Continued monitoring of the Dutch Norway lobster fleet and further methodological development (2019-2023)

A continuation and development of a science-industry partnership to improve date gathering for Norway lobster (*Nephrops norvegicus)* stock assessment

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[1] Wageningen Marine Research
[2]Nederlandse Vissersbond
[3]VisNed

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Summary

Background
Norway lobster (*Nephrops norvegicus,* hereafter indicated as Nephrops*)* are divided into stocks (functional units, FUs) across the North Sea, for which ICES provides separate advice. The Dutch fishery mainly catches Nephrops in FU5, FU33 and outer FUs, which are considered as data-limited stocks (DLS). The advice is currently based on average of (international) landings from commercial catch. For DLS, ICES applies the precautionary principle. By using discard data complementary to landings data, the assessments could be strengthened. Discard data of the Dutch fleet is collected through the Data Collection Framework (DCF), which however has limited coverage of the Nephrops metiers. This data has thus far not been used in the ICES Nephrops assessment.

A monitoring program started in 2019 to improve the discard data collection in FU5, FU33 and the outer FUs (OSW 2.0). It involved self-sampling by a reference fleet, combined with scientific observations. To measure total catch on-board, a static load cell system was developed (Bleeker et al., 2021). In 2019 and 2020, international scientists (ICES North Sea Working Group, WGNSSK) provided feedback on the monitoring methodology of OSW 2.0 and recommended improvements in sampling coverage and randomization. In the follow-up program (OSW 2.2, ran from 2020 to 2023) the reference fleet was expanded (from 3 to 5 vessels) and alternative monitoring techniques that would allow more flexible application on a larger number of vessels was explored. This report aggregates data collected in OSW2.0 and OSW2.2. OSW 2.0 and OSW 2.2 were funded under the European Fund for Maritime Affairs and Fisheries (EMFF).

Discard and landing monitoring of the reference fleet
The monitoring scheme ran from quarter two of 2019 to quarter two of 2023, in which the reference fleet sampled a 93 self-sampling trips and 10 observer trips. The number of sampled hauls was not equally distributed between the sampling areas. Coverage with sampling hauls of FU5 was more than twice as high as in FU33 and the outer FU areas. The analysis focussed on Nephrops landing and discard weights and length-frequency (LF) distributions. Potential spatiotemporal effects and potential differences between sampling areas, years, or seasonal differences between quarters were analysed using Generalised Linear Models.

Weight data
Total Nephrops landings were highest in the third quarter across all fully monitored years, accounting for over 30% of the total landings. In the discards, Nephrops contribution was considerably lower, with flatfish and round fish accounting for the largest portion of the discard weights. The main discard species were found to be European plaice (*Pleuronectes platessa*) and Common dab (*Limanda limanda*) among the flatfish, and whiting (*Merlangius merlangus*) and Grey gurnard (*Eutrigla gurnardus*) regarding round fish. Landings were dominated by Nephrops as well as by non-target flat- and round fish species, namely European plaice and turbot (*Scophthalmus maximus*) as well as anglerfish (*Lophius piscatorius*) and Atlantic cod (*Gadus morhua*).

Analysis showed that there are significant spatiotemporal effects on both the Nephrops LPUE and the DPUE, with differences found between areas, quarters, and years. The lowest LPUE and DPUE were found in area FU33, while LPUE and DPUE were highest in the outFU areas and FU5, respectively.

Length data
The carapace length of landed Nephrops ranged from around 2.5 cm to 6.4 cm, while carapace lengths of discarded Nephrops were, on average, smaller than the landed individuals. In both discards and landings, male Nephrops were significantly larger than females.

Significant spatiotemporal effects (originating from area, quarter, year) on the average length were found for Nephrops. In addition to this, the largest average carapace length of discarded Nephrops was found in FU33 and the smallest in FU5. The average length was highest in quarter three and smallest in quarter four in the discards. Regarding landed Nephrops, significant spatiotemporal effects (area, year) on the average carapace length was found as well. Differences between areas, years, as well as quarters were found. Comparable to the discards, the largest average carapace length was found in FU33 and the lowest in FU5. Across all years sampled, the first quarter had the highest average length recorded for landed Nephrops while the smallest ones were to be found in quarter four.

Validation

The validation of the self-sampling scheme data by using observer sampling data did not find any significant differences between sampling by fishers and observers, for neither LPUE nor DPUE. Regarding the average Nephrops carapace length, however, the validation process showed that discarded Nephrops were on average larger in the self-sampling compared to the observer sampling.

Alternative monitoring methods

Four alternatives to static loadcells for measuring catch weight were explored: standardized proportion factor of landed versus discarded Norway lobster, visual estimations by skipper and crew, 3D photogrammetry and mobile loadcells. These alternatives were evaluated on financial effort and time effort required for their application on board, data quality (accuracy of weight estimation compared to the loadcells), and ability to ensure randomization and spread across the monitoring fleet. While each of the methods had its own set of advantages compared to static load cells, many of these techniques could not be readily employed. Advantages were ease of monitoring across the fleet (visual estimations, mobile load cells, proportion factor discarded versus landed lobster). Especially the mobile load cells could show great advantages over the static load cells in terms of monitoring flexibility and costs, as it showed weight estimates close to that of the static load cells. Yet disadvantages were relatively large errors in the estimates (e.g. for visual estimation, proportion factor) and low cost-efficiency (3D photogrammetry). Further testing of these methodologies would be needed to draw definite conclusions, and further development could improve these shortcomings.

Communication and collaboration

The aggregated results were presented and discussed at an annual meeting for all research cooperation projects within WMR (OSW-day), which could be attended by the entire fishing industry, provided they were members of one of the participating Producer Organisations (POs). For the reference fleet, a Skippers-day and individual calls were organised, in which the project results were discussed and feedback on the project (collaboration, set-up, continuation) was collected. The skippers of the reference fleet could identify with the findings and the research collaboration was met with a very positive response, especially the contact with and cooperation of the observers.

Follow-up

To obtain a consistent time-series of discard data of at least five years, data collection should be continued for another year (until 2024). The data could then be raised to fleet level and be compared to the discard data as collected under the DCF to evaluate its accuracy. A continued use of static load cells is recommended for further data collection, provided that safety and maintenance of the load cells are ensured. Additionally, it is imperative to have continued engagement of a stable reference fleet. Moreover, effort should be put in a more standardized protocol (e.g. always measure cod-end at same hight to ensure measurement consistency) and potential influences on the measurement (e.g. water leaking from cod-end) should be examined. Ideally, the time-series contains five consecutive years of data to be used in the stock assessment models.

Samenvatting

Achtergrond
De afgelopen jaren is Noorse kreeft (*Nephrops norvegicus*, vaak langoustine genoemd) belangrijker geworden voor de Nederlandse visserij. De Noorse kreeftenvisserij in de Noordzee wordt vanuit de Europese Unie beheerd onder één totaal toegestane vangst (*total allowable catch*, TAC) onder het gemeenschappelijk visserijbeleid. De Internationale Raad voor het Onderzoek van de Zee (ICES) behandelt in hun vangstadviezen de soort echter in afzonderlijke bestanden, die "functionele eenheden" (*functional units*, FU's) worden genoemd. Voor elke FU geeft ICES een apart advies. De Nederlandse visserij vist voornamelijk op Noorse kreeft in FU5 (Botney Cut), FU33 (Off Horn's reef) en in het gebied buiten de aangewezen habitats (outFUs). ICES beschouwt deze FU's als data-arme bestanden (*data-limited stocks*, DLS). Voor zulke bestanden past ICES het voorzorgsprincipe toe in het vangstadvies, waarbij alleen een gemiddelde van de (internationale) aangelande vangsten uit commerciële vangstgegevens wordt gebruikt.

Wanneer ook discardgegevens gebruikt worden als aanvulling op aanlandingsgegevens, kunnen de berekeningen die ten grondslag liggen aan het ICES-advies worden versterkt. Dit kan uiteindelijk voor preciezere bestandschattingen en vangstadviezen zorgen, wat tot beter onderbouwde TAC's leidt. Sinds 2002 wordt het verzamelen van discardgegevens in de Nederlandse vissersvloot al verplicht gesteld vanuit de EU. Dit gebeurt onder het *Data Collection Framework* (DCF). Het DCF heeft echter een beperkte dekking van de Noorse kreeft-metiers, met name voor FU33. De discardgegevens vanuit het DCF worden wel ingediend bij de ICES, maar zijn tot nu toe nog niet gebruikt als onderdeel van de bestandsbeoordeling van Noorse kreeft.

Voortzetting en ontwikkeling OSW2.0
In 2017 werd een consortium tussen onderzoekers, de visserijsector, maatschappelijke organisaties en de overheid opgericht om een monitoringprogramma te ontwikkelen dat de gegevensverzameling over discards in FU5, FU33 en de buitenste FU's verbetert. Dit monitoringsprogramma omvatte zelfbemonstering door een geselecteerde referentievloot, gecombineerd met wetenschappelijke waarnemersreizen. Het doel van dergelijke zelfbemonstering is dat vissers zelf de gegevens verzamelen, zonder wetenschappelijke ondersteuning aan boord. Om de totale vangst (aanvoer, discards en 'afval') aan boord van een kotter te meten, werd een loadcell (giekunster) systeem ontwikkeld. Dit betreft een weegsysteem dat aan boord wordt geïnstalleerd en het mogelijk maakt om het gewicht van de vangsten te meten, terwijl gecompenseerd wordt voor de beweging van het schip.

Het monitoringsprogramma startte onder de noemer van '*Onderzoekssamenwerking (OSW) 2.0'* en liep van 2019 tot 2020 (Bleeker et al., 2021). In 2019 en 2020 hebben internationale wetenschappers (ICES North Sea Working Group, WGNSSK) feedback gegeven op de monitoringmethodologie van OSW 2.0 en verbeteringen aanbevolen in de dekking en randomisatie. In het vervolgprogramma (OSW 2.2, dat liep van 2020 tot 2023) werd de referentievloot daarom uitgebreid (van drie naar vijf vaartuigen) en werden alternatieve monitoringtechnieken onderzocht die een flexibelere toepassing op een groter aantal vaartuigen mogelijk zouden maken. OSW2.2 liep van 2020 tot 2023 en omvatte drie onderzoeksdoelstellingen: 1) Monitoring van de referentievloot en validatie van zelfbemonstering, 2) Evaluatie van alternatieve methoden voor monitoring van de discards en 3) verzekeren van communicatie richting de sector en andere belanghebbenden. In dit verslag zijn de gegevens samengevoegd die in OSW2.0 en OSW2.2 zijn verzameld. OSW 2.0 en OSW 2.2 werden gefinancierd in het kader van het Europees Fonds voor Maritieme Zaken en Visserij (EFMZV).

Resultaten discardmonitoring OSW2.2
Het monitoringschema liep van Q2 van 2019 tot Q2 van 2023. De referentievloot bestond uit één (2021) tot vijf vaartuigen (2022), die in de loop van de bemonsteringsperiode in totaal 93 reizen voor

zelfbemonstering en 10 reizen voor waarnemers hebben gemaakt. Het best bemonsterde jaar was 2022 met een maximum van 74 bemonsterde trekken tijdens de zelfbemonstering en 49 bemonsterde trekken bij de waarnemersreizen. Bij de zelfbemonstering werd kwartaal drie het best gedekt met een maximum van 68 bemonsterde trekken, terwijl kwartaal vier het minst gedekt was met 36 bemonsterde trekken. Het aantal bemonsterde trekken was niet gelijk verdeeld over de bemonsteringsgebieden. De dekking van de bemonsterde trekken in FU5 was meer dan twee keer zo groot als in FU33 en de outer-FU-gebieden.

De gegevens van OSW2.0 zijn ook gebruikt in de analyse om een overzicht te geven van de totale tijdreeks tot nu toe. Voor de analyse werden de gegevens gebruikt die werden verzameld tijdens de zelfbemonstering, namelijk het gewicht en lengte-frequentie (LF) verdeling van aangelande en discarded Noorse kreeft. Generalised Linear Models (GLM's) werden toegepast op de gegevens om mogelijke spatio-temporele effecten op de gegevens te analyseren en mogelijke verschillen tussen bemonsteringsgebieden, jaren of seizoensverschillen tussen kwartalen te identificeren.

Gewicht

De totale aanvoer van Noorse kreeft was het hoogste in Q3 van alle volledig gemonitorde jaren, met meer dan 30% van de totale aanvoer in dat kwartaal. Bij de discards was het aandeel van Noorse kreeft aanzienlijk lager, waarbij platvis en rondvis het grootste deel van het gewicht voor hun rekening namen. De meest voorkomende soorten in de discards waren schol (*Pleuronectes platessa*) en schar (*Limanda limanda*) bij de platvis, en wijting (*Merlangius merlangus*) en grauwe poon (*Eutrigla gurnardus*) bij de rondvis. De aanvoer werd gedomineerd door Noorse kreeft en door bijvangst van platvis en rondvis, namelijk schol (*Pleuronectes platessa*) en tarbot (*Scophthalmus maximus*), zeeduivel (*Lophius piscatorius*) en Atlantische kabeljauw (*Gadus morhua*).

Er zijn geen significante verschillen gevonden in het gemiddelde gewicht tussen de aanvoer per inspanningseenheid (LPUE) en de gemiddelde discards per inspanningseenheid (DPUE) van Noorse kreeft. Er zijn wel significante spatio-temporele effecten (waar en wanneer wordt gevist) op zowel de LPUE als de DPUE van Noorse kreeft. Dit betreft verschillen tussen gebieden, kwartalen, maar ook tussen jaren. De laagste LPUE en DPUE werden gevonden in gebied FU33, terwijl de LPUE het hoogst was in de outFU-gebieden en de DPUE het hoogst in FU5. De resultaten toonden ook aan dat de LPUE en DPUE 's nachts hoger zijn dan overdag, wat echter ook wordt beïnvloed door verschillen tussen kwartalen. Er werd geen significant verschil gevonden tussen LPUE en DPUE.

Lengte

De lengte van aangelande Noorse kreeft varieerde van ongeveer 2,5 cm tot 6,4 cm (gemeten op het carapax). De lengte van Noorse kreeft in de discards was gemiddeld kleiner dan die van de aangelande individuen. Bovendien waren zowel bij de discards als bij de aanlandingen de mannelijke Noorse kreeft significant groter dan de vrouwtjes. Er werden geen lengteverschillen gevonden tussen dag- en nachtvangsten. Voor Noorse kreeft in de discards zijn ook significante spatio-temporele effecten gevonden voor de gemiddelde lengte (gebied, kwartaal en jaar). Daarnaast is de gemiddelde lengte van Noorse kreeft in de discards groter in FU33 dan in FU5. De gemiddelde lengte was het hoogst in Q3 en het kleinst in Q4. Bij de aangelande Noorse kreeft werd ook een verschil tussen gebieden, jaren en kwartalen op de gemiddelde lengte gevonden. Echter is alleen het verschil in gebied en het jaar significant gebleken. Vergelijkbaar met de discards werd de grootste gemiddelde lengte gevonden in FU33 en de kleinste in FU5. In alle jaren van bemonstering werd in Q1 de grootste gemiddelde lengte voor aangelande Noorse kreeft gevonden, terwijl de kleinste in Q4 werden aangetroffen.

Bij de validering van de gegevens van de zelfbemonsteringsregeling aan de hand van de gegevens van de waarnemersbemonstering werden geen significante verschillen gevonden tussen de bemonstering door vissers en door waarnemers, noch voor de LPUE, noch voor de DPUE. Wat echter de gemiddelde lengte van Noorse kreeft betreft, bleek uit het validatieproces dat de aanlandingslengte significant groter was voor de gegevens van de zelfbemonstering dan voor de gegevens van de waarnemersbemonstering, terwijl er geen verschillen in lengte waren voor de discarded Noorse kreeft tussen de zelfbemonstering en de waarnemersbemonstering.

Resultaten alternatieve bemonsteringsmethoden
Vier alternatieven voor het meten van het vangstgewicht werden geëvalueerd. Deze alternatieven zijn niet afhankelijk van permanent aan boord geïnstalleerde meetapparatuur. Ze zijn geëvalueerd op basis van de financiële investering en de tijd die nodig is om ze aan boord toe te passen, de kwaliteit van de gegevens (nauwkeurigheid van gewichtsschatting) en de mogelijkheid om randomisatie en spreiding over de vloot te bevorderen. Aangezien het doel was om een eerste inzicht te krijgen in de deze kenmerken, werd spreiding van de testmethoden over tijd, locatie en vaartuigen niet meegenomen in de onderzoeksopzet.

Verhouding aangelande/discarded Noorse kreeft
De verhouding tussen aangelande en discarded (teruggegooide) kreeft in een vangst zou kunnen worden gebruikt om een indicatie te geven van het discardgewicht op basis van het gewicht van de aangelande Noorse kreeft. De verhouding tussen discarded (ondermaatse) en aangelande (maatse) Noorse kreeft werd berekend door het gewicht van de discards te delen door het aangelande gewicht per gebied en per kwartaal. Er is echter geen duidelijke verband gevonden tussen de discard en de aanlandingsgewichten. Een grote variabiliteit in zowel het discard- als aanlandingsgewicht werd gevonden tussen de verschillende FU’s, maar ook tussen kwartalen, wat de berekening van één enkele verhoudingsfactor bemoeilijkte.

Bij het berekenen van een verhoudingsfactor voor het schatten van de Noorse kreeft discards op basis van hun aanlandingsgewicht, wordt aanbevolen om meerdere trekken per reis te bemonsteren om de effecten van het bemonsteringsgebied en de seizoensgebondenheid (door kwartalen als variabele op te nemen) mee te nemen. Ook wordt aanbevolen om nader onderzoek te doen naar de verhouding tussen maatse en ondermaatse Noorse kreeft in de discards.

Visuele schatting
Visuele schatting door schipper en bemanning, zoals ook uitgevoerd in het demersale discard bemonsterings programma onder het DCF, werd onderzocht. De nauwkeurigheid van de methode werd geëvalueerd door het geschatte vangstgewicht te vergelijken met het "echte" vangstgewicht (alle discards verzameld en gewogen). Hoewel visuele schattingen haalbaar bleken in termen van tijd en kosten, en willekeurig toepasbaar zijn op de hele vloot, leveren ze geen nauwkeurige of precieze schatting op. Bovendien liepen de schattingen van de bemanningsleden sterk uiteen, waardoor het gewicht van de vangst over- of onderschat werd. Bovendien bleek uit het experiment dat de schattingen nauwkeuriger waren voor de meer voorkomende soorten in de vangst en dat wanneer de totale vangst van een trek relatief klein is, het gemakkelijker is om het vangstgewicht of -volume te schatten.

3D photogrammetry
SINTEF Ocean ontwikkelde 3D-photogrammetry als middel voor vangstschatting. De nauwkeurigheid van de methodologie werd geëvalueerd door het met 3D-analyse geschatte gewicht van de vangst (gebaseerd op het geschatte volume en de bemonsterde massadichtheid) te vergelijken met de statische loadcell-metingen. De methodologie toonde potentieel in het nauwkeurig schatten van de vangst. Afwijkingen waren waarschijnlijk te wijten aan onzekerheden in de analyse, waaronder de schatting van de dichtheid van de genomen monsters, openingen in de stortbak, en nauwkeurigheid van het gebruikte 3D-model. Momenteel moet de analyse worden uitbesteed en is er geen real-time terugkoppeling, waardoor de tijd en de financiële inspanningen sterk toenemen. Er zijn meerdere verbeteringen mogelijk om de nauwkeurigheid van de gegevens te verbeteren en er is ontwikkeling nodig om van fotogrammetrie een haalbaar alternatief te maken.

Mobiele loadcellen
Het gebruik van meer mobiele loadcellen (d.w.z. een op batterijen geladen loadcell die via Wi-Fi verbonden is met een bedieningskastje dat in een stopcontact is gestoken) zou het mogelijk maken om het systeem van het ene schip naar het andere over te zetten en zo een grotere dekking van de vloot te krijgen. De mobiele loadcellen werden getest door een bekend gewicht te meten tijdens zware en lichte deining. Het mobiele loadcell systeem liet nog vangstgewichtschattingen zien die qua

afwijkingen vergelijkbaar zijn met de metingen met de statische loadcell. Het gebruik van mobiele loadcellen heeft echter een voordeel wat betreft financiële inspanning en randomisatie over de vloot. Verschillende factoren hebben de metingen van de mobiele loadcellen tijdens dit experiment belemmerd, zoals fouten in het weegsysteem van de mobiele loadcellen (mogelijk door water dat in het systeem kwam) en de mogelijkheid dat de loadcellen niet vrij hing tijdens de metingen. Het wordt daarom aangeraden om uitgebreider mobiele loadcellen te testen.

Communicatie
De gebundelde en voorlopige resultaten werden gepresenteerd en besproken op een jaarlijkse bijeenkomst voor alle onderzoekssamenwerkingsprojecten binnen WMR (*OSW-dag*). Deze sessie kon worden bijgewoond door de hele visserijsector, op voorwaarde dat zij lid waren van een van de deelnemende PO's. Voor de referentievloot werden tevens een Schippersdag en individuele gesprekken georganiseerd, waarin de projectresultaten werden besproken en feedback over de samenwerking werd verzameld. Drie van de vijf schippers van de referentievloot hebben feedback gegeven. De onderzoekssamenwerking binnen OSW2.2 werd als positief ervaren, vooral het contact en samenwerking met de waarnemers.

De schippers van de referentievloot konden zich vinden in de gepresenteerde resultaten. De verdeling over de bemonsteringslocaties kwam overeen met hun visgedrag. De schippers beaamden ook de samenstelling van de meest voorkomende teruggooisoorten (vis en benthos). De schippers benadrukten vooral de toegenomen hoeveelheid schelvis en tot op zekere hoogte wijting als bijvangstsoorten. Zij gaven aan dat deze soorten pas de laatste een of twee jaar enorm zijn toegenomen in de Noordzee. Ook de verschillen in lengtes tussen de geslachten (d.w.z. grotere mannetjes ten opzichte van vrouwtjes) en hogere aanlandingen van Noorse kreeft per eenheid van inspanning in Q3 en Q4 werden herkend. Tot slot werd het verschil tussen zuidelijke (FU5) en noordelijke (FU33) gebieden bevestigd, waarbij FU33 een hogere aanvoer in Q3 en Q4 en grotere kreeften liet zien.

Meer dan eens werd het verschil tussen zuidelijke (FU5) en noordelijke (FU33) gebieden bevestigd. De schippers vermeldden dat in FU33 de kreeften vanaf Q3 verschijnen. Ze onderschreven ook dat hier grotere kreeften gevangen kunnen worden. Dit komt overeen met de resultaten van de zelfbemonstering. Een interessante ervaring die werd gedeeld, is dat niet alleen een verschil tussen zuid naar noordelijke gebieden zit, maar ook meer regionale verschillen te merken zijn. Vooral in de richting van het Friese Front ervaren de schippers meer lokale verdelingen van grotere en kleinere kreeften. Het zou interessant zijn om deze lengteverdelingen verder te onderzoeken.

Sommige schippers gaven aan dat de Brexit en/of de brandstofprijzen hun visserijgedrag hadden beïnvloed. De schippers merkten meermaals op dat de visserijdruk is toegenomen in de richting van de noordoostelijke habitats van Noorse kreeft, waarschijnlijk als gevolg van deze ontwikkelingen. Hogere brandstofprijzen leidden er onder andere toe dat ze langer aan wal bleven, minder trekken per visreis uitvoerden en meer noordwaarts trokken in de Noordzee.

Vervolg
Om een consistente tijdreeks van discardgegevens van ten minste vijf jaar te verkrijgen, zal de gegevensverzameling nog een jaar worden voortgezet (tot 2024). De gegevens kunnen dan op vlootniveau worden gebracht en worden vergeleken met de discardgegevens die in het kader van het DCF worden verzameld om de nauwkeurigheid ervan te evalueren. Voor de verdere gegevensverzameling wordt het gebruik van statische loadcellen aanbevolen, op voorwaarde dat de veiligheid en het onderhoud van de loadcellen gegarandeerd zijn. Een andere vereiste is de actieve deelname van een stabiele referentievloot. Bovendien moet worden gestreefd naar een meer gestandaardiseerd protocol (bv. meet de kuil altijd op dezelfde hoogte om een consistente meting te garanderen) en moeten mogelijke invloeden op de meting (bv. water dat uit de kuil lekt) worden onderzocht.

1 Introduction

1.1 Norway lobster fisheries

Norway lobster (*Nephrops norvegicus,* often referred to as langoustine; hereafter indicated as Nephrops) can be found in the Eastern Atlantic region, at depths of 20 – 800 meters (Holthuis, 1991). The species uses muddy sediment habitats to excavate their burrows. Nephrops are divided into separate stocks, the distribution of which corresponds to the presence of such sediments (Bleeker et al., 2021). The International Council for the Exploration of the Sea (ICES) refers to these delineated stocks as 'Functional Units' (FUs) (Figure 1).

ICES provides separate scientific advice for each of these stocks (ICES, 2022a, ICES, 2022b; ICES, 2022c). Ideally, fisheries management is also implemented at FU level to ensure sustainable exploitation of the stocks (ICES, 2022a, ICES, 2022b; ICES, 2022c). Nephrops in the North Sea is however managed with a single total allowable catch (TAC) under the Common Fisheries Policy (CFP).

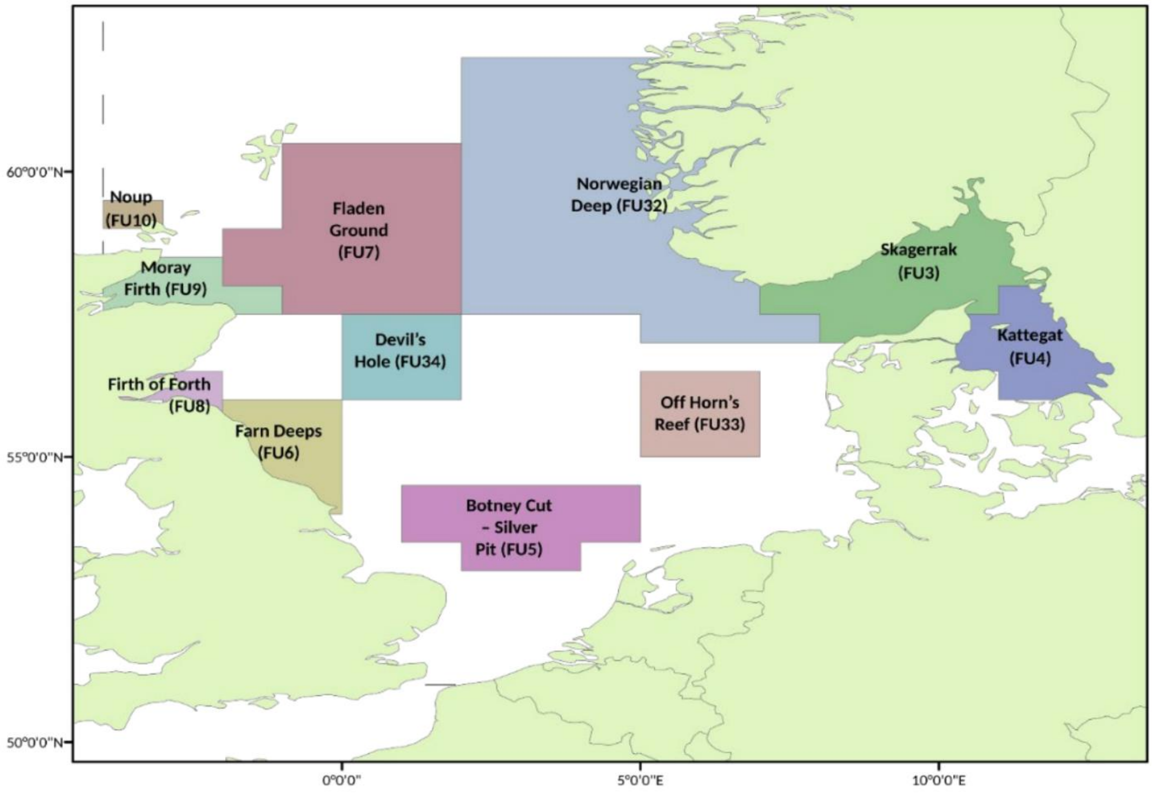

Figure 1. ICES Functional Units for Norway lobster in North Sea and Skagerrak-Kattegat regions (ICES, 2022b).

In recent years, Nephrops has increased in importance for the Dutch fishing fleet (VisNed, 2019). In 2022, 24 vessels under the Dutch flag have landed at least one trip consisting of 30% Nephrops[1]. These vessels use mostly (variations of) otter-trawl nets, but other fleet segments such as beam trawlers also show considerable amounts of Nephrops catches, though it not being a target species here. Landings of the species in the Dutch-flagged fleet show a seasonal pattern, with most Nephrops landed in the third quarter of the year (Figure 2).

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[1] Information extracted from the Wageningen Marine Research (WMR) VISSTAT database (*Visserij Statistieken*).

