only
51 occasional landings by Sweden, the Netherlands, Germany, or the UK.

52

53 1.2 The Norway pout fishery

54 The Norway pout fishery is a multispecies demersal fishery with both wanted and unwanted bycatch
55 species. The Norwegian and Danish fishing fleet are responsible for most of the Norway pout landings and
56 associated bycatch species, with only occasional landings by the fleet of Sweden, Netherlands, Germany,
57 and the UK. The fleet is composed by licenced industrial vessels, some of them specialized pelagic trawlers
58 and others are combination vessels (purse seine/pelagic trawling). The fishery is carried out by licensed
59 industrial trawlers, which target blue whiting (*Micromesistius poutassou*) and Norway pout, often during the
60 same trip. The license system is complex, with different vessels have different quotas for different species,
61 and some vessels being allowed to process by catch of white fish for human consumption. Some vessels,
62 if they hold a quota, can take out the bycatch of large fish such as saithe (*Pollachius virens*), European
63 hake (*Merluccius merluccius*), and monkfish (*Lophius piscatorius*), from the catch and deliver it for human
64 consumption. The fishing strategies also differ among vessels. Some vessels take most of their blue whiting
65 quota west of Ireland, whereas others save their quota in order to carry out a mixed blue whiting-Norway
66 pout fishery in the North Sea. Norway pout is caught in small-meshed demersal trawls (16–31 mm) in a
67 mixed fishery and is landed for reduction purposes (fish meal and fish oil). The landings peaked in 1974 at
68 740,000 metric tonnes and then decreased significantly after extensive regulations were imposed, including
69 closure of a large area of Fladen, east of Shetland, and bycatch limits. During the 1990s, annual landings
70 of Norway pout fluctuated around an average of 150,000 metric tonnes. In recent years, landings have
71 varied greatly due to recruitment and periodic closure of the directed fishery. In 2020, the catch was 129,497
72 metric tonnes, of which 65,607 and 63,777 metrics tonnes were caught by Denmark and Norway,
73 respectively (ICES, 2021).

74

75 Norway pout is a major prey species for many larger and commercially important predator species in the
76 North Sea, and therefore, the fishery is characterized by relatively large bycatch levels. White fish species,
77 such as cod (*Gadus morhua*), whiting (*Merlangius merlangus*), saithe, haddock (*Melanogrammus*
78 *aeglefinus*), European hake, and monkfish, and pelagic species such as mackerel (*Scomber scombrus*)
79 and herring (*Clupea harengus*) are considered to be unwanted bycatch species in the fishery. In contrast,
80 blue whiting, greater argentine (*Argentina sphyraena*), and horse mackerel (*Trachurus trachurus*) are
81 considered to be wanted bycatch species (Sparholt et al., 2002; Lambert et al., 2009; Cormon et al., 2016;

82 Nielsen et al., 2016, Eigaard, et al., 2012). The bycatch levels of these species have decreased in the
83 Norway pout fishery over the years due to management measures that have been enforced in the fishery
84 (ICES, 2016). Current reported levels of the 10 most common bycatch species caught in the Norway pout
85 fishery by Norwegian vessels in 2020 is as follows: Blue whiting (6,967 metric tonnes), Horse mackerel
86 (2,491 metric tonnes), Silver smelt *Argentina sphyraena* (1,879 metric tonnes), saithe (1,474 metric tonnes),
87 herring (1,341 metric tonnes), sand eel *Ammodytes marinus* (429 metric tonnes), silver cod *Gadiculus thori*
88 (282 metric tonnes), whiting (253 metric tonnes), haddock (115 metric tonnes) (Lassen and Chaudhury,
89 2021).

90 Because Norway pout is only used for reduction purposes, the profitability of the fishery is low, and this is
91 one of the reasons why the quotas are seldom fished. Profitability is improved by increasing the catch rates
92 of legally accepted bycatch species (i.e., horse mackerel, blue whiting, and greater argentine). In 2012, it
93 became mandatory to use a sorting grid with 40 mm bar spacing in the Norwegian Exclusive Economic
94 Zone (EEZ) and 35 mm bar spacing in the European Union EEZ. Sorting grids are efficient for reducing
95 bycatch of gadoids above minimum landing size, but grids fail at removing bycatch of small fish. Unwanted
96 bycatch species (mackerel, herring, cod, haddock, saithe, whiting, European hake, and monkfish) reduce
97 profitability if they are used for reduction rather than sold for human consumption. Because there are
98 exceptions to the requirement to use sorting grids in the Norway pout fishery in the Norwegian EEZ, is it
99 easier to control the landings of catches taken in EU waters. Due to different sets of regulations in the
100 Norwegian EEZ and the EU zone, a requirement was introduced in 2017 that prevents fishing of Norway
101 pout in both zones during the same trip (Norwegian Directorate of Fisheries, 2021).

102

103

104 **1.3 The management system and regulations for the Norwegian fleet**

105 Although Norway pout is a joint stock between the EU and Norway, it is not jointly managed. However, the
106 Parties agree in wishing for joint management of the Norway pout stock. The strategy is for both Parties to
107 achieve maximum sustainable yield fisheries, and to do so they base their regulations on advice from ICES,
108 which is based on the ICES advisory scheme for short-lived species (see for example ICES advice, 2021).
109 The EU also obtains advice from the Scientific, Technical and Economic Committee for Fisheries. The total
110 allowable catches (TAC) are set autonomously after annual consultations under the EU-Norway fisheries
111 agreement.

112

113 Many of the regulations for Norwegian industrial trawling in the North Sea (targeting Norway pout and blue
114 whiting) are in place to reduce the large bycatch problems. Explicit management objectives for Norway pout
115 have not been defined, but the EU and Norway have implemented a precautionary approach to ensure
116 sustainable fisheries. It is also recognized that it is important to ensure that the stock remains at a sufficiently
117 high level to provide food for a variety of predator species. In recent years, however, quotas have been set
118 to ensure that on January 1, after the fishing year ends, the remaining spawning stock should be greater
119 than 150,000 metric tonnes (ICES, 2021). In 2021, the stock was in good condition, the spawning stock
120 was considered to be large, and recruitment had been good for three years in a row (ICES, 2021). Current
121 regulations for the Norwegian industrial trawling in the North Sea targeting Norway pout are as follows: i)
122 area closures. Implemented in 2003 and still valid is the closure of the Egersund bank in the period between

123 01 November – 21 May. The Patch bank has remained closed since 2002. ii) seasonal closures, in which
124 the industrial fishery in the Norwegian EEZ in the North Sea is only open from 1 April to 31 October (ICES,
125 2016); iii) minimum mesh size codend regulations for the fishery (i.e., 16 mm mesh opening) and
126 compulsory use of a sorting grid (with some exceptions); iv) bycatch regulations to protect other fish
127 species: the maximum bycatch of cod, haddock, and saithe in industrial trawling in the North Sea is 20% in
128 weight by haul and by landing; the bycatch of herring is a maximum of 10%, and any bycatch of herring is
129 taken from the vessel's quota; the bycatch of greater argentine is a maximum of 10%; maximum bycatch
130 of monkfish is 0.5%, and landing of monkfish by trip should not exceed 500 kg (ICES, 2016, Lovdata 2021);
131 and v) a rigid sorting grid with a maximum 40 mm bar spacing has been mandatory in the Norwegian fishery
132 since 2010, and in the Danish fishery a grid with a maximum of 35 mm has been mandatory since 2012
133 (ICES, 2016). The introduction of the sorting grid in the Norwegian and Danish fishery has led to gadoid
134 bycatch reductions of between 80.9 and 100%, but it remains difficult to avoid small gadoids (Eigaard et
135 al., 2012; 2021). Simultaneously, grid systems lead to a 5–10% reduction in the catch of target species and
136 to a reduction of herring bycatch (ICES, 2016). In the Norwegian fishery, sorting grids have influenced
137 bycatch rates, but some vessels do not always use the grid because it is not mandatory in some parts of
138 the fishery (e.g., for those with quotas to catch and process saithe on board) (ICES, 2016).

139
140 To date, there is still great uncertainty about whether the catch registration is correct when receiving fish
141 for reduction purposes. Consequently, the reported levels of bycatch of TAC regulated species such as
142 much mackerel, herring, haddock, cod, whiting, is not accurate and expected to be larger than those
143 reported. The Norwegian Directorate of Fisheries has tried to solve this problem through increasing the
144 sampling effort of the catches at the landing stations, and by using the catch composition reported by the
145 vessels. However, as sampling coverage is not 100%, it has not succeeded in quantifying the bycatch that
146 goes unregistered (Norwegian Directorate of Fisheries, 2021).

147
148 The goal of the present study was to compare bycatch reduction capacity of two bycatch reduction devices
149 in the small-mesh mixed Norway pout-blue whiting trawl fishery in the Norwegian EEZ in the North Sea.
150 We compared a rigid sorting grid section and a flexible Excluder section. We discuss the results in terms
151 of existing management bycatch rules for the Norwegian fleet.

