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Kennisvraag

De aanlandplicht is een van de speerpunten van het Gemeenschappelijk Visserijbeleid (GVB) en heeft als doel voedselverspilling tegen te gaan en de visserijsector te stimuleren om te verduurzamen door de hoeveelheid discards te reduceren. De aanlandplicht stelt dat alle discards van quota-gereguleerde soorten moeten worden aangeland. M.a.w. zowel maatse als ondermaatse, marktwaardige en niet marktwaardige vis moet aan boord gehouden worden en in de afslagen worden aangevoerd. Deze maatregel wordt stapsgewijs ingevoerd en is sinds 2016 voor de demersale visserij van kracht voor de doelsoorten en zal vanaf januari 2019 volledig, voor alles soorten, geimplementeerd zijn.

De invoering van de aanlandplicht leidt tot veel onbegrip in de visserijsector omdat ze er zowel ecologisch alsook economisch geen voordeel in zien. In tegendeel, de visserij verwacht dat de aanlandplicht juist een negatief effect zal hebben op de visbestanden, bijvoorbeeld doordat de vis die eerder het discarden overleefde, dat onder de aanlandplicht niet meer kan. De sector stelt dat door het verplicht aanvoeren van jonge vis de visserijsterfte op de populatie zal toenemen. Ook verwacht de sector dat de invoering economisch z'n weerslag zal hebben. In het in 2014 en 2015 door het Europees Fonds voor Maritieme Zaken en Visserij gefinancierde project Best-Practices I werden de mogelijke economische gevolgen, bijvoorbeeld extra kosten bemanning en opslag, al in kaart gebracht (Baarssen et al. 2015). Mede op basis hiervan geeft de sector aan dat de implementatie van de aanlandplicht in huidige vorm niet naleefbaar, handhaafbaar en uitvoerbaar is en heeft bij het ministerie van Landbouw Natuur en Voedselkwaliteit gevraagd om de noodzakelijke rek en ruimte te vinden. Om deze te vinden is een wetenschappelijke onderbouwing noodzakelijk.

VisNed tracht binnen het door het Europees Fonds voor Maritieme Zaken en Visserij (EFMZV) en door VisNed zelf gefinancierde project Best-practices II een wetenschappelijke onderbouwing te bieden voor de mogelijke gevolgen van en oplossingen voor de invoeringen van een aanlandplicht. Wageningen Marine Research (WMR) is gevraagd om de ecologische en economische gevolgen van de aanlandplicht voor de Nederlandse demersale sector inzichtelijk te maken. WMR heeft in samenwerking met Wageningen Economic Research (WecR) in de periode 2016 tot en met 2018 aan vijf onderzoeksvragen gewerkt:

1) Identificeren van clustering van hoge en lage vangsten van discards in ruimte en in tijd aan de hand van statistische analyse van discardvangsten. Deze resultaten moeten inzicht geven in de haalbaarheid om discards te verminderen door vermijding (aanpassen van visserij-activiteiten in ruimte en tijd) met daarbij het verlies aan marktwaardige vangsten te beperken (Bijlage 1).
2) Inzicht geven in de potentiele reductie van scholdiscards wanneer de minimuminstandhoudingsreferentiemaat voor schol verlaagt wordt van 27 cm naar 25 cm (Bijlage 2)
3) Evalueren van het effect van overleving op de bestandsschatting van schol en tong, en simuleren van toekomstige trends in visbestanden (schol en tong) onder verschillende aannames ten aanzien van overleving met en zonder aanlandplicht. (Bijlage 3a en 3b).
4) Ecologische en economische effecten in kaart brengen van het vergroten van de maaswijdte van 80mm naar 90mm voor een pulskotter door middel van het vergelijken van de vangstsamenstelling (lengte) aan boord (Bijlage 4).
5) Economische analyses op korte en op lange termijn om het verlies aan vangst aan markwaardige vis als gevolg van de aanlandplicht te kwantificeren, in combinatie met het al dan niet vergroten van de maaswijdte (Bijlage 5a en 5b).

Elke van de onderzoeksvragen zijn beantwoord in aparte Engelstalige rapportages. De rapportages bevatten een uitgebreide samenvatting en beschrijving van de methodiek en resultaten, en zijn als bijlage bij de briefnota toegevoegd. Deze briefrapportage geeft een korte Nederlandstalige wetenschappelijke samenvatting per onderzoeksvraag.

Ruimtelijke verspreiding van discards in de Nederlandse boomkor vloot.

Deze studie beschrijft de ruimtelijke verspreiding - en de temporele variaties ervan - van de discard-intensiteit, dit is het verwachte gewicht aan discards voor een standaard trek van een boomkor. De analyse is uitgevoerd voor zes belangrijke soorten voor de Nederlandse boomkorvisserij, zijnde schol, tong, wijting, schar, tarbot en roggen.

Voor elke soort wordt de ruimtelijke verspreiding (kaarten per kwartaal voor de periode 2013-2017) geschat met behulp van statistische modellen die rekening houden met ruimtelijke en seizoensafhankelijke correlatie. Daarnaast is er ook gekeken naar het effect van een aantal factoren gerelateerd aan geografie, habitat, temperatuur, maanfase en vismethoden op de discard-intensiteit. Data waren afkomstig van door Wageningen Marine Research uitgevoerde waarnemersreizen en het discard zelfbemonsteringsprogramma; alsook van het onder Best-Practices II visserijsector eigen disardbemonsteringsprogramma. De statistische modellen gaven inzicht in de ruimtelijk en temporele structuur van discards van een bepaalde soort. Hierdoor is het mogelijk een inschatting te maken over de afstand nodig om een hogere of lagere discard-intensiteit alsook de aan of afwezigheid van een soort in de discards per trek te maken (decorrelatie afstand).

De spreiding van de verwachte discards per trek voor schar was zeer variabel. Schar discards zijn met name hoog voor de zuidelijke kust van Nederland in kwartaal 1. In kwartaal 3 zijn schar discards laag voor de Nederlandse kust en hoog in de Duitse Bocht. In kwartaal 2 en 4 zien we een gevarieerde verspreiding van schar discards.

Scholdiscards hebben een meer stabiele ruimtelijke en temporele verspreiding met hoogste discard-intensiteiten waargenomen in het meest zuidelijke deel van de Noordzee (tussen Engeland, Belgische kust en Zeeland). Daarnaast wordt er af en toe een hot-spot waargenomen aan de Duitse Bocht. Schol discards zijn meestal lager in het Noordwestelijke deel van het bemonsterde gebied. De decorrelatie afstand voor schol is geschat op 90 km.
Voor tong werden geen discards in het Noordwestelijke deel van het bemonsteringsgebied waargenomen. De gehele zuidelijke kust van Nederland daarentegen is een hot-spot voor tongdiscards. Deze zone breidt zich nu en dan uit naar Engeland of de noordkust van Nederland.

Voor 2016 was de discard-intensiteit van tarbot in het algemeen laag. In 2016 begon de hoeveelheid discard toe te nemen, maar bleef in eerste instantie beperkt tot een klein gebied in de zuidelijke Noordzee. Discards namen geleidelijk toe naar een groter gebied in de zuidelijke en zelfs het centrale deel van de Noordzee. Hoewel het ruimtelijk voorkomen van discard toenam, was de discard-intensiteit in het noordelijke deel laag. De decorrelatie afstand voor tarbot werd geschat tussen de 116 km (discard-intensiteit) en 208 km (aan of afwezig in de trek).

Voor wijting is de verspreiding van de discards-intensiteit erg variabel, gekenmerkt door een toename in het 4de kwartaal. De decorrelatie afstand voor wijting werd geschat tussen de 85 km (discard-intensiteit) en 407 km (aan of afwezig in de trek).

Rog discards vonden voornamelijk in toenemende mate in het westelijk deel van de Noordzee plaats. Met name in het zuidwesten bij Engeland. De toename is discard-intensiteit is voornamelijk vanaf 2016 zichtbaar. De decorrelatie afstand voor wijting werd geschat tussen de 65 km (discard-intensiteit) en 244 km (aan of afwezig in de trek).

In het rapport worden de methoden en resultaten in meer detail toegelicht. Zo wordt er ook ingegaan op de invloed van de vismethode en natuurlijke elementen (temperatuur, maanfase) op discards. Ook worden de waargenomen verspreiding en temporele variabiliteit verder besproken in het licht van de beschikbare informatie over de verspreiding en migratie van de soort alsook de beheersmaatregelen die van invloed kunnen zijn op het discarden van een soort.

Effect van het reduceren van de minimummaat voor schol

Het doel van deze studie is het kwantificeren van de gevolgen van het reduceren van de minimum maat voor schol van 27 cm naar 25cm wat betreft het verminderen van discardhoeveelheden. Wageningen Marine Research werkt jaarlijks aan de bestandsschatting voor schol. Hiervoor wordt routinematig de totale hoeveelheid discards voor de Nederlandse vloot geschat. Data vanuit het discard monitoringsprogramma worden van trip niveau naar vloot niveau opgewerkt. Voor deze opdracht werden de discardgegevens uit 2013 tot en met 2017 gebruikt.

In het Nederlandse discard monitoringsprogramma worden de boomkor en bordenvisserij het meest bemonsterd. De lengteverdeling van schol discsards verschilt per metier, waarbij het grootste deel van schol kleiner dan 25 cm wordt waargenomen in de vlootsegmenten met kleine maaswijdten (boomkor 70-99, Ottertrawl 70-99, langoustine 70-99). Voor de boomkor 70-99 vloot was in de geanalyseerde periode gemiddeld 81% van de schol kleiner dan 25 cm. Voor de boomkor met grotere mazen (100-119 en >120) was dit gemiddeld minder dan 50%.

Voor de visserij op Noorse kreeft zien we van 2015 een forse afname van de hoeveelheid schol discards, echter het lengtebereik blijft hetzelfde.
De conclusie van deze studie stelt dat het verlagen van de minimum maat naar 25 cm theoretisch een reductie van ongeveer 6460 ton in volume aan schol discards kan opleveren. Dit staat gelijk aan een reductie van 23.5% aan schol discards in de Nederlandse demersale vloot.

Effect van overleving van discards op Noordzee schol en tong

In dit onderdeel is WMR gevraagd te kijken naar de effecten van overleving van discards binnen de huidige bestandsschattingen en perceptie van het tong- en scholbestand in de Noordzee. Voor beide bestanden zijn scenario's variërend van een overlevingspercentage van 0% tot 100% (in stappen van 10%) doorgerekend. Het overlevingsscenario van 0% is in feite dezelfde aanname als toegepast in de huidige bestandsbeoordelingen. Onder de verschillende scenario's werden de fracties dode discards opnieuw berekend en de bestandsmodellen opnieuw gedraaid zodat de bestandsbeoordeling voor schol en tong gecorrigeerd werd voor de overleving van discards. Voor de verschillende scenario's hebben we veranderingen voor de belangrijkste parameters zoals paaibiomassa, visserijsterfte en aanwas geanalyseerd en zijn nieuwe referentiepunten (Fmsy) berekend. Vervolgens werd voor de voor discard-overleving gecorrigeerde bestandsbeoordelingen een voorspelling over een periode van 50 jaar (2017 – 2066) gemaakt onder de aanname van een aanlandplicht en een discard scenario (business as usual). Deze simulatie toont het effect van discard-overleving onder het business as usual scenario alsook het effect van de aanlandplicht waarin alle ondermaatse vis wordt aangevoerd.

De trend en de perceptie van beide bestanden veranderen niet wanneer rekening wordt gehouden met een overlevingspercentage voor discards. Echter, de totale biomassa van het bestand, visserijsterfte en aanwas worden overschat binnen de huidige (0% overleving) bestandsbeoordeling. De grootte van het effect op de bestandsparameters wordt groter naarmate een hogere discard-overleving wordt gemodelleerd, en is ook afhankelijk van natuurlijke kenmerken van het bestand, zoals de leeftijd waarop ze paairijp zijn, en de hoeveelheid waarmee het bestand daadwerkelijk gediscard wordt. Het effect van discard-overleving is groter voor schol in vergelijking met tong.

Ook is Fmsy voor de verschillende overlevingskansen voor een scenario met en zonder aanlandplicht bepaald. De analyse laat zien dat Fmsy toeneemt met hogere discard-overlevingspercentages. De toename is het best zichtbaar onder het scenario waarbij discarden is toegestaan. Uit de berekeningen blijkt dat er onder de aanlandplicht minder variatie voor Fmsy zichtbaar is. Dit komt omdat we onder de aanlandplicht aannemen dat alle vis meegenomen wordt en dus geen overlevingskansen heeft.

In het onderzoek werden ook de lange-termijn effecten van beide scenario's (business as usual en aanlandplicht) op de vangsten, aanwas, paaibiomassa en visserijsterfte geëvalueerd. Hierbij werd de aanname gemaakt dat de bestanden in de toekomst op Fmsy geexploiteerd zullen worden. De eerder verkregen Fmsy waarden werden dus toegepast in de bestandsschatting om zo de maximale opbrengst onder de verschillende scenario's te kunnen bepalen. Verschillen tussen scenario's nemen toe naarmate er een hoger discard-overlevingspercentage gehanteerd wordt in het model. De verschillen tussen beide scenario's zijn groot voor schol, maar marginaal in de simulatie van tong. De simulaties laten voor verschillende overlevingspercentages duidelijk minder schol aanvoer zien onder de aanlandplicht in vergelijking met het business as usual scenario. Ook zijn er meer dode discards onder de aanlandplicht, wat logisch is omdat vissen geen kans hebben om te overleven en met de vangst aangevoerd worden. Echter, onder het business as usual scenario mag er vis gediscard worden welke afhankelijk van het overlevingspercentage een kans heeft om te overleven. Hierdoor treed er minder visserijsterfte op bij de jonge gediscarde vis en mag er een hogere visserijsterfte op de marktwaardige vis (vaak oudere leeftijden) gerealiseerd worden in vergelijking met het aanlandplicht scenario. Als gevolg van de hogere toegestane visserijsterfte onder het business as usual scenario's zullen er meer vangstmogelijkheden voor de visserij realiseerbaar zijn. Echter, de paaibiomassa zal hierdoor wel afnemen (paairijpe schol wordt harder bevist) en lager zijn dan onder een aanlandplicht scenario.

Een belangrijke aanname in het onderzoek is dat overlevingspercentages niet leeftijd of lengte afhankelijk zijn. Het huidige overlevingsonderzoek laat nog geen leeftijd of lengte specifieke overleving zien. Indien er in de toekomst wel data beschikbaar komen, zou de impact hiervan bestudeerd kunnen worden, gebruik makend van de in dit onderzoek ontwikkelde methodiek.

Invloed van aanpassingen van de selectiviteit in de kuil voor tong en schol in de Noordzee pulskor visserij.

De Nederlandse tongvisserij met de traditionele boomkor met wekkerkettingen is grotendeels vervangen door de puls visserij die gebruik maakt van elektroden die stroomstootjes afgeven. Wageningen Marine Research is gevraagd experimenteel onderzoek te doen naar maaswijdteselectie van de pulskor. Hierbij wordt gekeken naar de effecten van het vergroten van de conventionele 80 mm maaswijdte in de kuil naar 90 mm op vangsten van tong en schol.

In 2017 hebben twee vergelijkingsreizen plaatsgevonden waarbij stuurboord en bakboord voorzien werden van een tuig met een verschillende maaswijdte voor de kuil. Daarnaast werd ook gebruik gemaakt van een overkuil met fijnere mazen (40 mm) om inzicht te krijgen in de totale aantallen vis die door het net is gegaan. Deze methode stelt ons in staat om de selectie-curves van een kuil met 79-80 mm en 87-88 mm te schatten.

Het vergelijkingsonderzoek laat zien dat met de conventionele maaswijdte de lengte waar 50% van de individuen in het net behouden blijven (L50) 19 cm bedraagt voor tong met een selectiebereik (SR) van 4.9 cm. Gezien de waargenomen lengteverdeling van de tong in de vangst resulteert dit in een verlies van 10% van marktwaardige tong met een lengte tussen 24-27 cm in de vangst. Tijdens de eerste vergelijkingsreis werd voor het net met grotere mazen een gemiddelde maaswijdte naar 87 mm vastgesteld. Dit resulteert in een L50 van 22 cm met een SR gelijk aan 4.9 cm. In de tweede reis werd een gemiddelde maaswijdte van 88 mm gemeten wat resulteerde in een L50 van 26 cm en SR van 4.9. Als gevolg van de grotere mazen was het verlies aan marktwaardige tong 24% in de eerste en 38% in de tweede vergelijkingsreis. Het verlies van marktwaardige tong werd voornamelijk geconstateerd voor tong met een lengte tussen 24 en 33 cm.

In vergelijking met tong, heeft schol een steilere selectiecurve. Wanneer gevist wordt met de conventionele 80 mm kuil kent schol een L50 van 14.4 cm (SR = 2.5) in reis één en 14.1 cm (SR = 2.1) in reis. Voor de netten met een grotere maaswijdte verschuift L50 naar 15.6 cm (SR = 2.5) en 18.7 cm (SR = 2.1) voor reis 1 en 2 respectievelijk.

Naast de selectiecurves is ook de verhouding scholdiscards per kilogram marktwaardige tong bepaald. Dit geeft weer hoe scholdiscards zich verhouden ten opzichte van marktwaardige tong. Indien de ratio groter is als 1, wordt er meer schol gediscard dan er marktwaardige tong wordt gevangen. Voor de eerste reis, was de ratio gelijk aan 0.4 kg scholdiscards per kilo marktwaardige tong gebruik makend van 80 mm kuil. De ratio nam toe naar 0.5 kg met een kuil van 87 mm. In de tweede reis waren deze verhoudingen groter, met een ratio van 2.3 kg voor het conventionele kuil en 2.5 kg wanneer 88 mm werd gebruikt.

Concluderend, het vergroten van de maaswijdte naar 90 mm zal niet direct de oplossing bieden om scholdiscards te reduceren. Naast het verwachte economische verlies door verlies aan marktwaardige tong, laat de ratio scholdiscards per kilogram marktwaardige tong zien dat het vergroten van de maaswijdte er zelfs toe leiden dat er meer schol (>24 cm) gediscard zal worden wanneer de totale toegestane vangst (TAC) voor tong volledige benut wordt door de vloot.

Simuleren van toekomstige trends in visbestanden onder aangepaste selectiviteit en overleving.

Deze studie evalueert de invloed van een veranderde selectiviteit van de visserij (verdeling van visserijsterfte over de leeftijden) op bestandsontwikkelingen, vangsten, aanvoer en discards van tong en schol. Hiervoor werden lange termijn simulaties zoals ontwikkeld in het onderzoek naar de effecten van overleving voor de bestandsontwikkeling toegepast. In de stochastische simulaties werden de exploitatiepatronen van de visserij aangepast aan de hand van resultaten uit selectiviteitsonderzoek (80 cm naar 90 cm) om zo de consequentie van veranderende maaswijdte weer te geven. Vervolgens werden projecties over 50 jaar gemaakt waarbij naast de aangepaste selectiepatronen ook drie overlevingsscenario's werden gebruikt. De overlevingsscenario's bestonden uit 0% overlevingskans, en de boven- en ondergrens van de huidige schattingen van de overlevingskansen. Voor schol en tong zijn de afgeronde boven en ondergrens respectievelijk 10 en 20% en 10 en 30%.

De verschillen in het effect op tong en schol van het gebruik van een 90 mm kuil zijn gerelateerd aan zowel het directe effect van het exploiteren van de bestanden met een ander exploitatiepatroon als aan de verschillende toegekende Fmsy-waarden. De effecten van het veranderen van de maaswijdte zijn groter voor tong dan voor schol, omdat het aandeel van de aangelande vangsten van de Nederlandse boomkorvaartuigen die momenteel met 80 mm vissen veel groter is voor tong dan voor schol. De voordelen (op de middellange en lange termijn) van het gebruik van een 90 mm-kuil zijn het grootst voor de 0% en 10% overlevingshypothesen (huidige ondergrens overlevingskans tong), maar zijn kleiner voor de aanname waarbij 30% van de discards overleeft (huidige bovengrens overlevingskans tong). Hoe groter de overlevingskans, hoe minder het loont om de selectiviteit van het vistuig te vergroten want met een hogere overleving hebben gevangen en gediscarde vis sowieso een grotere kans verder te groeien en een bijdrage te leveren aan de reproductie van het bestand.

Voor schol is Fmsy voor het 90 mm-net hoger dan voor het 80 mm-net in de scenario's met 0% en 10% overleving. Als gevolg van een hogere Fmsy mag er een hogere visserij-inspanning plaats vinden en worden vangsten, aanvoer en (ondanks de verbeterde selectiviteit van het net) discards hoger, maar wordt de omvang van het bestand lager als het 90 mm-net wordt gebruikt. Voor het scenario met 20% overlevingspercentage is Fmsy vergelijkbaar voor de maaswijdte van 80 mm en 90 mm. De verbeterde selectiviteit van het 90 mm-net resulteert dan in wat minder discards, wat op middellange en lange termijn resulteert in een iets groter bestand met iets hogere aanvoermogelijkheden.

Een belangrijke aanname in het onderzoek is dat de bestanden in de toekomst op Fmsy worden geexploiteerd. Echter, als de boomkorvloot naar 90 mm kuil zou overschakelen, zal de vangbaarheid (in ieder geval voor tong) afnemen. Dit wil zeggen dat er een hogere visserij-inspanning nodig zal zijn om dezelfde visserijsterfte op het bestand te verkrijgen. Het huidige onderzoek modelleert de vangbaarheid en visserij-inspanning niet expliciet en kan daardoor de mogelijke verandering van de visserij-inspanning niet kwantificeren wanneer de bestanden op Fmsy met het 90 mm-net zouden worden geëxploiteerd.

Economische analyses.

Verkenning van 80 naar 90 mm maaswijdte - korte termijn

Deze studie kijkt naar de korte termijn economische gevolgen van een mogelijke transitie van een 80 mm naar een 90mm kuil bij puls kotters onder de aanlandplicht. Er wordt gebruik gemaakt van de resultaten uit het experimentele selectiviteit onderzoek ook uitgevoerd in dit project. Door gebruik te maken van de beschikbare selectiviteitscurves voor schol en tong onder 80 en 90 mm kon de selectiviteit, vangstsamenstelling en hoeveelheid discards bepaald worden. Met behulp van economische informatie over afslagprijzen, olieverbruik, bemanningskosten etc... kon het jaarlijkse rendement per kotter berekend worden.

Voor de eurokotters (< 300pk) resulteert het vissen met 90 mm in een afname van 20% van de totale jaarlijkse besomming (= waarde van de vangst zonder aftrek van kosten). Het verlies aan maatse tong (ca. 27%) wanneer er met 90mm gevist wordt, is hierin een cruciale component. Daarentegen wordt er met 90 mm wel 35% minder ondermaatse schol gevangen. Echter, onder de aanlandplicht, zal de afname in kosten voor het verwerken van ondermaatse schol economisch niet opwegen tegen het verlies aan besomming door middel van de verkoop van maatse tong. Als gevolg zien we dat onder de aanlandplicht er per schip een groter negatief economisch resultaat geboekt wordt met 90 mm (- € 396.487) in vergelijking met 80 mm (- € 220.018).

De grote pulskotters (> 300pk) verliezen ongeveer 29% aan maatse tong en 25% aan schol discards wanneer er met 90mm gevist wordt. Dit resulteert in een 16% afname van de totale jaarlijkse waarde van de vangst (zonder aftrek van kosten). Onder de aanlandplicht, zou voor een kotter met 80mm nog een positief economisch resultaat behaald kunnen worden (€ 240.369). Echter, voor dezelfde kotter maar gebruik makend van een kuil met 90mm zou dit naar negatief economisch resultaat omslaan (- € 52.269).

Het is het belangrijk te weten dat de berekeningen voor zowel euro als grote pulskotters gebaseerd zijn op economische resultaten uit het project Best Practices I. Dit betekent 2 fte extra per schip. Echter, economische resultaten uit Best Practices II wijzen uit dat er gemiddeld 3.6 fte per schip nodig is om de werklasten aan boord gelijk te houden. Concluderend, een transitie van 80mm naar 90 mm zal op de korte termijn negatieve economische gevolgen kunnen hebben voor de vloot en is daarom geen interessant alternatief voor de boomkor vloot.

Combinatie aanlandplicht, overlevingskansen van discards, en 80 versus 90 mm maaswijdte – korte en middellange termijn

Wageningen Economic Research (WecR) werd gevraagd om de korte (1-3 jaar) en middellange-termijn (9-11 jaar) effecten van de aanlandplicht voor de Nederlandse boomkor vloot door te rekenen, waarbij rekening gehouden werd met de overlevingskansen van discards alsook innovaties met betrekking tot selectiviteit (bijv. het gebruik van een 90 mm kuil).

Er is gebruik gemaakt van een bio economisch model (SIMFISH, Bartelings et al. 2015)) waarin een terugkoppeling tussen de biologie (visbestanden) en economie (vloot dynamiek) verwerkt is zodat een analyse van langere termijn effecten mogelijk wordt. Het model bevat vijf aan elkaar gekoppelde elementen: vloot dynamica, visprijzen, investeringsgedrag, populatie dynamica en visserijbeheer. SIMFISH werd toegepast op de Nederlandse boomkor vloot (12-24m, 24-40m en > 40m) op schol, tong, tarbot en garnalen. Schol, tong en garnalen werden direct gemodelleerd, tarbot daarentegen werd gezien als bijvangstsoort en kreeg een vaste waarde voor de vangst per inspanningseenheid. Het model is gekalibreerd met data uit 2013 – 2015. Scenario's met betrekking tot de aanlandplicht of veranderingen in selectiviteit gaan in vanaf 2019 en projecties voor 12 scenario's zijn gemaakt tot 2030.

De 12 geëvalueerde scenario's omvatten combinaties tussen aanlandplicht (aan/uit), overleving (0%, boven- en ondergrens) en selectiviteit (80 of 90mm maaswijdte). De twee aanlandplicht scenario's bestaan uit een volledige implementatie (LO) of implementatie met volledige uitzonderingen (no LO). Onder LO worden er extra kosten voor het verwerken en bewaren aan boord alsook aanvoeren van discards meegenomen, maar worden er ook extra inkomsten gerekend vanwege de verkoop van de aangevoerde ongewenste vangst. Deze kosten zijn gebaseerd op onderzoekresultaten vanuit Best Practices I. De projecties houden dus geen rekening met de economische resultaten verkregen uit Best Practices II. Zo is er gerekend met 2 fte extra per schip in plaats van de 3.6 fte per schip. Daarnaast werd voor kleinere schepen (12-24m) extra tijd op zee aangenomen omdat ze vanwege hun beperkte opslagcapaciteit meer heen en weer zouden stomen tussen de visgronden en aanvoerhavens. Verder, zijn er drie overlevingsscenario's gedefinieerd: 1) Een scenario met 0% overleving (huidige aanname bestandsschattingen), 2) bovengrens en 3) ondergrens van de overleving voor schol en tong. De waarden voor de boven- en ondergrens van de discardoverlevingspercentages zijn schattingen afkomstig van het overlevingsonderzoek van WMR (Schram en Molenaar, 2018). Deze waarden werden afgerond naar 10-20% voor schol en 10-30% voor tong zodat gebruik gemaakt kon worden van de modelresultaten (paaibiomassa, Fmsy) uit het onderzoek naar de effecten van overleving op de bestandsontwikkeling. Als laatste werden twee selectiviteitsscenario's gedefinieerd, waarbij één scenario uitgaat van 80 mm maaswijdte (huidige toepassing) en een tweede uitgaat van een vloot vissend met 90 mm mazen. Met 90 mm werd de vangbaarheid per leeftijd voor schol en tong gecorrigeerd (lage vangsten).

<u>Effect aanlandplicht</u>

De implementatie van de aanlandplicht zal weinig invloed hebben op de visbestanden schol en tong. Er wordt bijna geen effect of schol waargenomen, maar voor tong is er een kleine toename van maximaal 6% in biomassa na 10 jaar. De LO zal wel een blijvende invloed hebben op de Nederlandse boomkor vloot. De 12-24m boomkor vloot zal minder gericht op tong en schol vissen, maar de inspanning verschuiven richting garnalen. Ondanks de verwachte lagere aanvoer van platvis en een afname in de prijs van garnaal (wegens elasticiteit) zullen er hogere opbrengsten gegenereerd worden. De toename in opbrengst van de verkoop wordt echter teniet gedaan omdat er ongeveer 27% extra brandstofkosten gemaakt worden als gevolg van extra stoomtijd die nodig is om de extra aanvoer van ongewenste vangsten te moeten lossen (capaciteitsprobleem aan boord). Voor de 24-40 m vloot zien we behoudt van de visserij activiteiten en schakelt slechts een deel van vloot de activiteit om van garnalen naar platvis. De extra kosten voor de aanvoer van ongewenste vangst leiden tot slechtere economische prestaties. De toevoeging van 2 bemanningsleden om de extra aanvoer van ongewenste vangst te verwerken en lossen leidt tot hogere arbeidskosten daarnaast zal de compensatie per bemanningslid gemiddeld 17 tot 20% lager komen te liggen. Voor het >40m segment laten de projecties een 10 tot 15% afname van de vloot zien binnen 10 jaar zonder LO. Ook laten de projecties ongeveer 10% toename aan visserijinspanning per schip zien wat resulteert in 10 tot 20% hogere aanvoer van tong en schol en dus hogere opbrengst. De hogere opbrengst wordt echter gecompenseerd door de extra kosten (brandstofkosten 10 tot 20% hoger Figuur 4.5) en extra kosten in verband met de aanvoer van extra vis.

Effect overleving

Wanneer overleving in het verleden is onderschat (en daarmee de bestanden overschat) zou de implementatie van de aanlandplicht een negatief ecologisch en economisch effect hebben. De oorzaak hiervan is dat onder een volledig ingevoerde aanlandplicht het positieve effect van overleving van discards teniet gedaan wordt.

Effect selectiviteit

Wanneer een maaswijdte van 90mm gebruikt wordt, veranderd de vangstsamenstelling. Er wordt voornamelijk minder schol en tong gevangen. Om het verlies aan vangst te compenseren zal de vloot meer visserijinspanning moeten leveren om het beschikbare tong-quotum op te vissen. Vooral het >40m segment zal 50 tot 70% meer tijd op zee zouden doorbrengen, wat leidt tot hogere brandstofkosten en lagere compensatie van de bemanning (-10 tot -15%). De winstgevendheid van de vloot wordt met 30% verminderd, maar blijft positief uitgaande van 2 extra fte. De combinatie van 90 mm en LO leidt tot een hogere beschikbaarheid aan quota per kotter waardoor minder schepen de vloot zullen verlaten. Daarnaast zal de extra visserij-inspanning leiden tot meer ongewenste ecologische effecten doordat er meer bijvangst en een hogere bodemimpact (slepen van de netten over de bodem) gegenereerd zal worden.

Limitatie en aanbevelingen

Het onderzoek naar de lange-termijn economische effecten is slechts op het einde van het project voltooi geweest. SIMFISH projecties maakten gebruik van resultaten uit de andere werkpakketten waaronder het selectiviteitsonderzoek alsook het effect van overleving op de bestandsschattingen. Echter, informatie over de extra arbeid die nodig was om de extra aanvoer van ongewenste vangst aan boord te sorteren en te verwerken, werd uit Best Practices I gehaald. Schattingen van deze economische kosten voor de vloot in Best Practices II laten zien dat de verwachte kosten twee keer zo hoog zijn (VisNed, niet-gepubliceerde gegevens). Dit heeft belangrijke implicaties voor zowel de economische prestaties van de vloot (extra kosten) als voor de sociale aspecten (zou er een verlies van salaris zijn? Hoe zou het zijn om extra bemanning aan boord te hebben?). Het is ook belangrijk te weten dat de uit dit project verkregen gegevens en kostenstructuur van de Nederlandse demersale vloot gebaseerd zijn op de puls visserij. Echter, volgens Europees besluit zal deze visserij techniek na 2021 niet meer worden toegestaan. Om een realistisch beeld te krijgen van de economische gevolgen voor de vloot, zouden de hier verkregen resultaten moeten worden aangepast in lijn met de alternatieve visserij technieken welke in de nabije toekomst door de vloot toegepast zullen worden.

Deze studie is een modelstudie naar de lange-termijn economische gevolgen van de aanlandplicht waarbij gebruik gemaakt wordt van een deterministisch model en wat-als-scenario's. Het is belangrijk te weten dat de resultaten projecties zijn en geen voorspellingen. Daarom moeten resultaten van de verschillende scenario's niet op zich zelf bekeken worden maar moeten deze onderling worden vergeleken. Door de verschillende werkpakketten in Best Practices II zijn er veel nieuwe gegevens beschikbaar gemaakt en als input gebruikt voor het model. Hoewel deze nieuwe parameters veel nieuwe informatie aandragen, vragen de data ook voor een gevoeligheidsanalyse; deze kon echter niet binnen deze studie uitgevoerd worden.

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Spatial distribution of the discards of the Dutch beam trawler fleet

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Contents

Summary

This study aims at describing the spatial distribution – and its temporal variations - of discarding intensity (i.e. expected weight of discards for a standard trawl haul) for the 6 main species discarded by the Dutch beam trawl fisheries.

For each species, the spatial distribution (quarterly maps for the period 2013 to 2017) is estimated using statistical models that take spatial and temporal correlation into account, which also allowed to test for the effect of a number of factors related to geography, environment, fishing practices and operational aspects on discarding. The data used to fit those models came from the observer trips and self-sampling program conducted at Wageningen Marine Research and from discards sampling trips conducted by the fishing industry. As by-product, the models provide descriptors of the temporal and spatial scales at which the discards of a given species are structured.

The distribution of the expected discards per haul for dab was highly variable from quarter to quarter, with generally high discarding intensity in front of the southern coast of the Netherlands in quarter 1, a discarding intensity which is high on the German bight and low in front of the Dutch coast in quarter 3, and variable distributions for quarter 2 and 4.

For plaice, the distribution was more stable, with high values consistently observed in the south of the area (between the south of the Netherlands and England), with occasional hot spots on the German bight.

For sole, discards were not observed on the north-western part of the area, and a hotspot of sole discarding was found consistently in front of the southern coast of the Netherlands, occasionally expanding towards England or to the northern coast of the Netherlands.

Discarding of turbot first occurred with a low intensity along the coast from Belgium to Germany. After the fourth quarter of 2015, high discarding started to occur, first limited to the small area in the southern North Sea, but progressively expanding to a larger area in the southern and central part of the North Sea, while discarding intensity remained low in the northern part of the area and in front of England.

The distribution discarding intensity for whiting was highly variably, characterised by hotspots suddenly appearing for most years in the fourth quarter, and disappear in the following first quarter.

Discarding of rays occurred mainly in the western part of the area, especially in front of southern England, with an increasing level since the fourth quarter of 2016.

The distributions observed and their variability were further discussed in the light the available information on the distribution and migration of the species and on the management measures potentially influencing discarding.

1 Introduction

Discarding is one of the main issues in demersal fisheries. It can occur for a variety of reasons, involving the spatial overlap of unwanted fish (undersized individuals, non-targeted species of insufficient commercial value, ...) with the targeted fish, the fishing gear used (and its selectivity) and fishing strategies or quota availability, among others.

This study specifically focusses on the spatial distribution of the discards for some of the main species caught by the Dutch beam trawler fleet. The central question was to determine whether discards display any specific spatial structure or if they occur randomly in space. In addition, if indeed discards are structured spatially, the study also needed to propose a descriptor of the scale of this structuration. Finally, a description of the temporal variability of this distribution should also be provided. Such a characterisation of the geographical distribution of discards can provide information that can potentially help the industry reducing discards, such as avoiding recurrent areas of high discarding (hot spots), assess the necessary distance to steam away from areas where discarding is high, assess how long discarding hot-spots persist and should therefore be avoided.

Aside from spatial aspects, this study also investigated the influence of a range of factors related to geography, environment, fishing practices and operational aspects on discarding.

These questions were addressed by the mean of spatial-temporal modelling of discard data collected during 3 different sampling programs. This type of method is frequently used to extract information on spatial distribution and the effect of other factors from data with high variability as it is often the case for fisheries data. That is for the example the case for abundance indices from scientific surveys, which can be estimated as year effects in spatio-temporal models (e.g. Jansen et al, 2015). Such methods have also been used on discards (Feekings et al 2012) or bycatch (Cosandey-Godin et al, 2015) data to identify spatial patterns

A new statistical framework was used here to model the spatio-temporal distribution of the discarding intensity of the Dutch beam trawlers and investigate the influence of a number of explanatory variables. The data used came from three different data collection programs : the scientific observer trips and the self-sampling program available at WMR and discard trips conducted by the industry in the context of this project.

Models are fitted separately for the main species of interest. The response variable analysed corresponds to the discarding intensity, which can be viewed as the average weight of discards of each given species occurring during a standardised fishing operation. Therefore the maps produced do not represent the spatial distribution of the total discards of the fleet, which also depends on the total fishing effort and its distribution in time and space, but rather maps of the expected discard weight for a single haul.

2 Data

The discards data used in this study came from 3 data collection program :

- The scientific observers program run at WMR
- The discard self-sampling program run at WMR
- The discard trips conducted by the industry in the context of Best Practices II.

The data set collated covered the period 2013 to 2017, and contained data from a total of 561 trips during which a total of 2042 hauls were sampled. The data from the 3 programs were collected following different sampling strategies. For the self-sampling program, every fortnight, 7 vessels are chosen randomly (out of a pool of around 22 vessels) and each take samples from 2 hauls. The number of trips sampled is therefore large with respect to the number of hauls sampled (table 1). For the observers program, data is collected for a smaller number of trips (6 to 8 per year), but the sampling intensity per trip is higher. This results in a different spatial distribution of the hauls sampled, with samples taken during observers trips being usually more clustered in space than samples from the self-sampling program (figure 1). The discard trips conducted by the industry provide data only since 2016. The number of trips conducted per year is lower than for the observers program, but the number of hauls sampled per trip is higher: every haul of the entire trip was sampled in the industry program, so that maximum spatial resolution was obtained.

Table 1 : number of trips and hauls sampled per year and per data collection program

	Number of trips sampled			**Number of hauls sampled**		
year	**industry**	**observer**	**Self-sampling**	**industry**	**observer**	**Self-sampling**
2013		7	85		124	171
2014		6	115		106	228
2015		7	94		137	188
2016	5	8	114	165	179	227
2017	3	7	110	158	142	217

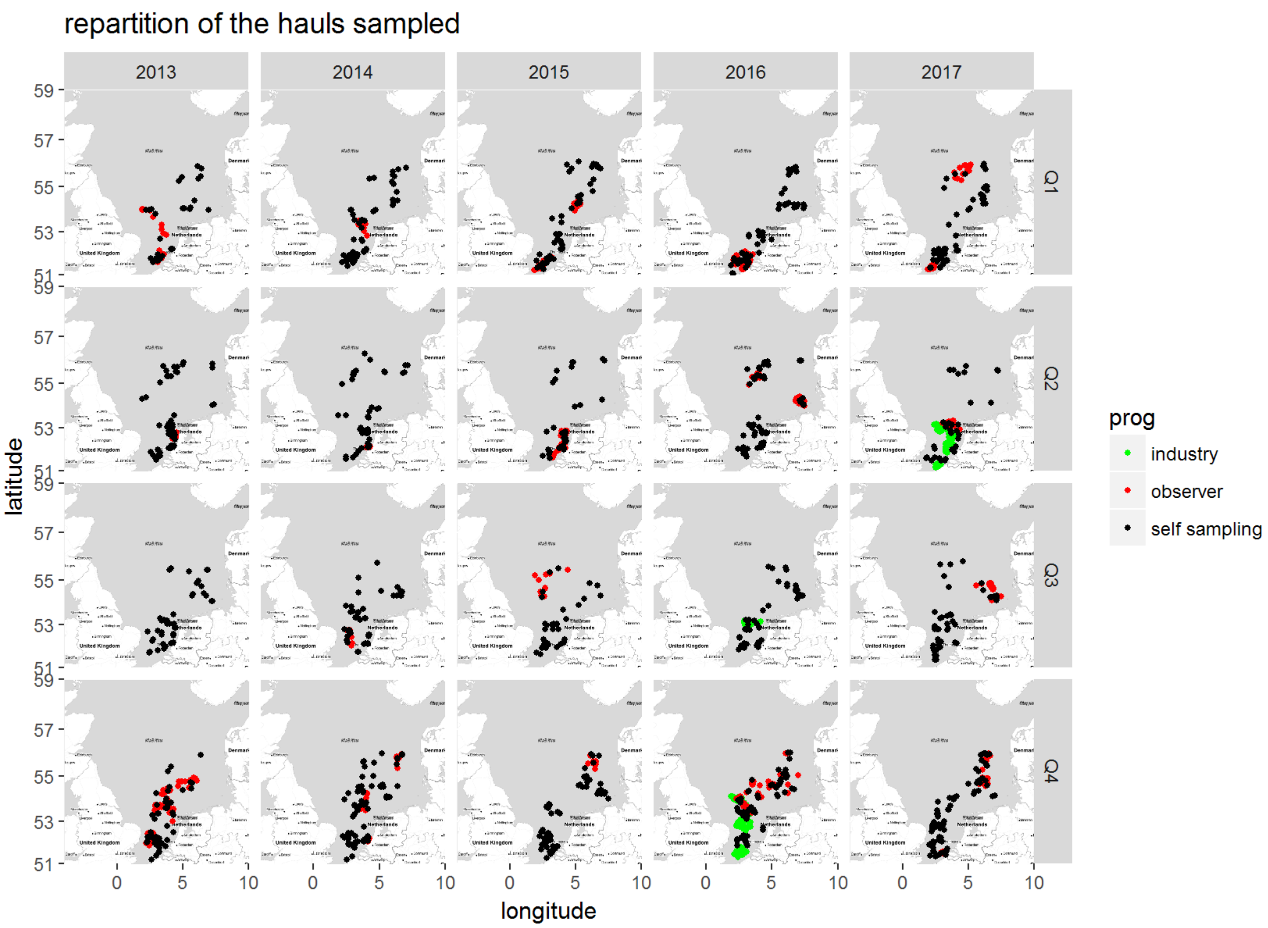


Figure 1 : distribution of the hauls sampled per year, quarter and data collection program

For the data collected by WMR, the raw data consisted in the number of fish caught per length class and per species for each trawl haul sampled, together with a number of variables related to the trawl haul (position, duration, bottom track, total catch of the haul) or related to the vessel (size, power, gear specifications). The raw data was aggregated in order to obtain a total catch per haul expressed both in number or in weight of fish, for the main species of interest (cod, dab, haddock, whiting, plaice, rays, turbot, brill, sole). Only the fraction of the discards corresponding to fish below the Minimum size were kept in this calculation (except for the rays, for which all sizes were kept).

The data from the industry trips was provided already aggregated in number or weight of fish discarded per haul, with the same complementary information as for the data from WMR.

In addition to the information available from the data bases, additional variables were added to the data based because they were considered (during project meeting with representatives of the industry) as potentially influencing the discarding intensity. These variables were : depth at shooting position of the haul, moon phase, bottom temperature, type of substrate. These variables were taken from data bases available online, from which the specific values for the location and time of each haul were extracted.

The main species discarded were dab and plaice, both with over 100kg on average per haul (figure 2), and almost discarded in 100% of the hauls sampled (figure 3). Discards of sole and whiting were found in around 70% of the hauls, but with much lower weight per haul than plaice and dab (around 8kg/haul). Other species were found less frequently in the discards (from 35% for the rays and turbot to around 10% for cod and brill, haddock was almost never discarded).

Because these species are less abundant and common in the discards, no spatial analyses were carried out for cod, brill and haddock.

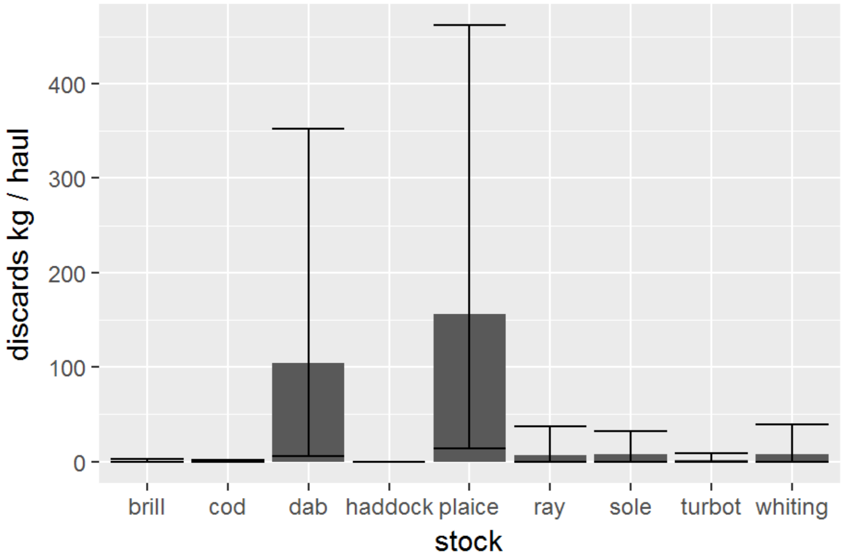


Figure 2 : mean discard weight per species (bars) with 5% and 95% quantiles of the distribution (error bars)

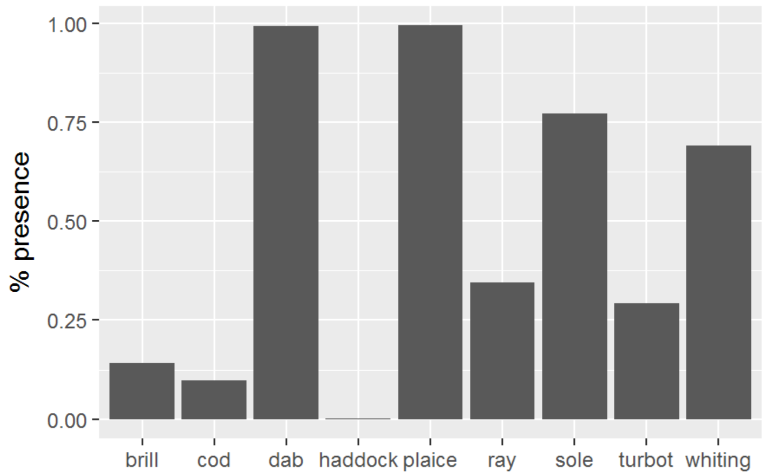


Figure 3 : proportion of the sampled hauls with discards for each species

3 Methods

3.1 Modelling approach

The discards in weight per haul were modelled using generalised linear model (GML) with spatial-temporal dependency. The models were fitted using INLA[1], a new computing effective method for Bayesian estimation, using the R package INLA. The spatial component in the model is represented by a Gaussian Markovian Random Field. This is a continuous Gaussian (spatial) field, in which correlation between nearby observations is estimated. This correlation between nearby located observations is represented using a Matern equation (mathematical expression in which correlation between observations decreases as a function of the distance between them). The estimated spatial component gives a representation of the spatial distribution of the data (i.e. a distribution map), when the effect of other factors is removed, and when the residual variability (according to the statistical distribution chosen) is removed.

When the data are collected in different periods of time (the case here) the model can be made more complex by the inclusion of temporal correlation (correlation of the successive values at a specific location). Temporal correlation was introduced here using a autoregressive model of order 1 (AR1). The model can then be thought of a combination of a GLM model with linear covariates, with a spatio-temporal latent process.

In addition to the spatial and temporal correlation structure, linear covariates were also incorporated in the model, as in a common GLM. The covariates investigated here were :

<u>Continuous variables</u>

- Duration of the haul
- Total catch of the haul
- Bottom depth
- Bottom temperature

<u>Discrete factors</u>

- Data collection program (observers, self-sampling or industry)
- Width of the beam trawl (4 or 12m)
- Type of beam trawl (conventional v.s. pulse)
- Moon phase
- Type of substrate

By using the duration of the haul as covariate, the effort corresponding to each haul is explicitly taken into account in the model.

3.2 Model formulation

Spatial models were fitted separately for each species. Owing to the difference in the statistical distribution of the discard weight values of the different species, and specifically the number of zero's (absence of discards in a given haul), different models were used depending on the species.

[1] integrated nested Laplace approximation

3.2.1 Stock with few zero's

For the species with few zero observations (5 for plaice and 8 for dab), the discard weight per haul were modelled using a Gamma model. A formal definition of the model is as follows:

$$y(s_i) \sim Gamma(\mu(s_i), \sigma^2)$$

$$\mu(s_i) = covariates(s_i) + \nu(s_i)$$

$$\nu(s_i) = \rho\ \nu(s_{i-1}) + u_i$$

$$u \sim GF(0, \Sigma)$$

The observed discard weight $y(s_i)$ for the i^{st} haul, taken on location s_i, , is distributed according to a Gamma distribution with a mean $\mu(s_i)$ and a variance σ^2. The mean is a linear function of covariates $covariates(s_i)$ plus a spatio-temporal correlation term $\nu(s_i)$ which follows an AR1 process with temporal correlation ρ and u_i is the Gaussian field (i.e. spatial distribution) for the time step in which observation *i* occurred.

3.2.2 Stock with many zero's

The analysis is complicated by the occurrence of exactly zero observations. It makes many statistical methods for continuous data inappropriate. For the species with many zero observations (sole, whiting, turbot and rays), a "delta-gamma" model approach was adopted. This approach consists in modelling separately the presence-absence using a binomial distribution and the positive data using a Gamma distribution (e.g. Bigelow, 2006, Lecomte et al. 2013). The expected discard weight is then obtained as the product of the probability of discard occurring times the expected discard weight for non-zero data.

A formal definition of the model is as follows:

$$y(s_i) \sim deltaGamma\left(\pi\ (s_i), \mu_{nonZero}(s_i), {\sigma_{pres}}^2, {\sigma_{nonZero}}^2\right)$$

$$\mu(s_i) = \pi\ (s_i)\ \times\ \mu_{nonZero}(s_i)$$

Where the expected discard weights $y(s_i)$ at the location s_i is the product of the probability of non-zero discard at location s_i, $\pi\ (s_i)$ by the expected discard weight for non-zero data $y_{nonZero}(s_i)$ with :

- The probability of non-zero discard, $\mathrm{pres}(s_i)$, modelled as a binomial distribution

$$\mathrm{pres}(s_i) \sim binomial\left(\pi(s_i), {\sigma_{pres}}^2\right)$$

$$logit(\mu(s_i)) = covariates(s_i) + \nu(s_i)$$

$$\nu(s_i) = \rho\ \nu(s_{i-1}) + u_i$$

$$u \sim GF(0, \Sigma)$$

- The discard weight for non-zero data modelled as above using the Gamma GLM :

$$y_{nonZero}(s_i) \sim Gamma(\mu_{nonZero}(s_i), {\sigma_{nonZero}}^2) \qquad \text{for } s_i \text{ with non-zero discards}$$

$$\mu_{nonZero}(s_i) = covariates(s_i) + \nu'(s_i)$$

$$\nu'(s_i) = \rho\ \nu'(s_{i-1}) + u'_i$$

$$u' \sim GF(0, \Sigma)$$

Other methods can be applied to biomass data set with zero data, such as compound Poisson-gamma models which were found to be more robust to deviations from model assumptions (Lecomte et al. 2013, Foster and Bravington, 2013). Such methods were not investigated here as they, to our knowledge, have never been applied in combination with the estimation of spatio-temporal correlation structure, as done here.

3.3 Model selection

The model selection approach consisted in building a series of models of increasing complexity, and choosing the best model on the basis of the lowest deviance information criterion (DIC). Given a collection of models for the data, DIC estimates the quality of each model by balancing the quality of the fit and the number of degree of freedom used, relative to each of the other models. The range of models tested were:

Model 1 : linear covariates

Model 2 : linear covariates + spatial structure

Model 3 : linear covariates + spatial-temporal structure with annual time steps

Model 4 : linear covariates + spatial-temporal structure with quarterly time steps

In addition, to take into account the fact that data collected from a same vessel might be correlated (e.g. due to difference of fishing efficiency between vessels) the model 1 to 4 were also run with vessel name as random effect.

The logNormal distribution was an alternative to Gamma distribution for modelling positive only continuous data (Dick, 2004). The choice of the Gamma distribution was made after fitting all the models using a logNormal distribution instead of a Gamma distribution and comparing the DIC. In all cases, the models with Gamma distribution performed better than with logNormal distribution

4 Results

4.1 Best models

For all species, the model with the lowest DIC was the model 4 (i.e with spatial distribution estimated quarterly) with random effects for vessels (except for the Gamma model for turbot and rays and the binomial model for sole and rays).

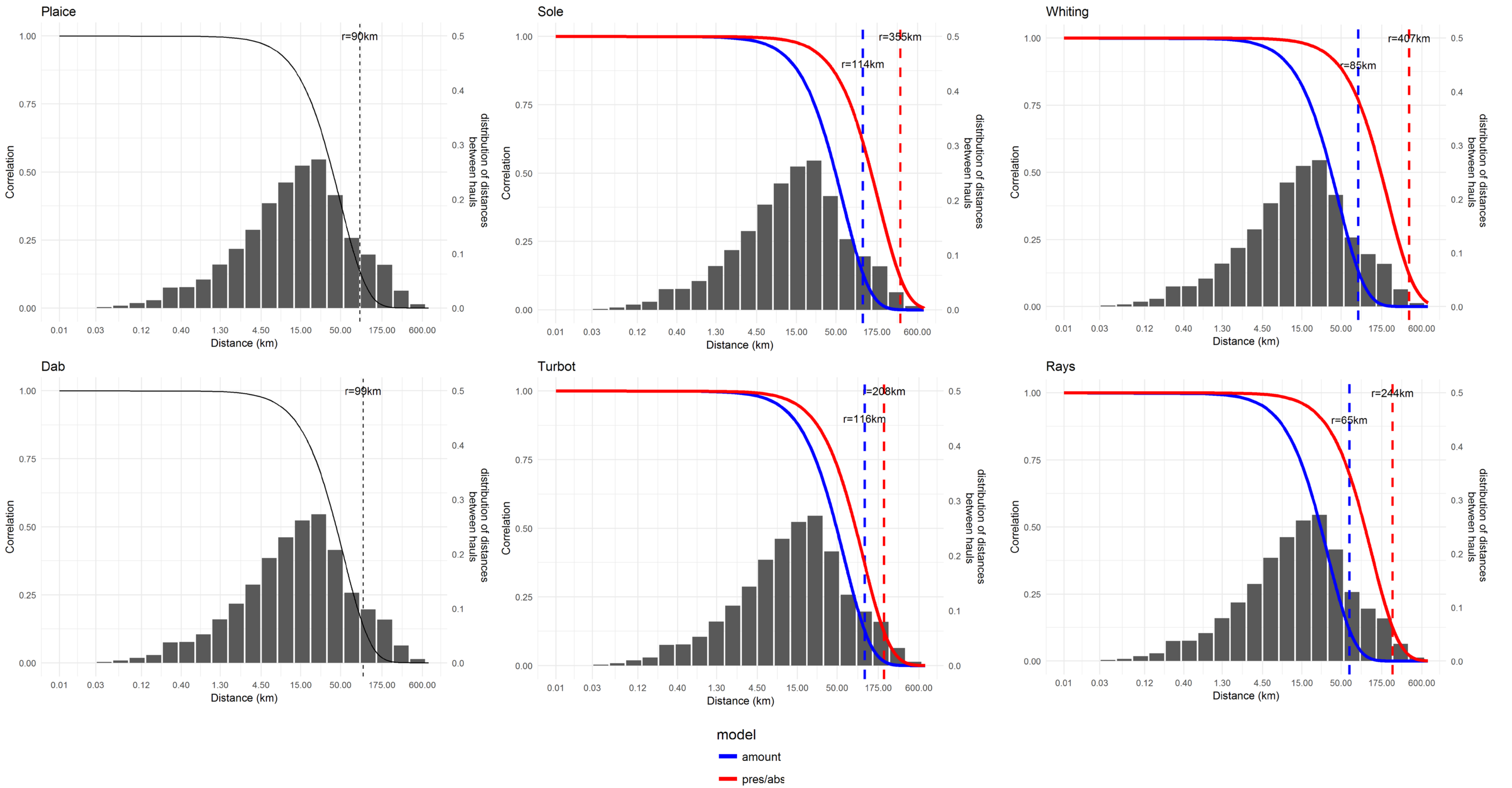
4.2 Spatial correlation

The spatial structure of the discards is estimated as a Gaussian process in which nearby observations are correlated according to a Matern covariance function. This function defines the covariance (i.e. correlation) between two contemporary (i.e. from the same quarter of the year) observations with respect to the distance separating the 2 observations. Following this function, a decorrelation distance can be defined, beyond which 2 observations are no longer correlated.

One of the parameters of the Matern function is the range, which corresponds to the distance where the correlation drops below 0.1. This estimated “decorrelation distance” is difficult to interpret concretely, but provides a useful descriptor to compare the degree of spatial correlation for different species. For the two species for which discards occur in every sampled haul, plaice and dab, the decorrelation distance is similar between 90 and 100km (table 2). For the species that do not always occur in the discards, the probability of occurrence is structured at a larger scale, with decorrelation distances varying from 208km for turbot to 407km for whiting. For these same species, the spatial structuration of the non-null observations is at a finer scale, particularly for rays (65km) and less so for sole and turbot (around 115km).

The value of the Matern function corresponding to the standard distance between two successive hauls is another, more concrete, descriptor of the spatial correlation in the discards. The histogram of the distances between successive hauls (based on the midpoints) show that successive hauls are typically 15 nm apart (bars on table 2). For this typical distance, the correlation for plaice and dab is high (0.65 and 0.70, respectively) which indicates that when a vessel has high (or low) discard for these species in one haul, it is usually also the case for the next haul. For the species that do not always occur in the discards, the probability of occurrence of discards in two successive hauls is correlated at around r=0.90 (for the typical distance between 2 hauls). This indicates that when a vessel is in an area where one of these species is found in (or is absent from) the discards, it is almost certain that the species will also occur in (or be absent from) the discards of the next haul. Correlation in the amount of discards (when discards a occurring) between two successive hauls 15 miles apart is high for turbot and sole (around 0.75), but lower for whiting and even more so for the rays (0.6 and 0.5).

Table 2 Matern correlation functions for the Gamma models for dab and plaice (black line) and for the presence-absence and gamma models for presence only for the other species (red and blue lines) with decorrelation distances (vertical lines) and distribution of the distances between the midpoint of successive trawl hauls (bars).



4.3 Temporal autocorrelation

Similarly to the decorrelation distance, the Gaussian latent process is also characterised by its temporal persistence, defined by the temporal autocorrelation in the AR1 process, ρ. Contrasting results are observed across species.

For the 2 species with the highest discards, dab has a low ρ value (table 3), indicating that the distribution of discards is susceptible to change substantially from one quarter to the next. The ρ value for plaice is higher, meaning that there is more stability in discards distribution between quarters.

Among the species modelled with the deltaGamma approach, all display a high ρ value (close to 0.90) for the presence-absence model, indicating that the spatial pattern of the probability of occurrence in the discards is very stable from quarter to quarter for these species. For the Gamma part of the model, sole and turbot show strong persistence of discard pattern through time (high ρ) while rays and whiting show highly variable distribution (low ρ).

Table 3 : estimated autocorrelation ρ in the AR1 process

MODEL	DAB	PLAICE	SOLE	TURBOT	RAYS	WHITING
BINOMIAL			0.98	0.88	0.87	0.93
GAMMA	0.37	0.69	0.89	0.78	0.26	0.04

4.4 Spatio-temporal distributions

The spatial-temporal component (Gaussian Markovian Random Field) estimated for all the models are presented in the annexes 1 to 6. The main features of these distribution and their variations are briefly described here.

4.4.1 Dab

Some patterns are observed recurrently from year to year. During the first quarter, high discarding intensity is generally observed in the southern part of the area (in front of the southern coast of the Netherlands, more rarely in front of the Wadden islands, as in 2017). Quarter 2 distribution is quite variable, with years with high discard values (e.g. 2013 and 2016) and years with little discarding of dab (2014 and 2017). In quarter 3, discards are consistently high in front of the German coast and lower in front of the Dutch cost. Finally, the situation is also quite variable for quarter 4, with years of low discards over the whole area (2014) and year with some hotspots (e.g. 2015).

As expect from the value of the autocorrelation ρ, discard distribution is highly variable from one quarter to the next (e.g. quarter 1 to 4 in 2017).

4.4.2 Plaice

As expected from the higher value of ρ, the distribution of plaice discards is less variable from one quarter to the next. Discards are consistently high in the south of the area (between the south of the Netherlands and England), with occasional hot spots in front of Germany. Discards tend to be lower in the north-western part of the area.

4.4.3 Sole

Probability of occurrence of sole discards is remarkably stable though time (for this species, the difference in DIC between model 3 and 4 was smaller than for other species, suggesting that a model with yearly time steps could have been equally good). Probability of discarding sole is high in the south-eastern part of the area and low in the north-western part of the area.

The distribution of the non-zero values is similar to the distribution of combining the binomial and gamma models. It shows a hotspot of sole discarding found consistently in front of the southern coast of the Netherlands, occasionally expanding towards England or to the northern coast of the Netherlands.

4.4.4 Turbot

Probability of occurrence of turbot discards shows a spectacular trend in time. The occurrence of discards is generally lower for the first years of the period studied, and mainly limited to the Dutch and German coasts. Starting from 2015, the probability of discarding increases, first remaining with a similar spatial distribution, but expanding to almost the entire area after the second quarter of 2016.

The distribution of the non-zero values is similar to the distribution of combining the binomial and gamma models. Overall discards are low until the last quarter of 2015, when higher values are observer in the southern part of the area. Then, high values progressively expand to a larger area in the southern and central part of the North Sea, while discards remain low in the northern part of the area and in front of England.

4.4.5 Whiting

The probability of occurrence of discards of whiting is in general high in the southern and eastern parts of the area (except in an area in the west of the Wadden Islands), and low in the north-western corner. The early part of the period studied (until the second quarter of 2014) does not conform to this pattern, as the probability of non-null discards is high only in the south-western part of the area.

The distribution of the non-zero values is similar to the distribution of the combined binomial and gamma models. The level and the distribution of whiting discards appears to be highly variables from one quarter to the other (very low ρ value for the Gamma model). In particular, discarding hotspot suddenly appear most years in the fourth quarter, and disappear in the following first quarter. Those hotspots do not occur consistently in the same areas. Higher discard values are also occasionally observed in small areas in other quarters (e.g. west of England in Q2 in 2014, southern area in Q1 and Q2 in 2017).

4.4.6 Rays

The probability of discarding rays is in general higher in the north-western half of the area and lower in the south-eastern part. In the earlier part of the period, most of the area has a low probability of discards of rays, but progressively the boundary between low and high probability moves to the east, and in 2017, the area of low probability is confined to the west of the German coast.

The distribution of the combined binomial and gamma models is also variable, with hotspots appearing for one or two specific quarters and disappearing afterwards (also a low ρ value for the Gamma model). In general, areas of higher discard value tend to be found in the front of the English coast, and in the north. Since the fourth quarter of 2016, higher discard values are consistently observed in front of the English coast

4.5 Effect of covariates

The GML included also effect of linear predictors. The table 4 gives a summary of which covariates were found to have a significant effect on the discarding intensity (the actual values of the estimated parameters with confidence intervals are given in annex 7).

In most cases, discard weights or the probability of discarding were not significantly influenced by the duration of the trawl haul (except for plaice discard weight and sole probability of discarding). For all species, discard weight per haul was positively related to the total catch of the haul. The probability of discarding of turbot, whiting and rays to occur (presence-absence model) was, however, negatively linked to the total catch of the haul. For these 3 species, this means that they are generally discarded in hauls that have a lower total catch, but among these hauls, the weight of discards increases with the weight of the total catch.

For all species, except for sole and turbot, discard weight and probability were higher for the large beam trawls (12m) compared to the smaller ones (4m). The effect of the pulse trawl (compared to the conventional gear) was significant for 4 species with different signs (higher discard weight of whiting, and higher chance of sole discarding to occur, but lower discard weight for turbot and rays).

Significant differences were also found between data collection programs. The hauls from trips conducted by the industry had higher plaice discards than hauls from observer trips or self-sampling trips. Hauls from industry trips also had a higher chance of containing discards of turbot, whiting and rays. Discard weights in the hauls sampled by the self-sampling program are higher for dab and lower for turbot than in other programs. The probability of sole discarding to occur is lower in hauls sampled during observer trips and the weight of whiting and rays are respectively lower and higher than in hauls sampled during other programs.

Environmental covariates also had significant influences in some of the models. Certain types of substrate influenced the probability of discard to occur (e.g. for turbot and rays). Temperature had a positive effect on discard weights for dab and a negative effect on the probability of whiting and rays discards to occur. Discards of sole, whiting and rays increased (both in probability of occurrence and in weight) with depth, while the probability of turbot discards to occur decreased. Finally, discards were linked to moon phase for plaice, sole and rays.

Table 4 : direction of the different effects included in the models, on discard amounts or presence /absence per species (only for statistically significant effects). Positive effect means that higher values of the covariate is associated to higher discard amounts or probability of discarding

Species	dab	plaice	sole		turbot		whiting		Rays	
Model / **co-variate**	**Discards amounts**	**Discards amounts**	**Discards presence/absence**	**Discards amounts**	**Discards presence/absence**	**Discards amounts**	**Discards presence/absence**	**Discards amounts**	**Discards presence/absence**	**Discards amounts**
Haul duration		Positive	Negative							
Total catch haul	Positive	Positive		Positive	Negative	Positive	Negative	Positive	Negative	Positive
Beam width	Higher for 12m	Higher for 12m					Higher for 12m	Higher for 12m	Higher for 12m	Higher for 12m
Conventional or pulse			Higher in pulse			Lower in pulse		Higher in pulse		Lower in pulse
Data collection program	Higher in self sampling	Higher in industry trips	Lower in observer trips		Higher in industry trips	Lower in self sampling	Higher in industry trips	Lower in observer trips	Higher in industry trips	Higher in observer trips
Bottom substrate					Lower in sand to muddy sand				Higher in mixed sediments	
Bottom temperature	Positive						Negative		Negative	
Depth				Positive	Negative		Positive	Positive	Positive	Positive
Moon phase		Lower for full moon and last quarter	Lower for full moon and new moon						Higher at new moon	

5 Discussion and conclusions

Using a modelling approach to study the spatial distribution of discards has many advantages compared to simply plotting the raw data in space:

- It provides descriptors for the spatial and temporal characteristic of the distribution
- It provides a framework to deal with the residual variability (noise) in the data with an appropriate statistical distribution, and therefore reduces the impact of extreme values or outliers on the distribution maps produced
- It allows for the estimation of the effect of covariates, and therefore produce maps in which these effects have been accounted for.

This work highlighted some general features of the distribution of the discards from the Dutch beam trawler fleet. First, the models estimated the decorrelation distance for the distribution of the discards of each species. Practically, this means that if a vessel has high discards of a given species in a given trawl haul, any other trawl haul realized at a distance smaller than the decorrelation distance is likely to also yield high discards (and the reverse also holds for trawl with low discards). This distance is comprised between 65km for rays and 114km for sole.

For species that did not occur systematically in the discards, the presence absence models show that there are large scale structures of the probability of occurrence (from 200km for turbot to 400km for whiting).

More generally, the distribution patterns observed probably reflect to a large extent the distribution of the undersized part of the populations. In the case of sole, the distribution of discards (especially for the presence-absence) from the model (annex 3) broadly corresponds to the distribution of undersized sole perceived from the Beam Trawl Survey (figure 4). A continuation to this study could consist of producing maps similar to figure 4 from available survey data for the other species and analyze the similarity between distribution of undersized fish in the surveys and spatial-temporal patterns estimated here in the discards. for instance, it would be interesting to compare the distribution of whiting in different survey to see if higher aggregations are observed in Q4 which would explain the higher discards in this quarter.

For some species, hotspots with high discarding intensity have been identified. In the case of rays, the hotspot of discards found in the model east of the English coast correspond to a known breeding ground for some species (e.g. Thornback ray, Hunter et al., 2006). For the rays, in addition to localized hotspots, there was also a general increase in the weights of discards per haul, especially since 2016, which could reflect the increase of population sizes observed in the surveys (ICES, 2018a).

Apart from the distribution of the resource, some other factors - not explicitly represented by the list of covariates incorporated in the models in this study – might also be responsible for the spatial-temporal components estimated by the models. For instance in the case of turbot (annex 4), the sharp increase in the level of the discards since the start of 2016 cannot be explained by changes in the abundance of undersized fish. Recruitments in 2015 and 2016 were indeed higher than previous and following years, but not by a magnitude that would explain the changes in the discards for 2016 and 2017. A more likely explanation is the change in the minimum size implemented by the Dutch producers organizations, which went from 27cm in January 2016 to 32cm in May 2016. This measure was implemented together with limitations on the amount of turbot landed per trip in order to regulate the landings, in a context were quota were insufficient. Similar measures are also implemented by the producer organizations for rays, but with landing limits per trip which are susceptible to be adjusted along the year. This might explain the high temporal variability in the discard patterns described for the rays.

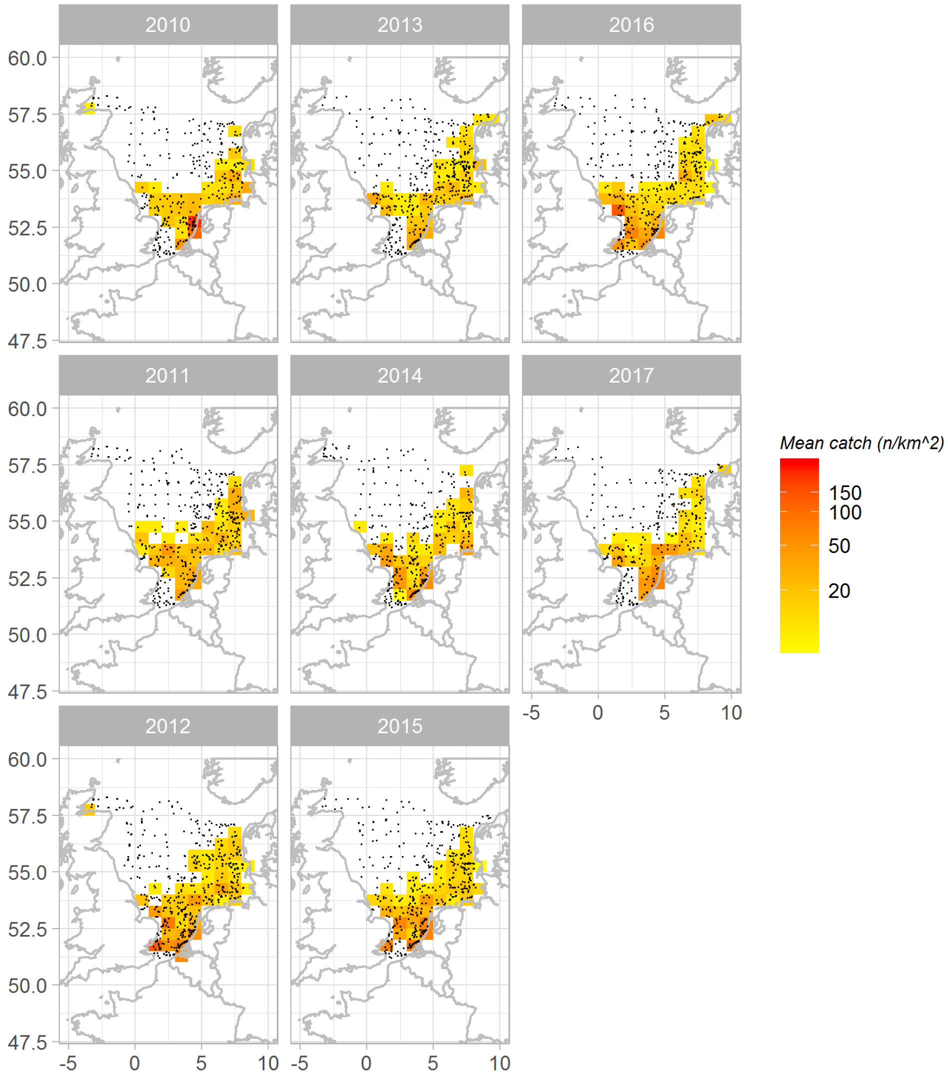


Figure 4 : perception of the spatial distribution of sole <24cm in Q3 from the Beam Trawl Survey (from Brunel and Verkempynck, 2018).

