Discard sampling of Plaice *(Pleuronectes platessa)* and Cod *(Gadus morhua)* in the North Sea by the Dutch demersal fleet from 2004 to 2006

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Abstract

Since 2002, Wageningen IMARES samples discards of the Dutch demersal (beamtrawl) fishery following the EC Data Collection Regulations (DCR) 1543/2000 and 1639/2001. In response to concerns about quality issues of these discard data, the Dutch Fish Product Board together with the Dutch fishing industry started its own plaice discards program in 2004. Samples of plaice and cod discards and landings are taken by fishermen on about 20 demersal vessels.

Previous analysis of the Product Board's dataset provided evidence for clear trends in time, spatial patterns, and differences between gears and individual vessels. Furthermore, it was pointed out that the IMARES program estimates higher discard percentages for plaice than the self-sampling program.

The Dutch Fish Product Board requested IMARES to analyze the data of the discard sampling program of the Dutch flatfish industry of 2006, including previous period (2004-2005) and additional length records of cod and plaice, and to answer the following questions:

1. Was the Product Board sampling program (2004-2006) statistically sufficient to obtain a good estimate of mean discard fractions?
2. How do the discard estimates of the self-sampling program and the DCR program of IMARES compare?
3. What are the spatial and temporal patterns in discard fractions during the period 2004-2006?
4. What is the effect of environmental and gear specific variables on the discard fraction?
5. Do the data of the self-sampling program meet the quality standard set for international stock assessments by the European Commission, like ICES WGNSSK?

Based on maximum likelihood estimation, the estimated discards fractions (volume) based on the Product Board surveys for 2004, 2005 and 2006 are 0.29, 0.28, and 0.39. Estimates for the IMARES surveys in these years are systematically higher 0.35, 0.44 and 0.55, respectively. The mean discard fraction estimated by the Product Board has smaller standard errors than the IMARES estimates in both 2004 and 2005. However, for 2006 the mean discard fraction of IMARES is slightly more precise than the estimate made by the Product Board.

In 2006 the Product Board also initiated a discard sampling program for cod. Current discard fraction estimates based on weight, volume and length measurements were 0.065, 0.074 and 0.183, respectively. Even though the estimates differ substantially between the different methods used, it nevertheless provides a first indication of the level of cod discards.

Results based on the PV data shows that discard fraction decreases further away from the Dutch coast. Close to shore, in the northern part of the Netherlands, discard percentages can be as high as 60%, while in the most northern regions of the North Sea, discard percentages are only a few percent. Temporal patterns reveal clear seasonal peaks, with the discard levels in September being twice those observed in late December. Also after correcting for these spatial and temporal effects, IMARES estimates are systematically higher than the Product Board estimates.

With some minor adaptations (see the recommendations) the current Product Board's program set up could, in theory, provide the age-structured data similar to those currently be used by international stock assessments. But first it is vital to assess and validate the accuracy of the data and clarify the difference between the two sampling programs.

The most important contribution of the data collected by Product Board and analyzing its properties, is that it provides a fundamental insight into plaice and cod discards and which processes play an important role. It acts as a different reference point, which leads to a critical review of the current way the data is collected by IMARES. Although this study did not lead us to suspect that the current IMARES estimates are inaccurate, the continuation of the comparison of methods (see next section 4.4) that is initiated by this Product Board discards sampling program may shed light on how accurate the current estimates of both sampling programs really are.

Samenvatting

Sinds 2002 bemonstert IMARES op grond van de Europese 'Data Collection Regulations' (DCR) 1543/2000 en 1639/2001 de vangst aan boord van Nederlandse vissersschepen. Per jaar maken biologen en onderzoeksassistenten daarvoor 10 reizen mee aan boord van commerciële schepen. De discardschattingen van schol, gebaseerd op deze onderzoeksreizen gaan naar de ICES-werkgroep WGNSSK, die ze gebruikt voor de bestandsschattingen.

Eind 2004 startte de visserijsector, onder leiding van het Productschap Vis (PV), een eigen discardonderzoek. Reden voor dit onderzoek was de scepsis in de visserijsector over het DCR-discardprogramma van IMARES. Vissers twijfelden of de geschatte fractie aan discards wel representatief was voor de totale vangst door de gehele Nederlandse demersale vloot. De sector veronderstelde dat IMARES die fractie te hoog schatte omdat ze niet voldoende rekening zou houden met verschillen in ruimte, tijd en de verschillende vormen van scholvisserij. Op een twintigtal Nederlandse demersale schepen nemen vissers nu zelf monsters van de vangst aan schol om de fractie aan discards te schatten. Het PV heeft IMARES eerder gevraagd deze gegevens te analyseren (Dekker & Van Keeken, 2005, 2006). Hieruit bleek dat er duidelijke ruimtelijke en temporele patronen bestonden in de fractie aan schol discards. Verder bleek IMARES de fractie discards significant hoger te schatten dan PV.

Het databestand van 2006, van het nog steeds lopende PV-onderzoek, bevat naast scholgegevens nu ook discard- en aanvoergegevens van kabeljauw. Daarnaast is het advies uit de twee vorige rapporten opgevolgd om ook de lengteverdeling te bemonsteren. Er worden nu lengtes gemeten van 50 'maatse' en 50 'ondermaatse' vissen uit een random genomen monster voor zowel schol als kabeljauw. Het PV heeft IMARES gevraagd de discardgevens van 2006 (inclusief de data van 2004 en 2005) te analyseren en een antwoord te geven op de volgende vragen:

1. Is de nieuwe bemonstering zoals die momenteel door de visserijsector is opgezet statistisch voldoende voor een goede schatting van schol- en kabeljauwdiscards?
2. Hoe verhouden de discardpercentages uit het bemonsteringsprogramma van de visserijsector zich met de discardpercentages die voortkomen uit het DCR bemonsteringsprogramma van IMARES?*
3. Wat zijn de ruimtelijke en temporele patronen in het discardpercentage?
4. Is er een effect van de in het bemonsteringsprogramma aangegeven variabelen op discardpercentages?
5. Is de bemonsteringsmethode van voldoende kwaliteit om als input te dienen voor internationale toestandsbeoordelingen (ICES WGNSSK)?

Niet gecorrigeerd voor de verschillende variabelen (gebied, periode, schip, etc.) zijn de waargenomen gemiddelde discardfracties (in volume) voor schol in 2004, 2005 en 2006 voor PV respectievelijk 0.29, 0.28 en 0.39. De door IMARES waargenomen gemiddelde discardfracties in diezelfde jaren zijn 0.35, 0.44 en 0.55 (figuur 3). De standaardfouten (SE) en de 95% betrouwbaarheidsintervallen over deze gemiddeldes geven aan dat de schattingen in 2004 en 2005 preciezer waren voor PV en in 2006 preciezer voor IMARES (onderzoeksvraag 1).

Sinds 2006 bemonsteren schepen in opdracht van PV eveneens kabeljauw discards. De huidige geschatte discardfractie voor kabeljauw gebaseerd op gewicht, volume en lengte metingen zijn respectievelijk 0.065, 0.074 and 0.183. Hoewel deze schattingen veel verschillen van elkaar, levert het toch een eerste indicatie van de mate van kabeljauw bijvangst.

Vervolgens zijn de schol discards gegevens gebruikt om met een statistisch model te onderzoeken wat het effect is van verschillende variabelen op de waargenomen discardpercentages (onderzoeksvraag 4). Daarbij zijn als variabelen niet alleen de plaats en het moment van het seizoen gebruikt, maar ook de maaswijdte en verschillende technische eigenschappen van het tuig, zoals bijvoorbeeld het aantal wekkers. Bij de berekening worden uiteindelijk de variabelen die het minst van invloed zijn op het discardpercentage één voor één weggelaten. Op die manier blijven alleen de variabelen die de meeste invloed laten zien over. De drie meest

* Het bemonsteringsprogramma van de visserijsector wordt in het verdere rapport aangeduid met 'PV programma' en het DCR bemonsteringsprogramma met 'IMARES programma'.

belangrijke variabelen zijn: 'het gebied', 'de periode van het jaar' en het 'aantal wekkers'. Dit betekent echter niet dat andere variabelen niet belangrijk zijn. Maar je kunt maaswijdte bijvoorbeeld niet los zien van het gebied, omdat in De Noord ruime mazen en in De Zuid nauwe mazen worden gebruikt.

Een vergelijking tussen beide bemonsteringsprogramma's (onderzoeksvraag 2), na correctie van deze ruimtelijke en seizoenspatronen, laat nog steeds (zoals ook in de twee eerdere analyses; Dekker & Van Keeken, 2005, 2006) een substantieel hogere fractie zien in de schatting op basis van de bemonstering door IMARES dan die op basis van de bemonstering door PV (figuren 8 en 9).
Een directe vergelijking tussen beide datasets, mogelijk gemaakt door het vrijgeven van scheepscoderingen, bood niet veel opheldering. Gedurende 3 jaar discardmonitoring is het twee keer voorgekomen dat waarnemers van IMARES een schip bemonsterden dat op het zelfde moment ook deelnam aan het discardprogramma van PV. Zo was het twee keer mogelijk om een directe vergelijking te maken tussen de schattingen voor een zelfde trek. Dit leverde grote verschillen op; bij de eerste trek schatte PV een discardfractie van 40% en IMARES 85.72% (in volume), bij de tweede trek schatte PV een discardfractie van 0% en IMARES 58.84% (in volume). Aangezien deze data onder dezelfde condities verzameld was, betekent het dus dat dit verschil niet verklaard kan worden door ruimtelijke en temporele verschillen in bemonstering of door het verschil in gebruikte vistuig.
Aangezien verdere statistische analyses geen uitsluitsel geven is het aannemelijk dat het verschil moet zitten in de werkmethode aan boord. Een evaluatie van beide methoden wordt daarom sterk aanbevolen. IMARES heeft in dit rapport een eerste methodische vergelijking gemaakt tussen de monstermethoden aan boord van een commercieel schip. Ze heeft zelf tijdens een reguliere visreis 10 trekken bemonsterd volgens beide methodes, maar dit gaf juist geen verschil in geschatte discardfracties (figuur 12). Gemiddeld leverde de PV-methode zelfs een iets hogere discardschatting op over de 10 trekken dan de IMARES-methode , maar het verschil tussen de gemiddelden was niet significant. Dit in groot contrast tot de resultaten van het statistisch model, die gemiddeld significant hogere fracties in de IMARES schattingen laten zien. Deze eerste analyse van de monstermethoden met 10 trekken is een eerste indruk en moet uitvoerig herhaald worden om een echt goed beeld te krijgen van de verschillen in de methodes.

Net als aangegeven in de twee vorige rapporten (Dekker & Van Keeken, 2005, 2006) zijn ook nu weer duidelijk interpreteerbare ruimte- en tijdafhankelijke patronen in discardpercentages gevonden (onderzoeksvraag 3). Het model laat duidelijk zien dat het percentage scholdiscards in de vangst kleiner worden, naarmate verder van de kust wordt gevist (figuur 6). Bovendien wordt er een duidelijk seizoensgebonden patroon waargenomen; hoge discardpercentages in september en lage discardpercentages in december (figuur 7).

Gezien de huidige opzet van het PV-programma is het mogelijk om de lengteverdelingen op te werken tot populatieniveau, en dus te gebruiken voor de bestandsschattingen van schol (onderzoeksvraag 5). Maar PV mist in vergelijking met IMARES in haar bemonstering nog veel van de 0- en 1-jarige schol (figuur 10). Dit vraagt om een verdere beoordeling van de uitvoering van de bemonsteringen door PV en IMARES. Alvorens discard schattingen gebruikt kunnen worden voor internationale bestandsschattingen is het essentieel om de kwaliteit van de waarnemingen (data) te waarborgen. Op dit moment verschillen de PV discard schattingen substantieel van de IMARES waarnemingen. Dit verschil wordt niet verklaard door ruimtelijke of temporele verschillen in de bemonsteringsintensiteit en eveneens niet door gebruik van verschillend tuig. De data verzameld door de vissers leidt tot een nieuw en verschillend referentie punt waaraan discarddata geijkt kunnen worden. Nu is het voor zowel PV als IMARES nodig om te begrijpen hoe deze verschillen verklaard kunnen worden, alvorens verdere stappen te zetten.

De belangrijkste bijdrage van het PV discards bemonsteringprogramma en de analyses uitgevoerd in dit verslag, is dat het een noodzakelijk inzicht verschaft in de mate van schol (en kabeljauw) discards en welke factoren (bijvoorbeeld regionale en seizoensverschillen) een rol spelen. Het verschaft een nieuw referentie punt dat laat zien dat de huidige (DCR) schattingen mogelijk niet de werkelijke mate van discards van de hele vloot benaderen. Hoewel deze studie alsnog geen aanleiding geeft om de huidige IMARES bemonstering te wantrouwen, stimuleert het PV discard programma een kritische evaluatie. Met name de voortzetting van de vergelijking van methodes (zie sectie 4.4) zal inzicht verschaffen in hoe accuraat de huidige schattingen eigenlijk zijn.