152

153 **2. Materials and methods**

154

155 **2.1 Fishing vessel, fishing grounds, and gear**

156 We conducted the experiment on board the 53 m long pelagic trawler "Fiskebank" from 1 to 10 October
157 2021, in the Norway pout fishing grounds in the northern part of the North Sea, along the Norwegian trench.
158 We used two identical Egersund 1500 meshes Expo trawls mounted with 100 m bridles and 30 m sweeps
159 in a twin trawl setup. The sweeps were connected to two 11 m² Thyborøn type 22 pelagic doors that
160 weighed 3.0 tons each and to a 5.5-ton roller-clump between the two trawls. The standard sorting grid
161 section (control) was mounted in one of the trawls and the Excluder section (treatment) in the other. The
162 two identical codends were attached to the trawls. They were 50 m long, were made of 24 mm nominal

163 diamond full meshes in nylon, and had a circumference of 1000 meshes. The mean mesh opening of the
164 Excluder codend and the grid codend was 24.1 mm (SD = 1.2, N = 50) and 24.1mm (SD = 1.4, N = 50),
165 respectively. The mesh measurements were done with a calliper, on wet meshes, and right after the last
166 haul. During fishing, the towing speed was kept between 2.9 and 3.3 knots. The geometry and performance
167 of the trawls was continuously monitored using trawl door spread, roll and pitch, and codend catch sensors
168 purchased from Scanmar (Scanmar AS, Åsgårdstrand, Norway). The Excluder and grid sections were
169 switched to opposite sides once during the cruise so that they both were fished at both port and starboard
170 sides.

171

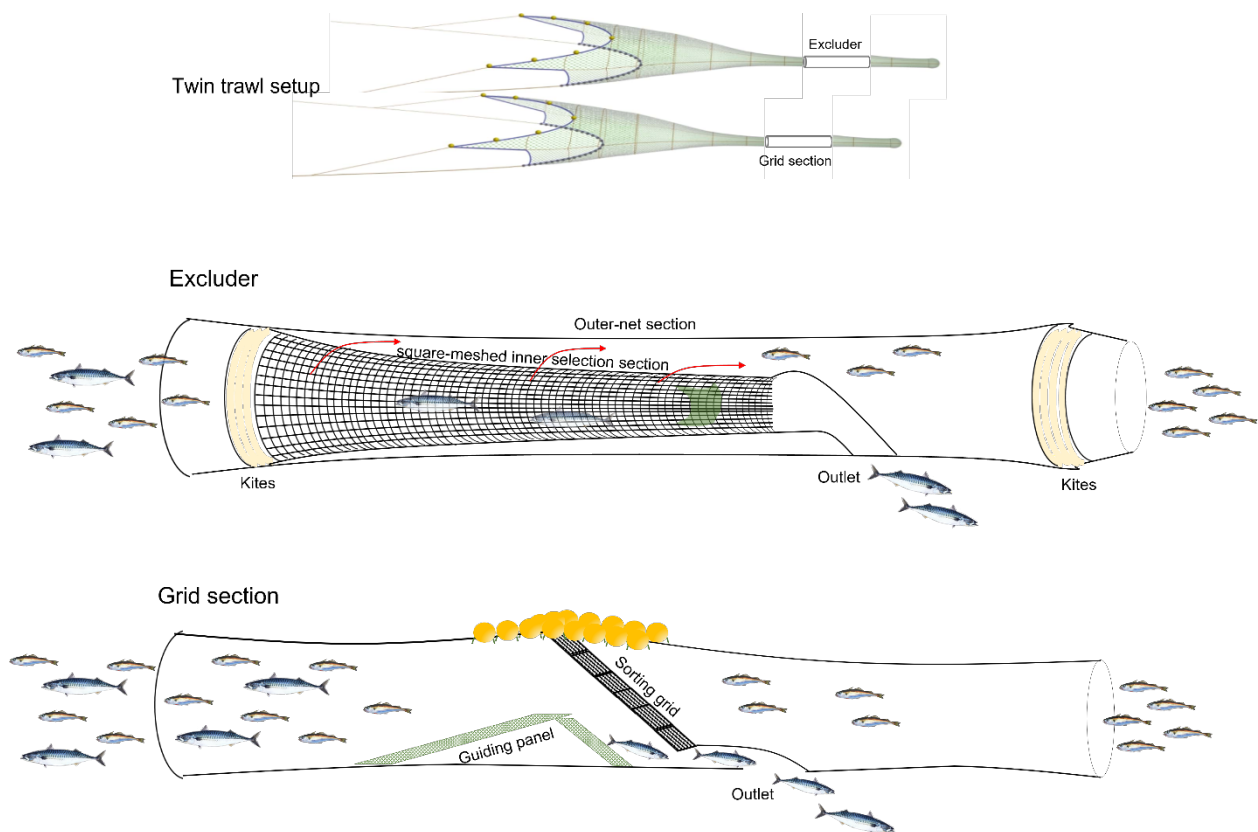
172 **2.2 Bycatch reduction devices**

173 The Excluder is a flexible net section that is inserted as an extension piece of the trawl. It consisted of a 30
174 m long outer net part and an 11 m square-meshed inner selection section. The outer net part of the Excluder
175 was made of diamond meshes with a mean mesh opening of 31.4 mm (SD = 0.6, N = 50). The square-
176 meshed inner selection section was cone-shaped and ended in an outlet in a bottom panel of the 30 m
177 extension piece, just before the codend. The square-meshed inner selection section of the Excluder was
178 made from 6 mm twine thickness knotless netting with a mean full mesh opening of 71.6 mm (SD = 0.8
179 mm, N = 50) (bar length of approx. 35.6 mm). The nominal mesh size of 70 mm for the square-meshed
180 inner selection section was chosen based on Eigaard et al (2021) fall-through experiment of Norway pout,
181 whiting, herring, and haddock. To reach the codend, fish must pass through the square meshes of the inner
182 net selective section and continue along to the codend (Fig. 1). The entrance and exit diameter of the outer
183 net part of the Excluder was kept opened by two cylindrical kites made from heavy PVC cloths. At the end
184 of the 11 m square-meshed inner selection section, a square PVC kite (0.6 x 0.6m) was mounted across
185 the section to partially block the water flow and force the fish to either actively bypass the kite or attempt
186 swimming through the square meshes of the inner selection section.

187

188 The standard metal sorting grid was 1.8 m wide and 3.5 m long and had six individual sections of 1.8 x 0.7
189 m lashed together. The mean bar spacing was 39.5 mm (SD = 0.8 mm, N = 50), and the mean bar width
190 was 10.1 mm (SD = 0.5 mm, N = 50). The sorting grid was mounted in a 40 mm full mesh size netting
191 section at an angle of 50° from horizontal with the bottom pointing backwards from the trawl mouth (Fig. 1).
192 A guiding panel made of square meshes (20 mm bar length) was inserted in front of the grid, causing all
193 fish to encounter the grid at its upper and middle sections, away from the outlet at the bottom of the grid.

194



195
 196
 197
 198 **Fig. 1. Schematic representation of the twin trawl setup and the sorting devices.** The target species
 199 (Norway pout) and bycatch species (for instance mackerel) enter the Excluder and the grid section
 200 simultaneously. In the Excluder, Norway pout swim through the square-meshed inner selection section and
 201 end up in the codend. Mackerel are not able to pass through the square-meshed inner selection section and
 202 are guided out of the Excluder. In the grid section, Norway pout swim through the sorting grid and end up
 203 in the codend. Mackerel are not able to pass through the grid and are guided out of the grid section.

204
 205 **2.3 Data collection**

206 After each tow, a sample of the catch (12 full baskets totalling approximately 340 kg) from each codend
 207 was taken spread during the pumping period. Each sample was sorted by species, and the weight of each
 208 species was recorded. Each fish in each sample was length measured to the nearest centimetre below,
 209 except for Norway pout and blue whiting, which were subsampled (subsamples varied between 8–16 kg).
 210 After recording species, weight, and length distributions to the nearest centimetre below, all samples and
 211 sub-samples were raised to total catch numbers by weight factors. The total catch per trawl was estimated
 212 for each haul by the skipper inspecting the catch indicators in the refrigerated sea water (RSW) tanks and
 213 noting the change in volume after the catches were transported from the respective codends, and onboard
 214 the vessel. The subsampling factors were calculated by multiplying the subsample factor based on the
 215 weight from the fish measured divided by the total sample weight and the sample weight divided by the
 216 total catch weight.