Interpretation of the effect of the different covariates is not straightforward. The models indicate here that for most species, the duration of the haul has no influence on the discards per haul. This goes again the expectation that the catches should be proportional to the fishing effort. The relationship between catch and effort, however, stands only if the effort measures the time spent actively targeting the species. In the present case, the dataset contains a collection of trips, potentially with different targeted species, which explains that the relationship effort-catch would not hold across trips for a given species. Furthermore, even when the species is targeted, the effort is mainly directly towards catching the marketable size fish, and not the undersized fish which will be discarded.

Discards weights were, on the other hand, almost always positively linked to the total catch of the haul. Since discards is an important compartment of the catch, the two should be inherently related. But other factors can explain this relationship. For instance, a saturation effect can affect the selectivity of the net and reduce the escapement rate of undersized fish when a large biomass is filling the cod end.

The probability of having sole discards was found to be higher in the pulse trawl. This is in agreement with the improved catch efficiency of sole by the pulse compared to the conventional tickler chain beam trawl (ICES, 2018b). For whiting, the higher discard weight in the pulse gear could be associated to a stronger reaction for gadoid species to the effect of the electric stimulation preventing them from escaping the gear. For turbot and rays, the lower probability of having discards in the pulse gear could be related to a lower catchability of these species by the pulse trawl compared to the conventional gear. The reduced catchability may be caused by specific gear characteristics (e.g. no tickler chains) as well as the fact that these species are strong swimmers and may have a higher chance to escape the pulse gear, which is towed at a lower speed (4.5Nm v.s 6Nm for the conventional gear).

The sampling program was frequently found to have an impact on the discards, suggesting some species related observation biases. In the case of the self-sampling program, only two boxes of discards are collected by haul sampled, and the crews might tend not to keep the larger fish which do not easily fit in the buckets used to take samples. This might explain the lower weight of turbot for the hauls sampled during this program.

Finally, for almost all cases, the models indicated that the vessels also had a significant effect on discards, even when the difference between small and large trawlers was taken into account (via the beam width effect). These differences might have a technical cause (related to vessel and gear characteristics) but also reflect different fishing strategies of the skippers.

The data used in the work come from a collection of fishing trips, which were not selected in order to obtain a balanced experiment (in which all the levels of all the factors would be sampled with a same intensity). This can, to some extent, make the model prone to confounding between different effects. For instance, the fleet was composed of two types of vessels (large and small cotters, using respectively 12 and 4m beams). Smaller cotters usually fish closer to the coast, while larger ones have the ability to fish offshore. If there is a gradient in the distribution of the undersize fish for a given species, there might be a risk that the model is not able to able to distinguish a beam width effect from a spatial effect. However, if the distribution of the hauls from both types of vessels has enough overlap (in space and time) the model might be able to estimate the effect of beam width independently from the effect of sampling the stocks in different areas. The fact that for some species (e.g. plaice and dab), the 12m beam result in higher discards and at the same time discards are high in the coastal areas (where most of the effort of the smaller vessels is concentrated) suggest that the model was able to estimate separately spatial components and gear effect.

6 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. This certificate is valid until 15 December 2018. The organisation has been certified since 27 February 2001. The certification was issued by DNV GL.

Furthermore, the chemical laboratory at IJmuiden has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2021 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation. The chemical laboratory at IJmuiden has thus demonstrated its ability to provide valid results according a technically competent manner and to work according to the ISO 17025 standard. The scope (L097) of de accredited analytical methods can be found at the website of the Council for Accreditation (www.rva.nl).

On the basis of this accreditation, the quality characteristic Q is awarded to the results of those components which are incorporated in the scope, provided they comply with all quality requirements. The quality characteristic Q is stated in the tables with the results. If, the quality characteristic Q is not mentioned, the reason why is explained.

The quality of the test methods is ensured in various ways. The accuracy of the analysis is regularly assessed by participation in inter-laboratory performance studies including those organized by QUASIMEME. If no inter-laboratory study is available, a second-level control is performed. In addition, a first-level control is performed for each series of measurements.
In addition to the line controls the following general quality controls are carried out:

- Blank research.
- Recovery.
- Internal standard
- Injection standard.
- Sensitivity.

The above controls are described in Wageningen Marine Research working instruction ISW 2.10.2.105. If desired, information regarding the performance characteristics of the analytical methods is available at the chemical laboratory at IJmuiden.

If the quality cannot be guaranteed, appropriate measures are taken.

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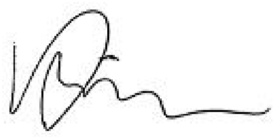
Justification

Report C015/19
Project Number: 4311400005

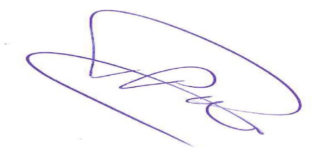
The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Ir. N.T. Hintzen
Research scientist

Signature: 

Date: 14 February 2019

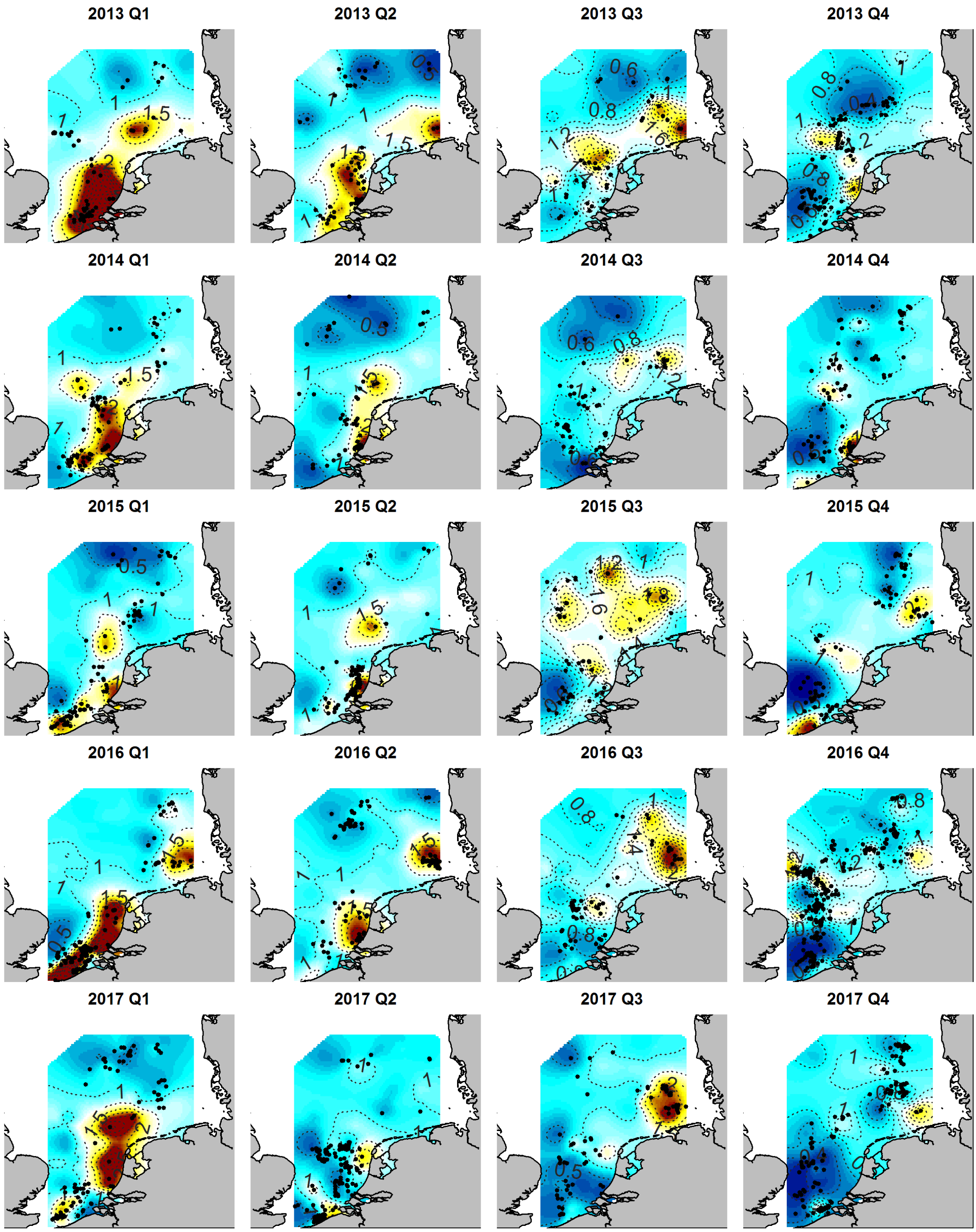
Approved: Dr.ir. T.P. Bult
Director

Signature: 

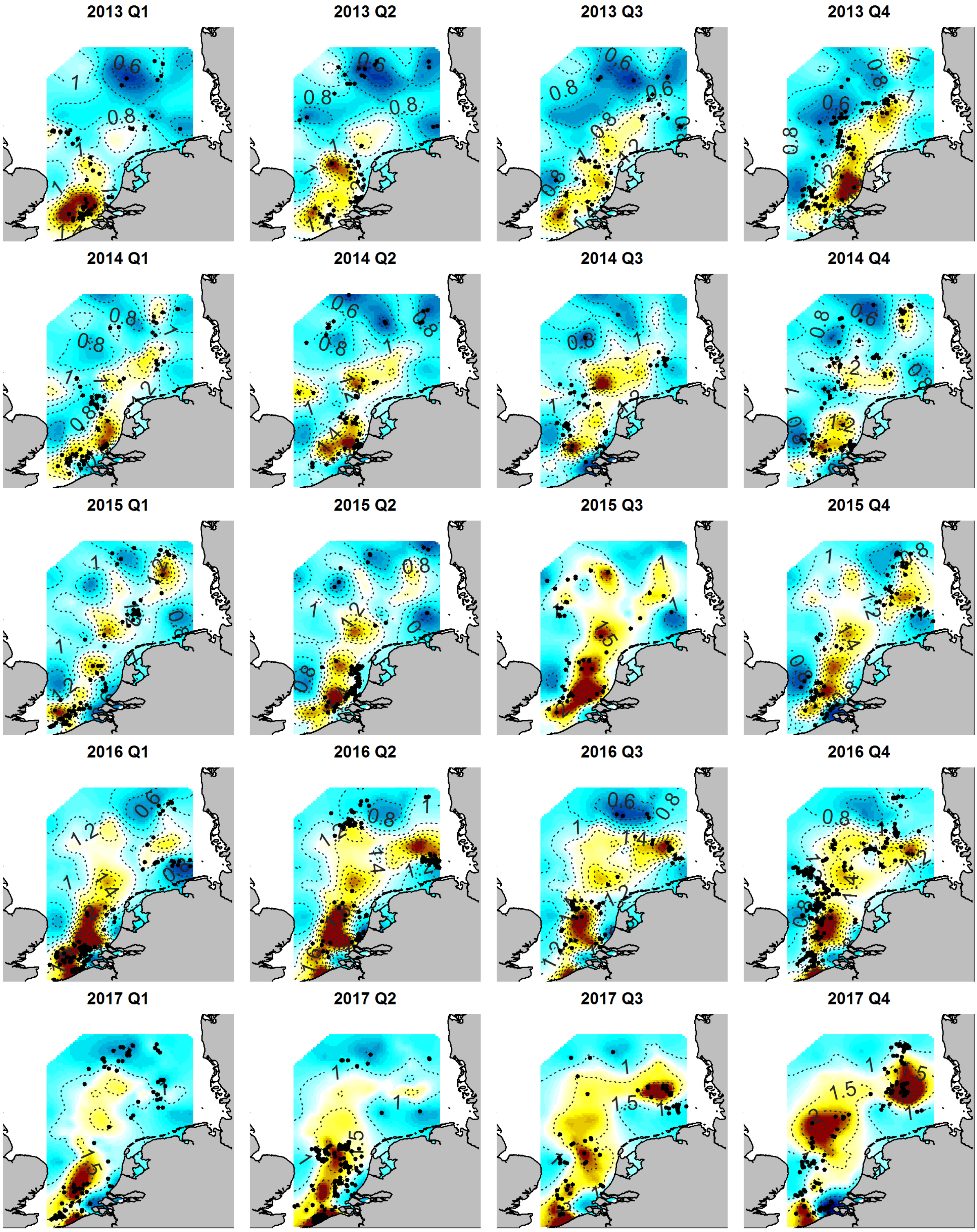
Date: 14 February 2019

Annexes

Annexe 1 : spatial-temporal component (Gaussian Markovian Random Field) estimated for DAB

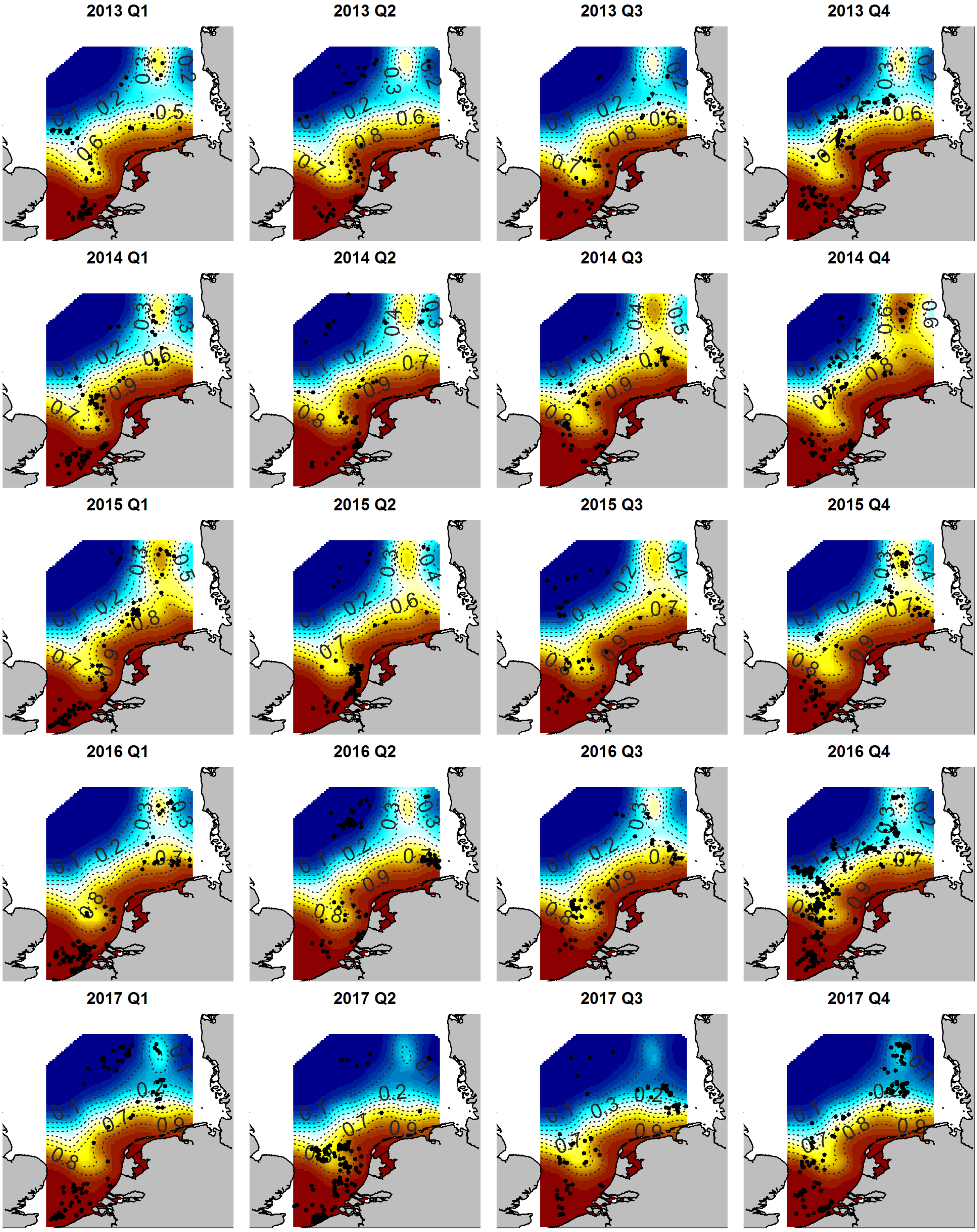


Annexe 2 : spatial-temporal component (Gaussian Markovian Random Field) estimated for PLAICE

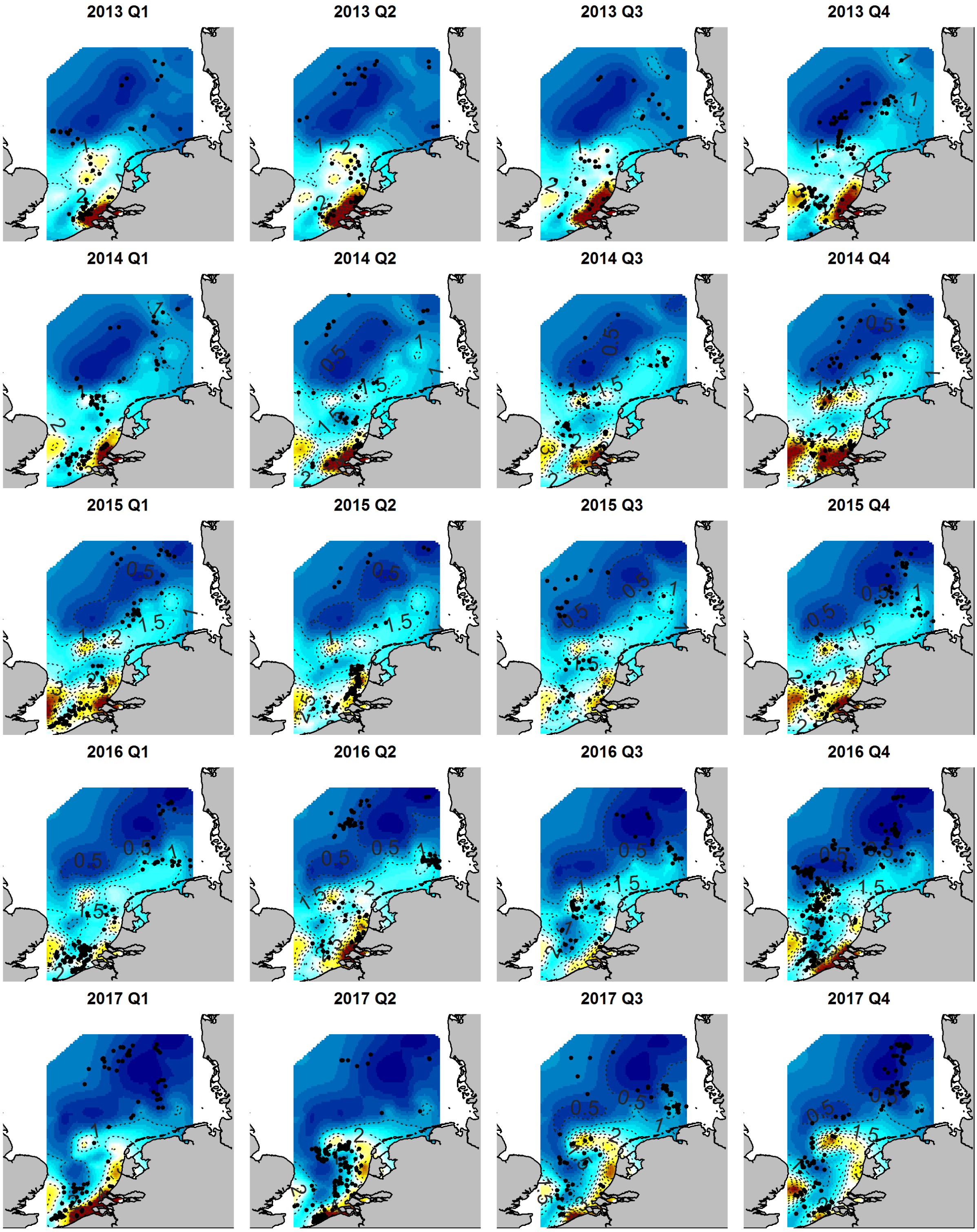


Annexe 3 :

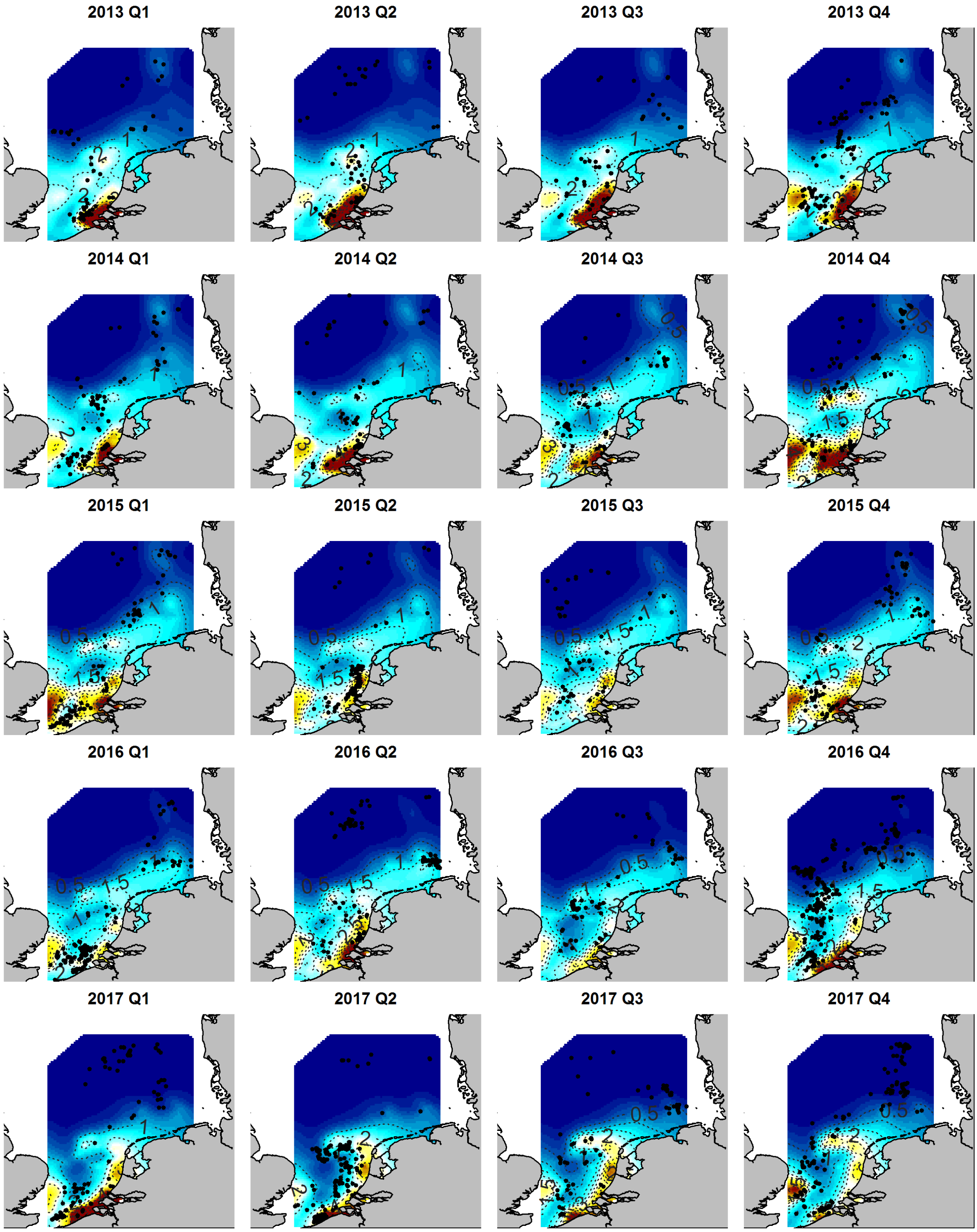
spatial-temporal component (Gaussian Markovian Random Field) estimated for SOLE for the presence absence model



spatial-temporal component (Gaussian Markovian Random Field) estimated for SOLE for the presence only model

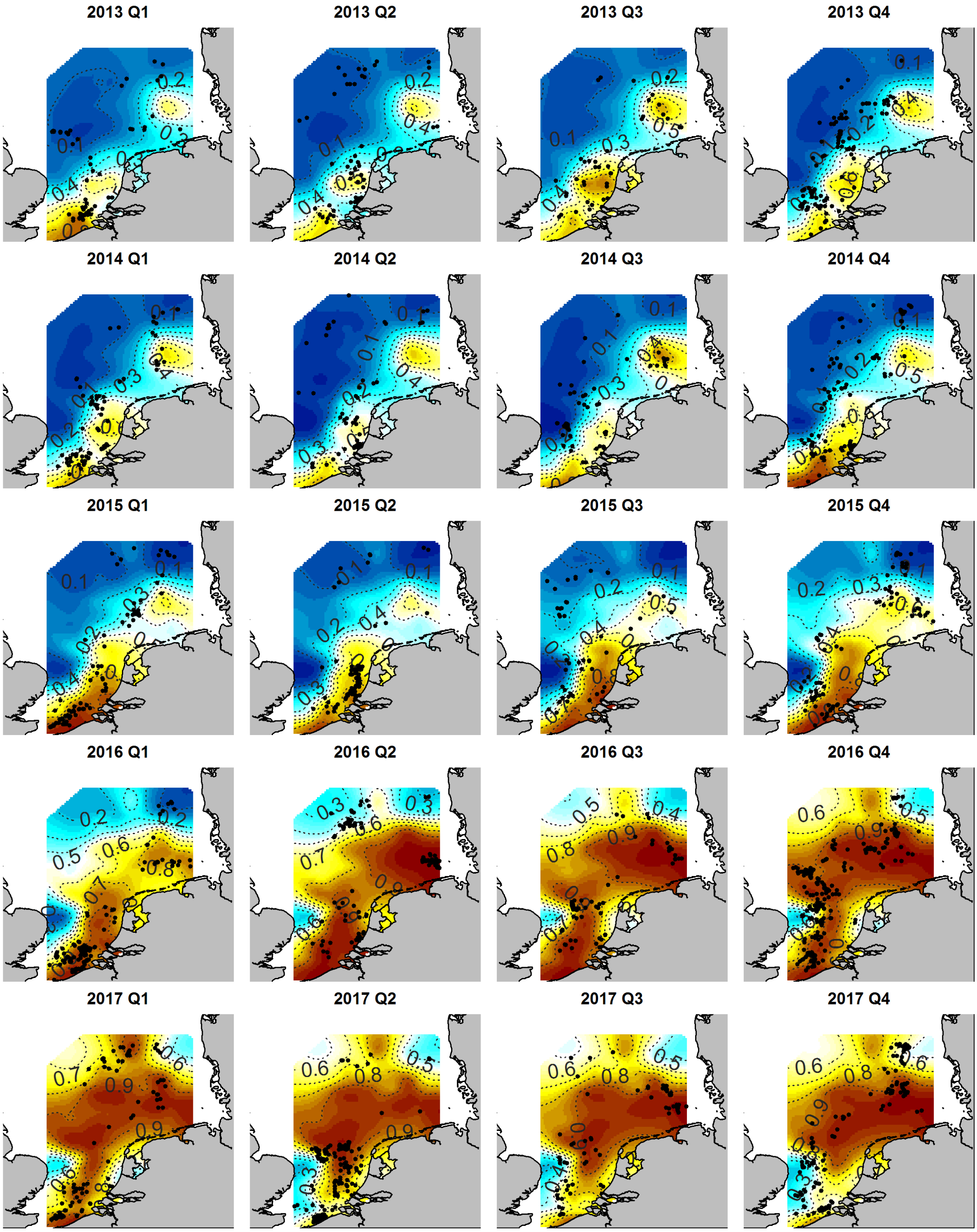


Product spatial-temporal components (Gaussian Markovian Random Field) estimated for SOLE for the presence-absence and for presence only models combined

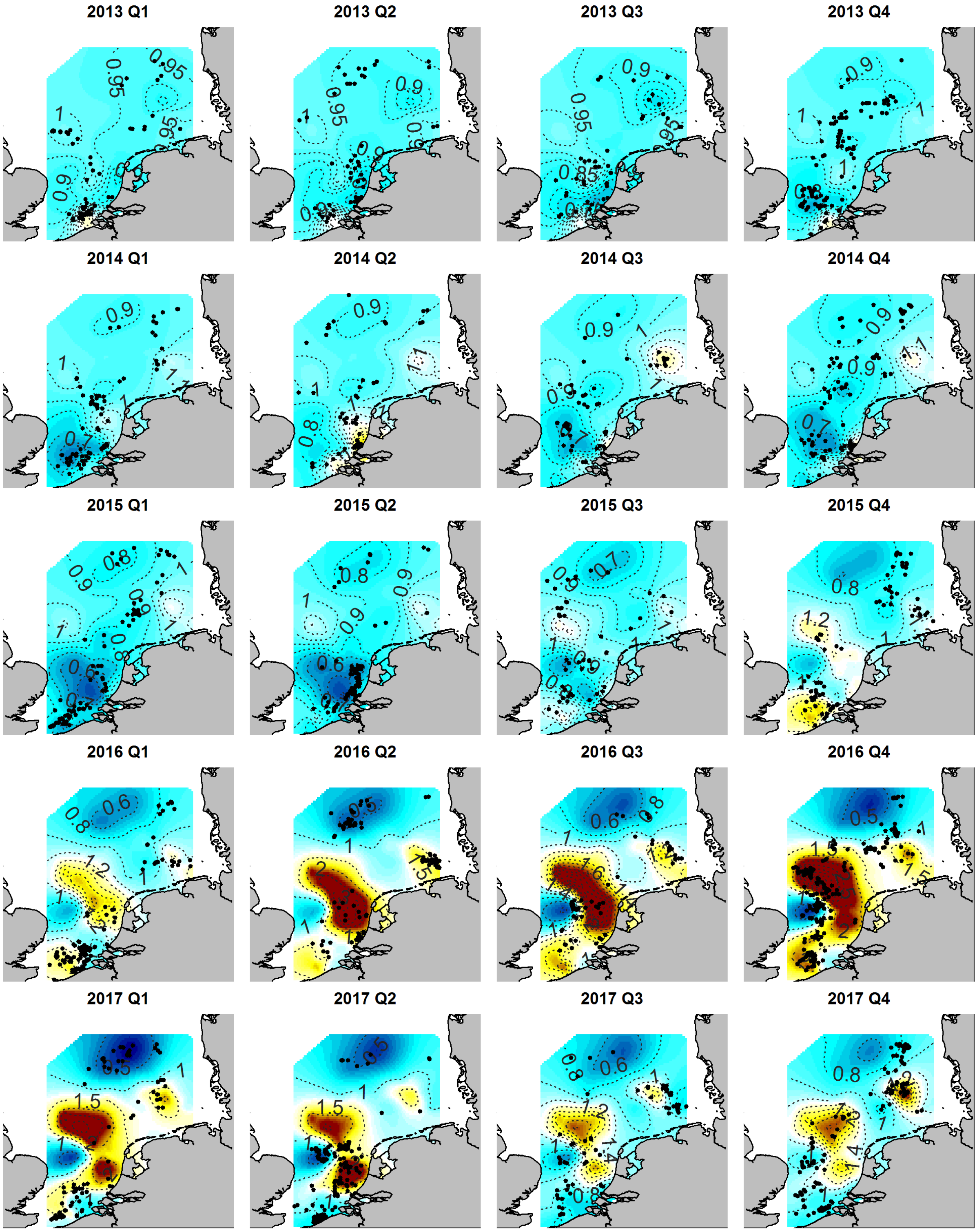


Annexe 4 :

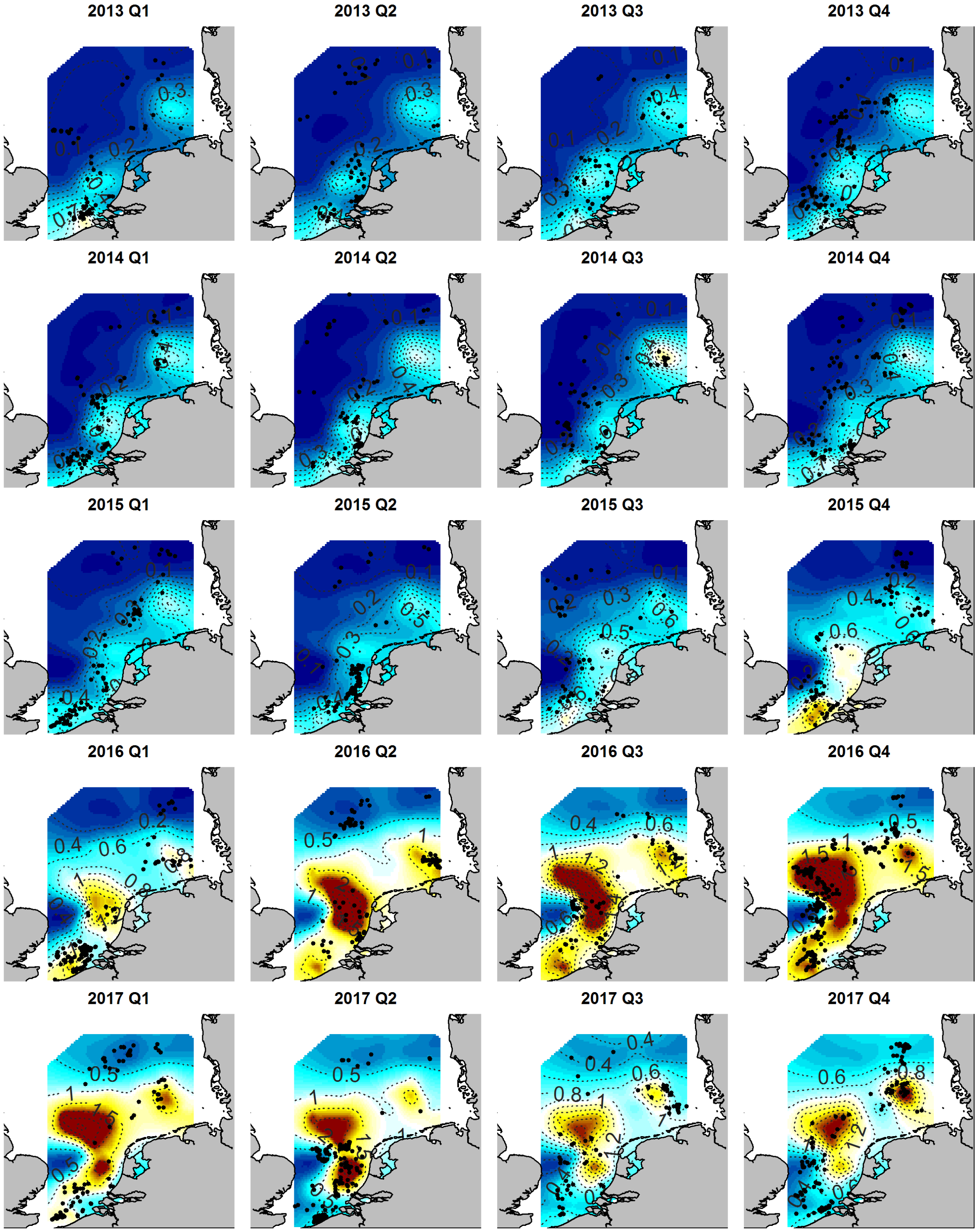
spatial-temporal component (Gaussian Markovian Random Field) estimated for TURBOT for the presence absence model



spatial-temporal component (Gaussian Markovian Random Field) estimated for TURBOT for the presence only model

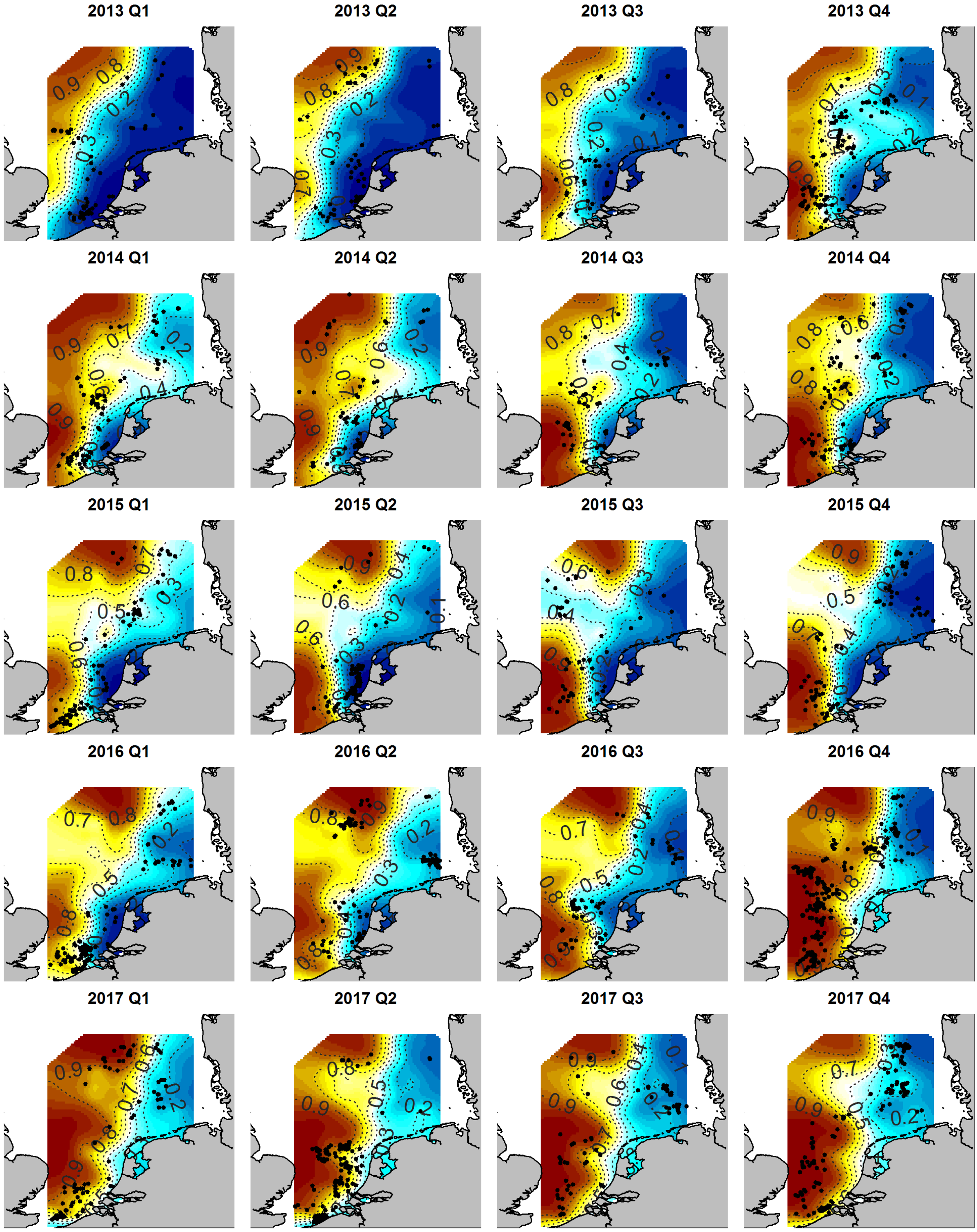


Product spatial-temporal components (Gaussian Markovian Random Field) estimated for TURBOT for the presence-absence and for presence only models combined



Annexe 5 :

spatial-temporal component (Gaussian Markovian Random Field) estimated for RAYS for the presence absence model



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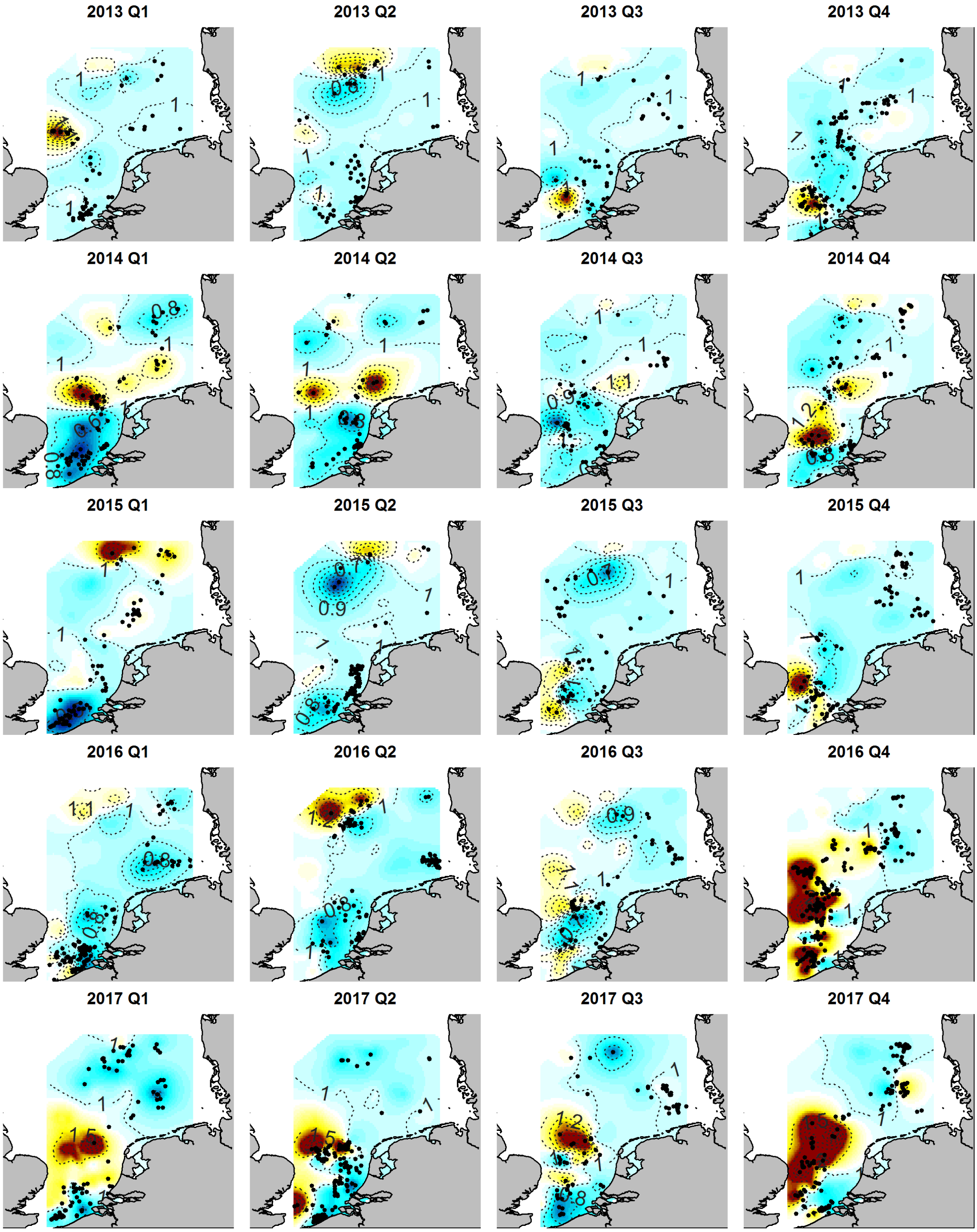
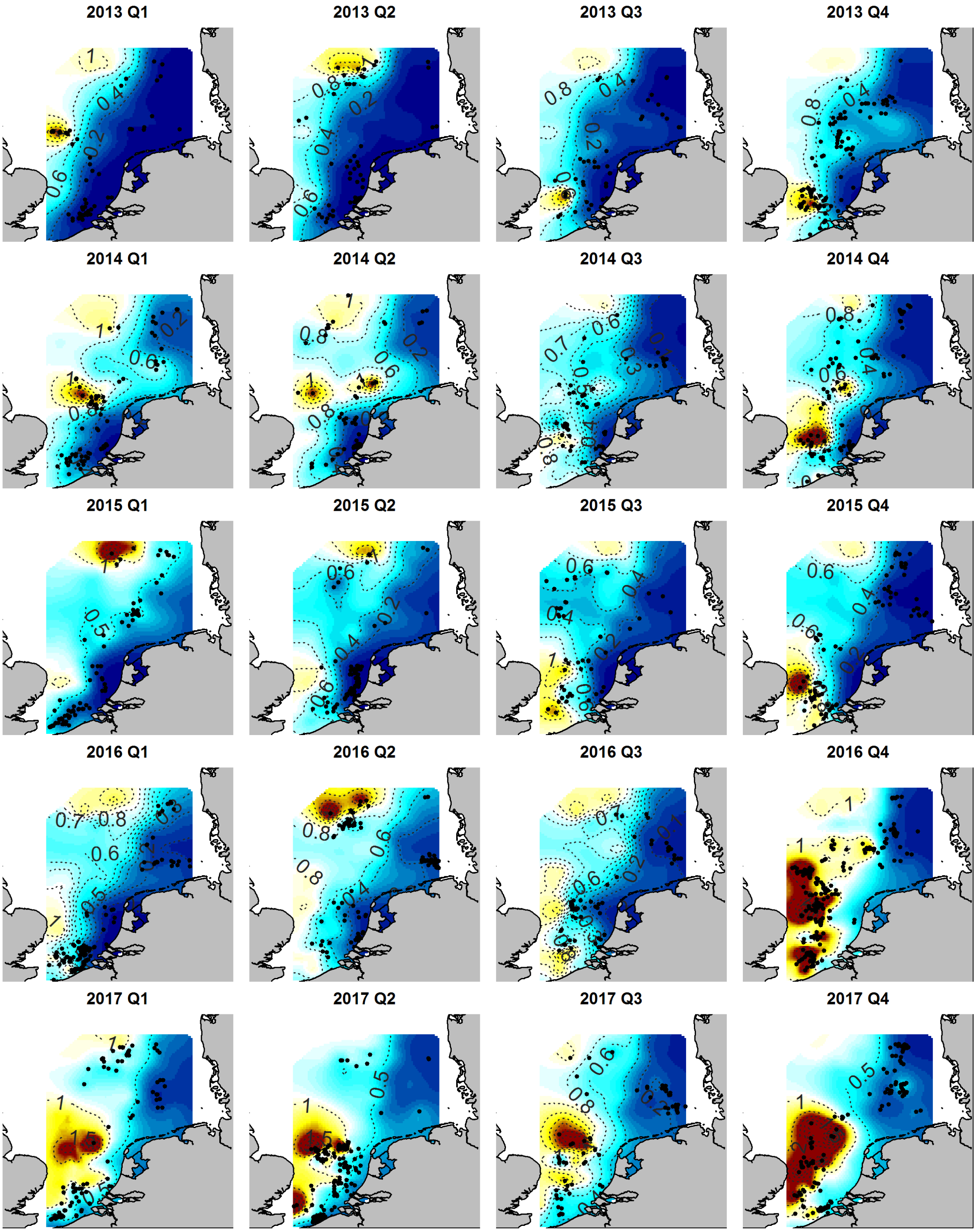
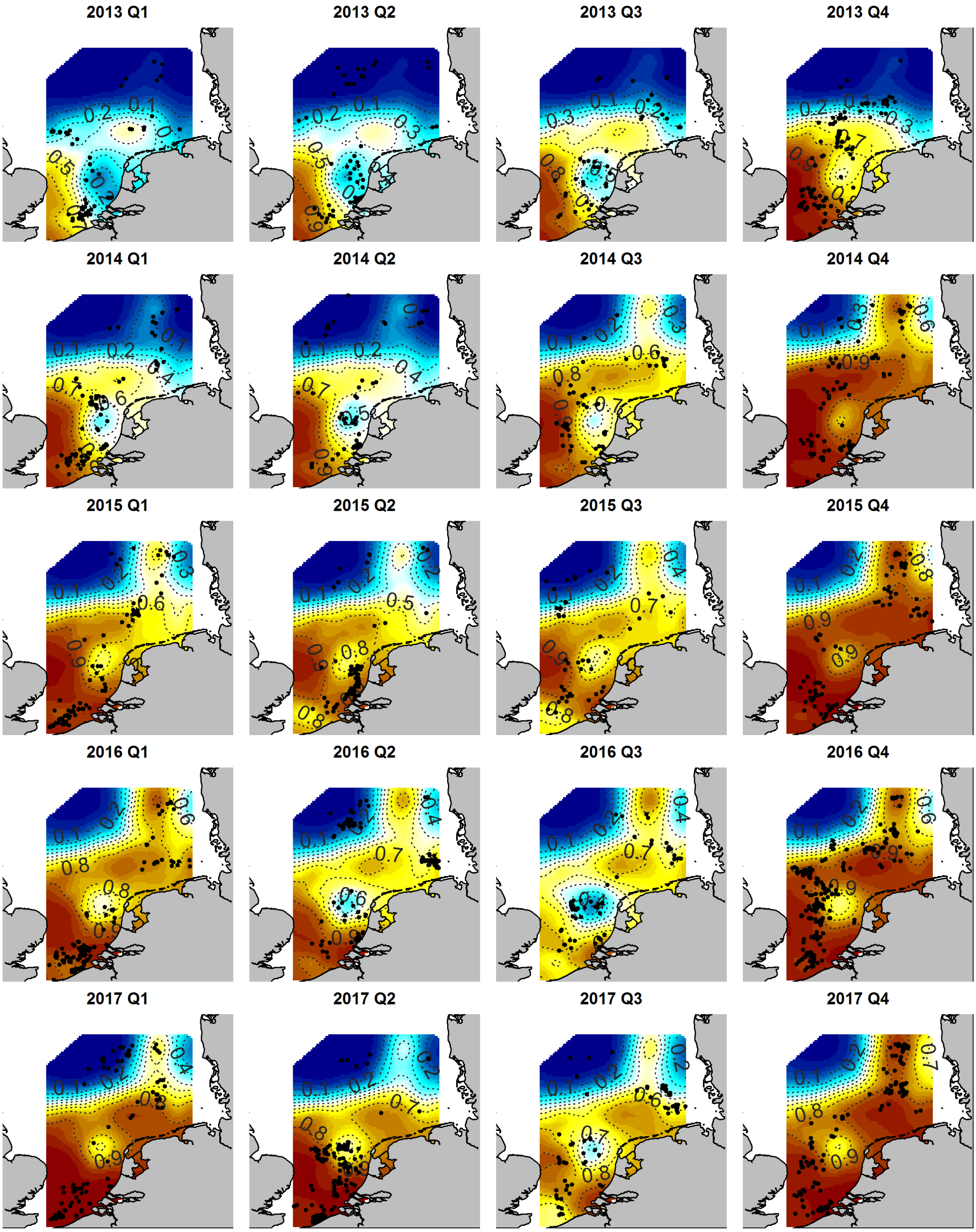


Product spatial-temporal components (Gaussian Markovian Random Field) estimated for RAYS for the presence-absence and for presence only models combined

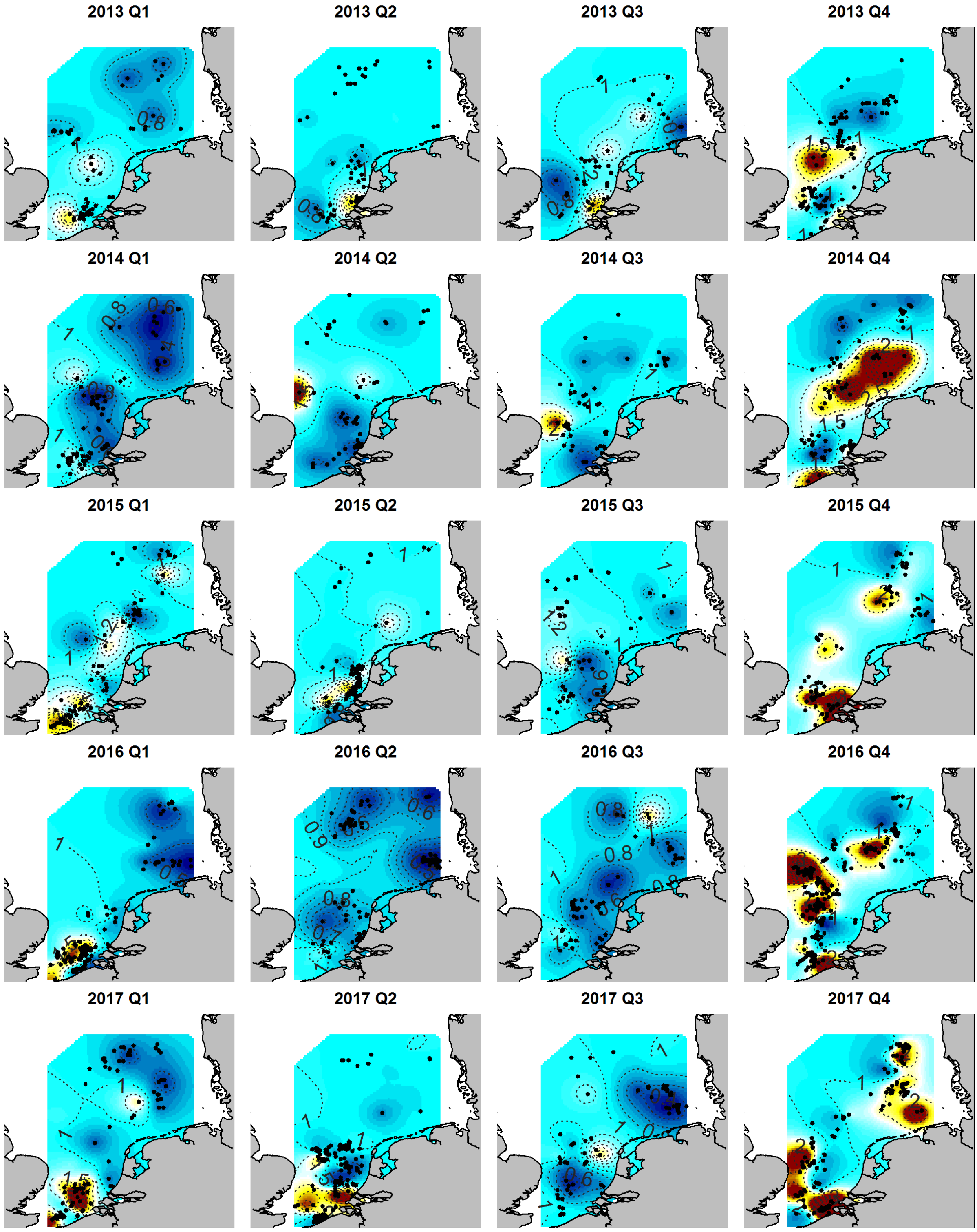


Annexe 6 :

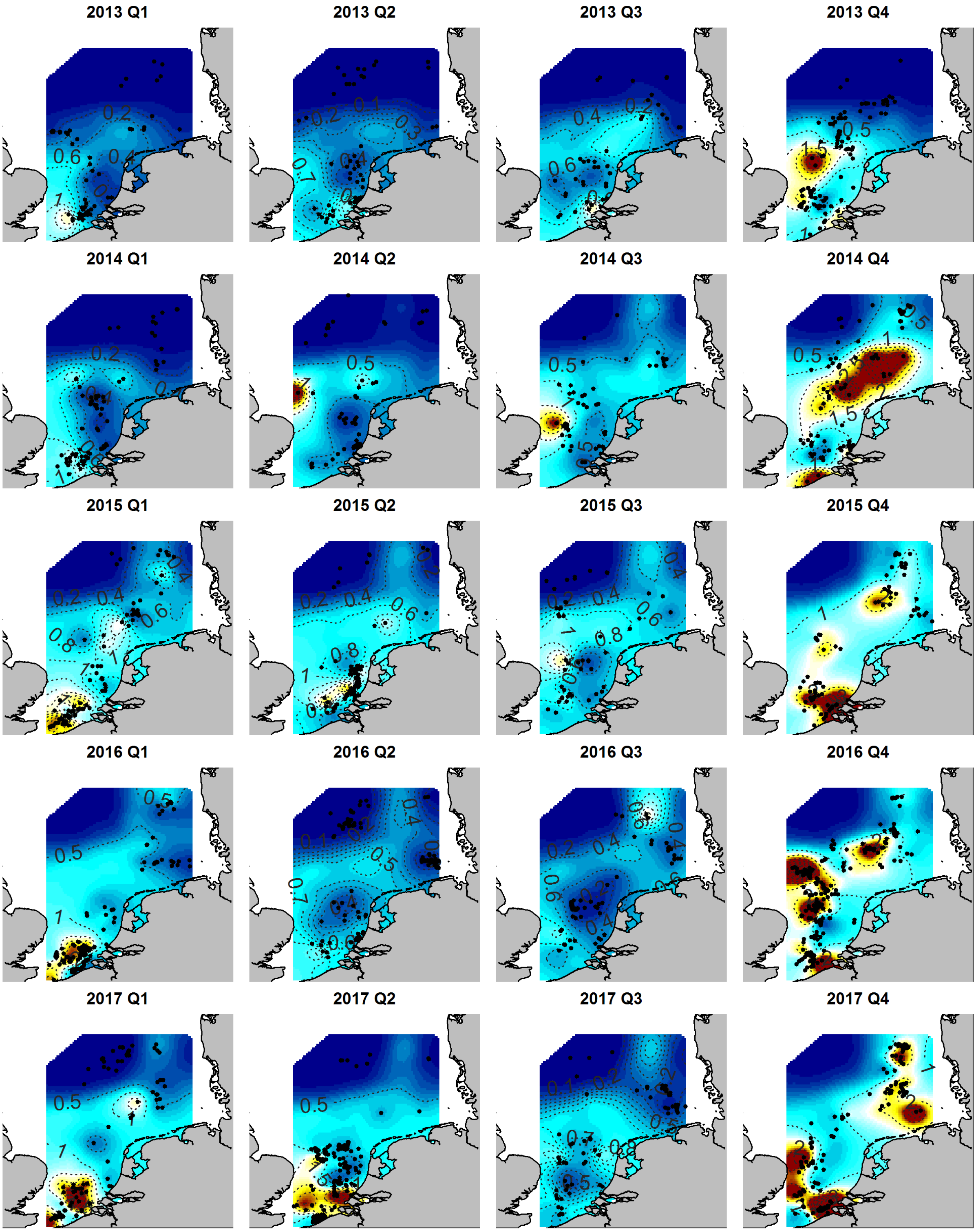
spatial-temporal component (Gaussian Markovian Random Field) estimated for WHITING for the presence absence model



spatial-temporal component (Gaussian Markovian Random Field) estimated for WHITING for the presence only model

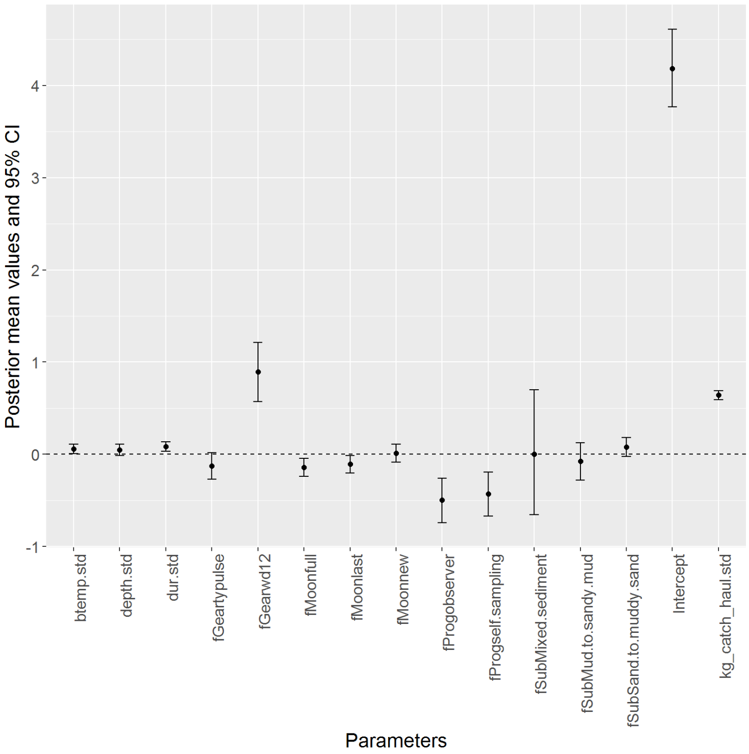


Product spatial-temporal components (Gaussian Markovian Random Field) estimated for WHITING for the presence-absence and for presence only models combined

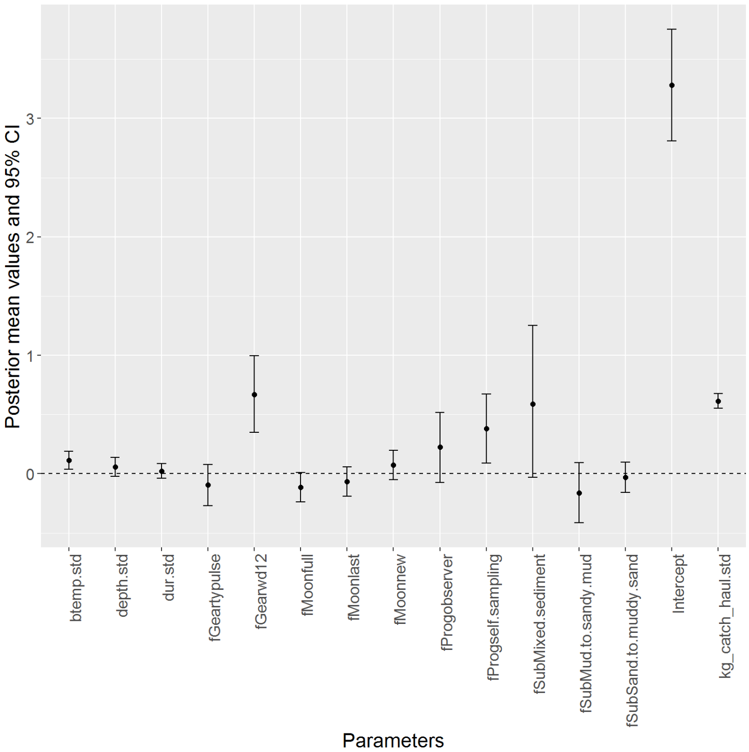


Annex 7 : estimated parameters for the covariates in the models

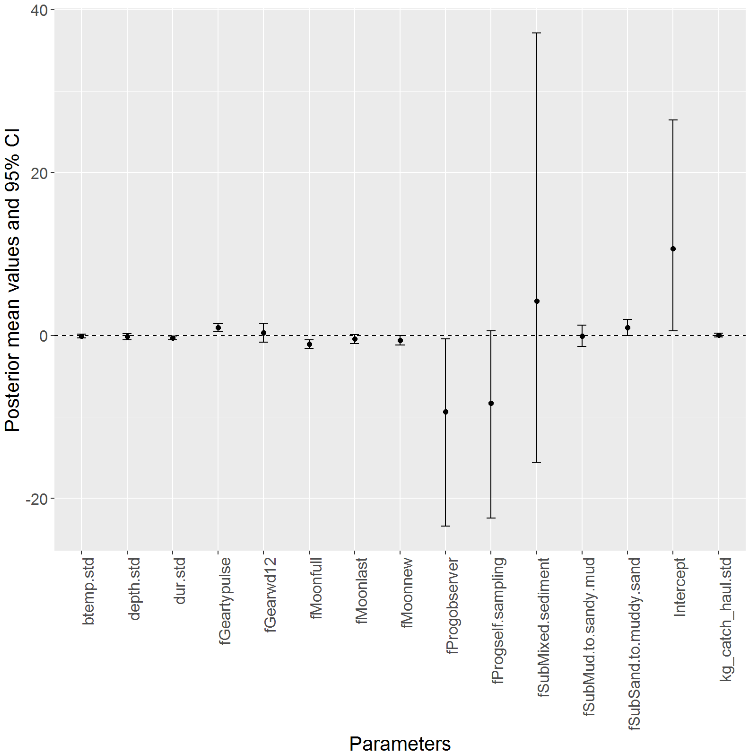
PLAICE (Discards amounts model)



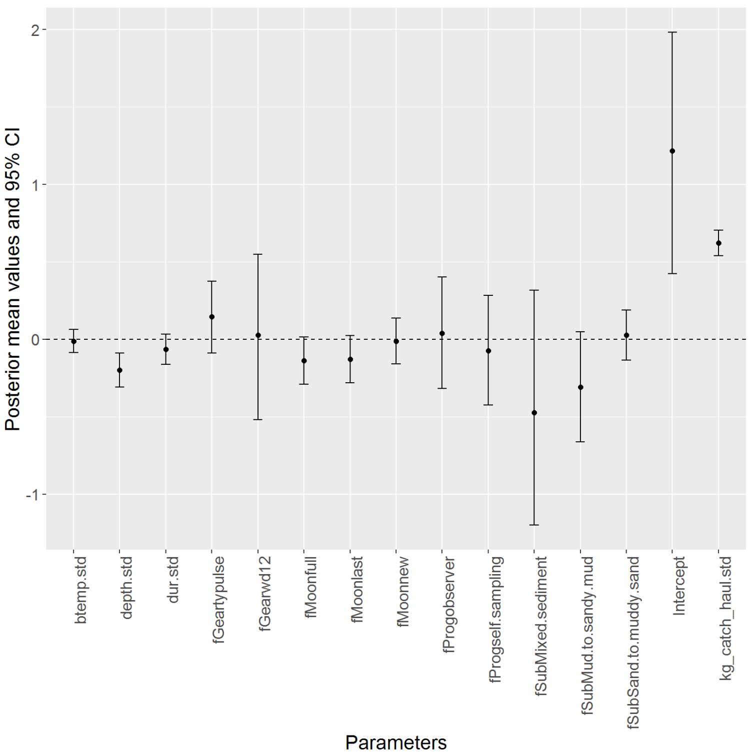
DAB (Discards amounts model)



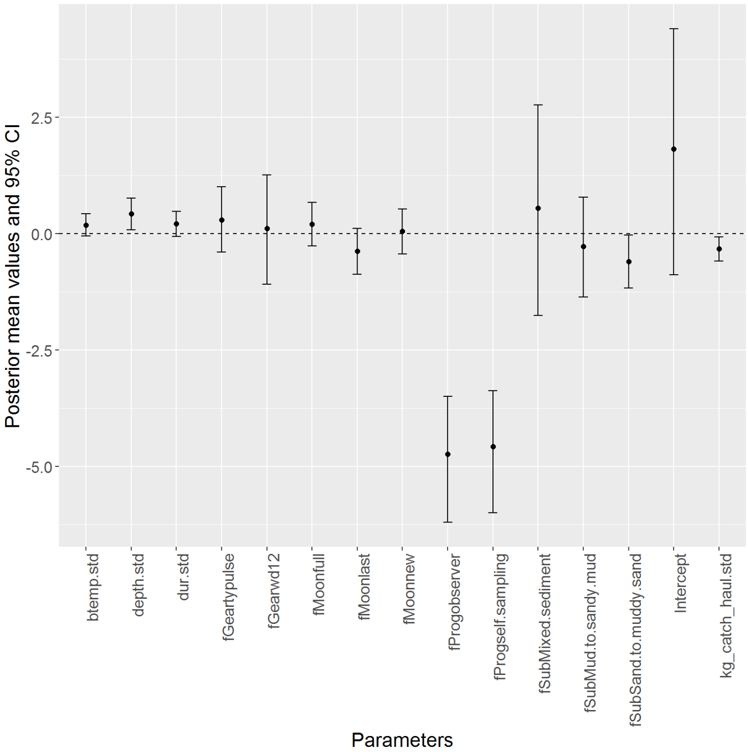
SOLE (presence –absence model)



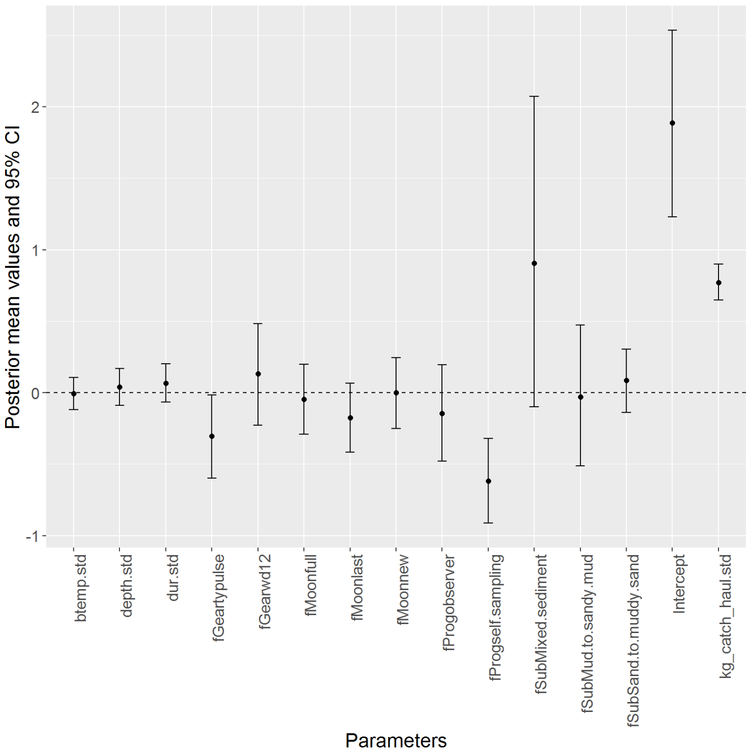
SOLE (Discards amounts for presence only)



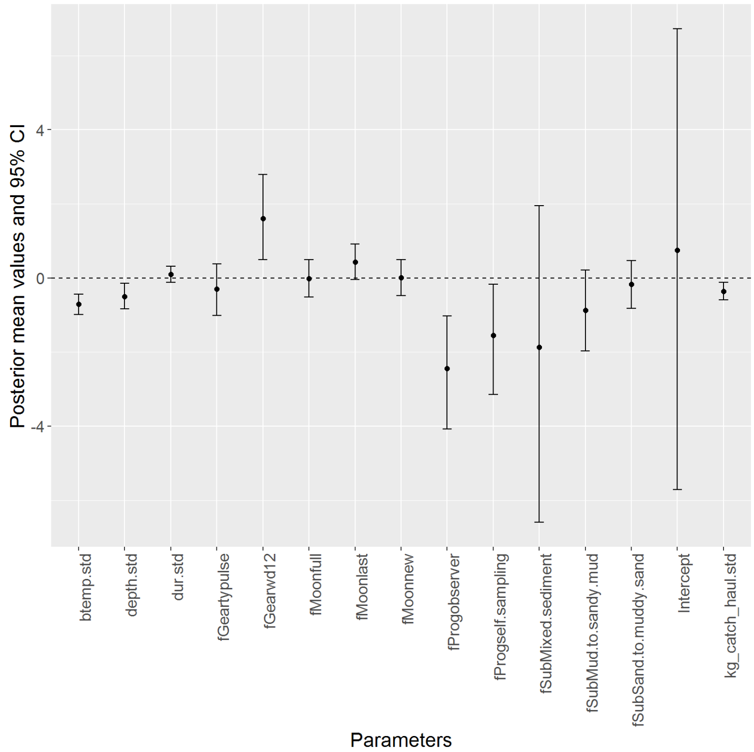
TURBOT (presence –absence model)



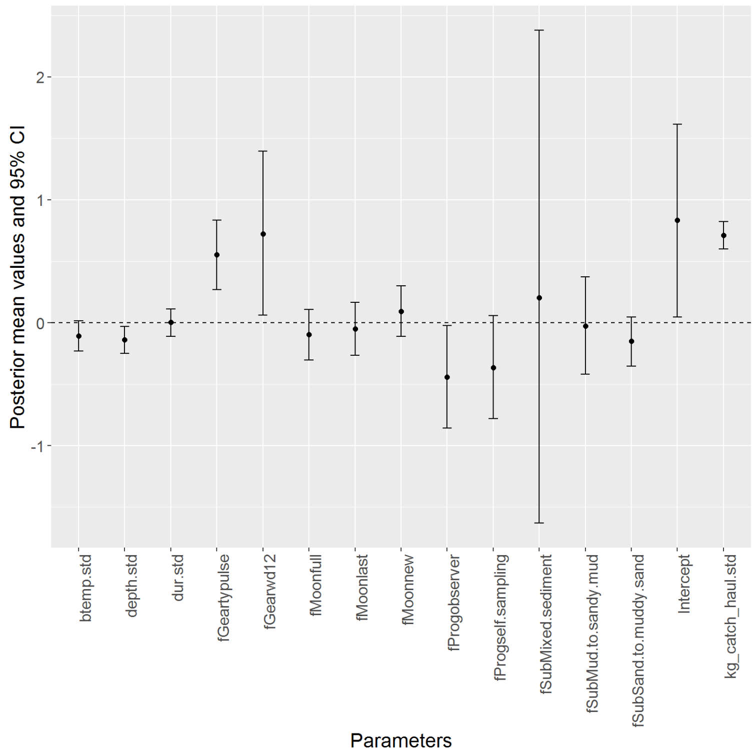
TURBOT (Discards amounts for presence only)



WHITING (presence –absence model)



WHITING (Discards amounts for presence only)



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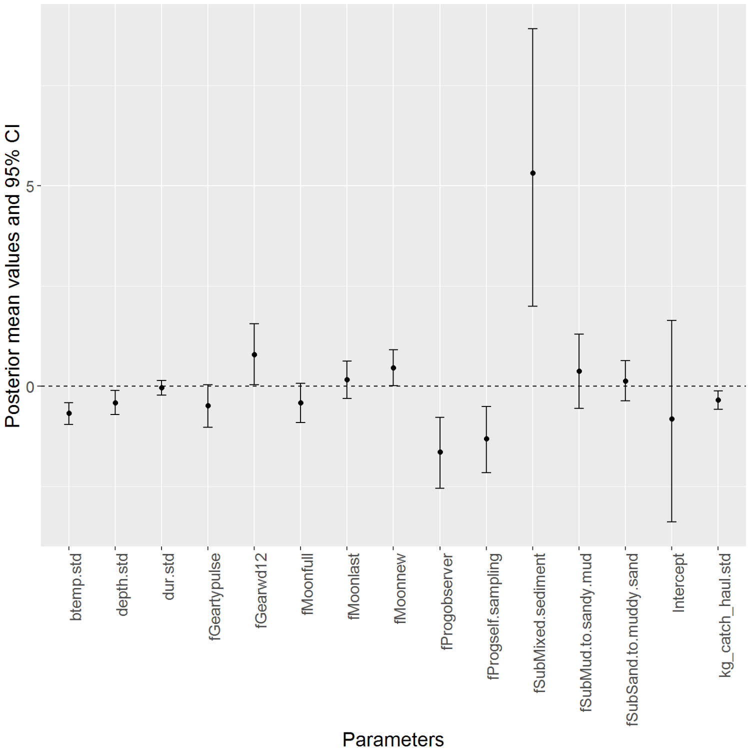

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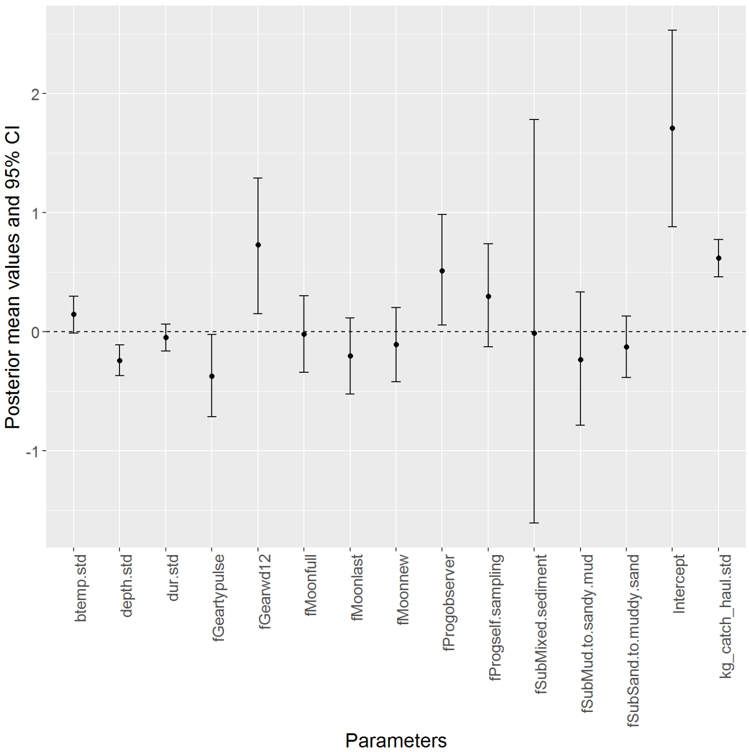

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Dear Mr. Van Broekhoven,

Subproject 5 effect of implementing a different minimum size

Background and aim

Substantial discarding of undersized plaice occurs in the beamtrawl fishery targeting sole (Verkempynck et al., 2018). Lowering the legal minimum conservation reference size of plaice would potentially reduce the discards of undersized plaice.