1. Introduction

Discarding is the practice of throwing fish or other sea creatures overboard that have been caught while fishing. In some cases, species are not of commercial interest, such as sea stars, sea urchins, etc. However, in some cases discards entail commercially valuable species (e.g. North Sea plaice (*Pleuronectes platessa*)). It is this type of discarding that is of interest to this report. Commercially valuable species are discarded because the individuals caught are below an legal Minimum Landing Size (MLS), because of lack of (sufficient) quota, or because of high-grading (i.e. removing low quality individuals). Discards represent a threat to the sustainability of fisheries, because of the high mortality of most discarded fish and other organisms. Discarding affects particularly young fish that are below the minimum landing size, which eventually results in reduction of the number of mature fish that can be caught or reproduce. In all cases, discarding reduces the future productivity of the fishery and alters the status of the ecosystem.

Discard estimates play an important role in stock assessments, since it is not the total amount of landings, but the total catch that drives changes in population size. These population estimates and their predictions that form the basis of the Total Allowable Catch (TAC). Reliable estimates of discard numbers (at age) are therefore essential. Since 2002, Wageningen IMARES samples discards of the Dutch demersal (beamtrawl) fishery following the European Council and Commission Data Collection Regulations (DCR) 1543/2000 and 1639/2001. These discard estimates are used in the stock assessment of North Sea plaice as part of the ICES Workgroup WGNSSK. Since only a small percentage (<1%) of the total fishing effort by the fleet is sampled, raising procedures are used to create annual estimates of total discard numbers for the entire national beam trawl fleet. Discard estimates vary considerably by age, season and region. Therefore, such raising procedures will inflate the existing inaccuracy in such estimates even further. Fishery biologists are well aware of this problem, and realize this can only be overcome by large sample sizes and a representative sampling regime in both space and time.

The Dutch Fish Product Board was concerned about the quality issues of these discard estimates. E.g. they are acquainted with the fact that the spatial distribution of juvenile plaice differs considerably compared to that of adults. As a consequence also discard percentages will vary spatially. They might suspect that (by chance) IMARES surveys are an unrepresentative sampling of the entire fleet, potentially leading to higher or lower overall discard estimates. Therefore, the Dutch Fish Product Board, together with the Dutch demersal fleet started its own plaice discards program in 2004.

Previously, (2005 and 2006) the Dutch Fish Product Board, as a representative of the flatfish industry, requested IMARES to analyze the data of the sampling program of the Dutch flatfish industry. This resulted in two reports: The first report, Dekker & Van Keeken, 2005, described statistical sufficiency (reliability) of the self-sampled data and gave recommendations on improvement and continuation of the self-sampling program. They concluded that the discard data gave clear interpretable results. Furthermore, Dekker & Van Keeken (2005) provided evidence for clear trends in time, spatial patterns, and differences between gears and individual vessels. In the second report (Dekker & Van Keeken 2006), a first comparison was made between the self-sampling discard program of the Dutch flatfish industry and the DCR program of IMARES. The results of this report point out that the IMARES program estimates higher discard percentages for plaice than the self-sampling program. Due to the anonymous character of the data at that time a direct comparison between participating vessels could not be preformed. Following the recommendations from these reports, the Dutch Fish Product Board extended their program. It is the Dutch flatfish industry's current aim to incorporate their discard data in the North Sea plaice stock assessment of ICES (WGNSSK). Therefore it was necessary to improve their discard program by including length records of individual fish in the survey. Besides plaice, it was also decided to sample cod (*Gadus Morhua*) discards in the program of 2006. This was done in view of the discussions as part of the cod recovery plan on possible high fishing mortality through discards by the beamer fleet.

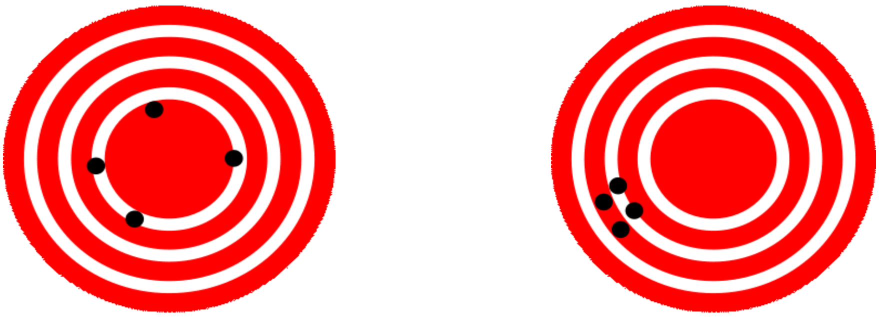
The Dutch Fish Product Board requested IMARES to analyze the data of the discard sampling program of the Dutch flatfish industry of 2006, including the period 2004-2005 and the cod data of 2006, and to answer the following questions:

1. Was the Product Board sampling program (2004-2006) statistically sufficient to obtain a good estimate of mean discard fractions?
2. How do the discard estimates of the self-sampling program and the DCR program of IMARES compare?
3. What are the spatial and temporal patterns in discard fractions during the period 2004-2006?
4. What is the effect of environmental and gear specific variables on the discard fraction?
5. Do the data of the self-sampling program meet the quality standard set for international stock assessments by the European Commission, like ICES WGNSSK?

2. Methods

2.1 Accuracy and precision of discard samples

Stock assessment studies require information on the total catch (C) by the commercial fleet, because it is the catch that determines the fisheries induced mortality (F) on the population. The catch contains a landing (L) and a discard (D) component. The total landings are often accurately recorded and well sampled, but data on discards that can be readily used for stock assessments, are only available from 2000 onwards and are based on international sampling programs with less than 1000 hours sampling effort, representing less than 0.5% of the Dutch fishing effort. For any estimate to be statistically reliable two aspects are important; precision and accuracy (Fig 1).



a. High accuracy, low precision **b.** High precision, low accuracy

Figure 1*. The difference between accuracy and precision. Precision represents the closeness of individual points to the mean estimate of all points. Accuracy represents the closeness of the mean estimate of the sample relative to the true, but often unknown, population parameters.*

Due to the large spatial heterogeneity in the distribution of fish, seasonal variability and differences in fishing gear used, discards estimates of single hauls can be very variable, and this can lead to *imprecise* mean discard estimates. If the sampling methodology used is incorrect or an unrepresentative sample of the fleet is taken, the mean discard estimate can also be quite different from the true total discards, i.e. the estimate can be *inaccurate*. In this report we will estimate mean discards for both the IMARES and the Product Board data, and quantify precision, and compare the two data sets. All estimates on plaice discard are expressed as volume-fractions, which are calculated as the observed volume of plaice discards divided by the total (landed and discarded) plaice in the sample. Multiplying these fractions by 100 would result in percentages. In Appendix B it is outlined how weights can be transformed into volumes and vice versa.

2.2 Product Board collection of plaice discard data

The discard data collection program set up by the Product Board is based on a sampling scheme restricted to demersal beamtrawl vessels which participate on a voluntary basis. The discard program requests vessels to estimate the discard fraction of plaice during two hauls per week. The first sampled haul is after 4:00 PM on Tuesday and the second haul is the haul after 4:00 PM on Thursday. From the total catch in a single haul a sub-sample of one or two boxes (approximately 40 or 80 liter, respectively) is taken. The total number of boxes of plaice above minimal landing size (27 cm, excluding the sample) from the complete haul is registered.
From the sub-sample, plaice above ("sized") and below minimum landing size ("undersized") are selected and placed in separate 20 liter buckets. Total volume (in liters) of each sample is registered. Fishermen measure length (in centimeters) of a random selection of 50 individuals of each group (sized and undersized). All data are recorded, as well as information on date and time location, gear type, haul number, and haul duration.

2.3 Product Board collection of cod discard data

All Cod, both above and below minimum landing size (35 cm) of each haul (complete trip) is kept apart and stored for future measurements. At the end of the trip total weight of sized as well as under-sized Cod is registered and recorded. From a random selection of 50 individuals of the total catch (from the complete trip) of each group (sized, undersized) length is measured and recorded. Eventually all sized Cod is weighed and landed. The undersized Cod is kept separately and is weighed under supervision of an employee of The Dutch Product Board.

2.4 Product Board discard data pre-processing

All data are collated by the Product Board and made available to IMARES for further analysis. The data spans week 41 in 2004 until week 52 in 2006. In total 29 vessels participated, resulting in a dataset with 1536 records (see table 1). However, the dataset is not complete. The number of missing records for mesh size, number of tickler chains and use of chain mats was 14, 288 and 499, respectively.
The cod discards fraction expressed in weight was only recorded in 21 unique cases. The cod discard fraction in volume had 58 complete records, even though it is practically very difficult to measure quantities of cod in volumes. The weights of cod from the category class I to V, were recorded in some cases, but total weights of undersized cod were often missing, even though the crew of the vessel did record some discards during that week.
In this report most emphasis will be placed on estimating discard fractions of plaice and its spatial and temporal properties. Due to the lack of sufficient data on cod discards, we will restrict ourselves to estimating a rough estimate of discard fraction for cod,

IMARES

Year	# ships	observations	Gear	Mesh size	observations
2004	7	207	tickler chain beam trawl	80	186
				100	21
2005	9	297	tickler chain beam trawl	80	268
				100	29
2006	11	285	tickler chain beam trawl	80	285

PV

Year	# ships	observations	Gear	Mesh size	observations
2004	17	227	tickler chain beam trawl	80	192
				100	6
			chain mat beam trawl	80	24
			quodrig	80	5
2005	16	701	tickler chain beam trawl	80	505
				100	62
				120	17
			chain mat beam trawl	80	90
			quodrig	80	24
			twinrig	80	3
2006	16	608	tickler chain beam trawl	80	451
				100	24
				120	12
			chain mat beam trawl	80	75
			twinrig	80	46

Table 1. *Summary of the number of observations in each year, gear type and mesh size. (PV= Product Board).*

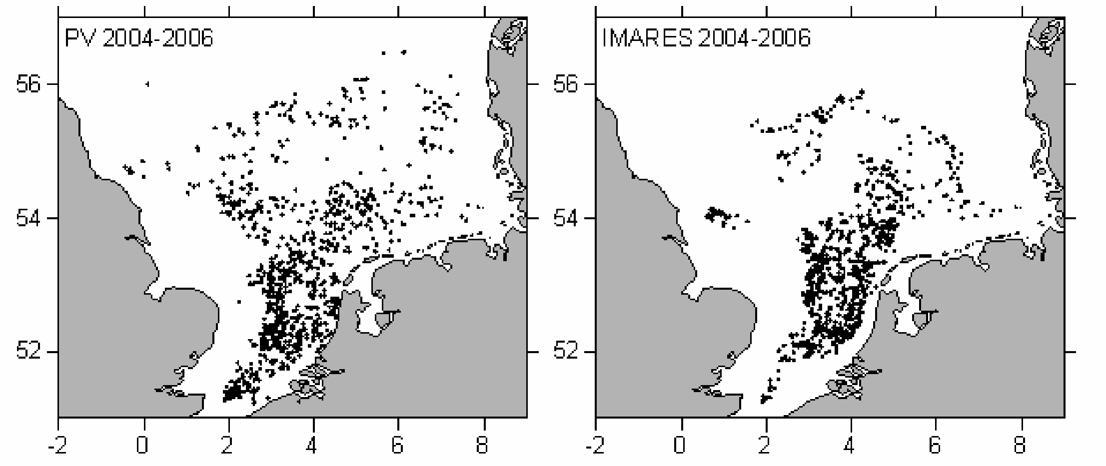


Figure 2. *Distribution of Product Board and IMARES data over the period 2004-2006. (PV= Product Board).*

2.5 IMARES discards data collection and pre-processing

Selection of the vessels in the IMARES discard data collection is quasi-random and based on co-operative sampling. This means that the skipper of the beam trawl vessel may refuse to participate. Vessels from different regions were selected to obtain a widespread coverage. During 2004 – 2006 a total of 25 trips were made on board beam trawl vessels. For every discard sampling trip, two observers went onboard a vessel, sampling at least 60% of the hauls (van Beek 2001). For each sampled haul, fish within a sub-sample of the discards were counted and measured. Benthic invertebrates were only counted. On a regular basis, otoliths were collected from the most important discarded fish species (plaice, sole, dab, cod, whiting) for age determination. Estimating total discards of a species (e.g. plaice) is a complex procedure. Below we explain in detail how this is done. In appendix A, a schematic representation is provided.
Wageningen IMARES takes samples of the total catch in one haul after fishermen remove all commercially valuable individuals. The landings were recorded and verified with the auction data. The remaining section contains non-commercial species (e.g. sea stars, urchins) and undersized individuals (e.g. undersized plaice). From these discards, a representative sample (40 liter) is taken. In most cases the length of all individual fish in that sample are measured, only when a species is extremely abundant in the discard sample, a smaller fraction is measured. Using species specific weight-length relations, we can use the measured length and estimate the weight of each individual. Next the estimated total catch, the sample size (40 liters) and the sub-sampling fraction can be used to estimate the total amount of discards of that species in the sampled haul.
Finally, to conform to the data collected by PV, total weight of plaice discards and landings, are transformed into volumes by multiplying by 0.89 and 0.83 respectively. A detailed description and an example of the raising procedure used can be found in Appendix B.