218 **2.4 Modelling the size-dependent catch efficiency of the trawls with different bycatch reduction**
 219 **devices**

220 The catch data were analysed by modelling the size-dependent catch efficiency (Herrmann et al., 2017)
 221 using the statistical software SELNET (Herrmann et al., 2016). This method models the length-dependent
 222 catch comparison rate (CC_l) summed over hauls, and its experimental form is described by the following
 223 equation:

$$224 \quad CC_l = \frac{\sum_{j=1}^m \left\{ \frac{nt_{lj}}{qt_j} \right\}}{\sum_{j=1}^m \left\{ \frac{nt_{lj}}{qt_j} + \frac{nc_{lj}}{qc_j} \right\}} \quad (1)$$

225
 226 where nc_{lj} and nt_{lj} are the numbers of fish of each species that were length measured in each length class
 227 l for the standard grid (control) and Excluder (treatment) trawls in haul j . qc_j and qt_j are sampling factors
 228 quantifying the fraction, based on weight, of the catch in the codends that were length measured in the
 229 respective hauls. m is the number of hauls in which sufficient numbers of each species were caught to be
 230 included in the analysis. The functional form for the catch comparison rate $CC(l, v)$ was obtained using
 231 maximum likelihood estimation by minimizing the following equation:

$$232 \quad - \sum_l \left\{ \sum_{j=1}^m \left\{ \frac{nt_{lj}}{qt_j} \times \ln(CC(l, v)) + \frac{nc_{lj}}{qc_j} \times \ln(1.0 - CC(l, v)) \right\} \right\} \quad (2)$$

233
 234 where v is the parameter describing the catch comparison curve defined by $CC(l, v)$. The outer summation
 235 in equation (2) is the summation over length classes l . When the catch efficiency of the standard grid and
 236 that of the Excluder trawl is similar, the expected value for the summed catch comparison rate would be
 237 0.5 (baseline). Therefore, this baseline can be applied to judge whether there is a difference in catch
 238 efficiency between the two trawls. The experimental CC_l was modelled by the function $CC(l, v)$ using the
 239 following equation:

$$240 \quad CC(l, v) = \frac{\exp(f(l, v_0, \dots, v_k))}{1 + \exp(f(l, v_0, \dots, v_k))} \quad (3)$$

241
 242 where f is a polynomial of order k with coefficients v_0 to v_k . The values of the parameters v describing $CC(l, v)$
 243 were estimated by minimizing equation (2), which was equivalent to maximizing the likelihood of the
 244 observed catch data. We considered f of up to an order of 4 with parameters v_0, v_1, v_2, v_3 , and v_4 . Leaving
 245 out one or more of the parameters v_0, \dots, v_4 led to 31 additional models that were also considered as potential
 246 models for the catch comparison $CC(l, v)$. Among these models, estimations of the catch comparison rate
 247 were made using multi-model inference to obtain a combined model (Burnham and Anderson, 2002). The
 248 ability of the combined model to describe the experimental data was evaluated based on the p -value. The
 249 p -value, which was calculated based on the model deviance and the degrees of freedom, should not be $<$
 250 0.05 for the combined model to describe the experimental data sufficiently well, except for cases for which
 251 the data were subject to over-dispersion (Wileman et al., 1996). Based on the estimated catch comparison
 252
 253

254 function $CC(l,v)$, we obtained the relative catch efficiency (also called the catch ratio) $CR(l,v)$ between the
 255 two trawls using the following equation:

256

$$257 \quad CR(l, v) = \frac{CC(l,v)}{(1-CC(l,v))} \quad (4)$$

258

259 The $CR(l,v)$ is a value that represents the relationship between the catch efficiency of the Excluder and the
 260 standard grid trawl. If the catch efficiency of both trawls is equal, then $CR(l,v)$ equals 1.0. A $CR(l,v)$ of 1.5
 261 would mean that the Excluder trawl catches 50% more of the species with length l than the standard grid
 262 trawl. In contrast, a $CR(l,v)$ of 0.8 would mean that the Excluder trawl catches only 80% of the species with
 263 length l compared to the standard grid trawl.

264

265 To provide significant differences for catch efficiency between the trawls, we estimated confidence limits
 266 for $CC(l,v)$ and $CR(l,v)$. The confidence limits (C) were estimated using a double bootstrapping method
 267 (Herrmann et al., 2017), which accounts for between-haul variability (the uncertainty in the estimation
 268 resulting from between-haul variation of catch efficiency in the trawls) as well as within-haul variability (the
 269 uncertainty about the size structure of the catch for the individual hauls, including the effect of subsampling).
 270 However, contrary to this double bootstrapping method, in the current study the outer bootstrapping loop
 271 accounting for between-haul variation was performed paired for the Excluder and standard grid, taking full
 272 advantage of the experimental design in which the trawls were fished in a twin trawl setup (in parallel). By
 273 multi-model inference in each bootstrap iteration, the method also accounted for the uncertainty due to
 274 uncertainty in model selection. We performed 1000 bootstrap repetitions and calculated the Efron 95% C 's
 275 (Efron, 1982). To identify sizes of species with significant differences in catch efficiency, we checked for
 276 length classes in which the 95% confidence limits for the catch ratio curve did not include 1.0. Finally, a
 277 length-integrated average value for the catch ratio was estimated directly from the experimental catch data
 278 using the following equation:

279

$$280 \quad CR_{average} = \frac{\sum_l \sum_{j=1}^m \left\{ \frac{nt_{lj}}{qt_j} \right\}}{\sum_l \sum_{j=1}^m \left\{ \frac{nc_{lj}}{qc_j} \right\}} \quad (5)$$

281

282 where the outer summation \sum_l covers the length classes in the catch during the experimental fishing period.

283

284 **2.5 Species dominance**

285 Catch dominance curves are often used to quantify information about the pattern of relative species
 286 abundances for a given sample. Here, we use catch dominance curves based on weight to quantify the
 287 dominance of the individual species in the catch. Generally, dominance curves are based on ranking of
 288 species in a sample in decreasing order of their abundance (Clarke, 1990). This implies that the species
 289 ranking could potentially vary among stations, making it difficult to compare dominance curves among
 290 different gears. Therefore, we kept the species ranking fixed according to the species ID (Table 1). We then

291 estimated the catch dominance curve for each net configuration using the following equation (Warwick et
292 al., 2008):

293

$$294 \quad d_{ij} = \frac{q_{ij} \times n_{ij} \times w_{ij}}{\sum_{i=1}^K \{q_{ij} \times n_{ij} \times w_{ij}\}} \quad (6)$$

295
296 where j represents the haul and i is the species index (species rank) that was predefined. n_{ij} is the number
297 of individuals of the species i being counted in the subsample in haul j . w_{ij} is the weight of the counted
298 subsample of species i in haul j , whereas q_{ij} is the fraction of species i in the catch being counted in haul j .
299 K is the total number of species considered.

300
301 To better represent species dominance patterns, we also estimated the cumulative dominance curves as
302 follows:

303

$$304 \quad D_{Ij} = \frac{\sum_{i=1}^I \{q_{ij} \times n_{ij} \times w_{ij}\}}{\sum_{i=1}^K \{q_{ij} \times n_{ij} \times w_{ij}\}} \quad \text{with } 1 \leq I \leq K \quad (7)$$

305

306 where I is the species index summed up to in the nominator.

307

308 The 95% CIs for the dominance patterns were estimated using (6) and (7) inside each of the bootstrap
309 iterations applied to estimate the uncertainties for the catch comparison and catch ratio curves.

310

311 3. Results

312

313 We conducted 14 hauls using the twin trawl setup during the fishing trials in October 2021, but we discarded
314 two of them from the analysis because one of the trawls was damaged during towing. The catches varied
315 between 9000 and 37,000 kg for the trawl with the grid and between 1500 and 17,000 kg for the trawl with
316 the Excluder. These hauls contained sufficient catches of Norway pout, blue whiting, herring, mackerel,
317 horse mackerel, whiting, haddock, European hake, and greater argentine to be included in the catch
318 comparison analysis (Table 1). The quantities of other species, such as cod, were too low for inclusion in
319 the catch comparison analysis. However, these species constituted only 0.6% of the total catch in weight.
320 Because cod were counted, we included this species in the species dominance analysis.

321

322 **Table 1. Total and mean catches.** Summed catch (kg) per species over 12 hauls using the twin trawl
323 setup with one trawl with the sorting grid (control) and the other trawl with the Excluder (treatment). Mean
324 catches in weight per haul. Values in parentheses represent the 95% CI which were obtained were obtained
325 by the double bootstrapping method based by using the information of total catch per species.

