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Estimation of total retained catch based on frequency of fishing trips, inspections at sea, transhipment, and VMS data

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The satellite-based vessel monitoring system in the Norwegian Economic Zone provides detailed information about individual trips by vessels. Vessel sizes are available through official registries, and the storage capacity for fish is estimated using the established conversion factors as a function of the vessel's gross registered tonnage. Scientists have had access to the database of both transport and fishing vessels, with records for individual trips, in addition to information about the total round weight (whole fish) of cod and haddock for trips inspected by the coastguard. The analysis assumes that trips with complete documentation of the fish on board are a random sample, so allowing estimation of the mean amount of both cod and haddock per trip, and annual totals give the number of trips per vessel annually. ICES has accepted this methodology for estimating illegal, unregulated, and unreported (IUU) catches, which has resulted in 15 000–166 000 t (3–35%) being added to the officially reported landings of Northeast Arctic cod during the years 2002–2008. IUU landings have decreased in recent years, but are so important for assessment and management that estimates continue to be made annually.

Keywords: Barents Sea, cod, haddock, IUU, transhipment, unreported retained catch, VMS.

Introduction

Illegal, unreported, and unregulated (IUU) fishing is a significant threat to marine ecosystems worldwide, representing challenges on a global scale, with the annual economic loss to nations and communities estimated to be €10 billion, or US$15 billion (EC, 2007). There is growing recognition of the need to take on these challenges, expressed by the Food and Agriculture Organization of the United Nations (FAO) in its "International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated fishing" (FAO, 2001).

A concern arose in 2002 that the transhipping of fish from the Barents Sea utilized loopholes in international control systems (and regulations) and hence led to trading of fish not counted against quotas. This was a high-priority topic for the coordinated control activities of the Norwegian–Russian Fisheries Commission in 2002 and was initiated by unease by Russia about the new development of transhipping fish in the open sea and by Norway because of the sudden decrease in landings in Norwegian ports. It is therefore believed that the magnitude of the unreported landings increased sharply in 2002 (ICES, 2004).

During the years 2002–2008, the Norwegian Directorate of Fisheries presented evidence of significant quantities of unreported catches of cod (*Gadus morhua*; since 2002) and haddock (*Melanogrammus aeglefinus*; since 2005) in the Barents Sea (Anon., 2006a). The fish were caught in the Barents Sea, but landed in countries not having a proper system for reporting the landings back to the respective national authorities that were managing the relevant stocks. Most catches were transhipped at sea to transport vessels that landed them in third countries (i.e. neither Russia nor Norway), but some fishing vessels did land the fish directly in those countries. Most of the transhipped fish by weight were Northeast Arctic cod and haddock fished by vessels carrying the Russian flag, and it is the total retained catch of these Russian fishing vessels that is estimated and presented in this paper.

The Joint Norwegian–Russian Fisheries Commission keeps account of all fishing vessels licensed to fish in the Barents Sea and adjacent waters (Anon., 2010). For 2005 (the example year), Table 1 shows the number of vessels >28 m by country licensed by Norwegian authorities to fish for cod and haddock in that area, north of 62°N. Not all vessels licensed to fish are necessarily active, however. In addition to this list, there is an unknown number of Russian vessels allowed to fish in the Russian Economic Zone, and 2346 Norwegian fishing vessels <28 m that fished and reported catches from the coastal Norwegian zone (Anon., 2006b).