2.6 Estimating the mean discard fraction of plaice observed by PV and IMARES

Discard fractions, like any fraction, exhibit two statistical properties that have to be accounted for when estimating their means. First of all discard fractions are not normally distributed (e.g. they are not symmetric around the mean). Second the accuracy at which discards fraction estimates are made, are not the same for all observations, but they depend on the total volume of plaice in the sample. E.g. a discard percentage of 25% based on 30 liters of landing and 10 liters of discards, is more informative than an estimate of 0% based on only 1 liter of (over-sized) plaice in the sub-sample.
To accommodate both aspects (non-normality and unequal variance) we calculate the so-called maximum likelihood estimate of the mean discard fraction assuming a binomial distribution for the response variable and weighting observations based on the total number of plaice in the sample. This means that those discard

estimates based on a small sample size (i.e. low volume of plaice in the sample), will have a low impact on estimated mean discard fractions.

2.7 Estimating mean discard fractions of cod observed by PV

In total there are 21 complete records on discard fractions expressed in weights and 58 complete records on discard fractions expressed in volume of cod. Additionally, there are many more weeks in which the length of a maximum of 50 individuals from each group (sized and undersized) were measured. Before May 2006, the participants were asked to count all extra individuals. In practice, these values were often unknown. Furthermore, in some cases (e.g. PV021, week 19), only individuals >35cm were recorded. E.g. in that week there were 6 individuals of 35cm, 8 of 36cm, 5 of 37cm, etc. This leads us to suspect that undersized individuals were not recorded in those cases. To provide a first estimate, we therefore (perhaps inappropriately) assume that in the absence of extra sized- and undersized individuals recorded, all individuals were measured. Using length-weight relations and the maximum landing size of 35 cm, it is possible to estimate the total weight *W* of under-sized (eq.1) and sized (eq. 2) individuals as follows

$$w_{l<35cm} = \sum_{l=1}^{34} n_l \, 0.0068 \cdot l^{3.101} , \qquad 1)$$

$$w_{l\geq 35cm} = \sum_{l=35}^{\infty} n_l \, 0.0068 \cdot l^{3.101} , \qquad 2)$$

where n_l is the total number of individuals of length *l* in the sample. This can than be used to estimate a discard fraction $p_{discards}$ for that week as follows;

$$p_{discards} = \frac{W_{l<35}}{W_{l<35} + W_{l\geq 35}} . \qquad 3)$$

2.8 Estimating the precision of the observed discard fraction

*E*stimating standard errors is difficult due to large (most often positive) within trip auto-correlation. Simply estimating standard errors using all *n* data points, in general will lead to an underestimation, since observations (i.e. hauls) within a trip are strongly correlated. In the extreme case where one would sample one vessel and measure a large number of trips, standard errors might be very small (i.e. the observations are very closely distributed around the mean), but the large variability between ships is not appropriately captured. Fitting a mixed-effect model (see e.g. Fox 2002, Pinheiro & Bates 2000) will capture both between and within variability and will correctly estimate standard errors of the mean discard fraction.

2.9 Comparison of Product Board and IMARES discard estimates

Dekker & Keeken (2006) estimated a mean discards fraction for plaice(expressed in volume) of 31%. This estimate was based on data from 2004 and 2005. At that stage Dekker & Keeken (2006) did observe a difference in discard percentages between Product Board and IMARES; 28% for the Product Board and 37% for IMARES. One hypothesis was that, by chance, IMARES surveys were conducted in areas, at times or by ships that have relative higher levels of discards. At that time, the Product Board did not reveal the true identity (i.e. ship registration number) of the vessels and therefore a case-by-case comparison was not possible. The ship identities have now been revealed for this analysis and it is currently possible to compare some data on a ship-by-ship and week-by-week basis. In the next section we will make three comparisons between the Product Board and IMARES estimates.

First we will compare the mean and distribution of discards fractions between IMARES and the Product Board on a yearly basis. This simple comparison will not account for spatial, temporal and gear-effects. Next we will compare discard estimates when IMARES personnel/staff joined a fishing vessel, the crew of which collected data for the Product Board discards survey in that very week. This occurred on two occasions. Finally we will compare discards estimates after accounting for spatial, temporal and gear-effects on the observed discards. We do this by investigating the effect of these variables on the observed the Product Board discards first, and next use the resulting model to predict what the discard fraction would be if they were collected under the same conditions under which the IMARES data was collected. In the next section we will describe in more detail how this is done.

2.10 Explaining the variability in discard fractions; model fitting and variable selection

Regression methods relate a response variable to one or more explanatory variables. A useful response variable is the number of liters of plaice (i.e. the number of trials *n*) of which *d* liters are discarded and *l* liters are landed. *p* is the discard probability or proportion. An alternative way of specifying that same response is to use the discards fraction as the response variable and use the total volume of plaice *n* (in liters) as weights. This specification is used in this report. The response variable is binomially distributed and modeled using a logit-link function ($g(\cdot)$ in eq. 4). We relate the linear predictor η (i.e. the logit of discard proportion *p*) as linear or smooth functions ($s(\cdot)$) of different explanatory variables (eq. 4). It is important to note that a linear function in the linear predictor η , leads to a S-shaped relationship between this variable and discard fraction. This allows for their non-linear effects on the response. The sub-index *k* refers to the *k*th data point.

$$
\begin{aligned}
&\hat{d}_k \sim \text{Binomial}(n_k, p_k) \\
&p_k = g^{-1}(\eta_k) = \frac{e^{\eta_k}}{1+e^{\eta_k}} \\
&\eta_k = b_0 + s_1(\text{lat}_\text{k}, \text{lon}_k) + s_2(\text{date}_k) + s_3(\text{landings}_k) + \\
&\quad \text{gear}_k + \text{chain mat}_k + \text{number of tickler chains from trawl head or shoe}_k + \\
&\quad \text{number of tickler chains from the ground rope}_k + \text{meshsize}_k
\end{aligned} \qquad 4)
$$

'Gear' is treated as categorical variable and modeled as a factor. 'chain mat' is treated as a categorical variable (i.e. yes or no). The spatial position of the sample enters the model as a smooth interaction between latitude and longitude.
Model fitting is done using the mgcv (minimized generalized cross-validation) package in R. In summary, this procedure suggests a smooth function of a variable using all but one data point and validates that proposition by comparing its prediction with the true value of that data point. This procedure is repeated for all data points, and suggests a function that minimizes the sum of deviances for all comparisons.
Next we apply backward elimination of the explanatory variables. We start with a full model (see eq. 4) and remove that variable that leads to the biggest drop in the Bayesian Information Criteria (BIC). BIC estimate the goodness-of-fit (i.e. a measure of how well the model fits the data) and penalizes for the number of parameters used, multiplied by the log of the number of data points (Burnham & Anderson 2002). For linear terms (e.g. 'number of tickler chains from trawl head or shoe') 1 parameter is used, but for smooth functions (e.g. a smooth function of 'date') more parameters are needed. Hence, BIC indicates how well the model fits the data and penalizes for complexity (i.e. the simpler the better). Variables are removed one-by-one, until no further decreases in BIC are observed.
The final model is used to visualize the effect of the variables on the discard fractions and to predict discard fractions for all the Product Board data. The residuals (observed discard fraction – predicted) are plotted to see if for some ships the model systematically over- or under-predicts discard fractions. This could reveal that some important variables are not included in the model.
Model (based on the Product Board data) predictions are also made for IMARES data. Plotting the residuals will indicate whether IMARES discards estimates are systematically higher, even after accounting for spatial, temporal

and gear-effects on data collection. If these residuals are distributed symmetrically around 0, this shows that an observed difference in discard fractions between two data sets is solely the result of spatial, temporal and gear effects. If this is not the case, e.g. residuals are systematically higher or lower than 0, observed differences in discard fractions between the Product Board and IMARES are *not* the result of unequal sampling effort, and are therefore caused by something else.

2.11 Comparing relative age-frequencies between the Product Board and IMARES discards

For the WGNSSK working group it is essential to obtain discard estimates at age. To fulfill that requirement, the Product Board has set up an extensive program in which fishing crew measure lengths of some individuals (both below and above minimum landing size). These length-frequencies can then be transformed into age-frequencies, using age-length keys. Although such calculations are straithforward, we restrict ourself to estimating and comparing length distributions, because it directly reflects the measurements that have been made.

2.12 Comparison between the PV and IMARES sampling methods

A previous study (Dekker & van Keeken 2006) revealed a difference in discard fractions between IMARES and the Product Board. One hypothesis is that the difference is explained by different methods being used. To investigate this, a direct comparison was made between the two sampling methods during a discard trip of IMARES on a commercial beamtrawl vessel in August 2007. Ten hauls of this trip were sampled using both methods, which makes it possible to compare the two methods at haul-level. Discard estimates of these hauls are certainly not representative for the total amount of discards in the North Sea, but they can indicate whether the methods itself produce systematically different results.

3. Results

3.1 Mean estimates of plaice discard fraction observed by PV and IMARES

Based on the maximum likelihood estimation, the estimated discards fractions (volume) based on the Product Board surveys for 2004 (last quarter only), 2005 and 2006 are 0.29, 0.28, and 0.39. Estimates for the IMARES surveys in these years are 0.35 (also last quarter only), 0.44 and 0.55, respectively. Fig. 3. shows the distribution of discard fractions by haul for both the Product Board and IMARES for the different years. Fig3. simply reflects the distribution of actual observations made. Statistical analysis (using 3 tests; t-test of normal and box-cox (Fox 1997) transformed discard fractions and binomial GLM) indicates a significant difference between the two estimates of mean discard fraction per year ($p<0.001$). This significant difference is remarkable and requires us to investigate what might cause this.

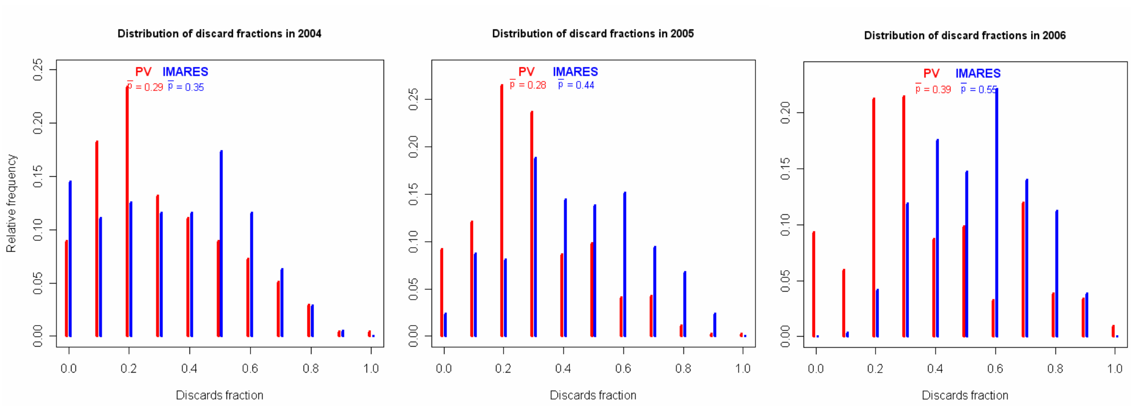


Figure 3. *Year by year comparison between discard fractions of plaice observed by the Product Board and IMARES. Plots contain histograms and reflect the variation in the data at haul-level, not mean estimates of discard fraction by trip. (PV= Product Board).*

The standard errors and confidence intervals of the mean discard fraction and the variability between and within ships, are estimated using the procedure described in section 2.6. A generalized linear mixed effect model is used, with an intercept for the fixed-effects and treating the variability between vessels as a random effect (see §2.6)

				95% Confidence Interval	
Year	**Data set**	**Mean**	**std error of logit(Mean)**	**lower limit**	**upper limit**
2004	IMARES	0.35	0.43	0.20	0.55
	PV	0.29	0.21	0.22	0.38
2005	IMARES	0.44	0.25	0.32	0.56
	PV	0.28	0.19	0.21	0.37
2006	IMARES	0.55	0.19	0.46	0.64
	PV	0.39	0.22	0.30	0.49

Table 2. *Precision of mean discard fractions. Standard errors and the confidence intervals quantify the precision of the mean discard fraction estimates for each year. (PV= Product Board). The confidence intervals are based on the standard error estimates and quantify the variability of the mean discard fractions directly. In contrast, the standard error applies to log(discard fraction)/(1-log(discard fraction)). This is more difficult to interpret, but it does allow for a valid comparison between years and the data sources (i.e. IMARES and PV)*

The mean discard fraction estimated by the Product Board has smaller standard errors than the IMARES estimates in both 2004 and 2005 (table 2). However, for 2006 the mean discard fraction of IMARES is more precise than the estimate made by the Product Board. This is surprising since IMARES has data from fewer vessels (11 instead of 16) and it has fewer observations overall (285 instead of 620) in that year. This can only occur when the variability of the Product Board data is larger between vessels or within vessels or both. Fitting a mixed-effect model using data from *all years* reveals that standard deviations which express the variability *between vessels* are exactly identical (0.88 on the scale of the linear predictor). So for Product Board-vessels, on average 95% of the vessels will have a mean discard fraction between 0.075 and 0.72, and for 'IMARES'-vessels, on average 95% of the vessels will have a mean discard fraction between 0.14 and 0.84. So this shows that there is large variation between vessels. However, the variability in the data *within vessels* is 0.97 for the Product Board and 0.43 for IMARES, and thus much larger for the Product Board. For the Product Board, 95% of the observations from a 'mean vessel' are between 0.064 and 0.75, while for IMARES observations from mean vessel are between 0.28 and 0.68.