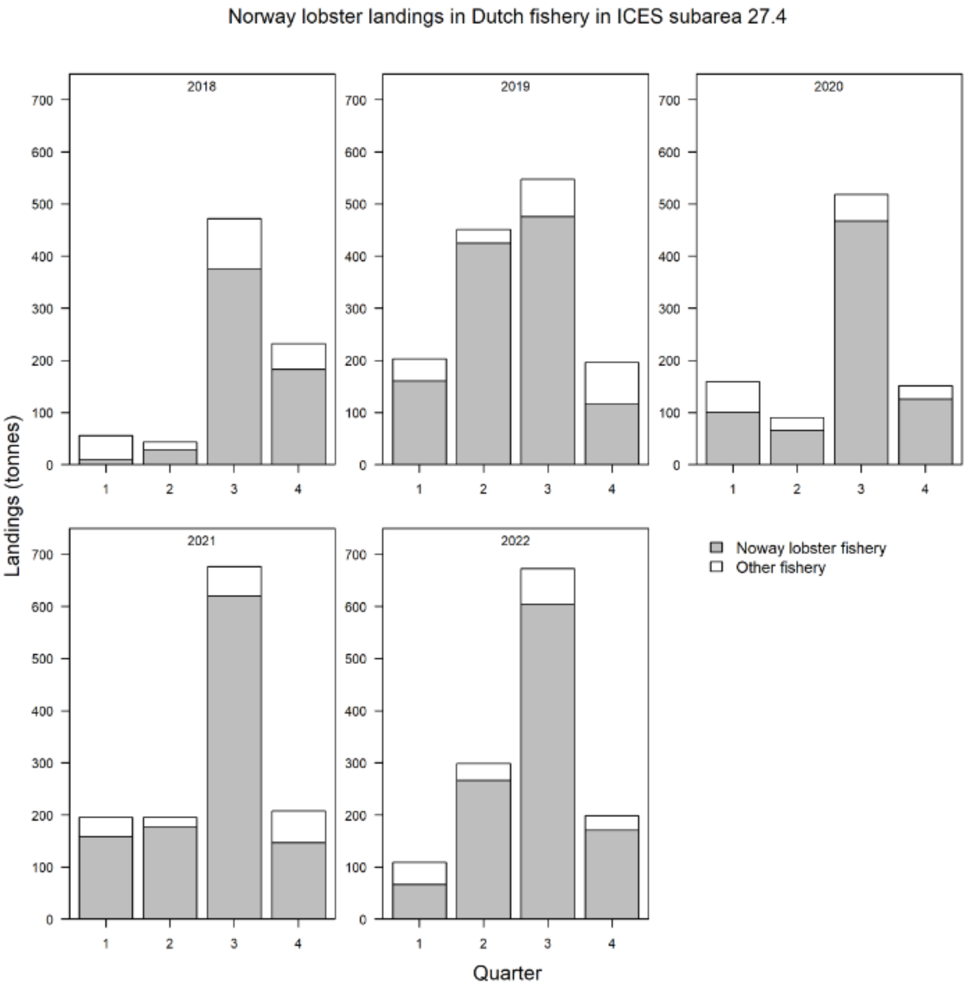

Figure 2. Landings of Norway lobster in in all Dutch-flagged vessels (Norway lobster-targeted and other target species) in Atlantic ocean (ICES subarea 27.4) over the years 2018 – 2022. Information extracted from the Wageningen Marine Research (WMR) VISSTAT database (*Visserij Statistieken*).

Norway lobster fisheries in the Netherlands are subject to multiple regulatory frameworks regarding the discards and landings of species. At EU level, Nephrops is regulated through annual quota. The annual Dutch catch quota typically fall below the annual landings (Figure 3). Quota are therefore traded with other nations. In 2021, landings of Nephrops in the Netherlands were 1278 tonnes, while the initially received national quota (excluding traded quota) were only 514 tonnes. Moreover, the minimum conservation reference sizes of Nephrops is set at carapace length of 25 mm (Regulation 2019/1241). Nevertheless, Nephrops is exempted from the EU landing obligation due to its listing as 'high survival' species, based on the likelihood of it being able to survive after being caught and discarded (Regulation 2018/2034). This exemption allows fishers to discard Nephrops below minimum conservation reference size[2].

Additionally, to support sustainable fishing practices and to prevent early closure of the quota, Dutch fisheries Producer Organisations (POs) have implemented a landing and trading measure. This measure includes a maximum landing amount of 30 lobsters per kg and a maximum landing of 16.000 kg per period of 4 weeks (VisNed, 2023; Vissersbond, 2023)

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[2] The exemption does not apply to Flyshoot vessels.

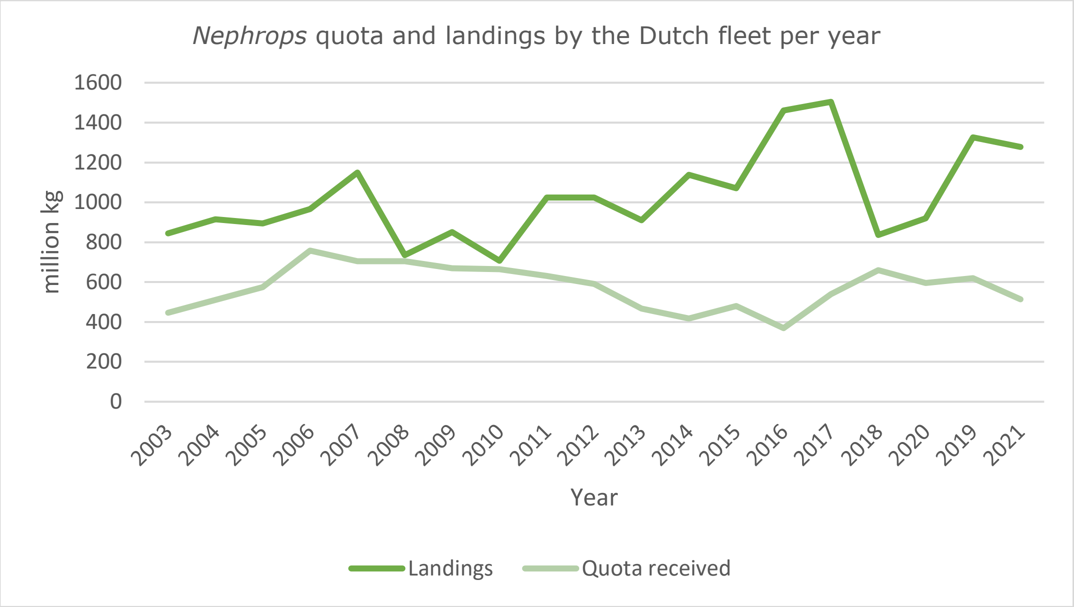


Figure 3. Dutch quota received (excluding the trades) and landings of Norway lobster in Dutch-flagged fleet per year (Visserij in Cijfers, 2023a; 2023b).

1.2 Data-limited stocks

The Dutch fishery mainly catches Nephrops in FU5 (Botney Cut), FU33 (Off Horn's reef), and in the area outside designated habitats (outer FUs). ICES considers these FUs as data-limited stocks (DLS). For DLS stocks, ICES applies the precautionary principle in their advice. For FU33, FU5 and outer FUs, advice is based on landings from commercial catches (ICES, 2022a, ICES, 2022b; ICES, 2022c). By using discard data complementary to landings data on Norway lobster, the assessments underlying the ICES advice could be strengthened and result in more precise stock estimates and catch advice.

Since 2002, the collection of such discard data is mandatory for all Member States and enforced by the European Union (EU) under the Data Collection Framework (DCF) (EU 1543/2000, EU 199/2008, EU 2016/1701, EU 2016/1251, EU 2017/1004, EU 2019/909, EU 2019/910). The DCF program includes the main métier targeting Nephrops, namely otter trawl (otter trawl (OTB), otter twin trawl (OTT) and quadrig (QUA)) fisheries with 70 – 99 mm mesh size. However, there is only limited coverage of the Nephrops metiers in the DCF discard scheme, especially for FU33 (Bleeker et al., 2023). The DCF discard data is submitted to ICES but has so far not been used as part of the Nephrops assessments. Demand emerged for additional data beyond the data series generated by DCF in these particular Nephrops habitats.

Therefore, in 2017, a consortium between research, fishing sector, Non-Governmental organizations (NGOs) and the government was created to develop a monitoring program to increase discard data collection in FU5, FU33 and the outer FUs (Bleeker et al., 2021). To collect data on discards within the Norway lobster fishing fleet, a monitoring scheme was developed to gather data through self-sampling combined with scientific observations. This ‘Fully-Catch-Monitored’ (FCM) system was subsequently tested in the follow-up project ‘*Onderzoekssamenwerking 2.0*’ (OSW 2.0) which ran from 2018 to 2021 (Bleeker *et al.,* 2021). This monitoring program was additional to the discard data collection under the DCF and did not involve vessels that participate in the DCF program.

1.3 Continuation of OSW 2.0

The monitoring methodology and preliminary outcomes of OSW 2.0 have been presented in the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) annually since 2019. Feedback by the NSSK experts has focused on the methodology and recommended for better spatial distribution of sampling across FUs, and a more random sampling scheme (ICES, 2019 & 2020). The sampling method developed under OSW 2.0 differs from the current method used in the DCF program. It depends on the installation of static loadcells which weigh the catch on board of three vessels allowing for a direct weight measure of the catch (Bleeker et al., 2021). The downside of this system is the difficulty of removing and moving it across vessels. To improve coverage across the fleet and thereby representativeness of the data with respect to the entire Dutch Norway lobster fleet, it was recommended to start exploring alternative monitoring technique that allows for more flexible application across a wider range of vessels.

Ideally, the monitoring program lasts for at least five consecutive years to get a consistent time series of data that can be used in the stock assessment models. The goal is to have a time series long and representative enough to be able to raise (extrapolate) the discard data from the sampled vessels to the entire Dutch fleet level. The consequent insights and data are intended to improve ICES' stock assessment of Norway Lobster. Data collection under OSW 2.0 started during 2019 and COVID-19 inhibited data collection during 2020. To establish a more resilient and extended time-series, there was a desire to persist with the monitoring program.
Therefore, a follow-up project '*Onderzoekssamenwerking 2.2'* was initiated in 2020 to continue the time series of collecting discard data from the Dutch Norway lobster fleet and further work towards an internationally accepted monitoring program. OSW 2.2 ran from Q3 2020 to Q3 2023 and involved multiple objectives:

1. To continue the monitoring scheme to ensure data collection and analysis of discards in the Dutch Norway lobster fleet, as well as ensuring opportunities to continue data collection after the project ends in 2023.

2. To explore innovative methods of monitoring that could increase flexibility in the sampling, consequently enabling the possibility of involving more vessels in the monitoring, and thereby improving the spatial coverage and randomization of the sampling.

3. To contribute to increase the accessibility of research for the fishing sector. Improve knowledge and experience of fishermen on data gathering, fisheries management and catch composition regarding the Nephrops fishery.

2 Methods

This project is a continuation of the OSW 2.0 project (2018 – 2020) and runs from 2020 up to 2023. The project includes multiple work packages: 1) Monitoring of the reference fleet and validation of self-sampling, 2) Evaluating alternative methods for discard monitoring and 3) Ensuring communication towards the sector and other stakeholders. The data from the previous project (OSW 2.0) is also used in the analysis for this report to provide an overview of the total time series thus far.

2.1 Monitoring reference fleet

The discard monitoring scheme as developed in the previous project OSW 2.0 (Bleeker et al., 2021) was continued within this project. This monitoring program consisted of self-sampling done by a reference fleet, and a validation of the self-sampling by scientific observations on board of fishing vessels. The monitoring scheme ran from quarter 2 of 2019 to quarter 2 of 2023.

2.1.1 Data collection

The alterations in data collection procedure compared to OSW 2.0 are discussed here. See Annex 1 for more detail on the data collection, including the load cell weighing system, self-sampling procedure and observer trips.

Reference fleet and sampling scheme
To improve randomization and spatial distribution within self-sampling, the reference fleet of OSW 2.0 was expanded from 3 to 5 vessels, following the selection criteria as described in Bleeker et al. (2021). Nephrops fishers that were not yet participating in the Dutch WOT (*Wettelijke OnderzoeksTaken*) discard monitoring program under the DCF were recruited for the monitoring program in consultation with sector representatives. Initially, the criterion '*vessel targets Nephrops fulltime'* was set. This could however not be always ensured, as the participating vessels were found to switch to other target species when experiencing difficulties in achieving high success rates with targeting Nephrops. This is a just transition that the project could not and would want to impede. Therefore, this criterion was abandoned.

To participate in the self-sampling, each participating vessel obtained an exemption from the EU landing obligation with the premise of collecting samples for scientific research. The application for these derogations was coordinated by the PO Nederlandse Vissersbond. Although all derogations were invoked, in some cases the application process took longer which delayed self-sampling in those years.

The number of participating vessels in the self-sampling monitoring scheme varied between 2019 and 2023 with the highest count observed in 2022 (5 vessels) and the lowest in 2020 (1 vessel). For the observer program, the number of participating vessels ranged from one to four vessels during the same period (Table 1, Table 2).

Over the course of the sampling years 2019 to 2023, a total of 93 self-sampling and 10 observer trips was conducted and was included in the analyses (Table 1, Table 2). All hauls that were included in the analyses used quadrig nets.

Table 1. Overview self-sampling scheme. The number of participating vessels in the self-sampling scheme between 2019 – 2023 as well as the number of trips done per quarter (Q1 – Q4) per year is shown. In addition, the number of overall hauls is listed per quarter and year next to the number of hauls sampled for discard and landings.

Self-sampling						
Number of participating vessels	**2019**	**2020**	**2021**	**2022**	**2023**	
	2	3	1	5	3	
Number of trips						**Total**
Q1	–	7	6	5	3	21
Q2	2	6	2	9	1	20
Q3	6	4	6	18	–	34
Q4	4	5	4	5	–	18
Total	12	22	18	37	4	**93**
Number of hauls / Number of sampled hauls						**Total**
Q1	0 / 0	150 / 14	126 / 12	104 / 10	50 / 6	430 / 42
Q2	44 / 4	112 /12	45 / 4	169 / 18	13 / 2	383 / 40
Q3	135 / 12	65 / 8	84 / 12	292 / 36	0 / 0	576 / 68
Q4	85 / 8	93 / 10	70 / 8	93 / 10	0 / 0	341 / 36
Total	264 / 24	420 / 44	325 / 36	658 / 74	63 / 8	**1730 / 186**

Table 2. Overview observer sampling scheme. The number of participating vessels in the observer sampling scheme between 2019 – 2023 as well as the number of trips done per quarter (Q1 – Q4) per year is shown. In addition, the number of overall hauls is listed per quarter and year next to the number of hauls sampled for discard and landings.

Observer-sampling						
Number of participating vessels	**2019**	**2020**	**2021**	**2022**	**2023**	
	2	1	1	4	2	
Number of trips						**Total**
Q1	–	1	0	1	1	3
Q2	1	0	0	1	1	3
Q3	0	0	1	0	–	1
Q4	1	0	0	2	–	3
Total	2	1	1	4	2	**10**
Number of hauls / Number of sampled hauls						**Total**
Q1	0 / 0	8 / 8	0 / 0	9 / 9	11 / 6	28 / 23
Q2	23 / 23	0 / 0	0 / 0	18 / 18	13 / 10	54 / 51
Q3	0 / 0	0 / 0	20 / 20	0 / 0	0 / 0	20 / 20
Q4	17 / 17	0 / 0	0 / 0	36 / 22	0 / 0	53 / 39
Total	40 / 40	8 / 8	20 / 20	63 / 49	24 / 16	**155 / 133**

2.1.2 Data import and management

Data was entered into Billie Turf 8.3. Measurement lists of collected data were archived at WMR and data were stored as plain text files in a centralised location for which daily back-up routine is in place. After all data of a sampled trip had been registered, checks for outliers took place. The checks were conducted using standardised scripts (R, SAS) and involved outlier checks for numerical values, consistency checks for text variables, relational checks such as length-weight relationships, and maps with the sampling positions. After file corrections, the data were stored in WMR'S centralised database FRISBE.

2.1.3 Data analysis

Data extraction from the FRISBE data base was done using SAS 9.4. Data exploration and all consequent analyses were done using R (4.2.2). The analyses presented in this report are based on the data that was collected both within the scope of this project (OSW 2.2) and the preceding project (OSW 2.0). The temporal range of all analyses therefore extended from the second quarter of 2019 to the second quarter of 2023.

A couple of complications were experienced during the monitoring schemes of OSW 2.0 and OSW 2.2 which have influenced the continuity of the overall data collection. For the years 2018 (setting up the monitoring scheme) to 2020 these have been described in Bleeker et al. (2021). Additional complications encountered in OSW 2.2, including missing weight information, issues with load cells, and trips overlapping areas, are addressed in the sections below.

Data quality checks and modifications

Data exploration was done to identify outliers and data-entry mistakes per variable (Table 3) which were then cross-checked with the raw data files. All errors identified in the process were corrected in the database so that the data used in the analyses was cleaned and was also corrected for future use. Consequently, all outlier data points that were included in the data analyses are a legitimate part of the dataset and are correctly collected data. To avoid doubling, only landings and discards of whole Nephrops were included in the analyses, excluding observations for which only tails were landed or only heads were discarded.

Table 3. Variable overview. Variables and their respective units used in the analyses. Units are displayed as SI units.

Variable name	Unit
Category Landing/Discard	–
Class length	cm
Coordinates (Latitude/Longitude)	Degrees (°)
Haul duration	min
Length increment	cm
Loadcell weight	kg
Number	Amount of individuals
Weight	kg

In 2019, weight information of subsamples was not always recorded according to protocol, resulting in missing weight information for most subsamples taken. Therefore, length-weight relationship calculations were done to approximate missing weights for Nephrops, fish, cephalopod, and benthos species. However, it is important to mention the consequent underrepresentation of particularly benthos in the 2019 data, as the required species-specific length-weight parameters (*a* and *b* in equations below) were not available for some of the species within this group.

For the remaining species, weights were calculated using the following length-weight relationship equations:

Fish and octopuses/squids

$$weight = \frac{number \times a \times (class\ length + 0.5 \times length\ increment \times 100)^{b}}{1000} \tag{1}$$

Nephrops and benthos

$$weight = \frac{number \times a \times (class\ length + 0.5)^{b}}{1000} \tag{2}$$

In addition to the underrepresentation of benthos in 2019, an overall underrepresentation of benthos was likely across the entire sampling period. This was caused by unclear labelling for certain categories found in the catch. This can include rocks, sediment, debris, algae, but also unidentified benthos specimens or parts of those. Therefore, these items are not included in the discard weight analyses.

Overlapping trips

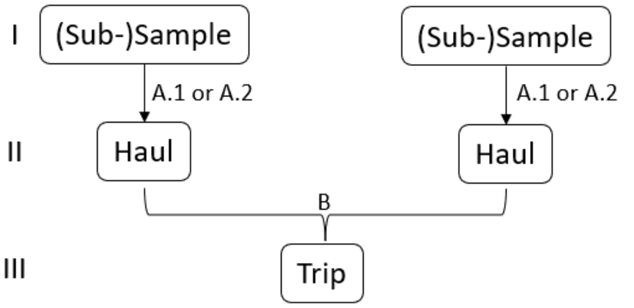
Data were analysed grouped by quarter and by pre-designated areas (FU33, FU5, outFU). Two trips were found to overlap across quarters. Several other trips took place in more than one of the pre-designated areas. To address this issue and enhance the balance of the dataset concerning quarterly and spatial distribution, it was decided to assign the two trips overlapping across quarters to quarter 2 and quarter 1, respectively. Regarding the spatial overlaps for single trips, a decision was made to assign the respective trip to the area where the sampled hauls were conducted. In instances where sampled hauls took place in more than one area, the trips were assigned to the most represented areas among the hauls of the respective trip.

Issues with load cells and resulting lack of total catch weight per haul

Throughout the data collection process of this project, a total of seven trips encountered issues with the load cells which resulted in lacking total catch weights for the respective trips. These seven trips were excluded from the dataset. In addition to this, three trips exhibited malfunctioning load cells during a single haul per trip. To compensate for the missing catch weight data, an alternative approach was employed, utilizing the average catch per fishing hour based on the total measured catch weights of the remaining hauls for each respective trip.

Raising data procedure and weight analysis

Weight and quantity data were raised from sample or subsample level to trip level in two distinct steps (A and B, see Figure 4). To analyse the landing and discard weights of Nephrops alone, the Catch Per Unit Effort (CPUE) was calculated as kilogram Nephrops per hour haul duration. Generalized Linear Models (GLMs) were then fitted to investigate differences between average Landings Per Unit Effort (LPUE) and Discards Per Unit Effort (DPUE), as well as the effects of different spatiotemporal predictors (area, quarter, year) on the average LPUEs and CPUEs, respectively. The respective GLM equations can be found in Annex 2 Table 11Table 11. Due to the spread of the data, Gamma log-link GLMs were used. The level of confidence was set at 0.95%.



A.1 $weight\ per\ species\ (kg) \times subfactor$

A.2 $number\ per\ species \times subfactor$

B $sum\ of\ both\ sampled\ hauls \times \frac{Total\ duration\ of\ all\ hauls\ of\ the\ trip}{Duration\ both\ sampled\ hauls}$

Figure 4. Flowchart raising procedure. The raising procedure of both weight and number of sampled individuals is shown for level I – III (subsample or sample level to sampled haul level to trip level). The subfactor used originates from the total loadcell weight per haul divided by the (sub-)sample weight taken per sampled haul. Chart layout inspired by Bleeker et al. (2023).

Length-frequency distribution analysis

For the length-frequency (LF) distributions distinctions were made between landings and discards, as well as between males and females. To investigate the sex-specific length-frequency distributions, specimens of unknown gender were excluded. This resulted in 4.4% of the discard observations and 6.8% of the landing observations being removed from the LF-analyses of self-sampling data.

In analysing the LF distribution, the proportion of Nephrops in the discard and landing samples at each length was calculated, relative to the total number of sampled Nephrops. Similar to the analysis of average LPUE and DPUE, GLMs were fitted to the LF-data. These GLMs aimed to explore differences in average length between discarded and landed, as well as male and female Nephrops. Additionally, the GLMs considered the effects of various spatiotemporal predictors (i.e. area, quarter, year) on the average length within both landings and discards. Given the distribution of the data, a Gaussian GLM was deemed most appropriate, setting the confidence level at 0.95%. The GLM equations used can be found in Annex 2 Table 12.

Species Composition

The species composition in the catch was examined by grouping species into six groups (Table 4). It is important to note that not every specimen was identified down to species level. Some were only categorized at family level (e.g. sea urchins (*Echinidae*)), others only at genus level (e.g. smooth-hounds (*Mustelus*)).

Table 4. Species groupings. Overview of species groups used for species composition analysis, and the species that are included in each group.

Species group	Species included
Nephrops	Norway lobster
Flatfish	e.g. European plaice, Common dab, turbot, sole, brill
Roundfish	e.g. Whiting, herring, Atlantic cod, anglerfish, Grey gurnard
Elasmobranch	Sharks, rays, skates
Cephalopods	Octopus, squids
Benthos	e.g. bivalves, gastropods, crustaceans, polychaetes, echinoderms, anthozoans

Validation of self-sampling

One objective of this project was to validate the self-sampling data on Nephrops CPUE and length-frequency distributions by conducting a comparative analysis with observer data. To validate the self-sampling protocol a comparative analysis between the self-sampling and onboard observer data was performed. Within the validation process, self-sampling data for Nephrops only were compared with the corresponding observer trip data from those same trips. By aligning the trips between self-sampling and observer sampling, it was aimed to perform a thorough and representative validation of the self-sampling trips. Both weight per hour effort and average carapace length were compared between sampling approaches. A total of 9 trips were included in the validation analysis, with 18 and 111 sampled hauls during self-sampling and observer trips, respectively (Table 5).

Table 5. Trip and haul overview. Number of trips and hauls per sampling scheme included in the validation analysis are provided.

Sampling scheme	Number of trips	Number of hauls
Self-sampling	9	18
Observer	9	111

For the validation, the same procedures for both self-sampling and observer data were used, as previously described for the collection of weight data and the calculation of the length-frequency (LF) distribution. Depending on the distribution of the data, a Gaussian or Gamma log-link Generalized Linear Models (GLMs) to the trip-level data was applied (for equations see Annex 2 Table 13Table 13). This approach allowed to investigate potential divergence in the average Catch Per Unit Effort (CPUE) and average length of Nephrops between the two sampling approaches.

2.2 Alternative monitoring methods

A review of four alternative methods for measuring catch weight, independent of permanently installed onboard measuring equipment (i.e. loadcell) was done. These methods were assessed based on financial investment, the time required for onboard implementation, data quality (accuracy in weight estimation), and their potential to enhance randomization and distribution across the monitoring fleet. Our primary objective was to explore and obtain initial insights into these alternative approaches. Therefore, the spread of experiments across different time periods, locations, or vessels was not taken into account.

2.2.1 Proportion discarded vs. landed Nephrops

The consortium suggested that a direct relation between the weights of landed and discarded Nephrops may be used to develop a calculation approach to estimate the weight of discarded Nephrops based on the weight of landed Nephrops. If that were the case, this approach would allow to gain insights on the amount of discarded Nephrops purely based on landings data, and therefore reducing time and financial efforts to collect discard samples. To explore whether such a relation could be identified, Nephrops weight and length data obtained from sampled hauls were raised to sampled haul level (Figure 4), both for discards and landings. The raised data was summed up per quarter and area for landings and discards, respectively. Then, the weight of discarded (undersized) Nephrops was divided by the weight of landed (sized) Nephrops per area and quarter.

2.2.2 Visual estimate

A visual estimate of the catch was trialled to explore whether this could provide a reliable estimation method. The method was tested on board a fishing vessel that is not part of the reference fleet to ensure the skipper and crew cannot provide biased estimates based on their experience with loadcells measurements. After a haul, each member of the fishing crew and one observer were asked to visually estimate the catch weight or volume in the hopper (Figure 5). In the case of catch volume estimation, a volume to weight conversion factor was calculated by weighing a 50L basket, resulting in a kg/L ratio. This conversion factor was usually around 0.7 kg/L. In case of catch weight estimation were done, no conversion ratio had to be applied. The mean of all estimates was calculated. The discard weight was calculated by taking the estimated catch weight minus the landings weight.

Figure 5. Visual catch estimation by observer and fishing crew (Source: Pieke Molenaar).

Moreover, the ‘true’ weight was measured by collecting and weighing all discards and landings (total catch). This was done by collecting all discards at the end of the sorting belt using a chute (Figure 6). All discards were then weighted. This was done for every sampled haul for which a visual estimate was made, allowing for a direct comparison with visual estimates. Also, a basket (50 litre) of discards was collected, which was weighed and sorted to species level. By raising the weights of target species in the discard sample to the weight of the total discards, the total weight of all discarded target species was calculated.

The proportion between the assessed and ‘true’ discard weight in the discards was calculated and the differences were analysed in R using paired sample t-tests for normally distributed data. A mean percentage difference and standard deviation were calculated, to indicate data accuracy and precision of this estimation method respectively.

Figure 6. Collection of discards by means of a chute (Source: Pieke Molenaar).

2.2.3 Estimate with 3D analysis software (photogrammetry)

Photogrammetry is a technology in which video or photos are used to create 3D models. It could be used to digitally estimate catch on board of a fishing vessel. The examination and analysis of this methodology was outsourced to SINTEF Ocean and performed in collaboration with WMR. SINTEF Ocean is a research institute experienced in 3D analysis techniques and the software required for that purpose. The process of estimating catch weights using photogrammetry comprised several sequential steps. Visual footage was collected on-board by the observer (video and photo) of both an empty hopper and a hopper with catch. The hopper was also measured. A catch sample was taken from the hopper to determine the catch volume ratio. SINTEF subsequently analysed the data using a Structure from Motion (SfM) technique. Following a scaling and transforming procedure, a 3D model of the hopper was made from which catch volume and catch weight were estimated (Figure 7). See Annex 3 for a detailed description of this procedure.

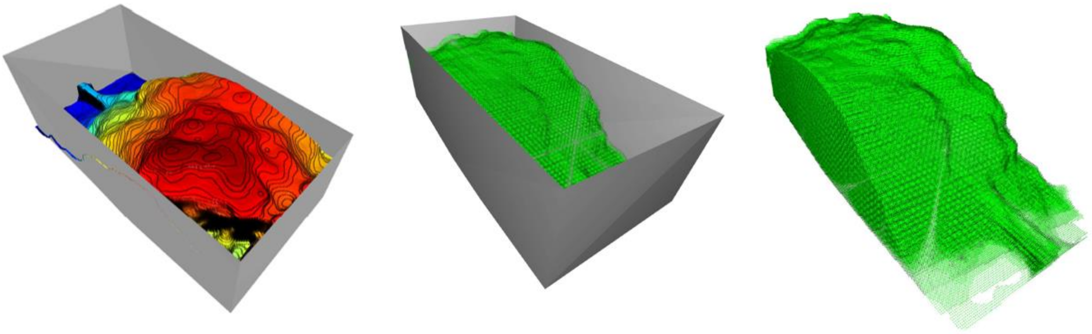


Figure 7. 3D photogrammetry output of extracted surface (left), volume in hopper (middle) and sampled volume (right) (Source: SINTEF Ocean[3]).

2.2.4 Mobile loadcell

The loadcells currently installed on board the reference vessels are static, i.e. the system cannot be easily disconnected (Figure 8). The use of mobile loadcells, such as those powered by a battery and connected via Wi-Fi and a control box plugged in a socket, would enable the system to be transferred from one vessel to another. This would allow to have a larger coverage of the fleet. Therefore, the application and measurement accuracy of a mobile motion-compensated loadcell was tested.

Validation of the mobile loadcells was done by measuring a known weight during heavy and light swell, making use of an intermediate bulk container (IBC). The IBC system was initially filled with a specific volume of water. The known weight of the empty IBC system (without water) was 54 kilograms. This weight was combined with the volume of water in the IBC to determine the overall weight, which we refer to as the "true weight" of the IBC system.

The experiment included measurements using the mobile load cell at four distinct measurement frequencies, namely, 10, 20, 50, and 90 weightings per unit of time, spanning from a few seconds to up to one minute. According to the experimental setup, a decision was made to make at least 10 measurements for each interval and IBC weight to test the accuracy of the load cells. Data was collected in multiple rounds:

- On the Wadden Sea (less movement/swell) with an IBC filled with 700 litres of water (total 754 kg)
- On the North Sea (heavier swell) with an IBC filled with 700 litres of water (total 754 kg)
- On the North Sea (heavier swell) with an IBC filled with 300 litres of water (total 354 kg)
- On the North Sea (heavier swell) with an IBC filled with 0 litres of water (total 54 kg)
- On the Wadden Sea (less swell) with an IBC filled with 700 litres of water (total 754 kg)
- In the harbour (little to no swell) with an IBC filled with 700 litres of water (total 754 kg).
- In the harbour (little to no swell) with an IBC filled with 0 litres of water (total 54 kg).