The aim of this subproject is to:

1. Quantify the potential benefits in terms of discards reduction (and therefore in gaining catch opportunities) of reducing the minimum size of plaice.

Workplan

A desk study assessing the effect of using a lower minimum conservation reference size (mcrs) for plaice on the total amount of plaice discards was conducted. The fishing industry has asked to investigate the effects of setting a 25 cm mcrs instead of the current 27 cm mcrs.

For stock assessment purposes, WMR routinely estimates the total amount of plaice discards at the national level by ‘raising’ the data collected within the WMR discards monitoring programme at the trip level.

For this task the data collected within the WMR DCF demersal discards monitoring programme (2013 - 2017) is used. The proportion of discards under and above 25 cm is calculated based on the samples collected at the trip level. This proportion is then multiplied with the total estimates of plaice discards at the national level, obtained from INTERCATCH (ICES database). This way, the discards volume corresponding to the implementation of a ‘new’ mcrs (i.e. 25 cm) is calculated by multiplying the proportion of plaice discards under 25cm of the sampled fleet with the total estimates of plaice discards at the national level.

There is occasional discarding of plaice above the current mcrs (27 cm). For this study the dataset contains only the discards under 27.1 cm.

Results

Table 1 shows the number of trips samples per metier of the course of the data time-series. Not all metiers are sampled throughout the time-series. Most of the sampling effort is directed at the beamtrawl and ottertrawl fleet with smaller mesh sizes (Beam trawl 70-99, Otter trawl 70-99, Nephrops trawl 70-99).

The length distribution of the discards of plaice differ per metier. Figure 1 shows the raised weight of discards plaice of all trips per metier per year. Figure 2 shows the proportion of discards under and above 25 cm per metier.

100years 1918 — 2018

Table 1: Table 1: Number of trips sampled per metier between 2013 - 2017 in the DCF demersal discards programme.

metier	2013	2014	2015	2016	2017
Nep 70-99	18	21	17	6	16
OTB 100-119	14	14	13	7	3
OTB 70-99	10	7	22	22	21
OTB G120	NA	1	4	2	NA
SSC 100-119	2	3	4	1	NA
SSC 70-99	NA	NA	9	1	NA
SSC G120	1	2	3	NA	NA
TBB 100-119	9	8	4	7	6
TBB 70-99	75	107	86	106	112
TBB G120	2	NA	2	1	1

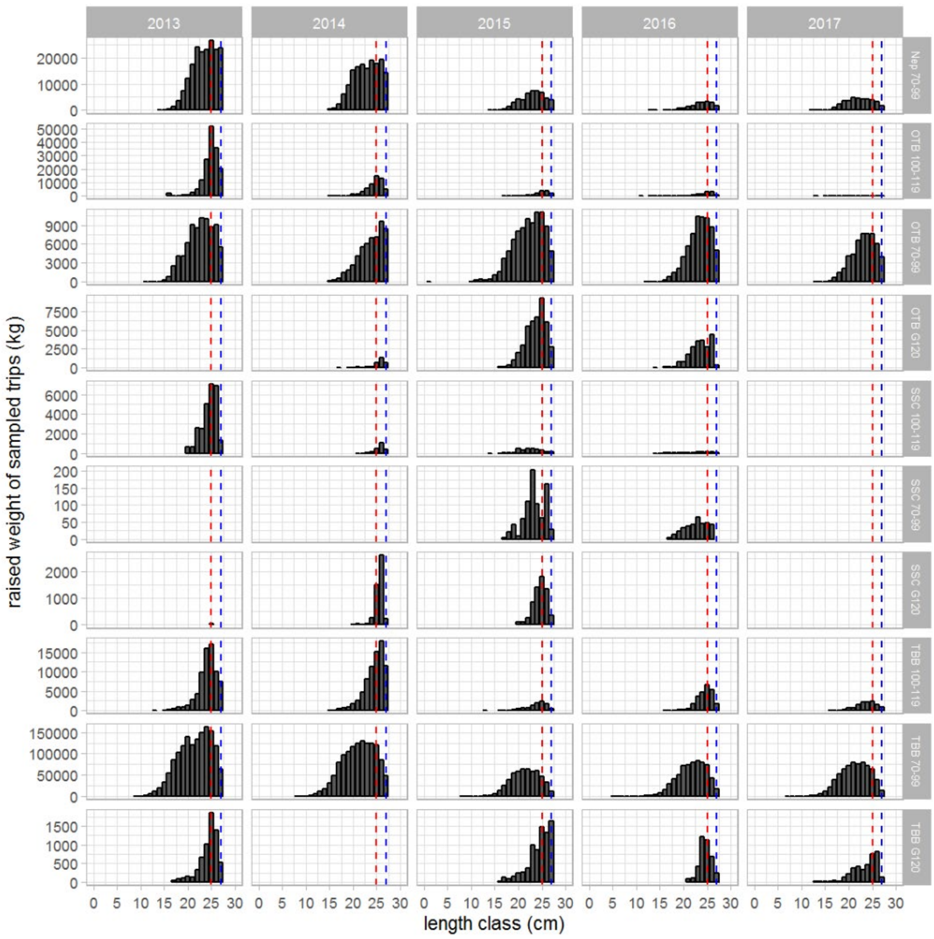

Figure 1, Length distribution of plaice discards per metier, blue line = 27 cm, red line = 25 cm.

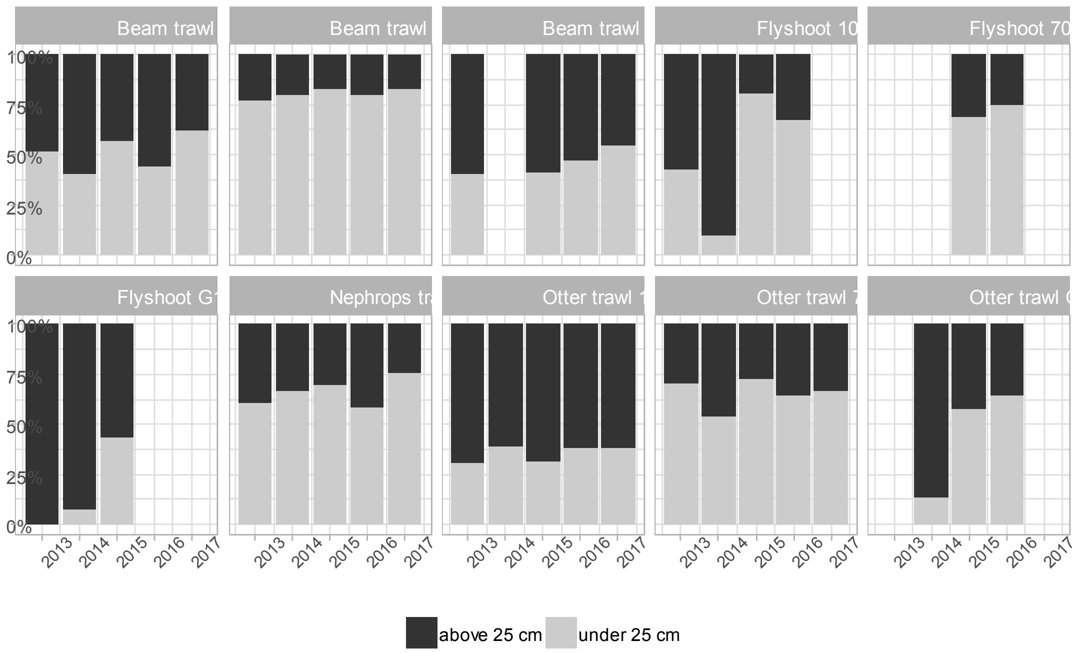

Figure 2, Proportion plaice discards under and above 25 cm per metier.

The proportion by volume (kg) and absolute volumes (kg) of discarded plaice per metier above and under 25 cm are shown in Table 1 and 2.

Table 2: Proportion plaice discards under and above 25 cm and average proportion over the time-series per metier.

metier	class	2013	2014	2015	2016	2017	average
Nep 70-99	above 25	0.39	0.33	0.3	0.41	0.24	0.33
Nep 70-99	under 25	0.61	0.67	0.7	0.59	0.76	0.67
OTB 100-119	above 25	0.69	0.61	0.69	0.62	0.62	0.65
OTB 100-119	under 25	0.31	0.39	0.31	0.38	0.38	0.35
OTB 70-99	above 25	0.29	0.46	0.27	0.36	0.34	0.34
OTB 70-99	under 25	0.71	0.54	0.73	0.64	0.66	0.66
OTB G120	above 25	NA	0.86	0.42	0.35	NA	0.54
OTB G120	under 25	NA	0.14	0.58	0.65	NA	0.46
SSC 100-119	above 25	0.57	0.9	0.19	0.33	NA	0.5
SSC 100-119	under 25	0.43	0.1	0.81	0.67	NA	0.5
SSC 70-99	above 25	NA	NA	0.31	0.25	NA	0.28
SSC 70-99	under 25	NA	NA	0.69	0.75	NA	0.72
SSC G120	above 25	1	0.93	0.56	NA	NA	0.83
SSC G120	under 25	NA	0.07	0.44	NA	NA	0.26
TBB 100-119	above 25	0.48	0.6	0.43	0.56	0.38	0.49
TBB 100-119	under 25	0.52	0.4	0.57	0.44	0.62	0.51
TBB 70-99	above 25	0.23	0.2	0.17	0.2	0.17	0.19
TBB 70-99	under 25	0.77	0.8	0.83	0.8	0.83	0.81
TBB G120	above 25	0.6	NA	0.59	0.53	0.45	0.54
TBB G120	under 25	0.4	NA	0.41	0.47	0.55	0.46

Table 3: Volume plaice discards (kg) per metier.

metier	class	2013	2014	2015	2016	2017
Nep 70-99	above 25	72844	51248	15170	7864	9278
Nep 70-99	under 25	111659	102227	34592	11097	28667
OTB 100-119	above 25	107675	33020	9663	7103	822
OTB 100-119	under 25	48742	21364	4428	4383	513
OTB 70-99	above 25	23359	25201	24714	23882	17628
OTB 70-99	under 25	55887	29699	66349	42684	34868
OTB G120	above 25	NA	2598	18110	7418	NA
OTB G120	under 25	NA	406	24891	13558	NA
SSC 100-119	above 25	15288	2008	539	334	NA
SSC 100-119	under 25	11488	212	2302	684	NA
SSC 70-99	above 25	NA	NA	251	91	NA
SSC 70-99	under 25	NA	NA	558	267	NA
SSC G120	above 25	28	4346	3516	NA	NA
SSC G120	under 25	NA	347	2718	NA	NA
TBB 100-119	above 25	34438	44514	4383	13789	4687
TBB 100-119	under 25	36827	30240	5840	10894	7603
TBB 70-99	above 25	335388	254346	92025	134382	116636
TBB 70-99	under 25	1138878	1015526	446659	539852	575800
TBB G120	above 25	3765	NA	4430	2046	1691
TBB G120	under 25	2517	NA	3100	1815	2055

The raised discard volumes at the national level are shown in Table 4.
For some years there are samples taken for certain metiers (e.g. TBB G120), but total estimates at the national level are missing for those years. This is due to inconsistent use of a cut-off value for sample size.

Table 4: Raised discards volumes (kg) of plaice at the national level per metier.

metier	2013	2014	2015	2016	2017
Nep 70-99	1669745	1976739	991425	316736	531042
OTB 100-119	519170	426812	250147	216353	137013
OTB 70-99	1109006	4514063	1088883	1914677	645311
SSC 100-119	365682	60731	83601	56765	NA
SSC 70-99	NA	NA	21094	44142	NA
SSC G120	2339	51484	78866	0	NA
TBB 100-119	647063	873567	944818	650496	164225
TBB 70-99	23440478	21845348	22079350	22681854	23099173
TBB G120	NA	NA	NA	NA	746117

By combining the proportion of plaice discards under and above 25 cm with the raised discard volumes of plaice at the national level, the potential reduction of discards of plaice is calculated. The resulting discard volumes per metier and per year and on average are shown in Table 5.

metier	class	2013	2014	2015	2016	2017	average
Nep 70-99	above 25	659235	660069	302233	131369	129849	376551
Nep 70-99	under 25	1010510	1316670	689192	185367	401192	720586
OTB 100-119	above 25	357389	259143	171538	133793	84346	201242
OTB 100-119	under 25	161780	167669	78609	82560	52667	108657
OTB 70-99	above 25	326897	2072114	295520	686924	216694	719630
OTB 70-99	under 25	782109	2441949	793363	1227753	428617	1134758
OTB G120	above 25	NA	NA	NA	NA	NA	NaN
OTB G120	under 25	NA	NA	NA	NA	NA	NaN
SSC 100-119	above 25	208790	54933	15865	18619	NA	74552
SSC 100-119	under 25	156892	5797	67736	38145	NA	67142
SSC 70-99	above 25	NA	NA	6552	11220	NA	8886
SSC 70-99	under 25	NA	NA	14542	32922	NA	23732
SSC G120	above 25	2339	47681	44479	NA	NA	31500
SSC G120	under 25	NA	3803	34387	NA	NA	19095

TBB 100-119	above 25	312685	520184	405102	363393	62632	332799
TBB 100-119	under 25	334378	353383	539716	287103	101593	323235
TBB 70-99	above 25	5332589	4375468	3771898	4520734	3890891	4378316
TBB 70-99	under 25	18107890	17469880	18307451	18161120	19208283	18250925
TBB G120	above 25	NA	NA	NA	NA	336804	336804
TBB G120	under 25	NA	NA	NA	NA	409313	409313

Table 5: Discards volumes (kg) of plaice at the national level and average over the timeseries under and above 25 cm per metier.

Conclusion

The theoretical reduced volume of plaice discards from lowering the minimum conservation reference size to 25 cm (calculated as the average reduction over the timeseries) is 6460279.16 kgs. Resulting in a reduction of 23.48 %.

References

Verkempynck, R., van Overzee, H., Dammers, M., 2018 Discard self-sampling of Dutch bottom-trawl and seine fisheries in 2014-2016, IJmuiden : Stichting Wageningen Research, Centre for Fisheries Research (CVO) (CVO report 18.007) - 102

Yours sincerely,

J. Batsleer

European Maritime and Fisheries Fund (EMFF)

Best Practice II

Effect of discard survival on North Sea sole and plaice

Authors: Ruben Verkempynck, Thomas Brunel, Jan Jaap Poos, Jurgen Batsleer

Wageningen University &
Research rapport C075/18A

Best Practice II

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Author(s): Ruben Verkempynck, Thomas Brunel, Jan Jaap Poos, Jurgen Batsleer

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Contents

Summary

This report investigates the effects of discard survival on the current stock assessment and perception of the North Sea sole and plaice stocks. By recalculating the discard fraction of the catches and rerunning the assessment model, the stock assessment of sole and plaice is corrected for discard survivability. Secondly, all discard survival corrected assessments of both stocks are forecasted over 50 years under a landing obligation and discarding (business as usual) scenario. This simulation shows the effect of discard survival under a landing obligation and under the discarding scenario.

The trend and perception of both stocks do not change when discard survivability is taken into account. But the fishing mortality, stock biomass, and recruitment are overestimated. The effect of taking into account discard survivability is a scaling depending on the characteristics of the stock (such as maturity at age) and the extent to which the part of the stock is being discarded. The effect of discard survival is greater in North Sea plaice than in North Sea sole, since the plaice is discarded more.

The Fmsy reference points increase with increasing discard survivability. However, the “F-targets”, the F corresponding to the maximal yield under the landing obligation, that are calculated to simulate the “landing obligation-scenario” do not show the same trend with increasing discard survivability.

The forecast simulation of North Sea sole and plaice was performed by projecting the stocks with targets for fishing mortality that maximise the yield of both stocks. This method gives insight in the effects of the discarding and landing obligation scenario on the catches, recruitment, spawning stock biomass, and fishing mortality. Differences between scenarios increase with increasing discard survivability, although differences are marginal in the simulation of sole (compared to the differences between scenarios in plaice). Mainly the catches are effected by discard survivability under the landing obligation scenario.

1 Introduction

In July 2016 Wageningen Marine Research was granted several tasks and activities in work packages 1 to 5 of the Best Practice II project by its client VisNed. Wageningen Marine Research (WMR) will carry this project out together with ILVO and Wageningen Economic Research. The project is part of an overall Best Practice II project that is managed and executed by VisNed. The project is financed by the European Maritime and Fisheries Fund (EMFF).

This report details the research carried out in the work package on the effects of discard survival on the North Sea sole and plaice stocks.

1.1 Research questions

This report will deal with two questions:

- What is the effect of discard survival on the stock assessment and current perception of the North sea plaice and sole stock?
- What happens when you take discard survival into account and project the stock forward for 50 years under the current situation and under the landing obligation?

1.2 Discard survival and landing obligation effect on stock

Since 2015, the European Union (EU) has incorporated a landing obligation (LO) as part of the Common Fisheries Policy (CFP). Under the LO species subject to a TAC may not be discarded at sea anymore but must be landed. This implies 100% mortality for all caught fish. If all other factors remain the same (i.e. fishing behaviour and selectivity), this would mean an increase in overall mortality in comparison with a similar fishery allowing discards, since some discarded fish may survive but no landed fish will.

The impact of discards in a fishery depends however on the survival rate that is linked to the species and the fishing gear, and the selectivity of the fisheries (Guillen et al., 2014). The Dutch demersal fisheries are very mixed, and are typically characterised by high discarding rates, particularly from the 80mm beam trawl fleet targeting sole (Verkempynck et al., 2018). Survival trials on board commercial fishing vessels do suggest that there is survival of at least part of the discarded fish (van der Reijden et al. 2017).

Likewise, it is difficult to predict how much selectivity could be improved under a landings obligation. WMR is currently evaluating the impact of the change to pulse trawl gears on selectivity of flatfish (mainly sole and plaice), but selectivity is impacted by more factors than gear changes alone (e.g. timing and location of fishing, haul duration, fishing speed etc.).This study is a continuation of the simulation study conducted in 2015 under the demersal discard processing project (Verkempynck and Machiels, 2015). The study is combined with a previous study analysing the sensitivity of the North Sea plaice assessment to the zero discard survival assumption (Miller and Verkempynck, in prep), thus adding a baseline for the simulation study. The focus in this project is on the North Sea sole and plaice stocks.

The relation between survival and the effect on the stock is a much debated and highly relevant topic under the landing obligation. In the current assessments of North Sea sole and plaice any possible discard survival is not accounted for. This means that these assessment models assume that all caught fish (discards and landings) die and thus amount to the total fishing mortality. In other words, discards survival is equal to zero.

From survival studies on board commercial fishing vessels survival of North Sea sole and plaice has been inferred (van der Reijden et al. 2017). Without discard survival taken into account, stock assessment models are likely to be biased in their estimates of SSB, total stock size, fishing mortality, and recruitment. As a result, biological reference points derived from these biased assessments may also be different from assessments including discard survival.

The bias in stock assessments that do not account for discard survival can be graphically explained through the following figures:

1. In the current assessments landings and discards from any year and age, combined with an assumption of natural mortality, are used to calculate stock sizes in the previous year and the previous age (Figure 1.1).

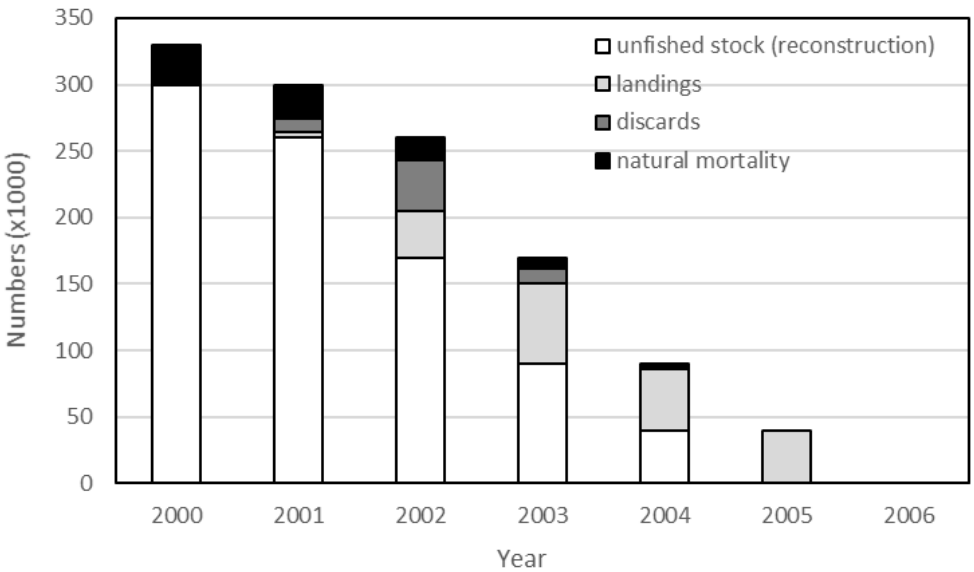

Figure 1.1: Graphical representation of the reconstruction of a single cohort (2000) in a stock assessment based on discards, landings and natural mortality. The total height of the bars is the size of the cohort (2000) at the start of the year. **Remark: Read the graph from right to left.**

2. When we consider discard survival (e.g. 50% survival), 50% of discards survive and thus the discard fraction and resulting catches are lower than without discard survival (0% survival) (figure 2). This difference between both situations is represented by the differences in the reconstruction of a single cohort, depicted as the difference in Figure 1.1 and Figure 1.2. Note that the bars for figure 3.2 are lower. For example, the estimate for this cohort in 2000 decreases from 330 thousand in figure 3.1 to 293 thousand in Figure 1.2.

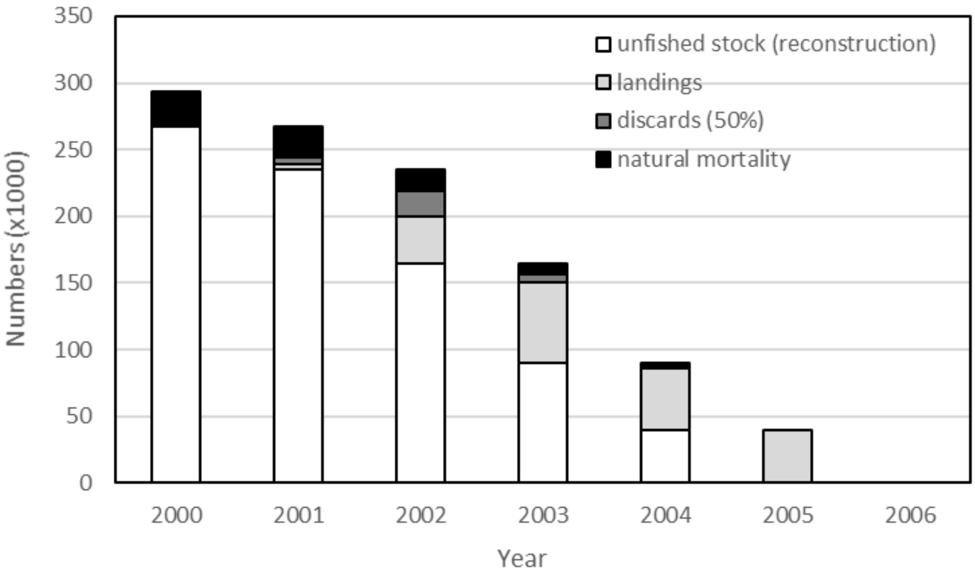

Figure 1.2: Graphical representation of the reconstruction of the same single cohort (2000) as in figure 3.1, but now assuming 50% discard survival. The total height of the bars is the size of the cohort (2000) at the start of the year. Remark: Read the graph from right to left.

1.3 North Sea sole

North Sea sole is a single stock in the North Sea, ICES area 27.4.

North Sea sole is taken mainly in a mixed flatfish fishery by beam trawlers in the southern and south-eastern North Sea (see Figure 1.3). Directed fisheries are also carried out with seines, gillnets, and twin trawls, and by beam trawlers in the central North Sea. The minimum mesh sizes enforced in these fisheries (80 mm in the mixed beam-trawl fishery) are chosen such that they correspond to the Minimum Landing Size for sole.

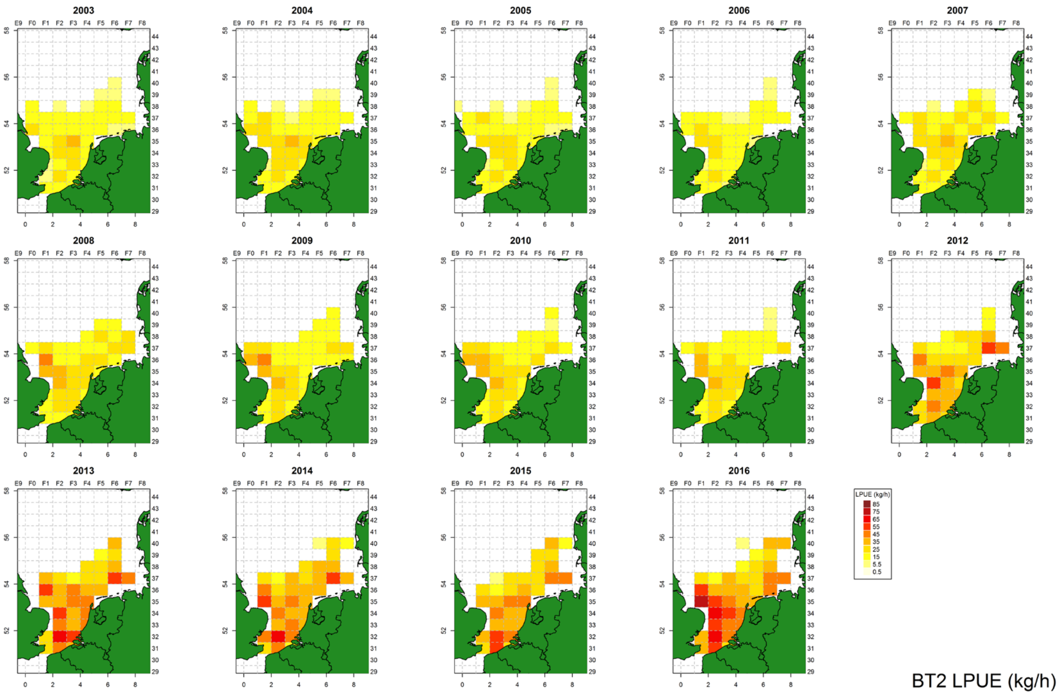

Figure 1.3: LPUEs (kg/h) by Dutch flagged BT2 (beam trawlers working 80 mm mesh).

Discards form a minor part of total sole catches, and discard rates have stabilised in the last years. The assessment at present includes 16 years of discards data obtained from discard sampling programs in several countries and is considered to be robust and consistent between years.

North Sea sole is the main species of commercial interest in the Dutch demersal fleet and subsequently most of the discards originate from the Netherlands. Observed discard quantities are shown on Figure 1.4. Strong cohorts are distinguishable when recruitment was high.

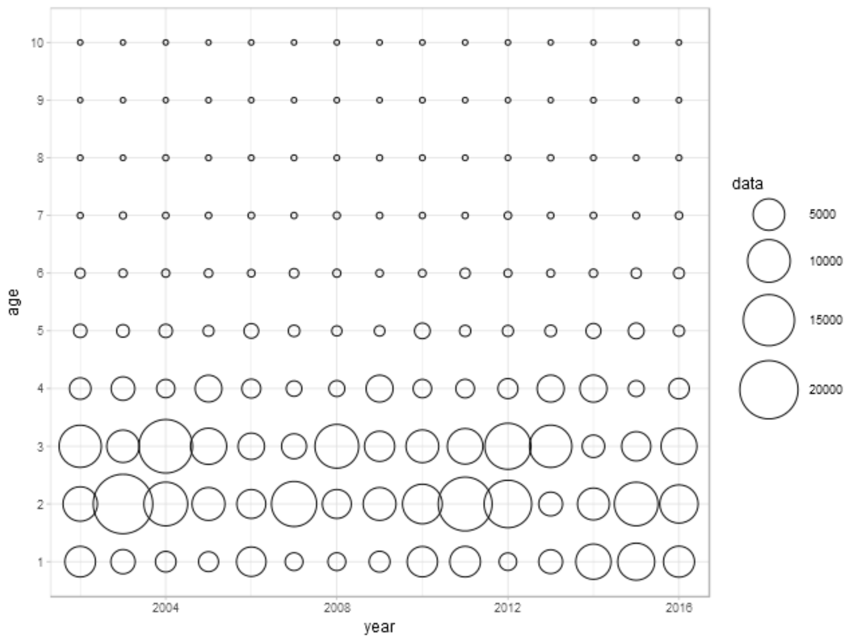

Figure 1.4: Observed discard numbers per age of North Sea sole for 2002 – 2016.

North Sea sole is assumed to be fully mature at age 3 (Figure 1.5). Age 1 and 2 are subsequently not part of the SSB. Since discards consist of mainly ages 1 and 2 and to a lesser extent age 3, the effect of discard survival on the SSB will be only slight.

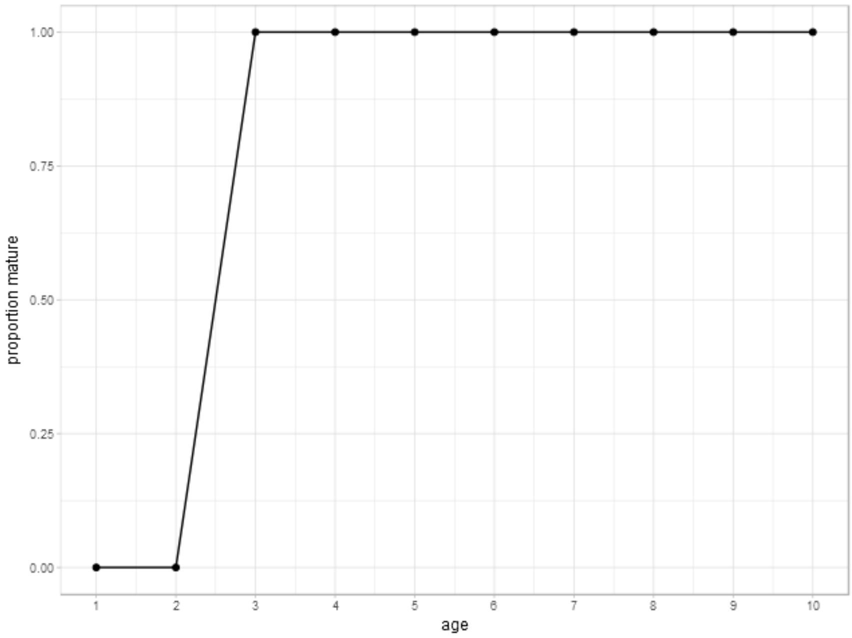

Figure 1.5: Assumed maturity ogive of North Sea sole.

1.4 North Sea plaice

North Sea plaice is mainly taken in a mixed flatfish fishery by beam trawlers in the southern and south-eastern North Sea. Directed fisheries are also carried out with seines, gillnets, and twin trawls, and by beam trawlers in the central North Sea. Due to the minimum mesh size enforced (80 mm in the mixed beam trawl fishery), large numbers of (undersized) plaice are discarded.

Discards make up a considerable part of the catches of North Sea plaice. The recent average discard rate (over years 2007 – 2016) of North Sea plaice is 38%. Discard sampling programmes started in the late 1990s to obtain discard estimates from several fleets fishing for flatfish. These sampling programmes give information on discards from 2000. For the period prior to 2000, a reconstructed discard time-series for 1957 – 1999 exists, based on a reconstructed population and selection and distribution ogives (Figure 1.6).

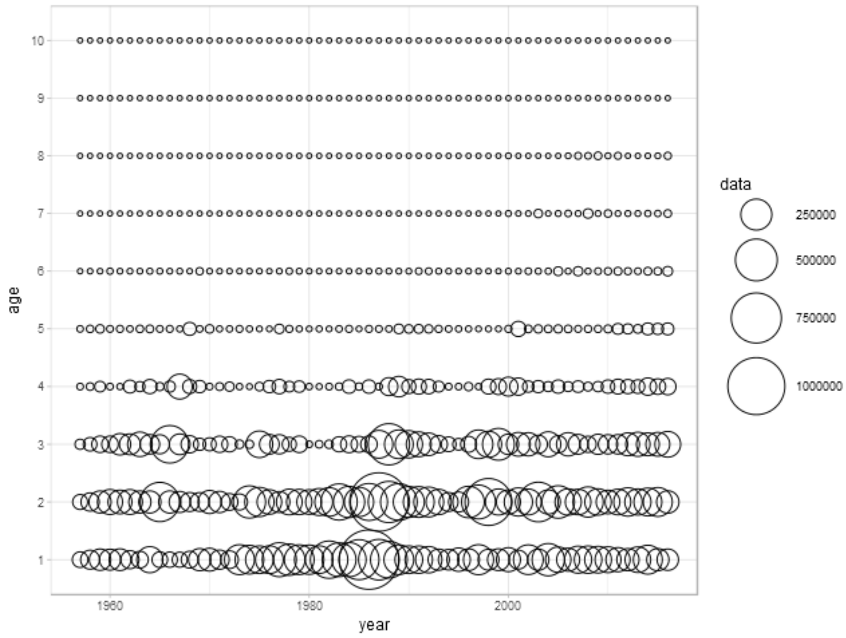

Figure 1.6: Observed discard numbers per age of North Sea plaice. Note: from 1957 – 2001 discards are reconstructed (where is this reference? Pastoors/Rijnsdorp/van Keeken?)

Age one is assumed to be fully immature, but both ages 2 and 3 are 50% mature (Figure 1.7). From age 4 onwards, it is assumed that all fish are fully mature and hence contribute to the SSB. Since up to age 3 fish are discarded, there is a substantial impact to be expected in the SSB.

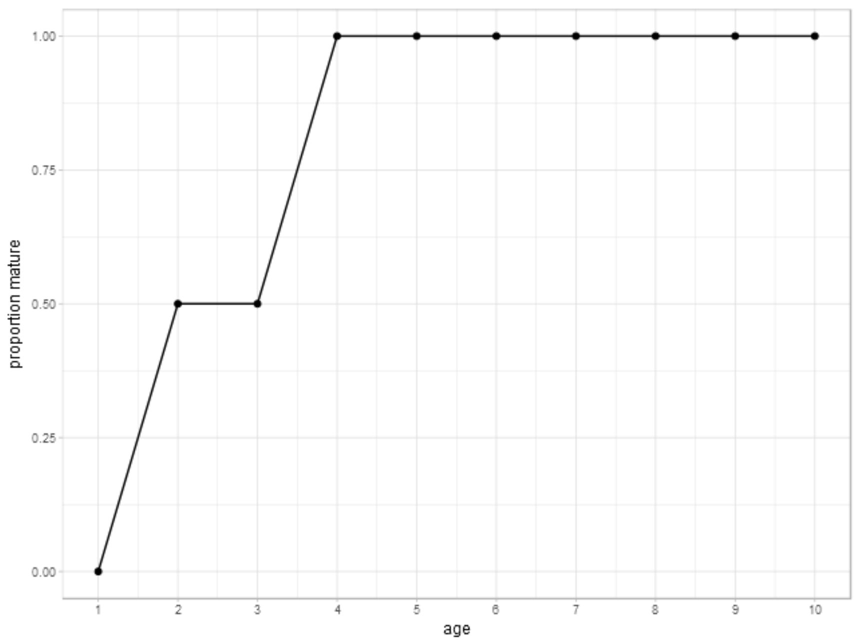

Figure 1.7: Assumed maturity ogive of North Sea sole.

2 Methodology

The assumption on discard survivability will effect both the current perception of the stock (i.e. the stock assessment model) and our prediction of future stock development (i.e. the forecast model). In addition, management reference points (e.g. FMSY) will also be affected.

2.1 Correcting stock assessment for discard survival

First, the stock assessment of North Sea sole and of North Sea plaice was recalculated according to different discard survival levels. Discard survival ranged from 0% to 100%. The 0% discard survival is basically the same assumption as under the current stock assessment.

Both the assessment of North Sea sole and of North Sea plaice was configured according to the settings of the most recent benchmark of those species (North Sea sole: ICES, 2015, North Sea plaice: ICES, 2017). Both assessments are based on a statistical catch-at-age model with flexible selectivity functions to reconstruct historical catches and estimate stock abundance (Aarts and Poos, 2009).

The assessment model was run for 11 discard survival scenarios, resulting in a recalculated stock assessment for sole and plaice for each run. Before each run the observed discard matrix (i.e. discards numbers and weights obtained for discard monitoring programmes) was multiplied by a survival rate (0% to 100%) (Figure 2.1-2), these discards thus represent the dead part of the caught discards in the assessment.

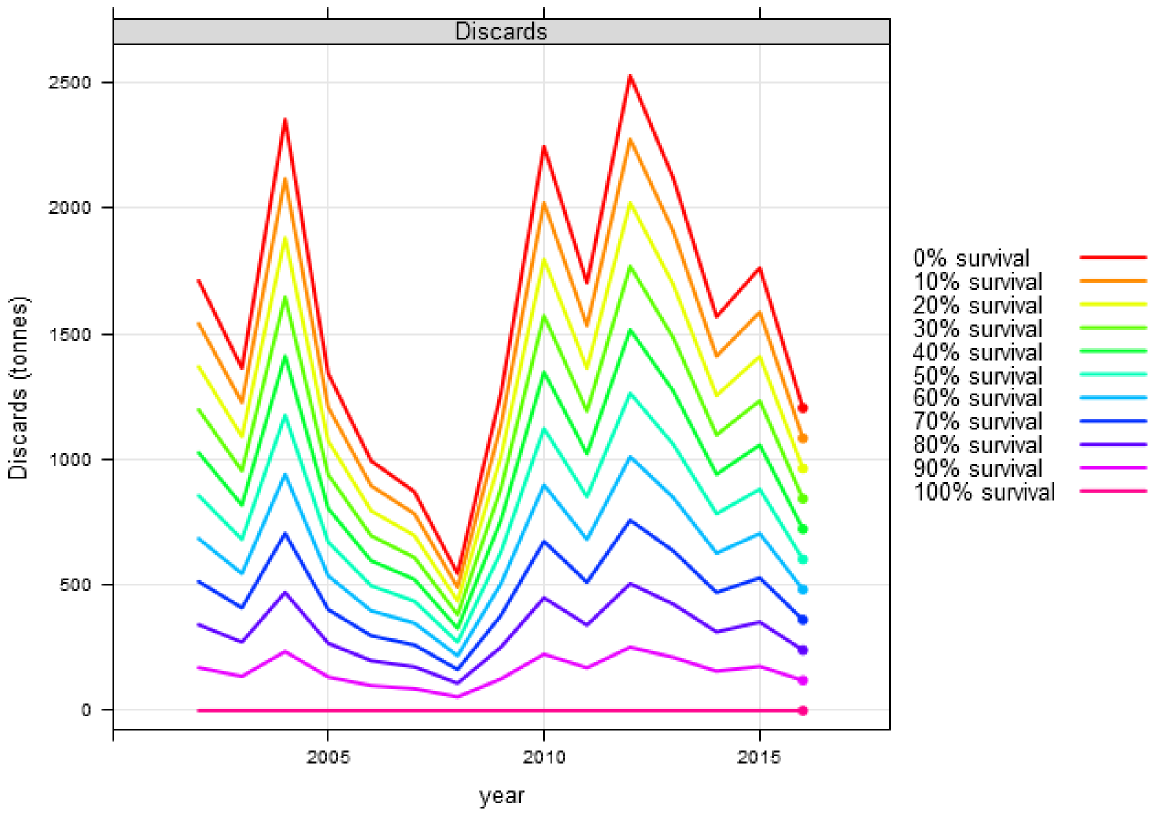

Figure 2.1: Total weight (tonnes) of dead discards as input for recalculations of the North Sea sole assessment according to different levels of discard survival.

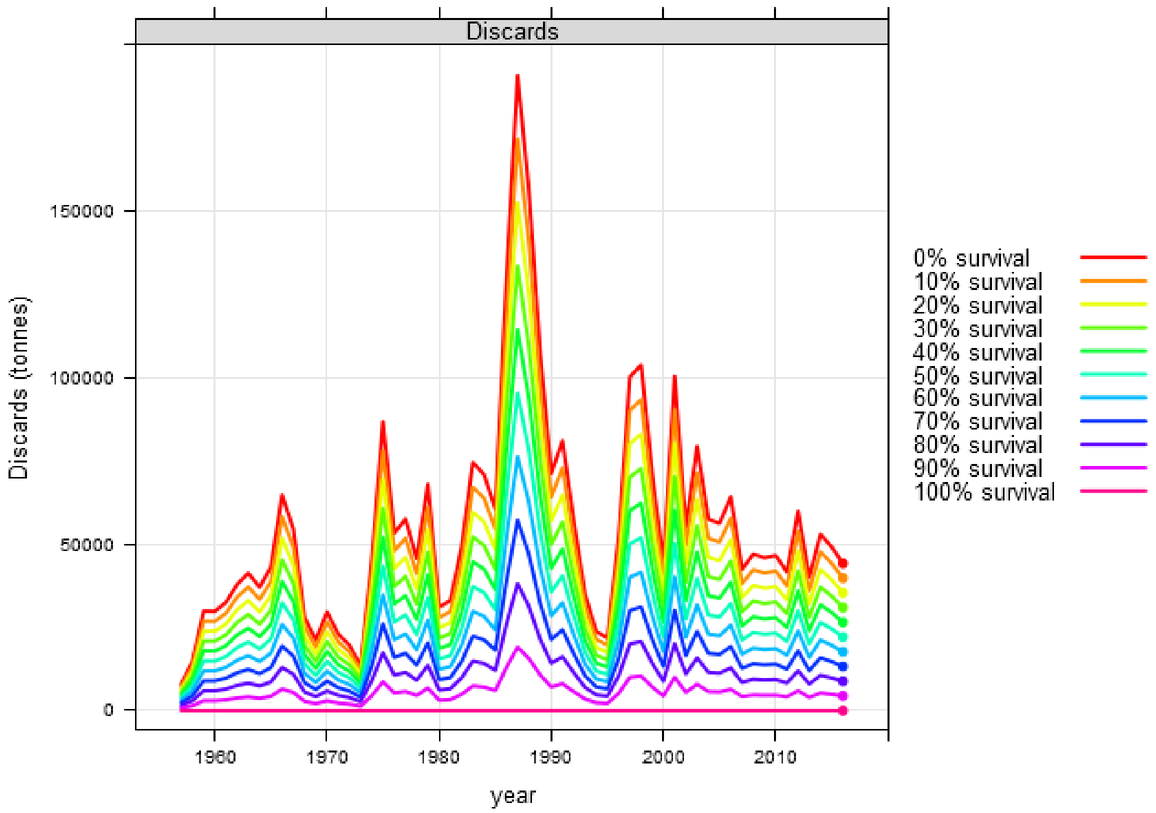

Figure 2.2: Total weight (tonnes) of dead discards as input for recalculations of the North Sea plaice assessment according to different levels of discard survival.

2.2 Reference point calculation under discard survival

Based on the stock assessment of North Sea sole and of North Sea plaice corrected for discard survival, reference points (Fmsy) were estimated. Each stock assessment run, corrected for discard survival, has a different estimated fishing mortality-at-age (selectivity). This discard survival-corrected selectivity and the corrected results for spawning stock biomass and recruitment form the basis for the calculation of the reference points under discard survival.

The EQsim software was configured and used according to the settings as described in the most recent benchmark of North Sea sole and North Sea plaice (North Sea sole: ICES, 2015, North Sea plaice: ICES, 2017). For North Sea sole, a segmented regression stock recruitment relationship is used (Figure 2.3), for North Sea plaice a combination of the Ricker, segmented regression, and Beverton and Holt stock recruitment relationship is used (Figure 2.4). The number of runs used for the EQsim analysis was 5000.

The reference points derived from the discard survival-corrected assessments are used in the forecast simulation (see Chapter 2.3).

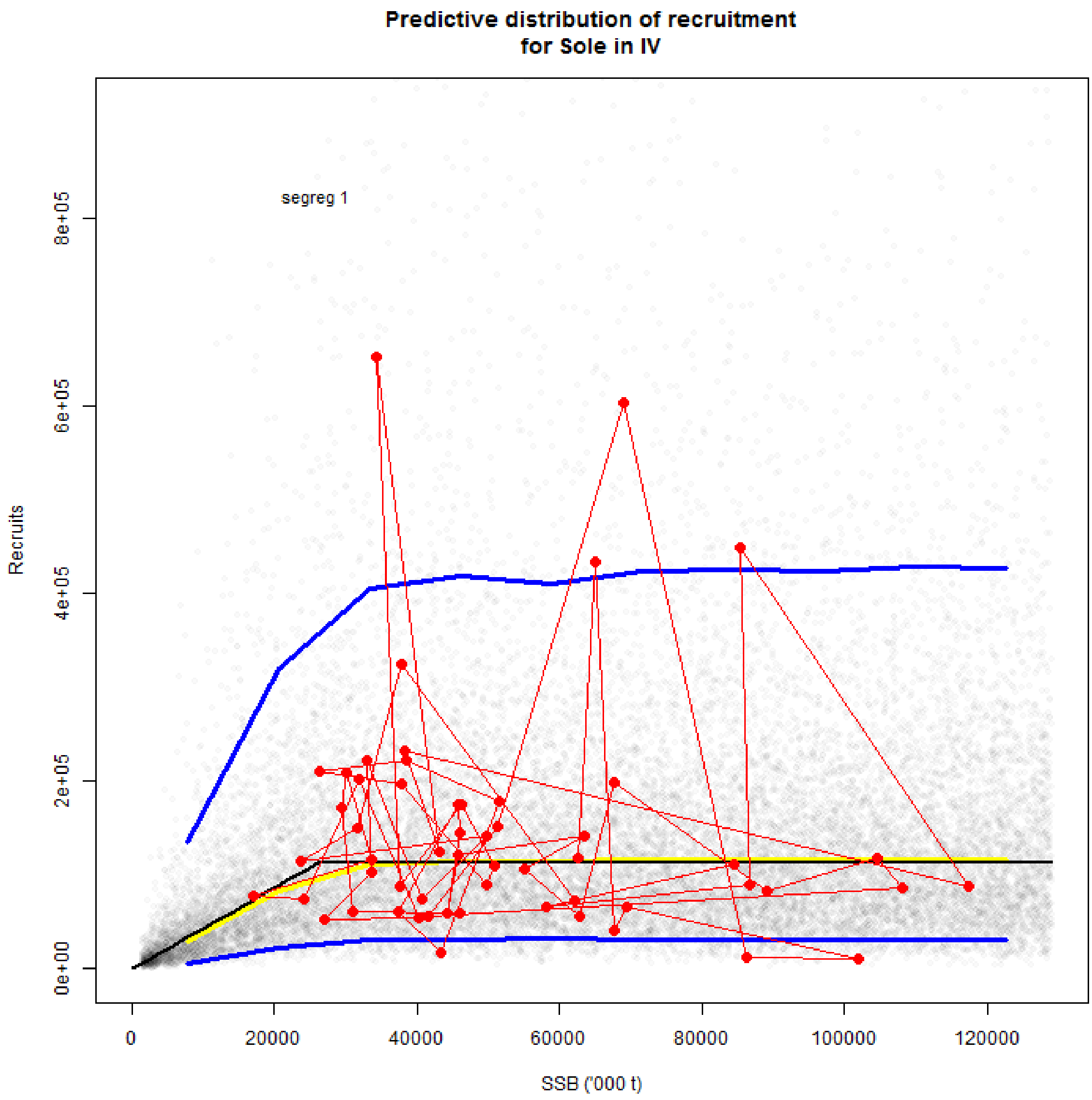

Figure 2.3: Stock-Recruitment relationship used for North Sea sole Fmsy reference point estimation during the most recent benchmark of North Sea sole (ICES, 2015).

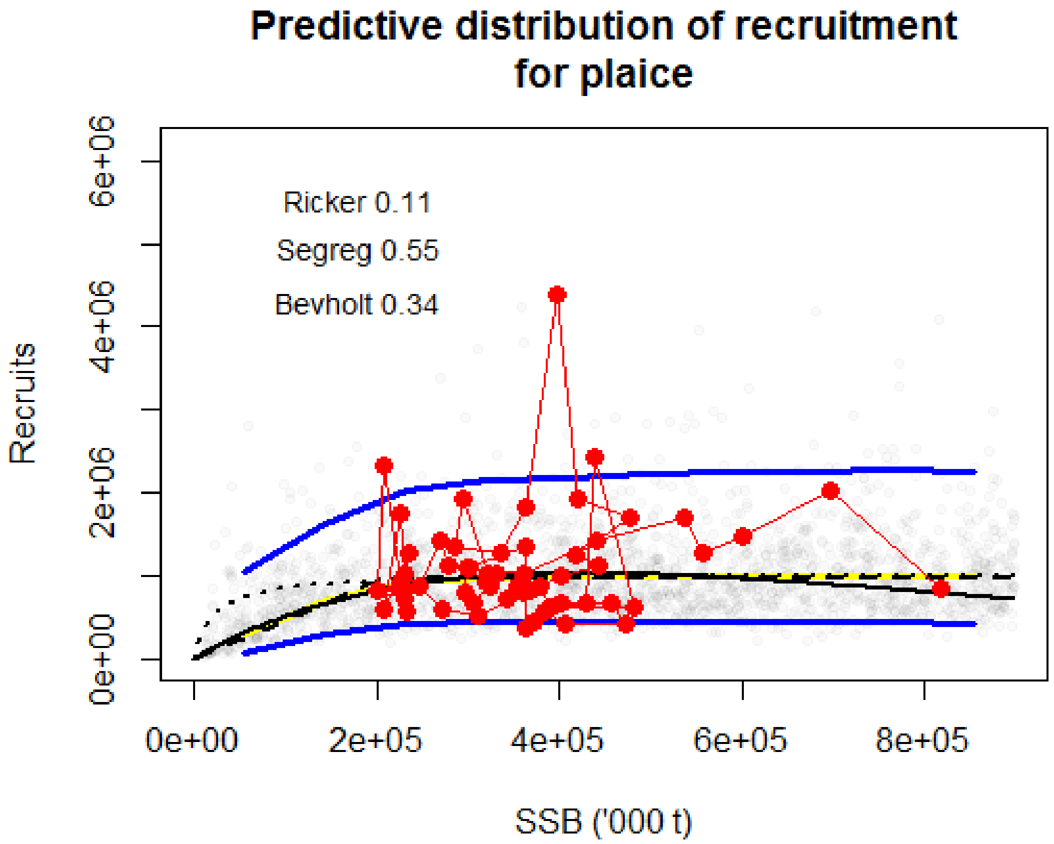

Figure 2.4: Stock-Recruitment relationship used for North Sea plaice Fmsy reference point estimation during the most recent benchmark of North Sea plaice (ICES, 2017).

2.3 Forecast simulation under current discarding practice and landing obligation

To assess the impact of discard survival under the landing obligation a 50-year forecast (2017 – 2066) was simulated starting from each discard survival-corrected assessment. Two scenarios were defined:

1. Discarding continues: the stock is projected with the Fmsy reference point from each discard survival-corrected assessment as F-target.

This scenario corresponds with the objectives of the EU common fisheries policy (Council Regulation No. 676/2007).The Fmsy reference points recalculation is described above (2.2 Reference point calculation under discard survival).

2. Landing obligation is implemented: for all discards of each stock from 2017 onwards, the stock is projected with an F-target optimized for maximum landings under a landing obligation (see below).

The F-target points that maximize the landings for forecasting the discard survival-corrected assessments under the landing obligation are derived from a second EQsim analysis. The procedure for this EQsim analysis follows the same configuration and settings as performed for the Fmsy reference point calculation (2.2 Reference point calculation under discard survival), but since all discards caught are landed under the landing obligation, the discards in each EQsim run are reset to the total observed discards corresponding to the total gear selectivity of both stocks (which are the discards observed in the stock assessment with 0% discard survival).

$$discards.n(stock) = discards.n(stock\_0\%)$$
$$discards(stock) = discards(stock\_0\%)$$

Doing this, the catch matrix and consequently the selectivity pattern for each discard survival-corrected assessment is changed so that the total dead discards are set to what can be maximally observed (discard estimates come from catch monitoring programmes).

After defining the F-target values each discard survival-corrected assessment under both scenarios the stock is forecasted 50-years using the FLR software (www.flr-project.org). A Beverton and Holt stock recruitment relationship is taken for defining the recruitment for each projected year. To account for uncertainty in recruitment the stock is projected forward with 500 iterations including stochasticity in recruitment. The results from the forecast simulation are then derived by taking the median over the iterations.

The historic part of the time-series of each stock (from 1957 to 2016) is identical for both scenarios. Both stocks have been corrected for potential survivability of discards for the historic part of the time series in the first part of this project (see Chapter 2.1). The scenarios differ for the future years. Under scenario 1 the stock is projected having the same discard survival as the survival rate with what it was corrected for in the historic part of the time-series. Following scenario 2, the stock is projected without discard survival (all discards of North Sea sole and plaice are landed).

3 Results

3.1 Discard survival-corrected stock assessment

3.1.1 North Sea sole

The assessment of North Sea sole was corrected for discard survivability, and the resulting stock development over time, including total dead catch, spawning stock biomass (ssb), total stock biomass (tsb), recruitment, and fishing mortality (fbar) for discard survival levels from 0% to 100% are shown in Figure 3.1 (a - e).

For discards, results vary according to their survival. As we assume the same survival over all ages in the discards, the discards are scaled by the corresponding survival rate (Figure 2.1). For catches, the effect of discard survival on the recalculated catches is less obvious (figure 3.1a). This can be explained by the fact that North Sea sole is not commonly discarded (current discard rate is ~ 11%) as it is a commercially important target species.

Results show that the ssb and tsb of North Sea sole is slightly overestimated in the current assessment (0% survival) if North Sea sole discards survive the catch process (Figure 3.1 b and c). However, the effect of discard survival is only slightly noticeable. Recruitment (Figure 3.1d) on the other hand, defined here as age 1, is mainly driven by discard survival and is scaled to the same extent as the discards.

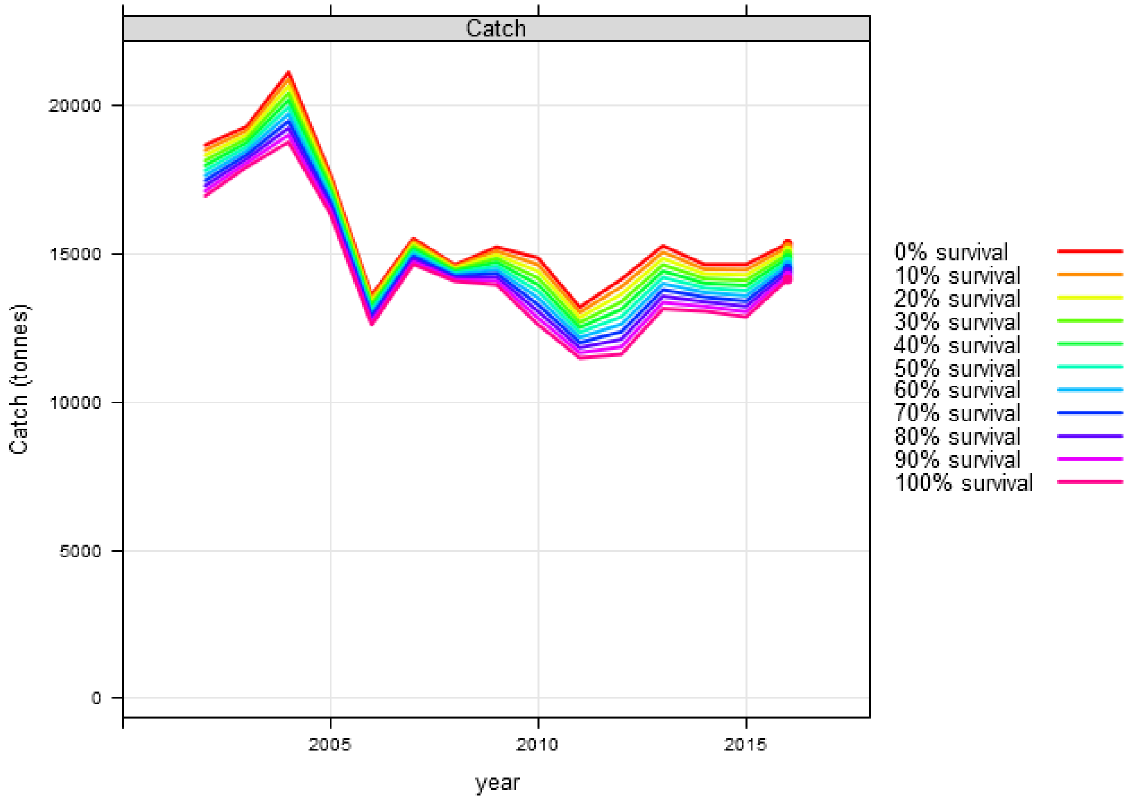

Figure 3.1a: Total weight (tonnes) of dead catches (landings + dead discards) as input for recalculations of the North Sea sole assessment according to different levels of discard survival.

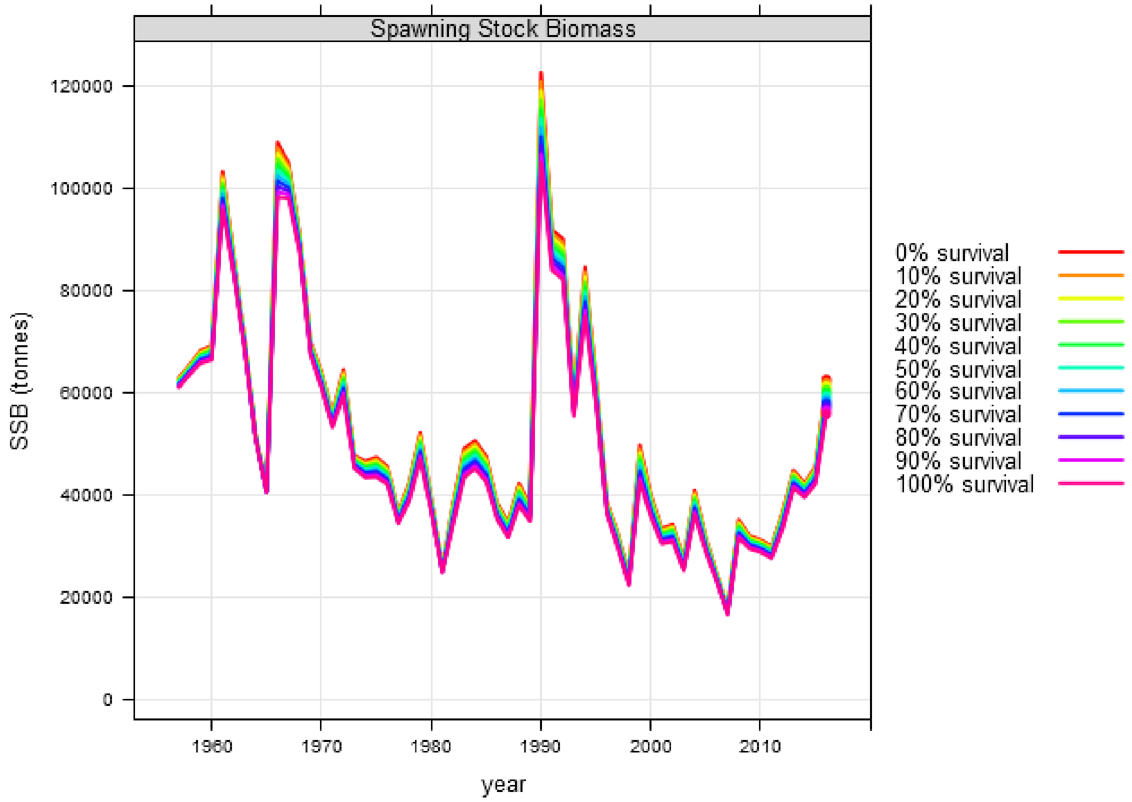

Figure 3.1b: Spawning stock biomass (1957-2016) of North Sea sole assessment under different scenarios of discard survival (0 to 100% discard survival).

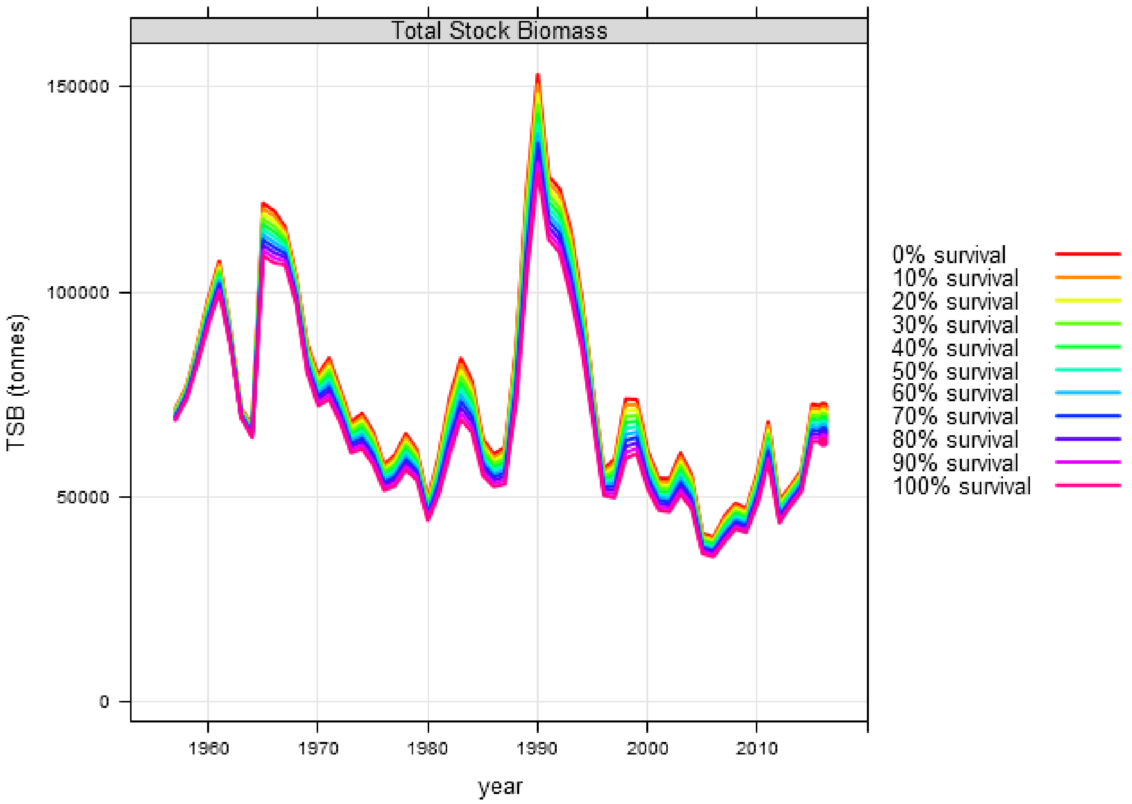

Figure 3.1c: Total stock biomass (1957-2016) of North Sea sole assessment under different scenarios of discard survival (0 to 100% discard survival).