3.2 Mean estimates of cod discard fractions observed by PV

The mean discard fraction (expressed in weight) for cod based on 21 complete records is 0.074. The mean discard fraction for cod based on 58 unique records is 0.065. The large number of missing data is likely to result in a non-representative sample of the entire fleet. E.g. catches with no or small cod discards or landings may not be recorded and in some cases discards may not have been recorded at al (see methods section). To increase sample size, data on length distributions have been used to estimate cod discard fractions (fig. 4). This results in a mean discard fraction of 0.183.

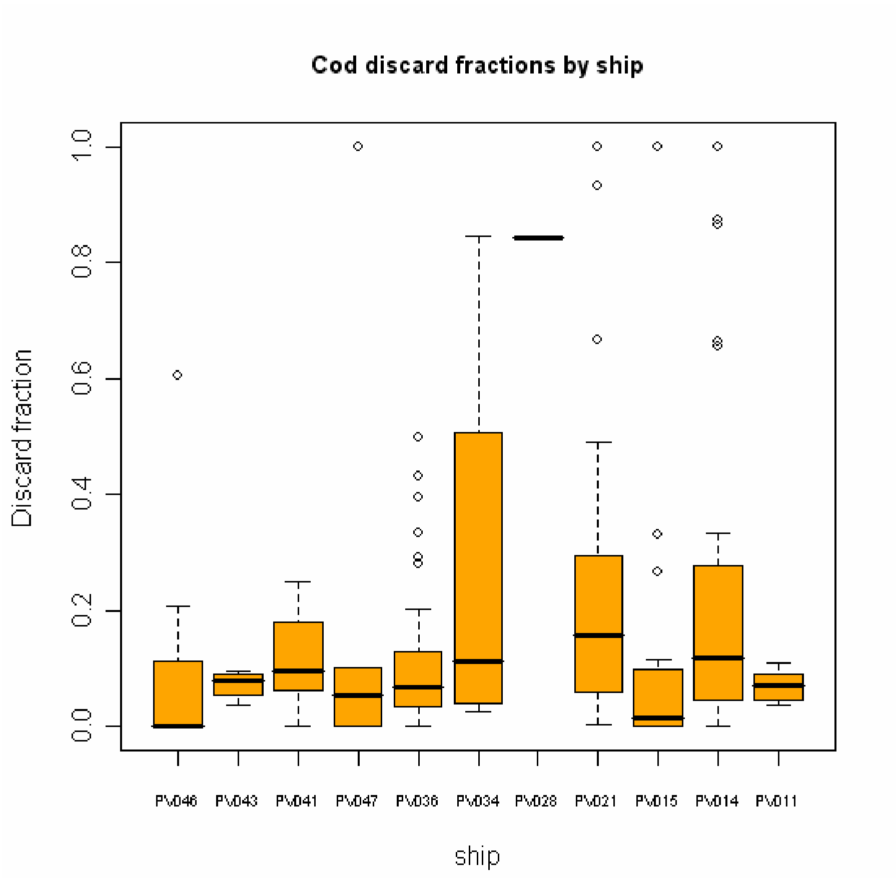


Figure 4. *Box plots (containing minimum (lower bar), 25% quantile (lower end of box), median (bold bar), 75% quantile (upper end of box), maximum excluding outliers (upper bar) and outliers (dots) of cod discard fraction by ship based on length measurements.*

Inspection of the data reveals that a large number of observations may be missing (see also section 2.7), which makes it difficult to quantify how accurate these discard estimates really are. In the discussion we will provide some general recommendations how to improve this. Nevertheless these estimates will give an first impression of the level of discards and a reference point for future comparisons.

3.3 Comparison of Product Board and IMARES plaice discard estimates

On two occasions both IMARES and the Product Board took discard measurements on the same vessel in the same week. The samples taken on board PV002 on 2/5/06 and 4/5/06 yielded a discards percentage of 40% (4 out of 10 liters) and 0% (0 out of 1 liter), respectively. In contrast, IMARES observes discards percentages of 58.84 and 85.72%, respectively, in those same hauls. The probability of observing such low outcomes (4 out of 10 or smaller, and 0 out of 1) or lower, given the IMARES discards fractions are P=0.19 and P=0.14, respectively.
For 8/3/2005 and 10/3/2005, both IMARES and the crew on board PV001 measured percentage discards. The haul number and time noted by the PV001 crew did not correspond with those recorded by IMARES. At this stage it is unclear what causes this discrepancy.
Nevertheless, if we assume that week and ship number are correctly recorded, we can compare the discard measurements for that week (Fig. 5b).

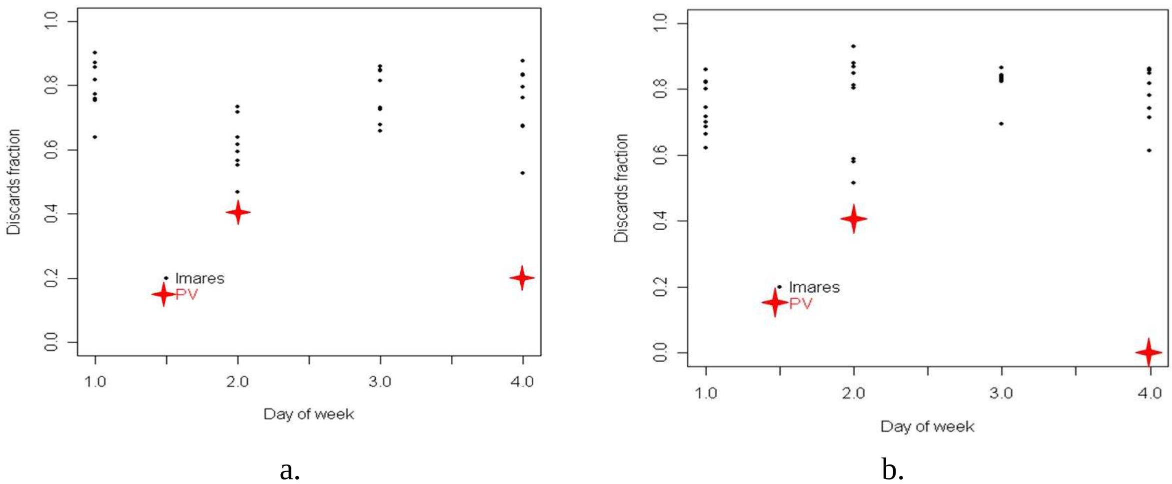


Figure 5 *Comparison between IMARES (black dots) and Product Board (red star) discard measurements by the same vessel in the same week. (PV= Product Board).*

In both weeks, the PV measurements were consistently lower than any other measurement made by IMARES during those two weeks. Because the same hauls were sampled, this difference could not be due to seasonal or regional difference in sampling, neither due to differences in gear. On Friday on board PV002 (Fig. 5b), Imares measures discard fractions between 0.6 and 0.85 (narrow range), while the crew sampling for PV only observes one liter sized plaice (hence a discard fraction of 0). This leaves us to suggest that either i) a different section of the haul is sampled and that the catch is not uniformly mixed, ii) the crew sampling for PV measures or records inaccurately, or iii) the actual methods used lead to different results.

3.4 Explaining the variability in discard fractions; model fitting and variable selection

Using the methods described in section 2.9, the explanatory variables on the discard fraction can be revealed. We start with the full model containing the variables presented in eq. (4). We remove terms one-by-one on the basis of changes in the Bayesian Information Criteria (table 3).

deleted variable	dBIC	% explained deviance
non (so all variables)		45.36
as.factor(chain mat)	-17.16	44.68
# ticklers from ground rope	-8.40	43.64
as.factor(gear)	-8.14	42.75
Mesh size	-6.02	42.76
# ticklers from trawl head or shoe	4.66	39.33
s(date)	11.07	34.91
s(lon,lat)	367.16	0

Table 3. *Results of backward model selection. dBIC represents the change in BIC. Negative values mean that removing the variable in question leads to a lower BIC, and thus a better model.*

The variables removed first are 'chain mat', 'number of tickler chains from ground rope', 'gear' and 'mesh size'. This leads to a drop in the explained deviance, which quantifies the goodness of the model fit to the data, of only 2.6%. Removing any other term leads to a lower quality model. It is important to note that the spatial component alone (the smooth interaction between latitude and longitude (s(lon,lat))), explains 34.9% of the variability. The best model (see section 2.10) is a model containing a linear relationship with 'number of tickler chains from trawl head or shoe', a smooth term for the day of the year and a smooth interaction between latitude and longitude. This model (table 3) will be used for further analysis. One may argue that the effect of the number of tickler chains is not linear. First of all, the relationship with the response is not linear, but s-shaped, because a logit-link is used. Furthermore, we also investigated non-linear effects using a smooth of the number of tickler chain, but a linear term (based on Minimized Generalized Cross Validation) was most appropriate.
One important thing to note is that application of backwards model selection necessitates using a dataset *without missing data for any of the variables*. After model selection, some variables with missing observations are excluded. So those observations with missing information for the excluded variables, but that have complete records for the variables in the model, can now be included in the final model (presented in table 4). Consequently, using more data leads to different parameter estimates, p-values and % explained deviance (54.5% instead of 42.8%).

```
Model:
Discard fraction ~ # ticklers from trawl head+ s(date) + s(lon, lat)

Parametric coefficients:
                           Estimate Std. Error z value Pr(>|z|)
(Intercept)                -0.98276    0.16171  -6.077   <0.001 ***
# ticklers from trawl head  0.03632    0.01952   1.860   0.0628 .
---
Approximate significance of smooth terms:
                 edf Est.rank Chi.sq p-value
s(date)        8.858        9  289.9  <0.001 ***
s(lon,lat)    26.192       29  985.2  <0.001 ***
---
R-sq.(adj) =  0.761   Deviance explained = 54.5%
UBRE score = 0.09238  Scale est. = 1         n = 1266
```

Table 4. *Final model used for further analysis. Significance codes used in the table: :'***' < 0.001, '**' < 0.01, and '*' < 0.05. Edf =effective degrees of freedom which reflects the effect number of parameters used for each term. Chi.sq = the value of the* Chi^2 *test statistics used. P-value reflects the significance of the term.*

Another important thing to note, is that those variables (e.g. mesh size) not included in the final model, are not necessarily unimportant. It just means that given the remaining variables, they don't add much to the explanatory power of the model. To illustrate this point. If we only fit a model using mesh size (table 5), mesh size becomes, significant, explaining 6.5 % of the deviance.

```
Formula:
Discard fraction ~ mesh size

Parametric coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)  2.034860   0.215460   9.444   <0.001 ***
Mesh size   -0.033462   0.002609 -12.826   <0.001 ***
---

R-sq.(adj) =  0.465   Deviance explained = 6.47%
UBRE score = 0.75637  Scale est. = 1         n = 1539
```

Table 5. *Results of model using mesh size as only covariate. These results illustrate the effect of collinearity between covariates. For more details see the legend of Table 4.*

This is because the mesh size is closely linked to spatial location. In statistical terms it means that two or more covariates (mesh size and spatial location in this case) are closely correlated. This dataset and the model used cannot detect whether it is the gear or the spatial position that influence the level of by-catch.

3.5 The effect of variables on the discard fractions

The final model includes 'number of tickler chains from trawl head or shoe', day of the year and spatial position. The latter is most important, explaining 35% of the observed variability in the data. For a given day (1st of July 2006 in this case) and a vessel with an average number of tickler chains (8 in this case) from trawl head, it is possible to plot how the discard fractions vary spatially (Fig. 6). It is important to note that discard fractions not only vary spatially, but also change seasonally and vary with the number of tickler chains. Consequently, the absolute discard values in Fig. 6 only apply to the arbitrarily chosen time (1st of July 2006) and vessel with 8 tickler chains. Nevertheless, the relative regional differences in discards captured by the model are the same under different conditions.