On 1 May 2007, the Northeast Atlantic Fisheries Commission (NEAFC) introduced its Port State Control System. Landings of frozen fish caught in the NEAFC Convention Area by the Contracting Parties are only allowed in designated ports, and at least 15% of landings or transhipments in these ports have to be inspected by port authorities during each reporting year (NEAFC, 2011). With respect to fisheries in the Barents Sea, the concept of this control system is that coastal states (UN, 2010) should have access to landings information for fish caught from stocks they manage when landings take place in a third country, i.e. the port state. The port state shall not allow a landing to take place unless the flag state of the vessel concerned has confirmed in writing that the fish have been caught legally. Documentation is made available immediately to the coastal state through the website of the NEAFC Secretariat. Before the NEAFC Port State Control System was introduced, the many different national-control systems did not meet the interests and management responsibilities of the coastal states, but the new measure has had a clear effect on the quantity of illegal frozen fish landed in Europe; levels of IUU fish in European markets have declined significantly (Anon., 2011; ICES, 2011; www.neafc.org).

Since 2002, the method for raising the documented landings data to an estimate of total landings has improved, along with the precision. For 2005, Norway's Institute of Marine Research obtained access to the Directorate's entire database of transport and fishing vessels, which included details of individual trips, in addition to information on the total round weights of cod and haddock for trips inspected by the coastguard and/or at landing sites.

Table 1. The numbers of international vessels of overall length ≥28 m holding a licence from the Norwegian authorities to fish for cod and haddock north of 62°N in 2005, including the NEZ of the Barents Sea and the Svalbard area.

Country	Number of licences
Faroe Islands	5
France	11
Germany	14
Greenland	2
Iceland	7
Ireland	1
Norway	94
Portugal	7
Russia	207
Spain	16
UK	6
Total	364

The overall aim of this paper is to estimate as accurately as possible the total catch of cod and haddock caught by a specific fleet segment fishing these species in the Barents Sea and adjacent waters north of 62°N, based on various documentation sources and using sound, simple, transparent statistical methods. We describe the original method used, the development of a more scientific approach, and the method later adopted by the authorities as a routine procedure. The main focus and results presented refer to the scientific method.

Material and methods

International vessel monitoring system (VMS) information constitutes the main basis for raising documented to total catches, providing an accurate assessment of the total fishing effort and sailings of cargo vessels (fish carriers) and fishing vessels. Unreported landings are then deduced simply by subtracting the official reported landings from the estimated total landings. The specific fleet segment belongs to 200 different fishing companies from eight regions of the Russian Federation, but mainly from the Murmansk, Arkhangelsk, and Karelian regions. Up to 16 vessel types with different catch efficiencies have participated in the Barents Sea cod and haddock fisheries (WWF, 2005), differing mainly in size and stipulated catch efficiency (experienced catch rates per day). Except for one longliner type, all are trawlers.

Data

Data from the satellite-based VMS in the Norwegian Economic Zone (NEZ) provide details about individual trips by vessel every hour. It is known when a ship enters and leaves the NEZ, and in what direction (Figure 1), which leads to knowledge of the total number of trips by each vessel in the NEZ. For unregistered (flag-of-convenience) vessels, the international Automatic