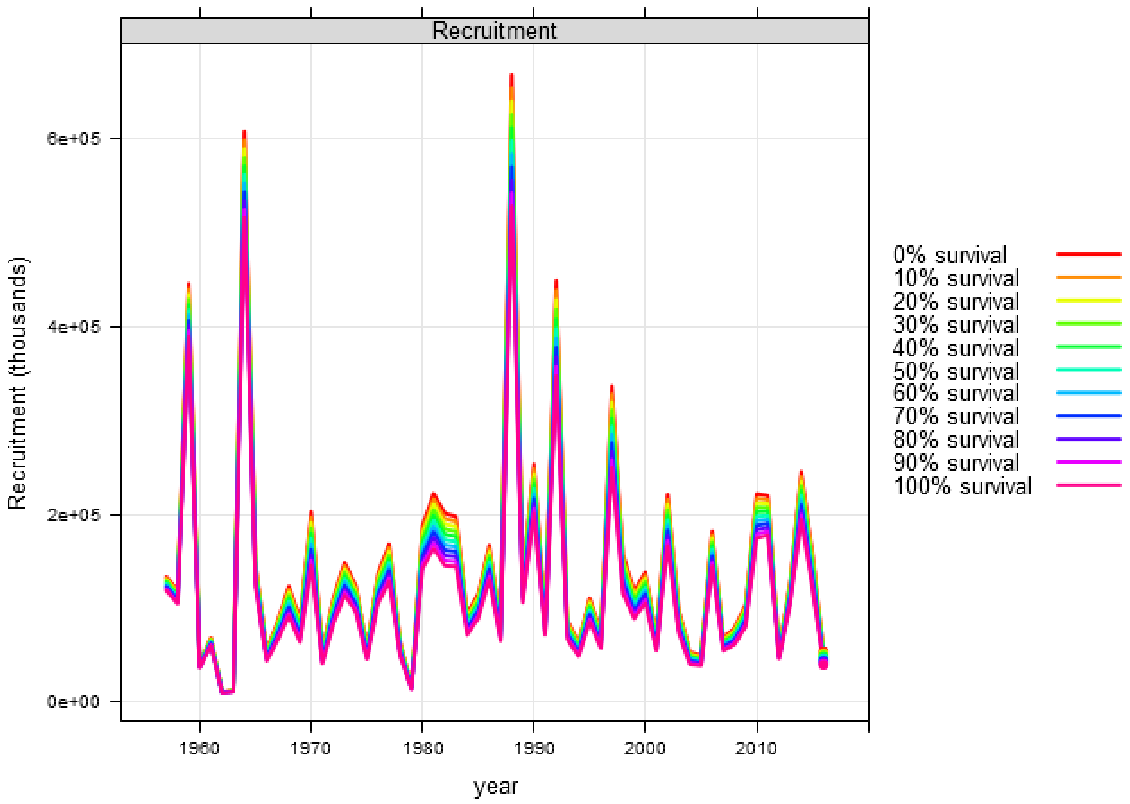

Figure 3.1d: Recruitment (1957-2016) of North Sea sole assessment under different scenarios of discard survival (0 to 100% discard survival).

The current assessment (0% discard survival) is overestimating the fishing mortality. When discard survival is taken into account the fishing mortality decreases with increasing discard survival levels (Figure 3.1e).

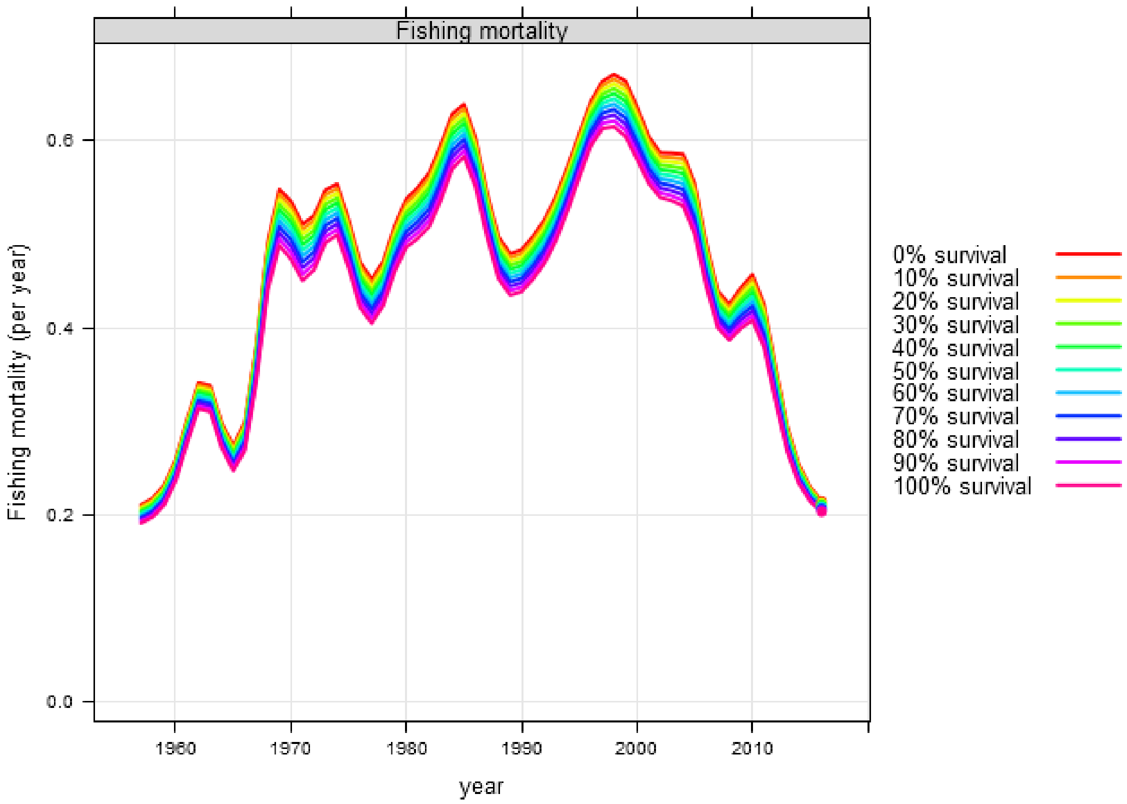

Figure 3.1e: Fishing mortality (1957-2016) of North Sea sole assessment under different scenarios of discard survival (0 to 100% discard survival).

The selectivity of the assessment (exploitation pattern over the ages in the population) changes with discard survival. There is a clear shift in fishing mortality from younger ages to older ages (figure 3.2) with increasing discard survival levels. Fishing mortality is lower under higher discard survival levels (Figure 3.1e) but the fishing mortality shifts to older individuals in the stock because there are less younger fish in the population that die because of fishing with higher discard survival rates.

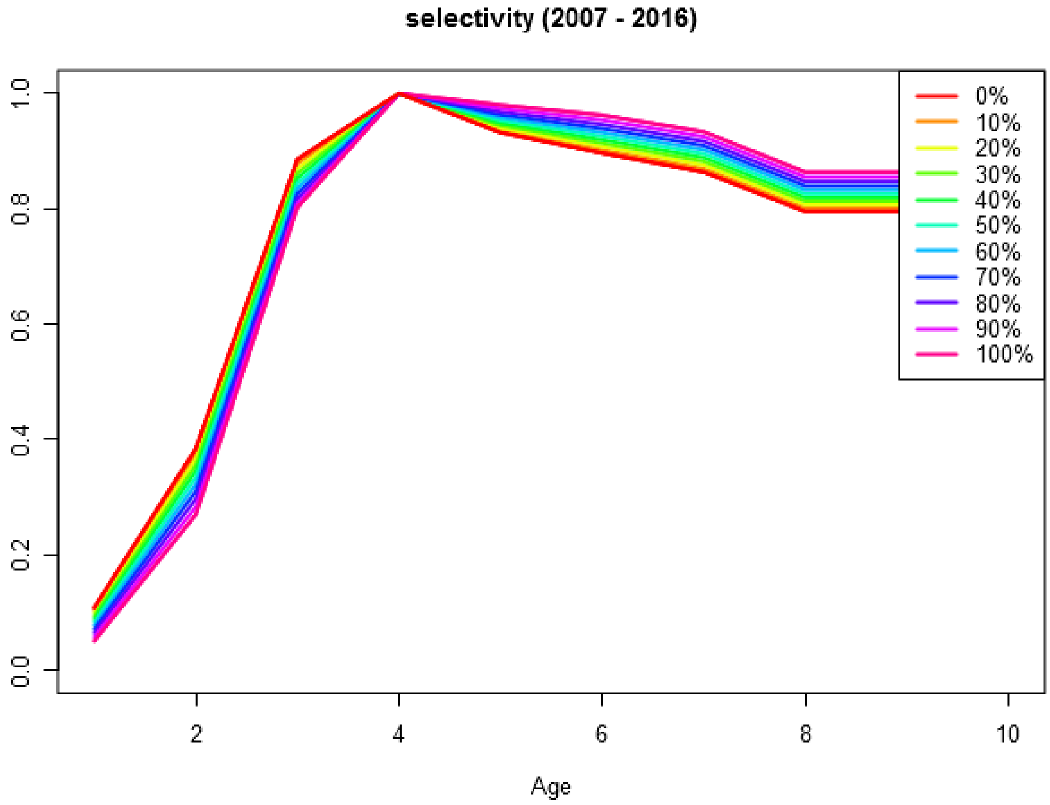

Figure 3.2: Selectivity's (fishing mortality-at-age scaled to maximum fishing mortality) for the period 2007-2016 under different scenarios of discard survival (0 to 100% discard survival).

3.1.2 North Sea plaice

The assessment of North Sea plaice was corrected for a range of discard survival levels (0% to 100%). The resulting stock development over time, including total dead catch, spawning stock biomass (ssb), total stock biomass (tsb), recruitment, and fishing mortality (fbar) are shown in Figure 3.3 (a to e).

For discards, results vary according to their survival, as we assume the same survival over all ages in the discards, the recalculated discards are scaled by the corresponding survival rate (Figure 2.2). For catches of North Sea plaice, the effects of discard survival on the recalculated catches is obvious (Figure 2.3a) as discards observed in the catches are considerable (currently a discard rate of ~ 36%).

Results show that the spawning stock biomass and total stock biomass of North Sea plaice is overestimated in the current assessment (0% survival) if North Sea plaice discards survive the catch process (Figure 3.3b - c). Recruitment on the other hand, defined here as age 1, is mainly driven by discard survival and is scaled in the same way as discards and catches (Figure 3.3d).

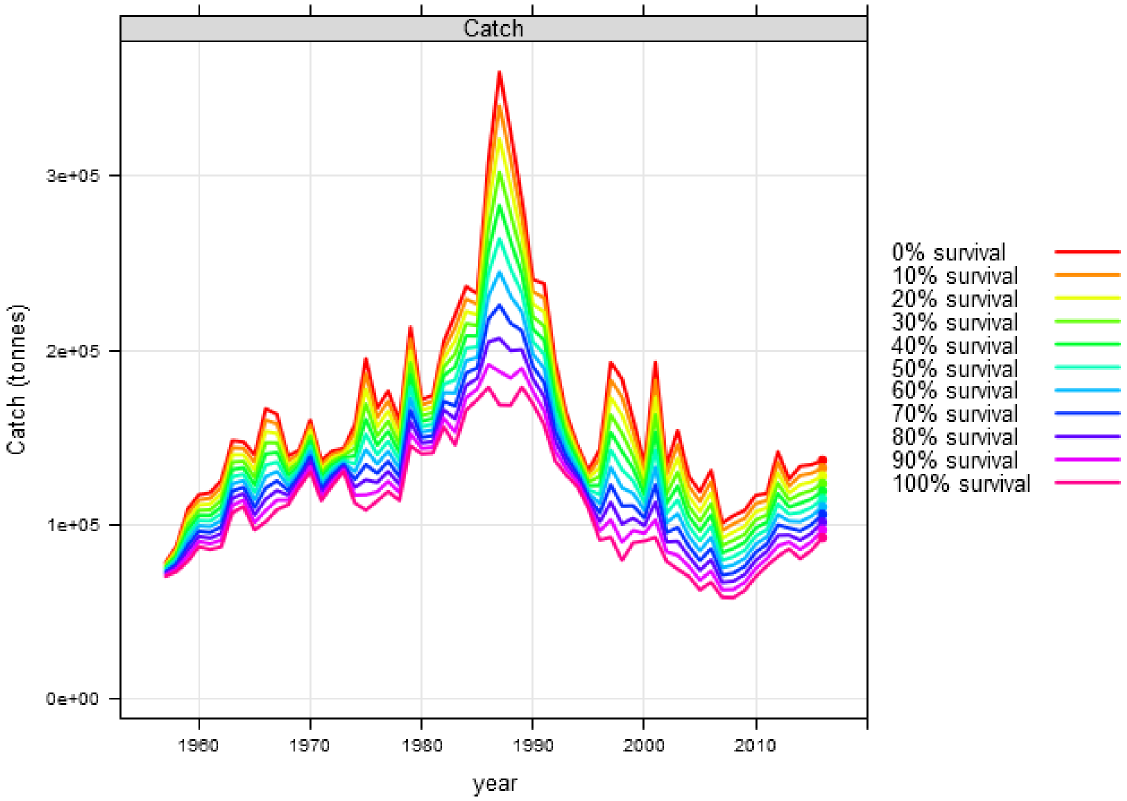

Figure 3.3a: Total weight (tonnes) of dead catches (landings + discards) as input for recalculations of the North Sea plaice assessment according to different levels of discard survival.

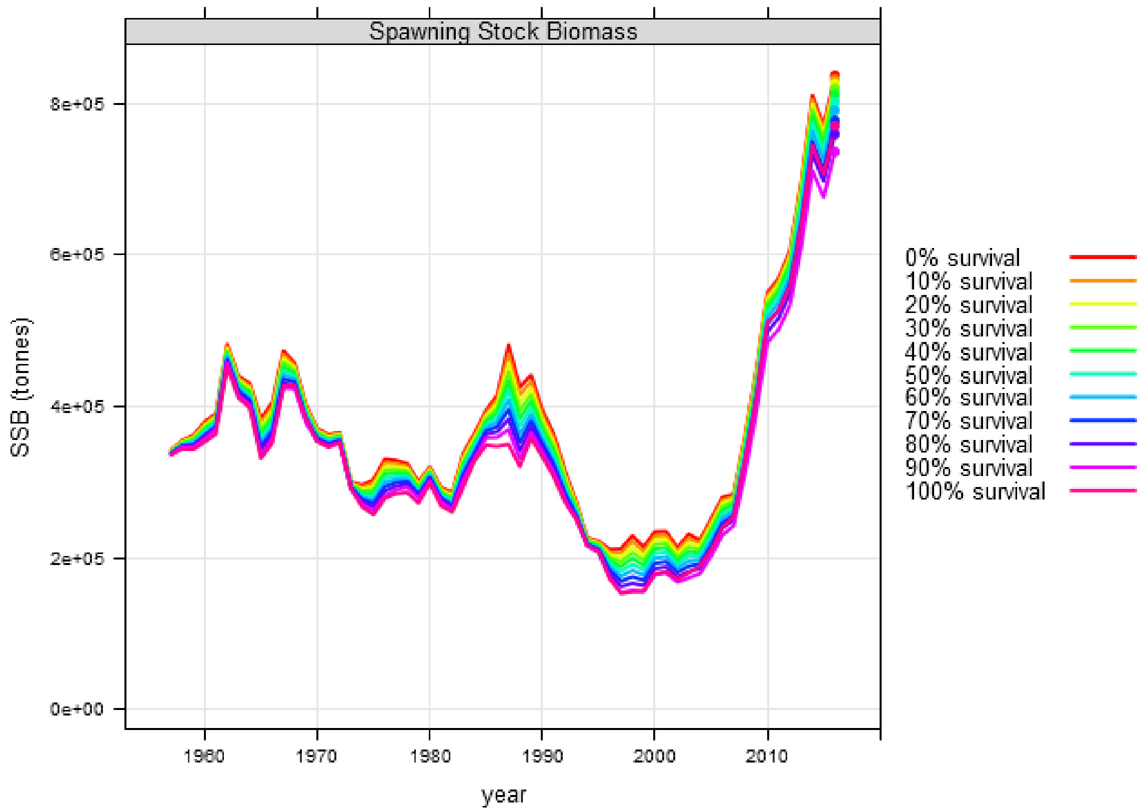

Figure 3.3b: Spawning stock biomass (1957-2016) of North Sea plaice assessment under different scenarios of discard survival (0 to 100% discard survival).

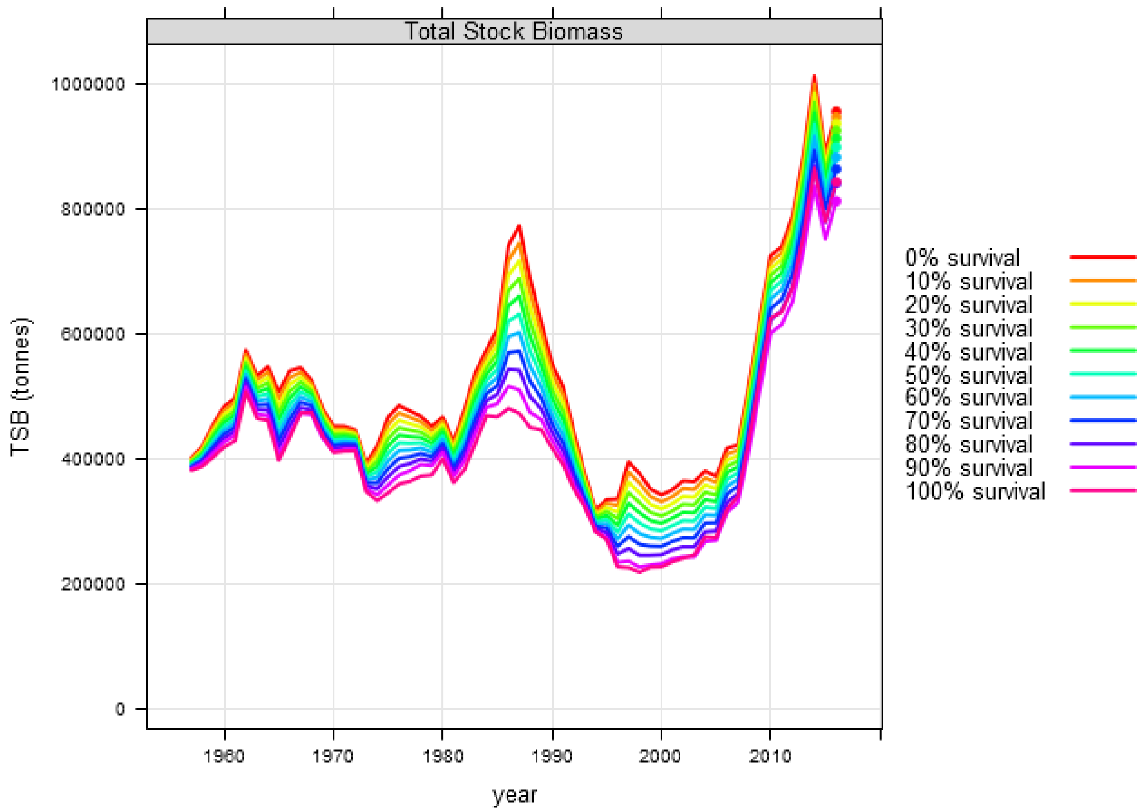

Figure 3.3c: Total stock biomass (1957-2016) of North Sea plaice assessment under different scenarios of discard survival (0 to 100% discard survival).

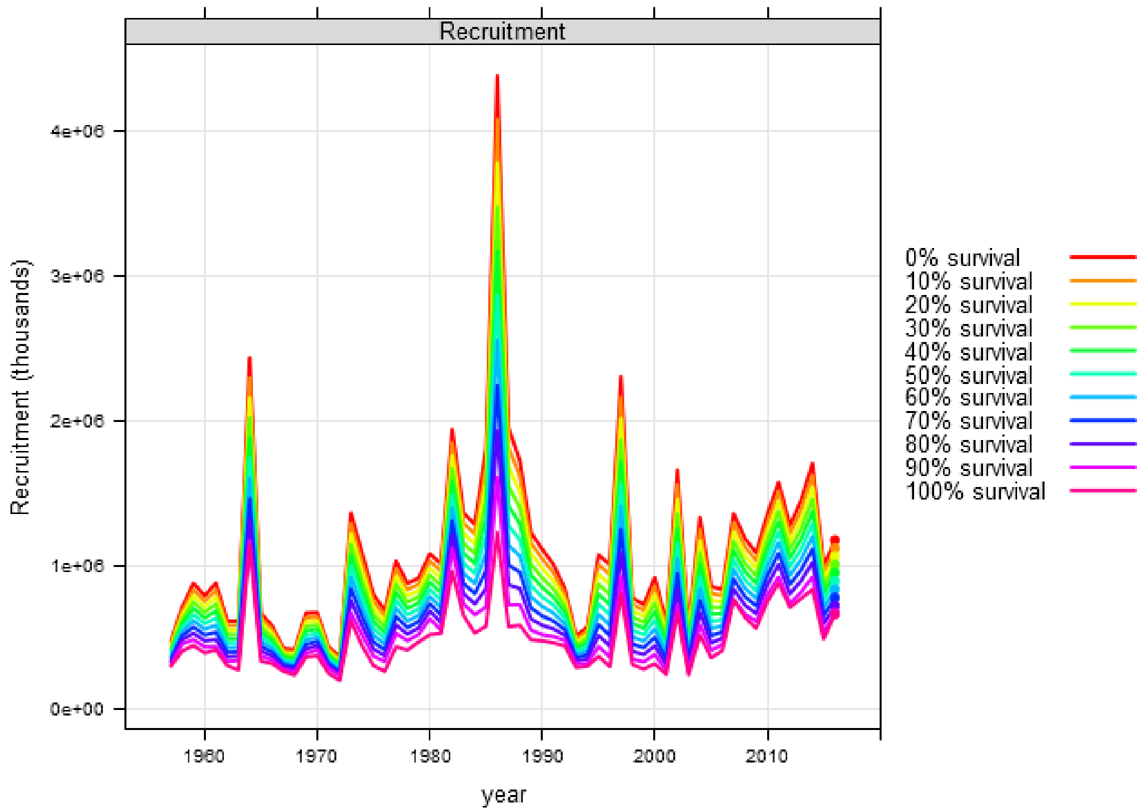

Figure 3.3d: Recruitment (1957-2016) of North Sea plaice assessment under different scenarios of discard survival (0 to 100% discard survival).

Also, when discards survive the catch process, subsequently the total fishing mortality is less than under the scenario where all discards die (Figure 3.3e). This is because part of the total fishing mortality caused by catching discards that die is less when discards survive.

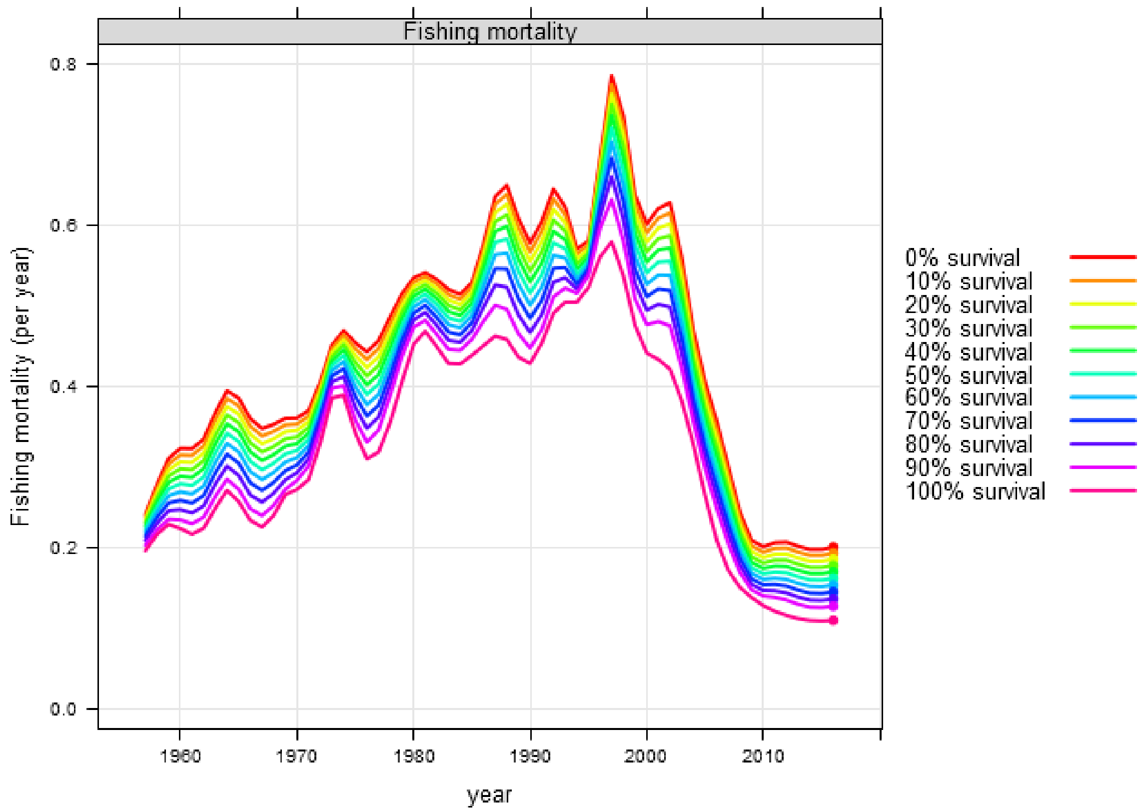

Figure 3.3e: Fishing mortality (1957-2016) of North Sea plaice assessment under different scenarios of discard survival (0 to 100% discard survival).

Selectivity of the North Sea plaice assessment changes with different discard survival levels. There is a clear shift from fishing mortality on younger ages of the population to older ages in the population (Figure 3.4) with increasing discard survival levels. Overall, fishing mortality is lower under higher discard survival rates (figure 3.3e) but at the same time the fishing mortality shifts to older ages in the population as the younger fish die less because of fishing under higher discard survival rates.

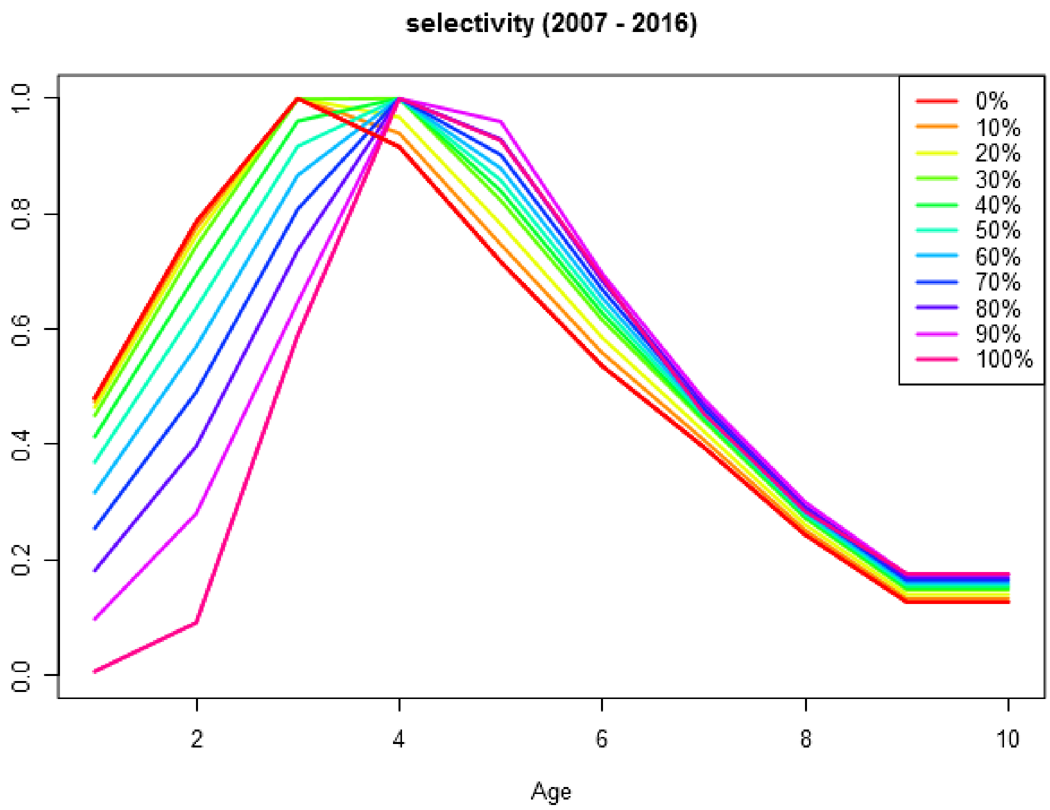

Figure 3.4: Fishing mortality (1957-2016) of North Sea plaice assessment under different scenarios of discard survival (0 to 100% discard survival).

3.2 Reference point recalculation under discard survival

3.2.1 North Sea sole

Fmsy reference points of North Sea sole were estimated for different levels of discard survival (0 to 100% discard survival). Fmsy reference points are higher with increasing discard survival. The Fmsy reference points for the different levels of discard survival are presented in Table 3.1 and in Figure 3.5.

The current Fmsy reference point of North Sea sole is (0.202). This value was calculated at the most recent benchmark of North Sea sole (ICES, 2015) using catch data and stock weights from 1957 to 2013 (available at that time). The reference points calculated from the discard survival-corrected stock assessments (Table 3.1) are calculated with the most recent catch data and stock weights (1957 – 2016).

Table 3.1: Fmsy reference points of North Sea sole for different levels of discard survival (0 to 100% discard survival).

Discard survival	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Fmsy	0.270	0.275	0.276	0.287	0.291	0.297	0.304	0.309	0.312	0.316	0.322

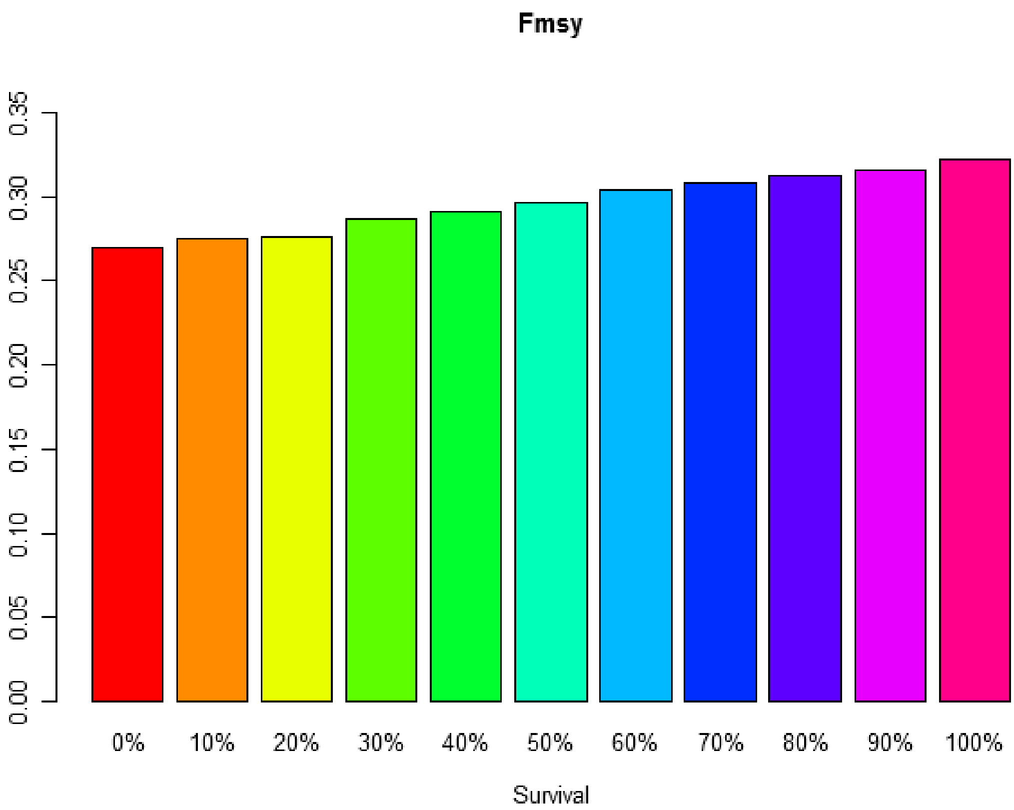

Figure 3.5: Reference points (Fmsy) of North Sea sole for different levels of discard survival (0% to 100% discard survival).

3.2.2 North Sea plaice

Fmsy reference points of North Sea plaice were also estimated for different levels of discard survival (0 to 100% discard survival). Fmsy reference points are higher with increasing discard survival. The current Fmsy reference point of North Sea plaice is (0.20). The Fmsy reference points for the different levels of discard survival are presented in Table 3.2 and in Figure 3.6.

Table 3.2: Fmsy reference points of North Sea plaice for different levels of discard survival (0 to 100% discard survival).

Discard survival	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Fmsy	0.202	0.205	0.222	0.223	0.225	0.226	0.228	0.232	0.239	0.263	0.262

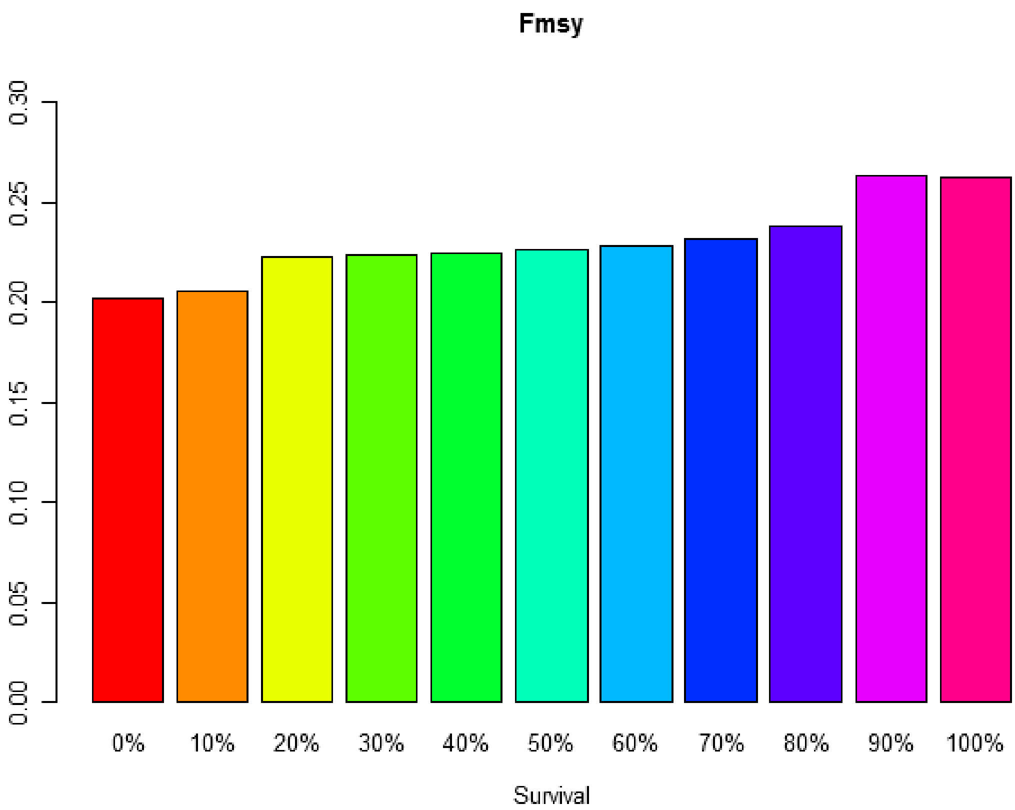

Figure 3.6: Reference points (Fmsy) of North Sea plaice assessment for different levels of discard survival (0% to 100% discard survival).

3.3 Forecast simulation under current discarding practice and landing obligation

3.3.1 North Sea sole

3.3.1.1 F-targets

First F-targets for the landing obligation scenario were calculated by resetting the discards to the total observed discards (which are the discards observed in the stock assessment with 0% discard survival), thus assuming the current gear selectivity. These F-targets are presented in Figure 3.7. These F-targets are approximately constant for different levels of discard survival.

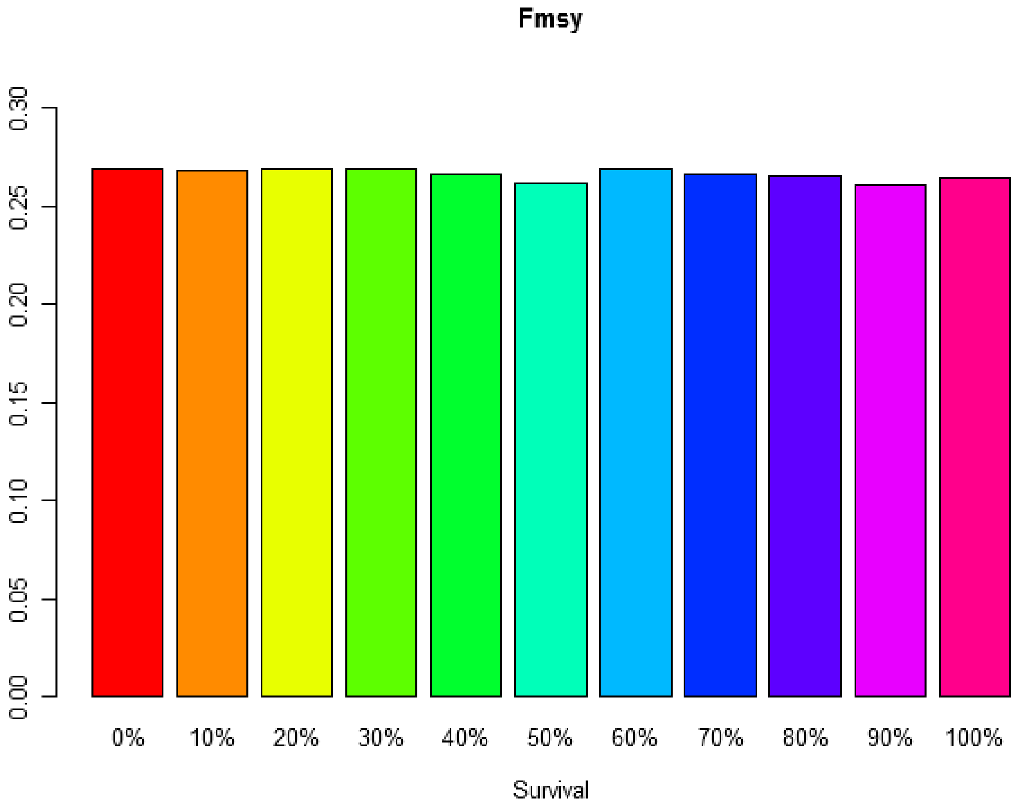

Figure 3.7: F-targets of North Sea sole for the landing obligation scenario of forecast simulation for different levels of discard survival (0% to 100% discard survival).

3.3.1.2 Forecast simulation

The forecast simulation of North Sea sole under the discarding scenario is shown for 0%, 20%, 40%, 60%, 80%, and 100% discard survival on Figure 3.8.

The forecast simulation of North Sea sole under the landing obligation scenario is shown for 0%, 20%, 40%, 60%, 80%, and 100% discard survival on Figure 3.9.

The graphical representation without the confidence bounds (only median values) of the forecast simulation of both scenarios is shown on Figure 3.10.

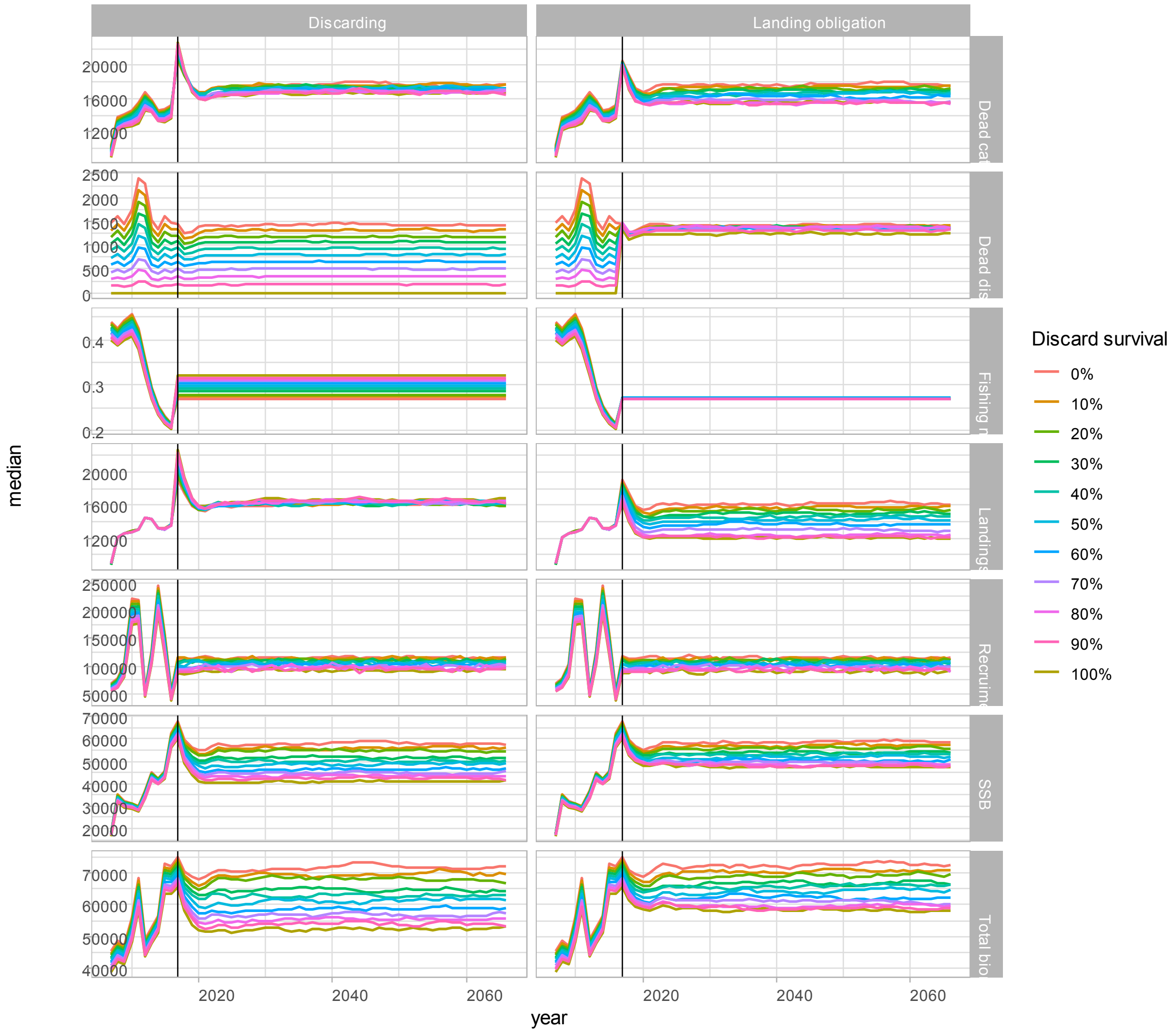

Figure 3.10: Forecast simulation of North Sea sole under two scenarios (only median values).

3.3.1.3 Comparing discarding and landing obligation scenario

The median results of the forecast simulation of North Sea sole for both the discarding as the landing obligation scenario for different levels of discard survival (0% to 100%) are shown on Figure 3.10. Only the results for the years 2021, 2031 and 2066 are shown for practical reasons.

The results clearly show less landings of North Sea sole under the landing obligation scenario than under the discarding scenario for the same discard survival levels. Also dead discards are greater under the landing obligation scenario than under the discarding scenario, since with discarding the fish that is set overboard will have a chance to survive. Under the discarding scenario, the fishing mortality can be higher than under the landing obligation for the same discard levels.

Median results of forecast simulation of North Sea sole under the discarding and landing obligation scenarios for different levels of discard survival and for the years 2021, 2031, and 2066.

The median results for landings, dead discards, ssb, and stock per 5-year step and the percentage change after the forecast simulation period between both scenarios are presented in Table 3.3.

Table 3.3: Median results for 2016 and 2066 and percentage change after forecast of North Sea sole.

Scenario	Indicator	Discard survival	2016	2066	Percentage change
disc	catch	0%	15150	17729	
lo	catch	0%	15150	17551	-1.00%
disc	catch	10%	14992	17622	
lo	catch	10%	14992	17474	-0.84%
disc	catch	20%	14833	17148	
lo	catch	20%	14833	17193	0.26%
disc	catch	30%	14675	17188	
lo	catch	30%	14675	16833	-2.07%
disc	catch	40%	14517	17224	
lo	catch	40%	14517	16755	-2.72%
disc	catch	50%	14359	17183	
lo	catch	50%	14359	16550	-3.68%
disc	catch	60%	14202	17074	
lo	catch	60%	14202	16225	-4.97%
disc	catch	70%	14047	17044	
lo	catch	70%	14047	15677	-8.02%
disc	catch	80%	13896	16880	
lo	catch	80%	13896	15336	-9.15%
disc	catch	90%	13753	16384	
lo	catch	90%	13753	15504	-5.37%
disc	catch	100%	13629	16778	
lo	catch	100%	13629	15556	-7.28%
disc	discards	0%	1484	1423	
lo	discards	0%	1484	1401	-1.55%
disc	discards	10%	1335	1339	
lo	discards	10%	1335	1408	5.15%
disc	discards	20%	1185	1172	
lo	discards	20%	1185	1375	17.32%
disc	discards	30%	1036	1049	
lo	discards	30%	1036	1344	28.12%
disc	discards	40%	887	936	
lo	discards	40%	887	1342	43.38%
disc	discards	50%	738	800	
lo	discards	50%	738	1351	68.88%
disc	discards	60%	590	656	
lo	discards	60%	590	1359	107.17%
disc	discards	70%	441	505	
lo	discards	70%	441	1346	166.54%
disc	discards	80%	293	344	
lo	discards	80%	293	1367	297.38%
disc	discards	90%	146	173	
lo	discards	90%	146	1324	665.32%

Scenario	Indicator	Discard survival	2016	2066	Percentage change
disc	discards	100%	0	0	
lo	discards	100%	0	1246.13	Inf%
disc	fbar	0%	0.22	0.27	
lo	fbar	0%	0.22	0.27	0%
disc	fbar	10%	0.21	0.28	
lo	fbar	10%	0.21	0.27	-3.57%
disc	fbar	20%	0.21	0.28	
lo	fbar	20%	0.21	0.27	-3.57%
disc	fbar	30%	0.21	0.29	
lo	fbar	30%	0.21	0.27	-6.90%
disc	fbar	40%	0.21	0.29	
lo	fbar	40%	0.21	0.27	-6.90%
disc	fbar	50%	0.21	0.3	
lo	fbar	50%	0.21	0.27	-10%
disc	fbar	60%	0.21	0.3	
lo	fbar	60%	0.21	0.27	-10%
disc	fbar	70%	0.21	0.31	
lo	fbar	70%	0.21	0.27	-12.90%
disc	fbar	80%	0.21	0.31	
lo	fbar	80%	0.21	0.27	-12.90%
disc	fbar	90%	0.2	0.32	
lo	fbar	90%	0.2	0.27	-15.63%
disc	fbar	100%	0.2	0.32	
lo	fbar	100%	0.2	0.27	-15.63%
disc	landings	0%	13665.95	16194.11	
lo	landings	0%	13665.95	16092.82	-0.63%
disc	landings	10%	13657.14	16270.71	
lo	landings	10%	13657.14	15852.15	-2.57%
disc	landings	20%	13648.04	15944.89	
lo	landings	20%	13648.04	15361.83	-3.66%
disc	landings	30%	13638.79	16081.36	
lo	landings	30%	13638.79	14958.18	-6.98%
disc	landings	40%	13629.46	16241.87	
lo	landings	40%	13629.46	14604.57	-10.08%
disc	landings	50%	13620.35	16322.01	
lo	landings	50%	13620.35	14232.76	-12.80%
disc	landings	60%	13611.97	16355.95	
lo	landings	60%	13611.97	13674.93	-16.39%
disc	landings	70%	13605.33	16522.93	
lo	landings	70%	13605.33	12882.29	-22.03%
disc	landings	80%	13602.51	16552.38	
lo	landings	80%	13602.51	12365.96	-25.29%
disc	landings	90%	13607.63	16216.36	
lo	landings	90%	13607.63	12169.76	-24.95%

Scenario	Indicator	Discard survival	2016	2066	Percentage change
disc	landings	100%	13629.1	16778.06	
lo	landings	100%	13629.1	11985.64	-28.56%
disc	recruitment	0%	53947.3	116088.4	
lo	recruitment	0%	53947.3	115753.3	-0.29%
disc	recruitment	10%	52491	114765.6	
lo	recruitment	10%	52491	112227.9	-2.21%
disc	recruitment	20%	51034.8	112969.3	
lo	recruitment	20%	51034.8	110734.7	-1.98%
disc	recruitment	30%	49578.6	109525.3	
lo	recruitment	30%	49578.6	106384.6	-2.87%
disc	recruitment	40%	48122.4	107785	
lo	recruitment	40%	48122.4	104650.1	-2.91%
disc	recruitment	50%	46666.3	105610.6	
lo	recruitment	50%	46666.3	109483.4	3.67%
disc	recruitment	60%	45210.6	98166.76	
lo	recruitment	60%	45210.6	101311.8	3.20%
disc	recruitment	70%	43757.1	102195.4	
lo	recruitment	70%	43757.1	99533.6	-2.61%
disc	recruitment	80%	42310	99899.58	
lo	recruitment	80%	42310	91100.42	-8.81%
disc	recruitment	90%	40879.9	98137.06	
lo	recruitment	90%	40879.9	93822.83	-4.40%
disc	recruitment	100%	39492.7	95854.06	
lo	recruitment	100%	39492.7	92911.59	-3.07%
disc	ssb	0%	62636.45	57547.33	
lo	ssb	0%	62636.45	58370.15	1.43%
disc	ssb	10%	61989.54	56050.97	
lo	ssb	10%	61989.54	57340.69	2.30%
disc	ssb	20%	61338.52	54409.71	
lo	ssb	20%	61338.52	55743.25	2.45%
disc	ssb	30%	60683.16	51368.52	
lo	ssb	30%	60683.16	53978.31	5.08%
disc	ssb	40%	60022.9	50490.32	
lo	ssb	40%	60022.9	53272.63	5.51%
disc	ssb	50%	59357.18	49048.4	
lo	ssb	50%	59357.18	51989.64	6.00%
disc	ssb	60%	58685.35	46567.03	
lo	ssb	60%	58685.35	50759.38	9.00%
disc	ssb	70%	58006.79	45512.22	
lo	ssb	70%	58006.79	48679.09	6.96%
disc	ssb	80%	57320.5	43568.76	
lo	ssb	80%	57320.5	48330.28	10.93%
disc	ssb	90%	56627.14	41760.59	
lo	ssb	90%	56627.14	48048.03	15.06%

Scenario	Indicator	Discard survival	2016	2066	Percentage change
disc	ssb	100%	55930.06	41670.32	
lo	ssb	100%	55930.06	47216.53	13.31%
disc	stock	0%	72111.78	72073.57	
lo	stock	0%	72111.78	72373.28	0.42%
disc	stock	10%	71268.4	69820.81	
lo	stock	10%	71268.4	70717.7	1.29%
disc	stock	20%	70420.78	66730.08	
lo	stock	20%	70420.78	69586.79	4.28%
disc	stock	30%	69568.68	64244.42	
lo	stock	30%	69568.68	66407.63	3.37%
disc	stock	40%	68711.55	63213.02	
lo	stock	40%	68711.55	66287.91	4.86%
disc	stock	50%	67848.97	61425.85	
lo	stock	50%	67848.97	64506.35	5.02%
disc	stock	60%	66980.34	58787.9	
lo	stock	60%	66980.34	62229.21	5.85%
disc	stock	70%	66105.54	57382.56	
lo	stock	70%	66105.54	60269.45	5.03%
disc	stock	80%	65224.42	55716.43	
lo	stock	80%	65224.42	59640.99	7.04%
disc	stock	90%	64339.41	53023.19	
lo	stock	90%	64339.41	58957.58	11.19%
disc	stock	100%	63458.14	53104.45	
lo	stock	100%	63458.14	58202.76	9.60%

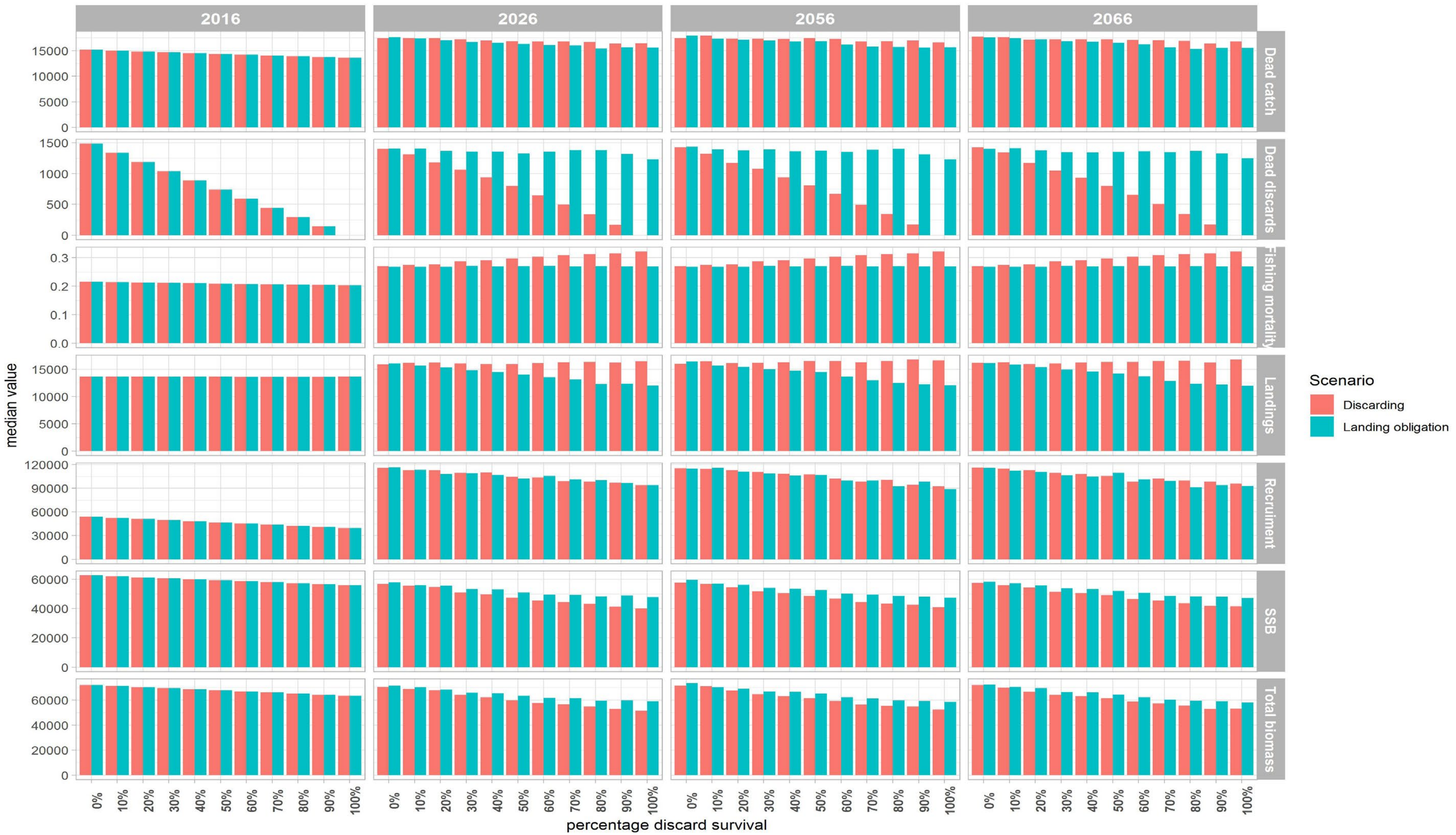

Figure 3.11: Median results of the forecast simulation of North Sea sole for different levels of discard survival and for the years 2016,2026, 2056, and 2066.

3.3.2 North Sea plaice

3.3.2.1 F-targets

First F-targets for the landing obligation scenario were calculated by resetting the discards to the total observed discards (which are the discards observed in the stock assessment with 0% discard survival), thus assuming the current gear selectivity. These F-targets are presented in Figure 3.12. These F-targets are approximately constant for different levels of discard survival.

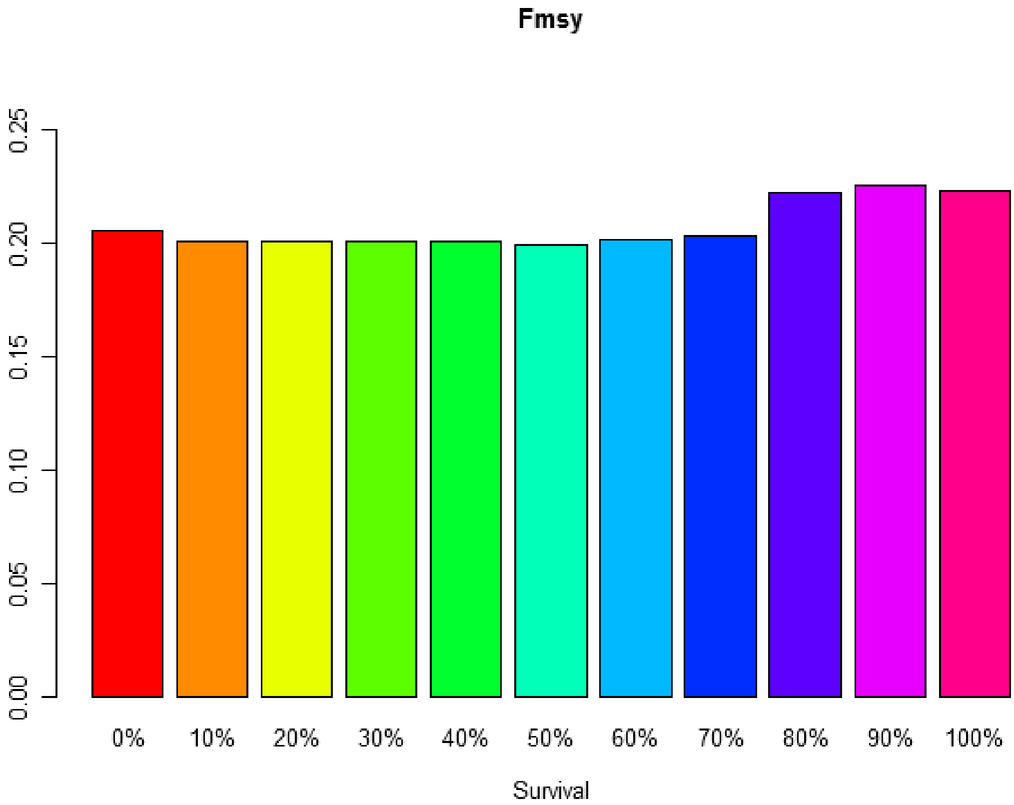

Figure 3.12: F-targets of North Sea plaice for the landing obligation scenario of forecast simulation for different levels of discard survival (0% to 100% discard survival).

3.3.2.2 Forecast simulation

The forecast simulation of North Sea plaice under the discarding scenario is shown for 0%, 20%, 40%, 60%, 80%, and 100% discard survival on Figure 3.13.

The forecast simulation of North Sea sole under the landing obligation scenario is shown for 0%, 20%, 40%, 60%, 80%, and 100% discard survival on Figure 3.14.

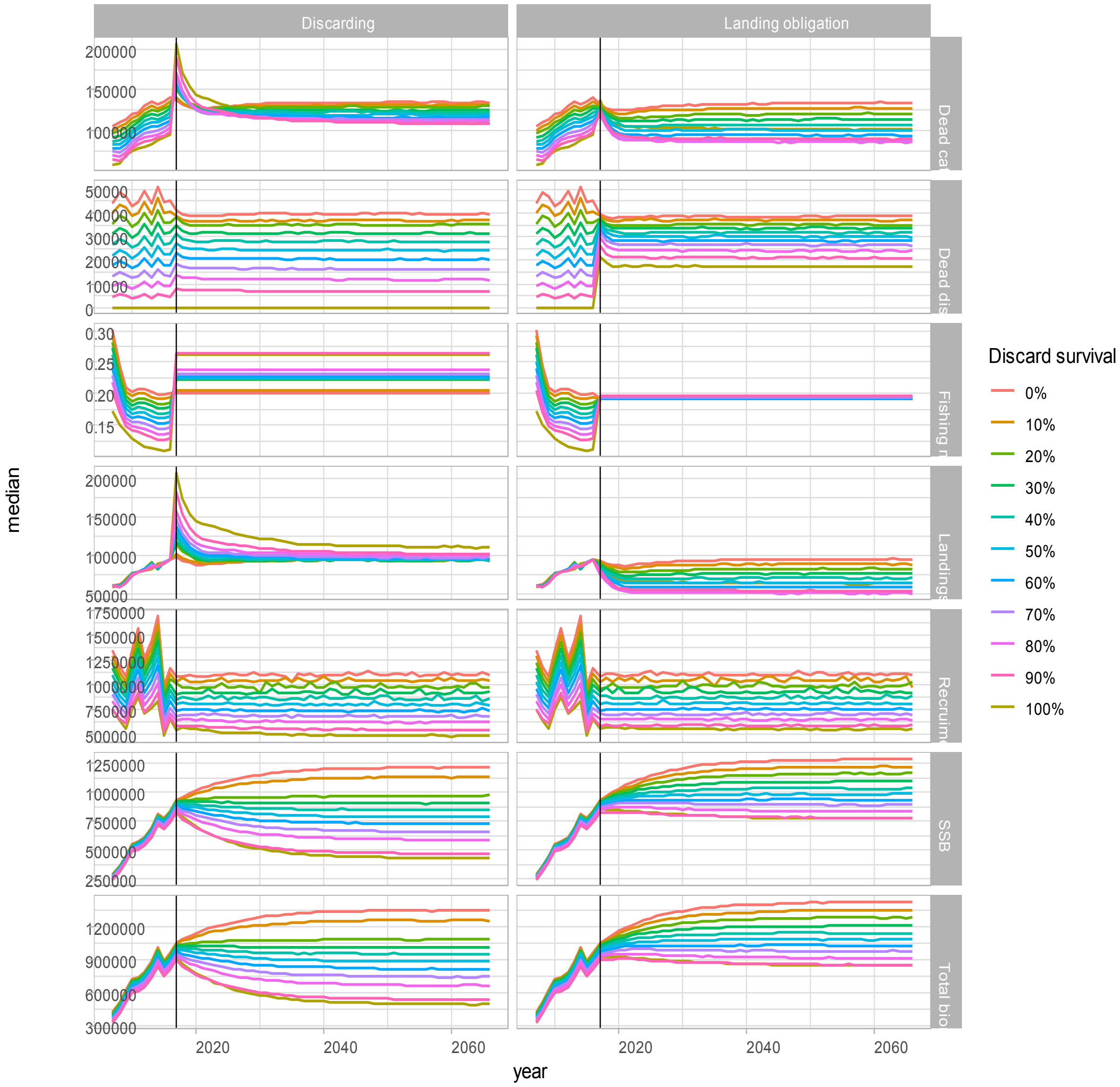

Figure 3.15: Forecast simulation of North Sea plaice under two scenarios (only median values).

3.3.2.3 Comparing discarding and landing obligation scenario

The median results of the forecast simulation of North Sea plaice for both the discarding as the landing obligation scenario for different levels of discard survival (0% to 100%) are shown on Figure 3.16. Only the results for the years 2021, 2031 and 2066 are shown for practical reasons.

The results clearly show less landings of North Sea plaice under the landing obligation scenario than under the discarding scenario for the same discard survival levels. Also dead discards are greater under the landing obligation scenario than under the discarding scenario, since with discarding the fish that is set overboard will have a chance to survive. Under the discarding scenario, the fishing mortality can be higher than under the landing obligation for the same discard levels.

Median results of forecast simulation of North Sea plaice under the discarding and landing obligation scenarios for different levels of discard survival and for the years 2021, 2031, and 2066.

The median results for landings, dead discards, ssb, and stock per 5-year step and the percentage change after the forecast simulation period between both scenarios are presented in Table 3.3.

Table 3.4: Median results per 5-year step and percentage change after forecast of North Sea plaice.

Scenario	Indicator	Discard survival	2016	2066	Percentage change
disc	catch	0%	139769.3	134216.3	
lo	catch	0%	139769.3	134015.1	-0.15%
disc	catch	10%	135232.5	131603.6	
lo	catch	10%	135232.5	126644	-3.77%
disc	catch	20%	130684.4	130188.7	
lo	catch	20%	130684.4	119473.7	-8.23%
disc	catch	30%	126121.7	125105.1	
lo	catch	30%	126121.7	113475.7	-9.30%
disc	catch	40%	121539.4	122059	
lo	catch	40%	121539.4	106495.3	-12.75%
disc	catch	50%	116930.1	118336.9	
lo	catch	50%	116930.1	100107.5	-15.41%
disc	catch	60%	112281.8	116159.8	
lo	catch	60%	112281.8	93907.5	-19.16%
disc	catch	70%	107572	113267.1	
lo	catch	70%	107572	87662.51	-22.61%
disc	catch	80%	102753.2	111351.6	
lo	catch	80%	102753.2	85756.57	-22.99%
disc	catch	90%	97698.96	107656.2	
lo	catch	90%	97698.96	89474.28	-16.89%
disc	catch	100%	94343.45	110198.8	
lo	catch	100%	94343.45	101135.6	-8.22%
disc	discards	0%	45146.27	39555.22	
lo	discards	0%	45146.27	38525.51	-2.60%
disc	discards	10%	40605.37	36778.37	
lo	discards	10%	40605.37	36993.21	0.58%
disc	discards	20%	36068.43	35057.11	
lo	discards	20%	36068.43	34964.1	-0.27%
disc	discards	30%	31535.29	31324.59	
lo	discards	30%	31535.29	33336.17	6.42%
disc	discards	40%	27005.92	27604.28	
lo	discards	40%	27005.92	31544.65	14.27%
disc	discards	50%	22479.85	24386.07	
lo	discards	50%	22479.85	29757	22.03%
disc	discards	60%	17956.75	20445.1	
lo	discards	60%	17956.75	28294.66	38.39%
disc	discards	70%	13436.21	16313.27	
lo	discards	70%	13436.21	26260.61	60.98%
disc	discards	80%	8918.67	11745.86	
lo	discards	80%	8918.67	23996	104.29%
disc	discards	90%	4411.79	6775.23	
lo	discards	90%	4411.79	21027.53	210.36%

Scenario	Indicator	Discard survival	2016	2066	Percentage change
disc	discards	100%	0.01	0.02	
lo	discards	100%	0.01	17313.68	86568300%
disc	fbar	0%	0.2	0.2	
lo	fbar	0%	0.2	0.19	-5%
disc	fbar	10%	0.19	0.21	
lo	fbar	10%	0.19	0.19	-9.52%
disc	fbar	20%	0.19	0.22	
lo	fbar	20%	0.19	0.19	-13.64%
disc	fbar	30%	0.18	0.22	
lo	fbar	30%	0.18	0.19	-13.64%
disc	fbar	40%	0.17	0.22	
lo	fbar	40%	0.17	0.19	-13.64%
disc	fbar	50%	0.16	0.23	
lo	fbar	50%	0.16	0.19	-17.39%
disc	fbar	60%	0.15	0.23	
lo	fbar	60%	0.15	0.19	-17.39%
disc	fbar	70%	0.15	0.23	
lo	fbar	70%	0.15	0.19	-17.39%
disc	fbar	80%	0.14	0.24	
lo	fbar	80%	0.14	0.2	-16.67%
disc	fbar	90%	0.13	0.26	
lo	fbar	90%	0.13	0.2	-23.08%
disc	fbar	100%	0.11	0.26	
lo	fbar	100%	0.11	0.19	-26.92%
disc	landings	0%	94622.98	93969.88	
lo	landings	0%	94622.98	94559.15	0.63%
disc	landings	10%	94627.07	94175.14	
lo	landings	10%	94627.07	87579.9	-7.00%
disc	landings	20%	94615.93	93627.81	
lo	landings	20%	94615.93	81440.57	-13.02%
disc	landings	30%	94586.4	93014.18	
lo	landings	30%	94586.4	76240.48	-18.03%
disc	landings	40%	94533.46	93314.74	
lo	landings	40%	94533.46	69973.42	-25.01%
disc	landings	50%	94450.21	93665.89	
lo	landings	50%	94450.21	64187.63	-31.47%
disc	landings	60%	94325.02	95144.78	
lo	landings	60%	94325.02	58112.75	-38.92%
disc	landings	70%	94135.81	96647.93	
lo	landings	70%	94135.81	52294.74	-45.89%
disc	landings	80%	93834.48	99121.12	
lo	landings	80%	93834.48	50059.16	-49.50%
disc	landings	90%	93287.17	100709.1	
lo	landings	90%	93287.17	53160.07	-47.21%

Scenario	Indicator	Discard survival	2016	2066	Percentage change
disc	landings	100%	94343.44	110198.8	
lo	landings	100%	94343.44	63110.86	-42.73%
disc	recruitment	0%	1173720	1100396	
lo	recruitment	0%	1173720	1102484	0.19%
disc	recruitment	10%	1118150	1048717	
lo	recruitment	10%	1118150	984119.1	-6.16%
disc	recruitment	20%	1062200	981998.7	
lo	recruitment	20%	1062200	1033830	5.28%
disc	recruitment	30%	1005800	932353.9	
lo	recruitment	30%	1005800	928857.3	-0.38%
disc	recruitment	40%	948912	864004.8	
lo	recruitment	40%	948912	899689.8	4.13%
disc	recruitment	50%	891553	798234.5	
lo	recruitment	50%	891553	817715.2	2.44%
disc	recruitment	60%	833890	740056.3	
lo	recruitment	60%	833890	759118.7	2.58%
disc	recruitment	70%	776466	681236.5	
lo	recruitment	70%	776466	701900.1	3.03%
disc	recruitment	80%	720918	637663.5	
lo	recruitment	80%	720918	652396.3	2.31%
disc	recruitment	90%	672663	548191.6	
lo	recruitment	90%	672663	598203.9	9.12%
disc	recruitment	100%	661220	490220.8	
lo	recruitment	100%	661220	557327	13.69%
disc	ssb	0%	836066.4	1216275	
lo	ssb	0%	836066.4	1291648	6.20%
disc	ssb	10%	831259.1	1129829	
lo	ssb	10%	831259.1	1219823	7.97%
disc	ssb	20%	825634.1	972919.4	
lo	ssb	20%	825634.1	1164135	19.65%
disc	ssb	30%	819000.3	904485.1	
lo	ssb	30%	819000.3	1097761	21.37%
disc	ssb	40%	811122.1	846348.8	
lo	ssb	40%	811122.1	1033003	22.05%
disc	ssb	50%	801700.8	784446.7	
lo	ssb	50%	801700.8	984822.4	25.54%
disc	ssb	60%	790347.4	722752.4	
lo	ssb	60%	790347.4	933240.4	29.12%
disc	ssb	70%	776493.6	655446.5	
lo	ssb	70%	776493.6	892176.7	36.12%
disc	ssb	80%	759121.4	587074.9	
lo	ssb	80%	759121.4	832414.6	41.79%
disc	ssb	90%	735799.1	462703.8	
lo	ssb	90%	735799.1	776468.1	67.81%

Scenario	Indicator	Discard survival	2016	2066	Percentage change
disc	ssb	100%	769693.1	427375.1	
lo	ssb	100%	769693.1	772125.3	80.67%
disc	stock	0%	956572.2	1345163	
lo	stock	0%	956572.2	1423834	5.85%
disc	stock	10%	947344.2	1249819	
lo	stock	10%	947344.2	1342045	7.38%
disc	stock	20%	937249.4	1086469	
lo	stock	20%	937249.4	1278572	17.68%
disc	stock	30%	926083.6	1015132	
lo	stock	30%	926083.6	1208479	19.05%
disc	stock	40%	913595.9	945809.7	
lo	stock	40%	913595.9	1135667	20.07%
disc	stock	50%	899468.5	882312.9	
lo	stock	50%	899468.5	1079841	22.39%
disc	stock	60%	883288.7	814108.2	
lo	stock	60%	883288.7	1024518	25.85%
disc	stock	70%	864455	744007.3	
lo	stock	70%	864455	975765.5	31.15%
disc	stock	80%	841893.2	666914.3	
lo	stock	80%	841893.2	911479.4	36.67%
disc	stock	90%	813020.4	534322.8	
lo	stock	90%	813020.4	853109.6	59.66%
disc	stock	100%	843931.7	494111.2	
lo	stock	100%	843931.7	845866.9	71.19%

Figure 3.16: Median results of the forecast simulation of North Sea plaice for different levels of discard survival and for the years 2016, 2026, 2056, and 2066.