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[3] Source attached in Annex 4: Results 3D photo analysis

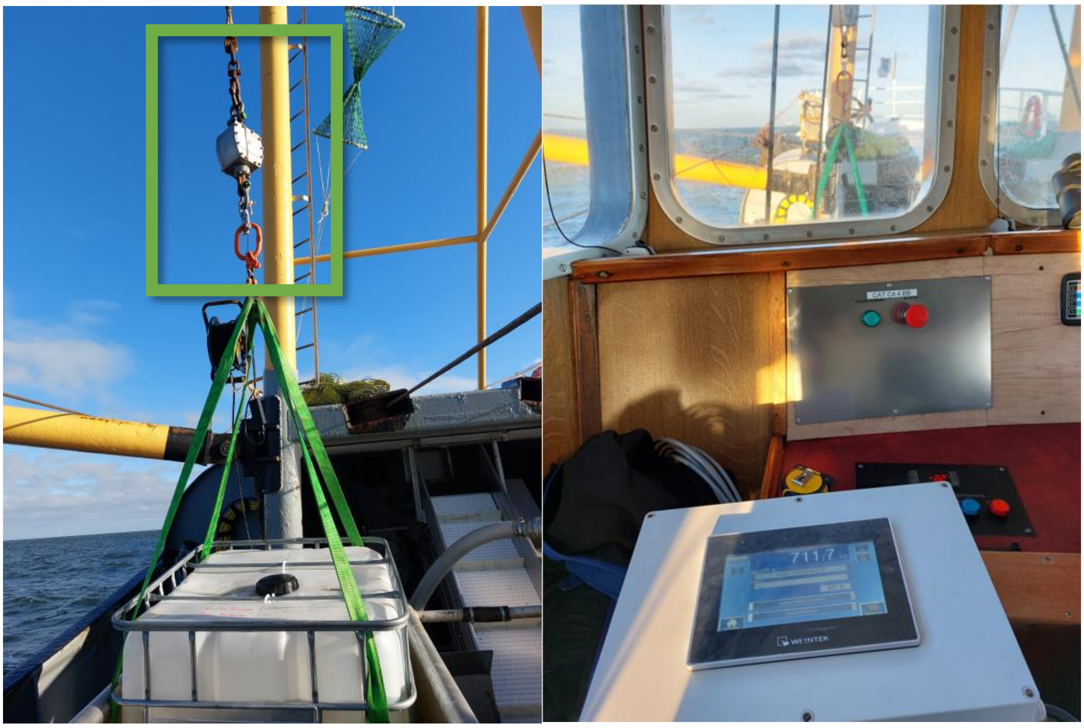

Figure 8. On the left, the mobile loadcell weighing the IBC system on board. On the right, the control box on which the interval is set and weight is shown real-time (Source: Tom Bangma).

2.3 Communication

This project aimed for adequate communication to the fishing industry about the research conducted, both within the project (to the reference fleet) and to the rest of the sector. Following each observer trip and during each quarter of the year, feedback is shared with the reference fleet vessels. Additionally, a ‘Skippers-day’ was organized for the reference fleet, during which the results are presented and discussed. This session serves as an opportunity to collect feedback on the project's execution (both from and towards the reference fleet) and the potential for future projects. The summarized results were also presented and discussed at an annual meeting for all research-collaboration projects within WMR (*OSW-day*). This meeting was open for the entire fishing sector to attend, provided they are member at one of the participating POs.

3 Results

3.1 Discard and landing monitoring of the reference fleet

The findings in this report merge data from both the preceding project, OSW 2.0, and the current project, OSW 2.2. As a result, the analysis encompasses discard and landing data spanning from 2019 to 2023.

A total of 93 self-sampling and 10 observer trips were conducted between 2019 and 2023. The number of trips conducted by vessels in the self-sampling program showed some fluctuations over the quarters and years, with the highest number of trips per year being recorded in 2022 (n = 37). Quarter 3 of 2022 had the highest number of trips across the entire program (n = 18). This can be attributed to the high number of participating vessels in 2022 (Table 1). In contrast, the observer program exhibited less variation in the number of trips conducted across the years and quarters, with a maximum of two trips in Q4 of 2022 (Table 2). The COVID-19 pandemic as well as high oil prices in 2021 also resulted in overall lower fishing activity. The lacking observer trip coverage in 2020 and 2021 can be explained by the COVID-19 pandemic and the consequent safety measures as well as the overall low fishing activity.

The total number of hauls done per year during self-sampling trips ranged from 63 in 2023 to 658 in 2022, with the maximum of total hauls across all years taking place in Q3 (n = 576; Table 1). The distribution of self-sampling hauls across different areas (FU5, FU33, outFU) exhibited an uneven pattern as most hauls were conducted in FU5, totalling 1139, of which 128 were sampled. In comparison, 280 and 311 hauls were done in outFU and FU33, with 28 and 30 hauls sampled, respectively (Figure 9, Figure 10). This distribution of trips and hauls across the areas goes along with our knowledge of FU5 being the most important area for the Dutch Nephrops fleet.

Regarding observer trips, 2022 exhibited the most comprehensive coverage in observer sampling, with 63 total hauls and 49 sampled hauls recorded. The second quarter demonstrated the highest number of hauls, with 54 total hauls and 51 sampled hauls (Table 2). In contrast to self-sampling, the area coverage in observer trips displayed a relatively more balanced distribution. Specifically, 44, 52, and 59 hauls were conducted in areas FU33, FU5, and outFU, respectively. Out of the total 155 hauls conducted in these areas, 133 were sampled (Figure 9, Figure 10). Maps showing the sampling locations per trip can be found in Annex 2 Figure 24 and Figure 25.

Overall, this translates to an average amount of 18.6 and 15.5 total hauls per trip for the self-sampling and the observer program, respectively. The haul duration in self-sampling ranged from 105 min to 495 min, with an average haul duration of 280.5 min. During observer sampling, the haul duration was comparable to the self-sampling, ranging from 135 min to 490 min with a mean of 286.5 min (Table 6).

In the following analyses, the focus was on self-sampling data, while the observer data was used exclusively for the validation process of the self-sampling data as well as for the purpose of the alternative monitoring methods calculating the proportion of discarded to landed Nephrops.

Table 6. Overview haul durations and hauls per trip. The minimum (Min), maximum (Max), and average (Mean) number of hauls per trip for both self- and observer sampling, including haul duration in minutes.

		Min	**Max**	**Mean**
Self- / Observer sampling	Number of hauls per trip	8 / 8	33 / 23	18.6 / 15.5
Self- / Observer sampling	Haul duration (min)	105 / 135	495 / 490	280.5 / 286.5

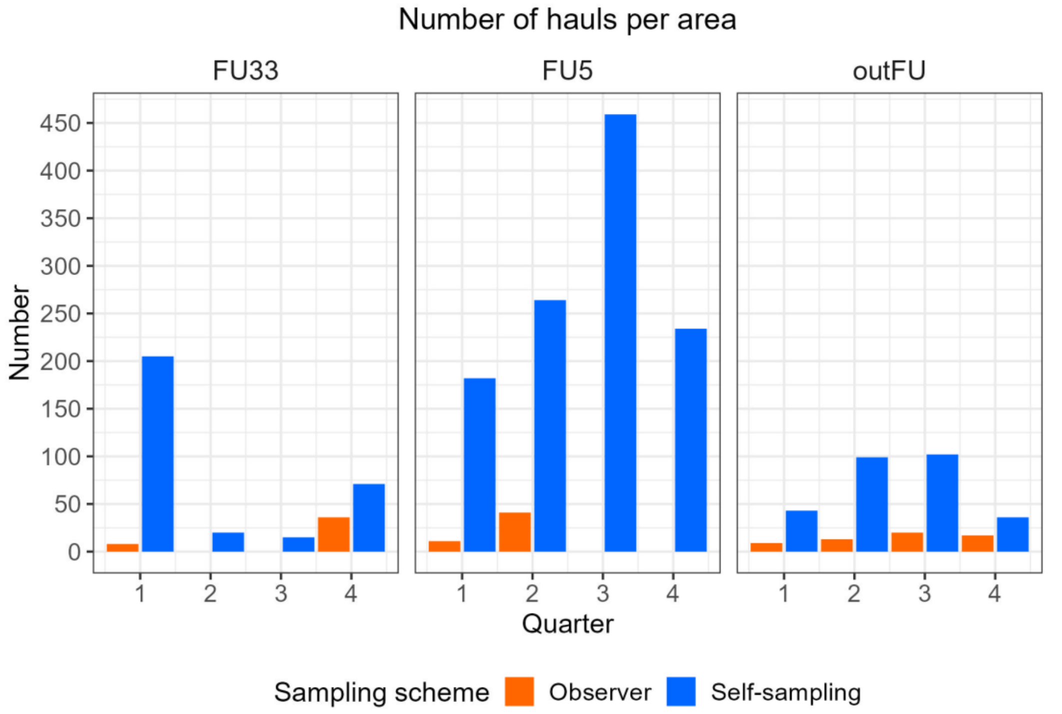

Figure 9. Hauls per area. The total number of hauls done between 2019 and 2023 per area is shown for the self-sampling (blue) and the observer sampling scheme (orange).

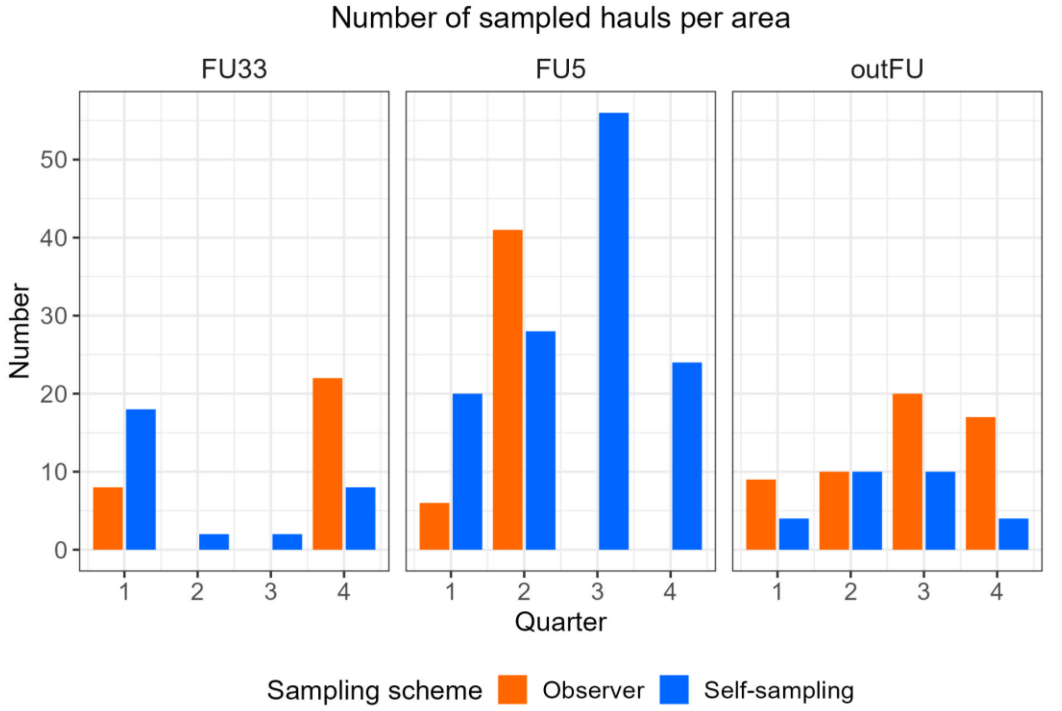

Figure 10. Sampled hauls per area. The total number of sampled hauls done between 2019 and 2023 per area is shown for the self-sampling (blue) and the observer sampling scheme (orange).

3.2 Weight data analysis for Nephrops

The analysis focused on examining the changes in the average weight of Nephrops catches (CPUE), landings (LPUE), and discards (DPUE) per hour across various spatiotemporal levels and encompassed variations in weight over the different years, quarters and areas. The term CPUE will be used for kilograms catch per hour, which consists of landings and discards combined.

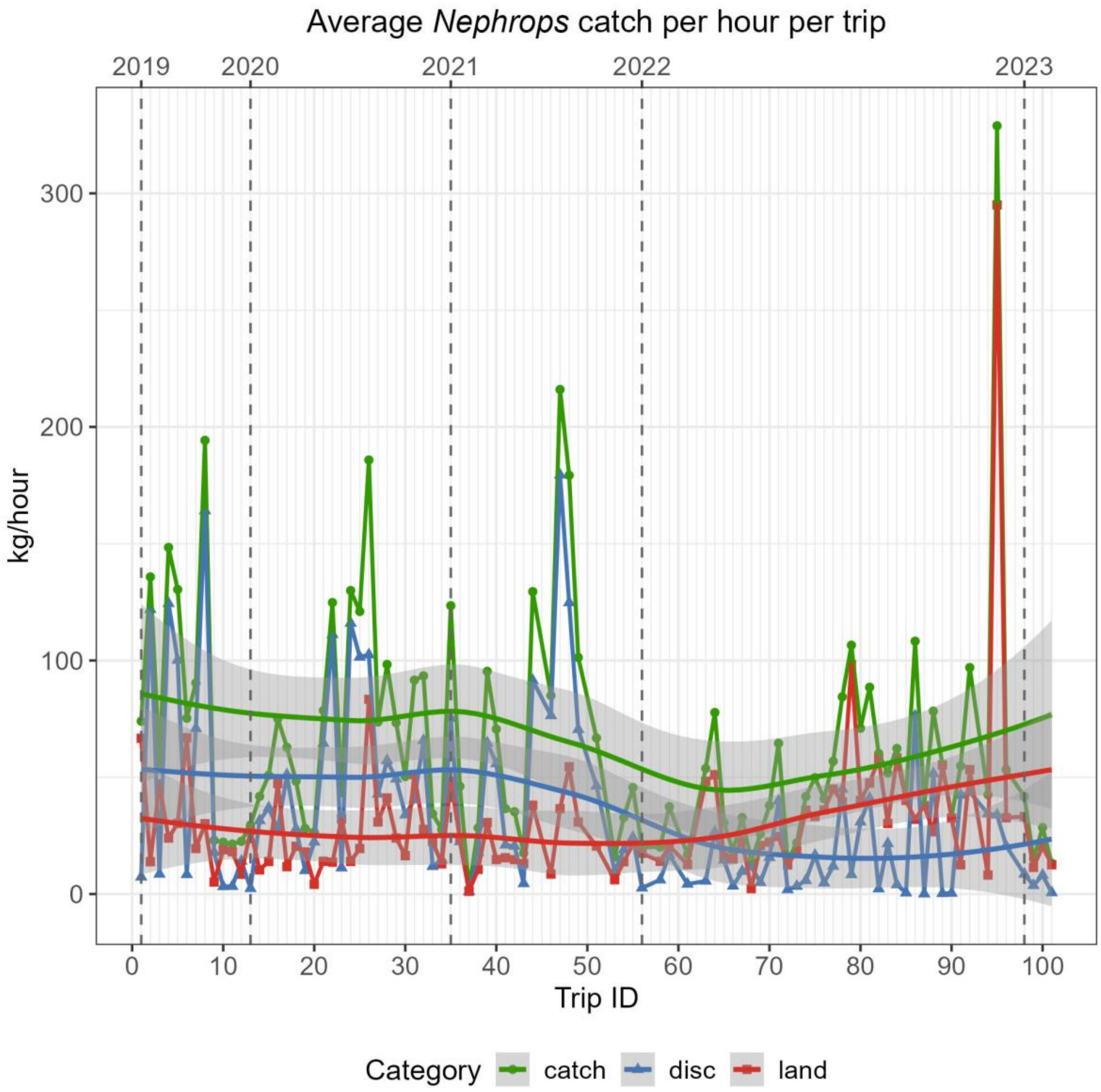

Figure 11. Nephrops weight overview over the course of the program. The catch (CPUE, green), landing (LPUE, red), and discard (DPUE, blue) per unit effort per self-sampling trip between 2019 and 2023 are shown in kilograms per hour. Non-linear smoothing techniques were utilized to visualize the trend patterns in CPUE, LPUE, and DPUE.

Over the course of the sampling program (2019 – 2023), no clear patterns could be found based on average CPUE, LPUE or DPUE at trip level, indicating the need to consider differences between quarters and areas (Figure 11). However, it is apparent that until the beginning of 2022 the CPUE was driven primarily by the DPUE. Starting in 2022 (Trip 56 and onwards), however, the CPUE was driven by the LPUE instead. In addition to this, both the DPUE and LPUE per trip and the respective non-linear smoothers indicate that, starting around Trip 60, the average LPUE is higher than the average DPUE, suggesting an interaction between year and LPUE in 2022. This change in CPUE driver could be a result of changes in fishing behaviour with e.g. different areas being fished. It is, however, important to note that the LPUE of Trip 95 in particular influenced the non-linear smoother of the LPUE, masking the decrease in LPUE observed from around Trip 80 onwards.

Across the years 2019 to 2023, CPUE, LPUE, and DPUE showed a very noticeable increase from Q1 towards Q3, as well as a decline towards Q4 (Figure 12). Particularly the change in proportions of

DPUE and LPUE accounting for the total catch weight per hour as described above for 2022 and 2023 was found in Q4 as well.

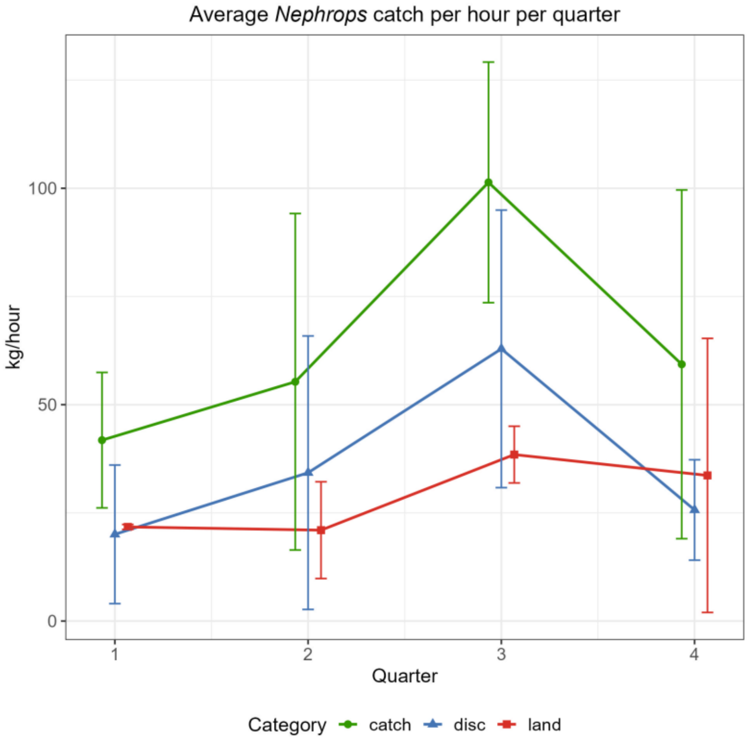

Figure 12. Nephrops weight overview per quarter. The average catch (CPUE, green), landing (LPUE, red), and discard (DPUE, blue) per unit effort per quarter (1 – 4) averaged across the years 2019 – 2023 are shown as weight in kilograms per hour, including standard deviation bars, for self-sampling.

The areas FU5 and outFU exhibited similar trends, with an increasing average CPUE and DPUE throughout the quarters as described earlier (Figure 13). The patterns observed in FU5 and outFU throughout the quarters are comparable to the one described before. For FU33, however, average CPUE and LPUE in Q4 exhibited high standard deviations (SD), showing clear differences when compared to the patterns of the other two areas. These high SDs are predominantly caused by the high LPUE value measured in Trip 95, which must be interpreted with care. Contrary to other observations described above, DPUE in FU33 decreased from Q1 towards Q3, and showed an increase towards Q4 (Figure 13).

It is important to highlight that the increase in overall LPUEs was more pronounced than the increase in DPUE, suggesting that the overall catch increase was primarily driven by the rise in LPUE. This observation suggests a high importance of Nephrops landings as a contributing factor to the variations in Nephrops CPUE across the time periods studied. Overall, it is implied that there is a difference in average catch weights per hour between years, quarters, and areas.

Throughout the quarters, the average LPUE and DPUE for Nephrops during the night demonstrated similar patterns as described for the outFU areas. In contrast, both the LPUE and DPUE recorded during the daytime, showed patterns resembling those of FU5 across the quarters. However, the large Standard Deviations (SD) in night DPUE of Q4, day DPUE in Q2 and Q3, as well as day LPUE in Q4 indicated high variations around the average LPUE and DPUE which may have influenced the observed patterns (Figure 14).

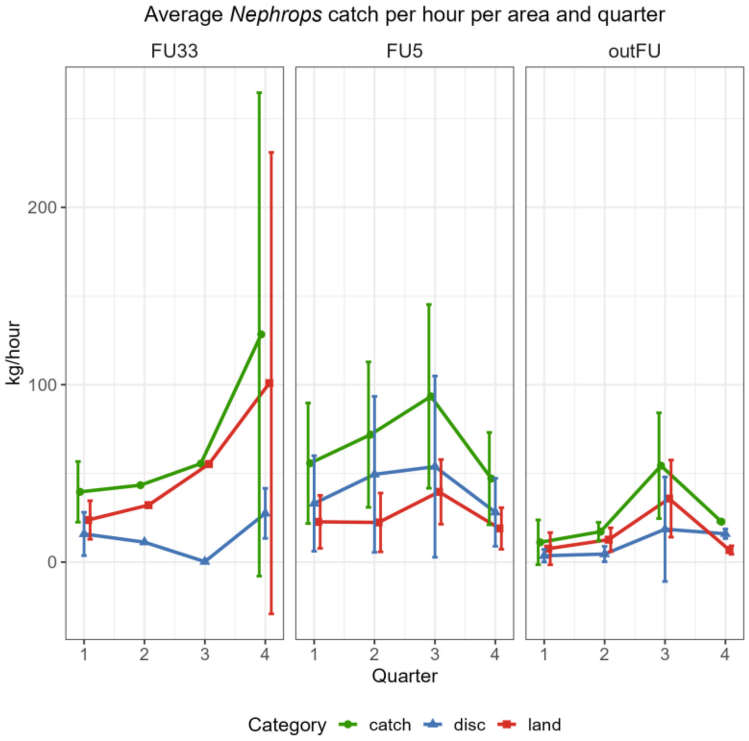

Figure 13. Nephrops weight overview per area and quarter. The average catch (CPUE, green), landing (LPUE, red), and discard (DPUE, blue) per unit effort for Nephrops are shown for the areas FU33, FU5, and the areas outside these two FUs (outFU) , including standard deviation (SD) bars. The weights (kg) per hour were averaged per quarter (1 – 4) and across the years 2019 – 2023, for self-sampling. Note, negative values in catch per hour arise from using SD as a measure of uncertainty.

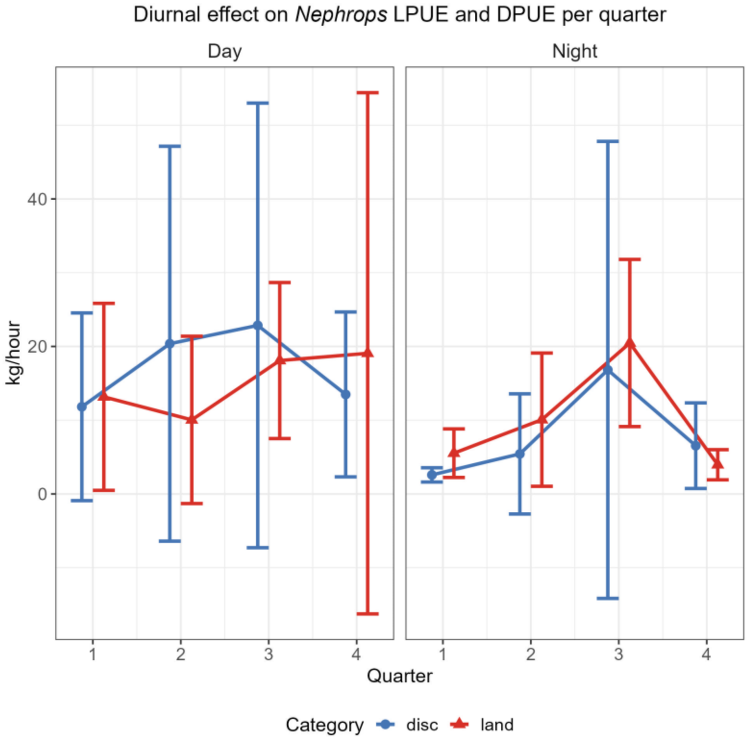

Figure 14. Diurnal effect on Nephrops weight. The average landing (LPUE, red) and discard (DPUE, blue) per unit effort for Nephrops during day and night are shown per quarter (1 – 4), summarised across the years 2019 – 2023. Standard deviation bars (SD) are included. LPUE and DPUE are expressed as kilogram weight per hour, for self-sampling. Note, negative values in catch per hour arise from using SD as a measure of uncertainty.

3.2.1 Statistical analysis of CPUE weights

To conduct a more in-depth analysis and explore potential variations in average weights per hour across different years, areas, and day-night periods, three distinct Generalized Linear Models (GLMs) were employed to analyse the corresponding LPUE and DPUE weight data. An overview of the statistically significant results can be found in Table 7 while the extensive result overview can be found in Annex 2 Table 11 A – C.

Model A

The Gamma log-link GLM fitted to the data did not show any significant differences between overall LPUE and DPUE ($p = 0.376$). Therefore, the subsequent analysis regarding weight per hour values did not differentiate between discard and landing categories.

Model B

In a second Gamma log-link GLM, the effect of the different quarters, years, and areas were added as predictors. In addition to this, the observed higher LPUE when compared to DPUE in the year 2022 and in the areas FU33 and outFU resulted in the decision to add interactions between Category (Landings/Discards) and Year, as well as between Category and Area as additional predictors. It shows that there are significant differences between quarters, and that the interactions of Category * Area and Category * Year are significant as well ($p < 0.01$). Looking at this in more detail, the GLM shows that the DPUE and LPUE in Q3 were significantly higher than in Q1 ($p < 0.001$). Both the average LPUE and average DPUE were highest in Q3 and lowest in Q1. The LPUE and DPUE outside the FUs were significantly higher than in FU33 ($p < 0.001$), while average LPUE and DPUE were highest in FU5 and lowest in FU33. In addition to this, differences between years were found. Both years 2022 and 2023 were found to have significantly higher LPUE and DPUE weights compared to 2019 ($p < 0.001$), while DPUE and LPUE were found to be highest in 2020 and 2021 and lowest in 2019. It is crucial to interpret these results with some caution, considering the differences in the number of trips conducted each year. The significant interaction between Area and Category originated from FU5, where average LPUE and DPUE were higher than those in FU33 but particularly pronounced for the LPUE weights. Moreover, the interactions between the years 2022 and 2023 were significant ($p < 0.01$ and $p < 0.05$, respectively). The average value found in these two years was particularly high for the LPUE which supports the visual results described above. In these years, LPUE was driving the overall CPUE.

Table 7. Selective GLM output Nephrops weight. The effect of different variables on average Nephrops LPUE and DPUE were tested average, as well as the effect of interactions between variables on the average Nephrops LPUE and DPUE. An overview of only the statistically significant ($p < 0.05$) output is presented here. The GLM equation is provided in italics. More detailed and extensive results can be found in Annex 2 Table 11**Table 11** A – C. Additional abbreviated statistical values provided: Df = degrees of freedom; AIC = Akaike Information Criterion; scaled dev. = scaled deviation; p = p-value.

Model	Variables (* = Interactions)	Df	Deviance	AIC	scaled dev.	p
B	*Weight ~ Quarter + Area * Category + Year * Category*					
	Quarters (1 – 4)	3	136.3080	1625.1990	15.7850	**0.001**
	Area * Category	2	133.1680	1622.0080	10.5940	**0.005**
	Year * Category	4	144.5520	1636.8280	29.4140	**<0.0001**

Model C

The third GLM analysed the effect of day and night sampling. It was observed that night weights per hour were significantly greater than day weights per hour ($p < 0.001$). However, there was no statistically significant interaction detected between Day/Night and Category. Table 11 Quarter three was overall found to have the highest LPUE and DPUE values across the quarters and is significantly different from Q1 ($p < 0.001$). These results support the suggestions that were made based on visual analysis above.

Overall, the suggested differences in average weights per hour (for discards and landings combined) as suggested in 3.2 were confirmed by the results of the statistical analysis. There was no statistical difference between average LPUE and DPUE, and both DPUE and LPUE were found to be highest in Q3 and lowest in Q1. Regarding years, 2020 and 2021 had the overall highest and 2019 the overall lowest average weight values per hour. The low values in 2019 and 2023 are likely to be a result from the lower number of trips done in these years. In the years 2022 and 2023 the LPUE was particularly high. Again, the limited number of trips in 2023 should be considered for the interpretation. The highest average LPUE and DPUE values per area were found in FU5 and the lowest in FU33, which was particularly pronounced for average LPUE values in FU5.

3.3 Discard and landing species compositions

To investigate the species composition in both discards and landings, the relative contribution per species group (see 2.1.3) to the respective category based on weights was used. It must be noted that due to lacking length-weight parameters for some benthos species as well as some cephalopod species in 2019, their weight contribution might be underrepresented and biased in that year. Furthermore, the lacking weight information on debris, rocks, and so on (non-live matter) mentioned in 2.1.3 should be noted. Therefore, it is important to emphasise that the species contribution to the total discard weights per quarter and year used in 3.3.1 is based on live matter discards only.