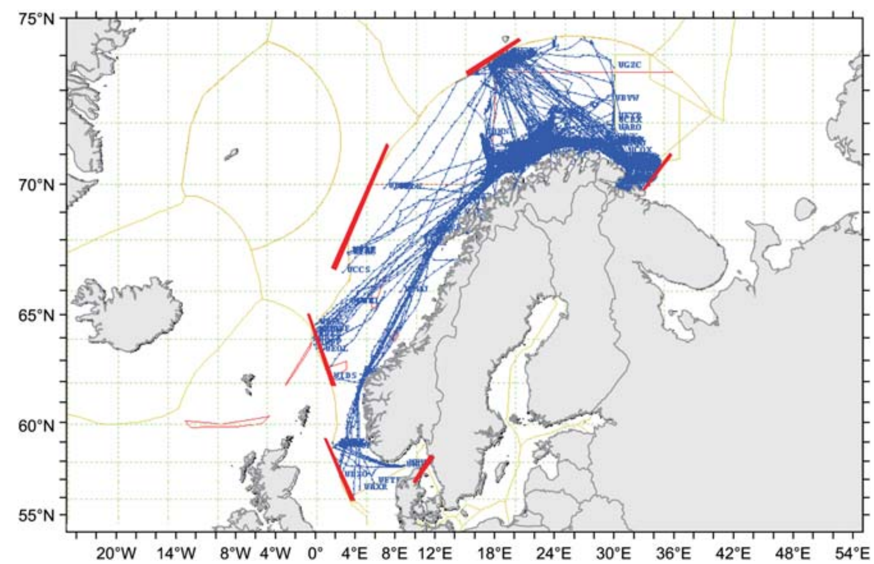

Figure 1. Satellite-tracking (VMS) records (blue) of foreign fishing and cargo vessels within the NEZ during 1 week in 2005. Light green lines show the boundaries of national zones, and red lines the main exit and entrance routes for the NEZ. Records include dates and times, whether the vessel is sailing in or out, and its direction.

Identification System (http://www.shipais.com/) and other means have been deployed to record harbour calls in Europe. Vessel sizes are available through official registries (e.g. the Lloyds Register Fairplay website, www.ships-register.com), and fish-storage capacity is estimated using the established conversion factors as a function of the gross registered tonnage (grt) of the vessel (Sintef, 2006).

The retained catch information for individual fishing vessels and transhipments is determined as equivalent round weight, i.e. the observed weight of transhipped product multiplied by an appropriate conversion factor to estimate the round weight of the original catch. As an example, consider a vessel of 983 grt. The net tonnage is then 590 t (an average 60% of the grt) and the net load capacity of fish product is 354 t (an average stowage factor of 60%). The factor for converting headless and gutted cod to round weight is 1.5 (Anon., 2003a, b), so for that product the load capacity corresponds to 531 t round weight of cod. On the other hand, if the vessel carried only cod fillets (conversion factor 3.25), then the load capacity would be 1150 t round weight.

Product type at an individual transhipment level, and hence the exact conversion factor, was not generally known. However, such information is available from the Norwegian coastguard when trips of the transport vessel, the fishing vessel, or both have been inspected. The coastguard collects information on the received (or delivered) quantities of fish at sea, the species composition, date of transhipment, and the vessel's destination after it leaves the NEZ. In addition to information from these inspections, landings data have been collected in Norway and in some EU countries. Although the coastguard could seek areas where fishers are active, there is usually no deliberate prior selection of vessels other than inspecting those that happen to be near the coastguard-patrol track. Therefore, we argue that the vessels, and consequently the trips, are sampled at random. Further details of coastguard operations will be found in reports from the Norwegian Directorate of Fisheries, e.g. Anon. (2006a) and others available at http://www.fiskeridir.no/english/fisheries/reports.

An important issue has been to avoid taking into account registrations of cod and haddock for vessels which may be carrying pelagic species. Data from Russian catch logs have therefore been checked to identify where fishing for cod and haddock has taken place. Our analysis only includes vessels believed to be transporting demersal species.

The available data were grouped by destinations in the EU, Russia, and Norway. The total available number of trips and those sampled are summarized in Table 2. In 2005, all 541 trips landing at Norwegian ports were fully documented, and of the

Table 2. Number of observed trips by the Norwegian Directorate of Fisheries, based on VMS data, aircraft surveys, and/or landing reports from foreign harbours, per type of vessel and trip destination in 2005.

Vessel type	To the EU	To Russia	Total to the EU and Russia	To Norway	Total
Cargo	312 (144)	86 (4)	398 (148)	6 (6)	404 (154)
Fishing	82 (15)	100 (14)	182 (29)	535 (535)	717 (564)
Total	394 (159)	186 (18)	580 (177)	541 (541)	1 121 (718)

Numbers in parenthesis are the trips with documented total quantities of cod and haddock.

580 trips to EU and Russian ports tracked by the VMS, complete documentation on the quantity of fish carried was available for 177. In addition to the latter, there was some, but incomplete, documentation on fish cargo for a further 125 trips.