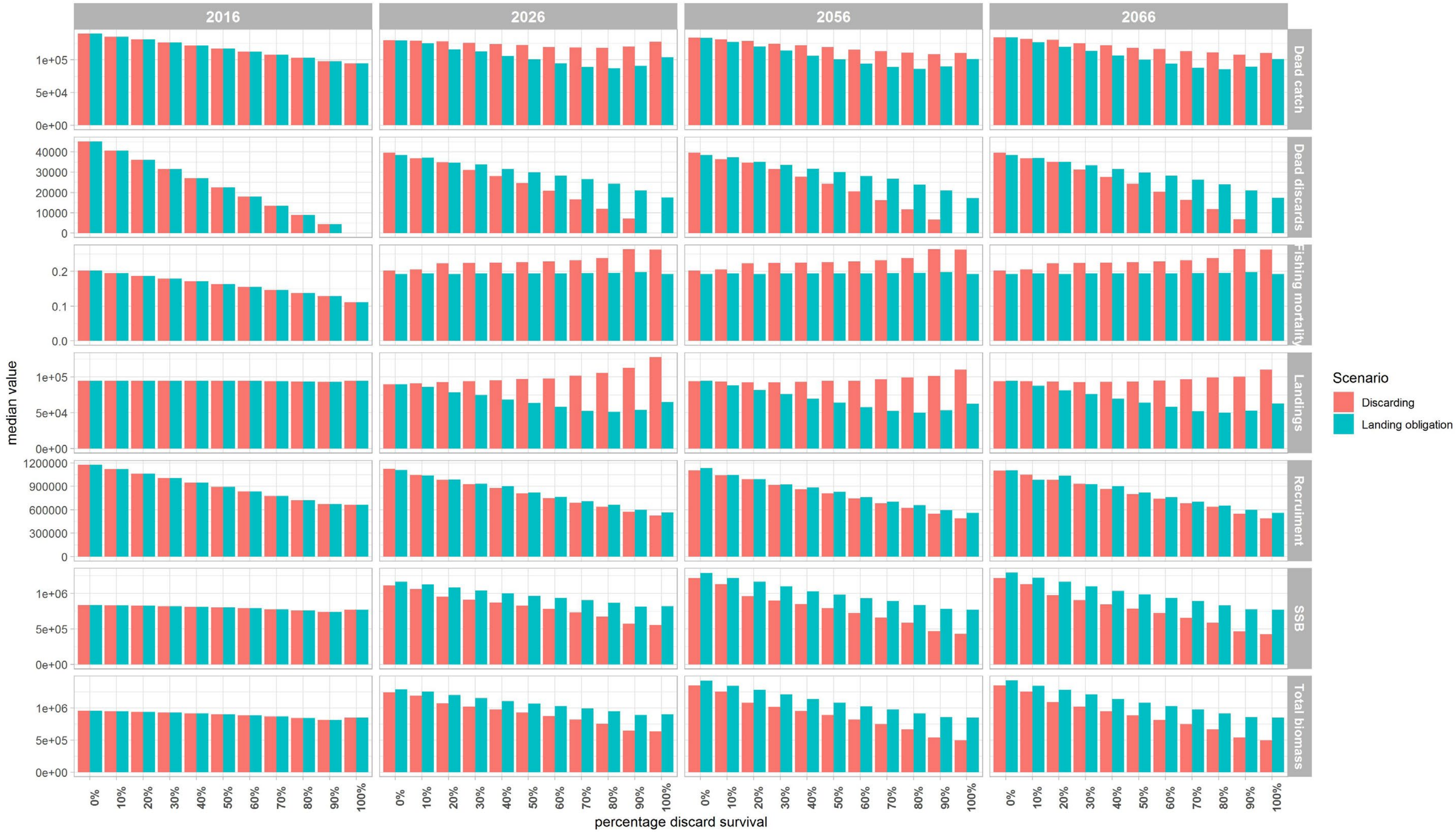

Figure 3.16: Median results of the forecast simulation of North Sea plaice for different levels of discard survival and for the years 2016, 2026, 2056, and 2066.

4 Discussion and conclusion

This study evaluated discard survival effect on the current assessment of North Sea sole and plaice. For both stocks experiments have shown that at least part of the discarded fish have potential to survive the catch process (van der Reijden et al. 2017). This would imply that the current assessments, assuming 0% discard survival, are biased.

The results shown in Chapter 3.1 show that when discard survivability is taken into account in the assessment of North Sea sole and plaice, the perception and trend of the stock does not change. But the fishing mortality, stock biomass, and recruitment are overestimated. The scale of the effect of the discard survival in the assessment is depending on the characteristics of the stock (such as maturity at age) and the extent to which the part of the stock is being discarded. The effect of discard survival is greater in North Sea plaice than in North Sea sole, since the plaice is discarded more.

Also reference points change when discard survivability is taken into account. The Fmsy reference points increase with increasing discard survivability (Chapter 3.2). However, the "F-targets", the F corresponding to the maximal yield under the landing obligation, that are calculated to simulate the "landing obligation-scenario" do not show the same trend with increasing discard survivability (Chapter 3.3.2.1). This can be explained because that when the landing obligation is implemented fishing mortality is higher on the younger ages (all discards are landed, and discards consist mainly of younger ages).

In order to get the highest yield under the landing obligation, the individual fish need to be able to grow (a compromise between catching many small individuals or catching fewer but larger individuals). With a lower F, the individual growth in the stocks is ensured, and the yield can be higher.
On the opposite, if there isn't any substantial fishing mortality on the younger ages and F only peaks at older ages (such as when discards are able to survive), the individual fish get to grow fully and can be exploited with a higher F.

The forecast simulation of North Sea sole and plaice was performed by projecting the stocks with targets for fishing mortality that maximise the yield of both stocks. Differences between scenarios increase with increasing discard survivability, although differences are marginal in the simulation of sole (compared to the differences between scenarios in plaice). Mainly the catches are effected by discard survivability under the landing obligation scenario.

The methodology used in the forecast simulation of North Sea sole and plaice gives insight in the effects of the discarding and landing obligation scenario on the catches, recruitment, spawning stock biomass, and fishing mortality. However, the most appropriate methodology to compare the effects of both scenarios would have been under a management strategy evaluation framework in which the assumption is made that the biological population has some degree of survival but that the assessment accounts for all discards and fishing mortality of those discards.

Finally, the discard survivability is assumed to be constant over all ages in the North Sea sole and plaice stocks in this study. However, there is evidence that discard survivability is not constant over all ages (Revill et al., 2013). The addition of age-specific discard rates would shed more light on the effect of discard survivability on the stocks of North Sea sole and plaice. But length-specific discard survivability estimates are not yet available (length-specific estimates can be converted to age-specific estimates with the von Bertalanffy growth equation) and were therefore not included in this study.

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Best Practices II

Effect on future development of sole and plaice of changing mesh size from 80mm to 90mm in the beam trawl fishery

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Wageningen University & Research report C016/19

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Contents

Summary

This study investigates the consequence for future development of stock size, catches, landings and discards of sole and plaice of changing the mesh size of the cod-end from 80mm to 90mm for the Dutch beam trawlers in theTBB 70-99 fleet currently fishing with 80 mm.

The question is addressed by means of long term stochastic simulations. Using the simulation framework developed to test the effect of implementing the landing obligation, the future fishery selection pattern (how the fishing mortality is distributed across ages) is modified based on the results of the selectivity experiment to represent the consequence of changing mesh size. Simulations were then run for the next 50 years for different assumptions on the survival rate for both stocks: a 0% survival rate, and the lower and upper bounds of the current estimates of survival for each species.

The differences in the effect on sole and plaice of using a 90mm net are related to both the direct effect of exploiting the stock with a different selection pattern and of applying different Fmsy values. The effects of changing mesh size are larger for sole than for plaice, because the share of the landings taken by the Dutch beam trawlers currently fishing with 80 mm is much larger for sole than for plaice.

For sole, fishing with the 90mm net results in lower discards (10 to 16%). Landings are also lower (up to 4%) in the short term, but the situation reverses and landings become higher in the medium and long term (up to 3% after 5 years). These results are explained by the fact that when the 90mm net is used, the cohorts are exploited at a slightly later age combined with a stronger targeting of the older ages. This exploitation patterns leads in the medium and long term to a larger stock (by 3 to 13%), which explains the higher landings. Those benefits (in the medium and long term) of using the 90mm net are largest for the 0% and 10% survival assumptions, but are smaller (especially for the landings) for the assumption with 30% survival: the higher the chance for a discarded fish to survive, the less it pays to increase the selectivity of the gear because fish caught and discarded have still a chance to join the stock and further grow and reproduce.

For plaice, in the scenarios with 0% and 10% survival, the Fmsy value for the 90mm net is higher than for the 80mm net. As a result, stock size is lower and catches, landings and (despite the improved selectivity of the net) discards are higher if the 90mm net is used. For the scenario with 20% survival rate, Fmsy values are similar for the 80mm and 90mm mesh size and the improved selectivity of the 90mm net indeed results in slightly lower discards, which in the medium and long term result in a slightly larger stock with slightly higher landings.

One important assumption in these simulations is that the stocks are exploited at Fmsy in the future. However, if the beam trawl fleet switches to the 90mm net, its catchability (at least for sole) will decrease, meaning that a higher fishing effort will be necessary to achieve a same fishing mortality on the stock. The present study does not model explicitly catchability and effort, and therefore cannot quantify the change in effort implied if the stocks were to be exploited at Fmsy with the 90mm net.

1 Introduction

This study investigates the consequence in term of future development of stock size, catches, landings and discards of sole and plaice, of changing the mesh size of the cod-end from 80mm to 90mm. To do so, this study combines the outcome of the work by Molenaar and Chen (2018) on the comparison of the selectivity of the 80mm and 90mm nets, with the simulation framework developed by Verkempynck et al (2018) to test the effect of implementing the landing obligation. First, the raw data from the selectivity experiments are combined with information on the length-age relationship to derive selectivity curves with respect to age (Molenaar and Chen, 2018 delivered selectivity curves with respect to size). The simulation model represents the biology of the stocks (weight and maturity at age, stock-recruitment relationships) and the fishery on the basis of the stock assessment output. In the present case, different assessments using different assumption on survival rate are used in separate simulations, corresponding to different characteristics in stock biology. The simulation are run independently for each stock. Simulations are conducted by bringing the stocks forward by step of one year, representing at each time step the different demographic processes in the population. As some processes, such as recruitment, are modelled in a random way, a large number of simulations (2000) are run in parallel for each scenario in order to define the complete envelop of the possible variations. To implement the change of mesh size, selectivity-at-age derived from the experiments is used to modify the fishery selection pattern (i.e how fishing mortality is distributed across ages) used in the future year in the simulation model. New values of Fmsy, corresponding to these new selection patterns are calculated and used as management target in the simulations.

Simulations are conducted for different assumptions on the survival rate for both stocks: a 0% survival rate, and the lower and upper bounds of the current estimates of survival for each species.

2 Methods

2.1 Implementing mesh size change in the simulation tools

2.1.1 Selectivity curves

The simulations for North Sea plaice and sole are based on an age-structured population model. The data collected during the selectivity experiments (Molenaar and Chen, 2018) are structured by length-class (no age information was collected), and the estimated selectivity curves calculated present the retention rate by the cod-end as a function of fish length. The first step to simulate the effect of changing the mesh size from 80mm to 90mm on the plaice and sole populations consisted in calculating selectivity curves as a function of age.

Two experiments were carried out to compare the selectivity of the 80mm and 90mm mesh size, with contrasting results (see Molenaar and Chen, 2018). For the present study, the decision was made to use only the data collected during the second experiment because the difference in mesh size in the two nets used in the first experiment was too small resulting in hardly any difference in the retention rate found for sole in the two cod-end.

In order to convert the results of the selectivity experiment from retention-at-length to retention-at-age, age-length keys were built for both stocks. The available biological sampling data for sole and plaice was extracted from WMR data bases: the data for fish above the minimum landing size (24cm for sole and 27cm for plaice) were extracted from the market sampling program, while the data for fish below the minimum size were extracted from the discards sampling programs (observers and self-sampling). The data was extracted for the 3rd quarter of the year 2017, for areas IVb-c, in order to match with the period and area in which the second selectivity experiment was conducted. The resulting age-length keys for sole and plaice are presented on figure 1.

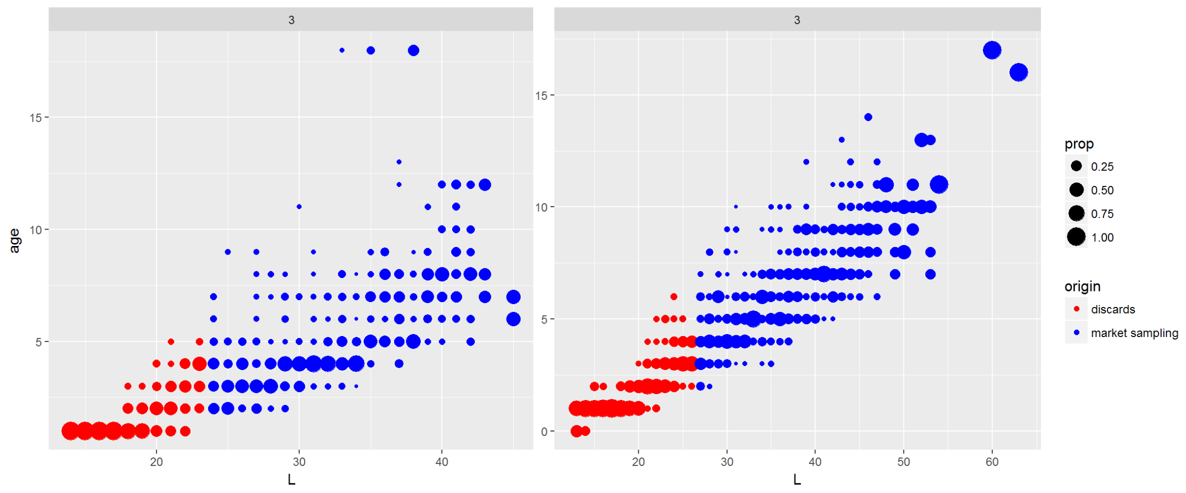

Figure 1 Age length keys for sole (left) and plaice (right) in the central and southern North Sea (ICES IVb and IVc) for the 3rd quarter for 2017.

The age-length keys were then applied to the raw data from the second selectivity experiment. The data are collected by trawl haul and give, for each mesh size (80mm and 90mm trawls used in parallel) and by 1cm length class, the number of fish retained in the cod-end and the number of fish escaping through the cod-end (and caught in the net covering the cod-end). These numbers of fish by length-class were then multiplied by the proportion of the different age-classes for the corresponding length-class in the age-length key to obtain the numbers of fish at age.

A binomial GLM model was then applied (as done in Molenaar and Chen (2018),) to fit a logistic model :

$Ret_i \sim binomial(\pi_i)$

With Ret_i is 1 for fish *i* retained by the net and 0 for fish retained in the net cover.
and

$E(Ret_i) = \pi_i$

$log\left(\frac{\pi_i}{1-\pi_i}\right) = I + age_i + mesh\ size_i$

The resulting selectivity curves are shown in figures 2 and 3. Changing the mesh size from 80mm to 90mm has a marked effect on the estimated selectivity curve of sole, with proportion of individuals retained lower for all age-classes, the difference being much larger for younger ages. For plaice, a lower selectivity is observed only for young fish (age 0 to 2).

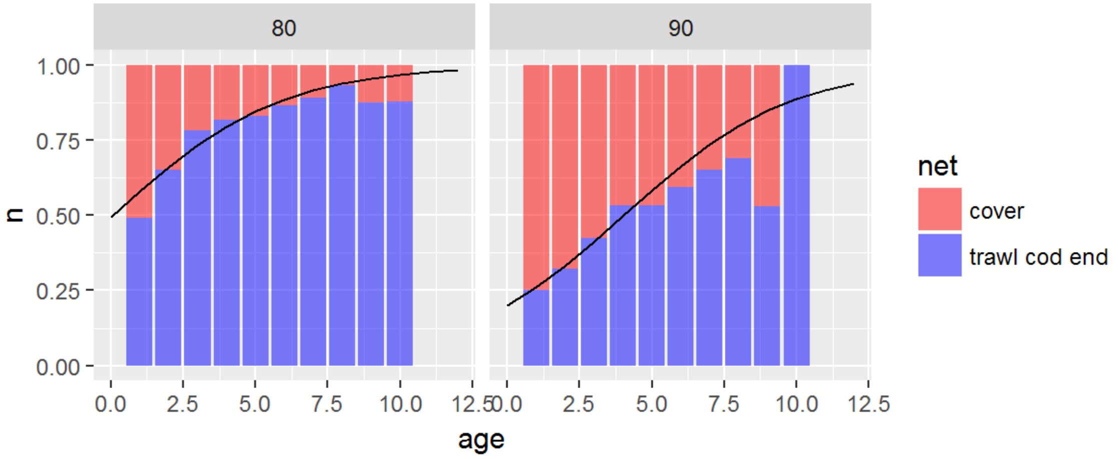

Figure 2 :proportion of sole retained in the cod-end per age-class (bar plots) and modelled selectivity curve for North Sea sole for the 80mm (right) and the 90mm (left) mesh sizes (black solid line).

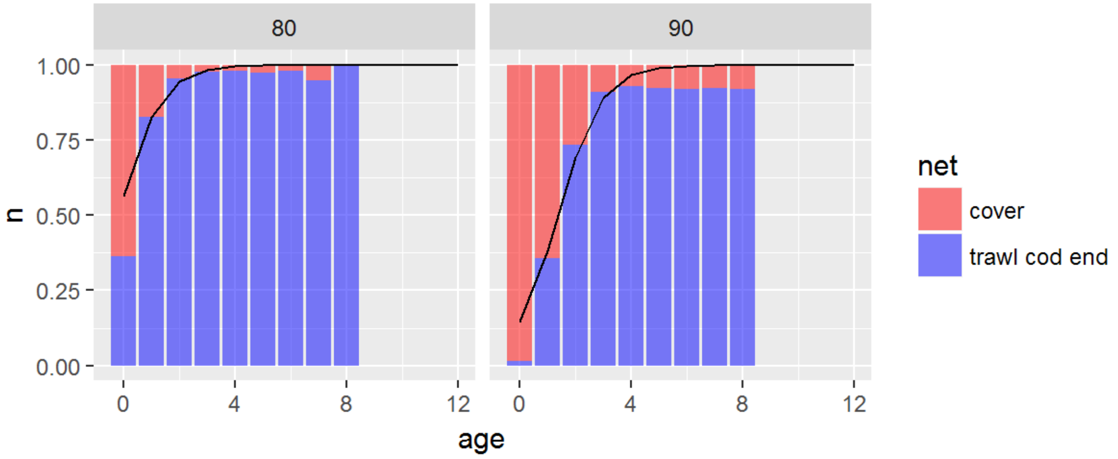

Figure 3 : proportion of plaice retained in the cod-end per age-class (bar plots) and modelled selectivity curve for North Sea plaice for the 80mm (right) and the 90mm (left) mesh sizes (black solid line).

2.1.2 Selection pattern to be applied in the simulations

In the simulations, the effect of changing mesh size is implemented by changing the selection pattern (i.e. the age profile of the fishing mortality) used in the future years. The assumption made on the future selection pattern in the analyses carried out by Verkempynck et al (2018) is that future selection is equal to the average of selection pattern over the last 3 years of the assessment period. We assumed here that this selection pattern is representative of a situation in which all vessels in the métier TBB_DEF_70-99_0_0_all use a 80mm net, corresponding to our base case. The selectivity-at-age curves are then used to compute the selection pattern that would correspond to switching to a 90mm net for all the TBB_DEF_70-99_0_0_all vessels.

Since the change in mesh size does not apply to all the vessels fishing sole in the North Sea, but only to the Dutch beam trawlers fishing with a 80mm mesh size, belonging to the métier TBB_DEF_70-99_0_0_all, the partial fishing morality for this métier was first calculated for the year 2017 (year in which the selectivity experiments were conducted). This was done by taking the landings and discards at age submitted by WMR to ICES for the stock assessment working group (WGNSSK 2018) for the TBB_DEF_70-99_0_0_all métier. The partial fishing mortality was then calculated

$$pF_{TBB\,XX\;\;a,2017} = F_{a,2017} \times \frac{C_{TBB\,XX\;\;a,2017}}{C_{a,2017}}$$

Then the decomposition of fishing mortality into catchability q and effort f was used :

$$pF_{TBB\,XX\;\;a,2017} = q_{TBB\,XX\;\;a} \times f_{TBB\,XX\;\;2017}$$

The catchability coefficient $q_{TBB\,XX\;\;a}$ represents the probability for a fish of age a to be caught by one unit of effort of the TBB_DEF_70-99_0_0_all métier. According to Laurec and Le Guen (1981), catchability is the combination of a number of components, some of which related to fish and effort distribution, to fish and fishermen behavior, all conditioning the probability of a fish to enter the gear (all summarized in the coefficient Q_a in the equation below), and a component representing specifically the chance of escaping thought the net : the selectivity $S_{80\;\;a}$:

$$q_{TBB\,XX\;\;a} = S_{80\;\;a} \times Q_a$$

Changing the mesh size modifies the selectivity as describe on figure 2 and 3, but is not expected to have any effect on the others components of the catchability, Q_a . Therefore, the partial fishing mortality for the métier TBB_DEF_70-99_0_0_all TBB with a mesh size of 90mm can be expressed :

$$pF'_{TBB\,XX\;\;a,2017} = S_{90\;\;a} \times Q_a \times f_{TBB\,XX\;\;2017}$$

And $$= pF_{TBB\,XX\;\;a,2017} \times S_{90\;\;a} \,/\, S_{80\;\;a}$$

And therefore the total fishing mortality can be obtained by:

$$F'_a = pF'_{TBB\,XX\;\;a,2017} + (F_{a,2017} - pF_{TBB\,XX\;\;a,2017})$$

Finally, the selection pattern to be use for the future years in the simulations for the 90mm net is calculated as :

$Sel'_a = \frac{1}{3}\sum_{y=2014}^{2017} Sel'_{a,y}$ with $Sel'_{a,y} = {F'_{a,y}}/{F'bar_{2-6,y}}$

2.2 Simulation scenarios

The effect of changing mesh size from 80mm to 90mm for the métier TBB_DEF_70-99_0_0_all was investigated for different scenarios summarised on the figure 4.

For both stocks, simulations were run for 3 scenarios on the survival rate: the lower and upper limits of the confidence bounds of the available estimates of survival rate, and a 0% survival. The limits of the confidence bounds for sole and for plaice are 13% and 28%, and 11% and 18% respectively (Schram and Molenaar, 2018). These percentages were rounded to 10% and 30%, and 10% and 20% so that the stock assessments, developed with these percentages by Verkempynck et al. (2018) can be used as a basis for these simulations, without having to set up new assessments.

As for the work done by Verkempynck et al. (2018), each of these survival scenarios were run twice, once in a scenario where discarding is allowed, and one in a scenario where the landing obligation is strictly implemented.
Simulations were run only for the modified selection patterns (representing the effect of changing to 90mm mesh size). The results for the base-case (80mm) are taken from the work carried out by Verkempynck et al. (2018). As the selection pattern applied in the new simulations is different, a new set of Fmsy values had to be calculated (one for each assumption on survival rate).
The same R scripts as developed by Verkempynck et al. (2018) for reference point estimation and for running the simulations were used here.

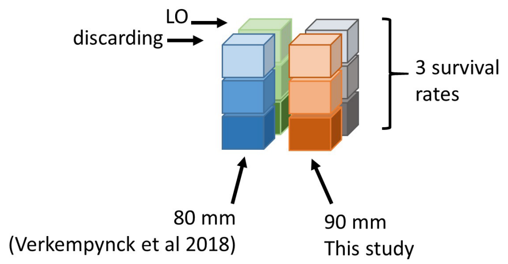

Figure 4 : representation of the 12 simulations scenarios compared in this study (2 LO scenarios X 2 mesh sizes X 3 survival rates). Simulations for the 80mm net were taken from Verkempynck et al (2018); simulations for the 90mm net were run for this study.

3 Results

3.1 Selection pattern

The figures 4 and 5 show the selection pattern for North Sea sole and plaice, corresponding to the mesh size 80mm and 90mm for the métier TBB_DEF_70-99_0_0_all calculated for a scenario where discarding is allowed, and for a scenario with the landing obligation implemented. The selection pattern represents how the fishing morality in the simulation is distributed across age-groups.

For sole, there was very little difference in the selection patterns estimated for the 3 survival rates in the base case (between vertical panels on figure 5). This comes from the fact that the stock assessment conducted with these 3 survival rates (Verkempynck et al. 2018) had similar output regarding the age profile of the fishing mortality. Since the 3 survival rates considered here are low, the selection patterns for a given survival rate is not markedly affected by whether discards are landed or not (little differences between horizontal panels on figure 5). More differences were observed for the effect of mesh size on the selection pattern (color of the curves on figure 5). For sole, the TBB_DEF_70-99_0_0_all métier represents a large proportion of the catches of the stock (70% on average across age-classes). The difference in retention rate by the cod-end between 80mm and 90mm mesh size is visible for all ages but is particularly large for younger fish (figure 2). As a result, the fishing mortality-at-age corresponding to the 90mm mesh is lower for all ages than for the 80mm mesh, but the difference is larger for younger ages, than older age. In terms of selection pattern, using the net with a 90mm cod-end results in applying a higher fishing mortality to older ages (5 and older) and lower fishing mortality for young fish (2 and 3 years old) for a same Fbar value.

In the case of plaice, there was also little influence of the assumed survival rate on the selection pattern (comparison across vertical panels on figure 6). As discard rates are high for young age-groups in plaice, discarding or landing the unwanted catch did have an effect on the selection pattern (differences in age 2 and 3 between horizontal panels on figure 6), but since the survival rates considered here are low, these differences in the selection patterns were small. The catches of the TBB_DEF_70-99_0_0_all métier represent 38% (on average across age-classes) of the total 2017 catches. The difference in selectivity-at-age between the 80mm and 90mm mesh size is mainly found for age 1 and 2. As a result, the fishing mortality-at-age corresponding to the 90mm mesh is lower only for young ages, and the magnitude of the difference is markedly smaller than for sole. In terms of selection pattern, this means that using the 90mm net results is targeting less ages 1 and 2, and targeting only slightly more older ages (4 and 5 year olds).

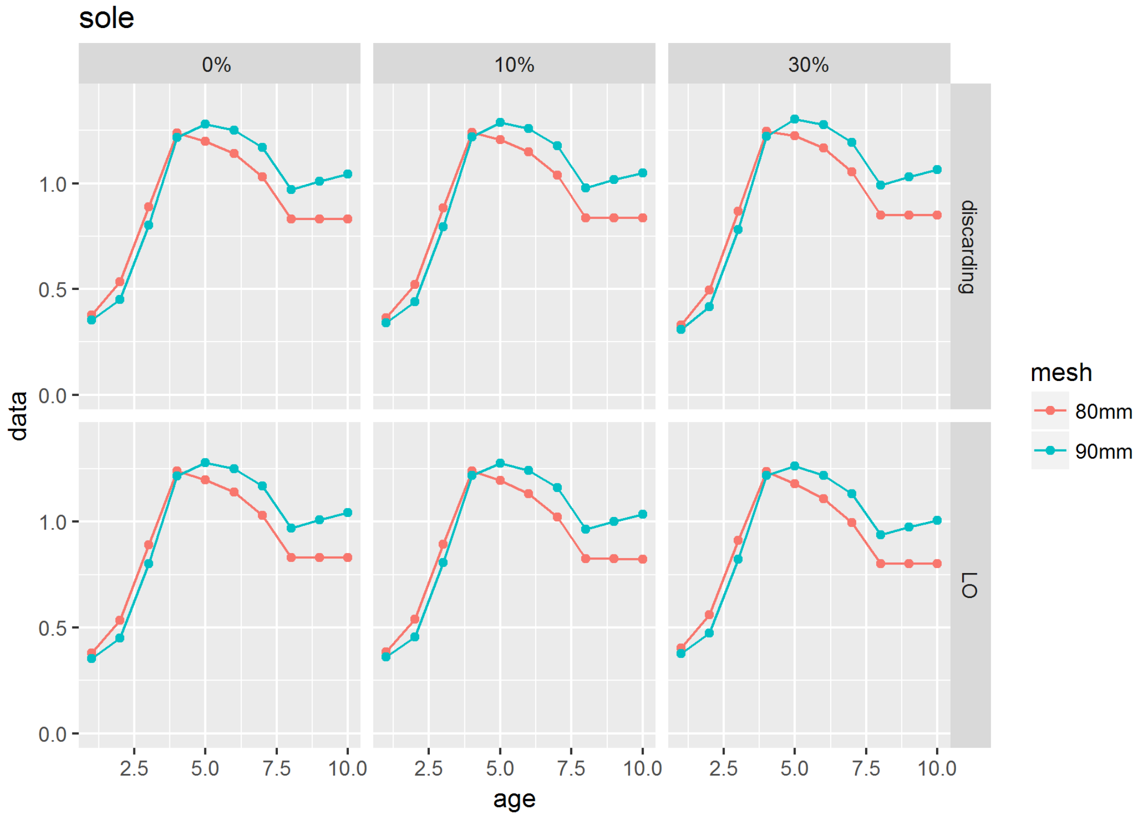

Figure 5 : Sole selection pattern for mesh size 80mm and 90mm based on stock assessment assuming 0%, 10% and 30% survival.

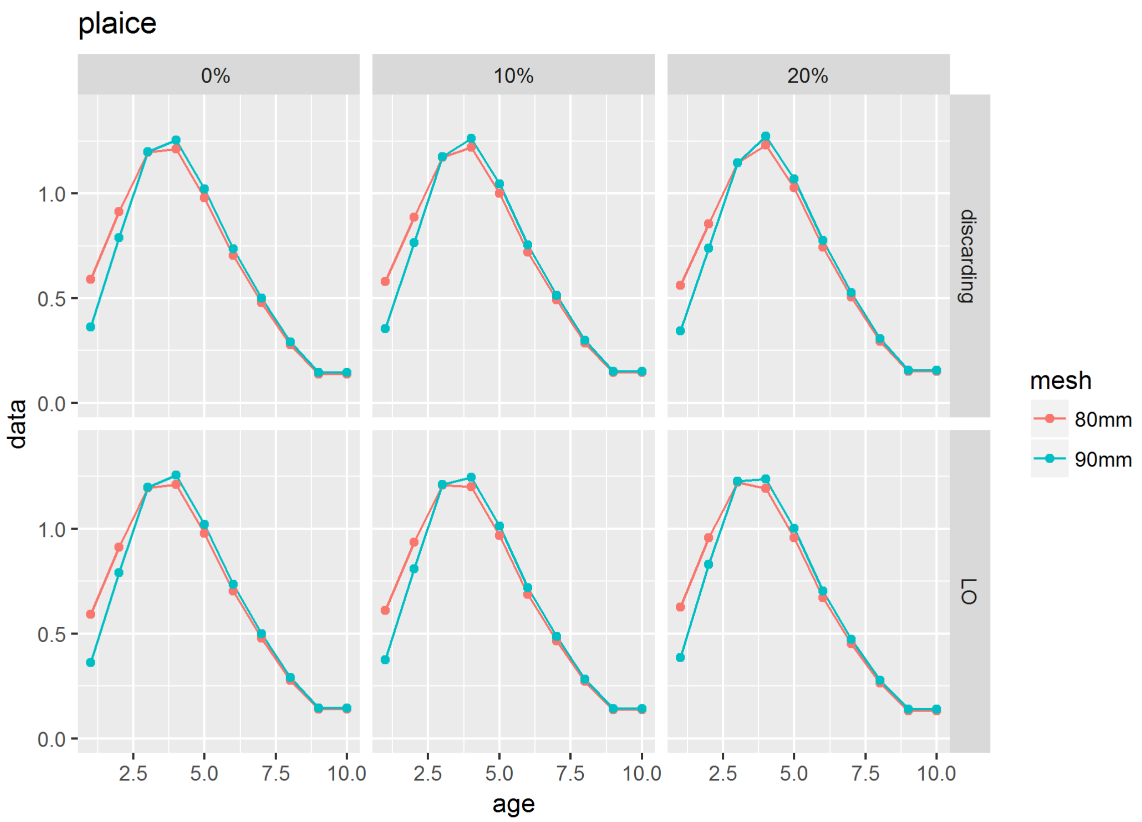

Figure 6 : Plaice selection pattern for mesh size 80mm and 90mm based on stock assessment assuming 0%, 10% and 20% survival.

3.2 Reference points

Reference points were calculated for each scenario to be implemented for the future years in the simulations on discarding (i.e. landed or thrown back at sea) and for the 90 mm mesh size. Values for the 80mm mesh size were taken from Verkempynck et al. (2018). Those reference points were used in the simulations to calculate future TACs in an MSE. By doing so, it was therefore assumed that managers are aware that changes from the current situation – using 80mm nets and discards not landed - to any other situation would require an update of the reference points.
The Fmsy values used in the different scenarios of the simulations are given in table 1. As observed in Verkempynck et al (2018), in cases where discarding is allowed, Fmsy values are larger for higher assumed survival rates. However, these differences disappear when discards are landed.
An almost systematic difference is observed in Fmsy between the 80mm and 90mm mesh sizes. Fmsy for the 90mm is roughly 0.03 lower for sole and 0.02 higher for plaice than for the 80mm gear. This contrast between sole and plaice comes from the difference in how the respective selection patterns of the 2 species is affected by the change in mesh size (i.e. mainly reduced targeting of young fish on plaice, and mainly increased targeting on older fish for sole).
One can also note that some differences in Fmsy values can be found between the non-LO and LO situation for the scenario with 0% survival, when there should not in principle be any (if all fish die, it makes no difference if they are landed or released). These differences (no larger than 2%) reflect the uncertainty in the estimation of Fmsy by the stochastic simulation tool used here.

Table 1 : Fmsy values estimated for the different simulation scenarios presented in figure 4

	Sole			Plaice		
	Survival rate	80mm	90mm	Survival rate	80mm	90mm
With discarding	0%	0.270	0.237	0%	0.202	0.222
	10%	0.275	0.244	10%	0.205	0.223
	30%	0.287	0.276	20%	0.222	0.223
Landing obligation	0%	0.269	0.232	0%	0.205	0.226
	10%	0.268	0.237	10%	0.201	0.220
	30%	0.269	0.233	20%	0.201	0.220

3.3 Simulation output

3.3.1 Sole

Future stock trajectories are show in appendix 1. The recent trend in fishing mortality is a decrease from high values (Fbar2-6>0.40) around 2010, to lower values in the last assessment year. Applying Fmsy in the first year of the simulation (2017) results in an increase in fishing mortality. This increase is of a larger magnitude for scenarios with a higher survival rate assumption (reflecting the differences in Fmsy values, table 1). The SSB has been on an ascending trend in the recent past. As a result of increasing the fishing mortality to apply Fmsy at the start of the simulation, SSB decreases slightly at the start of the simulation and quickly reaches a stochastic equilibrium. The increase in fishing mortality at the start of the simulation results in a jump in the catches and the landings, which then follow a similar trajectory as the SSB. The discards have been generally decreasing over the recent period and decrease further in the first year of the simulation until a stochastic equilibrium is reached. In none of the scenario tested the probability p(SSB<Blim) exceed 5%, implying that the stock always remained within safe biological limits.
Comparison of the mean stock size, landings and discard values in the short (2017-2021), medium (2022-2032) and long term (2033-2067) are given in table 2 and on figure 7. In the short term, using a 90mm mesh size results in a small loss in the landings (between 4.3% and 0% depending on survival rate assumed). The discards are also reduced by a higher percentage (from 10 to 16%). The resulting SSB is larger with the 90mm mesh size (by 0.5 to 5%). In the medium term, the difference in stock

size becomes larger (3 to 13% larger SSB if the 90mm mesh size is used). As a result of this larger stock, landings are also higher if the 90mm mesh size is used (by 2 to 3%) while the discards remain lower (by between 9 to 14%). Differences in the longer term between 80mm and 90mm mesh size remain similar to those described for the medium term.
The benefit of using a larger mesh size (reduction of discards, slightly higher landings) is largest for lower survival rate(e.g. upper row vs. lower row on figure 7).Assuming a survival rate of 0%, stock size in the medium and long term is around 12% higher (medium and long term) with the 90mm mesh size net than with the 80mm, the landings are 3% higher, and the discards are around 16% lower. Assuming a 30% survival rate, the SSB is 3% higher for the 90mm mesh size, landings are 2% higher and discards 9% lower. With low survival rate, improving selectivity to avoid catching small fish effectively results in a lower mortality at a young age, hence letting more time for cohorts to growth and contribute to reproduction before being targeted by the fishery. In a scenario with high the survival rate, small fish thrown overboard have a high chance to return in the population anyway, so there is less benefit in avoiding catching them. In a situation where the landing obligation is applied, the effect of using a 90mm mesh size net is similar to when discarding is allowed: small loss in the landings in the short term and a small gain thereafter, larger SSB, lower discards. There is however, no contrast between the different assumptions on survival rate: the differences between 90mm v.s 80mm net are similar for the 3 scenarios on survival rate (figure 7), close to the differences found for the 0% survival scenario in a situation where discarding is allowed.

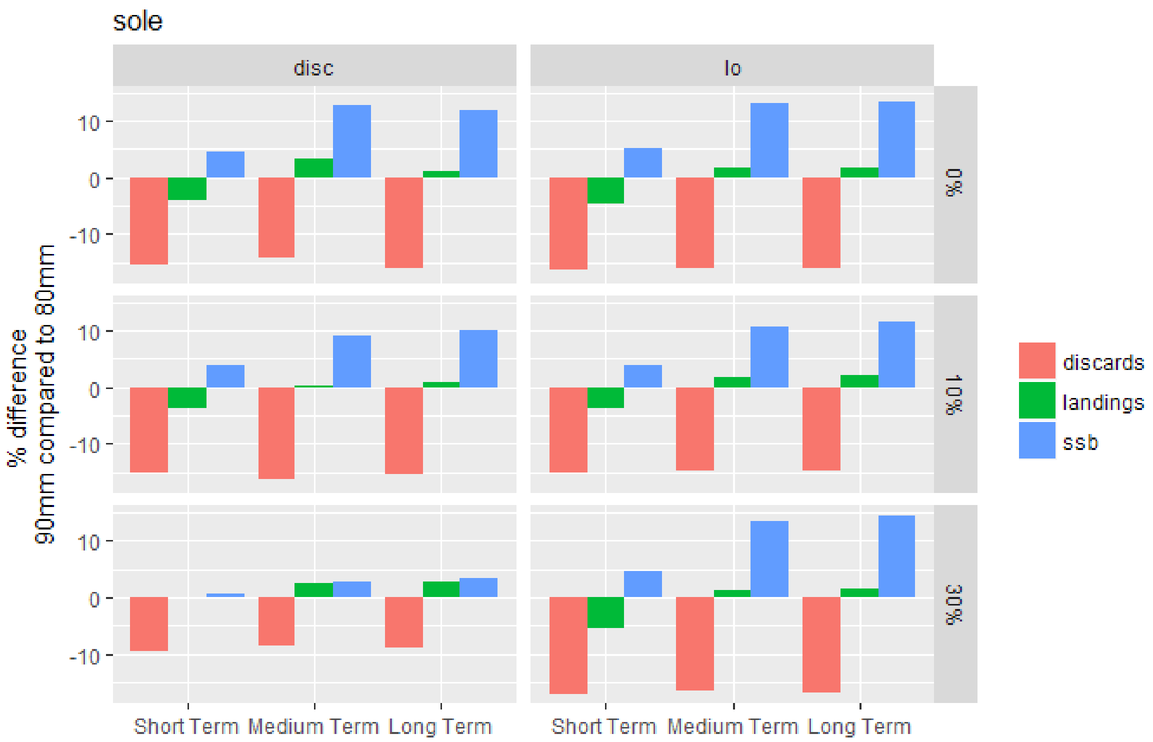

Figure 7 : percentage difference in the discards, landings and SSB for sole between the 90mm and 80mm nets. Differences are shown in the short, medium and long term, for the 3 scenarios on survival and the 2 scenarios on discarding

3.3.2 plaice

Future stock trajectories are shown in appendix 2. The recent trend in fishing morality is a steep decrease from high levels in 2007 (close to 0.30) to lower levels since 2010 (around 0.20). Applying Fmsy at the start of the simulations has different implications in each scenario. It results in a steep increase in fishing mortality for all scenarios with the 90mm mesh size and scenarios for the 80mm mesh size with discarding for an assumed survival rates of 10% and 20%. For the scenario with the

80mm net, the LO and 0% survival it causes a decrease in fishing mortality. Finally, it makes no change in fishing mortality for the other scenarios. The SSB has been increasing in the recent past and this increase continues, by a magnitude varying across simulation scenarios, until a stochastic equilibrium is reached in around 2040. Historical landing have been increasing since 2007 and reach a maximum in the first year of the simulation and decrease substantially the year after. The trend afterwards is similar to the increase in the SSB, until around 2040 when a stable level is reached. The discards have been varying with no specific trend in the recent past and decrease sharply for most scenarios at the start of the simulation and stabilize quickly to their long term level. As for sole, the risk of p(SSB<Blim) never exceeded 5%.

Comparison of the mean stock size, landings and discards values in the short (2017-2021), medium (2022-2032) and long term (2033-2067) is given on table 3. Contrasting results are observed between, on one hand, simulations for assumed survival rate of 0% and 10% and, on the other hand, assumed survival rate of 20%. For the assumed survival rates of 0% and 10%, using the 90mm mesh size results in a smaller SSB (by 2 to 7%) in the short, medium and long term. Landing and discards are higher in the short, medium and short term (by around 10% and 2% to 5% respectively). For the assumed survival rate of 20%, SSB is slightly larger for the simulations with a 90mm mesh size net (up to 4%), and landings are higher (by 4% to 9%) and discards are slightly lower (1 to 4%).

In a situation where the landing obligation is applied, as for sole, results are similar for the 3 assumptions used for survival rate, and similar to the results with discarding for the survival rate of 0%, but with larger differences between the 90mm and 80mm scenarios (8 to 10% smaller SSB, 3% to 15% higher landings, 6% to 8% higher discards).

Figure 8 : percentage difference in the discards, landings and SSB for plaice between the 90mm and 80mm nets. Differences are shown in the short, medium and long term, for the 3 scenarios on survival and the 2 scenarios on discarding

*Table2 : simulations results for **sole** in the short (2017-2021) medium (2022-2032) and long (2033-2067) term. Median across the 2000 replicates of the stock (average over the time period) and percentage difference between 80mm and 90mm mesh size. For each combination of survival rate and mesh size, results are presented for scenarios with discarding and with the landing obligation implemented.*

Sole summary of the results for scenario with discarding

survival rate		Short Term 80mm	Short Term 90mm	Short Term percentage difference	Medium Term 80mm	Medium Term 90mm	Medium Term percentage difference	Long Term 80mm	Long Term 90mm	Long Term percentage difference
0%	catch	18057	17114	-5.2	17409	17733	1.9	17716	17691	-0.1
0%	discards	1362	1151	-15.5	1416	1215	-14.2	1431	1202	-16.0
0%	fbar	0.27	0.24	-12.4	0.27	0.24	-12.4	0.27	0.24	-12.4
0%	landings	16668	15958	-4.3	15918	16428	3.2	16215	16415	1.2
0%	ssb	58654	61325	4.6	57164	64528	12.9	58026	64899	11.8
10%	catch	18071	17259	-4.5	17507	17324	-1.0	17575	17518	-0.3
10%	discards	1245	1059	-15.0	1322	1106	-16.3	1314	1110	-15.5
10%	fbar	0.28	0.24	-11.4	0.28	0.24	-11.4	0.28	0.24	-11.4
10%	landings	16807	16196	-3.6	16124	16144	0.1	16192	16335	0.9
10%	ssb	57475	59758	4.0	55725	60811	9.1	55999	61653	10.1
30%	catch	18212	18124	-0.5	17195	17476	1.6	17315	17660	2.0
30%	discards	1019	921	-9.6	1063	972	-8.6	1069	975	-8.8
30%	fbar	0.29	0.28	-3.8	0.29	0.28	-3.8	0.29	0.28	-3.8
30%	landings	17183	17197	0.1	16059	16432	2.3	16190	16607	2.6
30%	ssb	54967	55224	0.5	51432	52838	2.7	51682	53425	3.4

Sole summary of the results for scenario with landing obligation

		Short Term			Medium Term			Long Term		
survival rate		80mm	90mm	percentage difference	80mm	90mm	percentage difference	80mm	90mm	percentage difference
0%	catch	18062	17025	-5.7	17620	17619	0.0	17698	17770	0.4
0%	discards	1368	1143	-16.4	1417	1191	-15.9	1418	1189	-16.1
0%	fbar	0.27	0.23	-13.5	0.27	0.23	-13.5	0.27	0.23	-13.5
0%	landings	16671	15864	-4.8	16089	16345	1.6	16204	16500	1.8
0%	ssb	59117	62123	5.1	58062	65626	13.0	58704	66621	13.5
10%	catch	17834	17019	-4.6	17263	17271	0.1	17376	17494	0.7
10%	discards	1335	1134	-15.1	1392	1185	-14.9	1394	1186	-14.9
10%	fbar	0.27	0.24	-11.7	0.27	0.24	-11.7	0.27	0.24	-11.7
10%	landings	16338	15738	-3.7	15633	15882	1.6	15753	16087	2.1
10%	ssb	58255	60500	3.9	56517	62449	10.5	57104	63669	11.5
30%	catch	17686	16522	-6.6	16746	16642	-0.6	16958	16906	-0.3
30%	discards	1319	1092	-17.2	1365	1140	-16.5	1373	1141	-16.9
30%	fbar	0.27	0.23	-14.2	0.27	0.23	-14.2	0.27	0.23	-14.2
30%	landings	15910	15033	-5.5	14840	15024	1.2	15037	15280	1.6
30%	ssb	56428	59022	4.6	53373	60562	13.5	53996	61801	14.5

Table3 : simulations results for ***plaice*** *in the short (2017-2021) medium (2022-2032) and long (2033-2067) term. Median across the 2000 replicates of the stock (average over the time period) and percentage difference between 80mm and 90mm mesh size. For each combination of survival rate and mesh size, results are presented for scenarios with discarding and with the landing obligation implemented.*

plaice summary of the results for scenario with discarding

		Short Term			Medium Term			Long Term		
survival rate		80mm	90mm	percentage difference	80mm	90mm	percentage difference	80mm	90mm	percentage difference
0%	catch	130433	141580	8.55	130283	141593	8.68	134253	145094	8.07
0%	discards	39457	40858	3.55	39419	41151	4.39	39591	41451	4.7
0%	fbar	0.20	0.22	10.12	0.20	0.22	10.12	0.20	0.22	10.12
0%	landings	90690	100556	10.88	90205	99635	10.45	93855	102827	9.56
0%	ssb	986382	965078	-2.16	1111446	1055727	-5.01	1205636	1126559	-6.56
10%	catch	131062	140516	7.21	128894	139077	7.9	131392	141377	7.6
10%	discards	37025	37613	1.59	36671	38033	3.71	36812	38083	3.45
10%	fbar	0.21	0.22	8.77	0.21	0.22	8.77	0.21	0.22	8.77
10%	landings	93807	102740	9.52	91332	100162	9.67	93726	102502	9.36
10%	ssb	968039	948299	-2.04	1062000	1014503	-4.47	1124233	1062410	-5.5
20%	catch	136604	139855	2.38	127984	135551	5.91	128836	136969	6.31
20%	discards	35767	34493	-3.56	34784	34354	-1.23	34964	34468	-1.42
20%	fbar	0.22	0.22	0.54	0.22	0.22	0.54	0.22	0.22	0.54
20%	landings	100535	105089	4.53	92385	100485	8.77	93150	101839	9.33
20%	ssb	933677	934096	0.04	953477	974344	2.19	964989	1001476	3.78

Plaice summary of the results for scenario with landing obligation

		Short Term			Medium Term			Long Term		
survival rate		80mm	90mm	percentage difference	80mm	90mm	percentage difference	80mm	90mm	percentage difference
0%	catch	126645	143043	12.95	129255	142540	10.28	133156	144609	8.6
0%	discards	38287	41450	8.26	38467	41601	8.15	38516	41571	7.93
0%	fbar	0.19	0.23	17.53	0.19	0.23	17.53	0.19	0.23	17.53
0%	landings	88169	101422	15.03	89960	100091	11.26	93820	102161	8.89
0%	ssb	998540	960445	-3.82	1161613	1043399	-10.18	1274251	1096945	-13.91
10%	catch	123810	137289	10.89	124379	134796	8.38	127014	137907	8.58
10%	discards	37134	39098	5.29	37064	39165	5.67	37041	39414	6.41
10%	fbar	0.19	0.22	13.94	0.19	0.22	13.94	0.19	0.22	13.94
10%	landings	85325	96555	13.16	85376	93698	9.75	87990	96362	9.52
10%	ssb	984264	954576	-3.02	1122345	1025422	-8.64	1210635	1082200	-10.61
20%	catch	119864	133036	10.99	116821	129020	10.44	119864	130575	8.94
20%	discards	35510	37520	5.66	34879	37305	6.95	35124	37408	6.5
20%	fbar	0.19	0.22	14.24	0.19	0.22	14.24	0.19	0.22	14.24
20%	landings	81779	92727	13.39	79115	88314	11.63	81747	89767	9.81
20%	ssb	972062	942327	-3.06	1081567	996283	-7.89	1153500	1033498	-10.4

4 Discussion - Conclusions

Overall, the effect of using a 90mm mesh size is rather limited: most of the time the differences in SSB, landings or discards are smaller than 10%, which, given the large magnitude of stochastic fluctuations (width of the envelop around the median in the annexes) would probably not be detectable. The largest differences observed (>10%) is the larger stock size and lower discards for the 90mm mesh size of sole, and the higher landings for plaice.

The differences in the effect on sole and plaice of using a 90mm net are related to both the direct effect of exploiting the stock with a different selection pattern and of applying different Fmsy values. The effects of changing mesh size are larger for sole than for plaice, because the share of the landings taken by the Dutch beam trawlers currently fishing with 80 mm is much larger for sole than for plaice.

For sole, the results seem to be counter-intuitive: the net with 90mm mesh catches less fish for all age-classes (figure 2), but simulations indicate that landings are not dramatically impacted (even slightly larger), while discards are substantially reduced and stock size is larger. This is because, in the simulations, the change in gear selectivity is transposed into a change in selection pattern to be used in future years. Although gear selectivity is lower for all ages, the selection pattern has no dimension (scales so that average across age 2 to 6 is 1). It is therefore only the age-profile of the fishing mortality which has changed, not its overall level. The difference in shape of the selection pattern for sole implies that there is slightly less pressure on the young fish, and higher pressure on older fish. Exploited with the selection pattern corresponding to the 90mm mesh size, young fish survive slightly more and get exploited at an age where they are heavier. This explains the lower discards and the slightly higher SSB. Although the immediate effect of changing mesh size is to have slightly lower landings than if the current net is used, this negative effect is counter-balanced already after 5 years by the fact that there is a larger stock for simulations with the 90mm mesh size.

For plaice , the difference in selection pattern resulting from the use of the 90mm net is maximal for age 1 and 2 fish. Despite of this seemingly small difference, the Fmsy values corresponding to this new selection pattern are notably higher (around 10%) than for the current selection pattern (except for an assumed survival rate of 20%). This higher Fmsy to be implemented if the 90mm mesh size is used (for survival rate of 0 and 10%) explains the lower stock size and higher catch, landings and (despite the improved selectivity of the net) discards. For the scenario assuming a survival rate of 20%, Fmsy is similar for the 80mm and 90mm mesh size. For this scenario, the improved selectivity of the 90mm net indeed results in slightly lower discards, which in the medium and long term result in a slightly larger stock with slightly higher landings.

One important assumption in these simulations is that the stocks are exploited at Fmsy in the future. However, if the beam trawl fleet switches to the 90mm net, its catchability (at least for sole) will decrease, meaning that a higher fishing effort will be necessary to achieve a same fishing mortality on the stock. It is not sure if that is technically possible, and economically or ecologically sustainable. The present study does not model explicitly catchability and effort, and therefore cannot quantify the change in effort implied if the stocks were to be exploited at Fmsy with the 90mm net.

Finally, the selectivity trials were done on a pulse trawler and the selectivity curves derived in this study are therefore representative of this specific gear. For lack of similar data, the assumption had to be made that those selectivity curves also applied to the part of the fleet using the conventional gear equipped with tickler chains.

5 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. This certificate is valid until 15 December 2018. The organisation has been certified since 27 February 2001. The certification was issued by DNV GL.

Furthermore, the chemical laboratory at IJmuiden has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2021 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation. The chemical laboratory at IJmuiden has thus demonstrated its ability to provide valid results according a technically competent manner and to work according to the ISO 17025 standard. The scope (L097) of de accredited analytical methods can be found at the website of the Council for Accreditation (www.rva.nl).

On the basis of this accreditation, the quality characteristic Q is awarded to the results of those components which are incorporated in the scope, provided they comply with all quality requirements. The quality characteristic Q is stated in the tables with the results. If, the quality characteristic Q is not mentioned, the reason why is explained.

The quality of the test methods is ensured in various ways. The accuracy of the analysis is regularly assessed by participation in inter-laboratory performance studies including those organized by QUASIMEME. If no inter-laboratory study is available, a second-level control is performed. In addition, a first-level control is performed for each series of measurements.
In addition to the line controls the following general quality controls are carried out:

- Blank research.
- Recovery.
- Internal standard
- Injection standard.
- Sensitivity.

The above controls are described in Wageningen Marine Research working instruction ISW 2.10.2.105. If desired, information regarding the performance characteristics of the analytical methods is available at the chemical laboratory at IJmuiden.

If the quality cannot be guaranteed, appropriate measures are taken.

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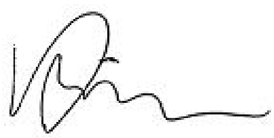
Justification

Report C016/19
Project Number: 4311400005

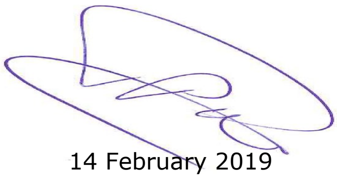
The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Ir. N.T. Hintzen
Research scientist

Signature: 

Date: 14 February 2019

Approved: Dr.ir. T.P. Bult
Director

Signature: 

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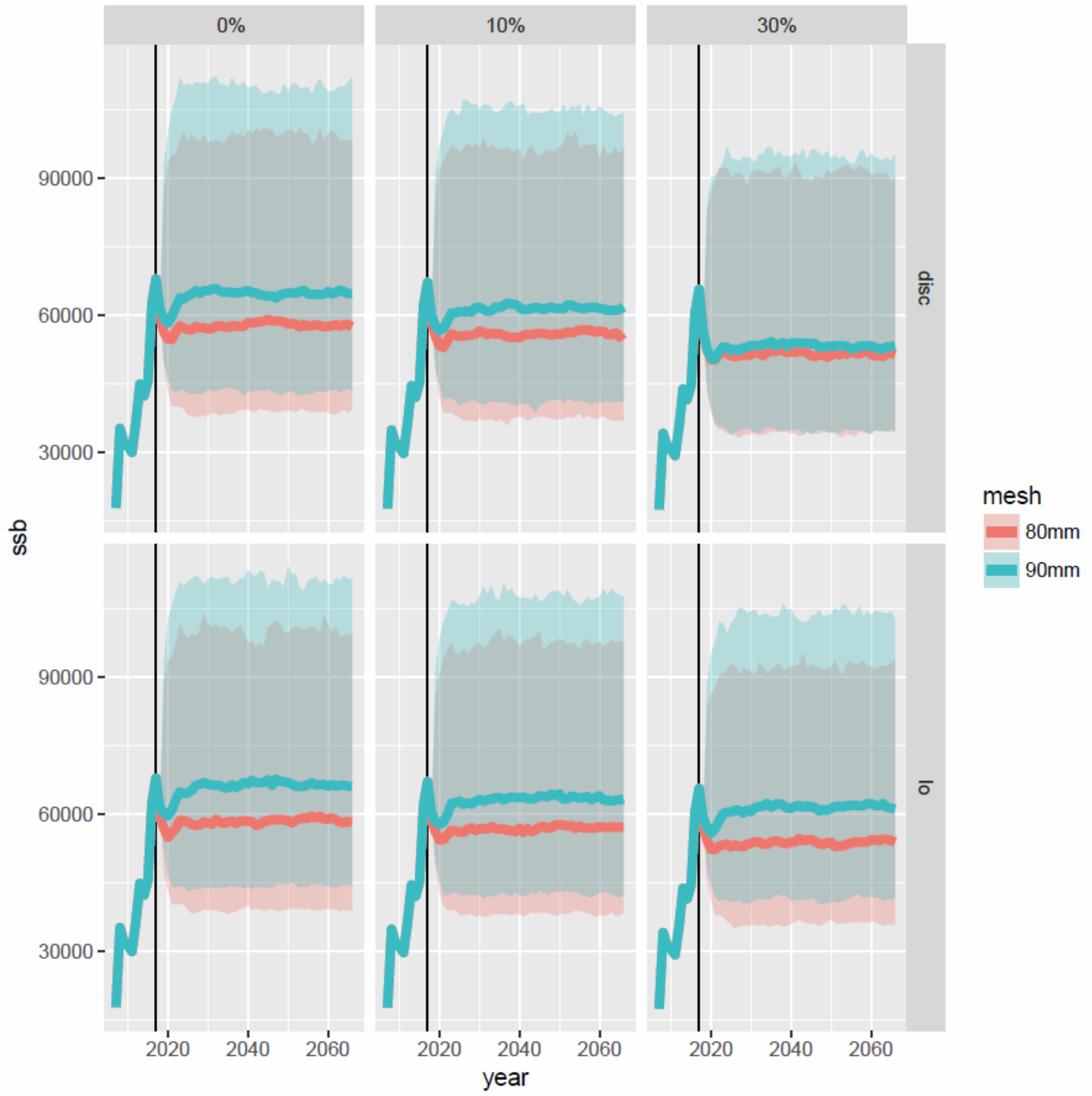
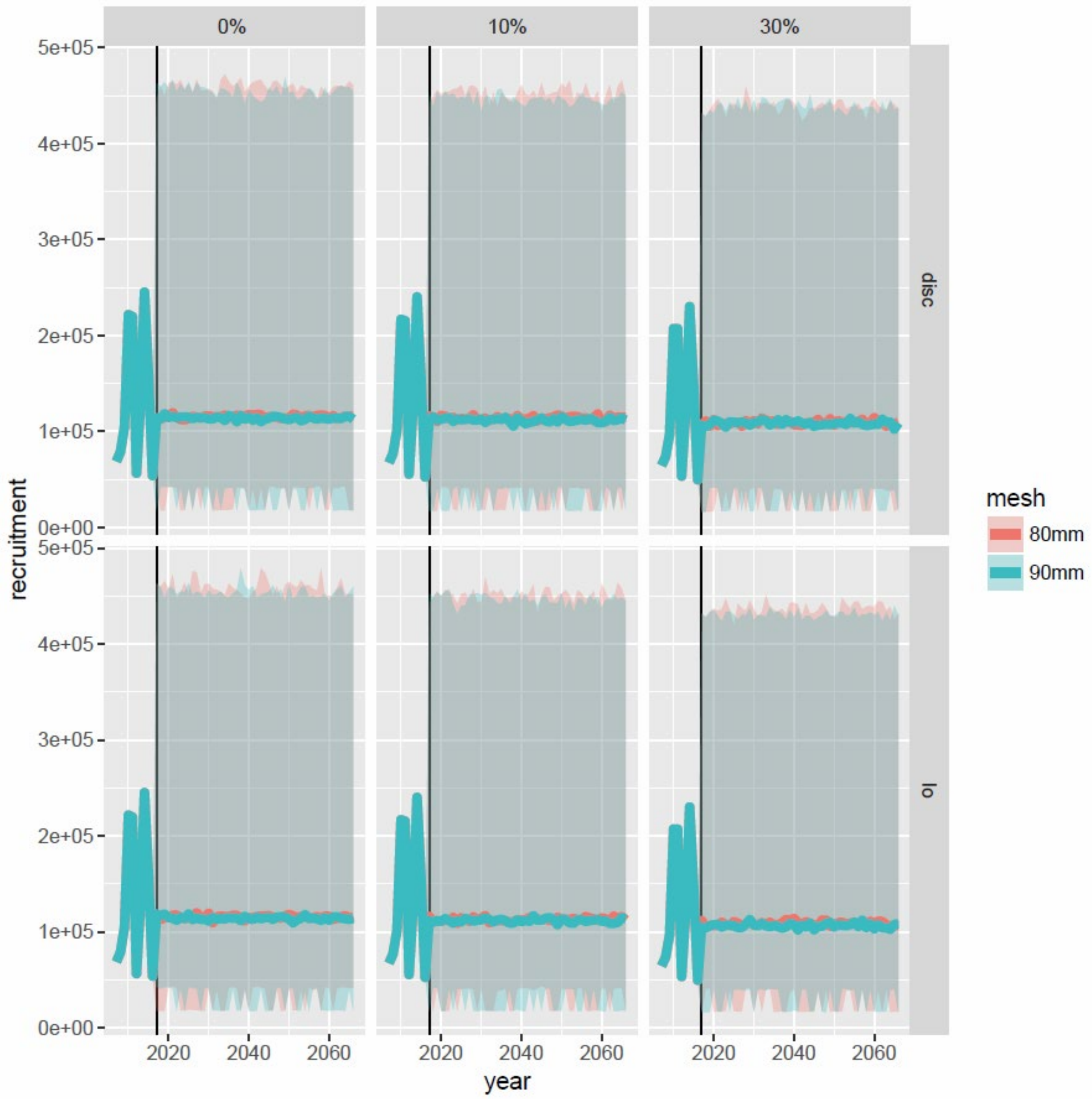
Appendix 1 : detailed stock trajectories for all simulations for sole (vertical panels represent different assumption on survival rate, horizontal panels represent





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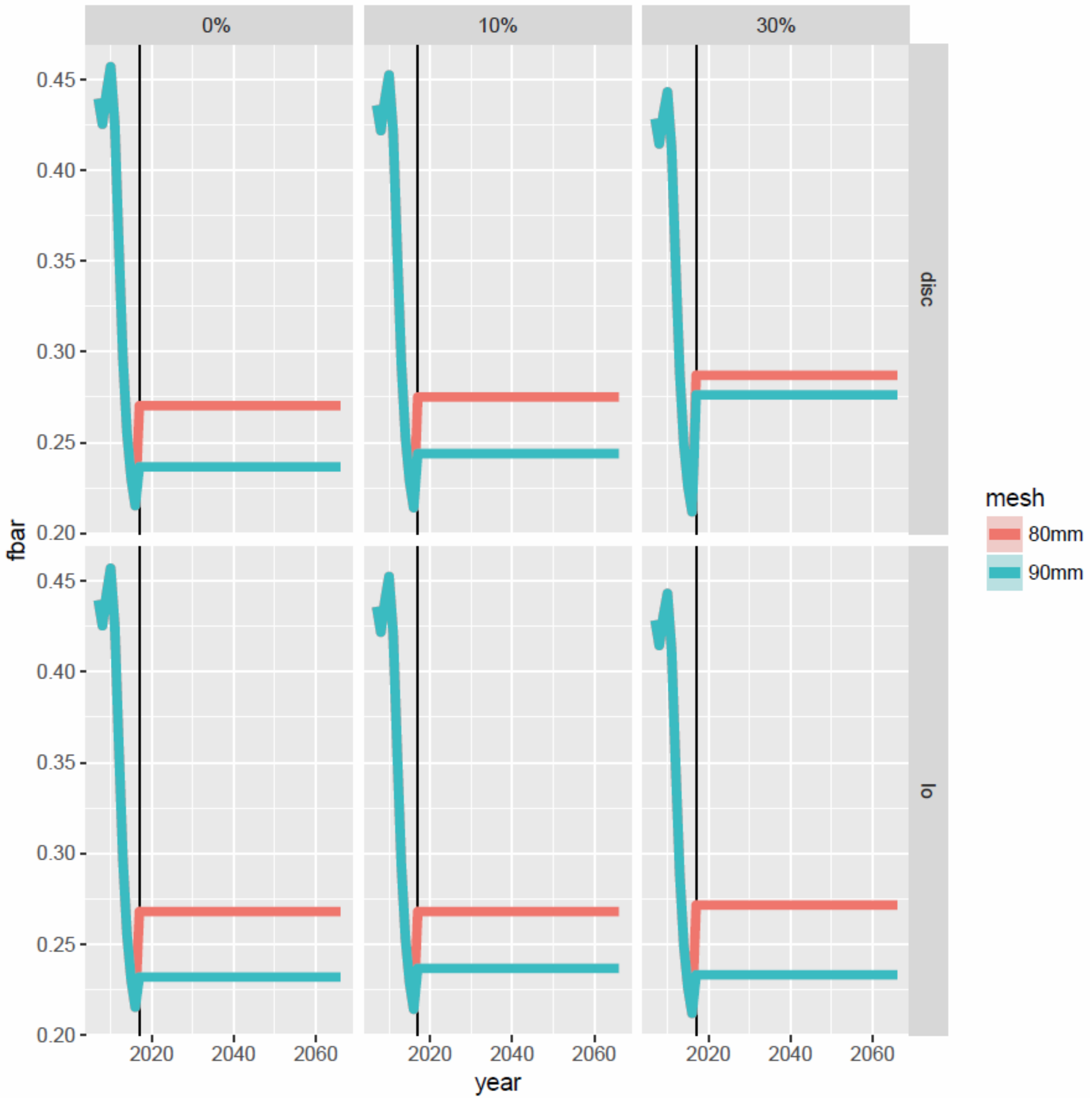
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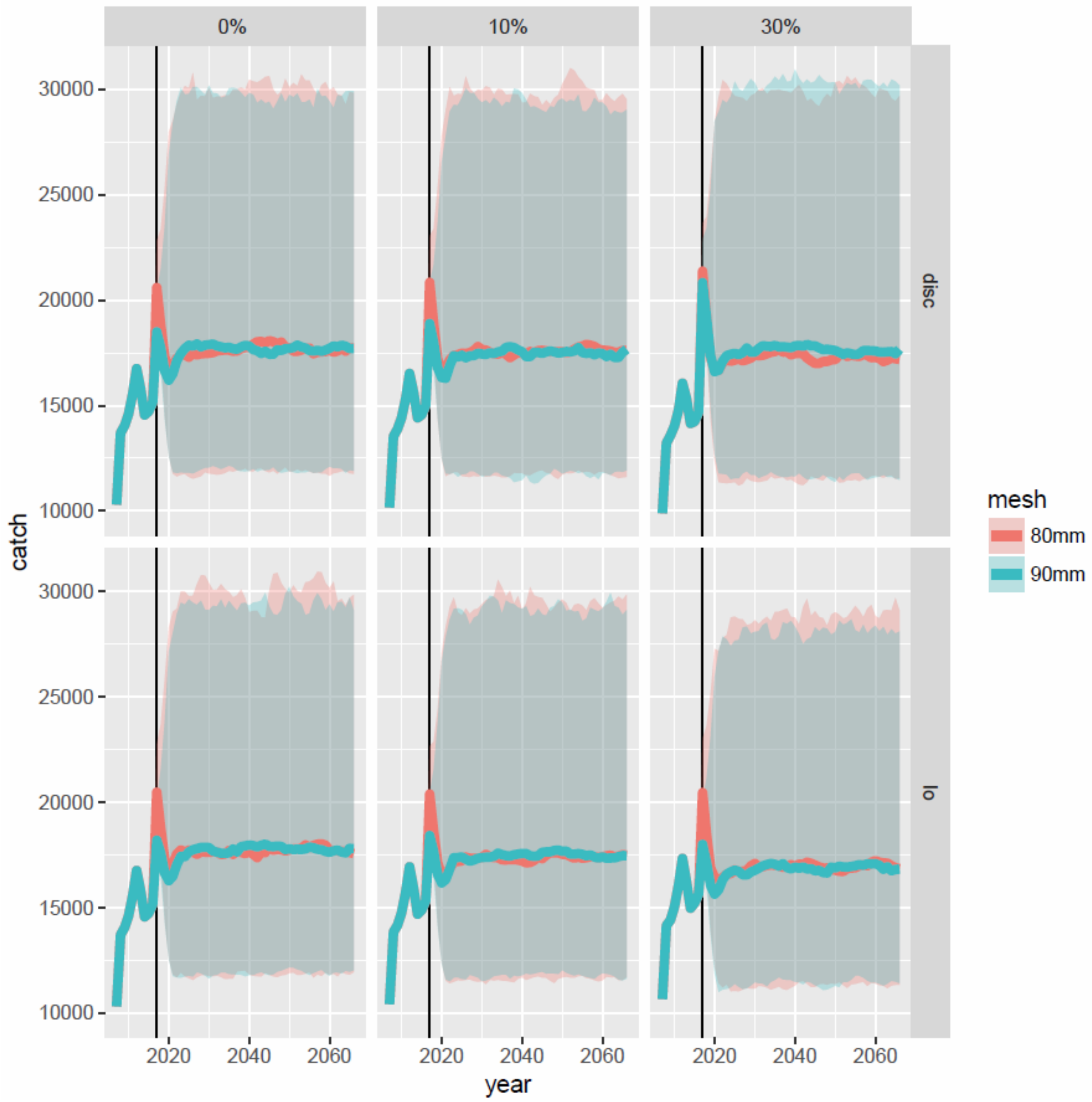