3.3.1 Discards

In the discards, flat- and roundfish collectively constituted the largest portion of weight, followed by Nephrops and benthos. Flatfish accounted for approximately 50% of the discard weight, while the contribution of roundfish varied between approximately 20% and 45% (Figure 15). Nephrops contribution to discard weights was up to about 15%, with an exception noted in Q3 of 2021 when Nephrops discard weights exceeded 30% of the total discard weights. In the discards, the dominant species were found to be European plaice (*Pleuronectes platessa*) and Common dab (*Limanda limanda*) (Annex 2 Figure 26) which overall made up for around 20 – 25% and 10 – 40% of the discard weight, respectively. The discarded roundfish were dominated by whiting (*Merlangius merlangus)* (15 – 40% of discard weight) and Grey gurnard (*Eutrigla gurnardus*) (around 5 – 20% of discard weight) (Annex 2 Figure 27).

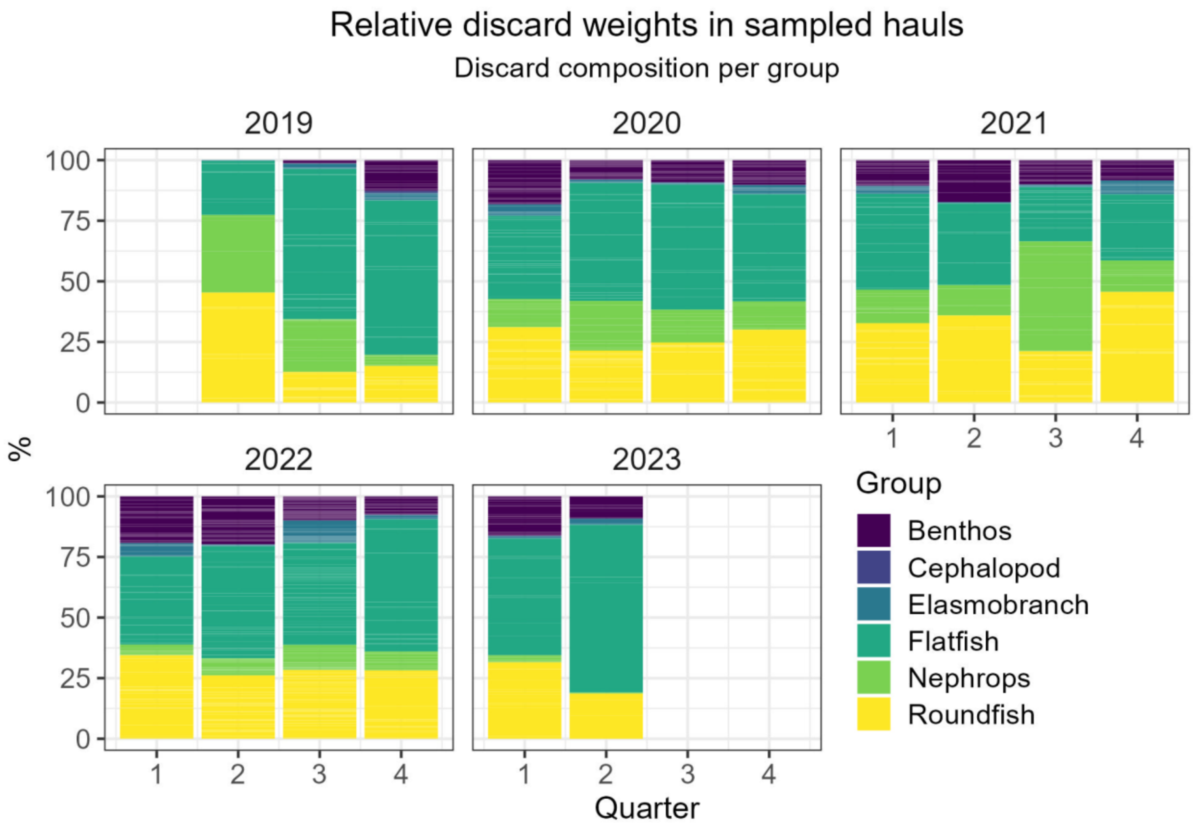

Figure 15. Discard species composition. The relative contribution to the total discard weight per quarter (1 – 4) and year (2019 – 2023) is shown per species group. Details about the species group categorisation can be found in Table 4.

3.3.2 Landings

The dominant species groups within the landings were Nephrops as the primary target species along with flatfish and roundfish as non-target species (Figure 16). Overall, Nephrops constituted approximately 30% to 75% of the total landing weights. Nephrops' relative contribution to the landing weights was highest in quarter three for the years 2020 to 2022, during which all four consecutive quarters were covered.

Among the non-target species, flatfish had the highest relative contribution to the landing weights. They represented about 25% to 60% of the landings. The proportion of flatfish in the total landing weights reached its lowest point during Q3, coinciding with the period when Nephrops made its most significant contribution. Conversely, the contribution of flatfish saw its peak during Q1 and Q2. Roundfish, although having the second highest contribution to landing weights of the non-target species, accounted for a maximum of approximately 15% of the landing weights (Figure 16). The dominant non-target species driving the landings weights of flat- and roundfish were the European plaice, turbot (*Scophthalmus maximus*) (Annex 2 Figure 28), Anglerfish (*Lophius piscatorius*) and Atlantic cod (*Gadus morhua*) (Annex 2 Figure 29).

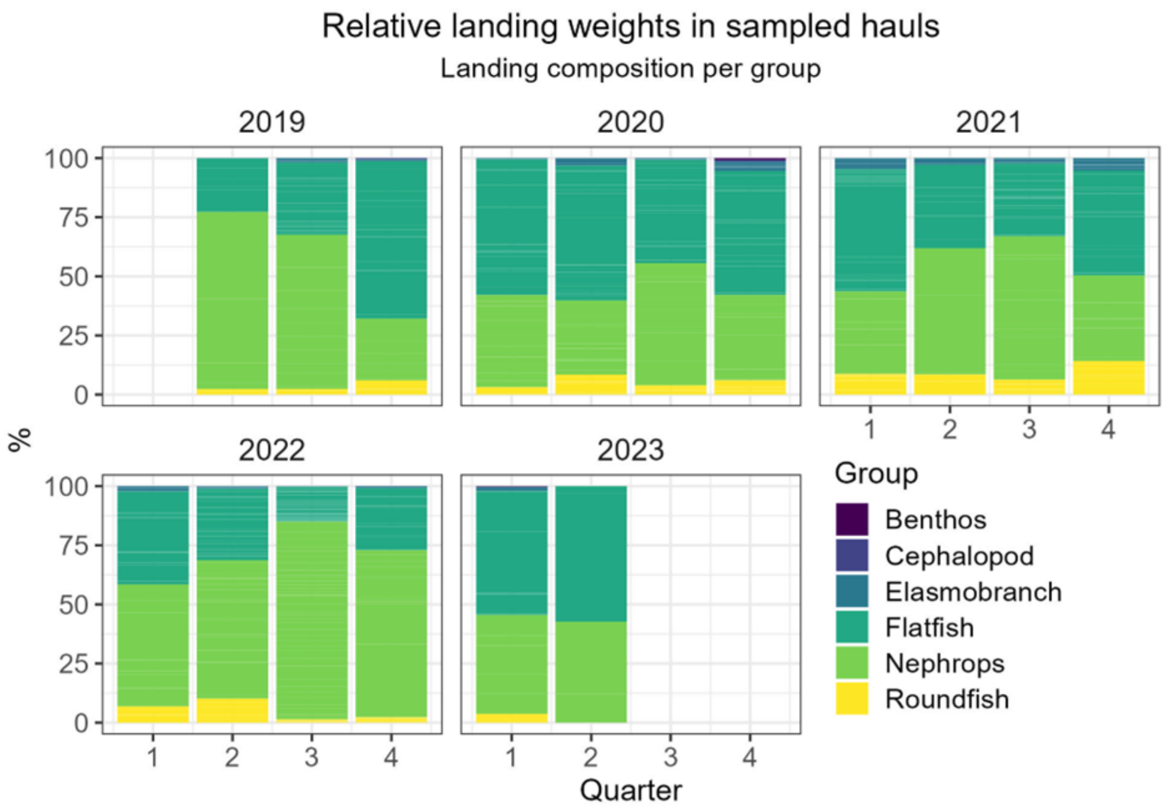

Figure 16. Landing species composition. The relative contribution to the total landing weight per quarter (1 – 4) and year (2019 – 2023) is shown per species group. Details about the species group categorisation can be found in Table 4

3.4 Length frequency distributions

The carapace length of landed Nephrops ranged from a minimum of 2.1 cm to a maximum of 6.4 cm. In the year 2021, however, the minimum carapace length of landed Nephrops was recorded at 3.0 cm, suggesting that, on average, larger Nephrops were caught that year. Across all the years studied, the majority of landed Nephrops fell within the range of 3.0 cm and 4.5 cm (Figure 17). Landed Nephrops of 5.5 cm and above were predominantly males. Particularly evident in 2021, landed males (especially > 4 cm) accounted for a larger fraction of the landings than females of the same carapace length, indicating male Nephrops to be larger than females. The amount of undersized landed Nephrops (< 2.5 cm) was negligible with these specimen accounting for less than 0.01% of the landed male or female Nephrops within one quarter of a year. In addition, the maximum deviation from the allowed landing size (2.5 cm) was observed to be 0.4 cm.

In discarded Nephrops, the carapace length ranged from 1.7 cm to a maximum of 5.6 cm, while the majority was found between 2.5 cm. The smallest discarded Nephrops specimen were predominantly females while the ones above 4.5 cm carapace length were predominantly males (Figure 17). Both in landings and discards, male Nephrops appeared to be larger than the females. Overall, LF distributions for both landed and discarded Nephrops seemed to vary between years.

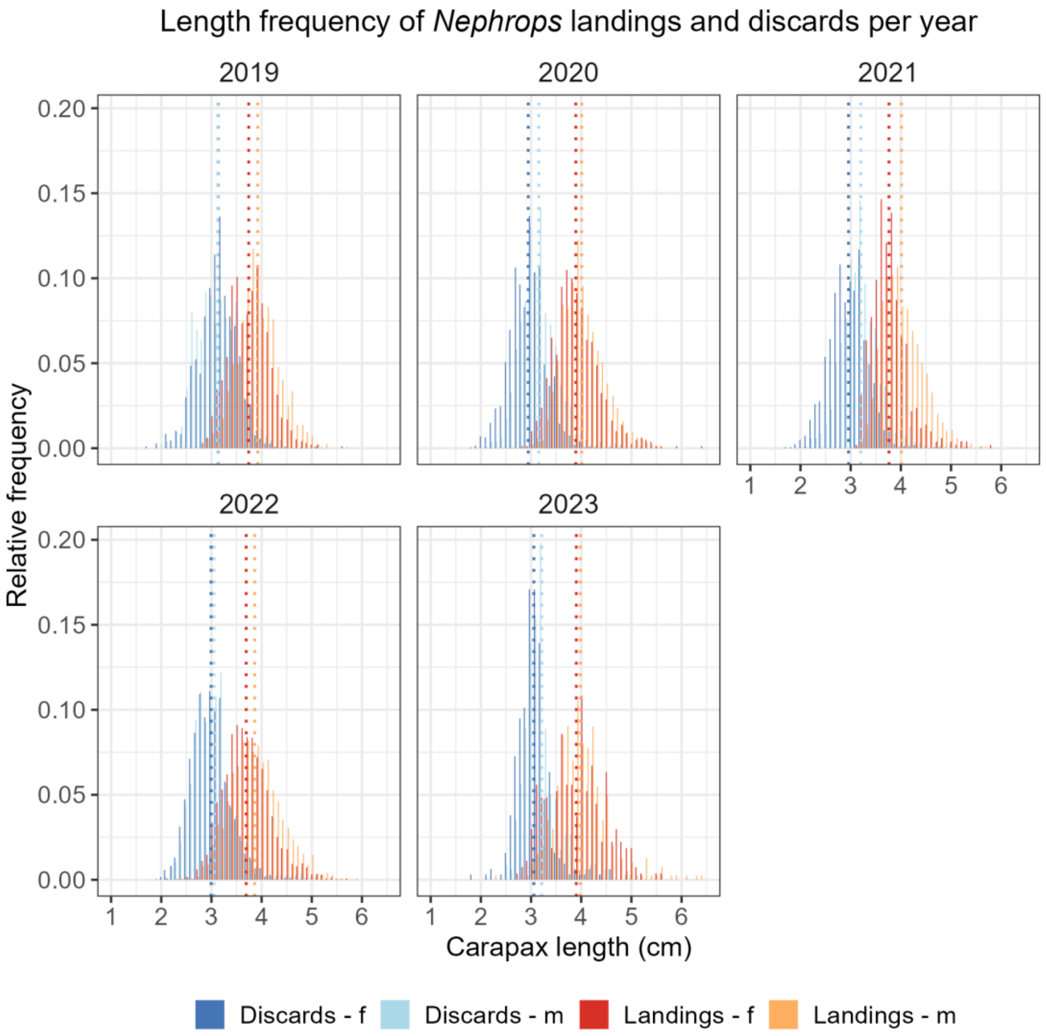

Figure 17. Length frequency distribution of landings and discards per year. Relative length-frequency (LF) distributions based on carapace length (measured in centimetres) observed in the self-sampling scheme for both Nephrops discards (represented in dark and light blue) and landings (in red and orange), segmented by year (2019 – 2023) combing the quarters 1 – 4. Average length per group is indicated by dotted line. A differentiation is made between female Nephrops (indicated by darker colours) and male Nephrops (represented by lighter colours).

When examining the LF distributions of landed Nephrops across quarters, it became evident that Nephrops tended to be larger in quarter one and four, with carapace lengths reaching up to 6.4 cm. Moreover, in these quarters, the were higher relative frequencies of Nephrops measuring > 5 cm (Figure 18). Around the 5 cm carapace length, there was a small peak in Q4, whereas the LF patterns in the other quarters appeared more uniform. As for the discarded Nephrops measuring < 2.5 cm in carapace length, they were more frequently observed in Q2 are compared to the other quarters. Additionally, the observed differences in male and female lengths, both landings and discards, were most pronounced in the second quarter, with males accounting for the majority of Nephrops larger than 4 cm. Overall, there was an indication of a difference between quarters for both landings and discards, as well as a distinction in male and female lengths within each quarter.

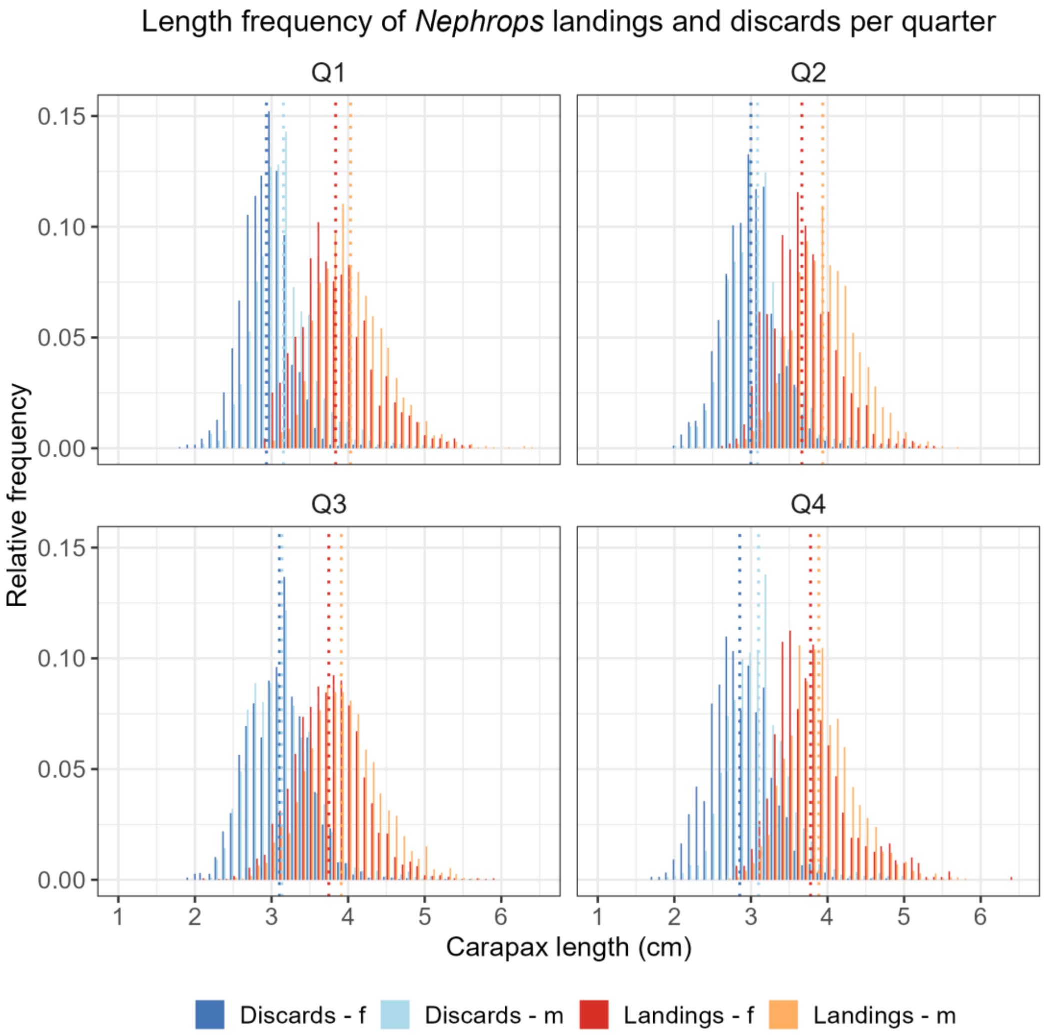

Figure 18. Length frequency distribution of landings and discards per quarter. Relative length-frequency (LF) distributions based on carapace length (measured in centimetres) observed in the self-sampling scheme for both Nephrops discards (represented in dark and light blue) and landings (in red and orange), segmented by the four quarters (Q1 to Q4) combing the years 2019 to 2023. Average length per group is indicated by dotted line. A differentiation is made between female Nephrops (indicated by darker colours) and male Nephrops (represented by lighter colours).

When comparing LF distributions between areas, the ranges of both landed and discarded Nephrops were comparable, starting at discard lengths of 1.7 cm in outFU and reaching maximum landing lengths of 6.4 cm in FU33. In FU5, the main fishing area for the Dutch fleet, the majority of landed Nephrops measured from 3.0 cm to 4.5 cm carapace length following a distribution that is approximately Gaussian in shape. Outside the FU areas, the majority of landed Nephrops ranged between 3.0 cm and > 4.5 cm and appeared to be larger than the FU5 Nephrops. Particularly LF distribution of landed females were found to exhibit a different pattern compared to FU5 and FU33. Female Nephrops displayed a relatively stable pattern (plateau-like) of relative frequencies between 3.0 cm and 4.0 cm in outFU. In FU33, the LF distribution pattern of landed Nephrops was comparable to the one from FU5. However, a larger proportion of Nephrops with a carapace length > 5 cm was found, suggesting an overall larger length in FU33. Regarding discarded Nephrops, FU5 had the highest frequencies of Nephrops < 2 cm, suggesting Nephrops from FU5 to be generally smaller. The LF pattern of discarded Nephrops from FU33 exhibited a notable peak around 3.0 cm length. This high relative frequency peak was driven predominantly by discarded females (Figure 19).

When comparing overall LF distributions between day and night hauls, there was no clear trend towards larger or smaller Nephrops landed or discarded during one of the times (Figure 20).

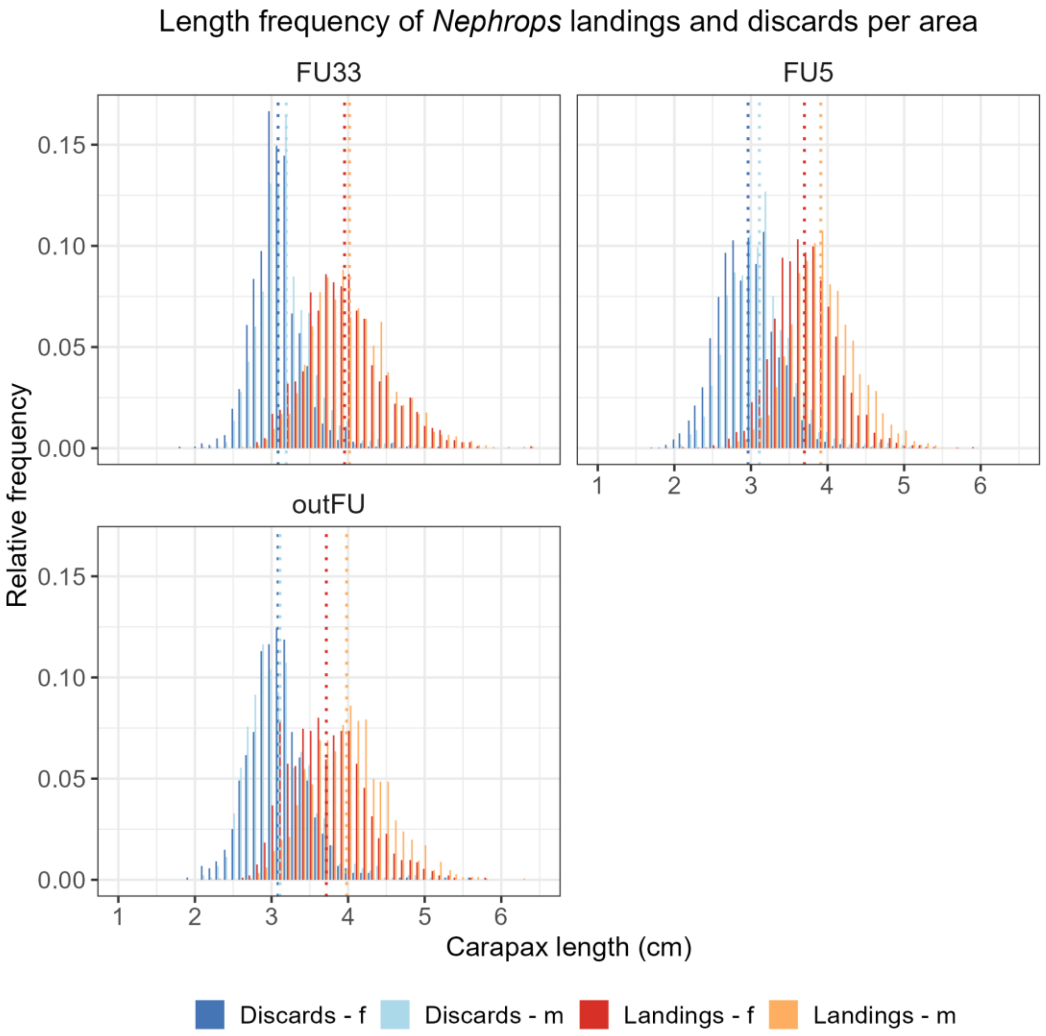

Figure 19. Length frequency distribution of landings and discards per area. Relative length-frequency (LF) distributions based on carapace length (measured in centimetres) observed in the self-sampling scheme for both Nephrops discards (represented in dark and light blue) and landings (in red and orange), segmented by the three areas (FU33, FU5, outFU) combing the years 2019 to 2023. Average length per group is indicated by dotted line. A differentiation is made between female Nephrops (indicated by darker colours) and male Nephrops (represented by lighter colours).

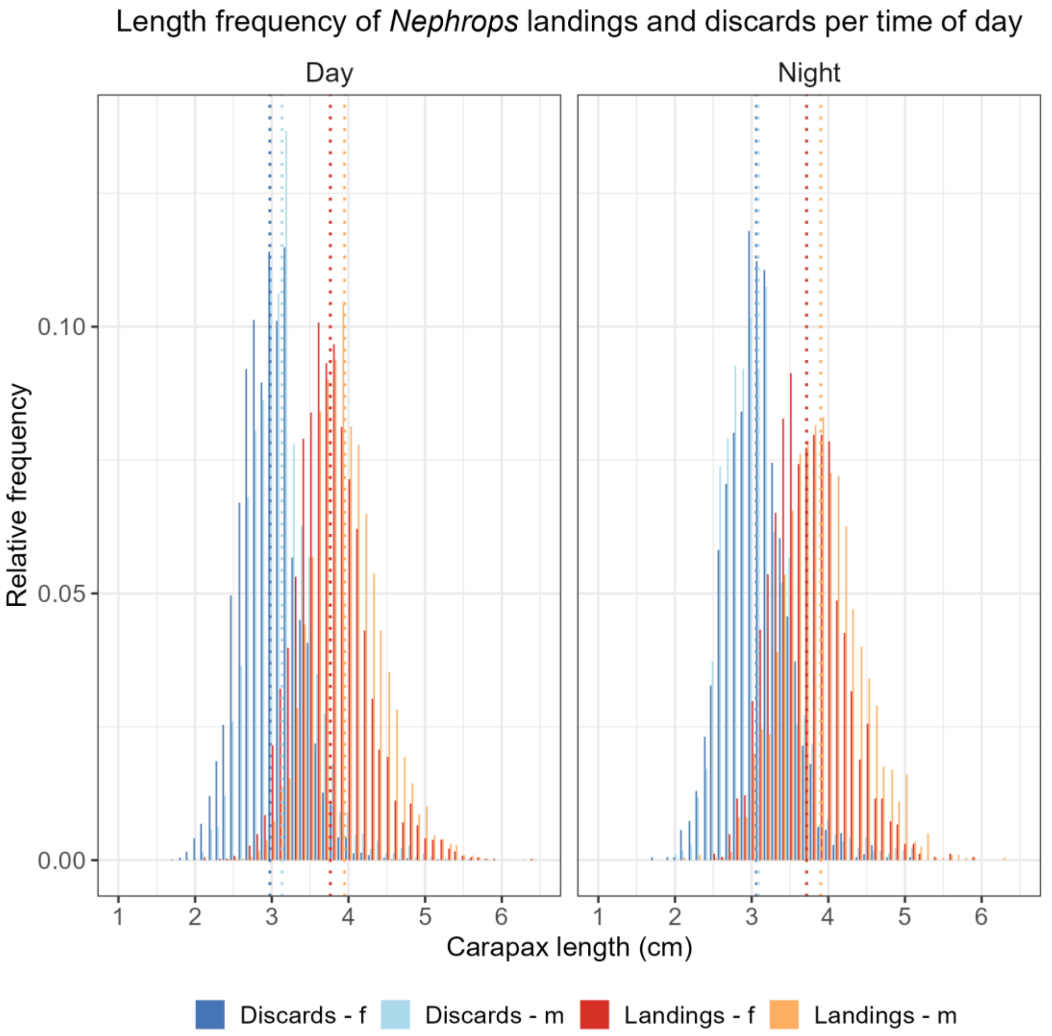

Figure 20. Length frequency distribution of landings and discards per day and night. Relative length-frequency (LF) distributions based on carapace length (measured in centimetres) observed in the self-sampling scheme for both Nephrops discards (represented in dark and light blue) and landings (in red and orange), segmented by day and night combing the years 2019 to 2023. Average length per group is indicated by dotted line. A differentiation is made between female Nephrops (indicated by darker colours) and male Nephrops (represented by lighter colours).

3.4.1 Statistical analysis of average Nephrops carapace length

To assess the effect of various spatiotemporal variables and differences in the average Nephrops carapace length between males and females, landings and discards, and across different spatiotemporal levels as described above, four different Gaussian GLMs labelled as A through D were fitted to the data. An overview of the statistically significant results can be found in Table 8Table 8 while the extensive result overview can be found in Annex 2 Table 12 Table 12A – D.

Model A
The length-frequency distributions from both landings and discards indicated variations in carapace lengths between males and females, as well as differences in lengths between discards and landings. To investigate these observations further, a GLM was applied to the data with the predictors "Category" (Discard/Landing) and "Sex" (Female/Male). The GLM analysis confirmed the presence of significant differences between average male and female Nephrops carapace lengths with males being significantly larger than females. Additionally, average landing lengths were significantly larger than discard lengths ($p < 0.0001$).

Model B
The second GLM was fitted to average length data, expanding Model A by including the time of the day (Day/Night) as predictor as well as interactions between both time of day and sex, and between time of day and "Category" (Discard/Landing). While both overall landing length as well as male length were found to be significantly higher than the discard and the female one ($p < 0.0001$), respectively, as expected from the visual and statistical observations described above, the time of the haul did not have any significant influence on the average landing lengths ($p = 0.4046$). In addition to that, neither of the interactions was significant ($p > 0.05$). Therefore, the other GLMs (Model C and D) were fitted to the data without including Day/Night as predictor. As the landing and discard lengths showed significant differences, the spatiotemporal effects on average Nephrops length on landings and discards were treated separately in the two additional GLMs.

Model C and D
Additional predictors included in the Gaussian models were Quarter, Year, and Area. This addition was informed by the visual analysis, which hinted at possible variations in average length associated with these factors. As also shown in Model A, both the average carapace length of male Nephrops in landings and discards were notably larger than those for females ($p < 0.001$). Within both categories the predictors Area and Year had significant effects on average length for both sexes ($p < 0.001$). Furthermore, Quarter had a significant effect on discard length only of both sexes ($p < 0.001$).

Examining the variables effecting landing length, it was observed that the average carapace length in Q4 was significantly smaller than in the first quarter ($p = 0.025$). Overall, Q1 was found to have the largest average length for landed Nephrops, while Q4 displayed the smallest. The largest landed individuals were found in FU33 with outFU areas having smaller sizes, and FU5 being significantly smaller ($p < 0.0001$) than FU33.

Regarding the years, 2022 stood out as significantly smaller than 2019 in terms of landings length ($p = 0.031$), with the highest average lengths in the landings recorded in 2021. Year 2022 is also significantly different from 2019 regarding discard length ($p = 0.024$), with the highest average lengths found in 2023 and 2021.

As for discard length, quarters were found to have a significant influence on average discard length, with Q3 being significantly different from Q1 ($p < 0.0001$) and the average length being largest in Q3. The same length pattern between areas were found in discard length as in landing length, with FU33 having the largest individuals in the discards, while outFU and FU5 were significantly smaller in average size ($p = 0.009$ and $p < 0.0001$, respectively).