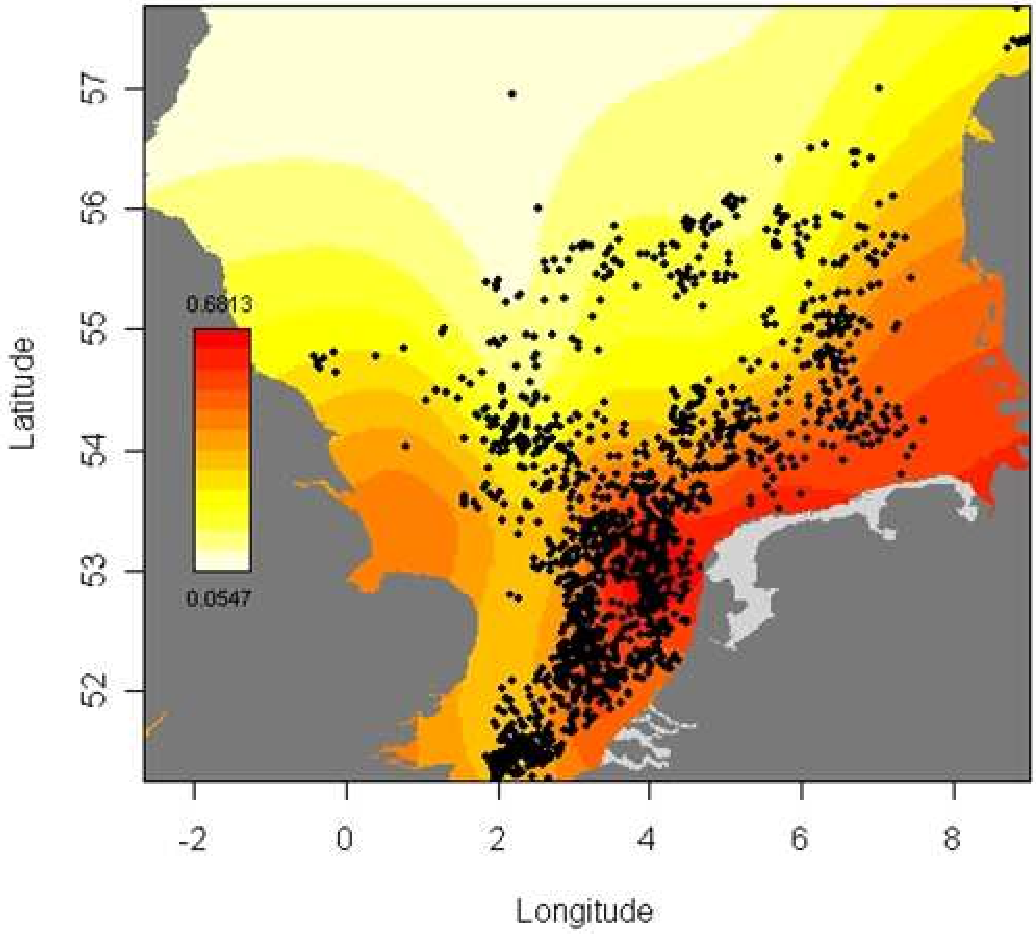


Figure 6 *Model (see table 4) predictions of plaice discard fractions and distribution of the Product Board data plotted on top. Predictions are made for the beginning of July for a vessel with 8 ticklers chains from the trawl head or shoe and the absolute discard levels only apply to those conditions.*

Figure 6 shows that discard fraction decreases away from the Dutch coast. Close to shore, in the northern part of the Netherlands, discard percentages can exceed (60%), while in the most northern regions of the North Sea, discard percentages are only a few percent. Another interesting feature is that further south, south-west of the province 'Zeeland', discard percentages are also lower (around 30 %), which is indeed also observed by fishermen. Spatial predictions along the UK coast and the coast of Denmark are based on almost no data points and thus very unreliable.
Similarly, the temporal changes in discard fractions can be plotted (Fig 7). Again, it is not possible to derive absolute trends in discards, but it can only be predicted for fixed values of the other variables in the model; spatial location (54° latitude, 4° longitude) and 'number of tickler chains from trawl head or shoes' = 8. Similarly to Fig. 6, the absolute discard fractions apply to these conditions only, but the relative trends in discard will be similar under different conditions (e.g. in different regions or for vessels with a different number of ticklers).

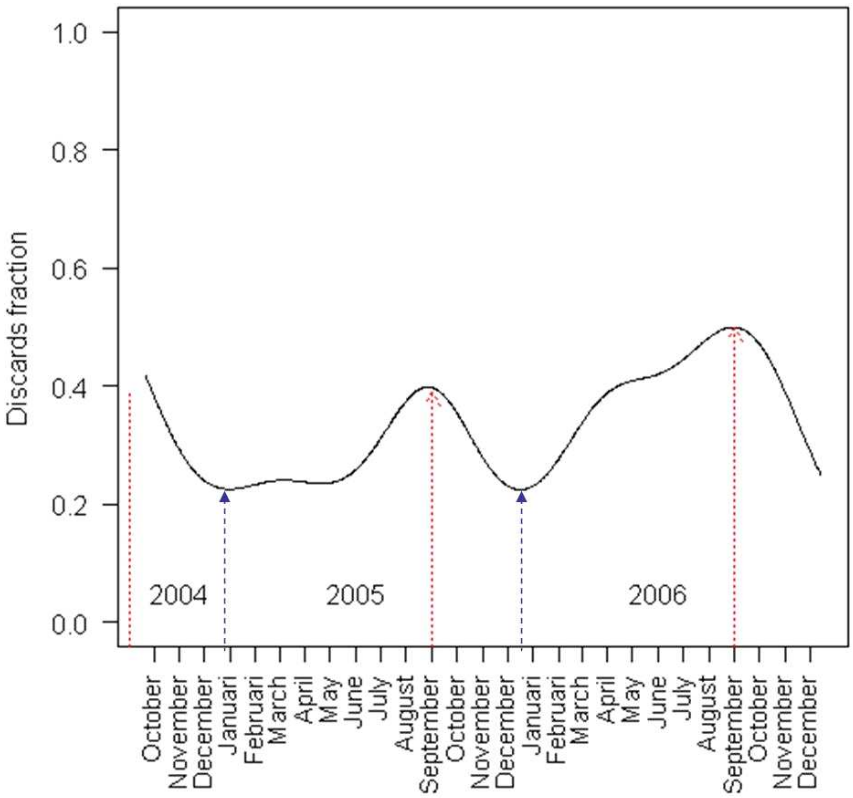


Figure 7. *Model (see table 4) predictions of plaice discard fractions for a point in space (54°latitude, 4° longitude) and a vessel with 8 tickler chains from trawl head or shoe.*

One interesting feature is that there are clear seasonal peaks, with the highest discard levels in September in both 2005 and 2006 (and probably also 2004, see red arrows in Figure 7), and lowest discard levels in late December (see blue arrows in Figure 7).
Finally we can investigate the effect of number of tickler chains from trawl head. For a similar spatial location (54° latitude, 4° longitude), in early October 2005, using 11 instead of 0 'number of tickler chains from trawl head or shoe' leads to an increase in discards from 30% to 39%.

3.6 Model residuals

It has been recognized that there has always been considerable difference in discards percentages between different ships. Are these differences reduced, due to the inclusion of spatial, temporal and gear-specific variables in the model? This can be inspected by comparing the observed discard fractions with model predictions (fig 8). Low residuals for a particular ship, means that a ship has relatively lower levels of discards than predicted by the model.

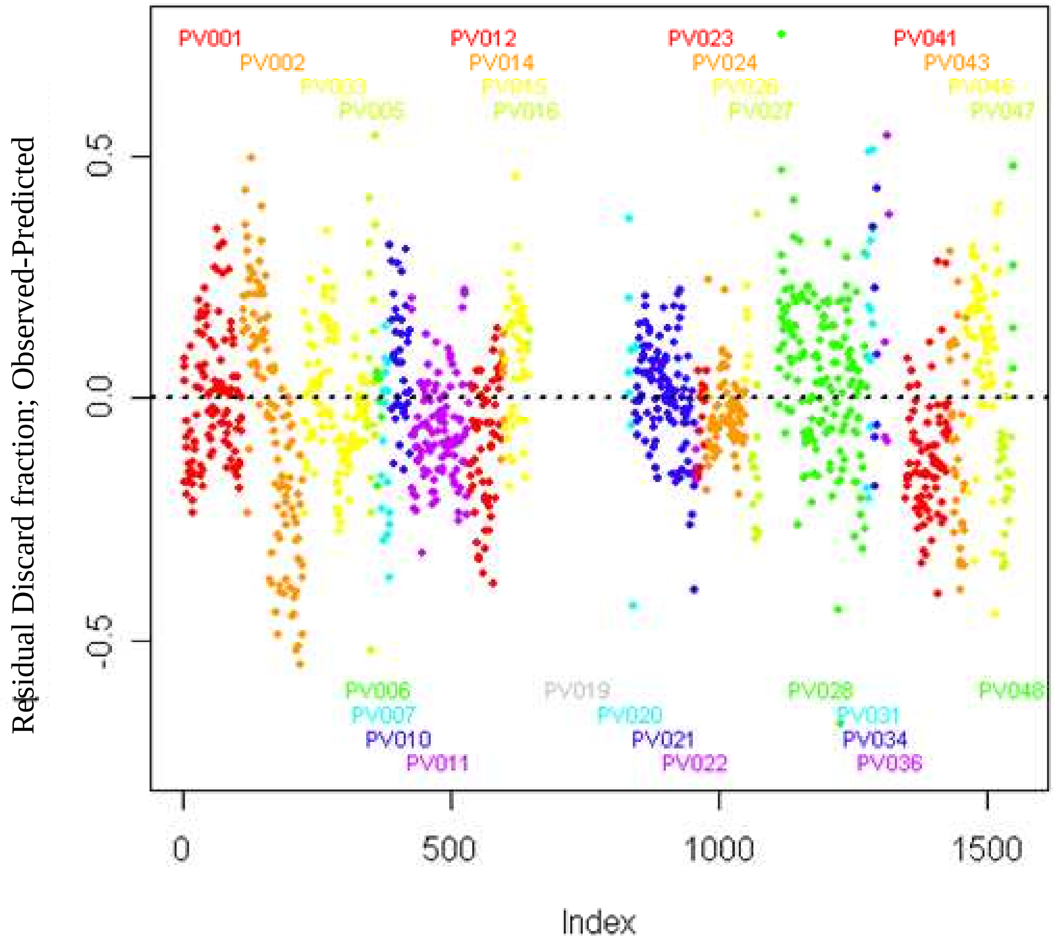


Figure 8. *Model (see table 4) residuals (Product Board: observed discard fraction – predicted discard fraction) colored by ship.*

Generally, residuals from each ship are distributed symmetrically around the mean of 0. Some exceptions are PV011, PV024 and PV041 having lower discard fractions and PV010 and PV046 having higher discard fractions than expected. At this stage it is unclear what causes these differences.
A similar analysis can be done for the IMARES data. The Product Board model can be used to predict the discard fraction for every IMARES observation with known values for the relevant covariates, and compare these predictions with the observed IMARES values (Fig. 9). The objective of this exercise is to investigate whether the observed difference in discard fractions between the Product Board and IMARES is the result of differences in effort in time, space and gear type used.

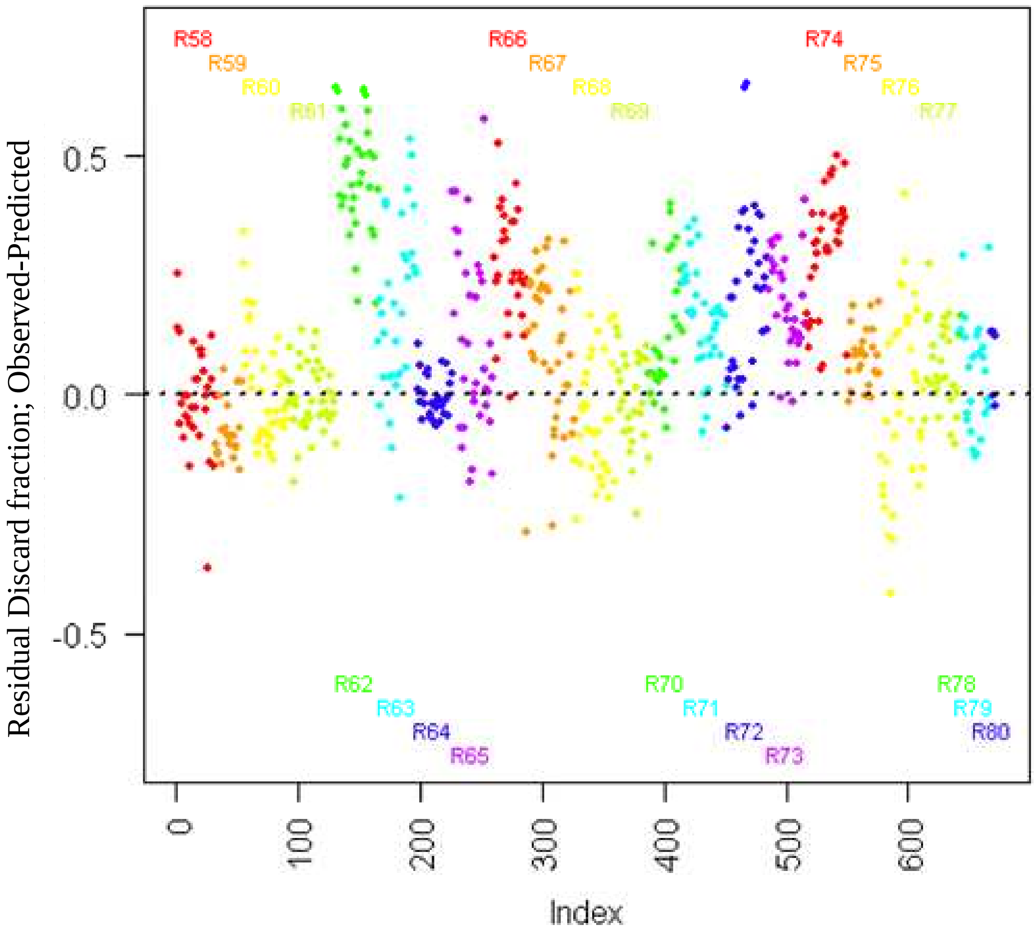


Figure 9. *Differences between the observed IMARES discard fractions and the discard fractions predicted by the Product Board model for those conditions (i.e. location and time) under which the IMARES data is collected.*

If residuals are on average 0 (the dotted line), this means that the observed difference in plaice discard estimates between PV and IMARES are the result of spatial or temporal differences in sampling effort, or because a non-representative sample of the fleet is taken. However, on average, higher discard values are observed for IMARES (Fig 9), compared to the model predictions. So, even after correcting for spatial and temporal effects, IMARES estimates are systematically higher than the Product Board estimates. It should be noted, however, that there are differences between the vessels, with some estimates being centered around the model predictions, while other vessels are centered higher than the model predictions. This is a reflection of the fact that the model and the variables currently measured do not capture all observed variation in plaice discards.