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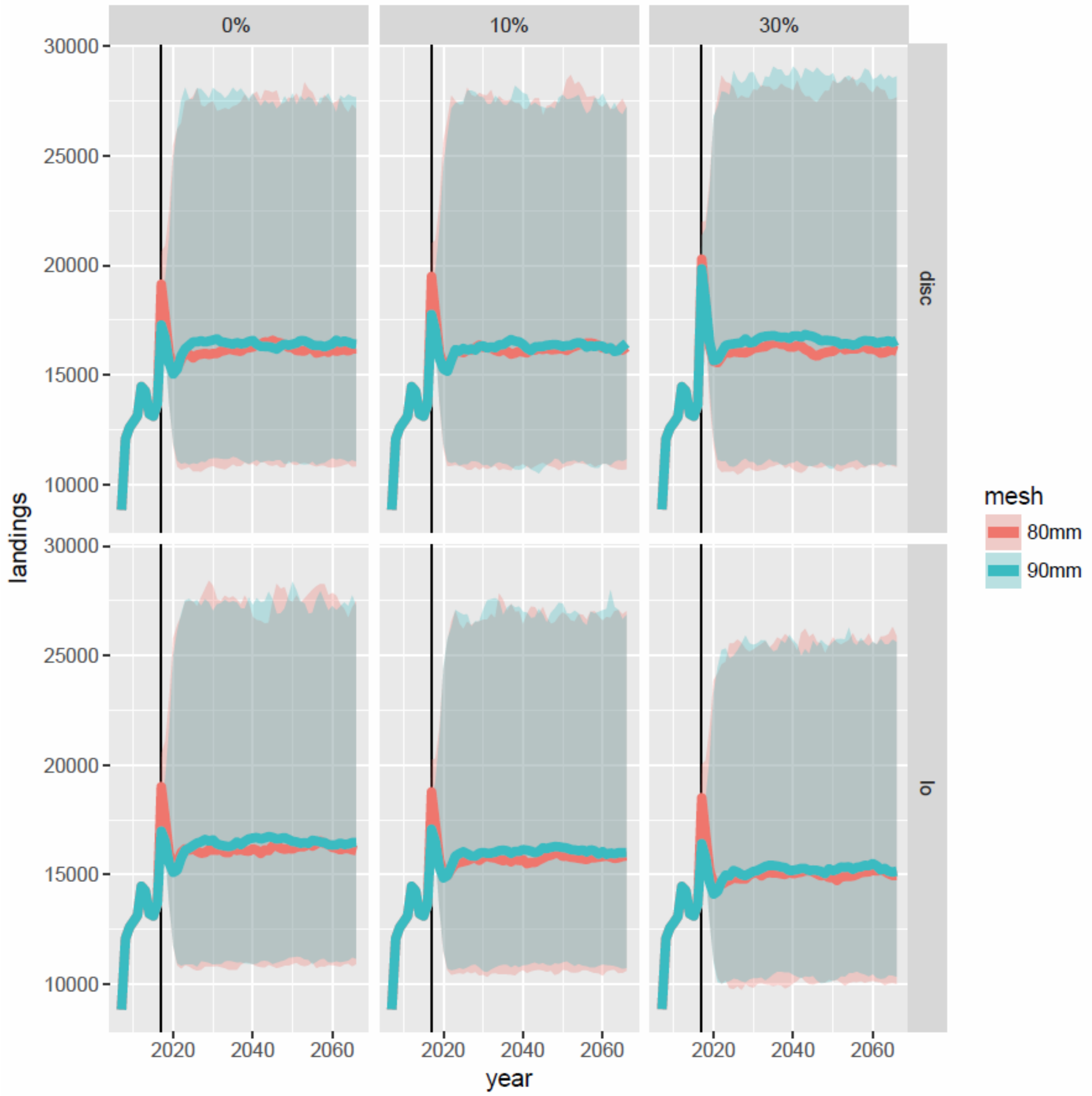
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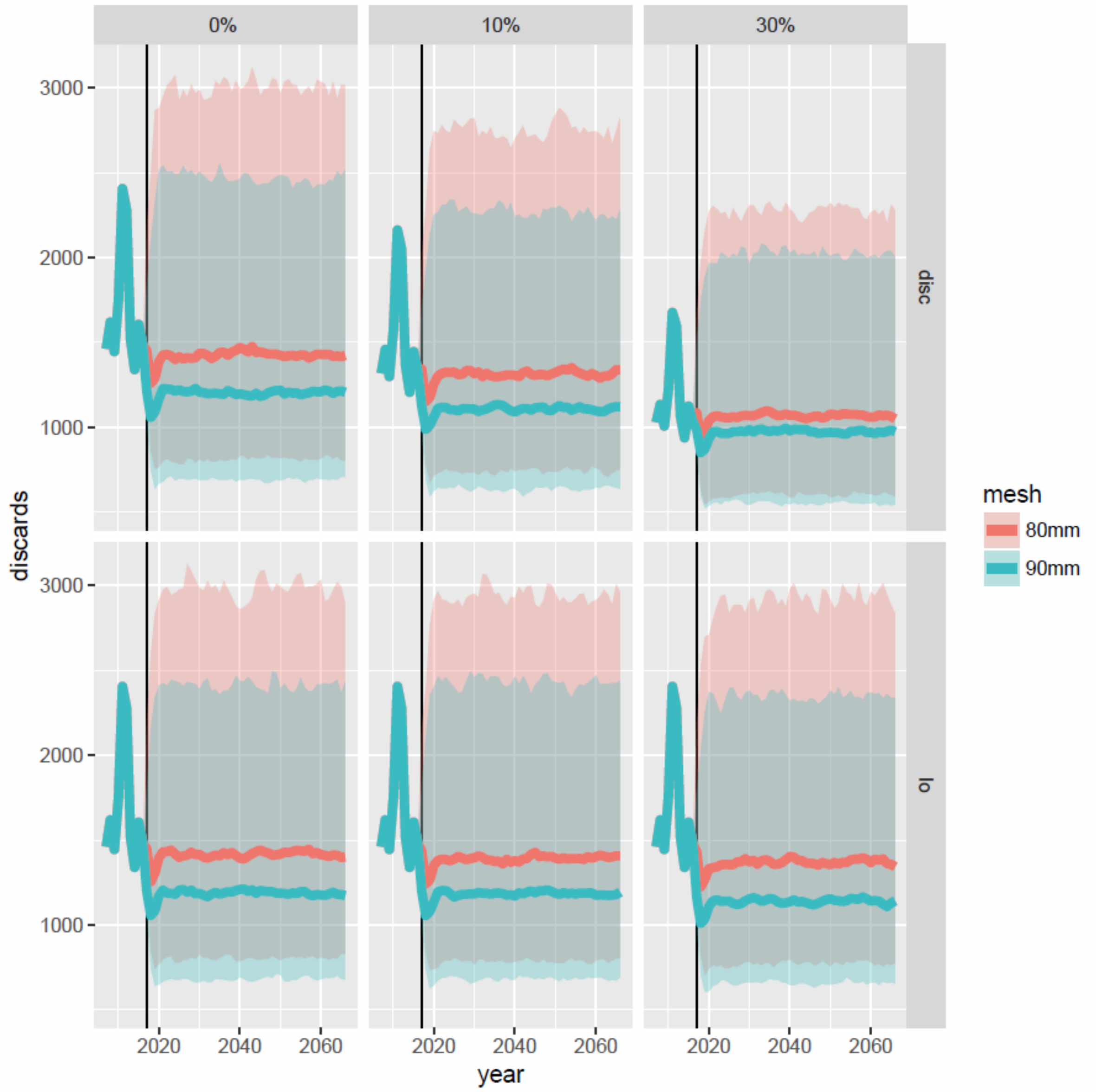
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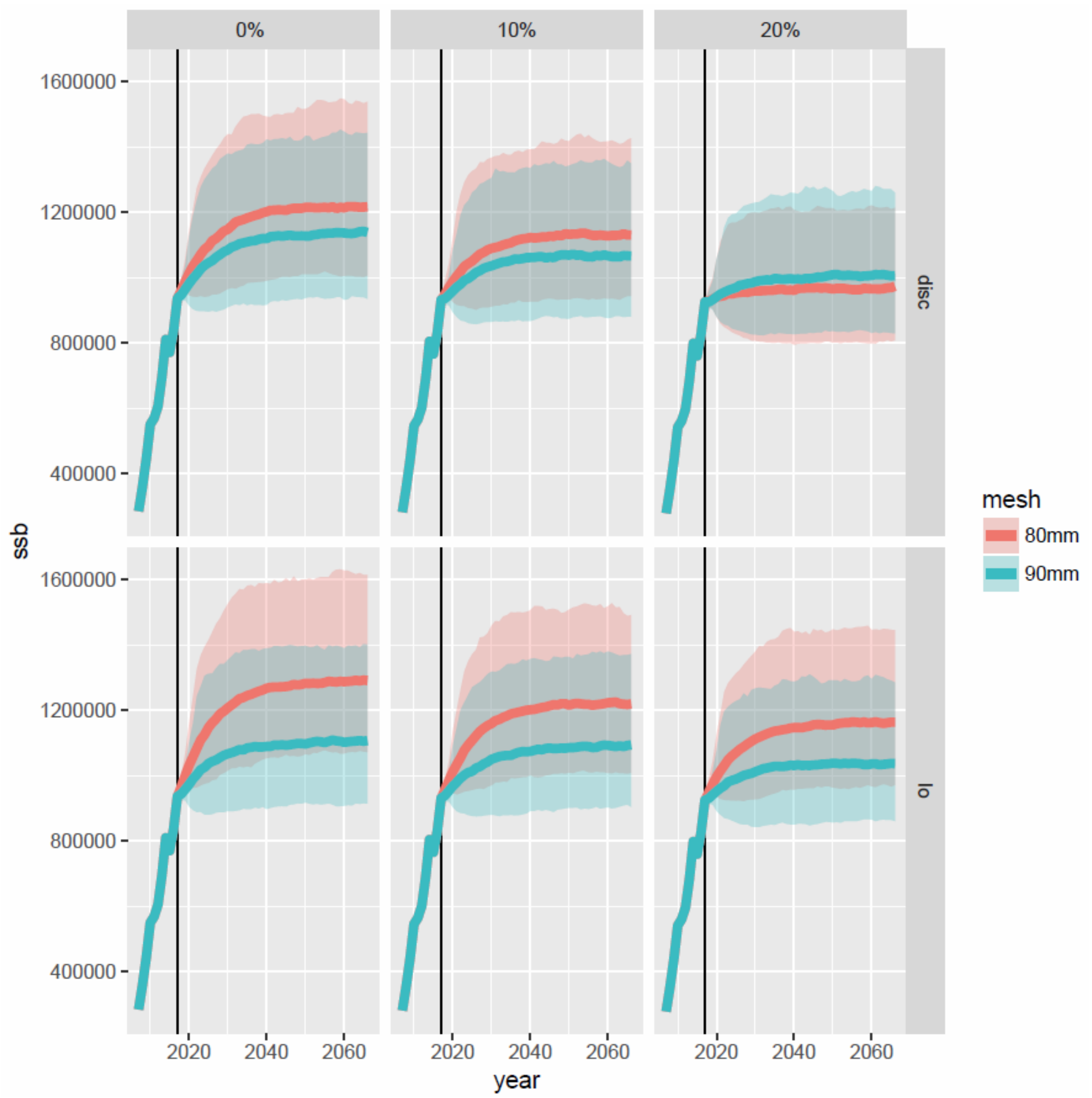
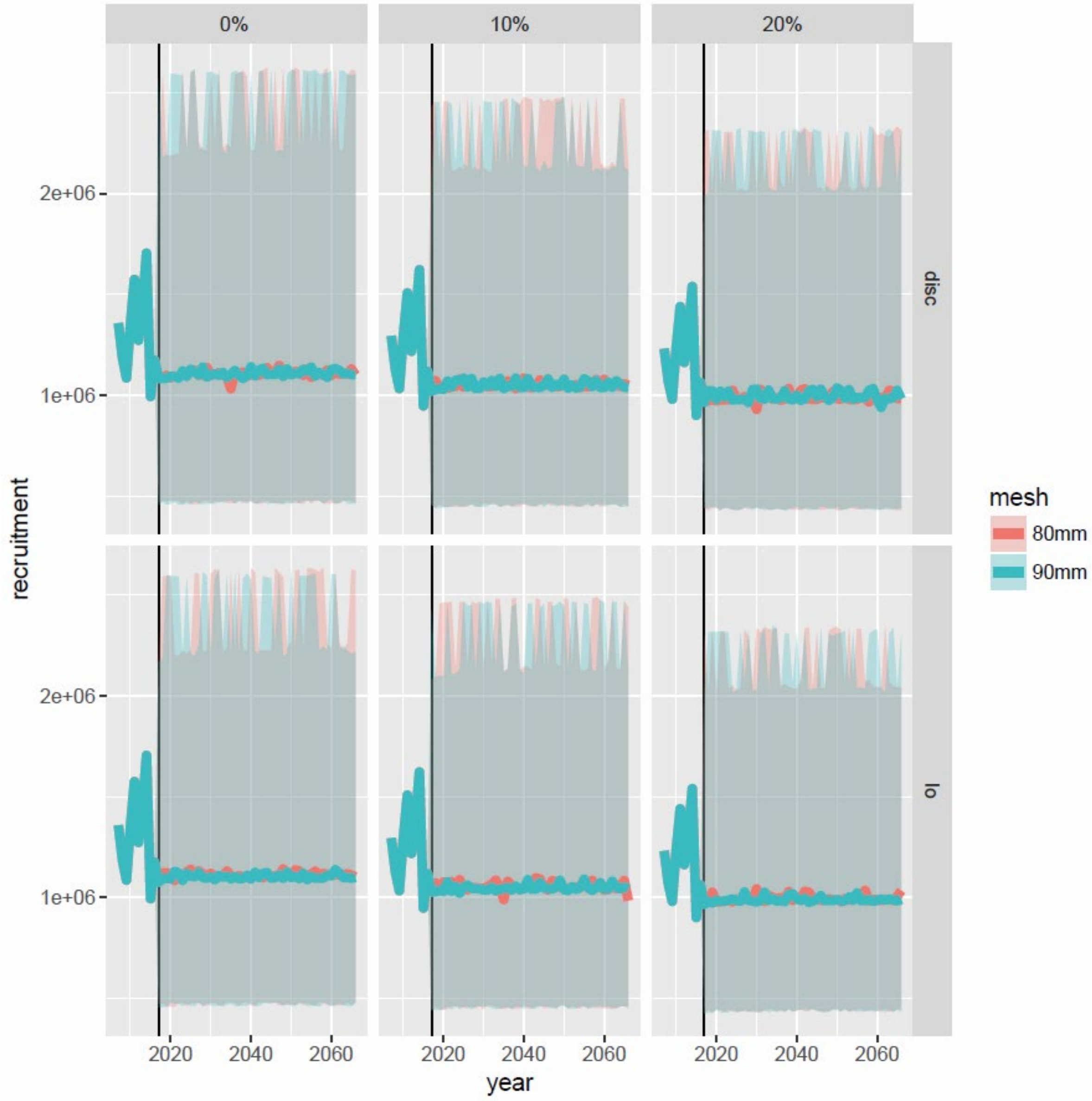
Appendix 2 : detailed stock trajectories for all simulations for plaice (vertical panels represent different assumption on survival rate, horizontal panels represent

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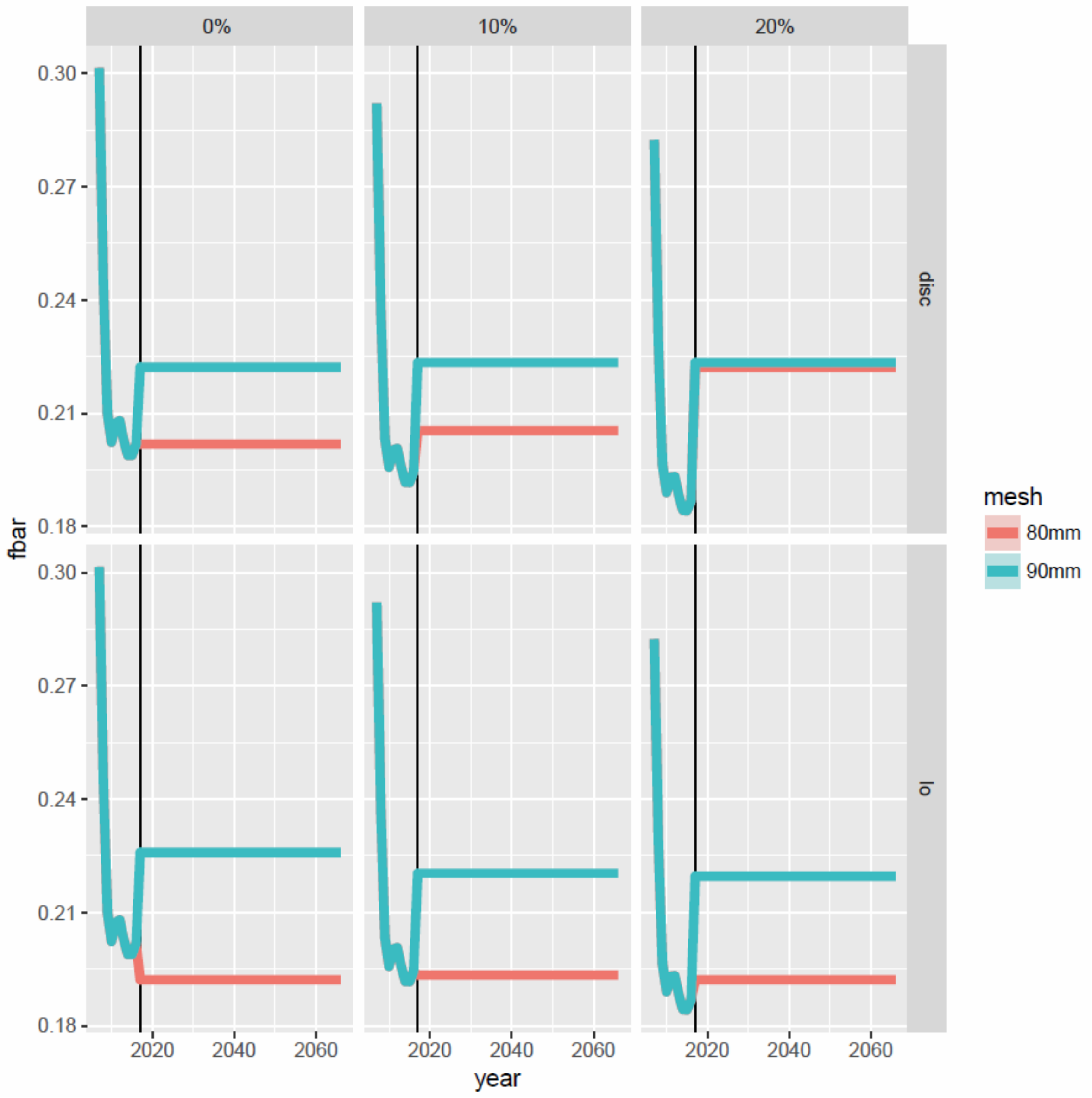
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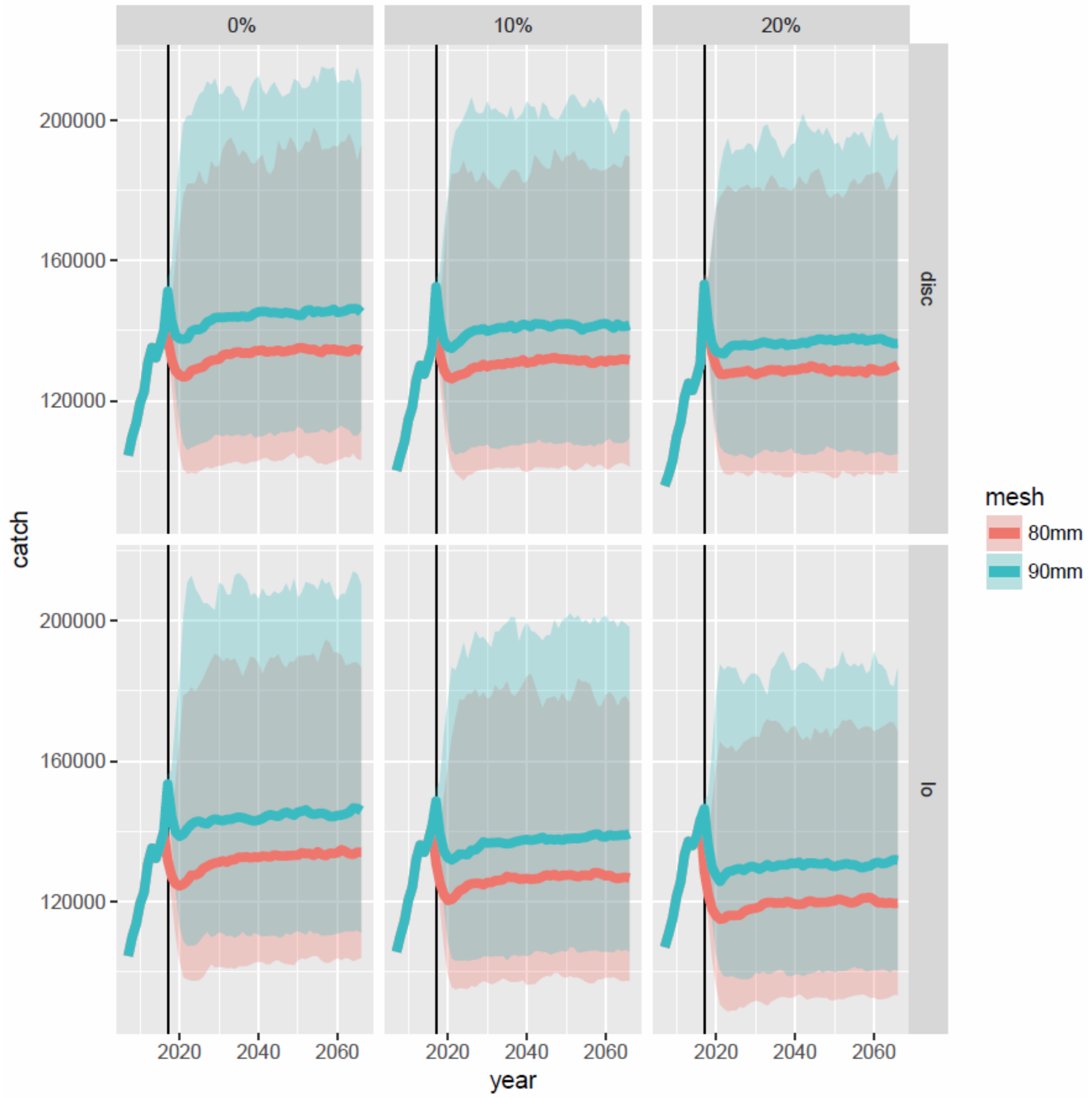
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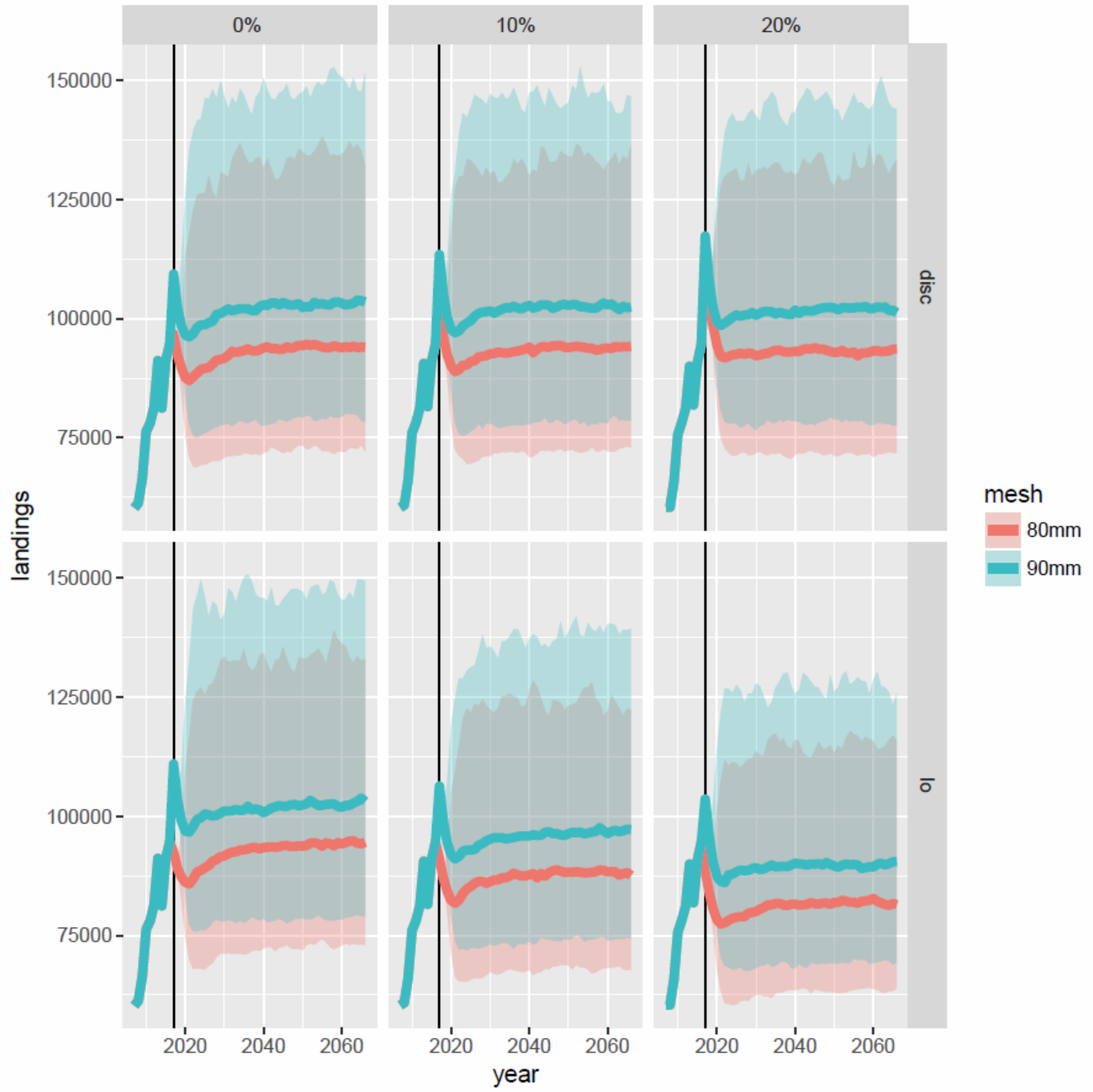
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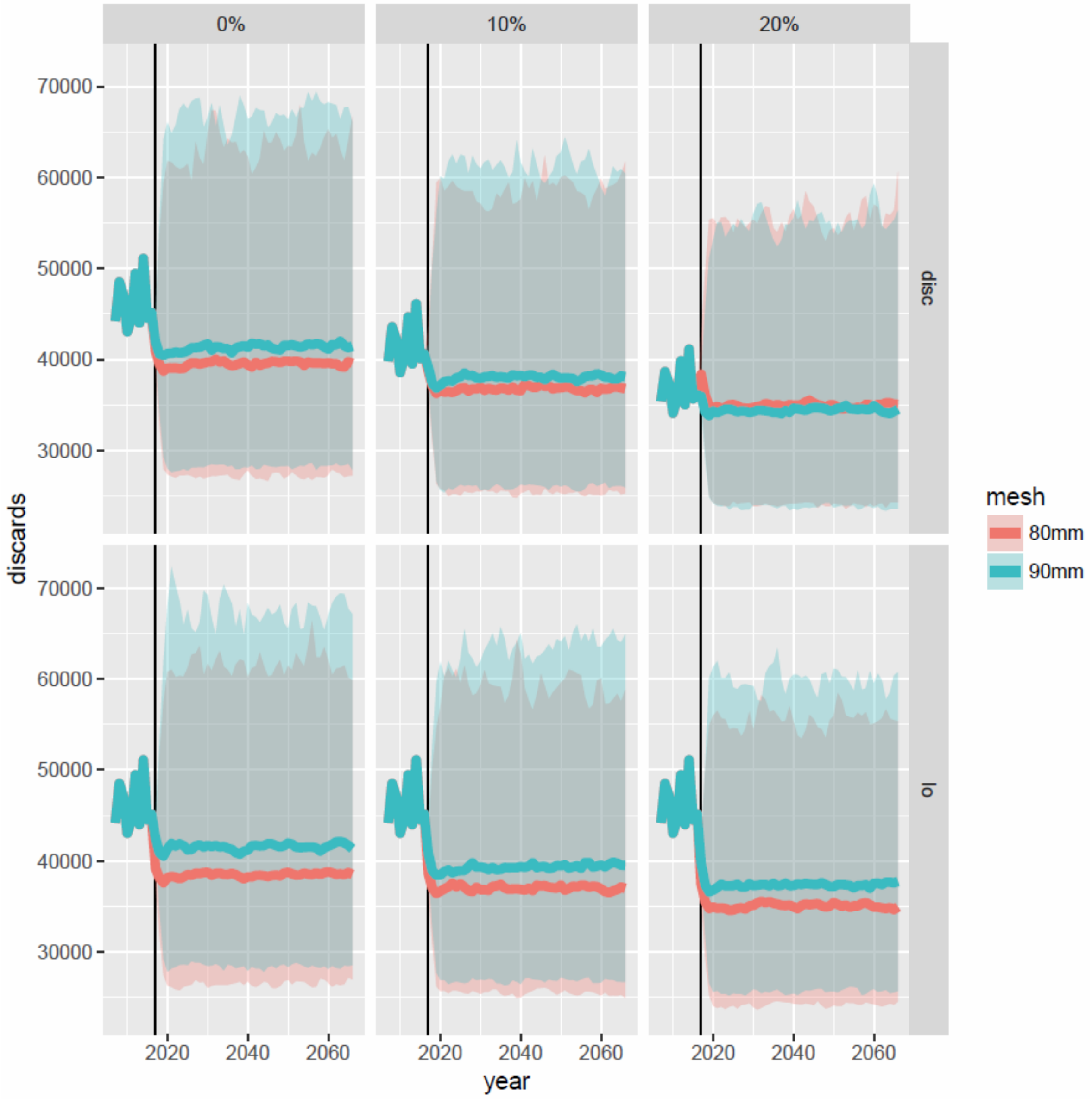
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Cod-end selectivity for sole (Solea solea) and plaice (Pleuronectes platessa) in North Sea pulse-trawl fisheries

Best Practices II – WP4 selectivity

Authors: Pieke Molenaar and Chun Chen

Wageningen University &
Research rapport C049/18

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Publication date: 18 July 2018

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IJmuiden, July 2018

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Contents

Summary

Electrified pulse trawls have replaced traditional tickler chain beam trawls in the North Sea fisheries for sole. This study investigates the mesh selection in pulse trawling of conventional cod-ends (80 mm cod-end mesh) used in the current pulse trawl fishery, and the effects of increasing the cod-end mesh size to 90 mm on catches of sole (*Solea solea*) and undersized plaice (*Pleuronectes platessa*). Cod-end selectivity was estimated for 79-80 mm and 87-88 mm cod-ends during two experiments on a commercial pulse trawler using a cover cod-end. The results show that with a mesh size of 79-80 mm the length where 50% of the individuals are retained (L50) for sole is 19 cm with a selection range (SR) of 4.9 cm. Given the observed length distribution of sole on the fishing ground this results in a 10% loss of marketable sole catches in the 24-27 cm length range. Increasing the mesh size in experiment one to 87 mm resulted in a L50 for sole of 22 cm with SR = 4.9 cm and in experiment 2 to a L50 of 26 cm and SR = 4.9 cm was found for 88 mm cod-end, resulting in a loss of marketable sole of 24% and 38% in experiment 1 and 2, respectively. These losses were detected in the 24-33 cm length range. Compared to sole, plaice showed steeper selection curve with a L50 of 14.4 cm (SR 2.5) and 14.1 cm (SR 2.1) for the 79-80 mm cod-ends in experiment 1 and 2, respectively. In the 87 mm cod-ends, this L50 shifted to 15.6 cm (SR 2.5) for experiment 1 and 18.7 cm (SR 2.1) for the second experiment. The ratio of plaice discards per kg marketable sole caught was 0.4 in experiment one for 80 mm cod-ends, and increased to 0.5 in a 87 mm cod-end. In the second experiment this was 2.3 for 79 mm and 2.5 for 87 mm. Increasing the minimum cod-end mesh to 90 mm thus increases the discard quantities of undersized plaice when the sole total allowable catch (TAC) is fully exploited.

1 Introduction

In many countries, capture fisheries only land the marketable part of the catch and discard undersized or unwanted species. Discarding is particularly pronounced in bottom trawl fisheries. Discarding reduces the sustainable yield and may cause unwanted ecological consequences. FAO estimated global discards at 27 million tonnes in 1994 and 7.3 million tonnes in 2005 ((Alverson et al., 1994);(Kelleher, 2005)). In order to reduce discarding the EU has imposed an obligation to land all fish caught in the 2012 reform of the Common Fisheries Policy ((Borges, 2015)). It is expected that a ban on discarding will create an incentive for fishers to avoid fishing grounds with large number of discards or develop discard saving technologies ((Condie et al., 2013a; Condie et al., 2013b)). Discarding may be reduced by improving the selectivity of the gear. Gear modifications may comprise of release and separation panels, net configurations such as large meshed top panels, square mesh and other trawl modifications.

The North Sea flatfish fishery is one of the bottom trawl fisheries characterised by a large catch of undersized fish, due to the use of a 80 mm cod-end mesh required to catch the slender sole ((van Beek, 1998)). The fishery also deploys a number of tickler chains to chase sole out of the seabed which leads to unwanted impacts on the benthic ecosystem ((Jennings and Kaiser, 1998); (Kaiser and Spencer, 1996; Bergman and van Santbrink, 2000)).

In order to reduce the ecosystem impacts of the beam trawl fishery, electrified bottom trawls, pulse trawls, have been introduced in 2009. Since then, the number of Dutch beam trawl vessels that switched to using the pulse trawl has increased to 78 in 2018 (ICES, 2018). It is expected that the pulse stimulus may improve the gear selectivity as the response to the electrical stimulation will be size dependent (Stewart, 1975, 1977; (Soetaert et al., 2015)). Van Marlen et al (2014) reported the results of a comparative trawling trial with two pulse trawlers and one traditional beam trawler carried out shortly after the introduction of the innovative gear. The results showed that the catch efficiency of the pulse trawl was not statistically different from the traditional gear for sole. For the other species such as plaice and dab, however, the pulse trawl caught significantly less per area swept. In addition, the pulse trawl caught fewer undersized plaice and sole. A comparative trawling trial in 2015 suggested that the pulse trawl caught significantly more sole (kg/ha), both market-sized (43%) and undersized (61%), than the traditional tickler chain beam trawl. Plaice catches were equal. Compared with the experiment in 2011, when pulse fishing was just introduced, sole catch efficiency increased (van der Reijden et al., in prep). Both comparative studies showed a reduction in the catch of benthic invertebrates of around 50%, in particular of infaunal species ((van Marlen et al., 2014); van der Reijden et al., submitted).

The differences in catch efficiencies estimated in the comparative trawling trials are the combined result of proportion of the fish in the trawl path that enter the net (available-selection sensu Millar and Fryer, 1999) and the proportion that is retained in the cod-end (contact-selection sensu Millar and Fryer, 1999). In the traditional gear, the tickler chains running at fixed distances in front of the ground-rope, prevent flatfish to escape underneath the ground-rope by digging into the sediment ((Creutzberg et al., 1987)). In the pulse trawl, the electrical stimulus invoke a cramp response, which disables the fish to respond to the gear. Once the fish is in the net and outside the electrical field, it recovers and return to its normal behaviour ((van Stralen, 2005); (de Haan et al., 2016)).

This study investigates the cod-end mesh selection of the trawl nets (80 mm cod-end mesh) used in the current pulse trawl fishery for flatfish in the North Sea, and study the effect of increasing the minimum cod-end mesh size to 90 mm on the catch of undersized sole (*Solea Solea*) and plaice (*Pleuronectes platessa*), and on the loss of marketable sized sole.

2 Research question

This study addresses the effects of increasing the minimum cod-end mesh size in the Pulse trawl fishery for sole from the current 80 mm to 90 mm cod-ends. The main interests are the effects on the catch of marketable sole and unwanted catches of undersized plaice. For those species a minimum landing size (MLS) of 24 cm for sole and 27 cm for plaice is implemented. The selective performance is compared in terms of weights, length frequency for marketable and undersized catches, and selection curves for both species. The numbers and weight of fish caught are dependent on abundance on the trawled area and its size composition. This is less the case for the selective performance of the gear, in particular the cod-end selectivity is dependent on mesh opening and its specifics and the morphology of the target species.

2.1 Experimental design

During two 4.5-day experimental trips, parallel hauls with covered cod-ends were conducted on board of a commercial pulse trawler on the commercial fishing grounds in the southern North Sea. The trawler deployed two pulswing trouser trawls with two cod-ends for each trawl. Except for the cod-end covers this rigging is similar to the commercial practice. In the experiment, new experimental cod-ends were used: two 80 mm cod-ends on starboard side and two 90 mm cod-ends on the portside trawl. To collect all individuals escaping through the meshes of each of the 80 and 90 mm experimental cod-ends (test), the covered cod-end method was used as described by Wileman et al., 1996. With this method a large small mesh cod-end is covering the cod-end to collect all fish that escape through the meshes of the cod-end. To account for potential catch efficiency differences between both trawls, halfway each experiment the portside cod-ends and accompanying cod-end covers were detached from the trawl and switched starboard, this was done the other way around for the starboard cod-ends and covers. For each sampled haul, weights of marketable commercial fishes as well as weights of undersized sole and plaice were recorded. Due to workload, length distribution of undersized plaice and undersized and marketable sole were measured only every second haul.

3 Materials and Methods

3.1 Experimental timing and locations

The cod-end selectivity experiments were conducted from June 12-16 (week 24) and August 14-18 (week 33) 2017 on board a Dutch commercial pulse trawler in the Southern North Sea (ICES area IV) on regular fishing grounds of pulse trawlers characterized by sandy substrate and muddy banks (Figure 1). Fishing depth ranges between 17-42m during the first experiment and ranges between 20m to 32m during the second experiment. The vessels specifics can be found in Table 1.

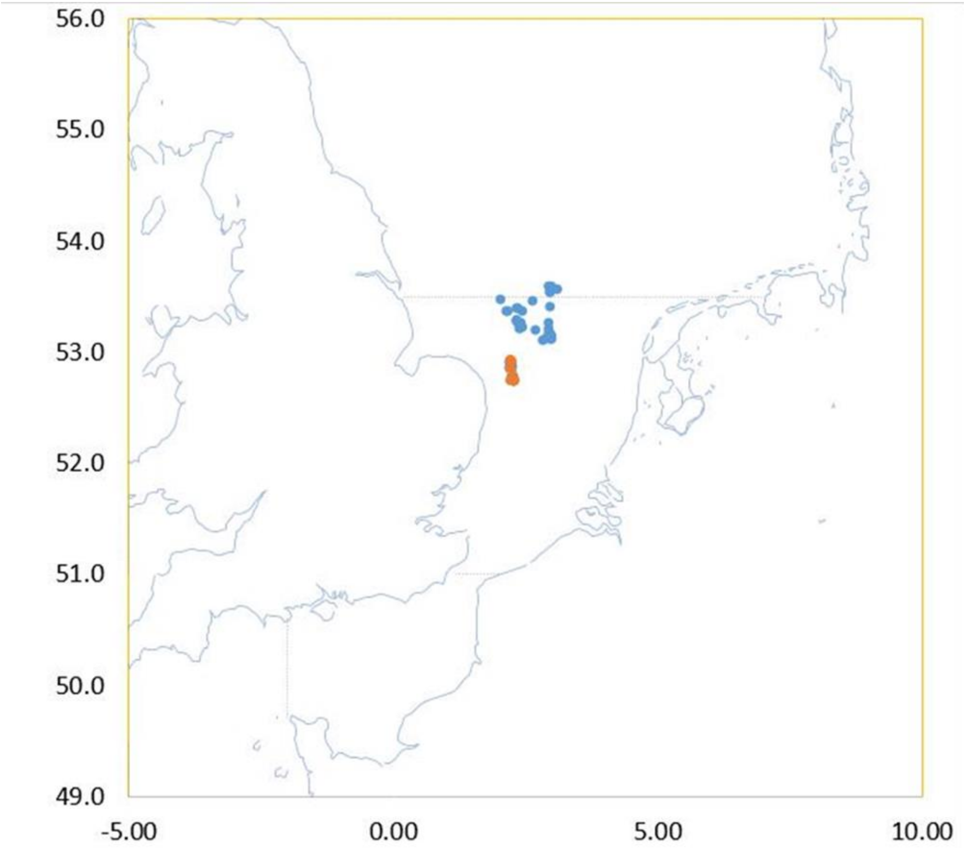

Figure 1. Sampled locations in the Southern North Sea for experiment 1 (orange) and experiment 2 (blue).

3.2 Gear

The commercial pulse trawls (pulswing) were used. Each pulse beam trawl consists of a 12m wide wing type beam (HFK) with 28 electrodes and a trouser trawl with two cod-ends. This type of trawl is representative for six vessels of the Dutch pulse trawlers. Commercial towing speed (4.5 knots) and haul duration (120 minutes) was applied for all hauls. Trawl specifications including electrode design, electrics pulse characteristics, ground rope and net material can be found in Table 1.

For the experiments four new 6.8 meter long cod-ends were constructed with a stretched cod-end mesh size of 80 mm and 90 mm. Cod-end material, number of meshes and twine thickness is presented in Table 1. For the second experiment, the same cod-ends and covers were used except for the two 90 mm cod-ends. Two new 90 mm cod-ends were constructed according the same dimensions (Table 1).

The cod-end cover length was limited to 1.5 times the cod-end length, due to the vessels limited operational lifting height capacity. Longer cover designs have handing difficulties on board of this type of beam trawler. All four experimental cod-ends were individually equipped by a single twine cod-end cover with 40 mm diamond (T0) mesh size (Table 1). In the covers upper panel an 2m opening was constructed to enable catch handling of the cod-ends. Before starting a new haul this opening was sewed with an rope. To protect the covers bottom panel from damage related to bottom contact it was protected over its full length by piece of net equipped with dolly ropes.

Each cover was equipped with three rubber 'fishermen's' kites (Figure 4) and three egg shaped floats (buoyancy: 2.5 kg) to ensure sufficient opening between cod-end and cover and minimize the risk of cod-end masking. Kites were constructed from 10 mm thick rubber mats (50 x 45 cm) and were connected to the trawl with two 20 cm ropes in the rear aft and 40 cm ropes in the front aft. To ensure an upright position in the water an additional float tied on top of the front aft. Prior to the trails the effectivity of the kites and floats were visually inspected during two short hauls with GoPro camera's

Table 1. Specifics of vessel, gear and cod-ends used in the selectivity trails

Specifics		
Vessel	Engine power (Kw)	1119
	Tonnage (GT)	424
	Length (m)	40
	Gear	Sumwing pulse
	Number of gears	2
	Fishing speed (kn)	4.5
Wing	Width (m)	12
	Length (m)	1.1
False ground rope	Type	Rubber discs
	Length (m)	12
	Diameter (mm)	250
Electrodes	Number	28
	Type	HFK
	Total length including isolated first section (m)	7.6
	Distance between electrodes (cm)	41.5
	Length electrodes on seabed (pulse field) (m)	4.8
Conductor elements	Number	10
	Diameter (mm)	30
	Length (mm)	125
	Distance between elements (mm)	22
Pulse	Power per trawl (kW)	7.2
	Width (μs)	260
	Frequency (Hz)	80
	Peak voltage over electrode (V)	60V
	Maximum exposure time to pulse field (s)	2.08
Trawl	Type	Trouser pulse trawl
	Number of cod-ends per trawl	2
	Total length (m)	40
	Twine cod-end	PE double knotted twine
	Twine thickness (mm)	4

Specifics		
Cod-end (80 mm)	Length (# mesh)	70
	Round (# mesh)	88
Cod-end (90 mm)	Length (# mesh)	64
	Round (# mesh)	80
Cover cod-end (40 mm)	Length (# mesh)	200
	Round (# mesh)	253
	Twine cover cod-end	PE single twine
	Twine thickness (mm)	3
	Number of kites	3
	Number of floats	3

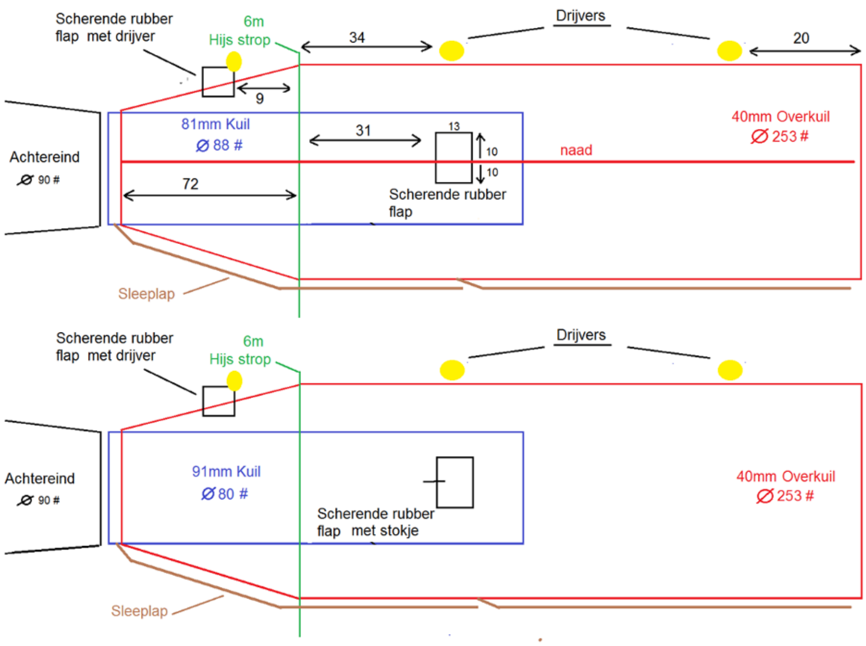

Figure 2. Schematic drawing of the cod-ends and covers including modifications (kites, floats) to prevent the cover masking the cod-ends meshes. Cod-end (blue) and cod-end cover (red) designs with floats (yellow) and kites (black squares), protection netting with dolly ropes (brown) and lifting rope (green).

Figure 3. Left image shows the double cod-end of the port side trouser trawl with cod-end covers (green) and kites (black/yellow). Right image shows the Pulswing beam with electrodes.

Figure 4. Ground rope the trawl (left) and a kite attached to the cover cod-end (right)

3.3 Sampling procedure

The first experiment 21 hauls were sampled for weight and of those 12 were sampled for length. The second experiment 25 hauls were sampled for weight and 14 for length (Table 2).
For each haul trawling position, duration, speed, depth were the trawl was deployed and sea state were recorded by the skipper on a trawl list. After hauling the trawls, the starboard and portside covered cod-ends were emptied in separate hoppers, the two 80 mm cover cod-ends were emptied in one hopper, where the both 90 mm cod-ends were emptied in the second hopper. After processing the catch from the covers the catch from the test cod-ends (80 and 90 mm) were processed separately. The catch was processed on a conveyor belt, all marketable fish and every individual sole and plaice were collected from the catch and stored in baskets. Catches of cod-end and cover were marked with a colour code to avoid confusion. Sole was sorted in marketable and undersized individuals prior to weighing the fractions. For all species, catch weights of marketable fish were collected from both test (80 mm, 90 mm) and cover (40 mm) cod-ends. Catch weight per fraction and species was measured on a sea state compensated Marelec scale. For every second sampled haul length distribution (cm-below) was determined for all sole (undersized and marketable sized) and undersized plaice. For each fraction, at least 300 fish were measured if available, in case of larger catch fractions a subsample was measured. During the second experiment (week 33) no subsampling was applied and all sole were measured for the length sampled hauls. The number of fish measured for each experiment are given in Table 2.

Table 2. Sampled hauls and hauls were sole and undersized plaice were measured.

Experiment	Hauls sampled (Weight)	Hauls sampled (length)	# Sole length measured	# Plaice length measured (<27 cm)
1	21	12	13.842	5687
2	25	14	6013	10.407

Cod end mesh size was measured with an OMEGA Gauge (Fonteyne et al. 2007) at 125 N (cod-end mesh) and 50 N (cover) for 20 meshes in the longitudinal direction of the net of all cod-ends and covers. For both trails, the mesh size was measured after haul 4 and after the last haul, the average mesh size is each cod-end and cover is given in Table 3.

Table 3. Average mesh size in mm (SD) for each cod-end and cover for experiment 1 and 2. For each cod-end, 20 consecutive meshes were measured with an OMEGA gouge in after the 4th haul and at the end of the trail.

	Cod-end 1	Cover 1	Cod-end 2	Cover 2	Cod-end 3	Cover 3	Cod-end 4	Cover 4
Experiment1	**79.7**(2.4)	40.7(1.2)	**79.6**(1.6)	41.1(1.7)	**87.3**(1.7)	40.5(0.9)	**87.2**(2.0)	40.5(1.1)
Experiment2	**78.8**(1.8)	39.6(1.4)	**78.7**(2.0)	39.5(1.0)	**87.4**(2.1)	39.2(1.7)	**88.1**(2.1)	39.3(1.6)

3.4 Data analysis

3.4.1 selectivity ogive

Collected data was digitized in Billie turf 8.0, checked for inconsistencies with SAS and analysed in R (R Development Core Team, 2004) and the R packages "lme4" (Douglas Bates etc., 2015). A glmm with binomial distribution of the response variable and a logit link function was applied. The response variables were expressed as the presence/absence in the cod-end. Fish length, mesh size and experiment ID (with their interactions) were included as fixed effects, while the haul ID was included as a random intercept. Model coefficients were estimated through maximum likelihood. The best fitted model was selected using minimum AIC.

4 Results

As presented in Table 3 measured mesh opening slightly deviated from 80 mm and 90 mm during both experiments. As mesh opening is important for the results, the average measured mesh opening for each experiment is used for describing and interpreting the results.

4.1 Catch composition

Catch weights of marketable turbot, brill, dab and red gurnard are presented in annex 8. forty-six hauls were included in the analysis for plaice and sole for marketable catches and discards. For experiment 1, 21 hauls were weight sampled including 12 hauls with length measurements. Experiment 2 included 25 hauls of which 14 with length measurements. Sole and plaice catch composition will be presented in average weights per haul for both landings and discards.

4.1.1 Sole catches per experiment in weight

Overall marketable sole catches (cod-end + cover) per trawl (cod-end plus cover) did not significantly differ between starboard and port-side nets for experiment 1 and 2. In experiment 1, on average 63 kg of marketable sole was caught per haul per trawl. Of the total marketable sole catch entering the trawl in the experiment, 89% was retained in the 80 mm cod-end while 76% was retained in the 87 mm cod-end. In experiment 2 the overall sole catches were lower, with a total of 29 kg for the 79 mm cod-end and cover and 32 kg for the 88 mm trawl. Of those catches 87% was retained in 79 mm and 62% in the 88 mm cod-end. Undersized sole catches were for both trawls on average 24 kg per haul for experiment 1, 55% was retained in the 80 mm where 41% was retained in the 87 mm. For experiment 2 this was 8.4 kg for the 79 mm cod-end and 9.8 for the 88 mm, for those undersized fish 51% and 29% was retained (Table 4 & Figure 6).

Table 4. Mean (SE) catch weight (kg) of sole landings (>24 cm) and undersized discards per haul for tip 1 and 2. Weights are given for cod-end and cover together, for the cod-end and cover separately and the weight percentage of the total weight that retained in the cod-end.

Experiment	Mesh size (mm)	Size Class	Total (Cod-end + cover)		Cod-end		Cover		Retained in cod-end (%)	
			Mean	SE	Mean	SE	Mean	SE	Mean	SE
1	80	landings	**62.8**	5.9	**56.4**	5.5	**6.4**	0.8	**89.6**	1.3
	80	discards	**24.5**	1.6	**13.4**	0.9	**11.1**	1.0	**55.0**	2.6
	87	landings	**63.2**	4.5	**48.9**	4.1	**14.3**	1.1	**76.4**	1.7
	87	discards	**24.0**	1.7	**9.6**	0.6	**14.4**	1.4	**41.4**	2.4
2	79	landings	**29.2**	1.9	**25.6**	1.8	**3.6**	0.4	**87.1**	1.3
	79	discards	**8.4**	1.1	**4.4**	0.7	**4.0**	0.5	**51.3**	2.3
	88	landings	**31.6**	1.8	**19.7**	1.3	**11.9**	0.8	**61.9**	1.6
	88	discards	**9.8**	1.0	**2.9**	0.4	**6.9**	0.7	**29.1**	1.9

tripID	SSE_CATEGORY	out_group	p_value	est_diff
trip1	d	cover	0.0	3.3
trip1	l	cover	0.0	7.8
trip1	d	test	0.0	-3.9
trip1	l	test	0.0	-7.5
trip2	d	cover	0.0	2.9
trip2	l	cover	0.0	8.4
trip2	d	test	0.0	-1.6
trip2	l	test	0.0	-5.9

Figure 5. Paired t-test result comparing average weight per haul in 87-88 mm vs. 79-80 mm mesh sizes, for landing and discards respectively. The results shown that the average landing as well as discards weight of sole significantly ($p<0.05$) differs between 87-88 mm and 79-80 mm mesh openings in both experiments.

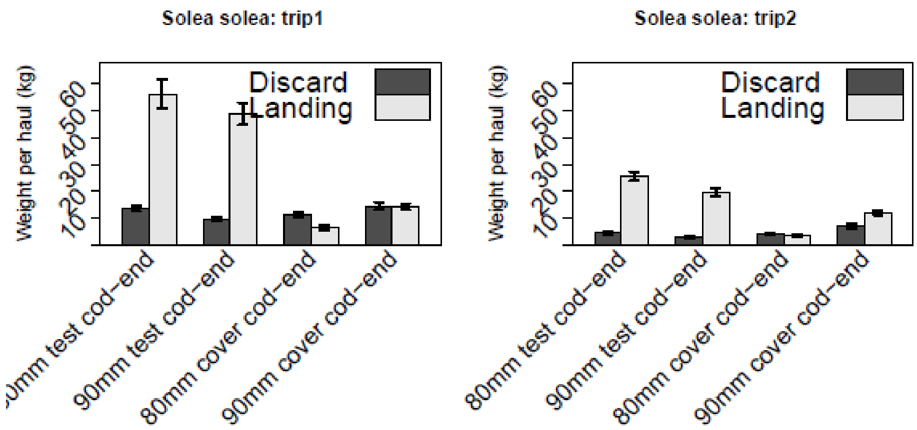

Figure 6. Average catch weights (kg) per haul for sole landings (>24 cm) and discards (<24 cm) in the 80 mm and 87 mm cod-ends and cover cod-ends for experiment 1 (left) and 79 mm and 88 mm cod-ends and cover cod-ends for experiment 2 (right).

4.1.2 Plaice catches per experiment in weight

For both experiments all marketable plaice (>27 cm) was found in the 79-80 and 87-88 mm cod-ends (Table 5). Overall undersized plaice catches (cod-end + cover) per trawl were different for experiment 1 and 2, on average 24 and 28 kg of undersized plaice was caught in trawls during experiment 1, of those fish 91% was retained in the 80 mm cod-end and 87% in the 87 mm cod-end. In experiment 2 the overall plaice catches were higher. For the undersized plaice a total of 58kg for the 79 mm cod-end and cover and 70 kg for the 88 mm cod-end. Of those catches 87% was retained in 79 mm and 62% in the 88 mm cod-end (Table 5 & Figure 8)

Table 5. Mean (SE) of the catch weight (kg) of marketable plaice (>27 cm) and undersized discards per haul for tip 1 and 2. Weights are given for cod-end and cover together, for the cod-end and cover separately and the weight percentage of the total weight retained in the cod-end.

Experiment	Mesh size (mm)	Class	Total (Cod-end + cover)		Cod-end		Cover		Retained in cod-end (%)	
			Mean	SE	Mean	SE	Mean	SE	Mean	SE
1	80	landings	**24.2**	2.9	**24.2**	2.9	**0**	0	**100**	0
	80	discards	**24.4**	3.2	**22.0**	3.0	**2.4**	0.6	**90.6**	2.2
	87	landings	**24.0**	3.2	**24.0**	3.2	**0**	0	**100**	0
	87	discards	**28.0**	4.5	**22.8**	3.2	**5.2**	2.1	**86.6**	2.5
2	79	landings	**56.5**	8.9	**56.5**	8.9	**0**	0	**100**	0
	79	discards	**58.0**	8.5	**51.9**	8.2	**6.1**	1.0	**86.6**	2.3
	88	landings	**59.4**	8.5	**59.4**	8.5	**0**	0	**100**	0

88	discards	**70.0**	8.8	**46.5**	7.2	**23.5**	3.2	**61.5**	3.3

tripID	SSE_CATEGORY	out_group	p_value	est_diff
trip1	d	cover	0.2	2.8
trip1	d	test	0.6	0.8
trip2	d	cover	0.0	17.4
trip2	d	test	0.0	-5.5
trip1	l	test	0.9	-0.2
trip1	l	cover		0.0
trip2	l	test	0.6	2.9
trip2	l	cover		0.0

Figure 7. Paired t-test result comparing average weight per haul in 87-88 mm vs. 79-80 mm mesh sizes, for landing and discards respectively. The results shown that the average discards weight of plaice significant ($p<0.05$) differs between 87-88 mm and 79-80 mm mesh size opening only in experiment 2.

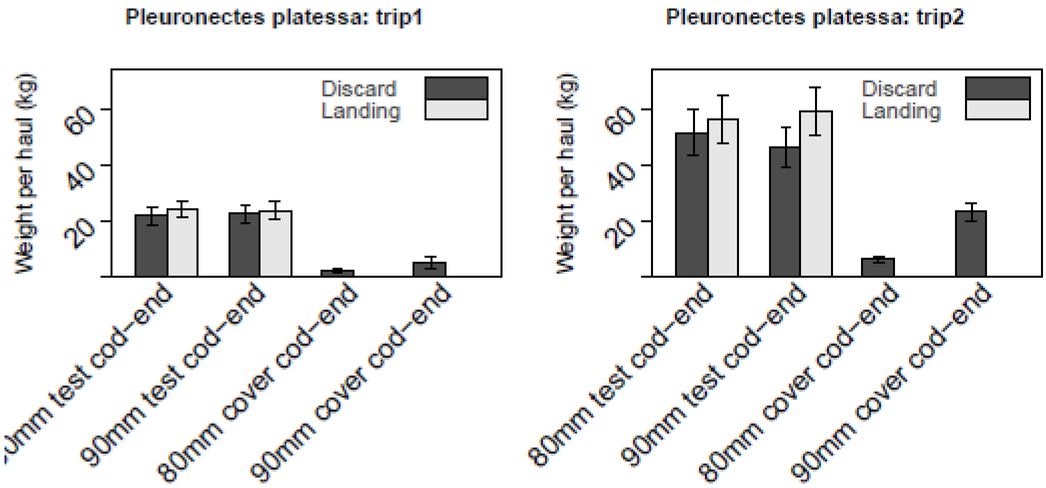

Figure 8 Average catch weights (kg) per haul for marketable- and plaice discards (<27 cm) in the 87-88 mm and 79-80 mm cod-ends and cover cod-ends for experiment 1 (left) and experiment 2 (right).

4.2 Length frequency distribution

Length of each individual fish in both cod-end and cover was measured for every second sampled haul, this enables to express the population length frequency (LF) distribution for each haul (annex 6 & 7). Sampled hauls show a large variation in the LF distribution of the population for both species, therefore the population LF is given for all individuals of a certain species per experiment.

4.2.1 Sole population distribution

The LF distribution for all catch fractions (test cod-ends and covers) and the total available population for each trawl is given in Figure 9. The total available populations (black line) were not different for both trawls (dashed 87-88 mm and solid 79-80 mm) during experiment 1, this is also visible for experiment 2 for sole larger than 23 cm and smaller than 19 cm, in between the numbers in the 88 mm trawl were higher. In experiment 1 only sole smaller than 27 cm escapes from the 80 mm cod-end, this increases towards 29 cm for the 87 mm cod-end. Similar pattern is visible for the 79 mm cod-end in experiment 2, although this is not present for the 88 mm cod-end. In this experiment sole up to 33 cm managed to escape through the 88 mm mesh openings.

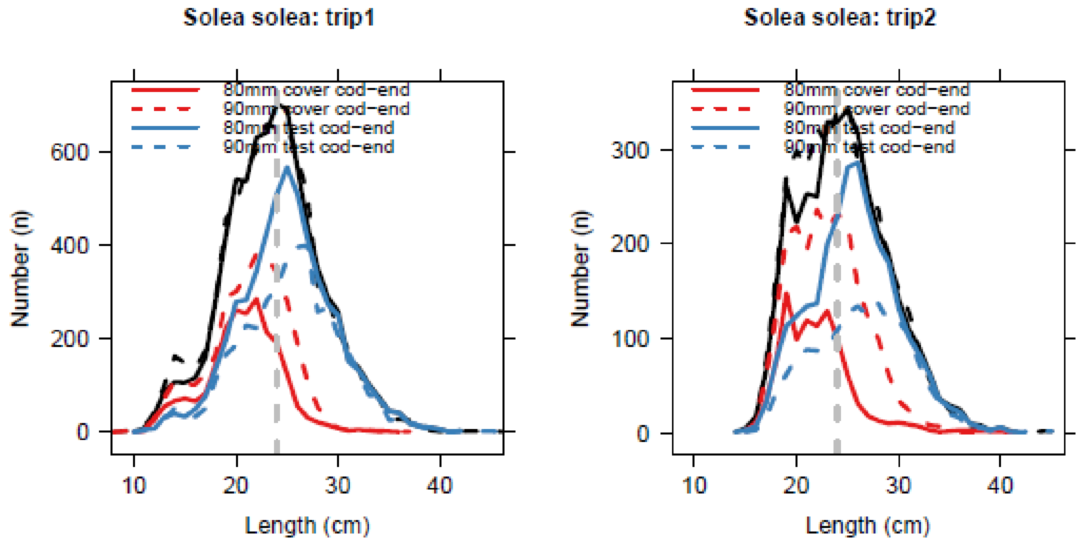

Figure 9. Sole length frequency per cod-end and covers caught for experiment 1 (left) and experiment 2 (right). The black lines indicates the population distribution of the cod-end (blue) and cover (red) together for 79-80 mm (solid line) and 87-88 mm (dashed line). The grey dashed line in the graph presents the minimum landing size (24 cm).

4.2.2 Plaice discards population distribution

The LF distribution for all undersized catch fractions (test cod-ends and covers) and the total available undersized population for each trawl is given in Figure 10. The total available populations (black line) were different for both trawls during experiment 1, Differences were mainly found in the 10-17 cm range with higher numbers in the 80 mm cod-end. For experiment 2 the available populations is comparable, with slightly higher numbers for 88 mm cod-end in the in the 19-23 cm range. In experiment 1 plaice smaller than 17 cm escapes from the 80mm cod-end, this increases towards 20 cm for the 87 mm cod-end. For the 79 mm cod-end in experiment 2 a similar pattern is visible, where plaice smaller than 18 cm could escape. For the 88 mm cod-end in experiment 2, plaice smaller than 24 cm managed to escape through mesh openings.

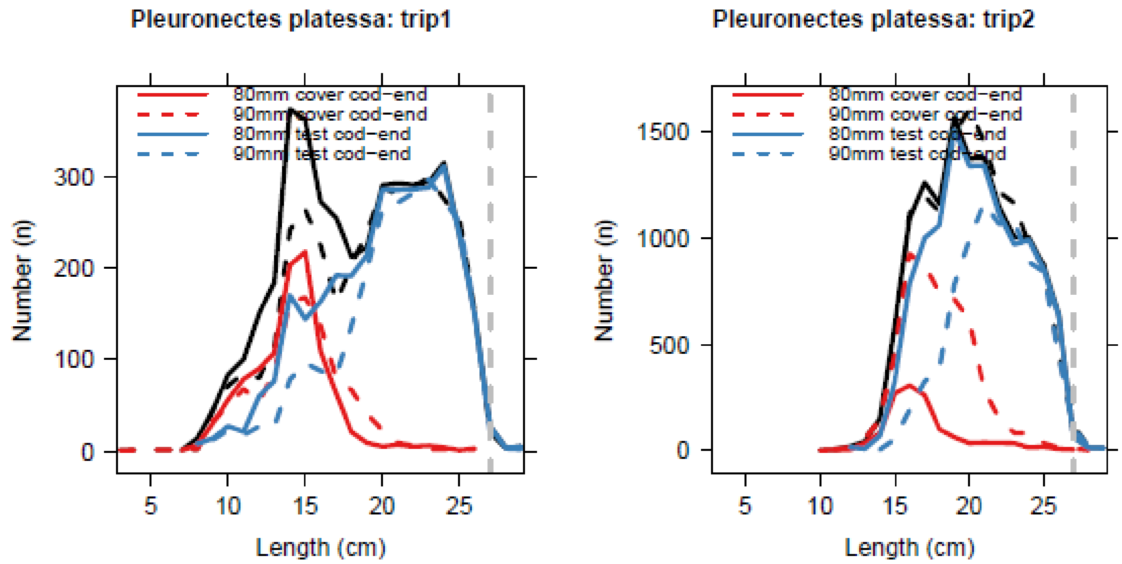

Figure 10. Plaice length frequency per cod-end and covers caught for experiment 1 (left) and experiment 2 (right). The black lines indicates the population distribution of the cod-end and cover together for 79-80 mm (solid line) and 87-88 mm (dashed line). The grey dashed line in the graph presents the minimum landing size (27 cm).

4.3 Selection curves

Cod-end selectivity curves and parameters were estimated for sole and plaice, the probability of retaining an individual of a certain length in the cod-end is expressed by the selectivity curve and range. The selected model with the minimum AIC includes the interaction between experiment and treatment (79-80 mm vs. 87-88 mm), implying that the mesh size effect differs between the two experiments. Different to sole, plaice has a different optimal model. The optimal model with the minimum AIC includes the interaction between experiment and treatment (79-80 mm vs. 87-88 mm), as well as the interaction between experiment and length. This implies that not only the mesh size effect, but the length effect also differs between the two experiments. In experiment 2, the length effect is also getting stronger. Therefore, the estimated selectivity is presented for each experiment separately.

Sole yields a flatter selectivity curve as compared to plaice, with a length at 50% retention (L50) of 18.9 and 19.3 cm for experiment 1 and 2 for the 79-80 mm cod-ends (Table 6 & Figure 11). No significant difference was detected for the 79-80 mm selectivity for both experiments (i.e. the optimal was without experiment interaction). In the 87 mm cod-end a L50 of 22.2 cm was estimated for experiment 1 and 26.1 cm for the 88 mm cod-end in experiment 2. The cod-end selectivity of the 79-80 mm and 87-88 mm was significantly different for both experiments.

Plaice showed steep selection curve with a L50 of 14.4 for the 80 mm and 14.1 cm for the 79 mm cod-ends (Table 6 & Figure 11) with no significant difference between experiments. In the 87 mm cod-ends this L50 shifted to 15.6 for experiment 1 and 18.7 cm for the 88 mm cod-ends in experiment 2. Although the larger undersized plaice (<27 cm) has a significantly higher chance of being retained in the 87-88 mm cod-end, for both mesh sizes a full cod-end retention for plaice is reached before the minimum landing size. Observed probabilities and estimated curves are per experiment and species are presented in annex 6 & 7.

Table 6. Estimated lengths at 50% cod-end retention (L50) and selection range with 95% confidence intervals for sole and plaice for experiment 1 and 2. CI UL & CI LL are Confidence Interval Upper limit and Lower Limit

Species	Experiment	Mesh size (mm)	L50 (95% CI)			Selection range		
			Mean	CI UL	CI LL	Mean	CI UL	CI LL
Sole	1	80	**18.9**	19.8	17.9	4.9	5.1	4.7
		87	**22.2**	23.1	21.3	4.9	5.1	4.7
	2	79	**19.3**	20.2	18.4	4.9	5.1	4.7
		88	**26.1**	27.0	25.2	4.9	5.1	4.7
Plaice	1	80	**14.4**	15.1	13.7	2.4	2.5	2.2
		87	**15.6**	16.3	14.9	2.4	2.5	2.2
	2	79	**14.1**	14.6	13.5	2.0	2.1	1.9
		88	**18.7**	19.2	18.2	2.0	2.1	1.9

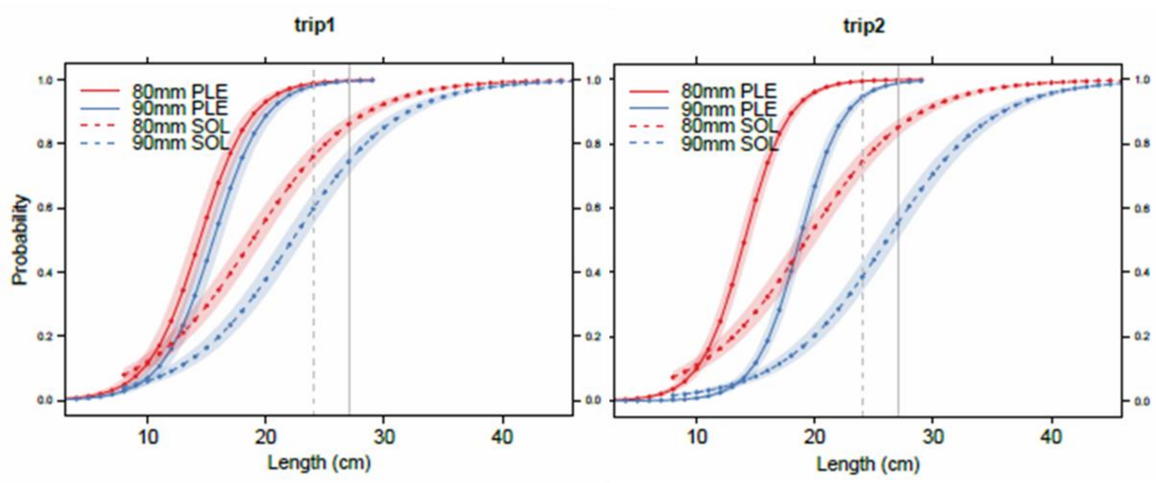

Figure 11. Estimated selectivity of 79-80 and 87-88 mm cod-ends with 95% confidence interval for Sole (SOL) and plaice (PLE) for experiment 1 and 2. The dashed grey line presents the minimum landing sized for sole (24 cm), the solid grey line the minimum landing size for plaice (27 cm).