Overall, the observations made from visual exploration stated in 3.4 were supported by the statistical analysis. Average Nephrops carapace length was significantly higher in landings than in discards, and males were larger than females. Both years and quarters varied in average length for discards and landings. In both discards and landings, the largest Nephrops were caught in FU33 and the smallest ones in FU5.

Table 8. Selective GLM output average Nephrops length. The effect of different variables on average Nephrops carapace length were tested average, as well as the effect of interactions between variables on the average Nephrops carapace length. An overview of only the statistically significant ($p < 0.05$) output is presented here. The GLM equation is provided in italics. More detailed and extensive results can be found in Annex 2 Table 12 A – D. Additional abbreviated statistical values provided: Df = degrees of freedom; AIC = Akaike Information Criterion; scaled dev. = scaled deviation; p = p-value.

	Variables (* = Interactions)	**Df**	**Deviance**	**AIC**	**scaled dev.**	**Pp**
A	*Length ~ Category + Sex*					
	Category (Discard/Landing)	1	157.2250	953.4230	955.4800	**<0.0001**
	Sex (Female/Male)	1	45.0785	55.1370	57.1940	**<0.0001**
C	*Length ~ Sex + Quarter + Area + Year*					
(Landings)	**Sex (Female/Male)**	1	22.4470	52.9800	33.9010	**<0.0001**
	Quarters (1 – 4)	3	20.8370	22.8580	7.7790	0.0510
	Areas (outFU, FU33, FU5)	2	22.0170	44.1930	27.1150	**<0.0001**
	Years (2019 – 2023)	4	22.5850	49.1230	36.0440	**<0.0001**
D	*Length ~ Sex + Quarter + Area + Year*					
(Discards)	**Sex (Female/Male)**	1	14.843	-115.14	36.38	**<0.0001**
	Quarters (1 – 4)	3	15.761	-97.052	58.468	**<0.0001**
	Areas (outFU, FU33, FU5)	2	15.106	-110.684	42.836	**<0.0001**
	Years (2019 – 2023)	4	14.573	-127.914	29.606	**<0.0001**

3.5 Validation self-sampling

Observer sampling was done simultaneously with self-sampling, aiming to achieve a balanced distribution of these sampling trips across quarters and areas (2.1.3). It's worth noting that self-sampling is primarily occurs in FU5 with fewer occurrences in FU33 and outFU. This pattern is not reflected in the observer sampling (Figure 9).

The validation was split in two distinct parts. Firstly, validating the average LPUE and DPUE weights (in kg per hour) as described in the Weight Data Analysis section (3.2.1), secondly validating the average carapace lengths for Nephrops as describe in the Length Analysis section (3.4.1). The validation itself was performed by applying GLMs to the data.

3.5.1 Average weights per hour

A GLM was fitted to the weight per hour data to assess potential differences between the average weight per hour recorded by self- and observer sampling. The output of the GLM can be found in Annex 2 Table 13Table 13-A.

A visual examination of the data for the sampling schemes separately showed, that both LPUE and DPUE data was skewed to the right. To address this in the application of a GLM, Gamma log-link transformation was performed on the data. As no differences between LPUE and DPUE for the self-sampling data were found (3.2.1), these two categories were combined in the GLM for comparison between sampling schemes (self- and observer sampling).

The analysis showed that there was indeed no significant effect of the Category (Discard/Landing) on the average weight per hour recorded ($p = 0.041$), while there was no effect of sampling scheme found on DPUE or LPUE ($p = 0.1060$).

3.5.2 Average lengths

The analysis on self-sampling carapace length data found significant differences in average Nephrops carapace length between landings and discards (3.4.1). It was therefore decided to fit separate GLMs to the landing and discard carapace length data. The output can be found in Annex 2Table 13 Table 13–B and Table 13–C.

For landing lengths, the data distribution of Nephrops suggested the use of a Gamma log-link GLM which used the sampling scheme (self- and observer sampling) as only predictor variable. The sampling scheme had no significant effect on average landing length of Nephrops ($p > 0.05$).

A Gaussian GLM was applied to the discard data, which found a significant effect of the sampling scheme, and found discarded Nephrops in the self-sampling to be on average 0.13 cm larger than during observer trips ($p = 0.0054$).

3.5.3 Species composition

In addition to carapace length and LPUE and DPUE, species composition in landings and discards of the observer trips was investigated as well. This showed that comparable to self-sampling trips, the main groups of non-target species in the landings were flatfish and roundfish, with European plaice, turbot, whiting, and grey gurnard being the dominant species. In the discards, the dominant species were Common dab, European plaice, anglerfish, whiting, Grey gurnard and Atlantic cod, which supports the species compositions found in the self-sampling. Furthermore, this suggests a resemblance in fishing practices and the coverage of similar habitats between the two sampling schemes.

3.6 Feedback gathered from WGNSSK

Preliminary results of Q2-2019 to Q4-2022 data were presented at the ICES WGNSSK (Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak) meeting, April 18th 2023, held in Den Helder, NL (ICES, 2023). The monitoring approach and sampling procedure were presented, along with preliminary results of length-frequency distributions for male and female Nephrops per year, quarter, and area. In addition, an outlook on upcoming analysis work was given.

One question arose regarding the origin of the prominent number of discarded males around 5.5 cm in 2021. However, more thorough data checks identified observations that were falsely categorized as "discards" within the database. Consequently, this was corrected in the database, and the observations in question did not show any unusual or unexpected patterns anymore.

3.7 Alternative monitoring methods

Four alternatives to the static loadcells currently used in the monitoring program were reviewed on their ability to provide accurate weight estimates, ability to ensure randomization and spread across a reference fleet, and their financial and time effort to be applied.

3.7.1 Proportion discarded vs. landed Nephrops

To calculate the proportion between discarded and landed Nephrops, the absolute weights (kg) of both categories were used as these are directly measured, without requiring additional calculations compared to e.g. using more standardised weight values such as LPUE and DPUE. The proportion from discarded to landed Nephrops was calculated following the approach described in 2.1.3.

The proportion results calculated from self-sampling data clearly show that the limited number of sampled hauls per trip ($n = 2$) cannot provide sufficient information to visually identify any trends in proportions between landing and discard weights (Figure 21). It is apparent that there is a high variability in both weights and proportions, not only between the quarters (as indicated by the different colours of data points) but also between areas. Furthermore, the large 95% confidence intervals shown in grey (Figure 21) are a direct result from the limited number of sampled hauls in a specific area and quarter.

Particularly when comparing the self-sampling with the observer data, a clear difference is shown in proportion trends between discard and landing weights. The increased number of sampled hauls per trip in the observer sampling allows for a clearer visual trend prediction. As expected, the amount of discarded Nephrops increases in all quarters in all areas with increasing landing weight of Nephrops. However, the slopes of the linear trend lines vary between areas and quarters within an area, indicating different discard to landing weight proportions depending on sampling area and quarter.

When looking at an overview of the proportion factors that are resulting from dividing discard weights by landing weights, a large range for these quotients is apparent, ranging from discard weights being 0.07 to 1485.75 times the weight of the landing weights in the self-sampling data, and ranging from about twice the landing weight to about 1303.11 times the landing weight in the observer trip data (Table 9).

It is also apparent that neither the mean nor the median factor would be able to capture the high variability in discard to landing weight proportions (Table 9). Consequently, no simple proportion factor can be calculated that would allow for an easy estimate of discarded Nephrops based on their landing weights.

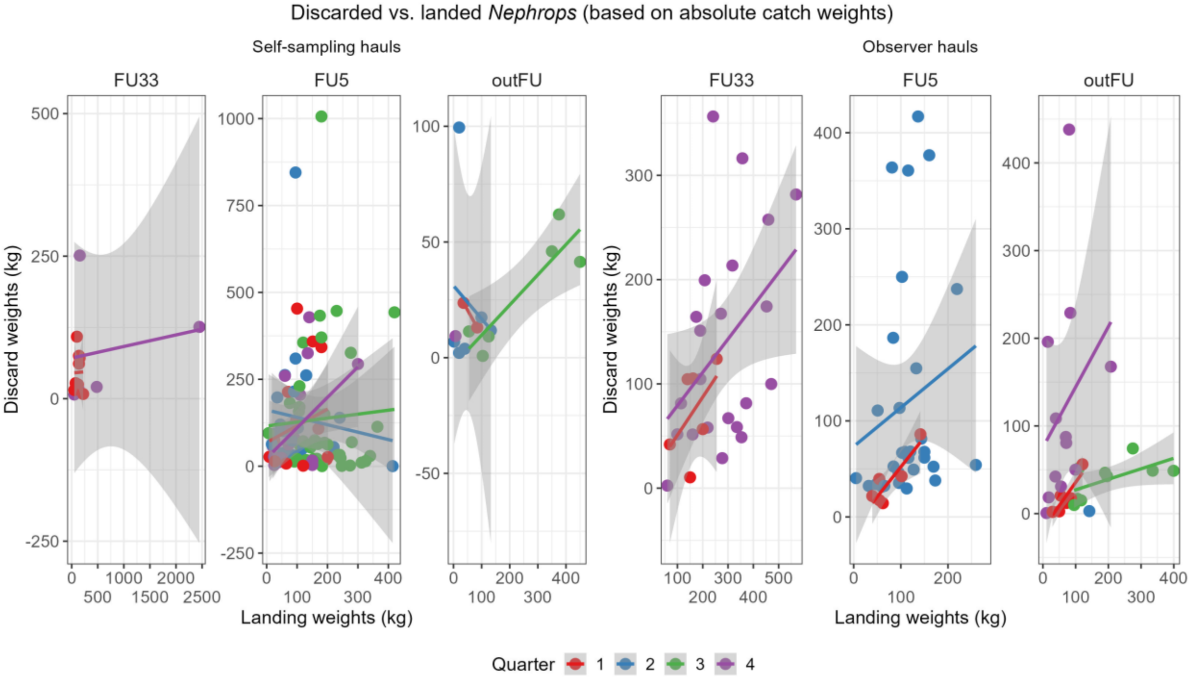

Figure 21. Proportion discard vs. landing weights. Discard weights of non-marketable Nephrops were compared against the landing weight of marketable Nephrops for self-sampling (left) and observer sampling scheme (right) and per Functional Unit (FU) separately. The relationship between discard and landing weight is visualised by a linear regression line for each quarter separately (quarters 1 – 4; red, blue, green, purple), including the corresponding grey 95% confidence interval for each regression line.

Table 9. Overview proportion discard vs. landing weights. For each sampling scheme (self- and observer sampling), the minimum (Min), maximum (Max), as well as the median and average (Mean) proportions of discard vs. landing weights are displayed, showing the wide range of values and the high variability found in discard-landing weight proportions, as visualised in Figure 21. The number of NAs (no proportion available) is given as well. They resulted from hauls for which no landings were recorded, not allowing for a proportion to be calculated.

Sampling scheme	**Min**	**Median**	**Mean**	**Max**	**NAs**
Self-sampling	0.07	47.30	126.04	1485.75	52
Observer sampling	2.01	51.80	98.17	1303.11	26

3.7.2 Visual estimation

The method of visual estimations of catch weight was tested on board of a beam-trawler fishing vessel targeting plaice and sole (van Mens, et al., unpublished). Nine hauls were sampled (each 45 to 60 minutes of length), for which the crew and one observer made visual estimates of the total catch weight. The estimates were compared to the true weight. The process of visually estimating the catch took up approximately 5 minutes per haul (pers. communication Allard van Mens). It did not require any monitoring equipment. The total discard weight ("true weight") of the sampled hauls ranged from 134 to 430 kg (van Mens, et al., unpublished).

The mean percentage difference of the visual estimates compared to the true weights was 111.2%, with differences per haul ranging from 62% to 156.9% (pers. communication Lennert van de Pol). The visual estimates among crew members showed great variety, with some crew members mostly overestimating, while others underestimated the catch volume and/or weight. The mean percentage difference from weighted values for target species through visual estimation compared to true weights ranged from 92% (for sole) to 140% (for plaice), with a standard deviation of 74 and 67 respectively (van Mens, et al., unpublished).

3.7.3 3D photogrammetry

A method for estimating volume of catch in hoppers using photogrammetry was developed by SINTEF Ocean. A test protocol (Annex 3) to support an observer in gathering the required data for the analysis was set-up. The outcomes were provided by SINTEF in a brief report (Annex 4). A summary and discussion of their findings is provided in this section. Data was gathered during two observer-trips (2022 and 2023). The first observer trip was used to test prepared guidelines by SINTEF that provided feedback on how to improve data collection to match the requirements for the photogrammetry analysis. During the second observer trip, footage was collected based on these improved data gathering guidelines. Data was collected for a total of six hauls, both for starboard and port side. Videos of two hauls appeared corrupted and could therefore not be used in the analysis. The accuracy of the methodology was evaluated by comparing the estimated catch weight (based on estimated volume and sampled mass density) to the static loadcell data. The total photogrammetry-estimated weight of each hopper (if using the average manually measured mass density of 1 kg/L) is +0.4% for starboard (20 kg, based on 6 hauls) and -13% (424 kg based on 4 hauls) for portside of the loadcell-obtained weight. The starboard errors are minor (ranging from 4.2% to 1.4%) compared to the portside estimate errors (ranging from 26% to 8%). The reason for higher errors on portside is likely because an empty starboard hopper was used for the 3D modelling of both starboard and portside. Moreover, the estimation of total weight of all hauls together has a lower error compared to each individual haul, which indicates a normal distribution in weight estimation error.

3.7.4 Mobile loadcells

Mobile loadcells as developed by the firm "Penko" were tested during an observer trip in 2023. The test involved weightings of a known weight of the water tank (IBC) with the mobile loadcell at sea in light and heavy movement (swell) under four different measurement intervals. At each interval, multiple measurements were done, ranging from 7 to 38 measurements. Leaving the port, both type of loadcells (mobile and static) were tested with light swell for the same IBC. On open sea, both types of loadcells were tested with heavy swell.

Some measurements failed at the start of the experiment, as the battery of the mobile loadcell appeared to be flat. Moreover, due to a quicker departure from the port than expected, too little time was left to connect the loadcell to the power grid and perform the weightings. Also, no measurements were made for the static loadcell in the harbour.

The results are shown in Annex 4. Figure 22 provides an overview of the measurements of the static and mobile load cell compared to the true weights at the different locations. The estimates for the static loadcell appear more accurate compared to the mobile loadcell (estimates lay closer to the true weight). Nonetheless, the mobile loadcell usually remained within a close range to the true weight, with a mean per location ranging from -0.4% (underestimation) to 17.9% (overestimation). The deviations as seen for the static loadcell compared to the true weight ranged from 6% to 19.2% (higher than the true weight) with an outlier of 91.3% (Annex 5 Table 15). The lower the measured weight, the higher the deviation seems to be for the static loadcell. This could be due to the relatively heavy weight of the load cells themselves (7 tons), compared to the mobile load cell (1 ton). This could cause larger deviations at lower weights.

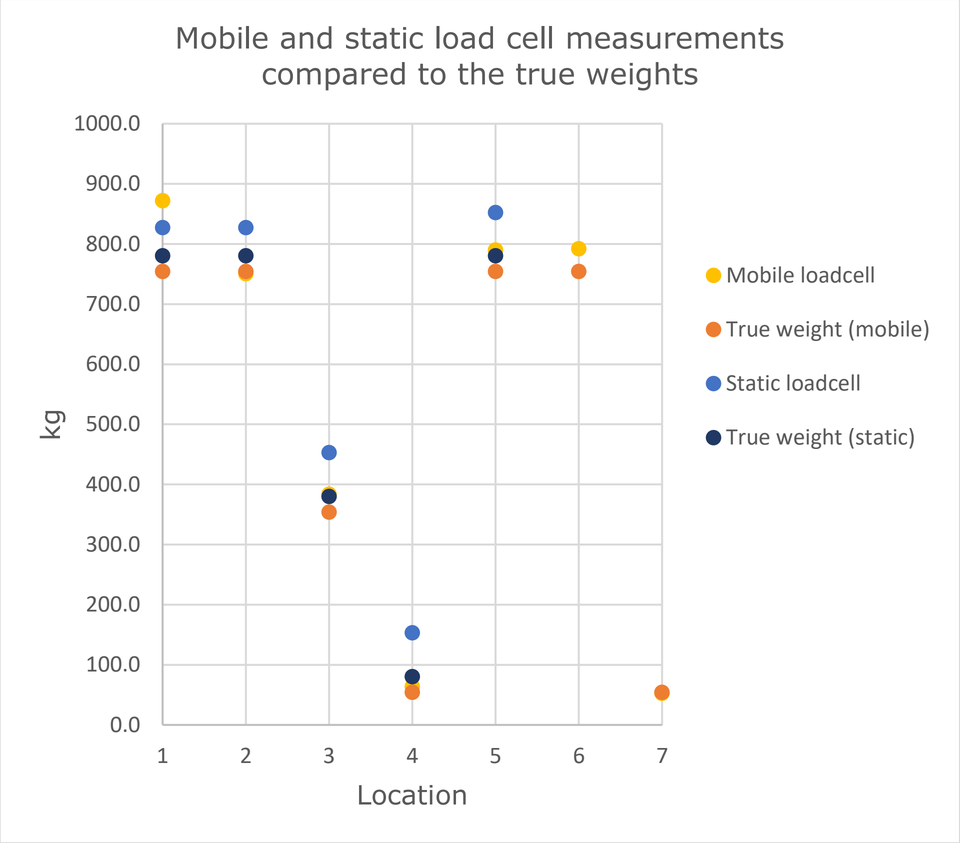

Figure 22. Mobile load cell (yellow) and static load cell (light blue) measurements compared to the true weight (orange for the mobile load cell experiment, dark blue for the static load cell experiment). Locations 1 and 5 are on the Wadden Sea (light swell), locations 2, 3 and 4 are on open sea (heavy swell), locations 6 and 7 are in the harbour (little to no swell).

3.8 Feedback from participating skippers

For the reference fleet vessels, a Skippers-day and individual calls were organised, in which the results were discussed and feedback on the collaboration within the project was collected. Three out of the five reference fleet skippers provided their feedback. The aggregated results were also presented and discussed at an annual meeting for all research cooperation projects within WMR (OSW-day), which could be attended by the entire fishing industry, provided they were members of one of the participating POs.

Feedback on results

Overall, the skippers of the reference fleet indicated that they identified with the presented results. The distribution among the sampling locations corresponds to their views on the fishing behaviour of the fleet. Some skippers indicated that Brexit and/or fuel prices had influenced their fishing behaviour. Higher fuel prices led, among others, to them remaining ashore longer, carrying out fewer hauls per trip and moving more northwards in the North Sea. Brexit mostly seemed to have impacted the skippers that target Nephrops in UK waters or those fishing under the German flag. The latter is because Germany receives only limited Nephrops quota and primarily used trading with the UK as their source for quota. It was noted multiple times by the skippers that the fishing pressure has accumulated towards the north-eastern Nephrops habitats, likely due to these developments. Another reason for avoiding UK waters by Nephrops fishers, is that different mesh size regulations are enforced here, which calls for mandatory gear conversion when fishing in these areas.

Skippers also recognized the composition of most common discard species (fish and benthos) identified in the discard samples. The increased amount of haddock ((*Melanogrammus aeglefinus*), *schelvis*) and to some extent whiting ((*Merlangius merlangus*), *wijting)* as a bycatch species was particularly highlighted by the skippers. They indicated that these species have only increased tremendously in the North Sea in the recent one or two years. Also the differences found in lengths across sexes (i.e. bigger male Nephrops) are in line with their experiences. Moreover, skippers confirmed the higher Nephrops LPUEs in Q2 and Q3.

More than once, the difference between southern (FU5) and northern (FU33) areas were confirmed. It was mentioned by skippers that in FU33, Nephrops start 'surfacing’ (appearing) from Q3 onwards. They also endorsed that larger sized lobsters can be caught here. This is consistent with the self-sampling results. An interesting experience that was shared is that apart from the larger sized lobsters encountered when moving from south to north, also more regional length variances are present. Particularly towards the Frisian Front, more local distributions of larger and smaller sized lobsters are experienced by skippers. It would be interesting to investigate these length distributions further.

Feedback on collaboration

The collaboration within OSW2.2 was met with a very positive response, especially the contact with and cooperation of the observers. Cooperation on board proceeded smoothly and the outreach and support of the research team was as desired. The protocol was also deemed sufficiently clear.

Initially the project aimed to periodically provide, trip-specific feedback after each observer trip in the form of an observer letter to the skippers of those trips. However, this was impracticable due to the lag in data gathering, data processing and analysis. The data flow took more time than expected, and the data analysis could only be performed towards the end of the project. For the same reason, the newsletters that were planned for each quarter of the year with aggregated results from the self-sampling were not sent. Although feedback on the results was less extensive than initially anticipated, this was not deemed a significant issue. Skippers indicated that sampling provided additional insights, for example the differences in occurrence of sexes.

Given the results on the alternative monitoring methods, skippers perceived no advantage in using 3D analysis (in its current form), visual estimation or proportion factor. They expressed satisfaction with the static load cells and frequently use them even apart from self-sampling procedures as a source of information during their fishing activities (e.g. insight in weight difference between port and starboard catch). The mobile load cells would, however, be of interest.

4 Discussion & recommendations

4.1 Monitoring output

4.1.1 Data handling

A more balanced dataset, especially across different areas, is desirable. However, implementing this in the self-sampling scheme is posing challenges. Mandating fishers to shift their fishing activities further north to reach FU33 would inevitably lead to increased costs for them. These costs as well as costs compensating for the reduced fishing time due to increased steaming time, present a complex trade-off that is difficult to reconcile solely for the sake of achieving a more balanced dataset.

The number of trips that took place in more than one area or quarter and were therefore assigned to one area or quarter (2.1.3) is very low and this procedure is not considered to have a significant influence on the results. The limited number of full-time Nephrops vessels that could participate in this project is limited (2.1.1). In addition to this, not all vessels of the Nephrops-fishing fleet are fishing Nephrops full-time (1.1). Therefore, it is at this point difficult to raise the data collected within the scope of OSW 2.0 and OSW 2.2 to fleet-level, but additional data collection could enable this. This is recommended in order to get a more realistic insight in the Dutch Nephrops fishery which could be used in the context of stock assessments.

4.1.2 Weight data

The high fluctuations in the Nephrops LPUE and DPUE results at trip level indicated the necessity to analyse weight data not at trip level but at a broader resolution, e.g. at quarter and area level. For follow-up analyses a monthly or bi-monthly scale could hold additional information on seasonal fluctuations in Nephrops LPUE and DPUE across the different fishing areas.

In addition to this, the clear shift in CPUE-driver from DPUE to LPUE in 2022 and 2023 could have been caused by changes in fishing behaviour due to increased oil prices. However, it will be of high value to further monitor the development and the patterns of LPUE and CPUE over the upcoming years to determine their importance for the Nephrops fishery fleet.

The observed high in Nephrops landings in the third quarter of this project goes along with the logbook data presented in the Wageningen Marine Research (WMR) VISSTAT database (*Visserij Statistieken*) as found in Figure 2. While Figure 2 shows absolute weights, the results from this project show that similar seasonality-related patterns are also found in the more standardised LPUE in kilograms per hour fishing effort.

In addition to this, the visual species composition analysis (3.3.2) showed that the landed Nephrops accounted for about 30% of the landings, also going along with the information extracted from the WMR VISSTAT database (*Visserij Statistieken*). This shows that despite this project having fewer vessels participating compared to the collected logbook data, the results of this project are representative and in accordance with the logbook data.

The higher night CPUEs compared to day CPUEs could be explained by the burrowing behaviour of Nephrops which spend their time hidden in their burrows during the day before leaving them during the night (Chapman & Rice, 1971). The decrease of LPUE and DPUE towards Q4 could also be explained by the burrowing behaviour as females carrying eggs hide in their burrows during wintertime (Chapman & Rice, 1971).

The results of this project show that there are effects of both spatial (Area) and temporal (Quarter, Year, Time of day) variables which should be taken into account in future analyses regarding stock assessments, suggesting to treat the Nephrops populations in FU5 and FU33 as separate stocks, as there is a significant area effect on average LPUE and DPUE, particularly for LPUE in FU5.

4.1.3 Length data

Overall, it was found that male Nephrops have a larger carapace length than females. This was true for both discard and landing data. This is in accordance with the observations that fishers provided as feedback to the OSW 2.0 project (Bleeker et al., 2021). The overall smallest Nephrops were caught in the fourth quarter which goes along with the decreasing LPUE and DPUE weights in that quarter. Potential reasons for this difference in carapace length between sexes could be the restriction in growth in females due to limited food-intake due to staying in their burrows when carrying eggs which would result in a reduced energy-intake during this time (Johnson et al. 2013).

A low relative frequency of Nephrops under the allowed landing length was found in the landings data of the self-sampling. These undersized landed Nephrops, however, had a maximum deviation of 0.4 cm from the allowed landing length of 2.5 cm. This deviation is considered very low and the relative frequencies negligible. The reason for these accidental landings are most likely to be caused by human error as particularly during the night with bad lighting or during rougher weather it is very likely to accidentally misjudge the carapace length. Overall, landed Nephrops were found to be significantly larger than discarded ones, which was expected.

The discarding of Nephrops of marketable length, however, could be motivated by discolouration of the shell, missing limbs, or other defects that would make these individuals not marketable.

The sampling data from this project showed that there was a difference in carapace length found between areas, with the on average largest Nephrops occurring in FU33 and the smallest in FU5. This was also reported by the fishers in their feedback on the OSW 2.0 project in 2021 (Bleeker et al., 2021).

Furthermore, the results show that there are effects of spatial (Area) and temporal (Year) variables on both Nephrops landing and discard lengths. For discarded Nephrops, the temporal variable Quarter was also found to have a significant effect on average carapace length. This effect was not found for landed Nephrops ($p = 0.0510$), which could be a result of too little observations.

Overall, both spatial and temporal fluctuations should be taken into account in future analyses regarding stock assessments.

4.1.4 Validation self-sampling

For validation of self-sampling data, observer trips were executed during the same trips in which self-sampling data was collected. Therefore, the data from the two sampling schemes are both spatially and temporally comparable which facilitates the direct validation.

Regarding both LPUE and CPUE, no significant difference between self-sampling and observer sampling was detected. However, regarding carapace length, there was a significant effect of the sampling scheme detected that indicated that the average Nephrops length in the discards was higher in the self-sampling than in the observer samplings. This difference could be caused by the behaviour of collecting preferably larger individuals by fishers, which could be motivated by the maximum of 30 individuals per kilogram (PO measure) or price-reducing factors such as discolouration of the shell, missing limbs.

4.1.5 Further monitoring

Ideally, to establish a consistent time series of data suitable for stock assessment models, the monitoring program should span a minimum of five consecutive years. Therefore, data collection will be continued for an additional year beyond OSW2.2. This data should then be compared to the discard data as collected under the DCF to evaluate its accuracy. In addition, the data should be raised to fleet level and compared with discard data of the same time series that has been submitted to ICES.

4.2 Innovative monitoring methods

4.2.1 Proportion discarded vs. landed Nephrops

The development of a factor based on discard to landing weights was suggested to be applicable to infer Nephrops discard weights based on landing weights. This, however, is found not to be a straight-forward process. The resulting factor highly depends on spatiotemporal characteristics, as shown by the significant differences between areas and quarters found in LPUE and DPUE. Moreover, the number of hauls sampled per trip used for the total trip landing and discard weights may influence the proportion factor. Although a positive relationship between absolute landing and discard weights was indicated when using an increased number of sampled hauls per trip (as in the observer sampling),, a difference in discard to landing weight proportions depending on both area and quarter remains present.

Additionally, the assumption that only undersized Nephrops are discarded does not always apply. Marketable sized Nephrops were also found to be discarded in the self-sampling scheme. This influences the proportion factor. Another limitation of this method is the high variation in discard weights of undersized Nephrops per quarter and area which does not allow for a clear interpretation of the results.

Additionally, a single proportion factor assumes the presence of discards and landings in every quarter and area combination. This appears not always to be the case, particularly when only considering the presence of undersized Nephrops in the discards. An example of this are several hauls in the third quarter of FU5 (self-sampling) for which discard weights of sized Nephrops are equal to or close to zero (Figure 21).

The findings suggests that the approach of a proportion factor between discard and landing weights for *Nephrops* is too simplistic and should include effects of seasonality and spatial components. Also other variables such as sampling and fishing behaviour due to e.g. oil prices or Nephrops market prices might have an effect and should be considered. When presenting the results to the skippers (Section 4.3), feedback also included that Nephrops catches even seem weather-dependent, e.g. more smaller lobsters caught in rough weather conditions.

Our findings indicate a need to augment the number of hauls sampled for discards per trip if these weight values are to be used in calculating proportion factors. It is important to note that this approach is not deemed precise, and it depends on several factors that introduce complexity and time-consuming calculations, making it impractical for straightforward use.

4.2.2 Visual estimate

The experiment was executed on a beam trawl vessel, which is not part of the Norway lobster fleet. Both the fishing methodology as the species composition is different in these fleet segments (otter trawl and beam trawl). In this experiment, a kg-volume ratio of 0.7 to 0.75 was used. In the Norway lobster fishery, catch composition would likely be different, leading to another ratio. Especially when the catch consists greatly of Nephrops, less volume per basket can be found, as Nephrops are ‘bulkier’ and therefore more air can fit between them in contrast to flatfish.

The methodology of visual estimation could be applied directly, as no additional time and financial effort is required. Although this method appeared to be highly achievable in terms of time and expenses, and is randomly applicable across the fleet, the experiment showed that it does not provide an accurate nor precise estimate of the discard weights. Moreover, the estimates of the crew and observer are likely influenced by their previous estimations. In other words, it appears that their estimates relied on the previous haul's estimate, which led to either an over- or underestimation of the catch weight. Additionally, this method makes it challenging to eliminate the potential for fishers to influence the results in favour of their preferred outcomes.