Species	Trawl with Sorting grid		Trawl with Excluder		% Reduction in weight
	Total catch	Mean catch	Total catch	Mean catch	
Norway pout	67 032	5 586 (3 989–7 197)	66 069	5 506 (4 269–6 796)	-1.4 (-15.3–16.0)
Blue whiting	75 038	6 253 (3 335–9 924)	48 302	4 025 (2 260–6 084)	-35.6 (-47.2– -20.7)
Greater argentine	4 372	364 (42–970)	3 301	275 (32–683)	-24.5 (-47.3– 18.3)
Horse mackerel	38 125	3 177 (2 282–4 049)	272	23 (4–54)	-99.3 (-99.9– -98.2)
Herring	34 248	2 854 (1 396–4 708)	3 458	288 (123–523)	-89.9 (-93.0– -86.2)
Mackerel	27 564	2 297 (672–4 277)	1 858	155 (41–282)	-93.3 (-97.9– -83.0)
Haddock	8 356	696 (310–1 127)	118	10 (3–18)	-98.6 (-99.5– -97.2)
Cod	151	13 (0–30)	4	0 (0–1)	-97.1 (-104.0– -5.0)
European hake	588	49 (14–95)	12	1 (0–3)	-98.0 (-100.2– -93.2)
Whiting	7 733	644 (390–963)	51	4 (1–8)	-99.3 (-99.8– -98.6)
SUM	263 207		123 445		

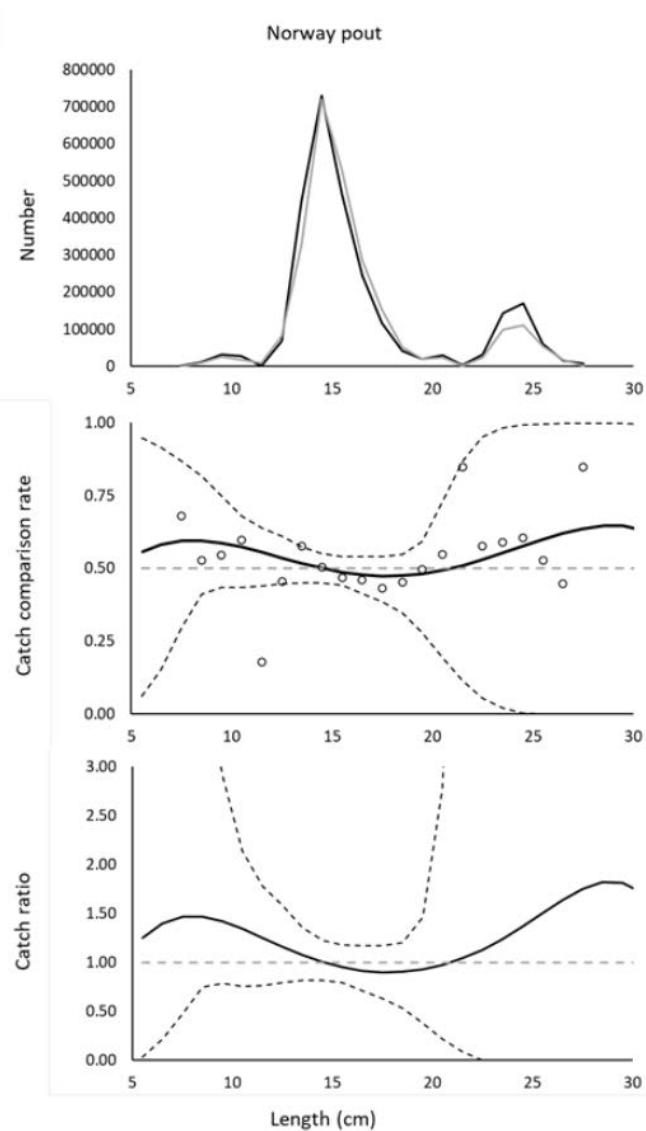
326
327
328 For the main target species, Norway pout, no significant difference ($p < 0.0001$) was observed in the catch
329 (in weight) (Table 2) or the length frequency distributions (Fig. 2) between the trawl with the Excluder and
330 the trawl with the sorting grid. The catch rate indicated a small but non-significant increase of the catch in
331 the trawl with the Excluder (103.81, CI: 86.74–125.61), which in weight represented 1.4% (Tables 1, 2).

332
333 **Table 2. Fit statistics for Norway pout.** Catch comparison results and number of fish observed between
334 the Excluder and the grid.

Norway pout	
p -value	< 0.0001
Deviance	81.68
DOF	16
$CR_{average}$	103.81 (86.74–125.61)
Number of fish Excluder	2124
Number of fish grid	2177

335

10



336

337 **Fig. 2. Catch comparison and catch ratio analysis for Norway pout.** Upper graph: the length frequency
 338 distribution of Norway pout captured by the trawl with the Excluder (black line) and the trawl with the sorting
 339 grid (grey line). Middle: the modelled catch comparison rate (black line). Circles represent the experimental
 340 rate. Lower: the estimated catch ratio curve (black curve). The 95% CI is represented by the black stippled
 341 curves. The grey stippled lines at 0.5 and 1.0 represent the point at which both gears have an equal catch
 342 rate.

343

344 The Excluder reduced the catch of wanted bycatch species (blue whiting, greater argentine, and horse
 345 mackerel) by 35.6%, 24.5%, and 99.3%, respectively (Table 1). For blue whiting, the catch ratio was highly
 346 length dependent; there was a large and significant reduction in catch ratio for individuals larger than 22.0,
 347 but no significant differences were detected for the smaller individuals (Table 3, Fig. 3). For greater
 348 argentine, the catch ratio also showed a tendency of length dependency, but the difference was not
 349 significant. For horse mackerel, the CI were very wide and therefore it is not possible to conclude whether
 350 there was a significant length dependency. When averaged over all length classes, the catch ratios for blue
 351 whiting and horse mackerel were significantly lower for the trawl with the Excluder than for the trawl with

352 the sorting grid, with the estimated catch ratios of the trawl with Excluder being 67.9% and 0.8% of the trawl
 353 with the sorting grid, respectively (Table 3, Fig. 3).

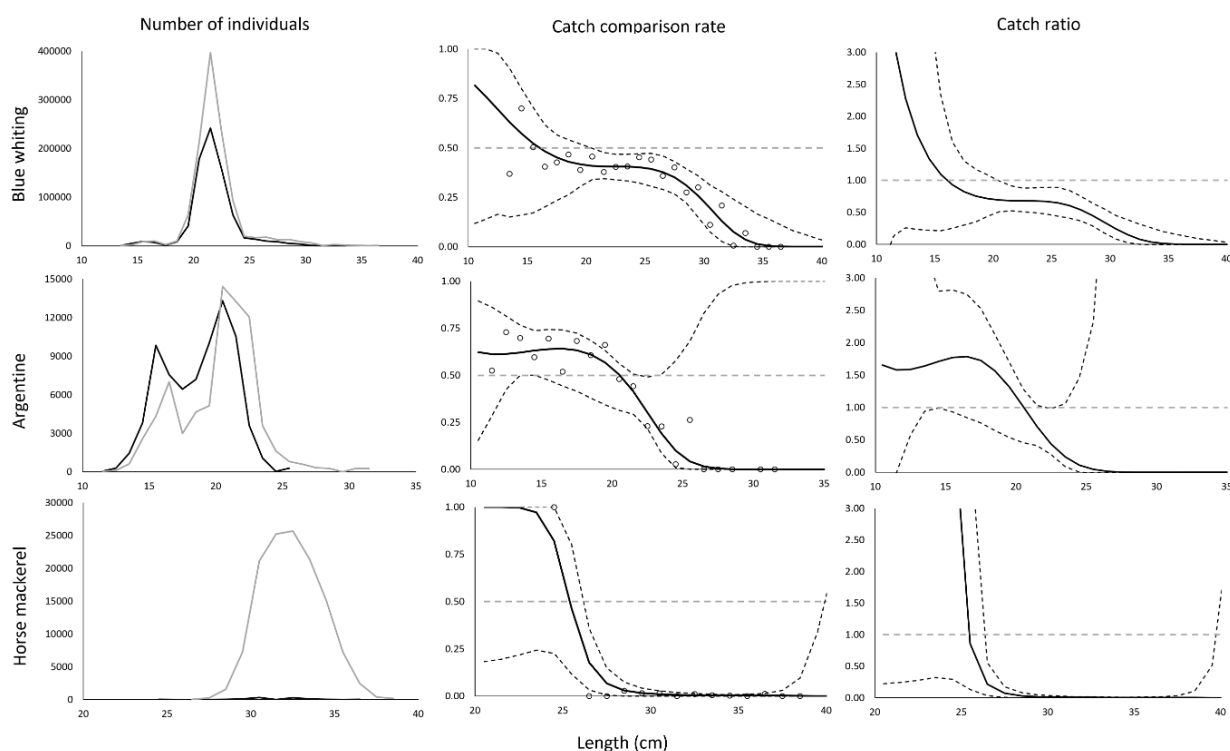
354 **Table 3. Fit statistics.** Catch comparison results and number of fish observed between the Excluder and
 355 sorting grid for blue whiting, greater argentine, and horse mackerel.

356

	Blue whiting	Greater argentine	Horse mackerel
p -value	< 0.0001	< 0.0001	< 0.0001
Deviance	59.32	46.71	373.57
DOF	19	15	9
$CR_{average}$	67.92 (55.60–87.28)	100.76 (82.12–130.52)	0.75 (0.13–1.96)
N fish measured Excluder	4008	997	30
N fish measured grid	3928	599	2057

357

358



359

360 **Fig. 3. Catch comparison and catch ratio analysis for blue whiting, greater argentine, and horse**
 361 **mackerel.** Left column: the length frequency distribution of fish captured by the trawl with the Excluder
 362 (black line) and the trawl with the sorting grid (grey line). Middle: the modelled catch comparison rate (black
 363 line) with 95% CIs (black stippled curves). Circles represent the experimental rate. Right: the estimated
 364 catch ratio curve (black curve) with 95% CIs (black stippled curves). The grey stippled lines at 0.5 and 1.0
 365 represent the point at which both gears have an equal catch rate.