4.4 Catches of plaice discards per kilo marketable sole

With recording the weight of the sole and plaice caches during both experiments the ratio of weight of undersized plaice per kilogram of marketable sole was calculated to assess the effectivity of reducing plaice bycatch by means of increasing the cod-end mesh size. The results are given in Table 7. During experiment 1 sole catches were good and there were limited catches of undersized plaice, this resulted in 0.4 kg undersized place per kilogram of marketable sole in the catches of the 80 mm cod-end. This ratio increased to 0.5 for the 87 mm cod-end. Sole catches were lower for experiment 2 while substantial amounts of undersized plaice were present. Subsequently the ratio went up to 2.3 kg undersized plaice per kilogram of marketable sole. For 88 mm cod-end this ratio was 2.5 during this experiment.

Table 7. Average weight ratio (SE) for catches of undersized plaice per kg marketable sole (kg/kg) for the 79-80 and 87-88 mm cod-ends for experiment 1 and 2.

Experiment	Mesh size cod-end	Ratio kg plaice discard per kg marketable sole	SE
1	80	0.4	0.1
	87	0.5	0.1
2	79	2.3	0.4
	88	2.5	0.4

4.5 Discussion

This study assesses the effect of increasing the minimum cod-end mesh size in the sole fishery from 80mm towards 90mm, the effects were primarily focussed on marketable sole and undersized plaice. The revenues of vessels in this 80mm pulse trawl fishery primarily rely on valuable sole catches, and a reduction in the catch of this target species will reduce the revenue and the economic profitability and income for the skipper and crew. The weight of the marketable plaice may be equal or higher than the sole, but due to their lower market value their contribution to the revenue is lower. The strong, slim and flexible morphological body characterises of sole result in a relative flat selection curve where even a proportion of the larger marketable fish may escape from the 80 mm cod-ends. Even with a 79 mm cod-ends, as used in the experiments, this flat selection curve with an L50 of 19 cm resulted in a 10-13% loss of the available marketable (>24 cm) sole escaping through the cod-end mesh. Those escapes were mainly found in the 24-27 cm length range. If this length range is abundant on certain fishing grounds the losses will exceed the weight percentages found in this study. For the 90 mm cod-ends, a smaller 87-88 mm mesh size was measured during the experiments. In the first experiment these cod-ends resulted in a L50 of 22 cm with 24% of the marketable sole weight escaping, those escapees were in the 24-29 cm. In the second experiment the cod-end selectivity curve shifted with the L50 of 26 cm well above the minimum landing size, resulting in a weight loss of 38% of the marketable sole weight, with escapees in the 24-33 cm range. The mechanism behind the difference in 90 mm cod-ends selectivity between both experiments is unknown but is likely due to the different cod-end used in the second experiment. This shift was not visible in 80 mm cod-ends for which the same cod-ends have been used.

The morphological characterises of plaice results in both trails in a steep selection curve, with a L50 of 14 cm in the 80 mm cod-ends. In both trials majority of the available undersized plaice population was above 14 cm therefore 87-91% of the undersized plaice weight was retained by the 80 mm cod-ends. Using 87-88 mm cod-ends resulted in a L50 of 16 cm and 87% cod-end retention, from 20 cm length a full cod-end retention was found. For the second trial this was and 17 cm and 62% cod-end retention for undersized plaice, with a full retention from 24 cm. Although a larger cod-end mesh size mitigate undersize plaice bycatch, the accompanied losses of marketable sole are larger. This visible in the relative shift in selection curve with increasing mesh sizes, the sole curve tends to shift faster towards larger lengths than the plaice curve. This effect of this shift difference is also visible in the ratio of undersized plaice weights per kilo marketable sole, this ratio increases where a shift from 79 mm to 87 mm mesh results in larger undersized plaice catches per kilo marketable sole. Assuming the available sole is fully exploited, fishers using 90 mm cod-ends need to deliver a higher fishing effort to catch their quota. Although less undersized plaice are caught per haul, the increased effort to fully exploit the sole total allowable catch (TAC) will result in higher discard quantities for undersized plaice and an increased bottom impact and CO_2 emissions as more area needs to be covered.

In the pulse trawl fishery a 79 mm cod-end is not a legal practice, new cod-ends for this 80 mm fishery are generally 86 mm and after several hauls the mesh shrinks to 81-82. When an average mesh size of 80 mm is approaching, the cod-end is replaced by a new 86 mm cod-end. Considering commercial sole losses 88 mm cod-ends in this trial, 86 mm will have substantial losses of the smaller marketable sole. Due to shrinking mesh twine, with a 90 mm minimum mesh size fishers may have to start with 95 mm cod-ends, this leads to larger reductions in marketable sole catches. Those substantial losses of legal marketable sole may enhance illegal measures to limit the mesh opening in commercial fisheries. Clearly increasing the minimum mesh sized in this fishery does not solve the bycatch problems, trawl innovations separating sole and the other catch may be the way forward to mitigate bycatch in this fishery.

Observed catch differences in this study for marketable turbot and brill are likely the results of natural variation in the abundancy on the fishing grounds. Both species are morphologically not able to escape from the assessed mesh sizes from the cod-end and are frequently caught in low numbers per haul. Therefore, several large individuals in one trawl could result in differences in catch weights per hour (Annex 8).

In commercial fisheries the cod-ends are circumvented with lifting bags with at least twice the mesh size of the cod-end. The lower part of this lifting bag is protected from bottom contact with small netting panels and dolly ropes. In this study the lifting bags were replaced by cod-end covers. The protecting bags with dolly ropes may reduce cod-end selectivity in a commercial fishery, however this never studied in this fishery.

The results of this study could be used to model a different exploitation pattern with a 90 mm fishery aiming for larger sole could. Short and long term economic consequences of a changing exploitation pattern could give more insights it weather is profitable to change to a larger mesh size on the long term.

5 Conclusions and recommendations

With a mesh size of 79 mm the L50 for sole is 19 cm and the selection range is 4.9 cm. With the available sole on the fishing grounds of this pulse trawler this results in a 10% loss of marketable sole (>24 cm) in the catch. Those losses were detected in the 24-27 cm length range.

Increasing the mesh size to 87 mm resulted in a L50 for sole of 22 cm and a selection range of 4.9 cm in experiment 1. In experiment 2 this was 26 cm with a selection range of 4.9 cm for the 88 mm cod-end. With the available sole on the fishing grounds this resulted in a 24% and 38% loss of marketable sole (>24 cm) in the catch in experiment 1 and 2, respectively. Those losses were detected in the in the 24-33 cm length range.

Plaice showed steep selection curve in both experiments with a L50 of 14.4 cm (SR 2.5) for the 80 mm cod-ends and 14.1 cm (SR 2.1) for the 79 mm cod-ends. In the 87 mm cod-ends this L50 shifted to 15.6 cm (SR 2.5) for experiment 1 and 18.7 cm (SR 2.1) for the 88 mm cod-ends in experiment 2.

The ratio of kg plaice discards per kg marketable sole was 0.4 in experiment one for 80 mm cod-ends and increased to 0.5 in a 87 mm cod-end. For the second experiment this was 2.3 for the 79 mm and 2.5 for the 88 mm cod-ends.

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Justification

Report C049/18
Project Number: 4311400005

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Dr. A.D. Rijnsdorp
Senior researcher

Signature: 

Date: 18 July 2018

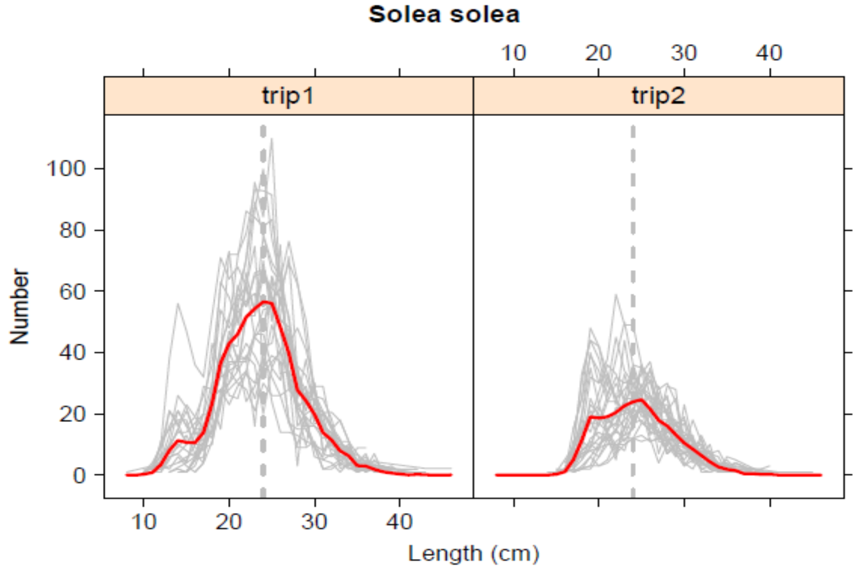
Approved: Dr. ir. T.P. Bult
Director

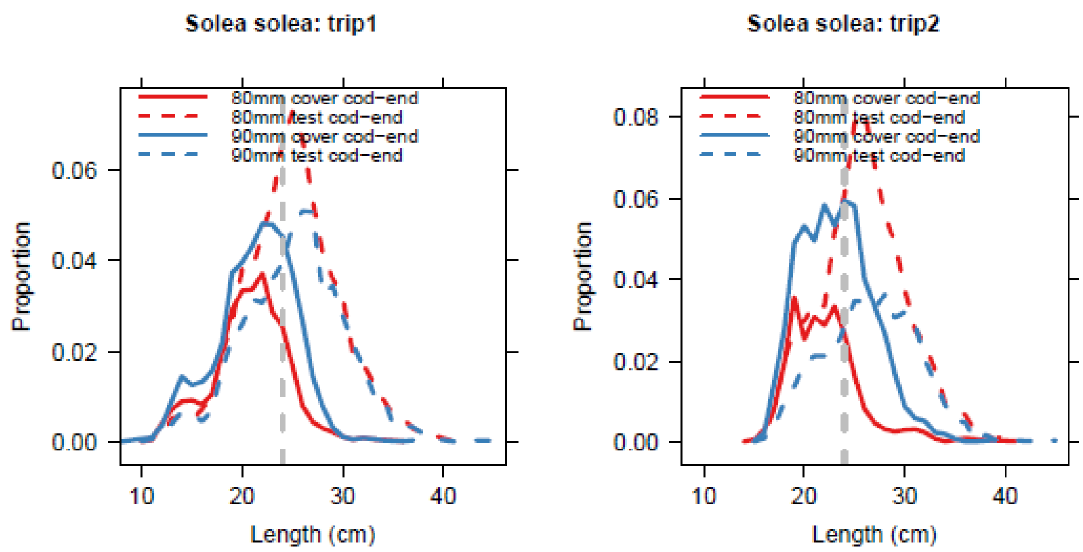
Signature: 

Date: 18 July 2018

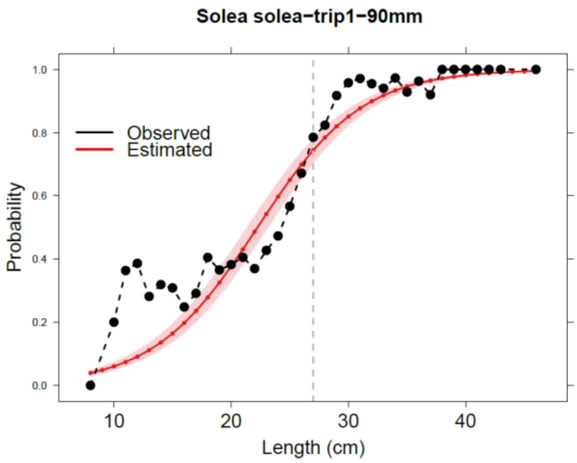
6 Annex sole length distribution and selectivity

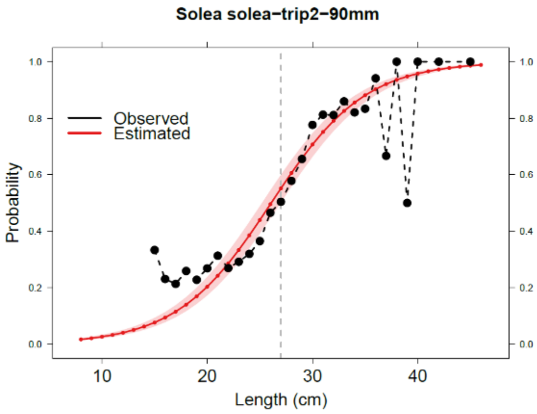
Length frequency per haul, below length frequency als propotion from total observed inividuals of length x.

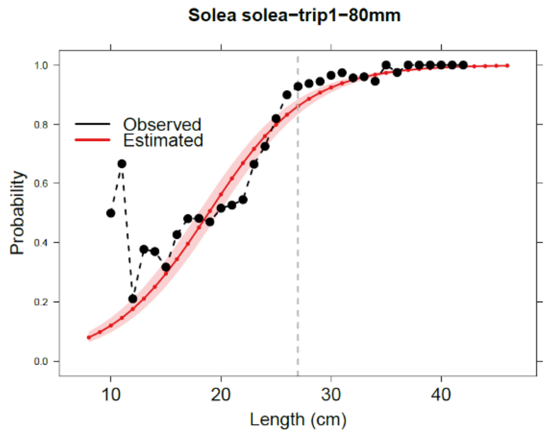


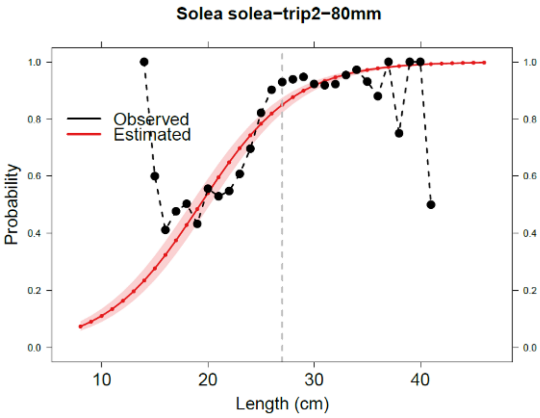


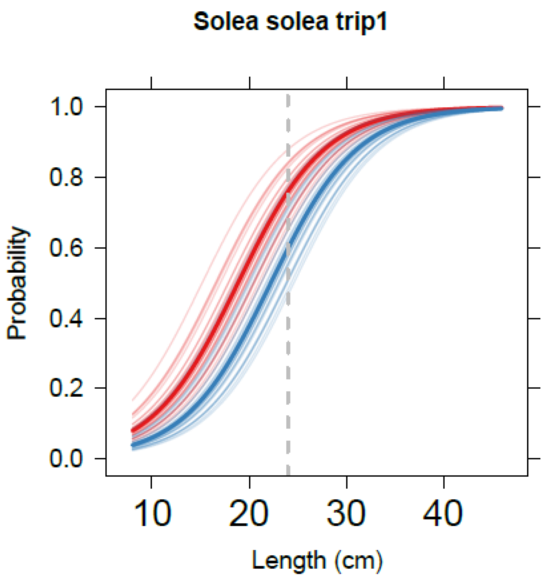
Seletive probabilities and filleted model trough the data poits. Below moddeled selection corves per haul

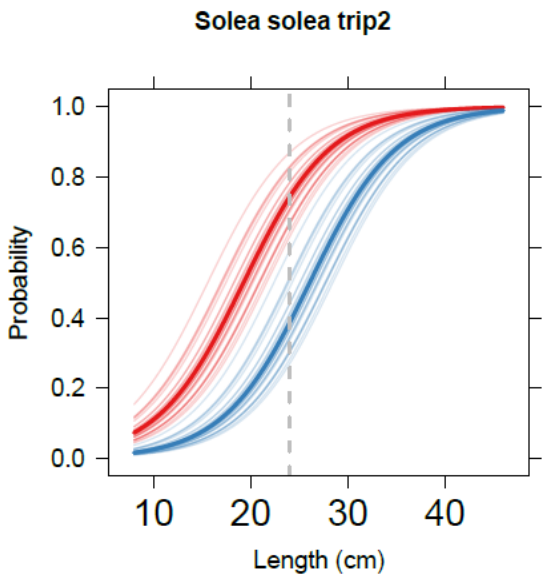












7 Annex plaice length distribution and selectivity

Selective probabilities and fitted model trough the data poits. Below moddeled selection curves per haul

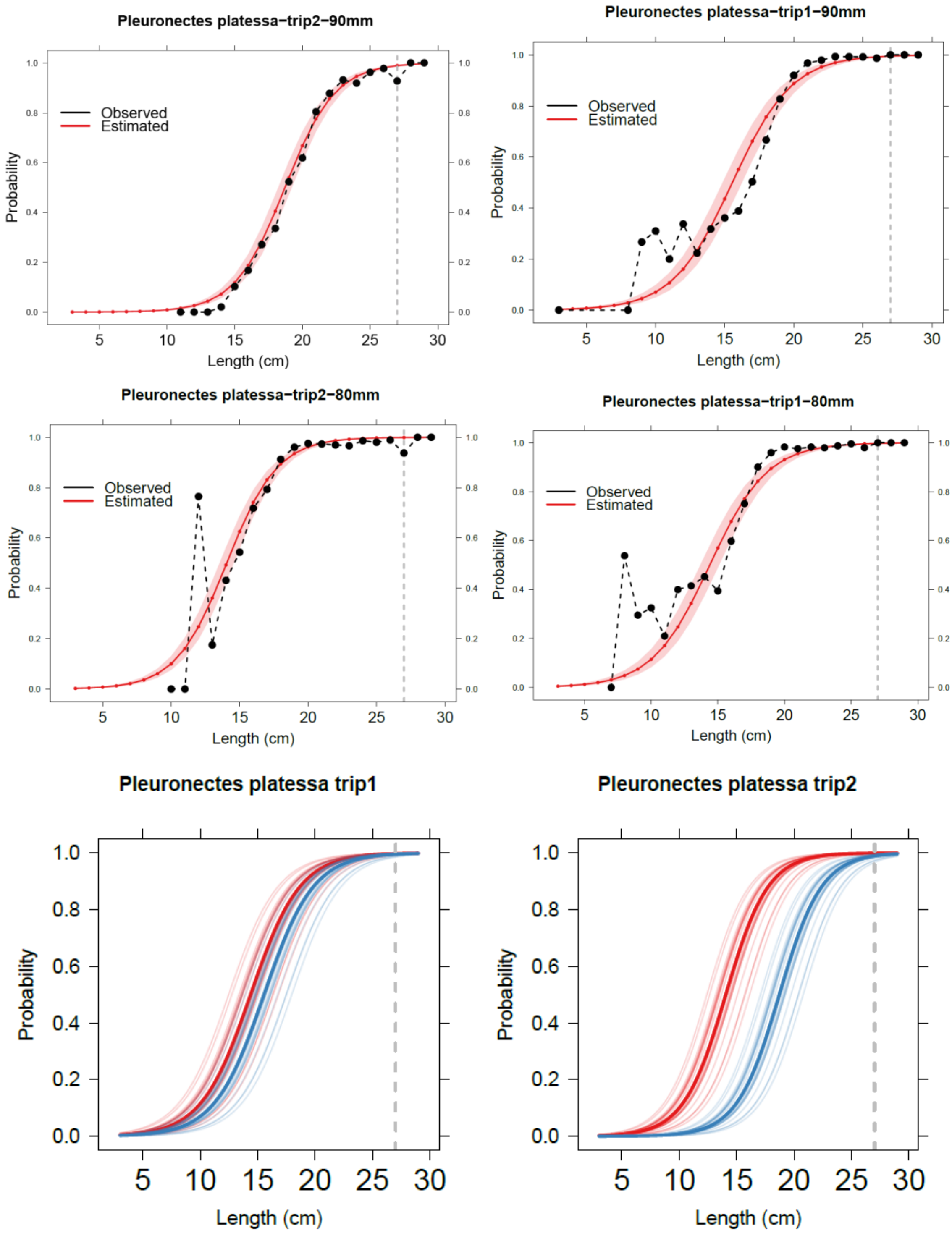
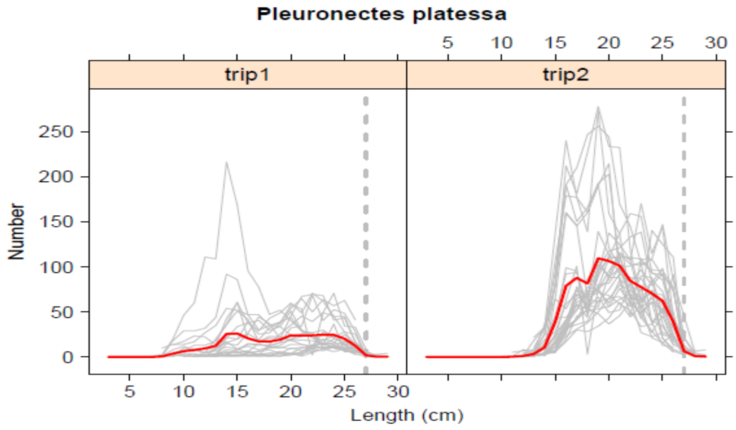
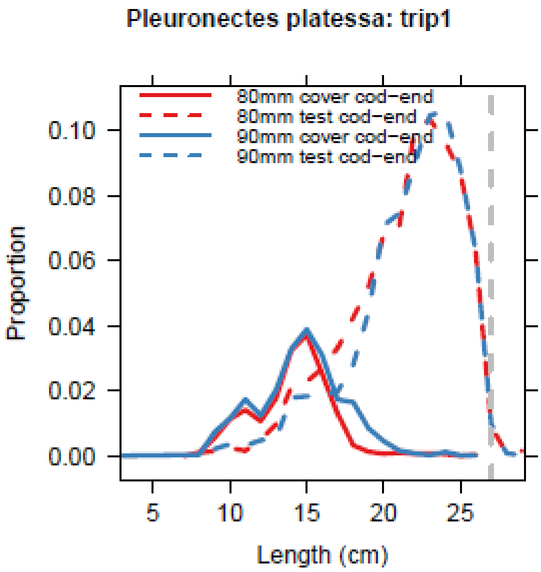
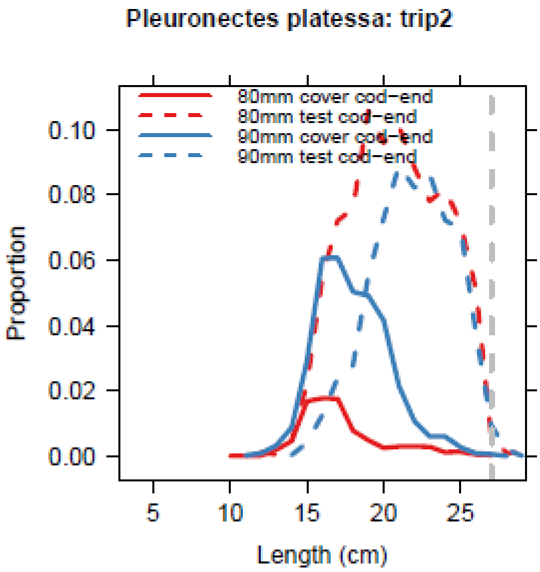


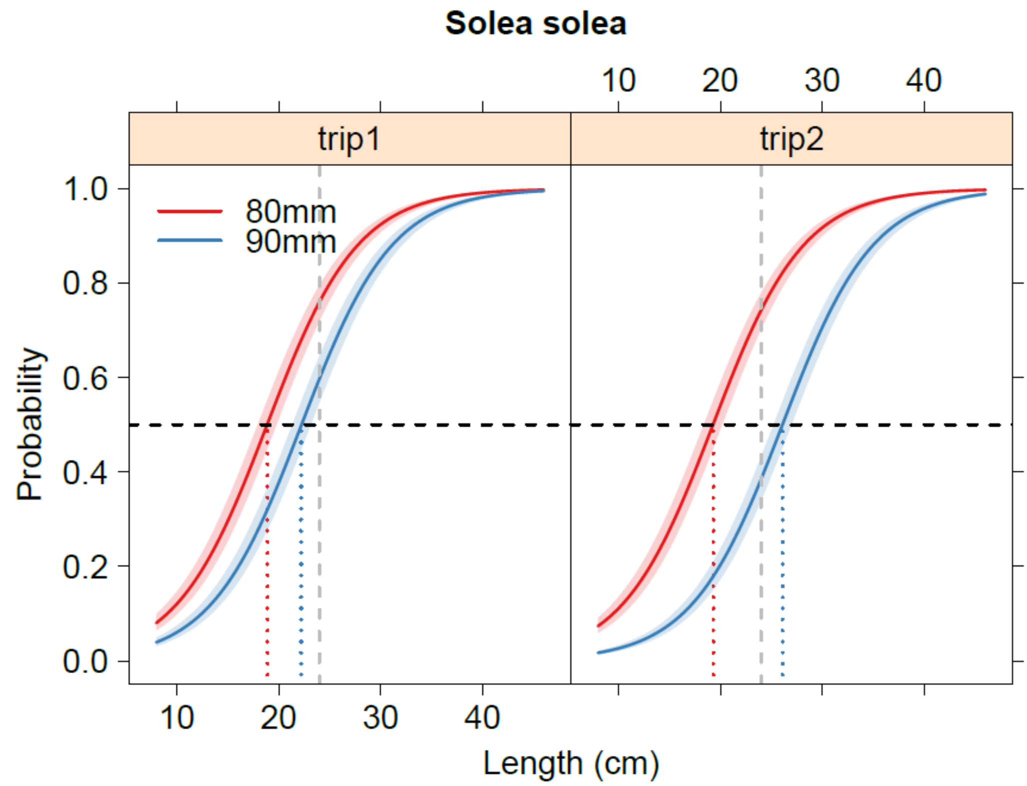
Figure 3: Estimated vs. observed selectivity curve for Solea solea. The observed selectivity is estimated by every 1 cm length bin.

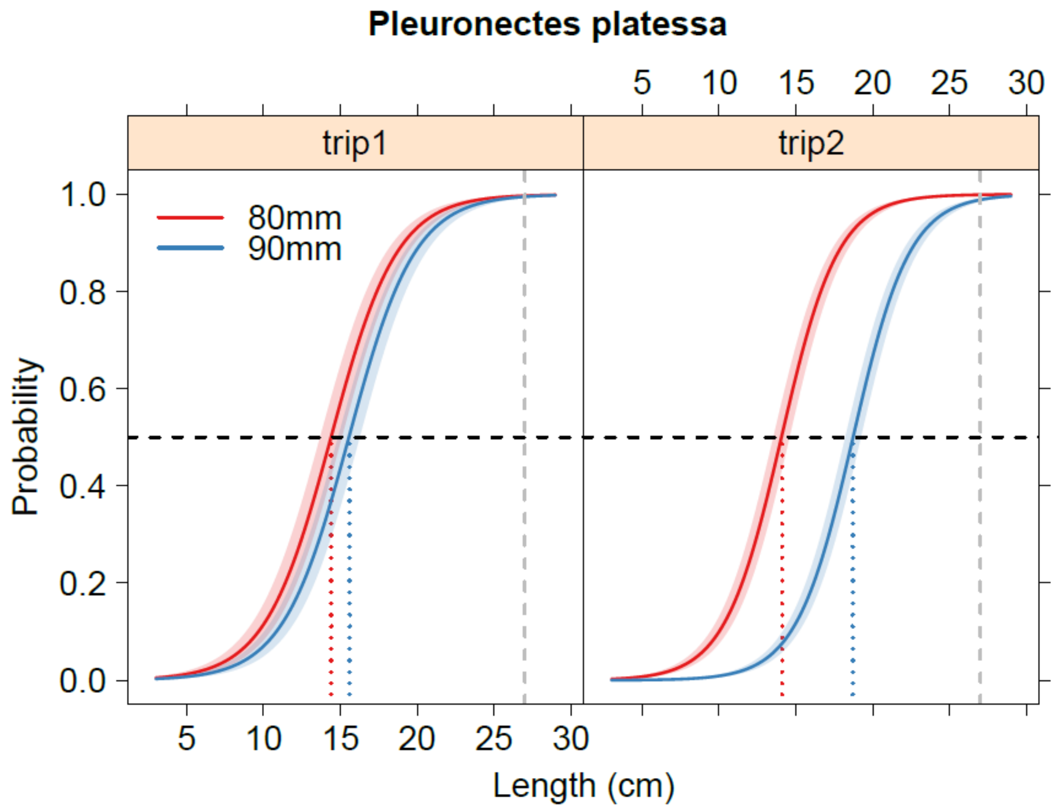
Length frequency per haul, below length frequency als propotion from total observed inividuals of length x



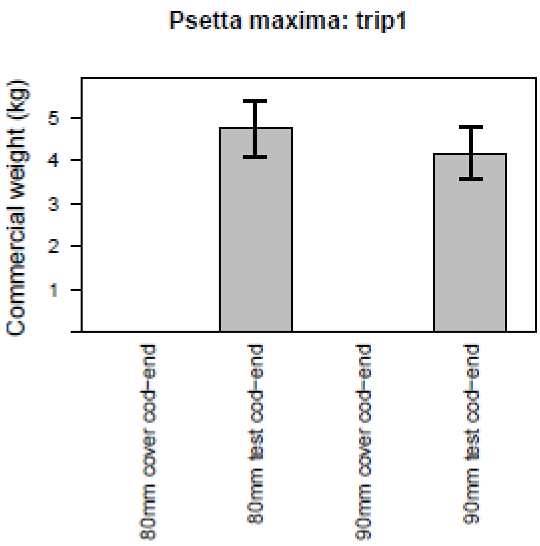


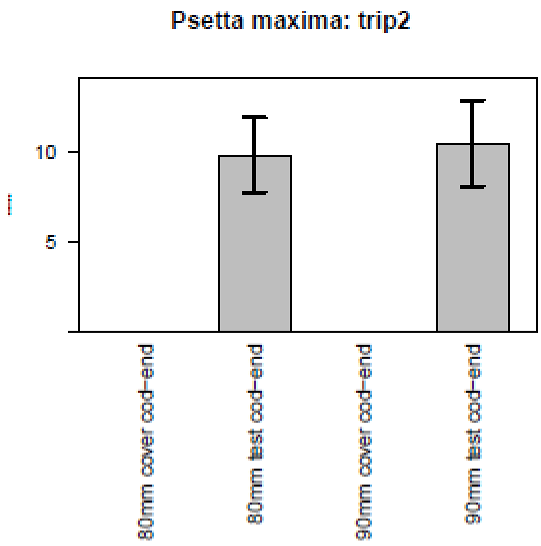


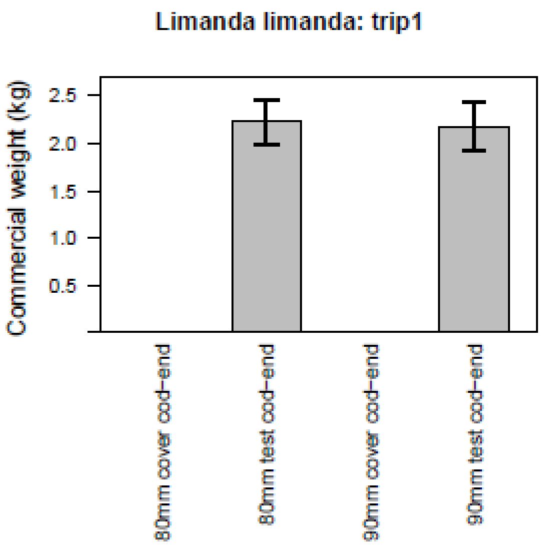

Solea solea
trip1
trip2
80mm
90mm
Probability
1.0
0.8
0.6
0.4
0.2
0.0
10
20
30
40
Length (cm)

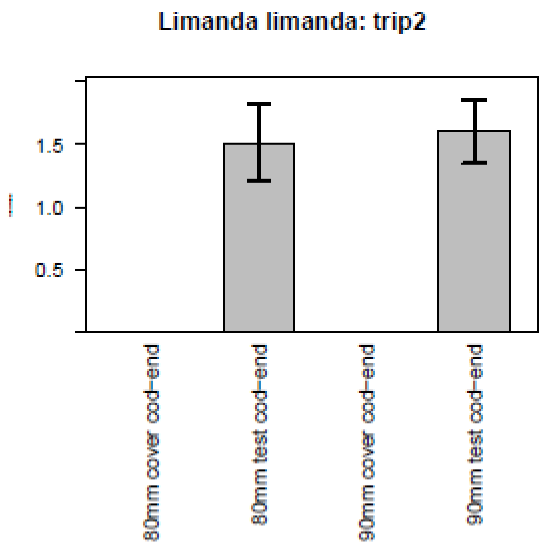

Pleuronectes platessa
trip1
trip2
80mm
90mm
Probability
1.0
0.8
0.6
0.4
0.2
0.0
5
10
15
20
25
30
Length (cm)

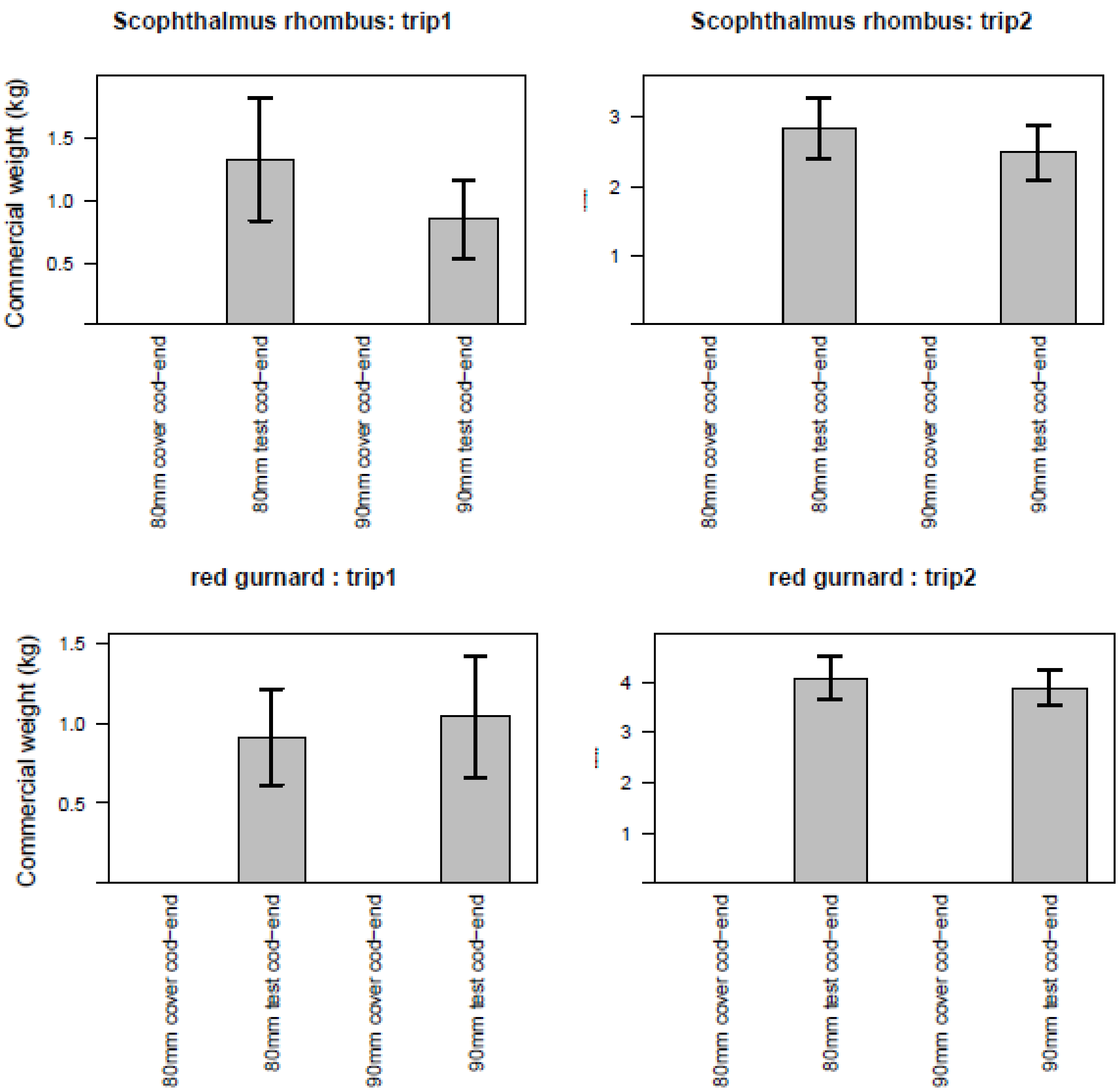
8 Annex average catch weights per haul for other marketable species










Scophthalmus rhombus: trip1
Scophthalmus rhombus: trip2
Commercial weight (kg)
0.5
1.0
1.5
1
2
3
80mm cover cod−end
80mm test cod−end
90mm cover cod−end
90mm test cod−end
red gurnard : trip1
red gurnard : trip2
Commercial weight (kg)
0.5
1.0
1.5
1
2
3
4
80mm cover cod−end
80mm test cod−end
90mm cover cod−end
90mm test cod−end

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Wageningen Marine Research is the Netherlands research institute established to provide the scientific support that is essential for developing policies and innovation in respect of the marine environment, fishery activities, aquaculture and the maritime sector.

Wageningen University & Research:
is specialised in the domain of healthy food and living environment.

The Wageningen Marine Research vision
‘To explore the potential of marine nature to improve the quality of life’

The Wageningen Marine Research mission

- To conduct research with the aim of acquiring knowledge and offering advice on the sustainable management and use of marine and coastal areas.
- Wageningen Marine Research is an independent, leading scientific research institute

Wageningen Marine Research is part of the international knowledge organisation Wageningen UR (University & Research centre). Within Wageningen UR, nine specialised research institutes of the Stichting Wageningen Research Foundation have joined forces with Wageningen University to help answer the most important questions in the domain of healthy food and living environment.

Best Practices II

Task 3.2. Desk study: selectivity curves and economic analysis (short term)

Geert Hoekstra & Katell Hamon.

23-03-2018

WAGENINGEN
UNIVERSITY & RESEARCH

Table of Contents

1. Introduction

This desk study has applied the results from the practical selectivity experiments performed by Wageningen Marine Research (WMR) in the project Best-practices II. In particular the estimated selectivity curves from the experiments were used. Observer trips were carried out with the conventional mesh size of 80 mm and the more selective 90 mm. By using paired observations of 80 and 90mm cod end a catch comparison of both undersized as well as marketable fish (kg per hour), including the percentage loss/reduction, could be made. To obtain a sample of the entire population a cover cod end sampling technique was used, in which the cover consisted of a 40 mm mesh. Observers from WMR collected data on the catches on a haul basis of both meshes (i.e. conventional mesh and selective). Sampling focused on the main target species, sole and plaice (Van der Reijden et al., 2014). Current selectivity curves observed for the sole targeting fleet were compared to the experimentally derived ones for the larger mesh sizes.

Based on the results of the experiments with tested gears, and the resulting catch composition in terms of species and size category, the short-term impact (in costs per fishing day) of the landing obligation on the profitability has been estimated of the fisheries fishing with the current gears (80 mm) and if the fleet were to change to the new gear (90 mm). The costs of operation has been based on the 'Best Practice I' costs (Baarssen, Luchies, Turenhout & Buisman, 2015; Buisman, Van Oostenbrugge & Beukers, 2013).

2. Methodology

- *Calculation of the catch composition by length and market category for the 80mm:*
  - Catch compositions by length of 80mm are calculated for four groups (<300 HP, plaice; <300 HP, sole; >300 HP, plaice; >300 HP, sole) as the proportion of catch at each cm-class in the market categories (see table 5 for the definitions of the market categories)
  - The landings weights are based on data from 2015 for the pulse cutters in 2015 of BedrijvenInformatieNet (Wageningen Economic Research).
  - The landings proportions are calculated as kg per sea day for each category based on the total number of sea days for the pulse cutters with <300 HP and >300 HP in 2015.
  - Prices per market category are based on the average annual prices per market category of the pulse cutters in 2015.
  - Finally, the values per length category are calculated by the price per market category multiplied by the kg per sea day per length size.

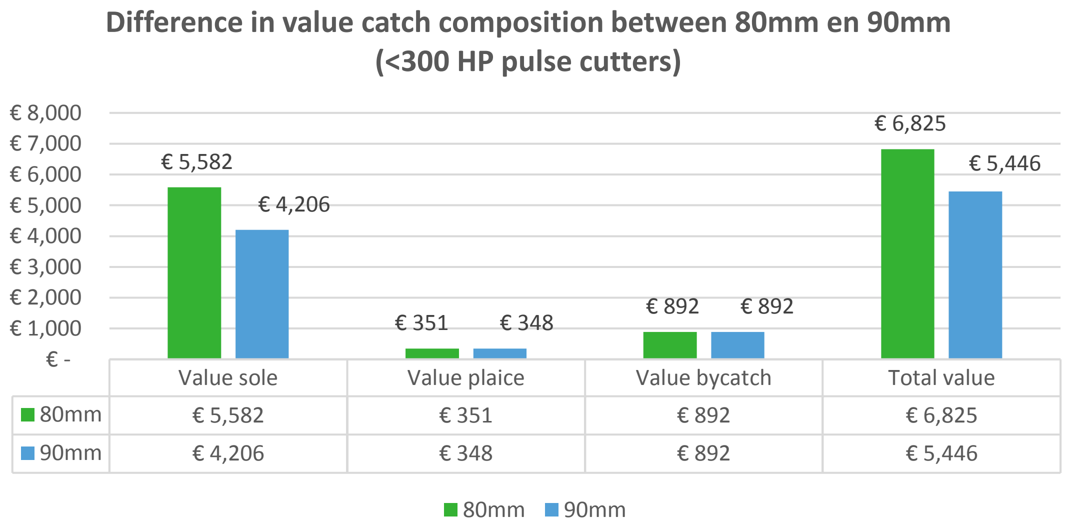
- *Calculation of the catch composition by length and market category for the 90mm:*
    - With the selectivity curves for sole and plaice (based on sampling data of WMR) a ratio was calculated to convert the kg per sea day per length category of the 80mm to the 90mm in kg per sea day for each length size.
    - The value per length category has been calculated by the kg per sea day multiplied by the price per market category for each length size.
    - Note the assumption that the selectivity curve for sole and plaice, derived from trips performed by a large >300hp pulse cutter, is also applied to <300hp cutters. In addition only the selectivity curve of trip 2 was used in the analysis. Within trip2 the difference in the actual mesh size between the 80 mm and 90 mm cod ends approximated 10 mm, i.e. 78.8mm and 87.8 mm. Within trip1 the difference between the meshes was lower, i.e. 7.6 mm. Given the smaller difference between the meshes, we assume changes in the economic performance will be smaller when using the selectivity curve of trip 1.

- *Calculation of the bycatch:*
    - The weights and value calculated per sea day has been based on 2015 for the pulse cutters in 2015 of BedrijvenInformatieNet (Wageningen Economic Research).

3. Results

Catch results with two different mesh sizes for small and medium sized pulse cutters (<300 HP).

Figure 1 Catch per sea day by pulse cutter <300 HP.



	Value sole	Value plaice	Value bycatch	Total value
80mm	€ 5,582	€ 351	€ 892	€ 6,825
90mm	€ 4,206	€ 348	€ 892	€ 5,446

Source: BedrijvenInformatieNet (Wageningen Economic Research), Sampling data (Wageningen Marine Research)

Table 1 Catch composition in weight and value by pulse cutters <300 HP.

Mesh size	80mm per sea day	90mm per sea day	Per cutter annually (80 mm)*	Per cutter annually (90 mm)*
HP class	2	2	2	2
HP	<300	<300	<300	<300
Weight sole**	517	377	82797	60323
Weight plaice**	233	232	37295	37174
Weight bycatch[1]	524	524	83867	83867
Value sole	€ 5,582	€ 4,205	€ 893,150	€ 672,883
Value plaice	€ 350	€ 348	€ 56,091	€ 55,731
Value bycatch[2]	€ 892	€ 892[3]	€ 142,739	€ 142,739
Total value	**€ 6,824**	**€ 5,445**	**€ 1,091,982**	**€ 871,353**

*Calculated on a mean of 160 sea days annually.

**All the weights (sole, plaice and bycatch) consists of dead/gutted fish for landing.

[1] 'bycatch' includes many fish species but exclude sole and plaice.

[2] The 'bycatch' consists of turbot with 4.24% (33.00 kg per sea day) and (European) flounder with 2.78% (267.75 kg per sea day) of the entire catch composition (including sole and plaice) in total value (euro). The other fish species compose on average 1% or less of the total value of the catch.

[3] The 'bycatch' has been assumed similar to a fishery using an 80mm mesh size in terms of catch composition in species, length, weight and value (prices).

Table 2 Economic results expected for pulse cutters <300 HP with the landing obligation.

MESH SIZE	80MM PER SEADAY	90MM PER SEADAY	PER CUTTER ANNUALLY (80 MM)*	PER CUTTER ANNUALLY (90 MM)*
TOTAL VALUE LANDINGS	**6,824**	**5,445**	**1,091,982**	**871,353**
FUEL COST[1]	1,068	1,068	170,880	170,880
CREW COST[1]	2,162	2,162	345,920	345,920
OTHER COST[1]	2,653	2,653	424,480	424,480
DEPRECIATION[1]	502	502	80,320	80,320
EXTRA DISCARD COST[2]	(3,119 kg)[2]	(2,213 kg)[2]	(499,040 kg)	(354,080 kg)
- PROCESSING ASHORE[3]	951	675	152,160	108,000
- PROCESSING ABOARD[4]	864	864	138,240	138,240
ECONOMIC RESULT	-1,376	-2,479	-220,018	-396,487

The numbers in table 2 are in € (euro).

*Calculated on a mean of 160 sea days annually.

[1] Reference: Baarssen et al, 2015.

[2] Calculated with the selectivity curve the discarded sole (kg) decreases with 63% and plaice (kg) with 35% per sea day by each cutter (<300 HP) with the 90 mm mesh size in 2015. The discards of bycatch in weight are approached to be equal to 80 mm mesh size, since there were no sampling data available to determine the selectivity curve. The 3,119 kg is based on the distribution of 29% (market category) landed fish and 71% consists of discards in weight (Baarssen et al., 2015).

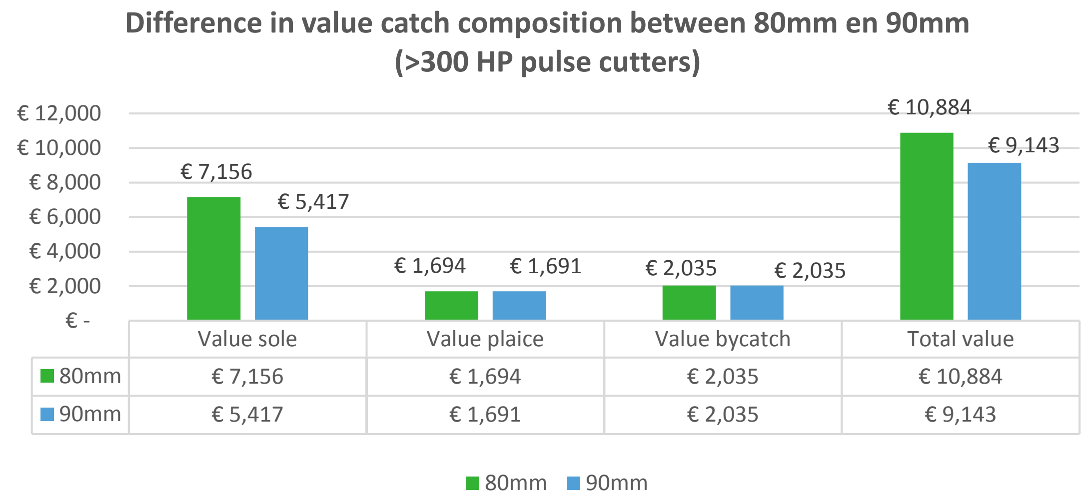
[3] Cost ashore per kg is €0.305 (Baarssen et al., 2015).

[4] Cost aboard is based on an estimated extra 2 FTE with cost of €432 per crew member per sea day (Baarssen et al., 2015). Based on the diminished weight of discards (-29%) by 90mm fishing it is assumed that the work load (in time) could decrease. However, from a logical perspective you should decrease by more than 50% weight of discards (and therefore -50% working time) to be

able to save one extra crew member. Since you could not save less than a whole crew member fishing for a whole week aboard. For the situation of 90mm it is assumed from this argument that despite 29% less discards (in weight) still 2 extra crew members are required.

Catch results with two different mesh sizes for large sized pulse cutters (>300 HP).

Figure 2 Catch per sea day by pulse cutter >300 HP.



Source: BedrijvenInformatieNet (Wageningen Economic Research), Sampling data (Wageningen Marine Research)

Table 3 Catch composition in weight and value by pulse cutters >300 HP.

Mesh size	80mm per sea day	90mm per sea day	Per cutter annually (80 mm)*	Per cutter annually (90 mm)*
HP class	5	5	5	5
HP	>300	>300	>300	>300
Weight sole**	688	490	130765	93133
Weight plaice**	1179	1165	224069	221514
Weight bycatch[1]	559	559	106293	106293
Value sole	€ 7,155	€ 5,417	€ 1,359,578	€ 1,029,289
Value plaice	€ 1,693	€ 1,690	€ 321,850	€ 321,255
Value bycatch[2]	€ 2,034	€ 2,034[3]	€ 386,574	€ 386,574
Total value	**€ 10,884**	**€ 9,142**	**€ 2,068,004**	**€ 1,737,119**

*Calculated on a mean of 190 sea days annually.

**All the weights (sole, plaice and bycatch) consist of dead/gutted fish for landing.

[1] 'bycatch' includes many fish species but exclude sole and plaice.

[2] The 'bycatch' consists of turbot with 8.22% (95.6 kg per sea day) and brill with 4.97% (81.5 kg per sea day) of the entire catch composition (including sole and plaice) in total value (euro). The other fish species compose on average 1% or less of the total value of the catch.

[3] The 'bycatch' has been assumed similar to a fishery using an 80mm mesh size in terms of catch composition in species, length, weight and value (prices).

Table 4 Economic results expected for pulse cutters >300 HP with the landing obligation.

MESH SIZE	80MM PER SEADAY	90MM PER SEADAY	PER CUTTER ANNUALLY (80 MM)*	PER CUTTER ANNUALLY (90 MM)*
TOTAL VALUE LANDINGS	**10,884**	**9,142**	**2,068,004**	**1,737,119**
FUEL COST[1]	2,102	2,102	399,380	399,380
CREW COST[1]	2,537	2,537	482,030	482,030
OTHER COST[1]	2,864	2,864	544,160	544,160
DEPRECIATION[1]	500	500	95,000	95,000
EXTRA DISCARD COST	(2,466 kg)[2]	(1,806 kg)[2]	(468,540 kg)	(343,140 kg)
- PROCESSING ASHORE[3]	752	551	142,905	104,658
- PROCESSING ABOARD[4]	864	864	164,160	164,160
ECONOMIC RESULT	1,265	-276	240,369	-52,269

The numbers in table 4 are in € (euro).
*Calculated on a mean of 190 sea days annually.

[1] Reference: Baarssen, J., Luchies, J., Turenhout, M.N.J., Buisman, F.C. (2015).
[2] Calculated with the selectivity curve the discarded sole (kg) decreases with 59% and plaice (kg) with 24% per sea day by each cutter (>300 HP) with the 90 mm mesh size in 2015. The discards of bycatch in weight are assumed equal to 80 mm mesh size, since there were no sampling data available to determine the selectivity curve. The 2,466 kg is based on the distribution of 50% market category fish and 50% consists of discards in weight (Baarssen et al., 2015).
[3] Cost ashore per kg is €0.305 (Baarssen et al., 2015).
[4] Cost aboard is based on an estimated extra 2 FTE with cost of €432 per crew member per sea day (Baarssen et al., 2015). Based on the diminished weight of discards (-25%) by 90mm fishing it is assumed that the work load (in time) could decrease. However, from a logical perspective you should decrease by more than 50% weight of discards (and therefore -50% working time) to be able to save one extra crew member. Since you could not save less than a whole crew member fishing for a whole week aboard. For the situation of 90mm it is assumed from this argument that despite 25% less discards (in weight) still 2 extra crew members are required.

4. Discussion

In this desk study the effect has been studied of using two different mesh sizes on a pulse trawl on the selectivity, and ultimately, the economic rentability. By using selectivity curves for both fish species (sole and plaice) and two mesh sizes (80 mm and 90 mm), the selectivity, and finally, the catch composition was calculated. Furthermore, the discards (below Minimum Reference Size, see Table 5) were calculated as well by the selectivity curve for the 90 mm mesh size.
Firstly, for a single pulse cutter with less than 300 HP (Horse Power) fishing with the 80 mm and 90 mm mesh size results into a total value of caught fish per sea day of €6,824 and €5,445 respectively. Based on 160 sea days annually this means €1,091,982 versus €871,353 respectively which is a decrease of 20% by average. This loss of income could be declared by the decrease of 27% marketable sole in weight (value loss of €1,377 per seaday). On the contrary, a decrease of 35% of plaice discards in weight results into less costs for discards processing of €492 per sea day. Finally, fishing with the 90 mm pulse gives despite less plaice discards an even more negative economic result of -€396,487 (-180%) compared to the traditional 80 mm mesh size (-€220,018) with the landing obligation.

Secondly, for a single pulse cutter with more than 300 HP (Horse Power) fishing with the 80 mm and 90 mm mesh size gives the total value of caught fish per sea day of €10,884 and €9,142 respectively. Based on 190 sea days annually this means €2,068,004 versus €1,737,119 for a single large pulse cutter respectively which is a decrease of 16% by average. This loss of income could be declared by the decrease of 29% marketable sole in weight (value loss of €1,738). On the other hand, there is a decrease of 25% of plaice discards in weight (less costs for processing of €309) per sea day. To conclude, despite less plaice discards (-25%) fishing with 90 mm pulse gives an economic result of -€52,269 (-122%) versus the traditional 80 mm mesh size (€240,369).
Finally, for both types of pulse cutters (less and more than 300 HP) there is a loss of income by an larger mesh size of 10 mm. Therefore it could be argued that fishing with 90 mm mesh size for the pulse trawl is from an economic perspective unattractive on short term compared to the traditional 80 mm mesh size.

5. References

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Buisman F.C., J.A.E. van Oostenbrugge J.A.E., R. Beukers (2013). Economische effecten van een aanlandplicht voor de Nederlandse visserij. Den Haag: LEI Wageningen UR, (LEI-rapport 2013-062) - p. 48

Van der Reijden, K. J., et al. (2014). Discard self-sampling of Dutch bottom-trawl and seine fisheries in 2013. CVO report: 14.007. Ymuiden: 74.

Table 5 Market category definition for sole and plaice.

Sole		Plaice	
Market category	**Lengths**	**Market category**	**lengths**
1 (Lap)	38 cm +	1	41 cm +
2 (GrootMiddel/GRM)	33-38 cm	2	35-41 cm
3 (KleinMiddel/KLM)	30-33 cm	3	31-35 cm
4 (I)	27-30 cm	4	*27-31 cm
5 (II)	*24-27 cm		

*Minimum Reference Size set by the EU

Table 6 Price per kg market category for sole and plaice (Pulse cutters, 2015).

Sole	<300 HP	>300 HP	Plaice	<300 HP	>300 HP
Market category			**Market category**		
1 (Lap)	€16.35	€17.10	1	€2.63	€2.63
2 (GrootMiddel/GRM)	€13.17	€13.57	2	€1.79	€1.65
3 (KleinMiddel/KLM)	€11.38	€11.89	3	€1.52	€1.46
4 (I)	€10.10	€10.15	4	€1.31	€1.32
5 (II)	€8.76	€8.49			

Source: BedrijvenInformatieNet (Wageningen Economic Research)
*Minimum Reference Size set by the EU

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BEST PRACTICES II: ECONOMIC IMPACT UNDER THE DIFFERENT SCENARIOS (TASK 1.3)

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1 WEcR

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Wageningen, June 2019

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Summary This study presents the long-term effect of the landing obligation on the Dutch beam trawl fishery. Scenarios on the survivability of discards and on change in selectivity of the sole fishery are investigated. While having little ecological benefits on the stocks of sole and plaice, the implementation of the landing obligation will have lasting negative effects on the fleets targeting sole. Assuming partial survivability of discards leads to worse outcomes for both stocks and fleets. Switching to 90mm mesh size instead of 80mm changes the balance between sole and plaice and the fleets need to spend more effort to try to catch their quota of sole but are limited by their plaice quota.

Key words: spatial modelling, SIMFISH, Landing Obligation, economic analysis

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Eindconcept I Wageningen Economic Research Report 2019-075

Contents

Preface

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Summary

The landing obligation (LO) is supposed to be fully implemented since the first of January 2019. For the Dutch fishery targeting flatfish with beam trawls this means that all the catch of the quoted species should be landed. This is particularly an issue for plaice representing the major part of the discards, but up to now, the fishery has benefited from an exemption for most of the plaice discards. This study aims at looking at the longer term impacts of the LO on the fishery using a set of scenarios on survivability and selectivity changes (from other tasks of this project).

To do this we used the SIMFISH model developed by Wageningen Economic Research (Bartelings et al. 2015). This model is a bio-economic model integrating the feedback effect between fish stocks and fishing fleets. It was applied to the Dutch beam trawl fishery comprising of three fleets based on vessel length (12-24m, 24-40m and >40m) targeting four species, sole, plaice, turbot and shrimp (sole, plaice and shrimp are explicitly modelled, turbot is taken as a fixed bycatch per unit of effort). The model was calibrated using 2013-2015 data, the LO or change in selectivity are included from 2019 onward and the projections ran until 2030. There are two LO scenarios, full implementation or full exemption (no LO). The full implementation includes extra costs linked to the processing, storing and landing of the extra fish (taken from previous projects), extra revenue from the sale of the unwanted catch. In addition smaller vessels (12-24m) are expected to have to increase their time at sea because they have to travel back and forth to unload the extra landings as their storage capacity is limited. There are three survivability scenarios, the 0% survivability (as it is currently used in assessment model) and the lower or higher bound of the estimates made by Schram and Molenaar (2018). Those include change in future survivability (in case discards are still allowed) and change in past survivability which have an impact on the initial size of the stocks. So the stocks sizes is corrected for survivability. The last set of scenarios are the two selectivity scenarios, using 80mm mesh-sizes (this is the current practice in the fishery) or using larger 90mm mesh-sizes. The catchability at age of sole and plaice is corrected, leading to lower catch rates.

Impact of LO

The implementation of the landing obligation will have limited impact on the fish stocks while having lasting effect on the Dutch beam trawl fleets. The extra costs associated to the sorting, storing and landing of extra, low value catch leads to poor economic performances of the fleets without alternative activities and ultimately the exit of up to 7 and 17% of the 24-40m and above 40m fleets respectively.

Impact of survivability

If past survivability has been underestimated (and the stocks are overestimated), the LO implementation would lead to worst outcome than expected as a positive flow of surviving discards would be cut out. This would lead to worse ecological and economic outcomes.

Impact of selectivity

The use 90mm nets leads to a change in the catch composition. To (try to) catch their quota of sole , fishers would need a lot of additional effort and would become limited by their plaice quota. This has economic and ecological negative consequences as more effort and higher costs are needed and more unwanted catch end up in the net and the nets are dragged longer on the bottom.

Limitations and recommendations

This task was completed at the end of the project while still overlapping with other parts of the projects that could have fed in the model. The data flow has been successful on selectivity and survivability data. However, the extra labour needed to sort and process the extra landings was taken out of a previous project and the estimates from the current project are twice as high as in the previous report (3.6 extra FTE instead of the 2 included in the model of the current study; VisNed, unpublished data). This would have important implications on both the economic performances of the fleets (additional costs) as on the social aspects (would there be a loss of salary for everyone? How would it be to have extra crew on-board?).

All the trials made in the project and on which data was estimated and the fleets cost structure are based on the use of pulse trawls while it will not be allowed anymore after 2021. The results should be adjusted to whatever gear is used as an alternative for pulse.

This study is a modelling exercise using a deterministic model and what-ifs scenarios. The results are projections not predictions and should be compared amongst them. A lot was added to the model for this study and sensitivity analysis for new parameters should also be performed.

1 Introduction

The current Common Fisheries Policy (CFP) aims at reducing discards by obliging fishers to land all catch including the potential discards, i.e. a landings obligation (LO). Under the LO, all discards of commercial species that are regulated by quota have to be landed.
The LO has a particularly strong impact on the Dutch demersal fishing industry as it is a mixed fishery where catches can contain many different species. The LO for the demersal fisheries has been introduced in phases over a number of years: It started on January 1st 2016 for cod, haddock, whiting, Norway lobster, sole, plaice haddock and Northern prawn. For the non-target quota species the LO has been enforced since January 1st 2019. For the Dutch flatfish fishery, exemptions in place mean that the LO is for the most part not yet implemented and the impact on the fishery is still limited.

The Best Practices II project aims to help the Dutch demersal fisheries sector prepare and adapt to the implementation of the LO by providing technical and economic insights into the consequences of its implementation.
BPII produces simulations of potential future developments of the main species of interest in terms of expected volume and value of the catches and stocks of interest.

This report deals with Task 1.3 of the project proposal, presenting an analysis (and evaluation) of the economic impact on the fisheries under different scenarios (Task 1.3), based on results from project tasks 1.1 and 1.2.

Innovations in fishing practices can improve fishing gear selectivity and can affect fish survival, both potentially mitigating negative consequences of the LO.
Based on the results of other tasks in the project, such as

- The projections of the expected stock sizes for different assumed levels of survival of the discards, considering that those are thrown overboard and not landed (1.1, 1.2).
- The quantification of the effect of switching 80mm mesh size for 90mm mesh size nets on selectivity and of the economic profitability of using 2 different mesh sizes . (T3.1).

we estimated the short (1-3 years) and medium-term impact (9-11 years) of the implementation of the landing obligations on the fleet performances and stock size. This is done using the bio-economic modelling tool SIMFISH developed by Wageningen Economic Research. This model contains a feedback loop between biology and economics and allows for longer term projections (10 years).

The model is applied to the Dutch fleets targeting flatfish with beam trawls. Sole, plaice, shrimps and turbot are included in the model as source of revenue for the fleets and sole and plaice have a full feedback loop between catch and stocks

2 Scenario definitions

Best practice II has focused on the implementation of the landing obligation under different assumptions regarding survivability of fish and selectivity of gear. To assess the medium term (10 years) effect of the landing obligation, we combined those assumptions and defined the set of scenarios presented in *Table 2.1*. All scenarios contain three components detailed in the following sections:

- Landing obligation (LO): full implementation (=LO) or full exemptions (=no LO)
- Selectivity: 80mm (current) or 90mm
- Survivability: 0% (current), lower range of survivability estimates or upper range of survivability estimates.

The scenarios described in the following sections have been defined together with the fishing sector (represented by the PO organisation VisNed) in a stakeholder meeting and subsequent email communications in autumn 2018. Additional data has been made available later and is not included here but is included for discussion.

Table 2.1 *Definition of scenarios*

Landing obligation	Selectivity	0% survival	Lower range survival	Upper range survival
Full LO implementation (100% retained)	80 mm	Scen1	Scen2	Scen3
	90 mm	Scen4	Scen5	Scen6
LO with full exemptions (i.e., No LO = 0% retained)	80 mm	Scen7	Scen8	Scen9
	90 mm	Scen10	Scen11	Scen12

2.1 Landing obligation

In the model we apply the same landing obligation scenarios to all fleets all gears. The landing obligation is investigated with 2 scenarios: full implementation, in which all the catch of sole and plaice is retained, or full exemptions, i.e. no implementation, where unwanted catch is discarded. No scenario with partial exemption is implemented in this project as it would have required additional work to estimate the variables in the table per metier. Full implementation scenario is only implemented from 2019 onward. Before that (2015-2018) no discards have to be landed. The current situation is close to the full exemption scenario as the Dutch fishery has currently an exemption for plaice which represents the largest part of the discards.

In case of full LO implementation, the TACs of sole and plaice are set on the catch, while for the non-implementation scenario (no LO) the TACs are set at the level of landings (with the expected unwanted catch based on the latest discards estimates already removed).

In addition to a difference in TACs, the LO scenario also has direct consequences on the economic performance of the fishery. Having more fish on board means extra labour costs to sort and process, extra landing costs and, for the smaller vessels not having the storage capacity to hold all the extra fish on board, extra steaming between fishing grounds and harbours to unload their catch (see the details of those extra costs in ***Table*** *2.2*).

Table 2.2 *Costs and revenue directly linked to the full implementation of the LO (sources from previous reports)*

Extra costs (Baarssen et al. 2015)	Extra revenue (Buisman et al. 2013)
Extra labour costs sorting and handling +28/36% labour costs + 2FTE for large cutter i.e. +0.23€/kg eurocuters / +0.38€/kg large cuters	Sale of previously discarded fish (undersized - no human consumption) 0.15€/kg
Extra processing discards ashore +0.30€/kg	
Extra steaming costs +30% steaming effort for vessels 18-24m (➔ loss of income)	

2.2 Survivability scenarios

The fishing industry has long claimed that a substantial proportion of the fish discarded survives after being thrown back at sea. The implications of a positive survivability are threefold:

1) In the application of the LO, exemptions can be granted on the basis of "high"[1] survivability of discards.
2) The stock assessment every year assumes 0% survivability, so the biomass estimated by the ICES stock assessment would actually be lower than the current estimates.
3) The implementation of the LO would potentially lead to an increase of the mortality of the species with positive survivability.

Here we are interested in the 3rd point. What would be the impact of wrongly assuming a null survivability? For this we use the results produced by Schram and Molenaar (2018).

In the study from Schram and Molenaar (2018), the discards survival probability for undersized plaice was estimated at 14% (95% CI 11-18%) and for undersized sole at 19% (95% CI 13-28%).Based on those estimates, we defined 3 survivability scenarios: the lower and upper limits of the confidence bounds of the available estimates of survival rate, and a 0% survival. The 0% survival scenario corresponds to the current assumptions used in ICES for stock assessment and TAC advice. The other scenarios are the lower and higher bounds of the ranges calculated by Schram and Molenaar (2018). Changing the assumptions on the past and current survival rates also means alternative initial biomass (because if the survivability is higher than what was assumed, this means that the stock was lower). We use the results of Verkempynck et al. (2018), regarding the initial biomass and reference points, target fishing mortality (Ftarget). To be able to use the model outputs of Verkempynck of regarding the initial stock size and reference points, the survival rate ranges were rounded at 10-20% for plaice and 10-30% for sole as shown in **Error! Reference source not found.** (because Verkempynck et al. (2018) made their calculation for 0 to 100% survivability by 10% intervals).

[1] what constitutes "high" survivability remains unclear

Table 2.3 *Characteristics of the survivability scenarios*

	Sole				Plaice			
Scenario	Survival rate	F target[2]	B trigger[3]	Initial SSB	Survival rate	F target	B trigger	Initial SSB
0%	0	0.23	37	51	0	0.202	565	856
Lower range	0.1	0.23	37	50	0.1	0.202	565	850
Higher range	0.3	0.23	37	49	0.2	0.202	565	844

2.3 Selectivity

The simulations investigate the effect of changing mesh size from 80mm to 90mm for the métier TBB_DEF_70-99_0_0_. The selectivity at age is taken from Brunel et al. 2019 (this project) and is used to compute the theoretical catch composition with 90mm mesh size instead of the current 80mm (see ***Figure*** *2.1*, ***Figure*** *2.2* and ***Table*** *2.4*). The blue part under the curve represents the proportion of the fish retained in the net and the red part the proportion of fish that escapes (and is found back in the "cover" part of the net during the experiment. For more details about the definition of the selectivity, see Brunel et al. 2019 (this project).

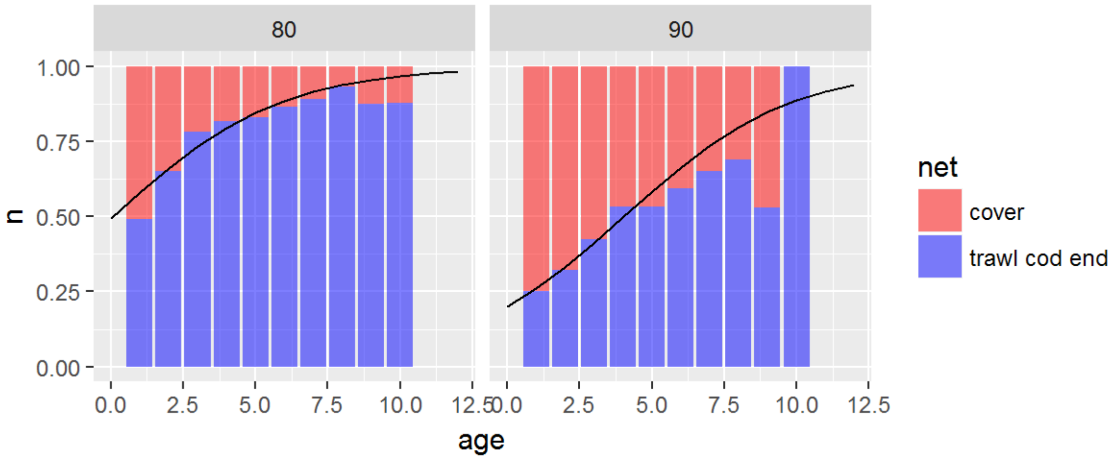

Figure 2.1 *Selectivity at age for the 80mm (left) and 90mm mesh size (right) for sole (from Brunel et al. 2019).*

[2] There is a discrepancy between the current Fmsy for sole and the one calculated by Verkempynck et al., we chose to use the one from Verkempynck et al. because it is consistent with the assumptions regarding the structure of the stock and the stock recruitment relationship. Despite having different reference points calculated for the different survivability scenarios, we only used the one provided for the scenario with 0% survivability as we want to show the differences linked to those assumptions with the current management (not assume that management targets have also been corrected).