The experiment has found that for more common species in the catch, estimations were more accurate (van Mens et al., unpublished). Moreover, when the total catch from a haul is relatively small, it is easier to estimate the catch weight or volume (van Mens et al., unpublished). These experiences indicate an inconsistent estimation pattern that varies on the amount of catch and species composition, consequently reducing data reliability. Concluding, visual estimation does not provide a suitable alternative to the static load cells at this moment, albeit more in line with DCF methodology. It would be useful for a follow-up study to look at how to give crew and skippers tools on how to make their visual estimates more accurate and consistent.

4.2.3 3D photogrammetry

The (variance in) errors in the 3D photogrammetry experiment are likely due to uncertainties introduced during the analysis process. This includes estimation of mass density of the sample taken by the observer, open hatch in hopper, accuracy of photogrammetry reconstruction, alignment, and scaling of the scan to 3D model, correctness of the 3D model to the empty hopper (see Annex 4, chapter 4 ‘Discussion’). Multiple adjustments could be made to improve data accuracy:

- Improve lighting on board and the stability of camera to improve data-quality.
  Process material directly on board, e.g. through a real-time analysis with a smartphone-app. This reduces the risk that poor data quality is only discovered after the trip.
- Ensure more accurate hopper measurements, e.g. by using a blueprint. The accuracy in alignment and scaling could be improved by installing easily detectable tags to the hopper.
- Errors will naturally occur when depending the weight estimate on a varying mass density between hauls (samples taken by the observer differ in kg/L). SINTEF’s analysis indicated that using an average value to estimate the weight of all hauls may lead to a lower error. However, it is more likely that due to seasonality and fishing behaviour, hauls and catch composition can still highly differ between fishing trips and even between hauls.

Moreover, although only simple equipment is required, the feasibility that fishers themselves will collect the necessary data (footage and sample) is a concern. In the experiment, the observer spent more time than expected during the hauls to collect the data. It is unlikely fishers would have time available for collecting footage. Mounting cameras on the vessel above the hopper could be a solution for this. 3D cameras are available that allow for capturing the correct range and accuracy to fully replace photogrammetry. In that case, the Structure from Motion (SfM) technique does not have to be applied, which would save time and effort. These cameras are however expensive.

The 3D photogrammetry methodology as performed for this project did not involve a real-time feedback system. It is not yet the case that this methodology can be performed directly on board (e.g. via a smartphone). This requires further research and development. If applied to multiple trips on multiple vessels during the year, both the financial effort and time effort are at this point not sufficiently developed to provide an alternative to the current loadcell measurement methodology.

4.2.4 Mobile loadcells

Several factors may have hampered the measurements of the mobile loadcells during this experiment, leading to errors. Especially for the first series of weightings (location Wad), a great difference between the expected weight (true weight of IBC system including water) and the weightings can be noticed. First, the loadcell could not be used correctly at the beginning of the experiment as the battery appeared to be flat. This obstructed weighing the IBC system (before the vessel left port). The problem was solved during leaving the port. Secondly, once the results were viewed with the producing firm, the observation was discussed that the loadcell did not hang freely and therefore hit the walls during the first measurements, hampering the accuracy of the weighing. Lastly, the water movement in the IBC might still influence the measurements as well.

The mobile loadcell system still showed estimations which are similar in deviations to the measurements as done with the static loadcell. It also has great potential in terms of financial effort (one loadcell can be applied on multiple vessels) and randomization across the fleet. It is therefore valuable to test this alternative further. Currently, a version that can measure up to 1000 kg is tested. For larger catches also a mobile loadcell that can measure beyond that weight should be tested.

4.2.5 Summary

A summary of the findings of the different weight measuring methods can be found in Table 10Table 10. The load cells currently used in the monitoring programme cannot be quickly and cost effectively disassembled and moved to other vessels. This prevents expansion of the reference fleet within the monitoring program, as well as the randomization of sampling. Despite all methods had their advantages over the static loadcells, most of the techniques were found to not be directly applicable. Particular advantages were ease of monitoring across the fleet (visual estimations, mobile load cells, proportion factor discarded versus landed lobster). Yet disadvantages were relatively large errors in the estimates (e.g. for visual estimation, ratio) and low cost-efficiency (3D photogrammetry). However, some methodologies have only been tested to a limited extent within this project to be able to draw definite conclusions, and further development could improve these shortcomings. Especially the mobile load cells could show great advantages over the static load cells in terms of monitoring flexibility and costs, as it showed weight estimates close to that of the static load cells.

Although purchasing and installing more static loadcells for the time being could be a next step to increase the coverage across the Norway lobster fleet, it is a risk due to current developments in the Dutch fishing fleet. Many vessels are putting a halt on their activities, and it is therefore uncertain how many vessels will remain both in general as well as in the reference fleet. When continuing with static loadcells, either the current amount and/or newly purchased ones, both safety and maintenance should be taken care of. Moreover, effort should be put in a more standardized protocol (e.g. always measure cod-end at same hight to ensure measurement consistency) and potential influences on the measurement (e.g. water leaking from cod-end) should be examined.

Table 10. Summary results alternative monitoring methodologies.

Method	Data accuracy	Time effort	Financial effort	Coverage reference fleet	Conclusion
Static loadcell	Accurate provided correct calibration and standardized protocol application across reference fleet.	Medium time effort, sorting out of discard sample is required but low effort recording the measurements.	Medium financial effort when bought for one vessel/small reference fleet, but procurement, instalment and repairs will lead to high costs for greater reference fleet.	Low, cannot easily (re)moved as it depends on an installed structure on board	Although not easily movable, applicable and reliable method for now
Proportion landed discarded lobster	Not very accurate when only a couple of hauls per trip are sampled. As soon as more hauls are sampled per trip, a trend is observable. But still large variations in trends between areas and quarters.	Not a lot of extra time, data is available.	Minimum costs, solely data analysis work to be executed which can be performed relatively quickly in a standardized format.	High, can be applied for any vessel	Not a suitable alternative
Visual estimation	Low, not very accurate nor precise. Could be improved by trial-and-error, estimates dependent on catch composition and catch size.	Not a lot of extra time	No costs.	High, can be applied for any vessel	Not a suitable alternative, however more in line with DCF methodology.
Photogrammetry	Relatively accurate, improved accuracy possible with further development and standardization.	High time effort in current format. No real-time feedback system, 3D photogrammetry and data analysis takes time. Also still sorting out of discard sample required.	High financial effort in current format. Outsourcing to third party (e.g. SINTEF Ocean) necessary.	High, can be applied for any vessel	Not a suitable alternative, however interesting to develop further
Mobile loadcell	Accuracy close/comparable to loadcells	Medium time effort, sorting out of discard sample is required but low effort recording the measurements.	Medium, one-time purchase with ongoing instalment/repair costs but can be moved across vessels (no new one needed per vessel).	High, can be applied for any vessel	Might be a suitable alternative, however interesting to test and develop further

5 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

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Justification

Report C065/23
Project Number: 4311400037

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. J. Batsleer
Senior fisheries scientist

Signature:

Date: 18 oktober 2023

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

Signature:

Date: 18 oktober 2023

Annex 1 Data collection procedure

Load cell weighing system

To measure the total catch (landings, discards, and debris) on board of a fishing vessel at sea, a static load cell system was used in this project, developed by the firm “Pat Kruger”. The load cell weighing system enables motion-compensated weight measurements on board of fishing vessels. The use of this technique provides an actual weight measure of the catch instead of a visual estimation of catch weight that is currently used in the DCF program.

At each side, the loadcells are mounted between the mast and the jumper block (Figure 23). Once attached to the jumper rope, the cod-end is lifted from the water, resulting in the full weight of the cod-end hanging under the loadcell. When the cod-end hangs free above the load box, the weighing can be started. As far as conditions allowed, weighing was only started once water had been drained from the cod-end. The weighing is done by the skipper in the bridge pressing a button on the system. The skipper then activates the weighing per side. In a period of 10 to 15 seconds per cod-end, several measurements are made so that an average can be calculated. The measurements are saved to an internal hard drive automatically, which can be extracted with a USB device. Then the cod-end gets emptied.

The weight of the empty (wet) cod-end is deducted from the measurements, to derive the total catch measurement. In cases where no empty (wet) cod-end measurements were available of a trip, the most recent measurements of the trip before were used.

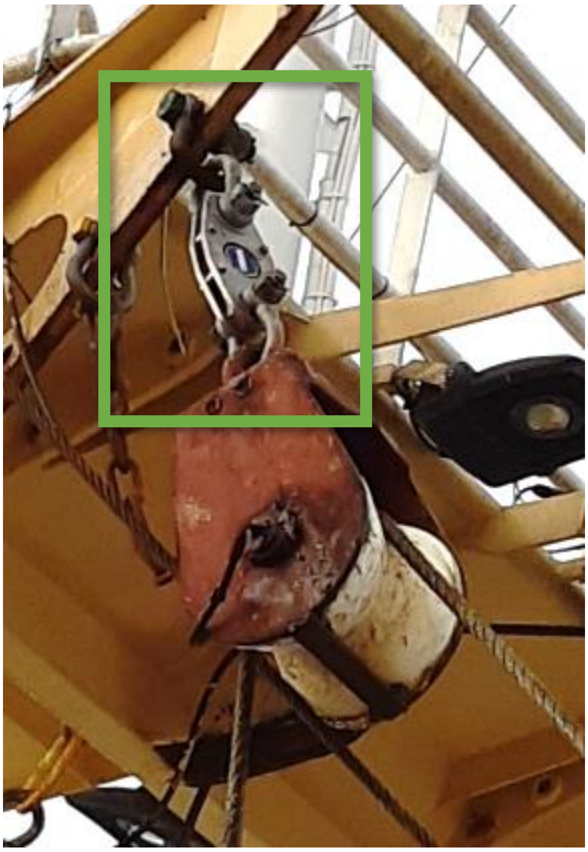


Figure 23. Load cell with safety plates mounted between mast and jumper block. Source: Tom Bangma.

On instalment, a new load cell gets validated by using an IBC system (see Section 3.7.2 and Table 15). The weighing capacity of the load cell system is up to 7 tons. In case weights exceeded the maximum of 7 tons, the system needs recalibration (using water bags of 2000 litres of water) as a stretch in elastic material used in the loadcell may cause deviations in the measurements. This however did not occur during the project and recalibration was therefore not needed.

Procedure self-sampling

In consultation with the skipper it was decided whether the selected week was suitable for self-sampling, often depending on crewmembers' availability, weather conditions and potential planned maintenance of the ship. A project member of WMR remained standby during a self-sampling trip to support skippers (e.g. about the sampling programme, technical problems, shortage of materials).

Trawl list

The skippers were required to fill in a trawl list for each sampled trip. For each haul, the skipper noted the weights of the total catch as measured by the loadcells for both port and starboard nets. The trawl list included information on the landings (per species) per haul, as well as operational data (e.g., vessel position at start and end; haul duration; depth; weather conditions). Each trip, the wet weight of the nets per side is recorded once with the loadcell to be able to subtract this weight from the catch weights.

Discard samples

For two hauls spread over the trip, ideally on different days, the crew took a sample of the catch. One sample should be done during daytime, and one during night-time. The skipper decides which hauls to sample. For each of these hauls a discard sample of 80 kg during the processing of the catch, by taking a sample of 20 kg at four different moments during the catch processing (i.e. at the start, twice during the processing, and at the end of catch processing).

The samples were brought to shore to be sorted out and identified per species (by firm “Visserijbedrijf van Malsen”). The samples are labelled with haul-number, date of sample, vessel-name. Haul-number relates the sample to the trawl-list and haul-information. The sample is stored in plastic bags with ice in the cooling storage of the vessel. After the trip, the samples are transferred to the cooling storage of the fish auctions, where WMR collects the samples. Data is then digitalized (by firm “Gebroeders Kaij”). Both firms are experienced and have demonstrated to meet the quality assurance standards which WMR uses for its personnel in relation to species sampling and determination. Only personnel or external parties that meet WMR standards (annual test), are allowed to carry out this work without supervision.

Length measurements of marketable lobster

From the landings of the two sampled hauls, a selection of 100 Nephrops individuals (approximately 5 kg) were taken, their lengths measured, and sex identified. These were collected at the beginning of the conveyor belt before size-sorting them. Ideally 50 male and 50 female individuals of Nephrops were measured to gain more insight in the sex ratio of the catch and size differentiation between sexes. If there were more than 50 individuals of one sex in the initial selection, only 50 needed to be measured. If less of one sex are in the initial selection, only the number that are in the selection are measured. This could therefore result in less than 100 individuals being measured. Also, the weight of the measured individuals per sex was recorded.

Procedure observer trips

The accuracy of data gathered through the self-sampling scheme was validated by scientific observer trips. A trained scientific observer (from Wageningen Marine Research) boarded a selected self-sampling trip of a reference fleet vessel. The trip selection was based on observer availability, seasonality (whether vessels targeted Norway lobster or not) and the coverage of the vessels (goal was to balance coverage among all reference vessels). Observers made independent observations on the size and composition of landings and discards. The scientific observer took approximately 40 kg discard samples on as many hauls as possible. Samples are sorted by species, then length and weight measurements of fish and Nephrops are taken, as well as counts and weights of benthos. Alongside the activities performed by the observer, the crew carried out the usual self-sampling protocol.

The data gathered by the observer was compared to the data gathered by the crew to validate the data accuracy. This method corresponds to the discard self-sampling program with the DCF (Bleeker et al., 2023). For each haul, the skipper noted the weights as recorded by the load cells, which are checked by the onboard observer. A report of each trip was made by the observer.

Annex 2 Results monitoring data

This Annex provides additional information on sampling locations for both the self-sampling and observer sampling schemes. In addition to this, it provides the statistical results for both the statistical weight and length analyses (3.2.1 and 3.4.1), and for the validation of the self-sampling scheme (3.5). More detailed information on both flatfish and roundfish species and their respective contribution to landing and discard weights is provided to supplement Section 3.3.

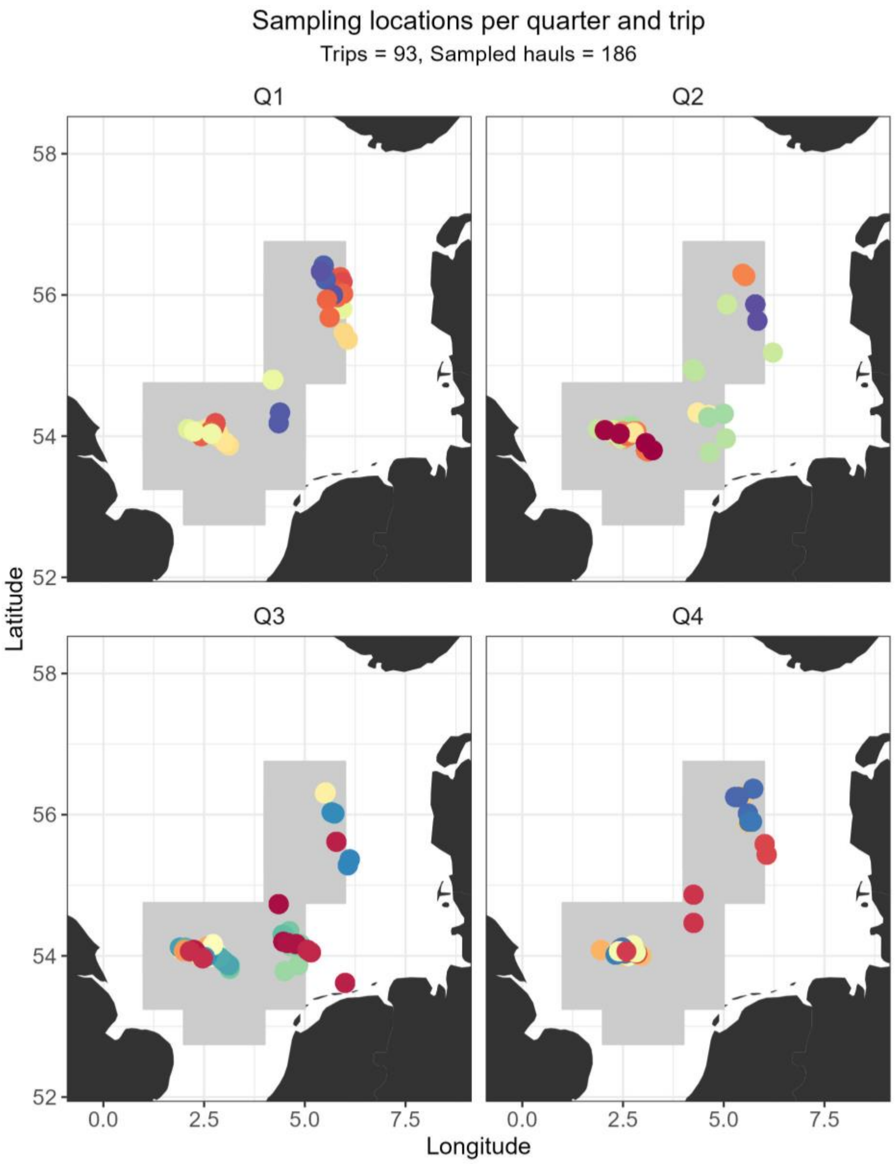


Figure 24. Sampling locations (self-sampling). The locations of sampled hauls as done in the self-sampling scheme are displayed for the quarters 1 – 4 (Q1 – Q4). The sampling areas FU33 and FU5 are indicated in grey, with FU33 being represented by the rectangular grey polygon further north. Each coloured point represents one sampled haul with each colour representing a separate trip. Note that some points can be overlayed by others if the sampling locations between the hauls overlapped.

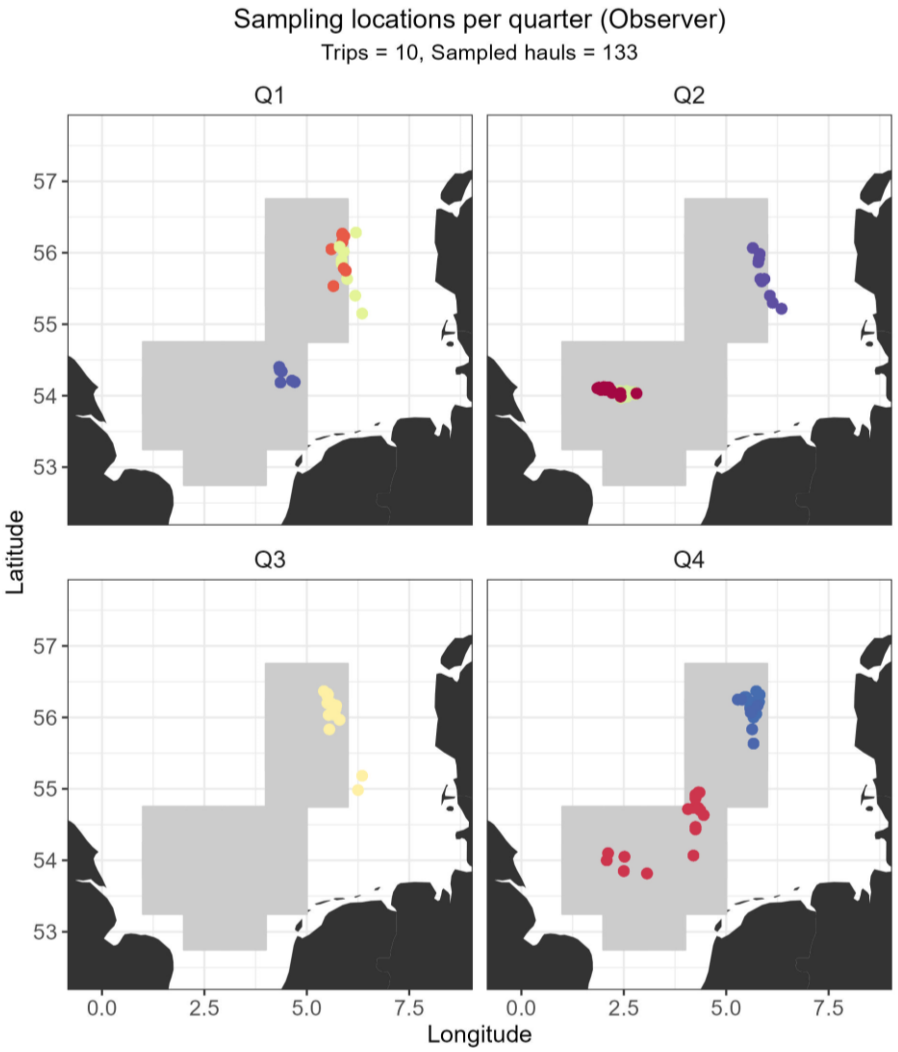


Figure 25. Sampling locations (observer sampling). The locations of sampled hauls as done in the self-sampling scheme are displayed for the quarters 1 – 4 (Q1 – Q4). The sampling areas FU33 and FU5 are indicated in grey, with FU33 being represented by the rectangular grey polygon further north. Each coloured point represents one sampled haul with each colour representing a separate trip. Note that some points can be overlayed by others if the sampling locations between the hauls overlapped.

Table 11. GLM output for Nephrops weight. The average Nephrops Landings Per Unit Effort (LPUE) and Discard Per Unit Effort (DPUE) were compared against each other, and the effect of different variables on LPUE/DPUE were tested. In addition, differences of LPUE/DPUE between various levels of the variables were tested. Therefore, three different Generalised Linear Models (GLMs; Model A - C) were fitted to the weight data. For each of these models, the used formula is provided in italics, including the variables and the interactions between variables (indicated by *) used. The statistical output is shown in two parts for each of the models The upper part shows the effect a variable (and its levels) has on the average LPUE/CPUE, while the lower part provides additional details on the differences between levels of a variable. Effects of a variable, interactions between two variables, and differences between variable levels that were found to be statistically significant (p-value < 0.05) are highlighted in bold. Additional abbreviated statistical values provided: Df = degrees of freedom; AIC = Akaike Information Criterion; scaled dev. = scaled deviation; p = p-value; Std. Error = standard error.

Model	**Variables (* = Interactions)**					
A	*Weight ~ Category*	**Df**	**Deviance**	**AIC**	**scaled dev.**	**p**
	Category (Discard/Landing)	198.7030	1678.0710	0.7880	0.3750	0.3756
		Estimate	**Std. Error**	**t value**	**p**	
	Intercept	35.3391	0.1128	313.33244	<0.0001	
	Landings	0.8679	0.1595	5.4415	0.3756	
B	*Weight ~ Quarter + Area * Category + Year * Category*	**Df**	**Deviance**	**AIC**	**scaled dev.**	**Pp**
	Quarters (1 – 4)	3	136.3080	1625.1990	15.7850	**0.001**
	Area * Category	2	133.1680	1622.0080	10.5940	**0.005**
	Year * Category	4	144.5520	1636.8280	29.4140	**<0.0001**
		Estimate	**Std. Error**	**t value**	**p**	
	Intercept	42.6836	0.3512	121.5407	<0.0001	
	Quarter 2	1.3563	0.1930	7.0291	0.1161	
	Quarter 3	1.9983	0.1808	11.0525	**0.0002**	
	Quarter 4	1.3425	0.1889	7.1066	0.1208	
	Area FU5	1.1629	0.2521	4.6125	0.5503	
	Area outFU	0.2618	0.3278	0.7987	**0.0001**	
	Landings	1.0945	0.4713	2.3225	0.8483	
	Year 2020	0.7072	0.3083	2.2938	0.2627	
	Year 2021	0.7016	0.3045	2.3039	0.2462	
	Year 2022	0.2810	0.2701	1.0403	**<0.0001**	
	Year 2023	0.1262	0.4769	0.2647	**<0.0001**	
	Area FU5 * Landings	0.4139	0.3380	1.2246	**0.0099**	
	Area outFU * Landings	1.0063	0.4471	2.2508	0.9889	
	Year 2020 * Landings	0.9178	0.4284	2.1421	0.8415	
	Year 2021 * Landings	1.0376	0.4231	2.4522	0.9306	
	Year 2022 * Landings	3.4657	0.3779	9.1706	**0.0012**	
	Year 2023 * Landings	4.7660	0.6576	7.2478	**0.0187**	
C	*Weight ~ Quarter +Time of the Day * Category*	**Df**	**Deviance**	**AIC**	**scaled dev.**	**p**
	Quarters (1 – 4)	3	865.6930	3995.7890	26.2190	<0.0001
	Day/Night * Category (Discard/Landing)	1	824.8630	3976.6790	3.1090	0.0780
		Estimate	**Std. Error**	**t value**	**p**	
	Intercept	12.0399	0.1499	80.2964	0.0000	
	Night	0.4936	0.1767	2.7936	**0.0001**	
	Landings	0.8688	0.1380	6.2938	0.3088	
	Quarter 2	1.2432	0.1794	6.9309	0.2254	
	Quarter 3	2.1521	0.1603	13.4288	**<0.0001**	
	Quarter 4	1.3291	0.1922	6.9139	0.1395	
	Night * Landings	1.5532	0.2472	6.2820	0.0755	

Table 12. GLM output for Nephrops length. The average Nephrops carapace length was compared at different levels by fitting four different Generalised Linear Models (GLMs; Model A - D). For each of these models, the used formula is provided in italics, including the variables and the interactions between variables (indicated by *) used. The statistical output is shown in two parts for each of the models The upper part in each model shows the effect a variable (and its levels) has on the average carapace length, while the lower part provides additional details on the differences between levels of a variable. Effects of a variable, interactions between two variables, and differences between variable levels that were found to be statistically significant (p-value < 0.05) are highlighted in bold. Additional abbreviated statistical values provided: Df = degrees of freedom; AIC = Akaike Information Criterion; scaled dev. = scaled deviation; p = p-value; Std. Error = standard error.

Model	**Variables (* = Interactions)**					
A	*Length ~ Category + Sex*	**Df**	**Deviance**	**AIC**	**scaled dev.**	**p**
	Category (Discard/Landing)	1	157.2250	953.4230	955.4800	**<0.0001**
	Sex (Female/Male)	1	45.0785	55.1370	57.1940	**<0.0001**
		Estimate	**Std. Error**	**t value**	**p**	
	Intercept	2.9991	0.0178	168.2292	<0.0001	
	Landings	0.7863	0.0257	30.5600	**<0.0001**	
	Males	0.1232	0.0251	4.9016	**<0.0001**	
B (Day/Night)	*Length ~ Day/Night * Category + Day/Night * Sex*	**Df**	**Deviance**	**AIC**	**scaled dev.**	**p**
	Day/Night * Category (Discard/Landing)	1	41.4930	1.6020	1.9440	0.1630
	Day/Night * Sex (Female/Male)	1	41.4520	0.8860	1.2280	0.2680
		Estimate	**Std. Error**	**t value**	**p**	
	Intercept	2.9846	0.0176	169.9238	<0.0001	
	Night	0.0309	0.0371	0.8339	0.4046	
	Landings	0.8156	0.0204	39.9680	**<0.0001**	
	Male	0.1489	0.0204	7.2968	**<0.0001**	
	Night * Landings	-0.0599	0.0431	-1.3893	0.1652	
	Night * Male	-0.0476	0.0431	-1.1038	0.2701	
C (Landings)	*Length ~ Sex + Quarter + Area + Year*	**Df**	**Deviance**	**AIC**	**scaled dev.**	**p**
	Sex (Female/Male)	1	22.4470	52.9800	33.9010	**<0.0001**
	Quarters (1 – 4)	3	20.8370	22.8580	7.7790	0.0510
	Areas (outFU, FU33, FU5)	2	22.0170	44.1930	27.1150	**<0.0001**
	Years (2019 – 2023)	4	22.5850	49.1230	36.0440	**<0.0001**
		Estimate	**Std. Error**	**t value**	**p**	
	Intercept	3.9565	0.0611	64.7220	<0.0001	
	Males	0.1540	0.0262	5.8717	**<0.0001**	
	Quarter 2	-0.0544	0.0450	-1.2090	0.2275	
	Quarter 3	-0.0108	0.0424	-0.2555	0.7985	
	Quarter 4	-0.1015	0.0451	-2.2507	**0.0250**	
	Area FU5	-0.1827	0.0437	-4.1841	**<0.0001**	
	Area outFU	-0.0396	0.0547	-0.7236	0.4698	
	Year 2020	0.0821	0.0501	1.6384	0.1023	
	Year 2021	0.0925	0.0493	1.8752	0.0616	
	Year 2022	-0.0941	0.0436	-2.1605	**0.0314**	
	Year 2023	-0.0769	0.0776	-0.9917	0.3220	
D (Discards)	*Length ~ Sex + Quarter + Area + Year*	**Df**	**Deviance**	**AIC**	**scaled dev.**	**p**
	Sex (Female/Male)	1	14.843	-115.14	36.38	**<0.0001**
	Quarters (1 – 4)	3	15.761	-97.052	58.468	**<0.0001**
	Areas (outFU, FU33, FU5)	2	15.106	-110.684	42.836	**<0.0001**
	Years (2019 – 2023)	4	14.573	-127.914	29.606	**<0.0001**
		Estimate	**Std. Error**	**t value**	**p**	
	Intercept	3.0872	0.0473	65.3347	<0.0001	
	Males	0.1232	0.0202	6.0906	**<0.0001**	
	Quarter 2	0.0997	0.0342	2.9116	0.0038	
	Quarter 3	0.1901	0.0320	5.9315	**<0.0001**	
	Quarter 4	-0.0226	0.0335	-0.6742	0.5006	
	Area FU5	-0.2063	0.0331	-6.2367	**<0.0001**	
	Area outFU	-0.1121	0.0428	-2.6188	**0.0092**	
	Year 2020	-0.0101	0.0393	-0.2574	0.7970	
	Year 2021	0.0731	0.0389	1.8772	0.0613	
	Year 2022	-0.0779	0.0344	-2.2662	**0.0240**	
	Year 2023	0.0773	0.0611	1.2656	0.2065	

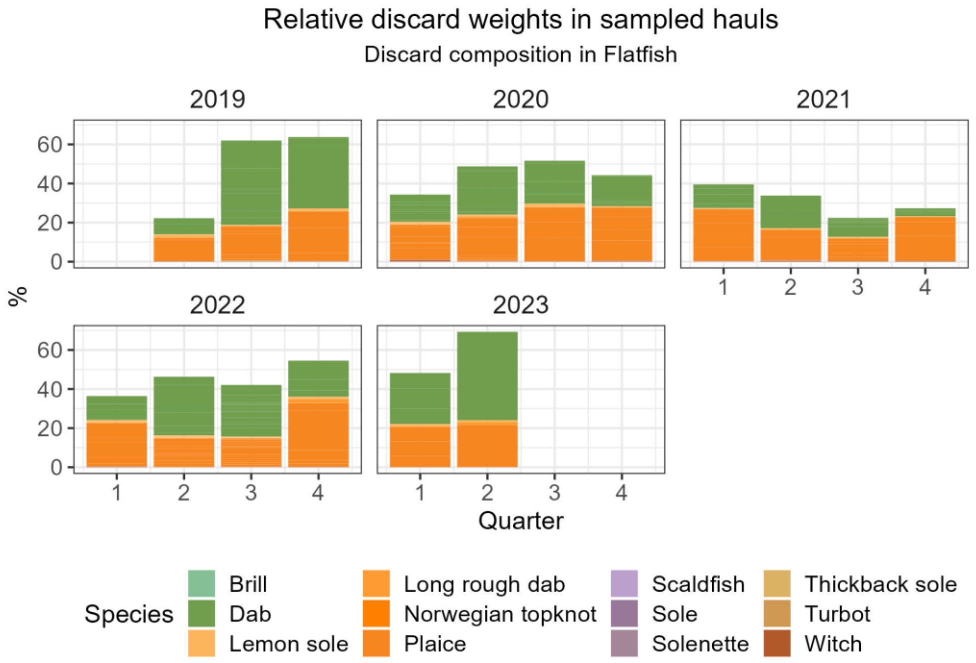


Figure 26. Discard species composition – Flatfish. The species composition in discarded flatfish is shown for each quarter (1 – 4) of the years 2019 – 2023 based on the percentual contribution of each species to the total discard weights across all species (%).