3.7 Plaice discard fractions per length class

ICES stock assessment working groups require information on absolute discard quantities for each age. Absolute landing estimates or total fishing effort in combination with the discard fractions estimated in this paper can be used to calculate total discards. To estimate discards per age, it is essential to have information on how the discard is distributed over the different length-classes.
Furthermore it is not only essential to have estimates of length-specific discards, it might also shed light on why discards estimates from IMARES and Product Board are different (Fig 10.). Using length distributions of the discard fraction in combination with age-length key tables, it is possible to estimate age-specific discards fractions.

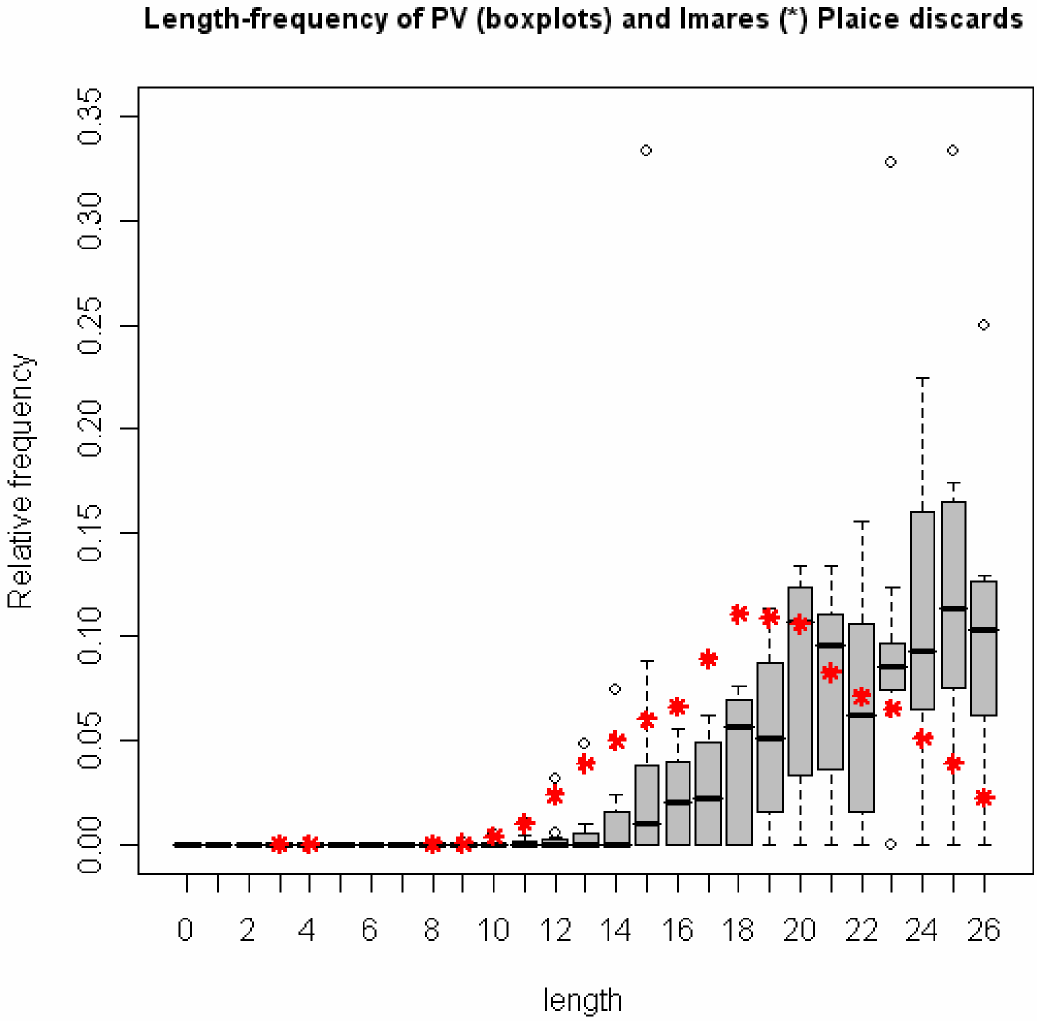


Figure 10. *Relative length frequency of discards for both Product Board (box plots) and IMARES (red stars), based on mean estimates for each vessel. Box plots (containing minimum (lower bar), 25% quantile (lower end of box), median (bold bar), 75% quantile (upper end of box). The dotted lines (bars) show the smallest/largest observation that fals within a distance of 1.5 times the box size the nearest hinge. Open circles are outliers of Product Board length frequency distribution. (PV= Product Board).*

Figure 10 illustrates a dissimilarity in discard length frequency distributions between the two programs. The relative length frequency distribution of IMARES shows an increase starting at length class 11, with a maximum at length class 18, and a continuous decrease after its maximum. However, the relative length frequency distribution of the Product Board starts at length class 13 and stabilizes at 20. This difference points out that according to the IMARES program relatively more smaller fish are discarded than the Product Board method suggest.

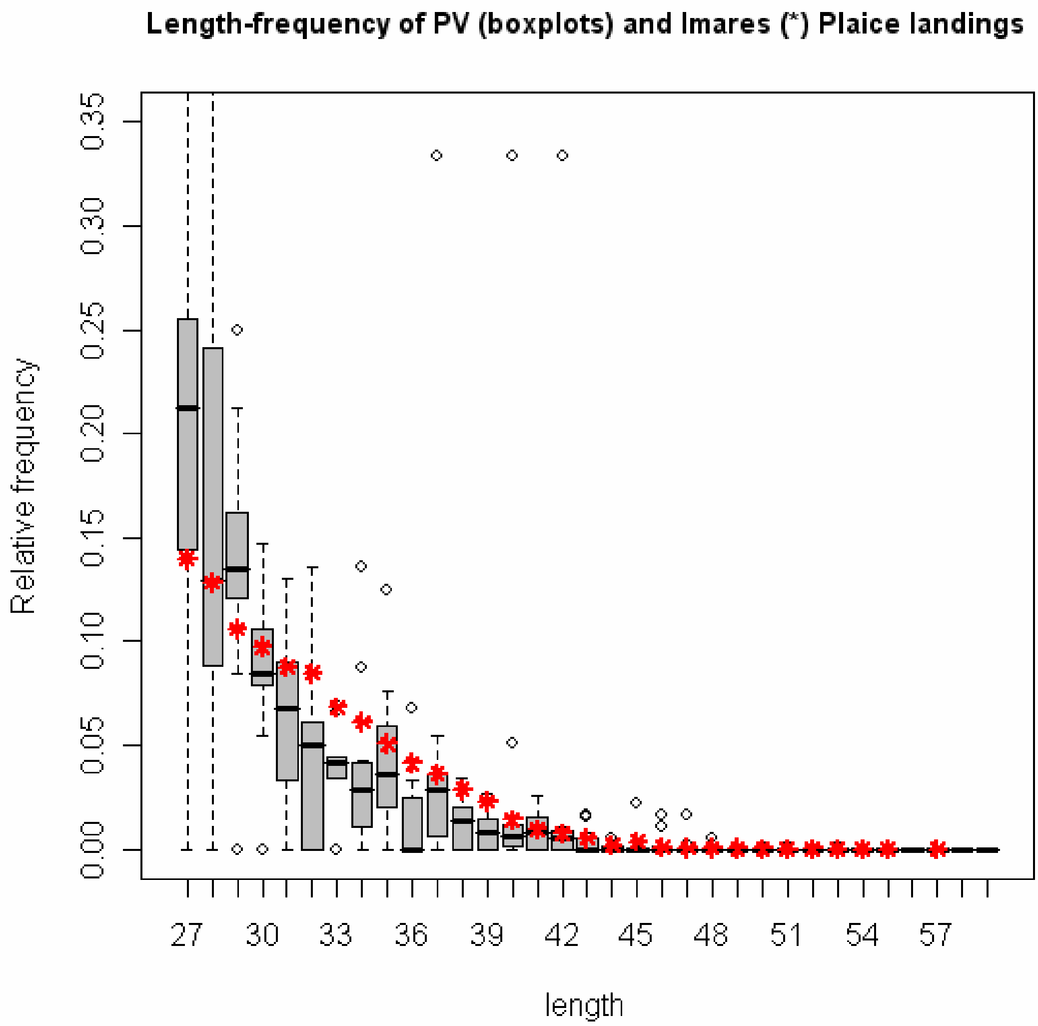


Figure 11. *Relative length frequency of landings for both Product Board (box plots) and IMARES (red stars), based on mean estimates for each vessel. Box plots (containing minimum (lower bar), 25% quantile (lower end of box), median (bold bar), 75% quantile (upper end of box). The dotted lines (bars) show the smallest/largest observation that fals within a distance of 1.5 times the box size the nearest hinge. Open circles are outliers of Product Board length frequency distribution. (PV= Product Board).*

Currently only a sample (a maximum of 50) of individuals from both the discard and landings section is measured. In some case the remaining number of sized and under-sized are counted as well, but only in the first few months and by some vessels. Additionally, to current length-frequency tables do not make a distinction between discards and landings. 2006 data from IMARES shows that individuals smaller than 27cm are sometimes landed and individuals larger than 27 are sometimes discarded. Due to these two limitations it is currently not possible to make statements about absolute length frequencies and it limits the estimation of discard fractions from these data. The relative frequency distribution of landings of both programs do not reveal any considerable differences.

3.9 Comparison between Product Board and IMARES sampling methods

The comparison between the two methods did not reveal the expected systematic difference between the estimates of discard fractions of the Product Board and IMARES. One time (haul 22) there was an exact match between the two methods. Seven times the Product Board method indicated a larger discard fraction than the IMARES method. Two times the IMARES method indicated a larger discard fraction. Over the total of ten hauls the Product Board method estimated a higher fraction of plaice discards than the IMARES method, but these differences are not significant
This experimental was performed in the northern part of the North Sea, an area that is characterized by low discard fractions (see fig. 6).

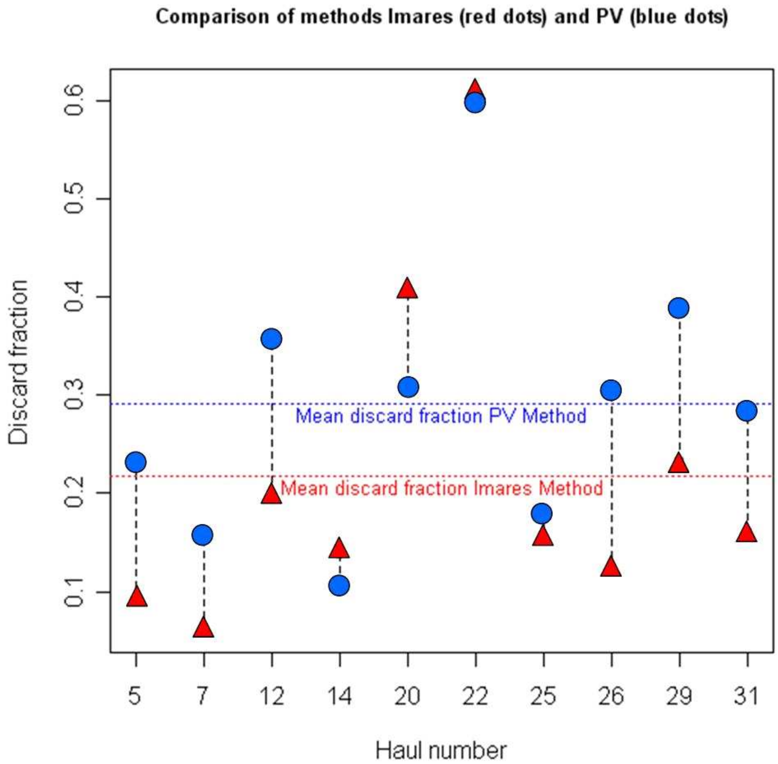


Figure 12. *Comparison of the data collection methods implemented by IMARES (red triangle) and Product Board (blue circle) on a haul-by-haul basis. (PV= Product Board).*

4. Discussion

4.1 Precision of Product Board data

Precision describes the closeness of the actual observations relative to the mean of those observations. In section 4.2 we will reflect on whether this *mean* estimate is actually accurate, i.e. whether it is close to the true population mean discard fraction (see also fig. 1). Quantifying precision requires an independent set of observations. Observations from the same vessel are strongly correlated. Simple using all observations and estimating standard errors would lead to underestimation of the variability, since this method will insufficiently capture the large variability between vessels. This reports shows that the variability between vessels is identical for both datasets. However, the variability within vessels is almost twice as large for the Product Board data compared to the IMARES data. Part of this will be due to larger spatial and temporal sampling variation within ships sampling for the Product Board, i.e. the Product Board dataset contains data from vessels that sample at different times of the year and in different regions. In contrast, the IMARES data from one vessel is collected in one week and within a small region. However, fig. 5 suggests that the Product Board observations might in fact be less precise. On Thursday 4/5/2006 the discard fractions observed in 8 hauls by IMARES are all between 0.6 and 0.85. Even though the same volume is sampled (40 liters), the crew of Product Board observes only 1 liter of plaice landings (leading to a discard fraction of 0). Further comparisons of the methods (e.g. see fig. 12) should reveal whether this is inherent to the method (e.g. selective sampling of a poorly mixed catch) or how precise the crew of the vessel measures or observes the samples..