366 For all unwanted bycatch species that normally are destined for human consumption (herring, mackerel,
 367 haddock, European hake, and whiting), the Excluder reduced the catch of these species compared to the
 368 grid by 89.9%, 98.3%, 98.6%, 98.0%, and 99.3%, respectively (Table 1). For all of these species, the catch

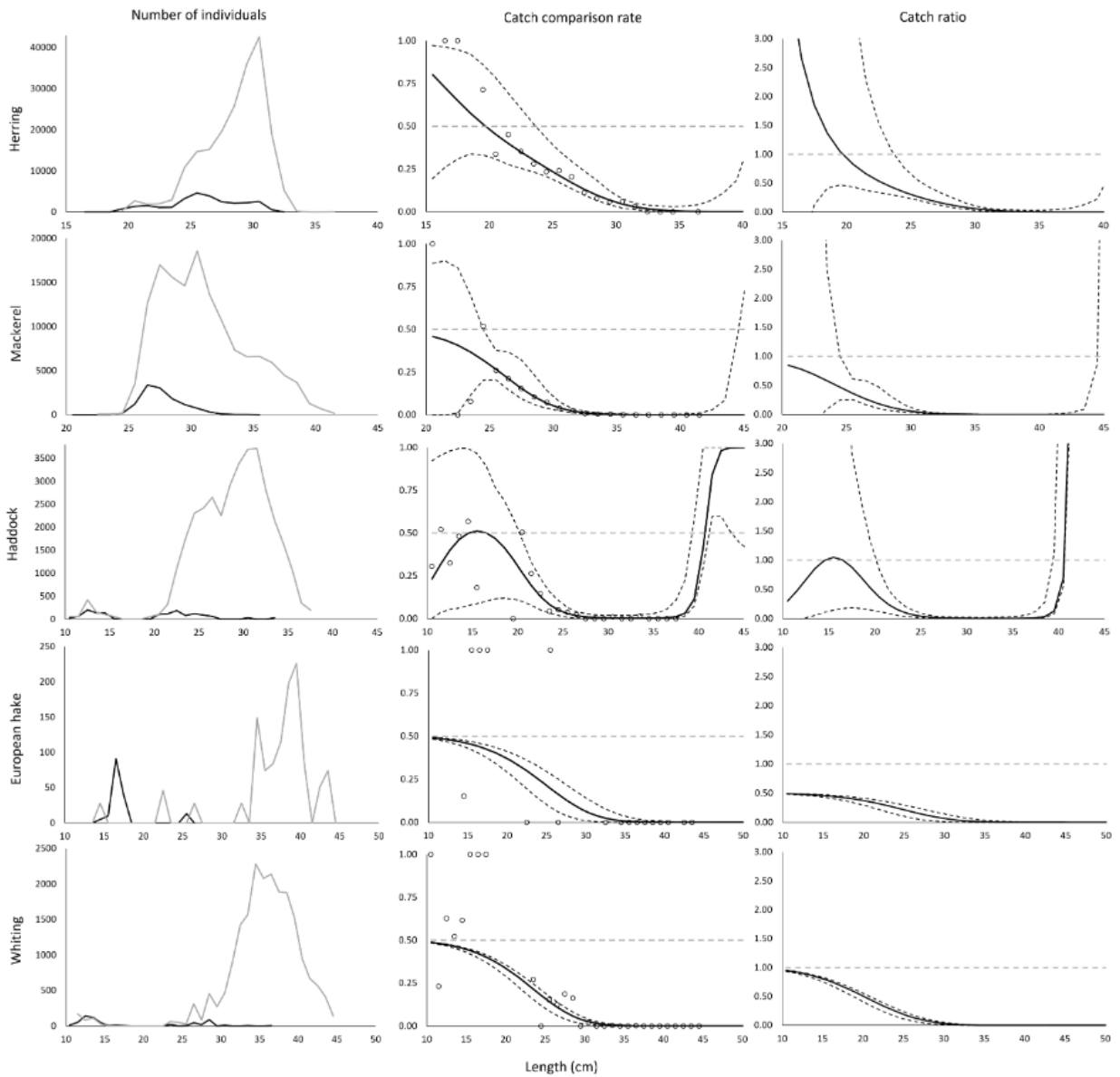
369 ratios were highly length dependent; there was a large and significant reduction for individuals larger than
 370 24.0 cm for herring, 25 cm for mackerel, and 21 cm for haddock, but no significant differences were detected
 371 for the smaller individuals (Table 4, Fig. 4). When averaged over all length classes, the catch ratios for
 372 herring, mackerel, haddock, European hake, and whiting were significantly lower for the trawl with the
 373 Excluder than for the trawl with the sorting grid, with the estimated ratios of the trawl with the Excluder being
 374 14.1%, 8.4 %, 3.9%, 13.3%, and 2.9 % of the trawl with the sorting grid, respectively (Table 4, Fig. 4).

375

376 **Table 4. Fit statistics.** Catch comparison results and number of fish measured between the Excluder and
 377 the grid for unwanted bycatch species.

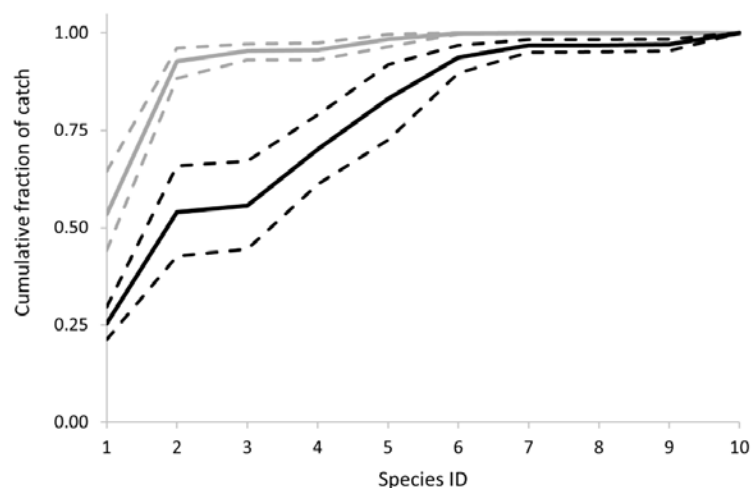
	Herring	Mackerel	Haddock	European hake	Whiting
<i>p</i> -value	< 0.0001	0.1281	< 0.0001	< 0.0001	< 0.0001
Deviance	67.24	22.49	151.30	72.32	110.37
DOF	14	16	20	16	25
$CR_{average}$	14.08 (09.53–19.36)	8.39 (00.00–11.95)	3.90 (01.71–07.50)	13.33 (03.42–61.90)	2.88 (01.39–04.90)
N fish measured Excluder	878	852	63	10	53
N fish measured grid	2643	2950	691	37	386

378



379
 380 **Fig. 4. Catch comparison and catch ratio analysis for unwanted bycatch species.** Left column: the
 381 length frequency distribution of fish captured by gear with the Excluder (black line) and gear with the sorting
 382 grid (grey line). Middle: the modelled catch comparison rate (black line) with 95% CIs (black stippled
 383 curves). Circles represent the experimental rate. Right: the estimated catch ratio curve (black curve) with
 384 95% CIs (black stippled curves). The grey stippled lines at 0.5 and 1.0 represent the point at which both
 385 gears have an equal catch rate.

386 The cumulative dominance analysis (Fig. 5) shows dissimilarity between the catch composition of the trawl
 387 with the Excluder and the trawl with the sorting grid, and significant differences were found for all pelagic
 388 species. While the proportion of target and wanted bycatch species summed up 95.5% in the trawl with the
 389 Excluder, it reached 70.1% in the trawl with the sorting grid. The unwanted bycatch species herring and
 390 mackerel that together constituted approximately 27.5% in the trawl with sorting grid were reduced to
 391 around 3 % in the trawl with the Excluder.



393
 394 **Fig. 5. Cumulative species dominance in weight for the Excluder (grey line) and the grid (black line)**
 395 **with 95% CIs (stippled lines).** The X-axis shows the species ID: 1 Norway pout, 2 blue whiting, 3 Greater
 396 argentine, 4 Horse mackerel, 5 Herring, 6 Mackerel, 7 Haddock, 8 Cod, 9 European hake, 10 Whiting. The
 397 Y-axis shows cumulative dominance.