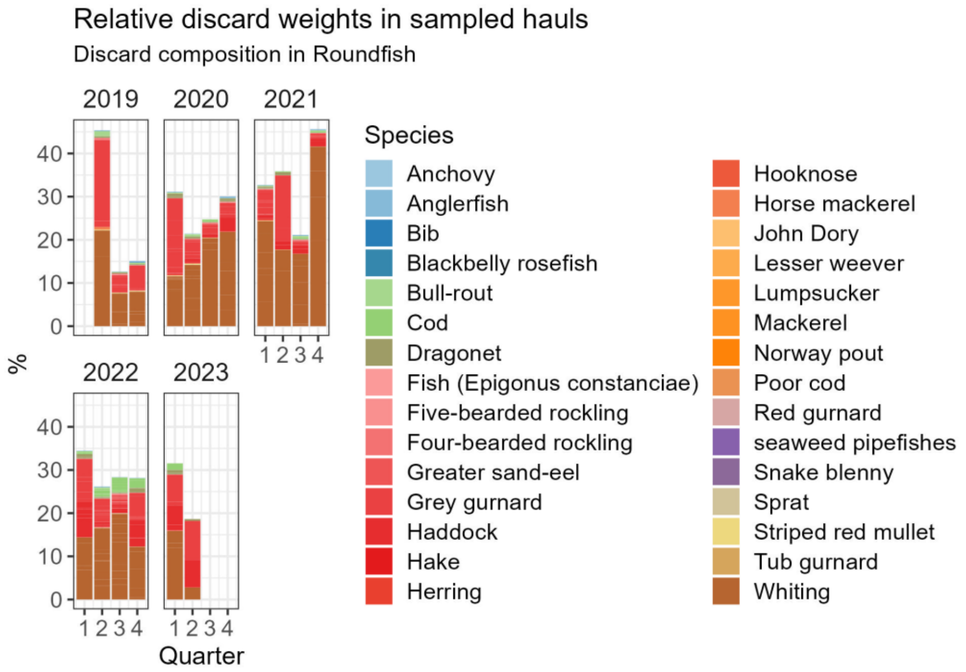


Figure 27. Discard species composition – Roundfish. The species composition in discarded roundfish is shown for each quarter (1 – 4) of the years 2019 – 2023 based on the percentual contribution of each species to the total discard weights across all species (%).

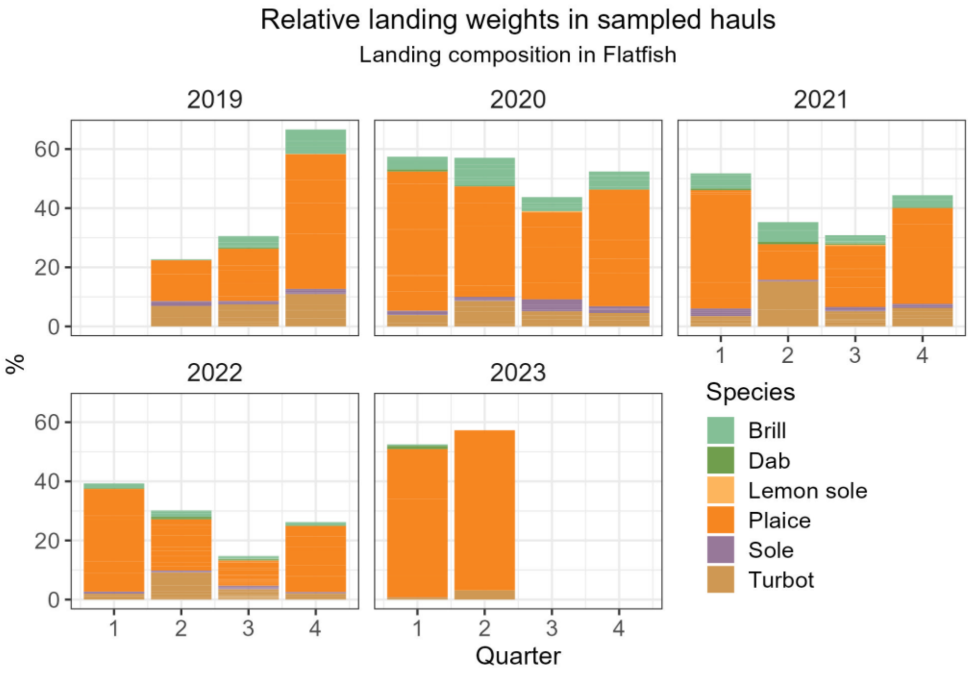


Figure 28. Landing species composition – Flatfish. The species composition in landed flatfish is shown for each quarter (1 – 4) of the years 2019 – 2023 based on the percentual contribution of each species to the total landing weights across all species (%).

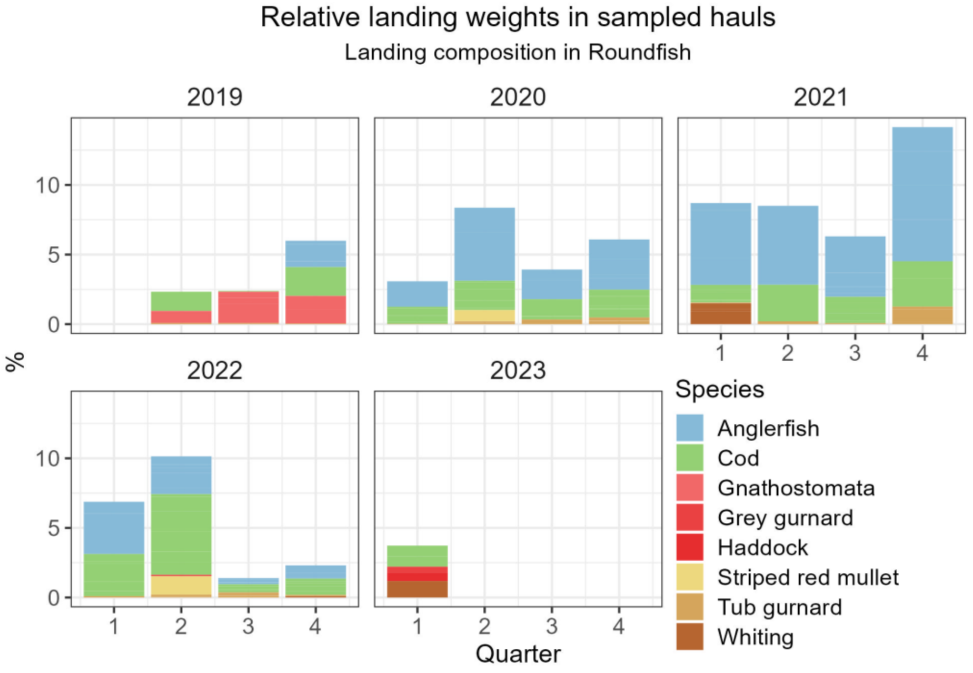


Figure 29. Landing species composition – Roundfish. The species composition in landed flatfish is shown for each quarter (1 – 4) of the years 2019 – 2023 based on the percentual contribution of each species to the total landing weights across all species (%).

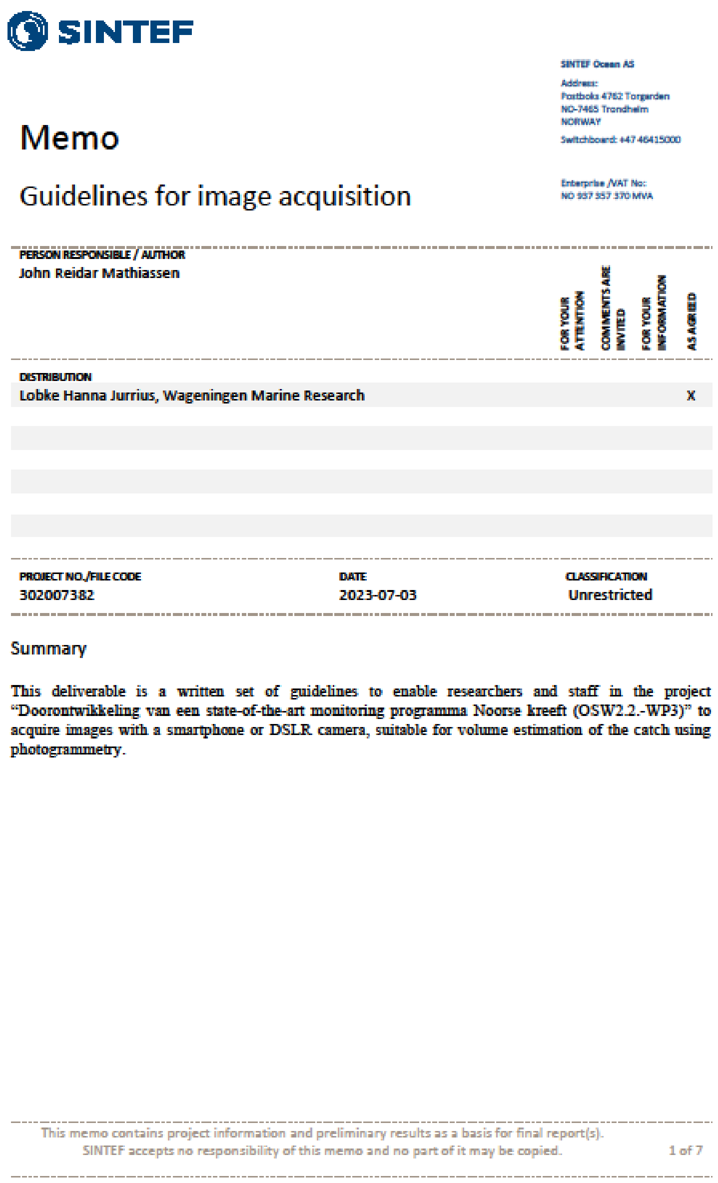
Table 13. GLM output for weight and length validation. Both the average Nephrops carapace length and the average Nephrops Landings Per Unit Effort (LPUE) and Discard Per Unit Effort (DPUE) from the self-sampling scheme were compared against the length and DPUE/LPUE data obtained from the observer trips, respectively. The effect of the sampling scheme was tested for both the weight and the length data. Therefore, three different Generalised Linear Models (GLMs; Model A - C) were fitted to the weight and length data. For each of these models, the used formula is provided in italics, including the variables and their levels used. The statistical output is shown in two parts for each of the models The upper part shows the effect a variable (and its levels) has on the average LPUE/CPUE, while the lower part provides additional details on the differences between levels of a variable. Effects of a variable and differences between variable levels that were found to be statistically significant (p-value < 0.05) are highlighted in bold. Additional abbreviated statistical values provided: Df = degrees of freedom; AIC = Akaike Information Criterion; scaled dev. = scaled deviation; p = p-value; Std. Error = standard error.

	Model	**Variables**					
Weight Analysis	**A**	*Weight ~ Category + Sampling Scheme*	**Df**	**Deviance**	**AIC**	**scaled dev.**	**p**
		Category (Discard/Landing)	1	106.1710	533.4060	2.6800	0.1020
		Sampling scheme (Self/Observer)	1	106.1180	533.3760	2.6500	0.1040
			Estimate	**Std. Error**	**t value**	**p**	
		Intercept	8.4176	0.2720	30.9457	<0.0001	
		Landings	1.6775	0.3141	5.3408	0.1041	
		Self-sampling	1.6726	0.3141	5.3253	0.1060	
Length Analysis	**B** (Landings)	*Length~ Sampling Scheme*	**Df**	**Deviance**	**AIC**	**scaled dev.**	**p**
		Sampling scheme (Self/Observer)	1	1.788	150.093	3.173	0.0750
			Estimate	**Std. Error**	**t value**	**p**	
		Intercept	3.8255	0.0057	674.6851	<0.0001	
		Self-sampling	1.0272	0.0151	67.9226	0.0770	
	C (Discards)	*Length ~ Sampling Scheme*	**Df**	**Deviance**	**AIC**	**scaled dev.**	**p**
		Sampling scheme (Self/Observer)	1	17.5810	53.0430	7.8170	**0.0050**
			Estimate	**Std. Error**	**t value**	**p**	
		Intercept	3.0184	0.0182	165.5639	<0.0001	
		Self-sampling	0.1338	0.0477	2.8067	**0.0054**	

Annex 3 Guidelines photogrammetry data analysis

This Annex provides the 'Guidelines for image acquisition' as provided by SINTEF Ocean. This file gives information on the photogrammetry methodology that was explored for a means of catch weight estimation on board, in specific guidelines for the observer to gather data on board. Please see full Guidelines for photogrammetry data analysis as provided by SINTEF Ocean below. A short summary of this memo is provided here.

1. Visual footage (photos and videos) was collected on board by the observer, using a smartphone camera. First, footage of the empty hoppers was collected. Also the dimensions of the hoppers, i.e. length, width and height were measured.
2. After discharging the catch into the hopper, the observer gathered visual footage (videos) of the hoppers. This involved creating a 360-degree angle video by circling around the hopper.
3. After collecting footage, a catch sample from the hopper was taken by the observer by filling a bucket of 40 litres. Subsequently, the bucket was weighed, allowing for the calculation of the catch volume ratio (kg/L).
4. The footage was shared with SINTEF and was processed to create a 3D representation of the hopper, using Structure from Motion (SfM). This step was executed for both the empty hopper, as well as the hopper filled with catch. The video made by the observer is post-processed, with 300 frames being selected based on sharpness and span. Processing the output in COLMAP resulted in a "point cloud". This point cloud showed the hopper in 3D by composing the 300 videoframes together. See Annex 2 for more detail on this step.
5. This 3D model was then scaled using the hopper dimensions. A simplified 3D model was thereby created. This simplified 3D model was used for 1) scaling and transforming the scanned point clouds (step 4) to get real-life units, and 2) estimating the catch volume by comparing the "bottom" of the simplified 3D model with the "top" of the scanned filled hopper (step 4). The scaling was based on the starboard hopper but was used for both starboard and portside analysis.
6. The simplified 3D model and a 3D model of a filled hopper were then connected using overlapping points. In case some areas had missing data, a combination of infilling and smoothing resulted in a solid surface. By sampling the area between the 3D model and the surface, the catch volume could be estimated. Volume multiplied by sample weight gave catch weight.



SINTEF Ocean AS

Address:
Postboks 4762 Torgarden
NO-7465 Trondheim
NORWAY

Switchboard: +47 46415000

Enterprise /VAT No:
NO 937 357 370 MVA

Memo

Guidelines for image acquisition

PERSON RESPONSIBLE / AUTHOR
John Reidar Mathiassen

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Lobke Hanna Jurrius, Wageningen Marine Research				X

PROJECT NO./FILE CODE	DATE	CLASSIFICATION
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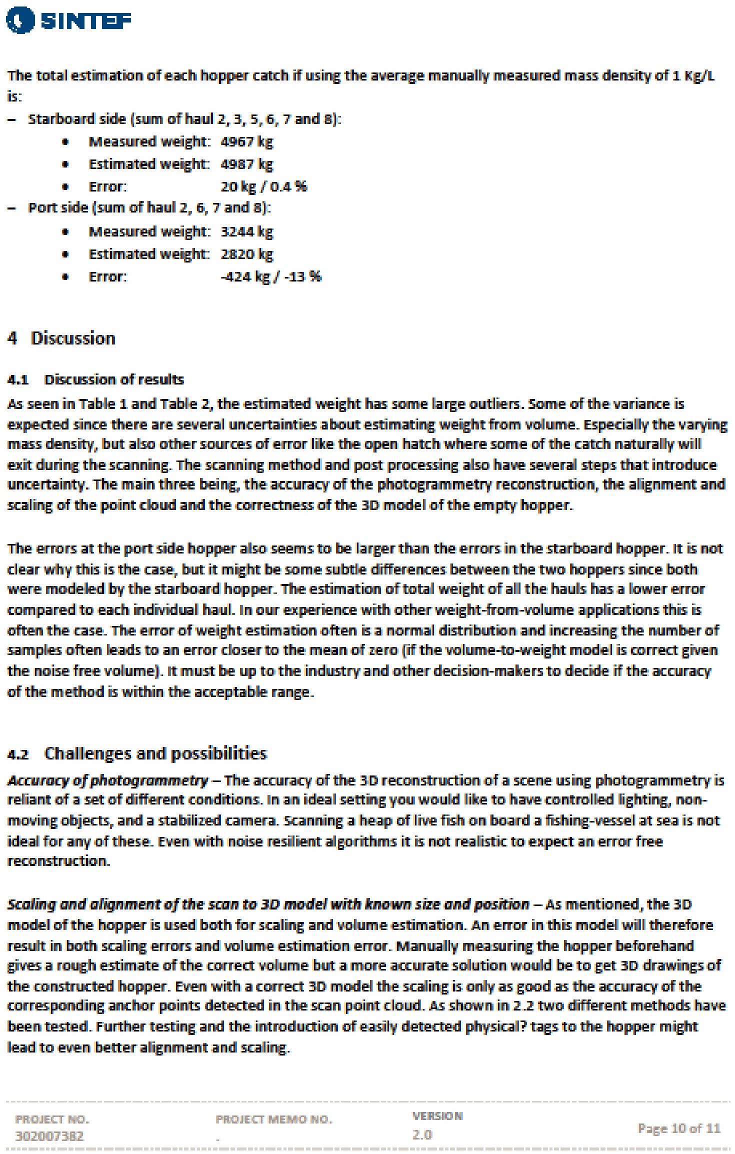
Summary

This deliverable is a written set of guidelines to enable researchers and staff in the project “Doorontwikkeling van een state-of-the-art monitoring programma Noorse kreeft (OSW2.2.-WP3)” to acquire images with a smartphone or DSLR camera, suitable for volume estimation of the catch using photogrammetry.

Annex 4 Results 3D photo analysis

This Annex provides the report developed by SINTEF Ocean in which the results of the 3D photogrammetry are elaborated.



SINTEF

The total estimation of each hopper catch if using the average manually measured mass density of 1 Kg/L is:

- Starboard side (sum of haul 2, 3, 5, 6, 7 and 8):
  - Measured weight: 4967 kg
  - Estimated weight: 4987 kg
  - Error: 20 kg / 0.4 %
- Port side (sum of haul 2, 6, 7 and 8):
  - Measured weight: 3244 kg
  - Estimated weight: 2820 kg
  - Error: -424 kg / -13 %

4 Discussion

4.1 Discussion of results

As seen in Table 1 and Table 2, the estimated weight has some large outliers. Some of the variance is expected since there are several uncertainties about estimating weight from volume. Especially the varying mass density, but also other sources of error like the open hatch where some of the catch naturally will exit during the scanning. The scanning method and post processing also have several steps that introduce uncertainty. The main three being, the accuracy of the photogrammetry reconstruction, the alignment and scaling of the point cloud and the correctness of the 3D model of the empty hopper.

The errors at the port side hopper also seems to be larger than the errors in the starboard hopper. It is not clear why this is the case, but it might be some subtle differences between the two hoppers since both were modeled by the starboard hopper. The estimation of total weight of all the hauls has a lower error compared to each individual haul. In our experience with other weight-from-volume applications this is often the case. The error of weight estimation often is a normal distribution and increasing the number of samples often leads to an error closer to the mean of zero (if the volume-to-weight model is correct given the noise free volume). It must be up to the industry and other decision-makers to decide if the accuracy of the method is within the acceptable range.

4.2 Challenges and possibilities

Accuracy of photogrammetry – The accuracy of the 3D reconstruction of a scene using photogrammetry is reliant of a set of different conditions. In an ideal setting you would like to have controlled lighting, non-moving objects, and a stabilized camera. Scanning a heap of live fish on board a fishing-vessel at sea is not ideal for any of these. Even with noise resilient algorithms it is not realistic to expect an error free reconstruction.

Scaling and alignment of the scan to 3D model with known size and position – As mentioned, the 3D model of the hopper is used both for scaling and volume estimation. An error in this model will therefore result in both scaling errors and volume estimation error. Manually measuring the hopper beforehand gives a rough estimate of the correct volume but a more accurate solution would be to get 3D drawings of the constructed hopper. Even with a correct 3D model the scaling is only as good as the accuracy of the corresponding anchor points detected in the scan point cloud. As shown in 2.2 two different methods have been tested. Further testing and the introduction of easily detected physical? tags to the hopper might lead to even better alignment and scaling.

Annex 5 Results mobile loadcell tests

This Annex provides the results from the testing of the mobile loadcell as well as the simultaneous validation of the static loadcells. The experiment involved measuring a known weight during heavy and light swell, making use of an intermediate bulk container (IBC). The IBC system was initially filled with a specific volume of water. The known weight of the empty IBC system (without water) was 54 kilograms for the mobile loadcells and 80 kilograms for the static loadcells (simply due to the static loadcell involving a heavier system). This weight was combined with the volume of water in the IBC to determine the overall weight, which we refer to as the "true weight" of the IBC system. The results are shown in Table 14 and Table 15.

Table 14. Results mobile loadcell tests using a IBC system (empty and filled with either 700, 300 or 0 litres of water) on board, tested during light swell (location 'Wad'), heavy swell (location 'Open Sea') and no swell (location 'Harbour'). Known weight of the IBC system (without water) was 54 kg.

Location	Interval	Measure-ments	Mean (kg)	Lower range (kg)	Upper range (kg)	Standard deviation	True weight (kg)	Difference load cell to true weight (kg)	Difference load cell to true weight (%)
Wad	10	20	**835.7**	709.1	1117.1	108.3	**754**	81.7	10.8%
Wad	20	19	**837.8**	748.7	919.8	44.0	**754**	83.8	11.1%
Wad	50	19	**892.9**	771.0	988.1	54.7	**754**	138.9	18.4%
Wad	90	22	**921.0**	757.5	1071.5	39.5	**754**	167	22.1%
Mean			**871.9**	**746.6**	**1024.1**	**61.6**	**754.0**	**117.9**	**15.6%**
Open sea	10	19	**756.9**	725.9	776.1	12.6	**754**	2.9	0.4%
Open sea	20	20	**759.0**	709.8	792.4	16.3	**754**	5	0.7%
Open sea	50	20	**741.6**	723.3	750.0	5.9	**754**	-12.4	-1.6%
Open sea	90	20	**745.2**	733.2	752.9	6.2	**754**	-8.8	-1.2%
Mean			**750.7**	**723.1**	**767.9**	**10.3**	**754.0**	**-3.3**	**-0.4%**
Open sea	10	21	**381.3**	365.6	394.2	6.7	**354**	27.3	7.7%
Open sea	20	20	**384.3**	378.5	390.0	3.5	**354**	30.3	8.6%
Open sea	50	21	**384.6**	379.0	388.0	2.2	**354**	30.6	8.6%
Open sea	90	24	**383.5**	379.7	387.5	1.9	**354**	29.5	8.3%
Mean			**383.4**	**375.7**	**389.9**	**3.6**	**354.0**	**29.4**	**8.3%**
Open sea	10	27	**64.0**	61.2	67.3	1.6	**54**	10	18.5%
Open sea	20	21	**63.9**	62.2	66.6	1.0	**54**	9.9	18.3%
Open sea	50	11	**63.4**	62.7	64.5	0.5	**54**	9.4	17.4%
Open sea	90	21	**63.4**	62.4	64.2	0.4	**54**	9.4	17.4%
Mean			**63.7**	**62.1**	**65.7**	**0.9**	**54.0**	**9.7**	**17.9%**
Wad	10	38	**790.4**	779.7	797.6	4.1	**754**	36.4	4.8%
Wad	20	20	**789.5**	785.1	793.0	2.1	**754**	35.5	4.7%
Wad	50	23	**789.6**	786.1	792.8	1.9	**754**	35.6	4.7%
Wad	90	18	**790.3**	786.1	794.1	2.6	**754**	36.3	4.8%
Mean			**790.0**	**784.3**	**794.4**	**2.7**	**754.0**	**36.0**	**4.8%**
Harbour	10	20	**791.4**	789.2	793.1	1.0	**754**	37.4	5.0%
Harbour	20	14	**792.0**	790.6	792.6	0.5	**754**	38	5.0%
Harbour	50	NA	**NA**	NA	NA	NA	**754**	NA	NA
Harbour	90	NA	**NA**	NA	NA	NA	**754**	NA	NA
Mean			**791.7**	**789.9**	**792.9**	**0.8**	**754.0**	**37.7**	**5.0%**
Harbour	10	6	**52.6**	52.5	52.7	0.1	**54**	-1.4	-2.6%
Harbour	20	4	**52.5**	52.4	52.6	0.1	**54**	-1.5	-2.8%
Harbour	50	7	**52.4**	52.3	52.5	0.1	**54**	-1.6	-3.0%
Harbour	90	NA	**NA**	NA	NA	NA	**54**	NA	NA
Mean			**52.5**	**52.4**	**52.6**	**0.1**	**54.0**	**-1.5**	**-2.8%**

Table 15. Results static loadcell tests using a IBC system (empty and filled with either 700L or 0L of water) on board, tested during light swell (location 'Wad'), heavy swell (location 'Open Sea') and no swell (location 'Harbour'). Known weight of the IBC system (without water) was 80 kg.

Location	Measure-ments	Mean (kg)	Lower range (kg)	Higher range (kg)	True weight (kg)	Difference load cell to true weight (kg)	Difference load cell to true weight (%)
Wad	79	**827.0**	814.0	842	**780**	47	6.0%
Open sea	811	**827.0**	722.0	848	**780**	47	6.0%
Open sea	77	**453.0**	393.0	469	**380**	73	19.2%
Open sea	141	**153.0**	116.0	224	**80**	72	91.3%
Wad	31	**852.0**	838.0	866	**780**	72	9.2%
Harbour	0	**NA**	NA	NA	**780**	NA	NA
Harbour	0	**NA**	NA	NA	**80**	NA	NA

Wageningen Marine Research
T +31 (0)317 48 7000
E: marine-research@wur.nl
www.wur.eu/marine-research

Visitors' address
- Ankerpark 27 1781 AG Den Helder
- Korringaweg 7, 4401 NT Yerseke
- Haringkade 1, 1976 CP IJmuiden

With knowledge, independent scientific research and advice, **Wageningen Marine Research** substantially contributes to more sustainable and more careful management, use and protection of natural riches in marine, coastal and freshwater areas.

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SINTEF Ocean AS

Address:
Postboks 4762 Torgarden
NO-7465 Trondheim
NORWAY

Switchboard: +47 46415000

Enterprise /VAT No:
NO 937 357 370 MVA

Memo

Guidelines for image acquisition

PERSON RESPONSIBLE / AUTHOR
John Reidar Mathiassen

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Lobke Hanna Jurrius, Wageningen Marine Research				X

PROJECT NO./FILE CODE	DATE	CLASSIFICATION
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Summary

This deliverable is a written set of guidelines to enable researchers and staff in the project "Doorontwikkeling van een state-of-the-art monitoring programma Noorse kreeft (OSW2.2.-WP3)" to acquire images with a smartphone or DSLR camera, suitable for volume estimation of the catch using photogrammetry.

1 Introduction

As part of OSW2.2.-WP3, an image processing pipeline was developed for converting a series of approximately 300 images from a smartphone-recorded video into a volume estimation of catch in hoppers, along with an estimate of the weight given a measured mass density.

Although there may be several improvements in the way this can be done, including potentially using 3D cameras that are fixed and mounted, or handheld, we will in the following assume the use of handheld 2D cameras, such as those found on a smartphone. For fixed and mounted 3D cameras, at least four 3D cameras will be necessary, with one in each corner of the hopper.

The guidelines address the following points in image acquisition and additional data collection:

- Image acquisition hardware and settings
- Additional data collection
- Image acquisition procedure.

2 Image acquisition hardware and settings

For the type of image acquisition hardware, there are very many options available, and almost any option will work. Any latest smartphone or tablet model is sufficient, and a digital single-lens reflex camera (DSLR) is also a possibility.

Depending on the model of camera or smartphone, there will be several settings to choose from. Find the video recording setting that provides the highest resolution and the least amount of compression, i.e. the highest quality setting on video recording is what to choose.