4.2 Accuracy of Product Board data; Difference in mean estimated discard fractions Product Board and IMARES

The ultimate objective of any statistical study is to estimate the true parameter, in this case mean discard fraction, as precise and accurate as possible. Normally, the standard error of the mean discard fraction is a valid measure to quantify both precision and accuracy. However, if there is a systematic bias, a high precision (see also fig 1a) might suggest that our estimate is very close to the true value, but in fact it can be very different. In practice, one never knows what the true discard fraction really is. This study shows that estimates made by the Product Board differ significantly from those made by IMARES. Furthermore, it is evident that this difference is not explained by difference in spatial and temporal sampling effort. Therefore, there is a very strong evidence that one or both datasets are very inaccurate.
One possible explanation is that these differences are caused by an incorrect estimation methodology (see also appendix C and D). Especially IMARES implements a complex procedure to estimate discard fractions. It relies on an estimation of the total catch and uses length-weight relations to calculate species specific discard weights. To test this hypothesis, an experiment was carried out in which IMARES used the Product Board and DCR method simultaneously. So figure 12 indicates the comparison of methods. This should not only indicate whether the on board procedures leads to different results, but also whether the calculations (i.e. the raising procedures) used by IMARES are incorrect. This experiment showed that there was no significant difference in discard fraction estimates between the two methods. The Product Board estimates were even slightly higher (but not significant).
Another possible explanation for this difference is that the catch in a single haul is not uniformly mixed. E.g. it might be possible, that younger individuals only accumulate in the net if larger individuals caught in the cod-end at the beginning of the haul, create a natural finer mesh-size. If this section of the catch is sampled, it might produce relatively higher numbers of large (and thus older individuals), and thus lower discard fractions. In contrast, IMARES attempts to select a uniform sample of the complete discard (i.e. including non-commercial species as well). Again, the experiment in which the two methods were directly compared, should have revealed a systematic bias if this non-random mixing took place. However, the sample size was small (10 hauls) and samples were collected in an area that is characterized by low levels of discards. This experiment should be repeated in different regions to provide more evidence (or lack thereof).
From the total sample (40 liters or 80 liters), it is unlikely that any large individual (above minimum landing size) is missed. However, by nature, small individuals have a much higher probability of not being spotted. Furthermore, smaller individuals are normally of no commercial value to the fishery, and due to unintentional selective sampling, fewer small individuals might be extracted. Also species recognition for smaller individuals is much harder. Comparison of the relative age-frequencies between the Product Board and IMARES discards (see fig.

10), indeed shows that younger (and therefore smaller) individuals are in relative sense less present in the Product Board sample. This might explain the lower discard fractions estimated from the Product Board data, then again smaller individuals do not contribute much to the total discard volume.

4.3 Spatial and temporal patterns in discards estimates.

The observed Product Board discard fraction reveal clear spatial and temporal trends. A model containing only (smooth functions of) latitude, longitude, date and number of tickler chains on the trawl head, explains 55% of the observed variability in the data. Spatial position of the fishing vessel, explains by far most of the observed variability.
Fig. 6 clearly reveals higher discard fractions close to shore. The observed pattern closely matches the actual distribution of the beamtrawl fisheries (Quirijns 2006) and is the result of the fact that most flatfish fisheries focusing on Dover sole. Current Dover sole fishery uses small mesh size (80 mm) and fish close to shore, an area characterized by large numbers of young plaice.
Also the existence of large temporal variability is evident (fig. 7), with highest discard fractions in September, and lowest around December. Insight from the Product Board and fishermen might shed more light on this phenomenon. One explanation is that summer growth of young individuals (1 and 2 year old) leads to sizes that increase the capture probability. In autumn and winter, mortality or redistribution (e.g. juveniles migrating to offshore areas) might set in, reducing discards again.

4.4 Can discard estimates from the Product Board be used in the WGNSSK

The discards estimates from the Dutch beam trawl fleet currently used in the WGNSSK are based on the sampling program by Wageningen IMARES. The observations from this sampling program are transformed into an age-structured discard estimates for the entire 80 mm Dutch beam trawl fleet. In the assessments these data are used in combination with the estimates from the English and Danish fleet. For any data to be used four aspects are important; 1) availability of all necessary data, 2) precision and 3) accuracy and 4) considerable time series or presence of existing ones, and 5) the ability to perform quality control checks

1. During the WGNSSK of 2007, discards estimations from the IMARES and the English sampling program are raised by effort ratio (based on HP days for the Dutch fleet, and number of trips for the English fleet). Discards at age from the Danish sampling program were raised by landings. Discards at age for the other fleets were calculated as a weighted average of the Dutch, Danish and UK discards at age and raised to the proportion in landings (tonnes). After some minor adaptations (see the recommendations section), the discards at length data of the Product Board could be transformed with age-length keys (ALK) into an age-structured dataset and be raised to population level using the same procedures as described above. However, there are two important points of attention. First of all, to get a representative sample of the length distributions of plaice and cod, it is desirable to measure all fish in the sample or divide the total sample in length classes and count them. A sub-sample of 50 individuals from the sample could cause a serious bias in the length frequency distribution, simply because randomly selecting individuals (and thus not being size selective) is in practice extremely difficult. Secondly, in the current set-up of the dataset, it is not tractable which individuals belong to the landings section and which to the discards. In the DCR method this distinction is made. The dataset is now simply divided at the MLS (e.g. 27 cm for plaice). It advisable to use different sheets for discards and landings, since individuals above the MLS are also frequently discarded (high-grading) and some individuals below MLS might end up as landings.

2. There are European guidelines on how precise such estimates need to be. However, in practice availability is more important than accuracy, i.e. it is more important to use at least some discard estimates in the assessment, than to use non whatsoever. These European guidelines are to ensure that the appropriate data is collected. For the working groups it is therefore essential to asses whether including discard estimates leads to more precise (and accurate, but see below) estimates. Whether this is the case, can simple be investigated by comparing standard errors of mean discard fractions estimates between the IMARES data and a combined datasets.

3. Thirdly, and most importantly the estimates need to be accurate. Currently there are large and significant differences between IMARES and the Product Board estimates, that cannot solely be explained by spatial and temporal differences in effort. As a consequence, at this moment it is not recommendable to use Product Board data in stock assessments before the explanation of this difference is unraveled (see also §4.2).

4. Stock assessment working group look at changes in population numbers between different year and age-classes. Future predictions heavily rely on past trends. For example, the individuals born 10 years ago have felt the impact of natural and fishing mortality, but a fraction is still part of the current stock and through reproduction, influence numbers of future generations. It is therefore essential that any sampling program is complete and extended for several years to be of significant use and impact on stock assessment methods. Currently discard estimates (from 2000) are being used in the WGNSSK. Consequently, additional data (such as the one addressed in this report) could be combined with existing data, but this would only be benificial if it leads to more precise or accurate estimates. The imprecision's in the discard estimates currently used in the WGNSSK are relatively small compared to its discrepancy with the discard estimates from the PV sampling program. Again it boils down to understanding what may cause this difference, in an attempt to approximate the true, but unknown discard levels

5. Finally, it is essential that any data source is of a sufficient quality and that it is, preferably, independently collected. This criteria is perhaps the most subjective of all. Currently the IMARES dataset differs from that of PV in two ways. First of all the data is collected by independent observers that are specifically trained and paid for this task, and that do not directly or indirectly benefit from a particular outcome. Secondly, all individuals of all species within a sample or subsample are measured. Using the current methodology used for plaice (see Appendix B) it is possible derive the total weight of the sample after the data is collected. If this is different from the actual size of the sample (e.g. 40 liters), this will indicate that a mistake has been made (quality control checks). As yet, this validation step is not possible for the data collected by the PV.

At the start of its sampling programme, PV correctly argued that the IMARES sample size is small (less than 0.5% of the Dutch fishing effort), and that this may lead to non-repesentative sample of the entire fleet. Indeed their view was supported by the data they collected within the PV sampling programme. However this study showed that the magnitude of the observed difference was not caused by a difference in sampling effort in space and time, and that this could not be attributed to non-representatively sampling of a few vessels. For the reasons describe above, it is currently not recommended to use the PV data for WGNSSK.
Perhaps the most fundamental contribution of the data collected by PV and analyzing its properties, is that it provides a fundamental insight into plaice and cod discards and which processes play an important role. It acts as a new reference point which has lead and will lead to a critical review of the current way the data is collected by IMARES. The continuation of the comparison of methods (see next section 4.4) that is initiated by this PV discards sampling program may shed light on how accurate the current estimates from both sampling programs really are.

4.5 Recommendations for discards sampling induce cause create

This and previous reports (Dekker & van Keeken 2005, 2006) have revealed some interesting spatial and temporal patterns in discard fractions. One of the most important finding of this report is the significant differences in observed discard fractions between the Product Board and IMARES. One important step to be taken is a re-evaluation of both data collection methods, not in an analytical sense, but by setting up experimental studies (like fig 12). Problems that need to be addressed are:

1. Do the methods itself inherently result in different discard estimates? A first step is undertaken (see section 3.8) in assessing the different methods being used, this investigation should be extended to other areas, seasons and vessels.
2. The crew sampling for PV make considerable effort to collect the data. Extracting all plaice (and cod) from a large sample (40 liter) of the haul, measuring their lengths and recording all data (including

location, time of day, ship characteristics, etc), is a tedious exercise. Especially so, when it is done to during, just prior or after processing their own catch. For some vessels, this is a reason not participate in the PV sampling program. The question is how this may impede the quality of the data collected, and how voluntary participation may bias the mean discard estimates. In the future it might be better to collect fewer, but more precise samples, from vessels selected randomly. This may be achieved with financial stimuli. It is more worthwhile to include fewer vessels with the intention to fully participate in the programme than including as many vessels as possible in the programme which, most likely, will jeopardize the quality of the data.

3. Currently discards estimates are based on an ad-hoc estimation of the total catch by observers, and species specific landings per haul estimated by the crew or skipper. How reliable are these estimates and what is the effect on estimated discard numbers?
4. The Product board advices to take one sample of the total catch at once. In contrast IMARES, samples repeatedly different sections of the entire haul. It is suspected that the catch is not uniformly mixed in regard to species and length composition? If this is indeed true, this will lead to different discard estimates depending on which section of the catch is sampled. Evidence for this can be obtained within an experimental setting carried out onboard commercial beam trawl vessels.
5. The current experimental setup used by the commercial crew sampling for the Product Board is to differentiate between landings and discards using the 27cm MLS. In practice discarding of fish above MLS, and landings of fish below MLS take place. Ignoring this, and applying the separation based on MLS, can lead to under- or over-estimate of discards, respectively. Currently no distinction between landings and discards is made. Also in the length-frequency tables it is not possible to assess whether a plaice of e.g. 29 cm was part of the discard or landings.
6. Furthermore, only 50 individuals from both sections are measured. Selecting individuals at random (the required approach), is in practice extremely difficult to achieve and will almost always biases towards larger individuals. A different set-up should be chosen to overcome length-induced biases.

It is essential to evaluate data quality as soon as possible, to restrict any misplaced effort in the future.

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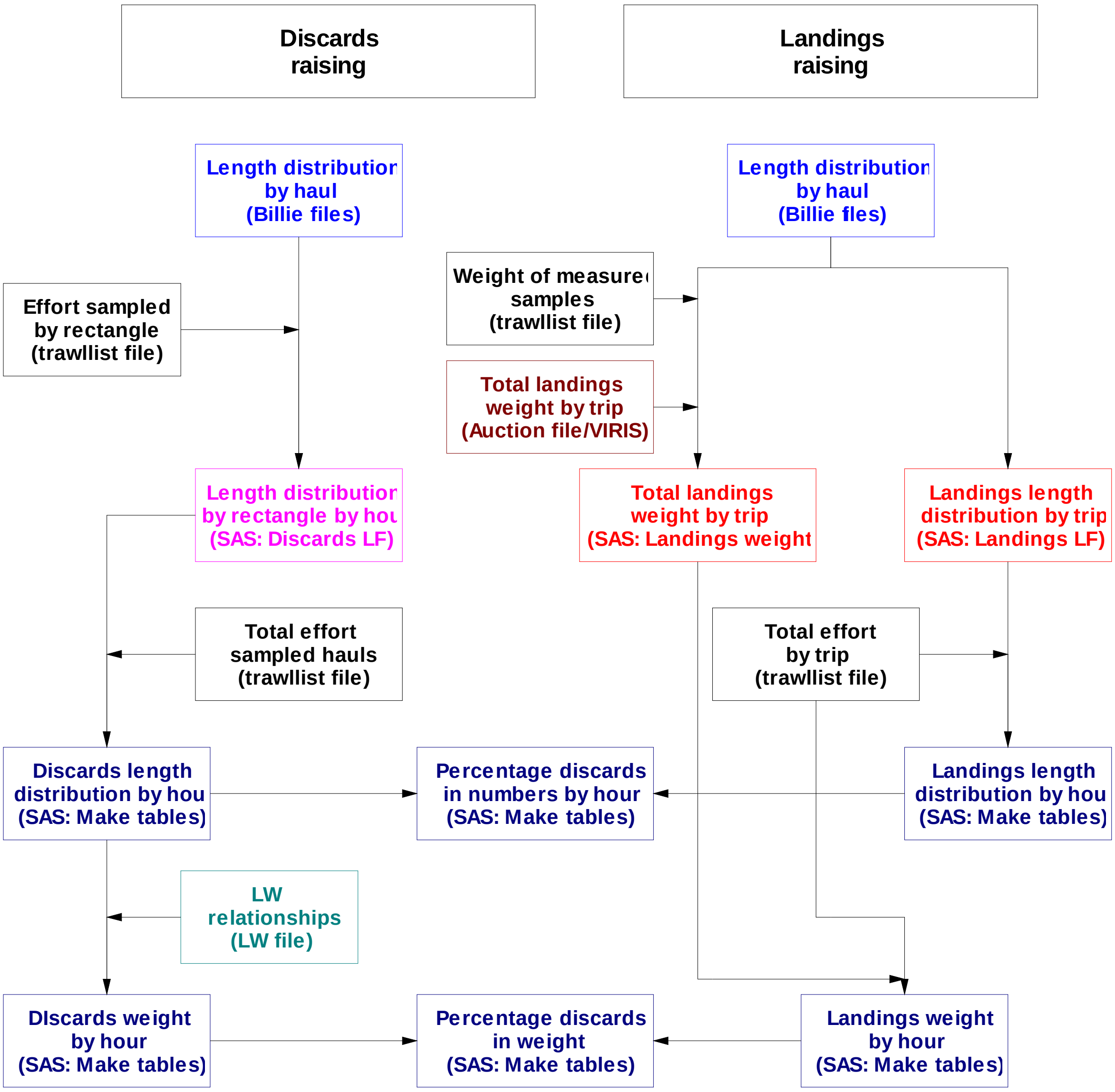
Appendix A