398

399 4. Discussion

400

401 In several trawl fisheries targeting small-sized fish species, the unwanted bycatch of juveniles, which often
 402 are of the same size as the target species, is a persistent issue (ICES, 2016; Larsen et al., 2018; Eigaard
 403 et al., 2021). The mixed fishery for Norway pout in the North Sea is one such fishery (Eigaard et al., 2012;
 404 2021). Small-meshed trawls with a minimum mesh size of 16 mm in the codend are little, or non-selective,
 405 and can contain large quantities of unwanted bycatch species. Although the introduction of the sorting grid
 406 has significantly reduced the catches of large gadoids, small gadoids and other unwanted bycatch species
 407 can still be caught in large quantities (Eigaard et al., 2012; ICES, 2016). Moreover, there is great uncertainty
 408 as to whether the catch registration is correct when landing mixed catches for reduction purposes, but
 409 bycatch levels of these species are expected to be relatively high (Norwegian Directorate of Fisheries,
 410 2021). Over time, the Norwegian Directorate of Fisheries has tried to solve this problem by increasing the
 411 effort of sampling the landings of vessels in the fleet. Therefore, a selection system that can help reduce
 412 the bycatch issues in the North Sea mixed fishery for Norway pout is needed.

413 Contrary to Dickson (1960), Bailey et al. (1983), and Wileman and Main (1994), who did not find any
 414 difference in behaviour that could be used to separate Norway pout from bycatch species destined for
 415 human consumption, the Excluder section tested in this experiment was very efficient at separating different
 416 fish species, even those in similar length classes. The Excluder section significantly reduced the bycatch
 417 of unwanted cod, whiting, haddock, and European hake by 97.1%, 99.3%, 98.6%, and 98.0%, respectively,
 418 without altering the catch of the target species, Norway pout. The Excluder also reduced the bycatch of
 419 other unwanted bycatch species, such as mackerel and herring, by 93.3% and 89.9%, respectively.
 420 However, the Excluder also reduced the bycatch of wanted bycatch species such as blue whiting (by
 421 35.6%), horse mackerel (by 99.3%), and greater argentine (by 24.5%). The Excluder bycatch reduction

422 was species and size dependent, meaning that larger fish were unable to pass through the Excluder's
423 square-meshed inner selection section and consequently were released from the trawl. This was the case
424 for most white fish species, except for the smallest length classes. The smallest individuals (< 22 cm) of
425 blue whiting and greater argentine were able to pass through the square-meshed inner selection section of
426 the Excluder and get caught, whereas larger length classes (> 22 cm) were released. Bigne´ et al. (2018)
427 reported that depth seemed to be correlated with bycatch levels, with juveniles of whiting, herring, and
428 especially Norway pout generally preferring shallower waters. However, the correlation between depth and
429 length classes and/or bycatch levels was not assessed in this study. The observed bycatch reduction
430 efficiency is explained by the larger sorting area of the Excluder relative to the grid's area, and by the
431 differences in behaviour between Norway pout and the bycatch species. The square PVC kite mounted in
432 the Excluder (Fig 1) apparently trigger an avoidance behaviour on Norway pout making them swim through
433 the square meshes of the Excluder inner selection section. This avoidance behaviour seems not to be as
434 strong other species and are gently guided out of the Excluder.

435
436 As the results of this study show, the poor selectivity of the 40 mm sorting grid system leads to the landing
437 of large amounts of mackerel (27.4 metric tons) and herring (34.2 metric tons) for reduction purposes and
438 therefore to poor utilization of the quotas of these species. In this context, the use of the Excluder system
439 can remove bycatch of these species during bottom trawling and allow these species to be fished for human
440 consumption purposes (by pelagic trawling for instance), and thereby obtain a higher price per kilogram. In
441 the case of the bycatch of white fish species (cod, haddock, whiting, European hake, and saithe), the grid
442 system is probably efficient to release most legal-size fish, but it fails to remove the smallest individuals.
443 Consequently, these fish, which have almost no market value, end up being used for reduction purposes
444 together with Norway pout. This is a bad example of ecosystem-based management, and it has a negative
445 impact on the stock biomass (Eigaard and Holst, 2004). In contrast, the Excluder is a better selection
446 system because most likely it releases most juvenile fish unharmed, thus enhancing future recruitment.
447 However, the Excluder technology may also lead to reduced catch of wanted bycatch species, such as
448 horse mackerel and blue whiting, which would result in economic losses for the fishers if all of the catches
449 are delivered for reduction purposes (meal and oil). Thus, the Excluder technology creates a dilemma for
450 both fishers and the management system. From the management perspective, the Excluder technology
451 contributes to the transition from a typical mixed fishery towards a single-species fishery. With this strategy,
452 the bycatch sorted out by the Excluder can be caught within the specific traditional seasonal fisheries for
453 Atlantic mackerel and North Sea herring for human consumption. Because the value per kilogram for these
454 two species when caught for human consumption is much higher than that of fish caught for reduction
455 purposes, single-species fisheries for the bycatch species may represent an adaptation that is more
456 valuable to fishers than that of today's traditional sorting grid technology. However, this may not always be
457 the case.

458
459 Considering that the average price of mixed catches delivered for reduction purposes (oil and meal) was 3
460 NOK/kg in September 2021¹, the value of the catches (Table 2) was 789,621 NOK for the trawl with the

¹ Price for oil and meal according to the Norwegian Fishermen's Sales Organization for Pelagic Fish, 2021.
(www.sildelaget.no).

461 grid and 370,335 NOK for the trawl with Excluder. Thus, the catch from the trawl with the grid gives a larger
462 income (plus 419,286 NOK) than that of the trawl with the Excluder. During this sea trial, 25,706 kg of
463 Atlantic mackerel and 30,790 kg of North Sea herring were sorted out by the Excluder technology. The
464 fisher's first-hand prices for these species destined for human consumption were 13.00 NOK and 7.00 NOK
465 per kilogram, respectively, in 2021², yielding a value of 549,708 NOK. Added to the value of the rest of the
466 catch delivered for reduction purposes (370,335 NOK), the total value of the catch would be 920,043NOK
467 using the Excluder. Compared to the total value of the catch using the sorting grid when delivered for
468 reduction purposes (789,621 NOK), use of the Excluder would result in a 16.5% more income for this trip.
469

470 The Norwegian and EU fleets targeting Norway pout in the North Sea are subjected to different technical
471 regulations to reduce bycatch. While the EU fleet uses sorting grids with 35 mm bar spacing, the Norwegian
472 fleet uses grids with 40 mm bar spacing. The system in which a 40 mm sorting grid is mandatory for those
473 Norwegian vessels without the capacity to process the bycatch of large white fish (e.g., saithe) leads to
474 large amounts of white fish, including juveniles and other bycatch of pelagic species, being landed for
475 reduction purposes. The 35 mm sorting grid required for the EU fleets may be better suited to reducing
476 bycatch of white fish, but large amounts of bycatch still are landed for reduction purposes (ICES 2016).
477 Additionally, Norwegian vessels have different combinations of quota rights, thus keeping some of the
478 bycatch species is a key strategy to increase profitability in the fishery. We do not know if there is a
479 difference between catch rates of Norway pout for 35mm and 40mm sorting grid, but we would assume
480 that the 35mm would have higher probability of losing part of the target catch. Likewise, we expect that the
481 bycatch reductions levels found in this study would be most likely less pronounced if a 35mm would have
482 been used instead the 40 mm grid.
483

484 In 2021, the fleet landed 71,954 tons out of the 255,319 tons of the advised TAC of Norway pout in the
485 North Sea (ICES, 2022), leaving nearly 72% of the sustainable catch and potential revenue in the water.
486 Similar to other mixed fisheries around the world (e.g., in the Gulf of Alaska and along the west coast of the
487 US) (McQuaw and Hilborn, 2020), it is apparent that the low utilization of quota of Norway pout in the North
488 Sea mixed fishery could be attributed to a combination of factors affecting the fishery. One of them is the
489 large levels of bycatch of TAC regulated species choke species and market price limitations when landings
490 are destined for reduction purposes rather than for human consumption.
491

492 **5. Conclusion**

493 The standard 40 mm grid system used in the Norwegian EEZ is not good enough to reduce the bycatch of
494 mackerel, herring, and gadoid fish species. This study documents that its use in the fishery leads to the
495 landing of large amounts of these species for reduction purposes. By assuming that the species and size
496 distributions encountered during the experimental fishing are representative of the commercial fishery, a
497 widespread replacement of the grid with the Excluder would not only lead to a substantial reduction in
498 bycatches. However, while it contributes to reduce bycatch of quota regulated species, the Excluder also

² Price for human consumption according to the Norwegian Fishermen's Sales Organization for Pelagic Fish, 2021.
(www.sildelaget.no).