Using smartphones with optic image stabilization (OIS) or electronic image stabilization (EIS) or hybrid image stabilization (HIS) is also a good idea. Not all smartphones have these settings. If using a smartphone with these settings, make sure to turn them on.[1]

In addition, it may be an advantage to use some kind of gimbal-based stabilizer, such as the DJI Osmo Mobile 6[2]. Ideally image acquisition will be done during daylight hours. For imaging done during the night/evening, floodlights will be necessary. The combination of camera settings and illumination for night/evening imaging will have to be determined specifically and experimentally. See the video recorded by Tom Bangma for hauls 3 and 7, for example of night-time recordings that worked under floodlight settings.

3 Additional data collection

There are two types of additional data collection that is needed.

- Measurements (with images) of an empty hopper, or an accurate 3D model of the hopper in e.g. stereolithography (STL) format.
- Specific density measurements of the catch in baskets.

We will explain these in the following.

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[1] https://www.androidauthority.com/image-stabilization-1087083/

[2] https://www.dji.com/no/osmo-mobile-6

Figure 1. Measurements of an empty hopper.

3.1 Measurements of an empty hopper

The image processing pipeline used requires in one of its steps a 3D model of the empty hopper. This is used to estimate the difference in volume between the volume inside the empty hopper and the volume inside the hopper filled with catch.

If a 3D model of the hopper (e.g. in a blueprint of the vessel) is available, then this can be used, e.g. in STL format.

If a 3D model is not available, then measurements of an empty hopper must be made by the scientist on board, and overlayed on images of the empty hopper by an image processing expert. An example of a correct way to do this is shown in Figure 1. The required measurements are the depth of the hopper, and length of all sides of the hopper in cm.

If there are any obstructions, such as e.g. the pipe in the above figure, then these must also be measured.

3.2 Specific density measurements of the catch in baskets

To convert the estimated volume of the catch into kg, it is necessary to have a known or an estimated specific density for the contents of the catch in the hopper, in kg/L.

This can vary significantly from catch to catch, from haul to haul, due to varying species composition and presence of non-fish contents.

One or preferably two individual samples of 40L baskets per hopper, per haul should be made. These should be representative of the contents of the hoppers. The weight of each sample must be noted, in kg. Two individual samples enables also to provide some estimate of the uncertainties in the specific density, which can be used to provide uncertainties in the weight estimation of the contents of the hopper.

If not immediately done on board (e.g. when data collection is done with pen and paper) measurements should eventually be digitalized, e.g. in an Excel spreadsheet.

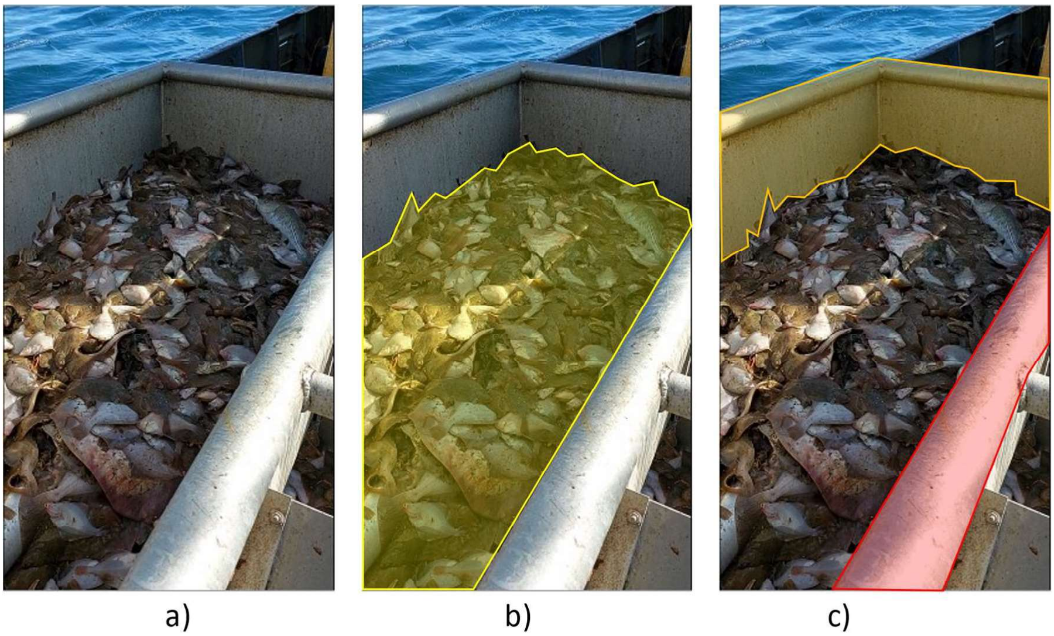

Figure 2. Image acquisition in portrait mode a), emphasizing the surface of the fish pile b), and the walls and top rail of the hopper c).

4 Image acquisition procedure

The image acquisition procedure should be done in portrait mode, as shown in Figure 2a, using approximately 2 minutes to record a video where the entire surface of the fish pile (illustrated in Figure 2b) as well as the walls and top rail of the hopper (illustrated in Figure 2c), are recorded from multiple angles while slowly walking around the hopper. If walking around the hopper is not possible, then other ways of imaging the hopper from all angles must be used. How to do this will need to be determined on a case-by-case basis.

Walk slowly, and pan, tilt, or scan the smartphone or camera slowly to minimize motion blur.

For the observer responsible for doing the image acquisition, imagine covering all the parts of the hopper with catch from multiple angles. If necessary, this can be done by the observer tilting the smartphone to look more down into the fish pile and see the surface better, and then scan or tilt up again to see the wall and rail before moving the vantage point again.

To illustrate how this can be done, see Figure 3.

We recommend that any observer new to the image acquisition procedure, view the videos recorded by Tom Bangma for this project, and use these videos to inform the viewing directions and focus of attention required to image the entire hopper with fish from a sufficient number of different angles and vantage points.

To provide a ground truth for the 3D model of the hopper, the image acquisition procedure should also be done on empty hoppers (both starboard and portside, if present).

Take care to avoid the following issues may be detrimental to the subsequent 3D analysis done on the images:

1. Shaking the camera, while moving.
2. Slipping or unstable footing, resulting in jerky movements.
3. Moving an arm or other parts of the body in front of the camera.
4. Moving fast under low light conditions, such as during night-time under floodlights.
5. Only filming the top of the catch, and not the entire side walls and top of the hopper.
6. Missing or forgetting to film a corner of the hopper from multiple angles.
7. A lot of water in the hopper such that the surface of the catch is partially submerged.

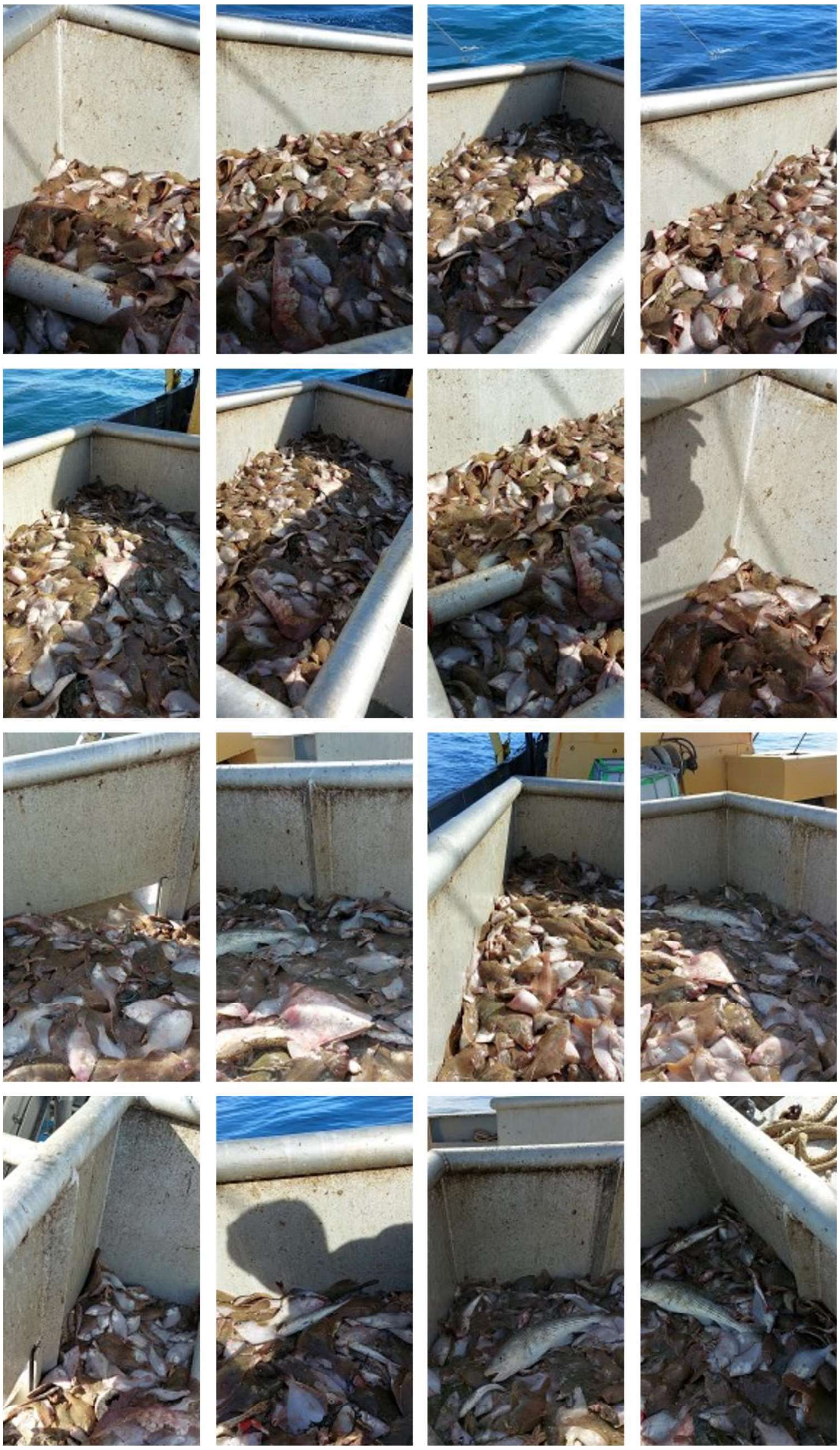
Figure 3. Illustration of the image acquisition procedure.

SINTEF Ocean AS
Address:
Postboks 4762 Torgarden
NO-7465 Trondheim
NORWAY
Switchboard: +47 46415000

Enterprise /VAT No:
NO 937 357 370 MVA

Project Memo

Photogrammetry for volume estimation of catch in hoppers

Summary

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AUTHOR(S)
Elling Ruud Øye, John Reidar Mathiassen

CLIENT(S)	CLIENTS REF.
Wageningen Marine Research	Lobke Hanna Jurrius

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ABSTRACT

This memo summarizes the work of creating a workflow for manually scanning a hopper and obtaining a volume estimation of the catch contained in it. The method involves using a camera phone and reconstructing the hopper in 3D using structure from motion. Then, by scaling the scan to real-life units and detecting the surface of the hopper content the method gives an estimate of the contents volume. The method has been evaluated by visual inspection and comparison to reported catch weight using manually sampled mass density to convert from volume to weight. While some of the results were promising other estimates show a large error. In summary the total weight estimate of the starboard hopper had an error of 0.4% of actual weight while the port side error was as large as -13%. In the discussion the different challenges with the workflow were addressed and some suggestions on how to improve the results were added.

PREPARED BY	APPROVED BY
Elling Ruud Øye	John Reidar Mathiassen

Document History

VERSION	DATE	VERSION DESCRIPTION
1.0	2023-06-15	Initial version
2.0	2023-07-03	Second version with corrections based on feedback from Wageningen Marine Research.

Table of Contents

1 Introduction

The goal has been to develop a workflow or pipeline where a videoscan is made of a hopper using a handheld device (in this case a camera phone) and from that video a volume estimate of the content of the hopper is obtained (3D photogrammetry). The methods and workflows have been developed and tested on two different datasets from cruises in 2022 and 2023. However, since only the last dataset contained weight data for validation, the focus in this document has been the data from the last cruise.

2 Workflow

2.1 3D-scanning

To obtain a 3D representation of the hopper we have used structure from motion (SfM). Structure from motion is a photogrammetric range imaging technique where a set of images of a scene are matched together to find corresponding points in images from each camera location and calculate the 3D position of each corresponding point. There is several software available to process SfM data. In this project we have mainly used COLMAP[1], but also some functionality from Meshroom[2]. COLMAP is a general-purpose Structure-from-Motion (SfM) and Multi-View Stereo (MVS) pipeline with a graphical and command-line interface. Meshroom is a free, open-source 3D Reconstruction Software based on the AliceVision Photogrammetric Computer Vision framework.

Figure 1: SfM image set example

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[1] https://colmap.github.io/

[2] https://alicevision.org/#meshroom

The collection of data was done by filming the hopper from "every" angle. A camera operator moved the camera around the hopper trying to keep the hopper in focus and avoid the movement of the camera from being too fast (to avoid motion blur). The video was post-processed, and 300 frames were selected based on sharpness and span of the video. The images were then processed using COLMAP.

The output from COLMAP is a dense point cloud with the estimated pose of each frame (camera pose) used from the video. It is important to remember that while the proportion of the 3D scene is correct, the scale is not. This means that obtaining a correct scaling is necessary to get a measurement in real life units (see 2.2).

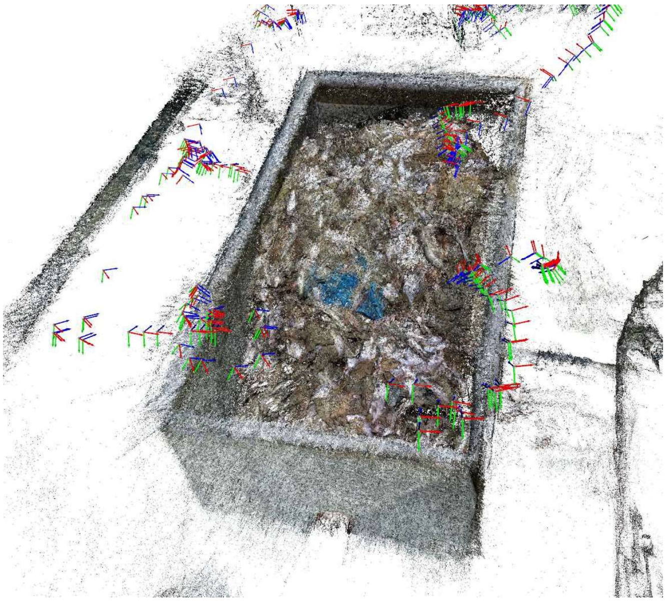


Figure 2: SfM output. This shows the point cloud representation of the hopper and catch, as well as camera locations represented as red-green-blue coordinate systems.

2.2 Scaling to real life units

Based on manual measurements of the real-life hopper combined with a SfM of the hopper while empty, a simplified 3D model was created (see Figure 3). The hopper used for both sides is based on the starboard hopper. The manual measurement showed that the dimensions of both hoppers are identical. The only difference is a pipe running through the starboard hopper.

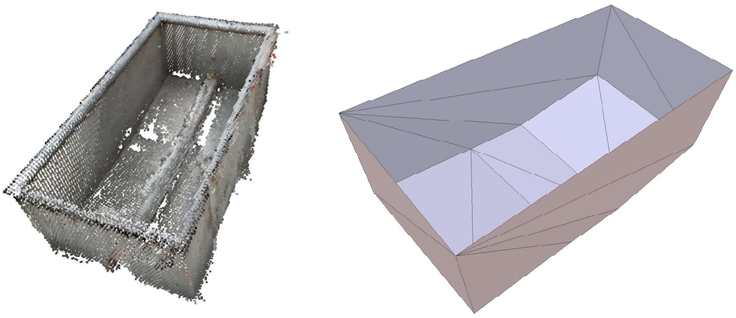


Figure 3: Point cloud (left) and 3D model (right) of hopper

The 3D model is used for two parts of the analysis. Firstly, it serves as anchor points for estimating the scaling and transformation of the scanned point cloud to transform it into real-life units. Secondly, once the surface of the content of the hopper is obtained we have the top surface, then the 3D model sets the bottom surface used when the volume between these two is estimated. To estimate the scaling and transformation a set of corresponding points between the 3D scan and the 3D model must be located. To ensure that all points are visible independent of hopper fullness the four upper corners of the hopper were selected to be anchor points. Two main methods for? were used and tested during the development of the pipeline:

Manually marking corresponding points in frames – A small set of images where one or more of the anchor points (upper corners of the hopper) are visible was manually marked. Based on the estimated position and rotation of each marked image, the intersection from each marking was calculated and the anchor points position in 3D was estimated.

Figure 4: Marked anchor points in frames (left) and ray casting in point cloud (right)

Manual placement of point in point cloud – Each corner was manually marked in the point.

Figure 5: Manually placed anchor points in point cloud

Both methods have their pros and cons. It is easier to automate the process of detecting points in images since there are several solutions available where physical markers (e.g. QR codes) can be placed beforehand. However, the method is dependent on accurate estimation of camera angles for each image since even a small deviation might lead to errors. Placing the points directly in the point cloud can be more robust since the most points are based on several frames, resulting in less noise. It is, however, more difficult to automate this process, especially if several different hopper models are going to be used. For processing the data used for evaluation only the manually placement of point in point cloud was used.

After a set of corresponding points is selected, the Kabsch–Umeyama algorithm[3] is used to estimate the scaling and transformation.

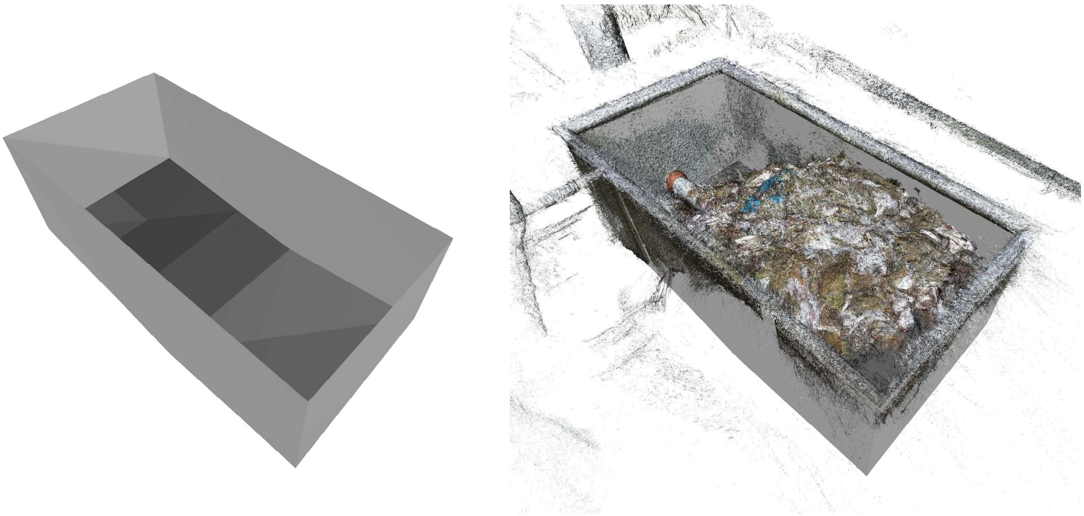
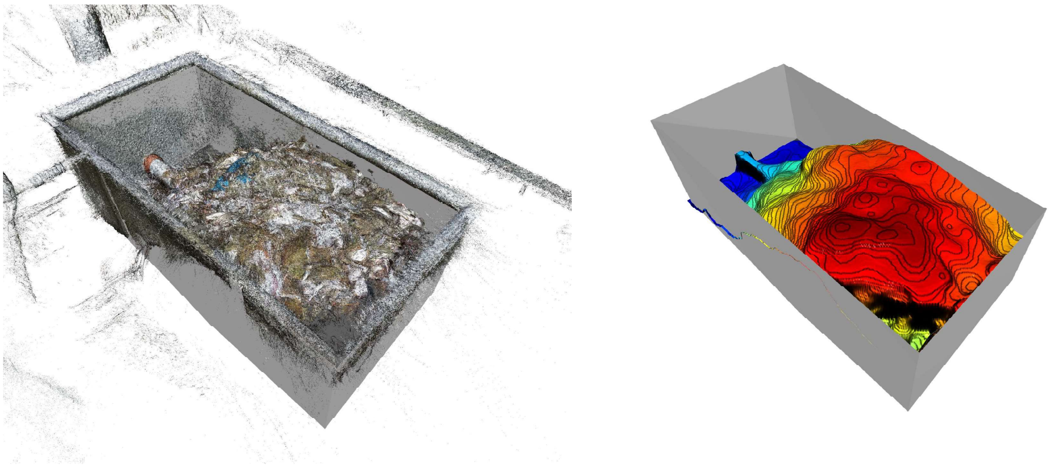


Figure 6: 3D model of hopper (left) and scan point cloud aligned to 3D model

2.3 Volume estimation

After placing the point cloud in the same coordinate frame as the hopper 3D model the point cloud is filtered to remove points outside of the hopper and remove statistical outliers. While the SfM method obtains readings of most of the surface, some areas might have missing data. A combination of infilling and smoothing of the height map of the surface results in a solid overlay of the scanned content of the hopper. We then obtain the volume by sampling the space between the 3D model and the solid surface. Be aware that the sampling area is different for the starboard hopper since it must remove the volume occupied by the pipe running through it.



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[3] S. Umeyama, "Least-squares estimation of transformation parameters between two point patterns," in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 13, no. 4, pp. 376-380, April 1991, doi: 10.1109/34.88573.

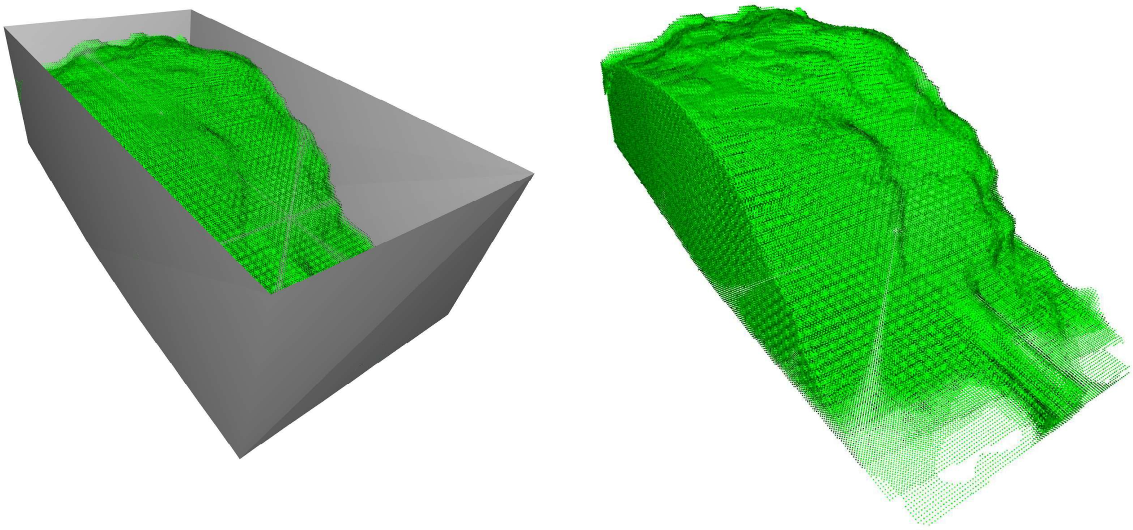

Figure 7: Aligned point cloud (top left), extracted surface (top right), sampled volume in hopper (bottom left) and sampled volume (bottom right)

3 Results

3.1 Visual evaluation

Validating the volume estimation itself is not possible since there is no practical way to measure it manually. It is possible to manually inspect the overlap between the overlayed surface and the video of each hopper (as seen in Figure 8). This gives some hint of how well the scan fits together with the detected height map of the hopper content.

Figure 8: Overlayed surface on selected frames

3.2 Weight estimation

Together with the videos of the hoppers, data of total catch weight for each hopper in the sampled hauls was also collected. Comparing the estimated volume with measured weight gives an indication about how well the method performs. The results are summarized in Table 1 and Table 2. Be aware that the videos of the port side hopper during hauls 3 and 5 were corrupted and could not be processed. In addition to the total catch weight a manual sample of each catch was also obtained.

				Starboard					
	Manual sample			Catch weight	Estimated	Analysis			
Haul number	Liters	Kg	Kg/L	Kg	L	Estimated Kg / L	Estimated Kg	Error Kg	Error %
2	40	43,8	1,10	890	801	1,11	878	-12	-1,4 %
3	40	41,7	1,04	1341	1232	1,09	1285	-56	-4,2 %
5	40	38	0,95	835	907	0,92	861	26	3,1 %
6	40	42,94	1,07	648	647	1,00	694	46	7,1 %
7	40	43,1	1,08	693	661	1,05	713	20	2,8 %
8	40	31,48	0,79	560	739	0,76	582	22	3,9 %

Table 1: Weight results, starboard

				Port					
	Manual sample			Catch weight	Estimated	Analysis			
Haul number	Liters	Kg	Kg/L	Kg	L	Estimated Kg / L	Estimated Kg	Error Kg	Error %
2	40	43,8	1,10	1088	817	1,33	894	-194	-18 %
3	40	41,7	1,04	766	x	x	x	x	x
5	40	38	0,95	849	x	x	x	x	x
6	40	42,94	1,07	738	635	1,16	681	-57	-8 %
7	40	43,1	1,08	697	692	1,01	745	48	7 %
8	40	31,48	0,79	721	678	1,06	533	-188	-26 %

Table 2: Weight results, port

Two sets of comparisons give feedback about the accuracy of the analysis. Firstly, a comparison between the manual sampled mass density (Manual sample -> Kg/L) with the estimated mass density based on catch weight and estimated volume (Analysis -> Estimated Kg/L). The second comparison can be done between total catch weight (Catch weight Kg) and estimated catch weight based on estimated volume and sampled mass density (Analysis -> Estimated Kg).

The total estimation of each hopper catch if using the average manually measured mass density of 1 Kg/L is:

- Starboard side (sum of haul 2, 3, 5, 6, 7 and 8):
    - Measured weight: 4967 kg
    - Estimated weight: 4987 kg
    - Error: 20 kg / 0.4 %
- Port side (sum of haul 2, 6, 7 and 8):
    - Measured weight: 3244 kg
    - Estimated weight: 2820 kg
    - Error: -424 kg / -13 %

4 Discussion

4.1 Discussion of results

As seen in Table 1 and Table 2, the estimated weight has some large outliers. Some of the variance is expected since there are several uncertainties about estimating weight from volume. Especially the varying mass density, but also other sources of error like the open hatch where some of the catch naturally will exit during the scanning. The scanning method and post processing also have several steps that introduce uncertainty. The main three being, the accuracy of the photogrammetry reconstruction, the alignment and scaling of the point cloud and the correctness of the 3D model of the empty hopper.

The errors at the port side hopper also seems to be larger than the errors in the starboard hopper. It is not clear why this is the case, but it might be some subtle differences between the two hoppers since both were modeled by the starboard hopper. The estimation of total weight of all the hauls has a lower error compared to each individual haul. In our experience with other weight-from-volume applications this is often the case. The error of weight estimation often is a normal distribution and increasing the number of samples often leads to an error closer to the mean of zero (if the volume-to-weight model is correct given the noise free volume). It must be up to the industry and other decision-makers to decide if the accuracy of the method is within the acceptable range.

4.2 Challenges and possibilities

Accuracy of photogrammetry – The accuracy of the 3D reconstruction of a scene using photogrammetry is reliant of a set of different conditions. In an ideal setting you would like to have controlled lighting, non-moving objects, and a stabilized camera. Scanning a heap of live fish on board a fishing-vessel at sea is not ideal for any of these. Even with noise resilient algorithms it is not realistic to expect an error free reconstruction.

Scaling and alignment of the scan to 3D model with known size and position – As mentioned, the 3D model of the hopper is used both for scaling and volume estimation. An error in this model will therefore result in both scaling errors and volume estimation error. Manually measuring the hopper beforehand gives a rough estimate of the correct volume but a more accurate solution would be to get 3D drawings of the constructed hopper. Even with a correct 3D model the scaling is only as good as the accuracy of the corresponding anchor points detected in the scan point cloud. As shown in 2.2 two different methods have been tested. Further testing and the introduction of easily detected physical? tags to the hopper might lead to even better alignment and scaling.

Varying mass density of the catch – As shown in Table 1 and Table 2, both the manual sampling and the estimated ratio between measured catch weight and estimated volume points to a varying mass density between hauls. Estimating the weight based solely on volume with a varying mass density will naturally lead to errors. However, it is possible that the mass density of the total catch over several hauls tends to converge to a constant value (in the case of the data available from these hauls 1 Kg/L). As shown in 3.2 using this value to estimate the weight of all hauls in total leads to a lower error.

Feasibility of the hopper scanning – During the final meeting the concern about how feasible it is for the fishers to collect the data necessary to do the structure from motion 3D reconstruction. While the equipment needed, just a camera phone, is easily available, the time available during the haul might not be enough to do a prober scan using the camera. Other solutions like mounting cameras above the hopper were discussed. In this case one could look into industrial 3D cameras that might have the correct range and accuracy to replace the step of photogrammetry. In this case the methods from the rest of the workflow can still be used (2.2-2.3) to obtain a similar volume estimation as with structure from motion.

5 Conclusion

Based on two datasets collected in 2022 and 2023 a method for estimating volume of catch in hoppers using photogrammetry has been developed. The method involves using a camera phone and reconstructing the hopper in 3D using structure from motion. Then, by scaling the scan to real-life units and detecting the surface of the hopper content the method gives an estimate of the contents volume. The method has been evaluated by visual inspection and comparison to reported catch weight using manually sampled mass density to convert from volume to weight. While some of the results were promising some estimates show a large error. In summary the total weight estimate of the starboard hopper had an error of 0.4% of actual weight while the port side error was as large as -13%. In the discussion the different challenges with the workflow were addressed and some suggestions on how to improve the results were added.