[3] Btrigger of the assessment is used

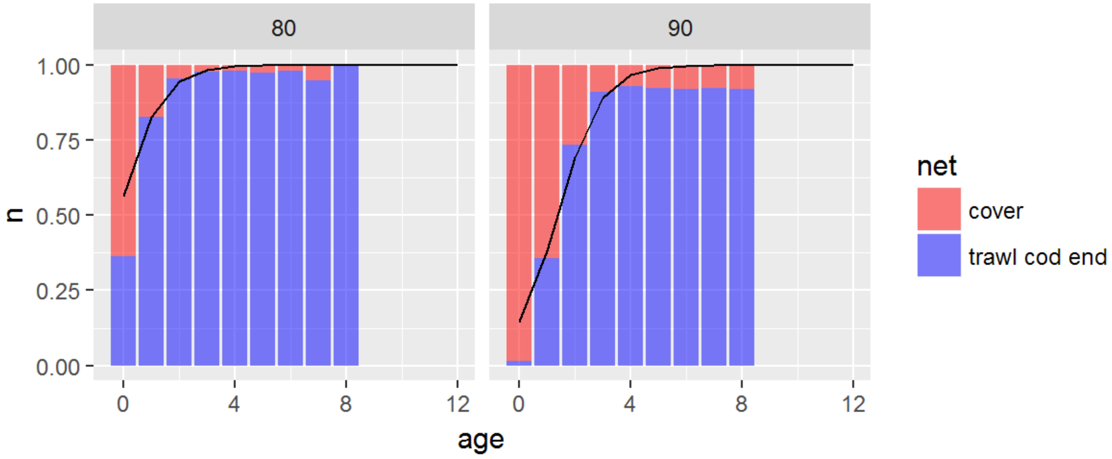

***Figure 2.2** Selectivity at age for the 80mm (left) and 90mm mesh size (right) for plaice (from Brunel et al. 2019).*

The selectivity with 90mm is expressed as a percentage of catch retained at age compared to the current selectivity and the catch $C_{f,90,s,a}$ per fleet *f*, for species *s* and age *a* is calculated as follow:

$$C_{f,90,s,a} = Sel_{90,s,a}C_{f,80,s,a}$$

Where the selectivity factors $Sel_{90,s,a}$ are given in ***Table** 2.4*.

***Table 2.4** selectivity factor $\mathbf{Sel_{90,s,a}}$ at age for 90mm mesh size for sole and plaice*

age	1	2	3	4	5	6	7	8	9	10+
Sole	0.45	0.5	0.56	0.63	0.69	0.75	0.8	0.85	0.89	0.92
Plaice	0.46	0.73	0.91	0.97	0.99	1	1	1	1	1

As for the LO , the 90mm selectivity is applied from 2019 onward affecting the catch, landings, discards, revenue and variable costs. When selectivity is changed, the fleets adapt their effort within the limits set in the model. To allow for the fleets to compensate the loss of catches, the effort limits are raised as seen in *Table 2.5*. For the two larger fleets, we allow for 15 and 23% extra seadays (resp. for the TBB_2440 and TBB_40XX) when switching to 90mm nets. For the smaller vessels (TBB_1224), we also assume the possibility to increase the activity per vessel by 15% and we also include the possibility to increase the seadays by 30% in the LO scenarios.

***Table 2.5** max seadays limit per fishing vessel allowed in the model the different fleets*

	TBB_1224	TBB_2440	TBB_40XX
Status quo (2015)	131	166	202
LO	170	166	202
90mm	150	190	250
LO+90mm	195	190	250

3 Methods and data

3.1 Description of the Spatially explicit model SIMFISH and model development

The method used in this study is based on the bio-economic model SIMFISH (Spatially Integrated Model for FISHeries) published in 2015 (Bartelings et al. 2015). The original model contains several modules linking medium and short term fleet dynamics to fish population dynamics while taking the economic and management developments into account.The advantage of this model is the integration of fleet and fish stocks dynamics. The activity of the fishing fleets impact the fish stocks which in turn, through catch rates impacts the choices made by the fishing fleet.

***Figure** 3.1* illustrates the model framework which consists of five interacting parts: fleet dynamics, prices, investment behavior, population dynamics and management policies. The fleet dynamics model optimizes the short-term behavior of the fleets, i.e. determines the effort allocation to fishing areas and metiers in order to maximize the total profit of the fleets in the model. The annual profit is optimized through effort allocation given some restrictions on effort and maximum catch and landings. The fleet dynamics module mutually interacts with the other four modules.

The investment module determines the long term development of the fleet size, namely the entry/exit behavior based on past profits and the utilization of fishing capacity. Investment behavior impacts the potential effort which is proportional to the number of vessels in the fleets. The price module computes both fuel and fish prices which affect the profitability of fleets.

For each species the population dynamics module computes the available biomass per area. The population dynamics can be calculated with a global model (of polynomial or logistic form) or with an age-structured model. The population dynamics function is set separately for each species in the model. The spatial fish distribution (by age class) is exogenously defined but can change through time. The biomass is used to calculate total allowable catch (TAC) in the management module. The TACs are then divided in quotas constraining the activities of the fleets. With the spatial component of the model, area closures have been included as management measures. It is also possible to include effort limitation policies.

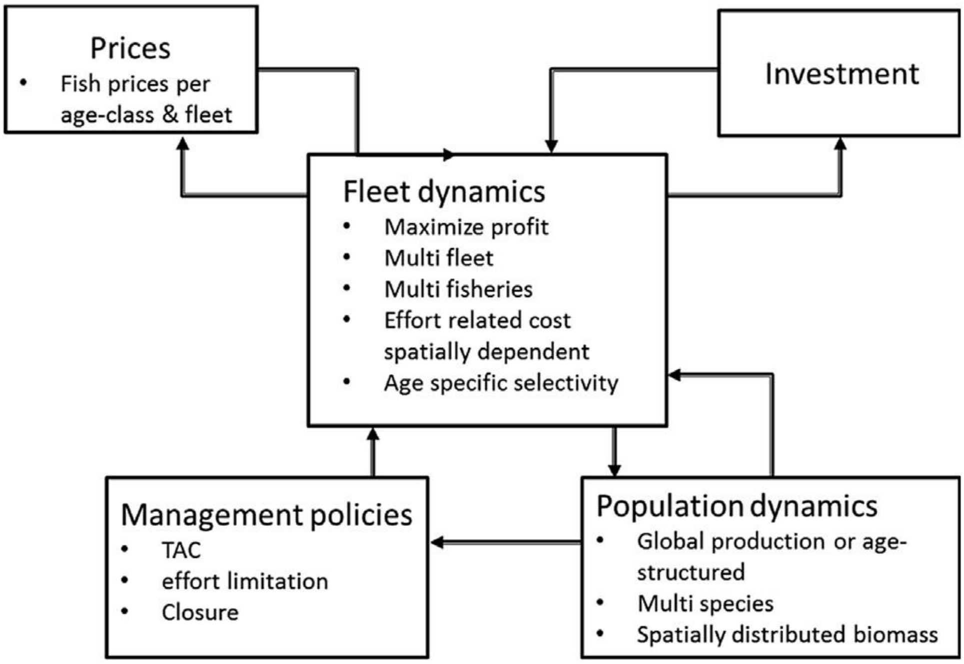

Figure 3.1 *Simplified framework of SIMFISH*

To analyse the impact of the landing obligation, gear selectivity and fish survivability we needed to extend the basic SIMFISH model as described in Bartelings et al (2015) to include these features.
The following features have been added:

1. Landing obligation

Since both over quota discards and undersized discards are already included in the model, only economic costs and revenues related to the discard ban needed to be added. Therefore revenue of landed discards are added to the revenue calculation and increased fuel costs and crew costs due to the landing obligation are added to the model.

2. Selectivity

Selectivity has been added to the model by changing the catchability and adding an age-specific factor to the model. The data for this parameter is described in paragraph 2.2. In addition, the production function now calculates catch (instead of landings previously) and discards are now calculated as a proportion of catch using a fixed age and gear specific factor.
In the original SIMFISH model we assumed that the total catch of a species consists of both the catch of fleets taken into account in the model as well as catch by fleets not in the model. We assumed that the catch of fleets outside the model could be calculated as a fixed proportion of the catch of fleets within the model. This implicitly assumes that fleets not included in the model exhibit similar behaviour as fleets taken into account in the model. With regards to selectivity analysis this is no longer a probable assumption. We assume that the fleets not included in the model will not change their target age classes. Therefore the calculation of catch of other fleets will use a predefined age distribution parameter.

3. Survivability

In the past we implicitly assumed that survivability of discards was zero. We adjusted the stock calculation in the model to include a survivability parameter for the discards. Thus depending on the scenario the survivability of discards could be higher than zero. This in turn affects the quota calculations and therefore the future catch of a species.

3.2 Data and assumptions

Based on the selectivity of the different scenarios and the resulting catch composition in terms of species and size category (from task 1.1 & 1.2), we estimate the medium-term impact of the landing obligation on the profitability of the flatfish demersal fleets with and without improvement in selectivity. The model is calibrated using 2015 data, and running until 2030. The changes in LO implementation and selectivity are implemented from 2019 onward. The costs of operation are based on recent data from Wageningen Economic Research BedrijvenInformatieNet (BIN) and estimates of additional costs incurred because of the landing obligation are taken from the Best Practice I project (see scenario description). The level and composition of landings are taken from logbook data and Wageningen Marine Research sampling. Wageningen Marine Research sampling was also used to determine fish prices at age. Price elasticity is estimated using literature Given that the model is an optimisation model maximising the total profit of the fleets, an analysis like this only has value if used in comparison to other projections to assess the relative effects of changes and cannot be seen as a prediction of future economic results.

3.2.1 Underlying biology/ biological assumptions

Four species are included in this application of the North Sea flatfish fishery: sole, plaice, shrimp and turbot. Sole, and plaice are the main target species; shrimp is a complementary activity for a large part of the smaller vessels and is included because changes in the flatfish fishery can affect the shrimp fishery and vice-versa; turbot is only included as (valuable) by-catch.

The sole and plaice stocks are modelled using the dynamics used in ICES stock assessment. Here we have an age-structured model, with use the natural mortality, weight at age and the maturity index of the assessment (ICES WGNSSK, 2017). The numbers at age are taken from Verkempynck et al. (2018) for the different survivability scenarios. The stock recruitment relationship is Beverton and Holt, consistent with Verkempynck et al. (2018).

Shrimp is model using a polynomial growth function as in Bartelings et al. (2015).

Turbot is not explicitly modelled and a fixed constant CPUE is used, using logbook data.
The initial biomass of sole, plaice and shrimp is taken as an average of the 2013-2015 biomass.

3.2.2 Fleets

The three fleets included in the model are the Dutch data collection framework (DCF) fleets fishing mainly with beamtrawls (TBB). The three fleets are defined based on their vessel length (12-24m, 24-40m and >40m). The fleets were selected as they target either flatfish (sole and plaice) and they are important fleets for the fishery. For the three fleets included in the model, catch and effort data were based on log-book data. Discard data per metier were estimated based on the Wageningen Marine Research sampling, also used to raise the data for ICES stock assessment. The economic data was based on the data submitted to STECF (2017). The fleets were parameterised based on data for 2013-2015. Additional data per metier (gear/mesh-size) were extracted from the interne Wageningen Economic Research database (BedrijvenInformatieNet - BIN).
The fish prices used in the model are prices per market category, per metier averaged over the period 2013-2015. They are converted in at-age prices using Wageningen Marine Resource market sampling. We only use a price elasticity for sole (0.025) and for shrimp (0.36). The price of plaice is estimated to be pretty inelastic because of a high substitutionability. Given that turbot is taken as a bycatch, we do not set a price elasticity on its value. In addition to the price elasticity, an annual increase of fish prices by 1% is added for all species.

Real fuel prices are used for the period 2015-2018. After that period a 1% increase per year is assumed.

3.2.3 Management options

TACs are calculated for sole and plaice using the target F and the biomass. In case of positive survivability, the corrected biomass is used to calculated TACs and TACs will differ from historic values. The TAC of turbot is assumed constant at the 2015 value.

The LO is implemented in two variants: full implementation, meaning no exemptions and additional costs, or full exemption, meaning no additional costs (see scenario definitions for the specifics). The current situation is somewhere in between where most plaice is exempted. The fishery has currently little additional costs due to the landing obligation (based on discussion with the sector).

4 Results

Results are shown for 2 periods: short term, 2019-2021, i.e. directly after the implementation of the LO and/or the meshsize change and medium term, 2028-2030, about 10 years later as an average for the scenarios compared to the reference scenarios. All results are presented as percentage relative to the reference scenario. The size of the boxes corresponds to 25 and 75% percentile of the dispersion of the values obtained with the different scenarios.

4.1 Effect of the landing obligation

When looking at the effect of the LO, the reference scenarios are the ones without implementation. In Table 4.1 as shown by the arrows, scenario 1 is thus compared to scenario 7, scen2 to scen8, scen3 to scen9, etc.

Table 4.1 *reference scenarios to look at the effect of the LO. Arrows point to the reference for each scenarios*

Landing obligation	Selectivity[1]	0% survival	Lower range survival[2]	Upper range survival[2]
Full LO implementation (100% retained)	80 mm	Scen1	Scen2	Scen3
	90 mm	Scen4	Scen5	Scen6
LO with full exemptions (i.e., No LO = 0% retained)	80 mm	Scen7	Scen8	Scen9
	90 mm	Scen10	Scen11	Scen12

References scenarios

Impact of the LO on the stocks

There is little impact to be seen on the sole and plaice stocks. Hardly any effect can be observed for plaice. The slight biomass increase for sole of maximum 6% after 10 years (*Figure 4.1*) is due to a lower sole quota uptake (up to 3% lower, ***Figure 4.2***) limited by plaice quota, which is fully used..

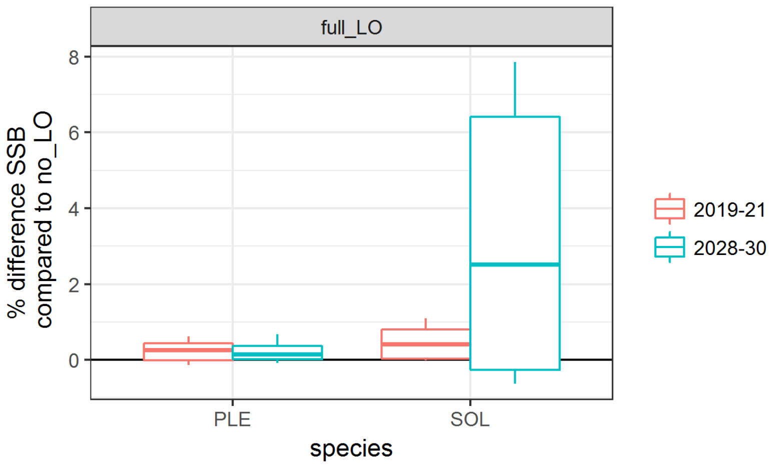

Figure 4.1 *Effect of the LO on the biomass of plaice (PLE) and sole (SOL) immediately after implementation (2019-2021) and ten years later (2028-2030).*

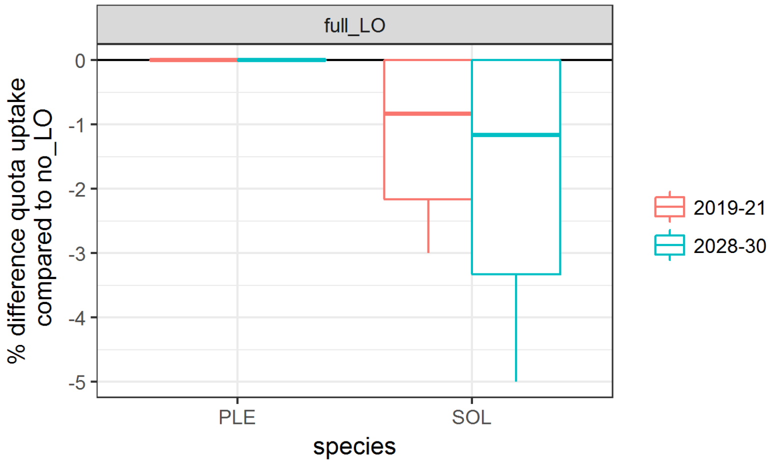

Figure 4.2 *Effect of the LO on the quota uptake of plaice (PLE) and sole (SOL) on the short (2019-2021) and medium (2028-2030) terms*

Impact of the LO on the fleets

- TBB 12-24m: this fleet reallocated part of their activity to shrimps, targeting less sole and plaice (***Figure 4.3***), this leads to higher revenues (+7 to 10% ***Figure 4.4***) despite the lower landings of flatfish and the price of shrimp decreasing due to elasticity. However they also have about 27% extra fuel costs due to extra steaming needed to unload the extra landings of unwanted catch (***Figure 4.5***). The LO has a positive impact on the economic performance of this fleet in terms of gross cash flow (up to 10% increase in the short term, up to 4% in the medium term **Figure 4.6**) as well as NPV of profit (15 to 25% higher than without LO ***Figure 4.7***). But it should be noted that the benefits are only felt by the vessel owners. Crew remuneration goes down 20% per crew (***Figure 4.8***) and days at sea would increase by 30% (***Figure 4.9***), meaning substantially less time on land.

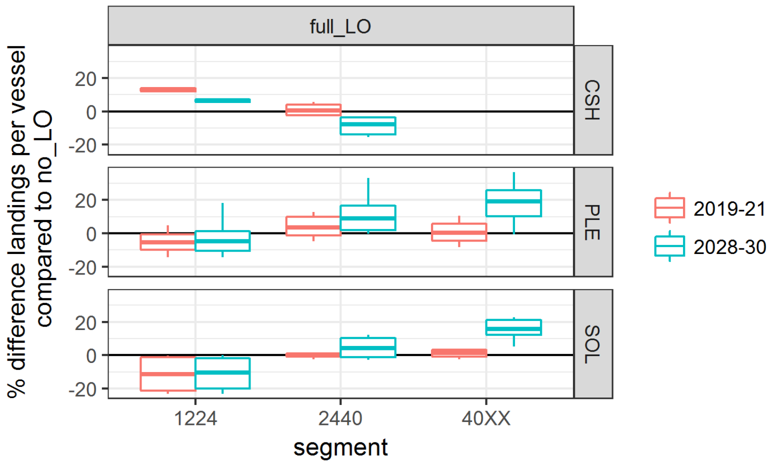

Figure 4.3 *Effect of the LO on the landings of marketable fish of shrimp (CSH), plaice (PLE) and sole (SOL) per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

- TBB 24-40m: This fleet maintains most of its activity, switching some of the activity from shrimp to flatfish (***Figure 4.3***). The extra costs of landing unwanted catch lead to poorer economic performances. The addition of 2 crew members to sort and handle the extra landings leads to higher labour costs but still compensation per crew member is on average 17 to 20% lower (***Figure 4.8***). The gross cash flow (value left to pay labour, the crew, and capital, the vessel owner **Figure 4.6**) stays much lower about 50% to 60% lower than without LO. This leads to about a 40% lower net present value of profit after 10 years (***Figure 4.7***) and up to 6% of the fleet exiting within 10 years (***Figure 4.10***).
- TBB 40-XXm: The decrease of the fleet size by 10 to 15% from what it would be without LO within 10 years (***Figure 4.10***) leads to an increase of fishing effort per vessel by about 10%

(***Figure 4.9***), resulting in 10 to 20% higher landings of sole and plaice (***Figure 4.3***) and revenue (***Figure 4.4***) per vessel but it does not compensate the extra costs (fuel costs 10 to 20% higher ***Figure 4.5***) and extra costs related to the landing of extra fish. This fleet economically performs poorer than without LO. On the short term the gross cash flow is between 60 and 80% lower than without LO (**Figure 4.6**) and a NPV of profit about 25% lower (***Figure 4.7***).

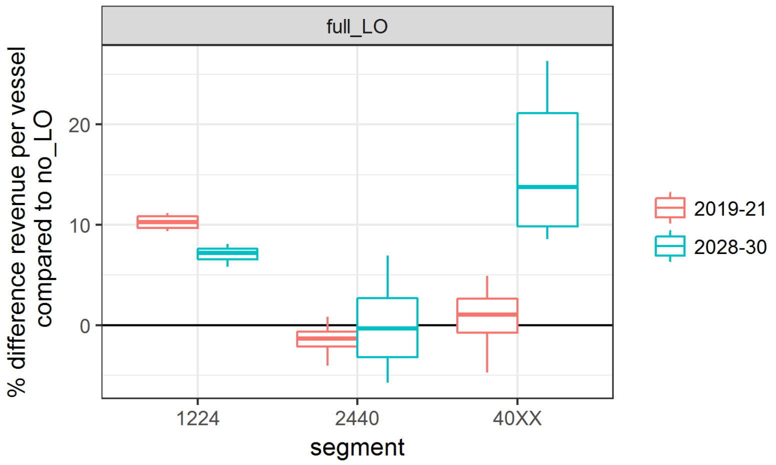

Figure 4.4 *Effect of the LO on the revenue per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

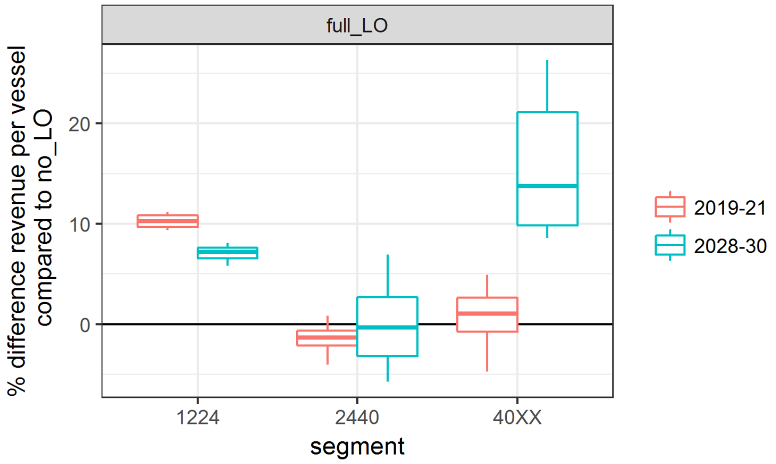

Figure 4.5 Effect of the LO on the fuel costs per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms

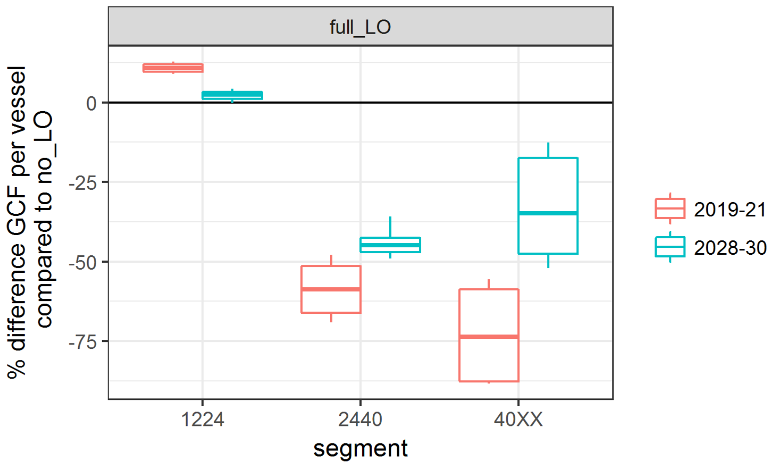

Figure 4.6 *Effect of the LO on the gross cash flow per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

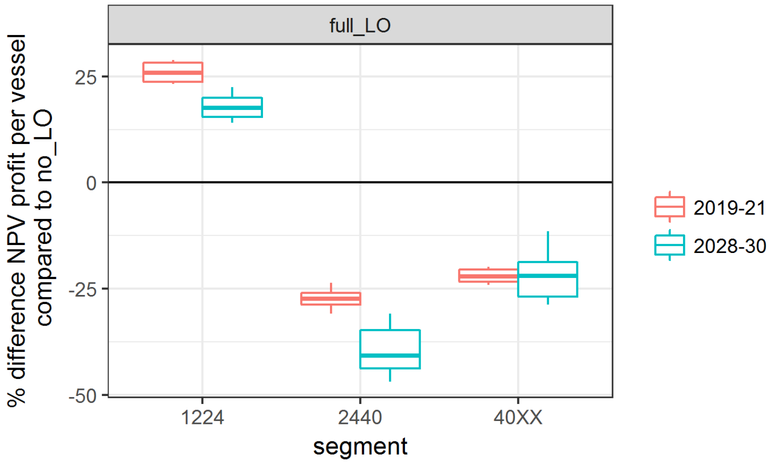

Figure 4.7 Effect of the LO on the net present value (NPV) of profit per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms

Social impact

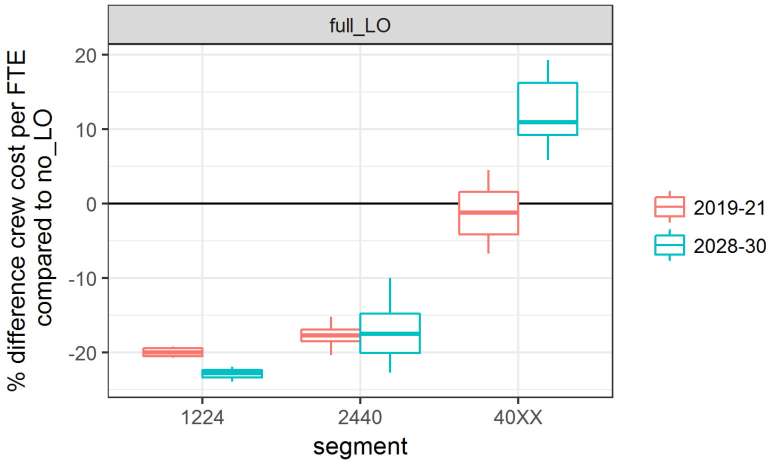

Figure 4.8 *Effect of the LO on the crew cost per FTE per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

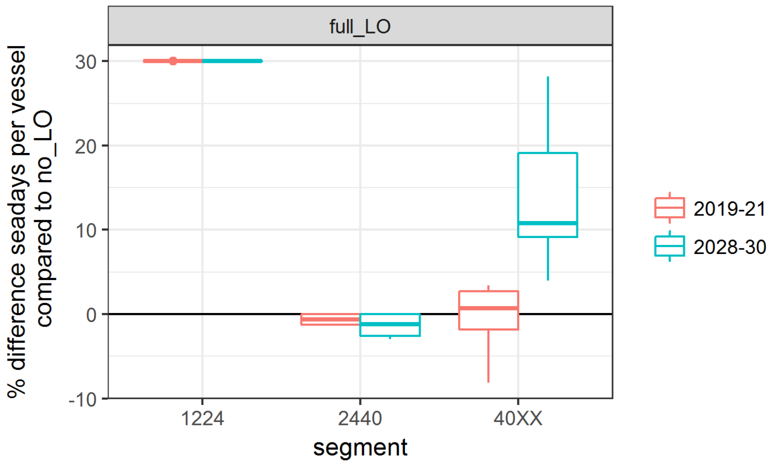

Figure 4.9 *Effect of the LO on the seadays per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

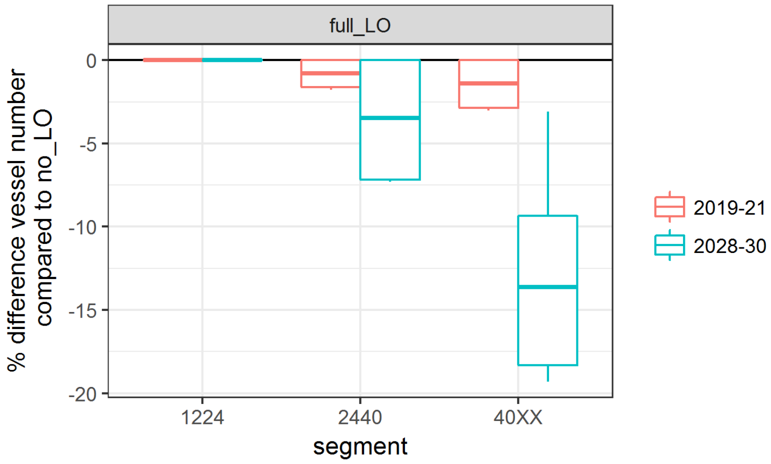

Figure 4.10 *Effect of the LO on the number of active vessels per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

4.2 Effect of survivability scenarios

After looking at the impact of the LO in general, we specifically look at the difference between the three survivability scenarios. We use the same references as in Table 4.1 but we plot the results per survivability scenario in order to identify differences in the way the LO will impact the fishery. The survivability scenarios are meant as past survivability which carries on in case of no LO and suddenly drops to 0 as the LO is fully implemented (as fish landed have a 0% survivability).

The positive impact of the LO on the biomass of sole and plaice in the 0% survivability case is reduced more the higher the past survivability (*Figure 4.11*). In the high survivability the plaice stock doesn't seem to benefit at all from the LO while the sole stock still increases by 1 to 4% within 10 years. The quota being adjusted to the stock size (initially lower the higher the survivability), quota uptake of sole is higher with survivability but the full quota cannot be taken because plaice quota remains limiting for all cases (see ***Figure 4.12***). The fleet can therefore not increase their landings of plaice which decreases with scenarios of past survivability (***Figure 4.13***), survivability has little impact on sole or shrimp landings. This is expected as those species are hardly discarded.

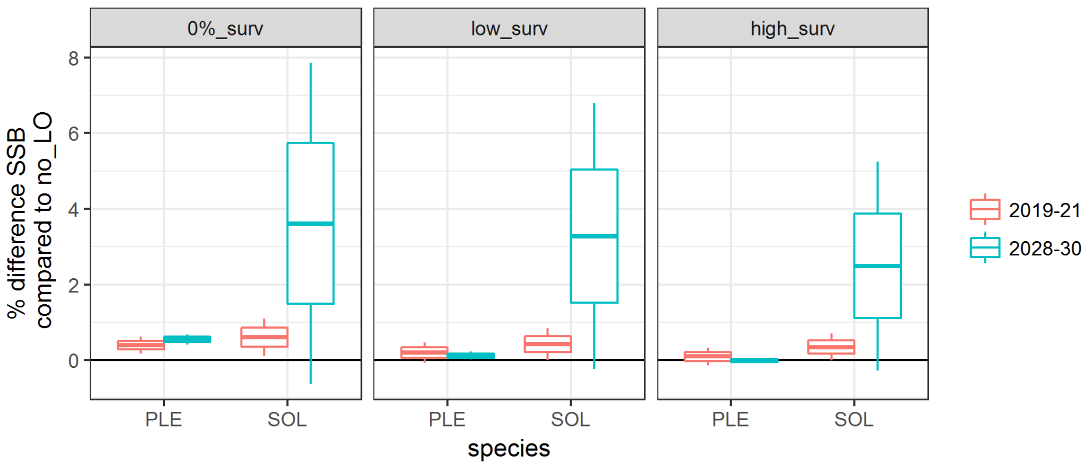

Figure 4.11 *Effect of the LO with the different survivability scenarios on the biomass of plaice (PLE) and sole (SOL) immediately after implementation (2019-2021) and ten years later (2028-2030).*

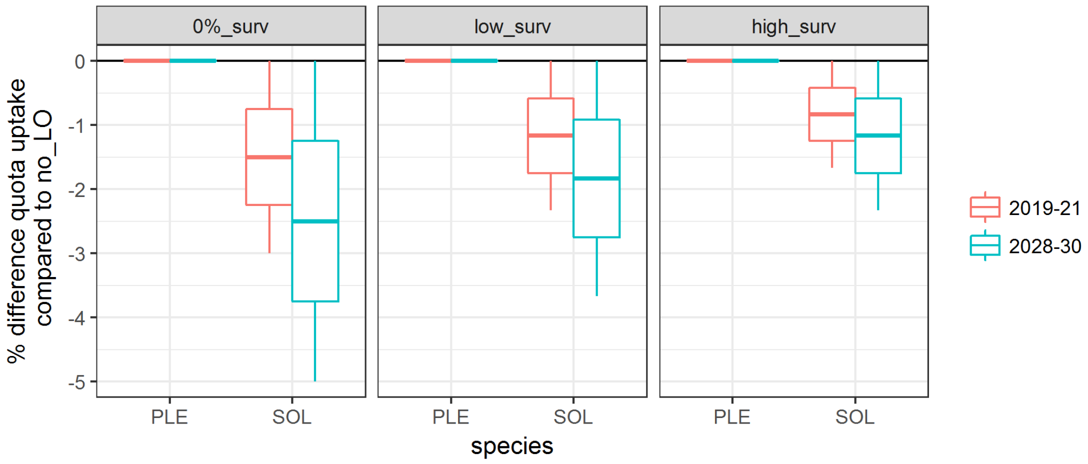

Figure 4.12 *Effect of the LO with the different survivability scenarios on the quota uptake of plaice (PLE) and sole (SOL) on the short (2019-2021) and medium (2028-2030) terms*

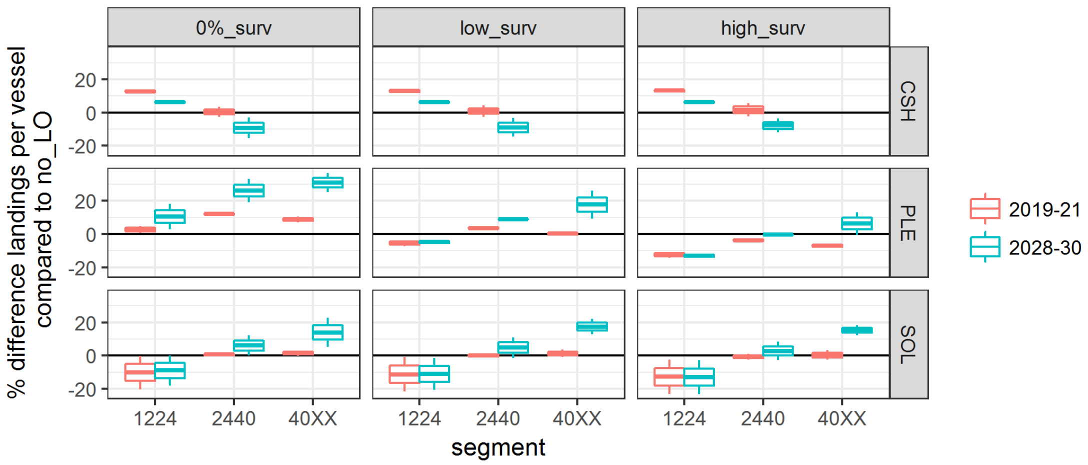

Figure 4.13 *Effect of the LO with the different survivability scenarios on the landings of marketable fish of shrimp (CSH), plaice (PLE) and sole (SOL) per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

The economic performances of the larger fleets (more dependent on plaice)decrease with the survivability . Lower plaice landings leads to lower revenue (***Figure 4.14***) and despite lower fuel cost (***Figure 4.15***) because effort is limited by the plaice quota, gross cash flow (**Figure 4.16**) and net present value of profit (***Figure 4.17***) also decrease for the fleets 24-40m and >40m. For those fleets, this means lower salaries for the crews (***Figure 4.18***). For the larger vessels, above 40m, this also mean an extra 5% of the fleet exiting the fishery in case of LO implementation (***Figure 4.19***). The only positive aspect on the social side is that the limited effort due to quota shortage means less seadays (***Figure 4.20***).

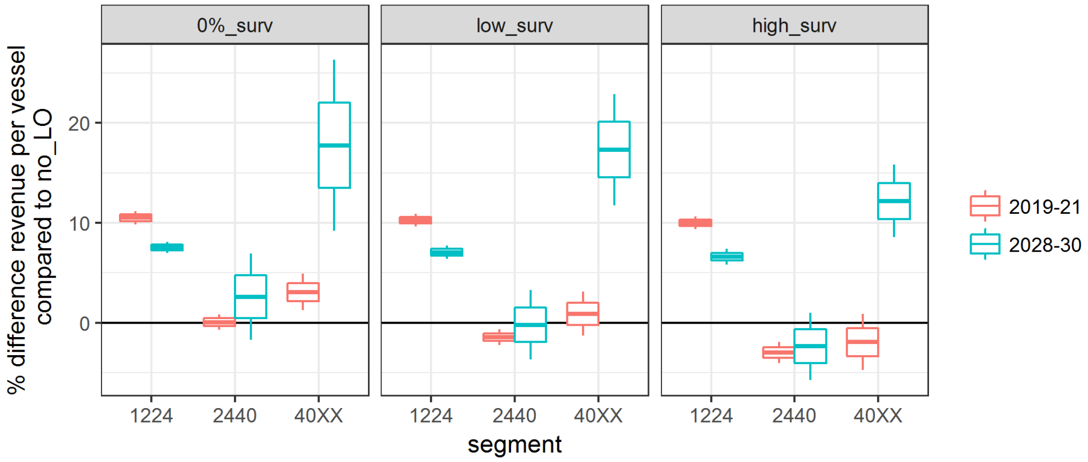

Figure 4.14 *Effect of the LO with the different survivability scenarios on the revenue per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

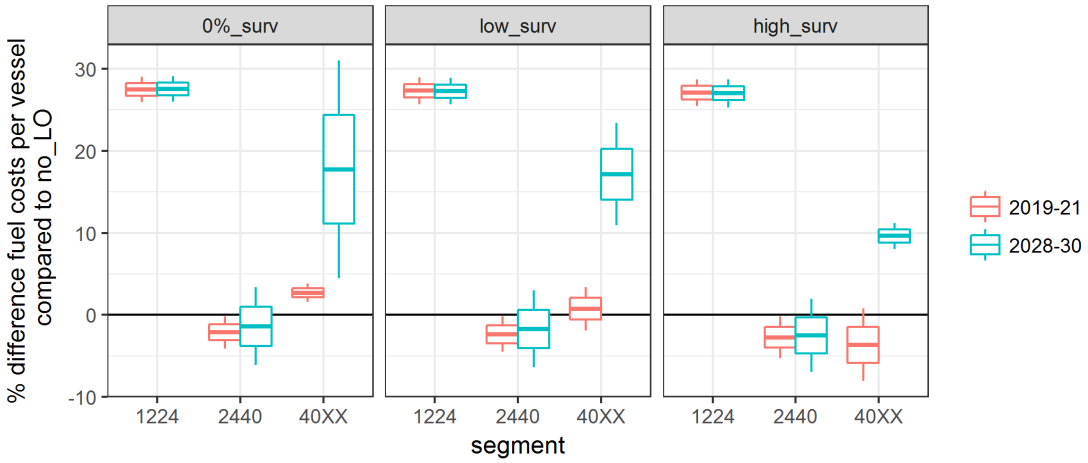

Figure 4.15 *Effect of the LO with the different survivability scenarios on the fuel costs per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

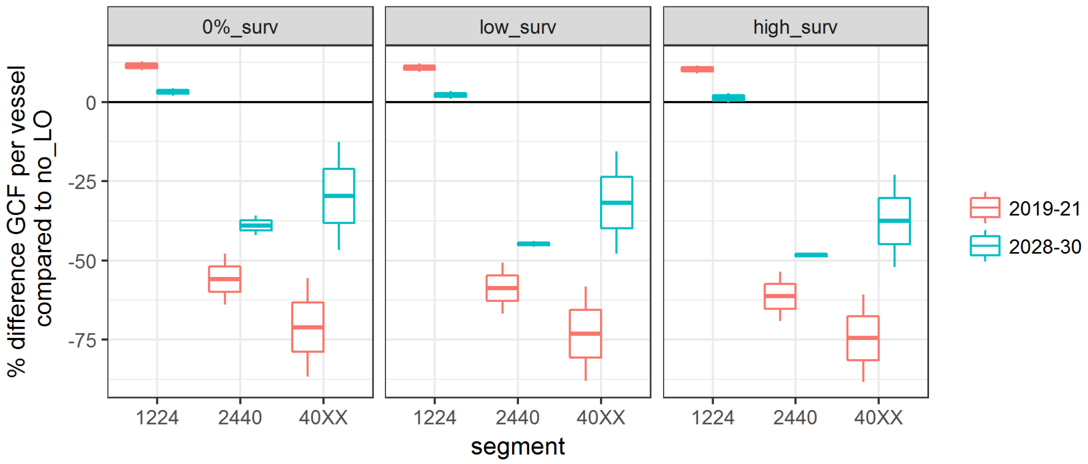

Figure 4.16 *Effect of the LO with the different survivability scenarios on the gross cash flow per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

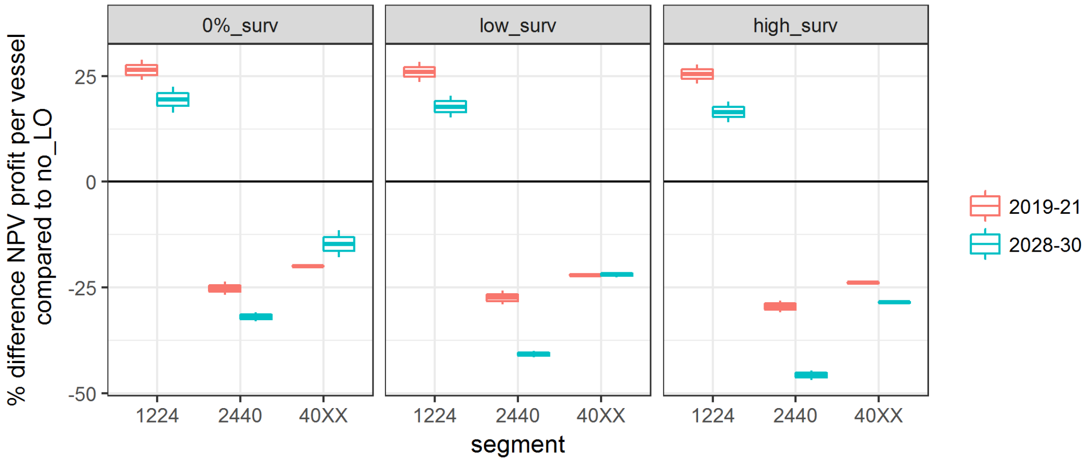

Figure 4.17 *Effect of the LO with the different survivability scenarios on the net present value (NPV) of profit per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

Social impact

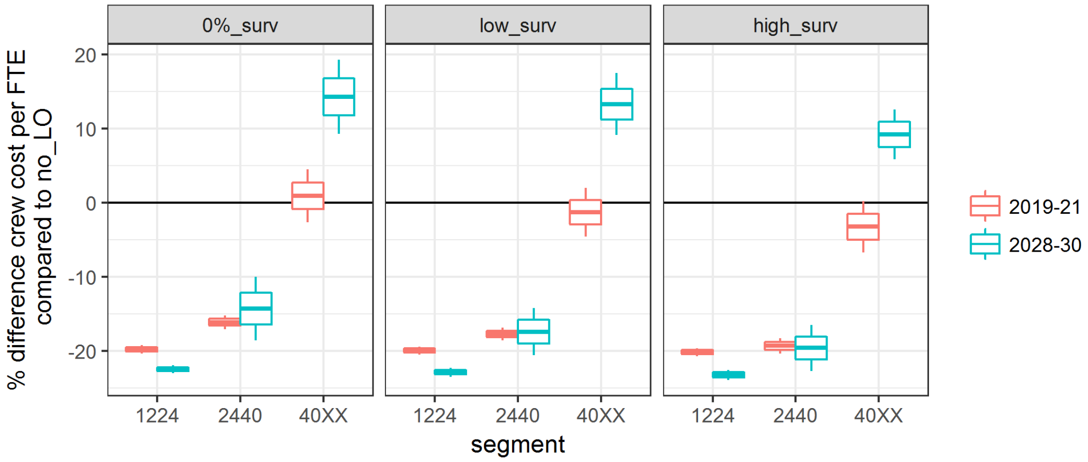

Figure 4.18 *Effect of the LO with the different survivability scenarios on the crew cost per FTE per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

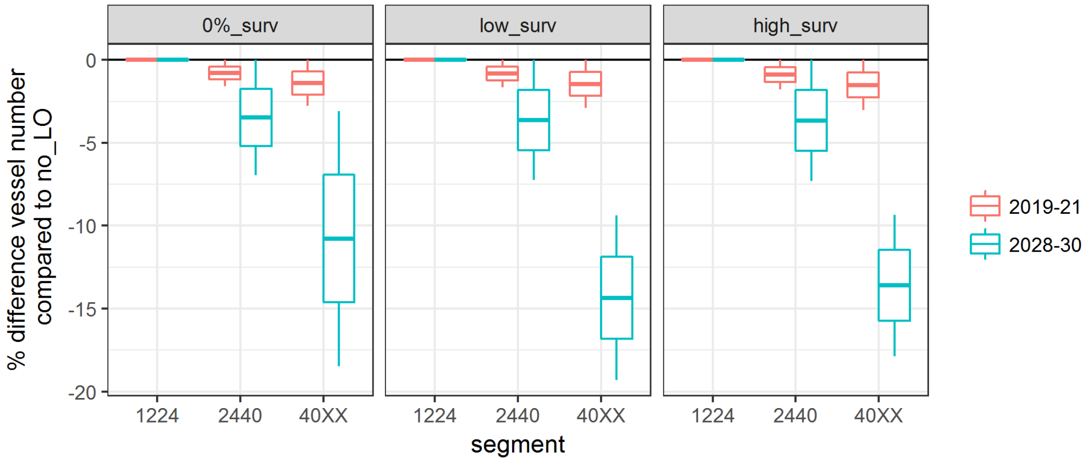

Figure 4.19 *Effect of the LO with the different survivability scenarios on the number of active vessels per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

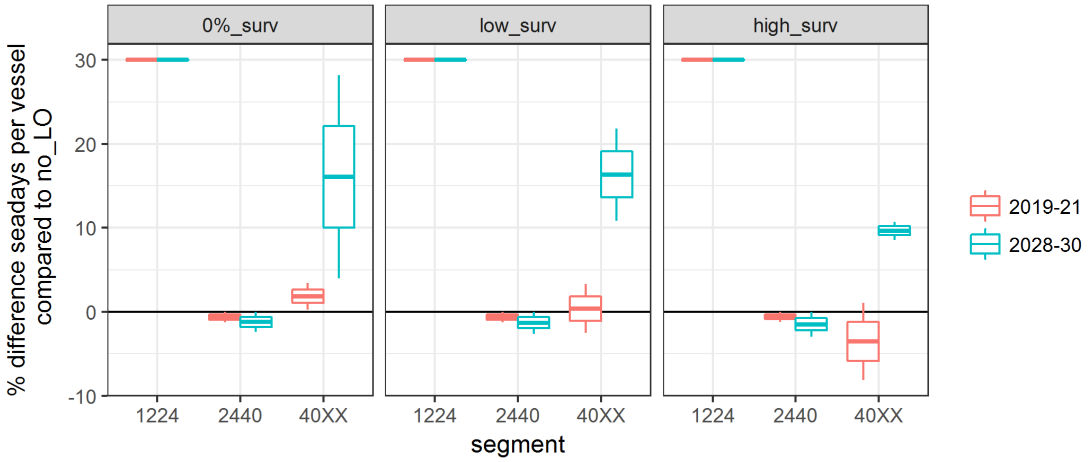

Figure 4.20 *Effect of the LO with the different survivability scenarios on the seadays per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms*

4.3 Effect of a change in selectivity

In this section we look further at the impact of the change to 90mm mesh size from 2019 with or without the LO. For this section the 90mm scenarios are compared to the 80mm ones (see **Table 4.2**).

Table 4.2 *reference scenarios to look at the effect of the change of selectivity. Arrows point to the reference for each scenarios, the scenarios in the boxes are the reference scenarios.*

Landing obligation	Selectivity[1]	0% survival	Lower range survival[2]	Upper range survival[2]
Full LO implementation (100% retained)	80 mm	Scen1	Scen2	Scen3
	90 mm	Scen4	Scen5	Scen6
LO with full exemptions (i.e., No LO = 0% retained)	80 mm	Scen7	Scen8	Scen9
	90 mm	Scen10	Scen11	Scen12

References scenarios

Impact of the 90mm on the stocks

Using the 90mm nets instead of the 80mm leads to a positive effect on the stock of sole (from 3 to 9% higher than with the 80mm fishery *Figure 4.21*), this is due to lower landings of sole and a quota uptake 15% lower in the first years and 5 to 8% lower after 10 years (***Figure 4.22***). This impact is greater than the impact of the LO on the sole stock, especially on the short term. For plaice, the initial effect is slightly negative (-2%) but disappears on the short term.

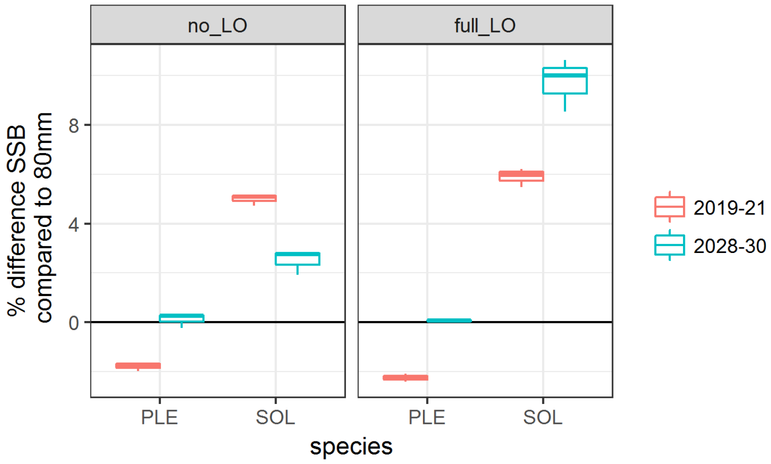

***Figure 4.21** Effect of the change to 90mm meshsize nets on the biomass of plaice (PLE) and sole (SOL) immediately after implementation (2019-2021) and ten years later (2028-2030) in case of no LO implementation (left) or full implementation (right).*

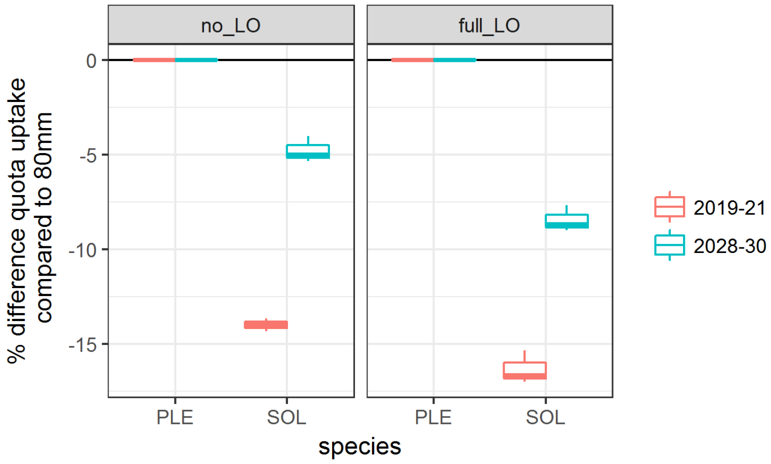

Figure 4.22 *Effect of the change to 90mm meshsize nets on the quota uptake of plaice (PLE) and sole (SOL) on the short (2019-2021) and medium (2028-2030) terms in case of no LO implementation (left) or full implementation (right).*

Economic impact

To compensate the loss of catchability and try to maintain their level of landings (***Figure 4.23***), all fleets increase their effort (***Figure 4.24***) but especially the fleet of larger beam trawlers that would spend 50 to 70% more time at sea.

The performances of the different fleets are described below:

- TBB 12-24m: The initial decrease of landings of sole is compensated by the increased landings of shrimp and plaice (***Figure 4.23***) leading to a slight increase in revenue (5% ***Figure 4.25***). Despite the effort and fuel costs increase by 15%-20% (***Figure 4.24*** & ***Figure 4.26***), the growth cash flow improves with the 90mm nets (**Figure 4.27**) and the NPV of profit increases by 7% (in case of LO) to 11% (without LO ***Figure 4.28***).
- TBB 24-40m: effort & fuel costs increase by 15% and 30-40% resp (***Figure 4.24*** and ***Figure 4.26***). A slight increase of plaice landings (***Figure 4.23***), leads to higher revenues (***Figure 4.25***). Those do not compensate the higher fuel costs (***Figure 4.26***), leading to 10-50% lower GCF (**Figure 4.27**) and 10 to 15% lower NPV of profit (***Figure 4.28***). The economic situation is initially worse with LO implementation and 90mm for this fleet, leading to 7% less vessels after 10 years (***Figure 4.30***). The economic performances of the remaining vessels improves as they can increase their individual landings of sole and while the impact of introducing 90mm mesh sizes is still negative, the remaining vessel fares better than without LO.
- TBB 40-XXm: to compensate the lower catchability, the effort is increased by 40 to 70% per vessel (***Figure 4.24***) leading to higher fuel costs (***Figure 4.26***) and lower crew compensation (-10 to -15% ***Figure 4.29***). The increase in plaice landings compensate the decrease in sole landings (***Figure 4.23***) and lead to up to 10% increase in revenue (***Figure 4.25***). But even

though the revenue is higher, the profitability of the fleet is reduced by 30% (***Figure 4.28***) but remains positive. The combination of 90mm and LO leads to less vessels exiting the fleet (***Figure 4.30***) because of the effort needed and quota availability.

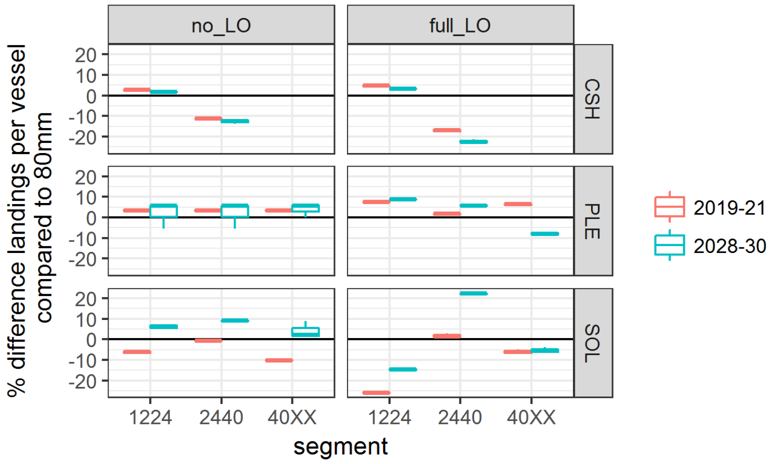

Figure 4.23 *Effect of the change to 90mm meshsize nets on the landings of marketable fish of shrimp (CSH), plaice (PLE) and sole (SOL) per fleet segment on the short (2019-2021) and medium (2028-2030) terms in case of no LO implementation (left) or full implementation (right).*

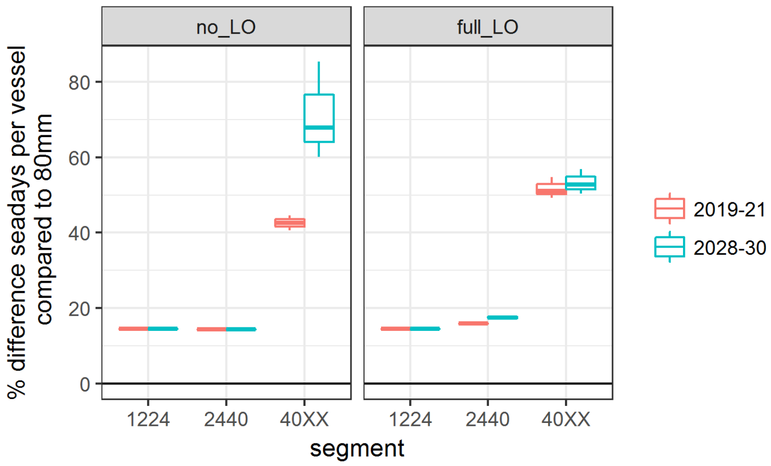

Figure 4.24 Effect of the change to 90mm meshsize nets on the seadays per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms in case of no LO implementation (left) or full implementation (right).

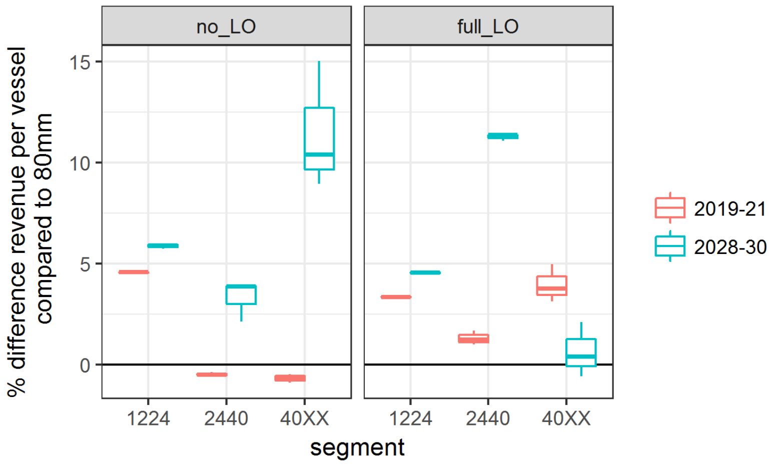

Figure 4.25 *Effect of the change to 90mm meshsize nets on the revenue per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms in case of no LO implementation (left) or full implementation (right).*

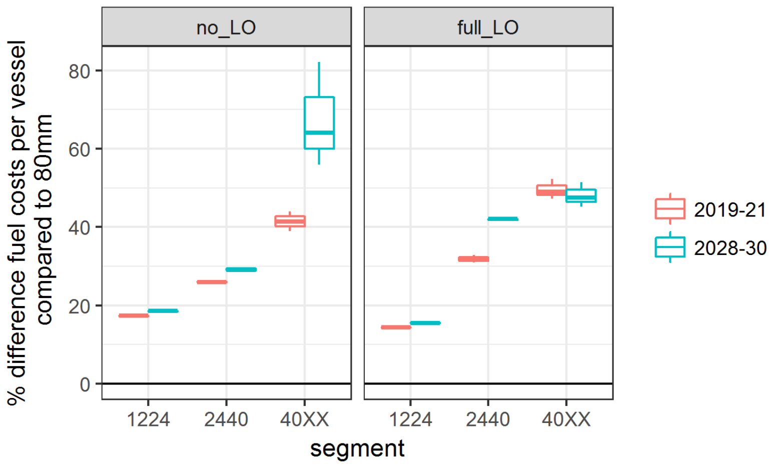

Figure 4.26 *Effect of the change to 90mm meshsize nets on the fuel costs per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms in case of no LO implementation (left) or full implementation (right).*

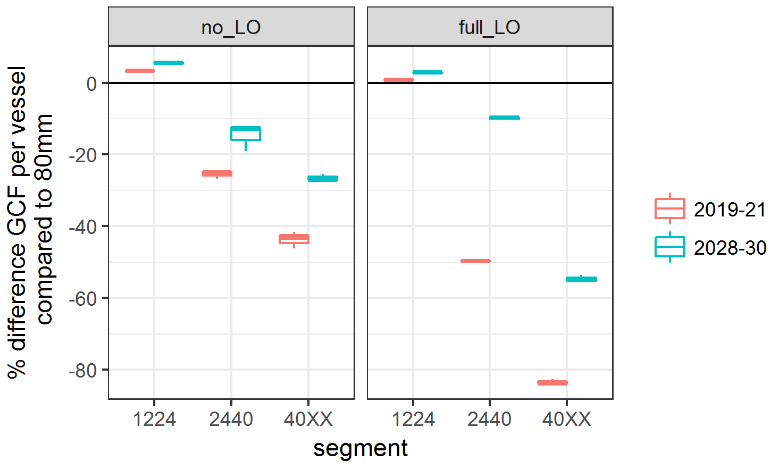

Figure 4.27 *Effect of the change to 90mm meshsize nets on the gross cash flow per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms in case of no LO implementation (left) or full implementation (right).*

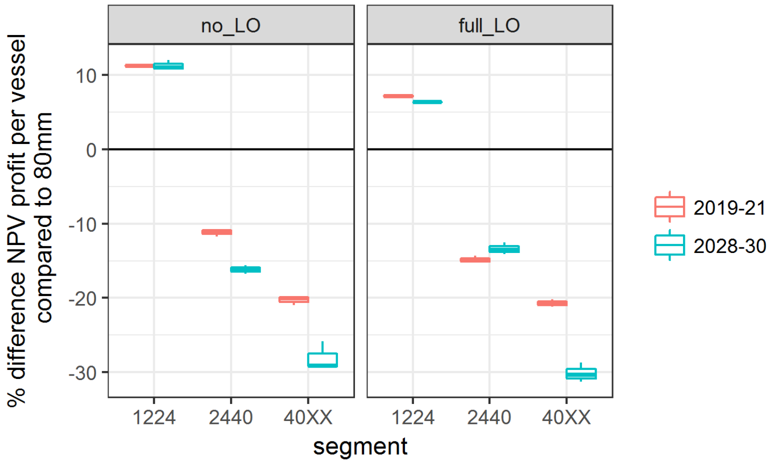

Figure 4.28 *Effect of the change to 90mm meshsize nets on the net present value (NPV) of profit per vessel per fleet segment on the short (2019-2021) and medium (2028-2030) terms in case of no LO implementation (left) or full implementation (right).*

Social impact

Crew costs tend to follow the trend of the GCF and an improvement is seen in the remaining vessels of the 24-40m fleet because of the exit of vessels in the LO scenario. Switching to 90mm nets would mean extra seadays for vessels in all fleets (***Figure 4.24***), having a serious impact on their work-life balance by limiting the amount of time spent on land.

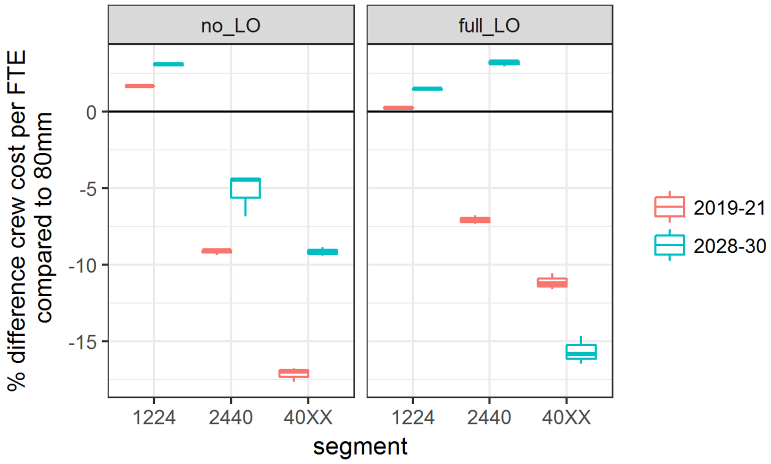

Figure 4.29 *Effect of the change to 90mm meshsize nets on the crew cost per FTE per fleet segment on the short (2019-2021) and medium (2028-2030) terms in case of no LO implementation (left) or full implementation (right).*

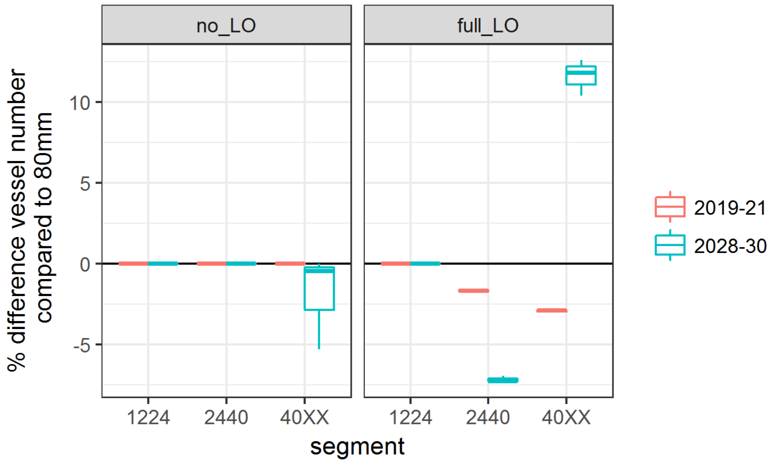

Figure 4.30 *Effect of the change to 90mm meshsize nets on the number of active vessels per fleet segment on the short (2019-2021) and medium (2028-2030) terms in case of no LO implementation (left) or full implementation (right).*

5 Discussion

In this study we were asked to evaluate the medium term impact of the LO (after 10 years), and to look at the impact of a number of scenarios on survivability and change in selectivity. The results are discussed below, first on the LO in general and then looking at the survivability and selectivity change. The limitation of the current approach is discussed after.

The implementation of the LO without plaice exemptions will have lasting effect on the Dutch flatfish fishery. In this study we looked at the effect of the LO on three fleets (defined based on their vessel length as in the EU DCF data) targeting sole and plaice with beam trawls.
The impact of the LO implementation on the stocks are quite limited for plaice (<1%), variable for sole depending on the scenarios. The impact of the change of mesh size has a much larger impact on the sole stock than the LO because changing the relative catchability of sole and plaice makes the plaice quota even more limiting and reduces the uptake of sole quota.
The LO would be felt differently by the three fleets. Some of the extra effort allowed in the model for the smaller vessels (12-24m) so that they can steam to and from fishing grounds to compensate the limited onboard storage is used to target shrimp (not impacted by the LO). By decreasing slightly their effort towards flatfish, the fleet could allocate 130% of that freed effort towards the shrimp fishery (in our scenarios there are no limit on effort or landings for shrimps) leading to the improvement of its economic situation on short and medium term. The fleets fishing exclusively or semi exclusively on flatfish and for which no extra effort allowed show poor economic performance due to the introduction of the LO. So much so that the LO results in a substantial decrease of the fleets after 10 years, up to 7% for the 24-40 fleet and between 10 and 17% for the vessels larger than 40m (40XX).

While the smaller vessels benefit at the vessel level, the extra crew needed during flatfish trips mean that on average, remuneration of the crew would immediately decrease by 20% and 22% on the long term. For the 24-40m fleet, the crew cost per FTE also decrease by about 18%, only the larger vessels seem to end up with better crew remuneration. However, those results are obtained based on estimates on extra labour at sea from the best practice 1 project (Buisman et al. 2013), more recent trials done during this project, indicate that for larger vessels 3.6 extra FTEs (compared to the 2 extra FTEs used in the model; or almost twice as much extra labour) are needed to sort out all the additional landings (VisNed, unpublished). Those results have not been taken in this task by lack of time, but should be included in a later study where scenarios should be investigated as to how this extra labour is compensated (e.g. by decreasing the individual remuneration or proportionally increasing labour costs, or a solution in between).

The real past survivability of plaice remains uncertain. With the estimated survivability, not only would the benefit of the LO to the stock decrease, it would also worsen the economic situation of the fleets, and the degradation of economic profitability only increases in time. If the estimates of Schram and Molenaar (2018) are accurate, the full implementation of the LO on plaice (currently still largely exempted) would have worse consequences than what has been expected and the need to adapt their selectivity to avoid unwanted catch would be stronger.

The 90mm selectivity has a beneficial impact on the stock of sole because the quota cannot be caught anymore as the plaice quota become limiting but not on plaice as the fleets compensate by fishing more, reducing their profitability and the crew remuneration. Unfortunately, the 90mm nets reduce too much of the wanted part of the catch to become a viable gear, even after 10 years. The effort needed to catch the (most part of the) sole quota is much higher than what is needed with 80mm nets. This not only has an impact on bycatch species that still cannot escape 90mm nets but also on the habitat. Nets have to be dragged longer on a larger surface to catch the same amount of the target species, sole. In a political environment where the space still available for fishing is threatened to be drastically reduced (PBL, 2018) and crowding effect is expected, spending more time at sea to catch the same amount of the target species would certainly be controversial.

Limitations to the approach

Modelling approaches are very data consuming and the quality of the data put in is reflected in the quality of the output. In this study we based most of the parameterisation on results from this project. However, large uncertainties on survivability and selectivity remain as the trials have been limited. In addition, all trials have been done with pulse trawls while it will not be allowed after 2021. Given the claims that pulse was more selective than the traditional beam-trawl, reverting back to the traditional gear will likely worsen the impact of the LO.

The model is very sensitive to the data put in and the constraints set on the behaviour of the fleets. The model optimises profit within a set of constraint, as long as fishing is profitable, the model is very much driven by those constraints. The total sea-days that are allowed for each fleet are one of those constraint that has been adjusted to allow extra fishing due to 1) larger steaming proportion for the fleet of 12-24m vessels and 2) lower catchability of the 90mm gear. Of course this extra time at sea comes at a cost, less time on land for repair or free, social time. This cost is not included in the dynamics of the model and how much would a vessel really increase their time at sea is probably fisher-specific. In this model we chose ad-hoc limits depending on the scenario (*Table 2.5*) those should be revisited based on data collection with fishers. And sensitivity analysis should be ran to check how those limits impact the results of the simulations.

6 Conclusions

Negative economic consequences for the flatfish exclusive fleets for little biomass improvement

Despite being implemented to reduce the bycatch and discarding of unwanted catch, the model projections suggest that the LO would have very little impact on the stock of plaice, which is the most discarded species under quota of the North Sea flatfish fishery. This is due to the fact that the fishery is very much driven by the landings of high value sole and that the technical interactions between sole and plaice cannot yet be reduced by beam trawling. The stock of sole would benefit from lower catches as the quota of plaice becoming limiting and the uptake of sole quota would then be lower.

The fleets on the other hand would be severely impacted with on average 3 to 13% fewer vessels in the 24-40m and above 40m fleets leaving the fishery within 10 years of LO implementation. The remaining vessels also suffer from the LO and display 20 to 40% lower NPV of profit after 10 years.

The LO would lead to worst outcome than expected inif the current survivability is positive

The slight increase in plaice biomass gained through the implementation of the LO would be completely dissipated if the actual survivability of discards is non null (as assumed by stock assessment). Indeed, given the importance of plaice discards, the survivability of 20% of those discards would have an importance at the population level. And while using the adjusted biomass to calculate the TAC leads to its reduction on the short term and to a worsened economic situation for the flatfish exclusive fleets, it avoids overexploiting the stock on the short term which would have even more dire consequences for those fleets on the medium term.

Switching to 90mm would lead to worse economic and ecological situation

The limited trials with 90mm mesh-sized nets have not been encouraging, the loss of catchability of marketable sole can only be compensated by additional fishing effort at the cost of bycatch species, habitat and the economic performances of the fleet. Additional work is still needed to design a gear that would maintain the fishing capabilities of the target species sole while decreasing the bycatch of other less desired species.

The social costs of LO, changing work practices and social balance

The current implementation of the LO (with plaice exemption), has had little impact on the fleet as the volume of unwanted catch that must be landed remains low. For this reason, some aspects remain unclear and the parameterisation of the model reflect that. Recent results (VisNed, unpublished) indicate that the extra labour needed to process the catch on-board could be twice as high as previously estimated (Buisman et al. 2013) or about double the number of crew on-board (with the impact it would have on space on-board). Beyond the quantitative assessment of the LO implementation, lifting the exemption on plaice and processing the unwanted catch on-board will have deep impacts on the life on-board. The extra work will completely transform the practice on-board, potentially halving the level of remuneration.

The extra time at sea expected to catch the sole quota would profoundly alter the life of fishers and the organisation of the fishery, leaving less time for activities on land, connected to work such as vessel maintenance or meeting attendance or simply time to socialise, be part of a community and a family.

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The mission of Wageningen University and Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 5,000 employees and 10,000 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.