499 can potentially affect the profitability of the fishery. Unwanted bycatch species such as mackerel and herring
500 could be targeted separately and landed for human consumption, while juveniles of gadoid species would
501 be potentially released unharmed, thus enhancing future recruitment.
502

503 **6. Supporting information**

504
505 **S1 Catch data and sampling factors.** The number of individuals measured in the treatment (nt) and
506 control (nc) trawls and corresponding sampling factors (qt and qc , respectively) in each haul per species.
507

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509
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514

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65th PLENARY REPORT
(PLEN-20-03)

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Abstract

Commission Decision of 25 February 2016 setting up a Scientific, Technical and Economic Committee for Fisheries, C(2016) 1084, OJ C 74, 26.2.2016, p. 4–10. The Commission may consult the group on any matter relating to marine and fisheries biology, fishing gear technology, fisheries economics, fisheries governance, ecosystem effects of fisheries, aquaculture or similar disciplines. The Scientific, Technical and Economic Committee for Fisheries held its 65th plenary as virtual meeting from 9 to 13 November 2020.

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6.2 Assessment of the potential impact on the exploitation pattern of species by-caught in the Norway Pout fishery with an alternative species selective device

Background provided by the Commission

The new Technical Measures Regulation (TMR)⁷ introduces the process of regionalization to amend certain regional baseline selectivity standards. Member States with interests in a given region may adapt various aspects of fisheries management, while ensuring that activities carried out are consistent with the objectives of the TMR. This permits the tailoring of detailed and technical rules so as to take into account regional specificities.

In this regard, the Scheveningen Regional Group has previously developed the attached joint recommendation in accordance with article 15 of the TMR and article 18 of Regulation EU no 1380/2013. This joint recommendation was assessed by the STECF (PLEN 20-01/PLEN 20-02) in order to determine to what extent it goes in line with achieving the objectives and targets set out in Articles 3 and 4 of the TMR, and does not lead to a deterioration of selectivity standards.

Previous STECF (PLEN 20-01) evaluations identified a number of data and information gaps that prevented a positive assessment that the alternative gear fulfilled the criteria set out in TMR article 15. The majority of these have been resolved (PLEN 20-02). However, STECF raised additional concerns (PLEN 20-02) regarding the potential for the excluder to increase catch rates of by-catch species particularly if the length was below 15cm. The Scheveningen Regional Group has supplied additional data and information to redress the concerns expressed by the STECF on this particular point with a view to permitting the use of the excluder trawl as an alternative to the selection grid specified in annex V of the TMR.

Specifically, STECF concluded that *"the Excluder design shows substantial (and statistically significant) reduction (30-95% in number depending on species) in bycatches of larger individuals of herring, mackerel, whiting, long rough dab and witch flounder compared with the currently required grid design. More specifically bycatches larger than 21-26 cm (whiting, herring and mackerel) and 15-17 cm (long rough dab and witch flounder) were significantly reduced by numbers."*

⁷ Regulation (EU) 2019/1241 of the European Parliament and of the Council of 20 June 2019 on the conservation of fisheries resources and the protection of marine ecosystems through technical measures, amending Council Regulations (EC) No 1967/2006, (EC) No 1224/2009 and Regulations (EU) No 1380/2013, (EU) 2016/1139, (EU) 2018/973, (EU) 2019/472 and (EU) 2019/1022 of the European Parliament and of the Council, and repealing Council Regulations (EC) No 894/97, (EC) No 850/98, (EC) No 2549/2000, (EC) No 254/2002, (EC) No 812/2004 and (EC) No 2187/2005

However, STECF also concluded “that for Norway pout and for comparable bycatch species of similar size and morphology (e.g. gadoids smaller than 15 cm) the Excluder design can be expected to result in increased catches of around 32% by numbers (CI: 3-95%)”.

The Danish authorities have provided additional information regarding the observed length frequency of the by-catch species typically encountered in the fishery and length frequency data from experiments comparing the grid and excluder device. From the comparative selectivity experiments, it appears that there is a substantial length dependent reduction in by-catches associated with the excluder. Given the typical length distribution encountered in the fishery and the experimental data comparing the relative selectivity at length between grid and the excluder, the excluder may present an alternative to the grid that could provide a positive change in the exploitation pattern for the by-catch species.

Background documents are published on the meeting’s web site on: <https://stecf.jrc.ec.europa.eu/plen2003>

Request to the STECF

On the basis of Article 15(4) (5) and (6) of the TMR, STECF is requested to evaluate the additional information supporting the joint recommendation on the use of the “excluder” grid device in the Norway Pout fishery in the North Sea. STECF should assess to what extent the joint recommendation helps at achieving the objectives and targets set out in Articles 3 and 4 of the TMR for by-catch species encountered in the fishery.

More specifically, STECF advice is requested to assess, in particular:

- Based on the additional data provided, if the excluder achieves or improves upon the by-catch reduction rates compared to the grid across the length distribution typically encountered in the fishery and if the use of the excluder would maintain or improve the exploitation pattern of the by-catch species.

Documentation: Joint recommendation of the Scheveningen Group: Use of the ‘Excluder’ grid in the Norway pout fishery; Length frequency data from experimental trials comparing the length specific performance of the excluder device and grid and length data of by-catch species obtained from national catch sampling programmes.

Summary of the information provided to STECF

Three documents were provided to PLEN 20-03 to support this request:

(a) an updated version of the scientific manuscript underpinning the JR "A netting-based alternative to rigid grids in the small-meshed Norway pout (*Trisopterus l. esmarkii*) trawl fishery" by Eigaard et al. A previous version of the manuscript was evaluated and summarized by PLEN 20-01 and PLEN 20-02.

(b) An excel file " DK harbor sampling NOP fishery_ 4A_Q4_2012-2020_STECF_ver2.xlsx" consisting of catch composition data in the Danish Norway pout fishery. This provides data on commercial catches that is representative of the fishery and comparable to the experiment by Eigaard et al. The submitted dataset consists of sampled landings from the North Sea during the 4th quarter of the years 2012 to 2019 (i.e. since the sorting grid was introduced in the Norway pout fishery). More specifically, the information consists of a subset of samples of industrial landings performed by the Danish Control Agency. As the regular control samples only measure catch composition (assuming that all catches are landed) by weight, the subset provided to PLEN 20-03 were the part of the samples that are regularly analysed further by DTU Aqua (e.g. otoliths reading and length measurements). Each sample consists of approx. 5 kg of unsorted landings. Data is recorded on the numbers at length and weights of all species from 136 sampled trips for the years 2012 to 2019.

An overview of the provided information is presented in Table 6.2.1 (weight composition per species) and 6.2.2 (length frequency per species).

Table 6.2.1. Catch proportion (by weight) in the Norway pout fishery. Danish landing sampling data 2012-2019. The table was constructed by STECF on data provided in supporting document b.

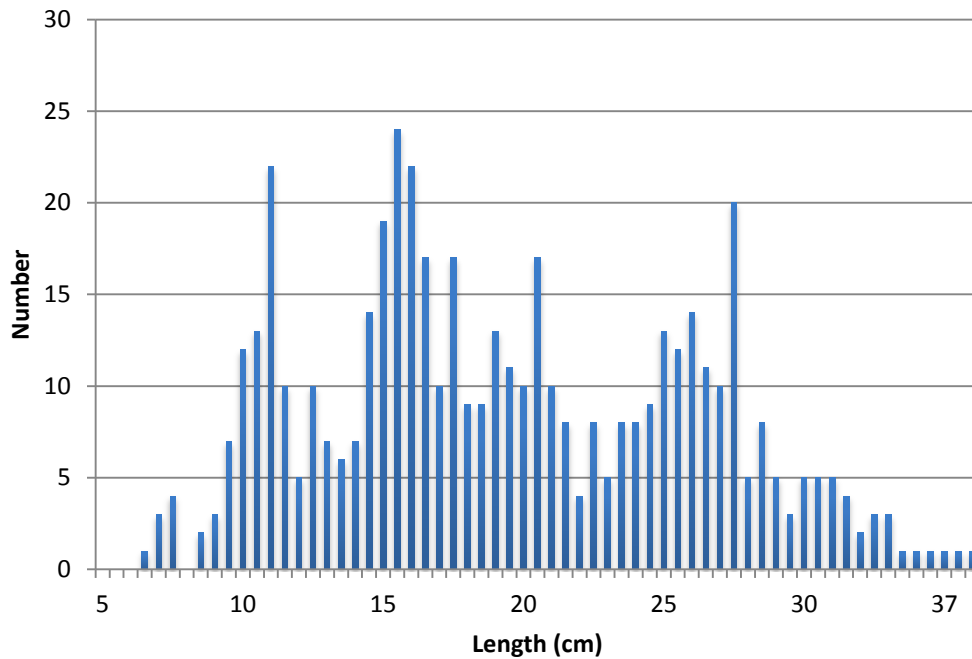
Species/Year	2012	2013	2014	2015	2016	2017	2018	2019	Average
Norway Pout	96,93%	99,26%	97,91%	99,62%	99,64%	100,00%	99,77%	99,36%	99,06%
Herring	2,59%	0,26%	0,11%	0,03%	0,14%	0,00%	0,00%	0,20%	0,42%
Whiting	0,20%	0,15%	0,30%	0,07%	0,06%	0,00%	0,22%	0,21%	0,15%
Blue whiting	0,03%	0,00%	1,35%	0,03%	0,00%	0,00%	0,00%	0,00%	0,18%
Lesser silver smelt	0,11%	0,14%	0,23%	0,09%	0,06%	0,00%	0,01%	0,18%	0,10%
Long rough dab	0,09%	0,02%	0,04%	0,05%	0,05%	0,00%	0,00%	0,00%	0,03%
Northern shrimp	0,03%	0,05%	0,02%	0,06%	0,02%	0,00%	0,00%	0,01%	0,02%
Haddock	0,00%	0,05%	0,02%	0,00%	0,00%	0,00%	0,00%	0,02%	0,01%
Cod	0,00%	0,03%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Silvery cod	0,00%	0,01%	0,00%	0,03%	0,01%	0,00%	0,00%	0,00%	0,01%
Hake	0,02%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Other species	0,01%	0,03%	0,03%	0,03%	0,02%	0,00%	0,00%	0,01%	0,01%

Table 6.2.2. Number of length measured individuals of all species encountered in Danish landing samples from the Norway pout fishery 2012-2019. Also shown is the number of samples per year. The table was constructed by STECF on data provided in supporting document b.