Schematic overview of procedures raising discard data by IMARES



Appendix B

Detailed description of the IMARES procedure to estimate discard fractions

Wageningen IMARES takes samples of the total catch (*C*) in one haul after fishermen remove all commercially valuable individuals (*L*). These landings were recorded and verified with the auction data. The remaining section (referred to as *W*) contains non-commercial species (e.g. sea stars, urchins) and undersized individuals (e.g. undersized plaice). From this, a sample *S* is taken. The sample *S* contains one basket of 40 liters. In some cases the length of all individual fish in that sample are measured. However, often (especially for the abundant species) a fraction *f* (e.g. $\frac{1}{8}th$) is taken. Using known length-weight relations, we can estimate the weight $w_{i,l}$ (in kg) of an individual from species *i* and length *l* (in centimeters). For plaice, the formula to calculate the weight is as follows:

$$w_{plaice,l} = 0.0082 \cdot (l)^{3.026} / 1000 . \qquad \text{B1)}$$

We can also estimate the total number of individuals *N* from species *i* of length-class *l* in the catch C in volume of one haul.

$$\begin{aligned} & N_{plaice,l} = n_{plaice,l} \cdot \frac{W}{S} \cdot \frac{1}{f}, \\ & where \\ & W = C - \sum_{\text{all species}} L. \end{aligned} \qquad \text{B2)}$$

where $n_{plaice,l}$ is the total number of individuals from length-class *l* in the sample (S) or sub-sample (S·f), *W* is the total volume discarded (including non-commercial species) and $\sum_{\text{all species}} L$ is the total volume of landings of all commercial species.

Finally, the total discards per haul of one species, e.g. plaice can be calculate as follows

$$D_{plaice} = \sum_{all\_lengths} \left(N_{plaice,l} \cdot w_{plaice,l} \right) \ . \qquad \text{B3)}$$

So *W* is the total volume of discards including all species, both commercial and non-commercial. *D* is a species-specific amount of discards, expressed as a weight. To conform to the data collected by the PV, total weight of plaice discards and landings, D_{plaice} and $L_{landings}$ respectively, are transformed into volumes by multiplying each by 0.89 and 0.83 respectively. Finally discard fractions are calculated as

$$p_{discards} = \frac{D_{plaice}}{(D_{plaice} + L_{plaice})} \ . \qquad \text{B4)}$$

As an example: if the total catch is 18 baskets, 7 of which are commercially valuable species, *W* equals 11 baskets (440 liter). From this, 1 basket (*S*=40 liter) is taken and for plaice a fraction of $f = \frac{1}{8}$ is measured. We observe 12 plaice of 22cm in our sub- sample. The average weight of a plaice of 22cm is

$$w_{plaice,l} = 0.0082 \cdot (l)^{3.026} \cdot 1000 = 0.0082 \cdot 22^{3.026} / 1000 = 0.094 \text{ kilogram} \qquad \text{B5)}$$

The total number of 22cm plaice in the catch ($N_{plaice,\ 22cm}$) is

$$N_{plaice,22cm} = n_{plaice,22cm} \cdot \frac{W}{S} \cdot \frac{1}{f} = 12 \cdot \frac{11}{1} \cdot \frac{1}{1/8} = 1632 \qquad \text{B6)}$$

Consequently, the total weight of 22cm plaice is 0.094kg·1632 = 153.408kg. This calculation is repeated for all length classes and summed over all lengths (B3). Finally, weights are transformed into volumes and a discard fraction (B4) is estimated.

Appendix C

Sampling method on board commercial vessels (IMARES).

Bemonsteringsprocedure Discards Demersaal IMARES

1) Het schatten van de totale vangst (hoops).

2) Het verzamelen van een discardmonster.
    i) Een discardmonster bestaat uit 1 standaard mand die in delen wordt genomen uit het begin, midden en einde van de verwerking van de trek.

3) Het meten van het discardmonster.
    i) Alle vissoorten worden uit het discardmonster gesorteerd, gemeten, geteld en genoteerd op lengteklasse.
    ii) Alle benthos wordt op soort gesorteerd, geteld en genoteerd.
    iii) Noteer de subsampling factor ten opzichte van de standaard mand.

4) Het meten van een landingsmonster.
    i) Bemonster van de maatse doelsoorten (schol, tong, schar) tussen 10-15 kg. Vaststellen gewicht monster. Alle individuen meten en noteren op lengteklasse.
    ii) Bemonster (wanneer mogelijk) van de bijsoorten (kabeljauw, wijting, tarbot, griet, bot, nephrops) tussen 10-15 kg. Vaststellen gewicht monster. Alle individuen meten en noteren op lengteklasse.

5) Het verzamelen van discards voor leeftijdsanalyses op het lab.
    i) Voorgeschreven soorten: Schol, Tong, Schar.
    ii) Andere soorten (wanneer mogelijk): Kabeljauw, Wijting, Schelvis.
    iii) De monsters voor leeftijdsanalyses hoeven uitsluitend te bestaan uit ondermaatse vis. Indien de visserij zich beperkt tot een enkel gebied, dan volstaat 1 monster van 3 vissen per cm-groep. Indien de visserij in duidelijk verschillende gebieden plaatsvindt, dan dienen discardsmonsters te worden verzameld per gebied.

6) Het schatten van de aanvoer per trek.
    i) De aanvoer per trek van de hoofdsoorten en bijsoorten wordt geschat door de bemanning (eventueel op navraag van de opstappers). De schipper wordt verzocht om de aanvoergegevens per trek per soort bij te houden in het door IMARES verstrekte logboek.

Minimaal moet per reis 60% van de trekken worden bemonsterd. Van belang is dat de bemonsterde trekken worden gespreid over dag en nacht.

Appendix D

Sampling method PV

Instructies voor het discardsonderzoek naar schol en kabeljauw door de visserijsector

Schol

1. Iedere week bemonstert u de eerste trek na dinsdag- en donderdagmiddag 16.00 u. Dit is een gewone trek (geen speciale vistijd o.i.d.) zoals bij u aan boord wordt uitgevoerd om een zo goed mogelijk beeld te krijgen van het normale vispatroon. Op dinsdag bemonstert u de stuurboord vangst en op donderdag bemonstert u de bakboord vangst. Als u hier van afwijkt (bijv. omdat u op donderdag al binnen bent), meldt u dit op het registratieformulier.

2a. Na het legen van het net in de opvangbak neemt u een monster door de gestandaardiseerde vismand vol te scheppen tot en met de bovenste rand met gaatjes. U probeert hierbij een zo representatief mogelijk monster te nemen. Het is dus niet de bedoeling dat u een speciaal deel van de vangst selecteert dat bijvoorbeeld alleen uit schol bestaat.

2b. Wanneer er maar weinig (ondermaatse) schol en / of zeer grote hoeveelheden benthos (bodemdieren en andere “rommel”) aanwezig zijn in het monster (u bepaalt dit op basis van uw eigen inzicht), neemt u de dubbele hoeveelheid van een monster. Het is belangrijk dat twee keer dezelfde hoeveelheid (dus 2 keer een vismand) bemonstert. Omdat u maar 1 gestandaardiseerde vismand heeft, moet u de eerste mand leeg gooien en deze inhoud tijdelijk in bijv. een viskist bewaren. In de lege mand kunt u uw tweede monster scheppen. U verwerkt de beide monsters verder samen als 1 groot monster. Wanneer u een tweede mand bemonstert, is het belangrijk dat u dit duidelijk op het registratieformulier aangeeft!

3. De vismand (en evt. de viskist als u een dubbele hoeveelheid bemonstert) zet u apart en u verwerkt de rest van uw vangst op de voor u gebruikelijke wijze.

4. Vervolgens wordt het monster uitgezocht. U zoekt de schol en kabeljauw uit de vismand (en evt. viskist). De rest, de overige (commerciële) vis en bodemdieren kunt u naar believen verwerken. De kabeljauw verwerkt u volgens de instructies op de ommezijde .

5. De schol uit de vismand (en evt. viskist) wordt verdeeld over twee emmers. Eéntje met de maatse schol en de andere emmer met ondermaatse schol.

6. Op de standaard emmers staat een schaalverdeling. U leest de hoeveelheid (=volume) maatse en ondermaatse schol af van de schaalverdeling. Dit noteert u op het registratieformulier.

7. U meet de lengte* van 50 maatse schollen en 50 ondermaatse schollen met behulp van het meetplankje (grens ligt op 27 cm). De resultaten turft u op de turflijst. Heeft u meer schollen gevangen, dan hoeft u deze niet te meten. Bij minder vissen, meet u ze allemaal.

8. De maatse schol kunt u daarna verder verwerken. De ondermaatse schol moet u weer overboord zetten.

9. U noteert een aantal gegevens van de visreis en de bemonsterde trek op het registratieformulier.

10. Van uw afslagbrief neemt u de hoeveelheid maatse schol in kilogrammen per categorie over op uw registratieformulier.

Kabeljauw

1. Gedurende de hele reis verzamelt u uit alle trekken alle kabeljauw, dus zowel de maatse als de ondermaatse. U bewaart de ondermaatse kabeljauw apart van de maatse kabeljauw in viskisten. De ondermaatse vis moet in een viskist en in een doorzichtige plastic zak komen.
2. De ondermaatse kabeljauw blijft ongestript. De maatse vis kunt u verwerken zoals u gewend bent.
3. Na de laatste trek meet u de lengte* met behulp van het meetplankje. Hiervoor neemt u willekeurig 50 maatse kabeljauwen uit de vangst. Heeft u er minder dan 50 gevangen, dan meet u ze allemaal. De lengtes noteert u op de turflijst.
4. U meet ook de lengte* van 50 willekeurig gekozen ondermaatse (kleiner dan 35 cm) kabeljauwen met behulp van het meetplankje. Heeft u er minder dan 50 gevangen, dan meet u ze allemaal. De lengtes noteert u op de turflijst.
5. Na de laatste trek noteert u het aantal kisten met ondermaatse kabeljauw. Op de terugreis naar de haven/afslag meldt u dit aantal bij de AID en de afslag waar u gaat verkopen. Ook geeft u de te verwachten aankomsttijd door.
6. Zowel de maatse als de ondermaatse kabeljauw levert u af bij de afslag. De ondermaatse kabeljauw moet u aanbieden in normale viskisten maar moet u verpakken in doorzichtige plastic zakken die voordat ze worden aangevoerd, dichtgebonden moeten worden met tie-raps. Elke zak moet u voorzien van een goed leesbaar vaartuigbriefje.
7. Bij aflevering bij de afslag wordt de ondermaatse kabeljauw apart gehouden en gewogen door de visafslag onder toezicht van de buitendienstmedewerker van het Productschap Vis. De buitendienstmedewerker noteert de hoeveelheid en geeft dit door aan u. De maatse kabeljauw wordt volgens het normale traject gewogen.
9. U noteert deze gegevens van de afslag samen met nog een aantal gegevens over de visreis op het registratieformulier.
10. De buitendienstmedewerker zorgt er verder voor dat uw ondermaatse kabeljauw gedenatureerd (ongeschikt gemaakt voor menselijk gebruik) en afgevoerd wordt.

Verzamelde gegevens

Iedere maand stuurt u de verzamelde gegevens naar het Productschap Vis. Dit kan per post (postzegel is niet nodig) t.a.v. discardsonderzoek, Antwoordnummer 10387, 2280 WB Rijswijk, maar bij voorkeur per e-mail aan discards@pvis.nl.

Vragen?

Als u vragen heeft, kunt u contact opnemen met uw visserijorganisatie of met Fenneke Brocken van het Productschap Vis, tel: 070-3369606 / 06-10938639 of e-mail: fbrocken@pvis.nl

* Lengte meten

De lengte wordt gemeten van snuit tot en met staart en in hele centimeters genoteerd. Een vis van 27,8 cm noteert u als 28 cm en een vis van 35,3 cm noteert u als 35 cm.