Species/Year	2012	2013	2014	2015	2016	2017	2018	2019	Total
Norway Pout	4655	5956	4324	1738	5119	269	1412	4732	28205
Herring	89	21	3	1	10			8	132
Lesser silver smelt	29	30	12	8	8		1	17	105
Blue whiting	5		84	0					89
Whiting	10	12	4	10	5		3	13	57
Long rough dab	14	10	7	6	11			1	49
Silvery cod	2	32		5	5			2	46
Haddock		2	4	1				5	12
Pouting			10						10
Hake	4		0		1				5
Witch flounder	1		3						4
Sprat		2						1	3
Poor cod		3							3
Cod		2							2
Fourbeard rockling	1								1
Horse mackerel				1					1
Dab					1				1
Hagfish		0		1	0			0	1
Sum all species	4810	6070	4451	1771	5160	269	1416	4779	28726
<i>No. Sampled trips</i>	<i>33</i>	<i>40</i>	<i>16</i>	<i>10</i>	<i>22</i>	<i>1</i>	<i>3</i>	<i>11</i>	<i>136</i>

Table 6.2.1 and 6.2.2 show clearly that Norway pout dominates the catch samples both in weight and by numbers (99.1% and 98.2% respectively). Overall bycatches are sparse and consist of less than 20 fish species in total over the years. Due to the scarcity of

bycatches, analyzing yearly species-specific length distributions is not feasible. The length frequency of all bycatch species combined for all years is shown in Figure 6.2.1.



Figure

Figure 6.2.1. Length distribution of all bycatch species combined in Danish landing samples from the Norway pout fishery 2012-2019. The figure was drawn by STECF on data provided in supporting document b.

Of the 498 length measured bycatch species in the samples from the 136 sampled trips (Figure 6.2.1.), 125 individuals (25 %) were smaller than 15 cm, thus on average less than one individual of any bycatch species per sampled trip. Table 6.2.3. shows the number per species of the bycatches smaller than 15 cm.

Table 6.2.3. Number of individuals per bycatch species smaller than 15 cm in Danish landing samples from the fishery for Norway pout 2012-2019. The table was constructed by STECF on data provided in supporting document b.

Species	Number
Long rough dab	33
Blue whiting	28
Whiting	24
Silvery cod	23
Lesser silver smelt	11

Pouting	10
Haddock	8
Sprat	3
Witch flounder	3
Dab	1
Cod	1

(c) This document "NOP Excluder versus grid trial length data by haul_STECF_ver2.xlsx" provided all sampled data of all species from the experimental trial presented in document (a) (Eigaard et al.). Data was presented haul-by-haul and included length distributions of all species and haul details (location, depth, environmental variables etc.).

STECF comments

The STECF comments focus on the new information provided in response to the request for additional information by the Commission to the Scheveningen group. They follow from the evaluations by PLEN 20-01 and PLEN 20-02. Specifically, STECF focused here on the question of the ToR to PLEN 20-03 *"based on the additional data provided, if the excluder achieves or improves upon the by-catch reduction rates compared to the grid across the length distribution typically encountered in the fishery and if the use of the excluder would maintain or improve the exploitation pattern of the by-catch species"*.

STECF notes that the main point raised from previous evaluations was the applicability of the results of the Eigaard et al. study to the effects on bycatch species in the wider fishery. Specifically, this relates to the identified increase in catch efficiency of smaller (<15 cm) individuals when using the Excluder compared to the grid. PLEN 20-02 concluded that the evidence presented suggests that the Excluder design will improve selectivity for bycatches larger than 15-20 cm but likely reduce selectivity for bycatches smaller than 15 cm. The latter conclusion was inferred from the reduced selectivity for Norway pout smaller than 15 cm. These conclusions were the background to why PLEN 20-02 could not fully evaluate whether the Excluder device is compatible with the objectives of Regulation (EU) 2019/1241. As bycatches smaller than 15 cm were limited or absent in Eigaard et al., this raised the question whether the lack of small-sized bycatches in the study is representative for the wider fishery or not.

PLEN 20-01 and 20-02 reviewed the revised version of the manuscript (Eigaard et al.), supplemented as document (a). The changes in this latest version provided to PLEN 20-03 are of cosmetic nature and not in substance. Therefore, the document was not reevaluated by STECF.

Similarly, STECF considers that the information provided in document (c) was of limited relevance for the request to PLEN 20-03 because the remaining question was focused on the applicability of the study results on smaller bycatches in the wider fishery as such information was largely lacking in Eigaard et al. Previous evaluations by PLEN 20-01 and PLEN 20-02 had already evaluated the quality and robustness of the study itself.

STECF notes that document (b) provided such catch composition data from the commercial fishery. The sampling procedure comprised a single sample (around 5 kg) taken from each sampled trip, which is also acknowledged in document b. STECF considers that the main limitations with this sampling design is the potential bias in terms of representativeness of one small sample from a large, naturally size-sorted catch and the low probability that rare species or larger sized individuals will at all be included in a small sample. However, as the intermixture of smaller sized bycatch species (similar size as Norway pout) is of main interest here, these limitations probably have minor implications given the quite large number of samples collected over time. STECF considers that indeed this large number of samples to be the main strength of the data provided (samples of landings from 136 trips covered between 2012 and 2019), i.e. since the current grid was introduced in the fishery.

STECF further notes that bycatches are limited in the unsorted landing samples provided from the Norway pout fishery. In total, 1.8% of all individuals in the samples consisted of species other than Norway pout. Among these species, the most common are quota species such as herring, blue whiting, whiting and argentine. Few cod, haddock, hake and sprat were recorded. As the number of individuals of the bycatch species in the whole dataset was very small, up to 132 individuals for herring but more typically less than 20, it makes no sense to analyze the length frequencies by species by year in detail. Of all bycatch species recorded, 25 % were smaller than 15 cm and around 50% larger than 20 cm.

STECF notes that this information provides a better prediction of the possible effects of the Excluder. As PLEN 20-02 concluded that bycatches larger than 15 to 20 cm (depending on species) will be significantly reduced and bycatches smaller than 15 cm may increase, STECF considers that if the dominance of larger sized bycatches and the smaller proportion of small bycatches in the samples are representative of the wider fishery, the use of an Excluder would achieve an overall reduction in bycatch rates (in weight and number) in comparison to the grid for most species caught.

Consequently, STECF observes that the exploitation pattern of bycatch species is likely to be maintained or improved. This based on the modest proportion (25%) of bycatches smaller than 15 cm in combination with the limited predicted increase in catch efficiency (32%), compared to the larger reductions (from 30 % up to 95% depending on size class) for the larger share of bycatches above 15 to 20 cm. This is particularly relevant for bycatch species that tend to grow larger than Norway pout and that are normally classified as juveniles up to over and above 25 cm in length. For smaller species with L-infinity of less than 15 cm this may not hold true. However, the scarcity of bycatches in the data provided indicates that the Norway pout fishery has a limited impact on most bycatch stocks.

STECF conclusions

- *if the excluder achieves or improves upon the by-catch reduction rates compared to the grid across the length distribution typically encountered in the fishery and if the use of the excluder would maintain or improve the exploitation pattern of the by-catch species.*

STECF concludes that the risk of increased catches for comparable bycatch species of similar size and morphology (e.g. gadoids smaller than 15 cm) the Excluder design, as identified by PLEN 20-02, is low. This is evidenced by both a low percentage by weight (less than 2%) and a low number of individuals in the catches and that among these, individuals smaller than 15 cm constitutes only a small proportion. Most of the bycatches in the fishery are larger than 15 cm and will hence be substantially reduced with the Excluder.

STECF concludes that the use of an Excluder device will likely result in reduced bycatch rates (in weight and number) and a maintained or improved exploitation pattern for bycatch species that grow larger than Norway pout (e.g. such as gadoids) compared with the sorting grid.