The data show that using VMS to track the vessels in and out of the NEZ may give inaccurate trip durations, because the time a vessel spends outside the NEZ is not covered by the Norwegian VMS. For example, in some cases, the data show that the transhipping vessel received fish from a fishing vessel some days before entering or after leaving the NEZ, so transhipment of fish evidently takes place outside as well as inside the NEZ. However, this does not influence the results unless a vessel has spent the whole trip outside the NEZ, when the trip would not have been registered by either inspections at sea or VMS.

Original method

The first method for documenting and estimating the total amount of cod and haddock fished in the Barents Sea is described in Anon. (2006a). VMS data determine the total fishing and transhipment effort to which the documented catch data are raised, using the documented quantities whenever available, and subject to certain assumptions, the quantities for trips with no documentation are estimated. First, it is assumed that all fish recorded are headless and gutted, i.e. a conversion factor of 1.5 is used to determine the equivalent round weight, and the storage capacity is calculated as described above. Based on the available documentation, whether complete or incomplete for the entire trip, the average filling percentage of the boat is calculated, along with the average proportions of cod and haddock. These results allow estimates to be made of the quantities for trips with no documentation of the fish load itself, but whose fishing or transhipment activity was recorded. For further details, see Anon. (2006a).

Scientific method

The use of vessel-tracking information, provided it is auditable, gives an accurate overview of vessel movements over time. Utilizing these data to assess a total of N trips within a given area, of which the fish quantities are observed directly on n trips, we estimate the mean quantity per trip and the total for the fleet segment. Assuming that the n trips are a random sample, the precision (variance) of the estimates comes from standard statistical methods and is unbiased. The total quantity of fish for the N trips is $Y = N\bar{Y}$, where $\bar{Y}$ is the average per trip. As the amount of fish is observed only for the sample of size n, $\bar{Y}$ is replaced by its estimator $\hat{\bar{Y}}$, such that the estimated total quantity is $\hat{Y} = N\hat{\bar{Y}}$. Perhaps the most intuitive estimator for $\bar{Y}$ is the simple mean per sampled trip. However, if the quantity of fish on board depends on the storage capacity x of the vessel for the specific trips, a common approach within sampling theory is to utilize such auxiliary data to provide a more efficient estimator than the simple mean. We therefore consider a linear-regression estimator (Cochran, 1977) to determine $\bar{Y}$. More specifically, we assume that

$$y_i = \alpha + \beta x_i + \varepsilon_i, \quad (1)$$

where y_i and x_i are, respectively, the amount fish on board and the storage capacity of the vessel making trip i, ε_i a random error term with mean 0 and variance σ_ε^2, α the intercept, and β the slope of the model. The linear-regression estimator for the population mean is then

$$\hat{\hat{Y}} = \bar{y}_{\rm lr} = \bar{y} + \beta(\bar{X} - \bar{x}), \quad (2)$$

where $\bar{y}$ is the sample mean of the observed quantities of fish, $\bar{X}$ the population mean (for all trips) and $\bar{x}$ the sample mean of the storage capacity. Unlike the simple mean per trip, this estimator takes account of the actual size composition of the vessels. Given a random sample n drawn from N trips, this estimator is a consistent and unbiased estimator for $\bar{Y}$ (Cochran, 1977), and its variance is approximated by

$$\mathrm{Var}(\bar{y}_{\rm lr}) \approx (1-f)\frac{s_y^2}{n}(1-\rho^2), \quad (3)$$

where $f = n/N$ is the proportion sampled (the finite-population correction factor), s_y^2 the sample variance of y, and ρ the correlation between the amount on board and the storage capacity. Note that the variance is reduced by the factor $(1-\rho^2)$ relative to that calculated using the simple mean. If there is no correlation between y and x, $\rho = \beta = 0$, and the simple-mean and linear-regression estimators are the same for both the population mean and its variance.

The estimator for the variance of $\hat{\hat{Y}}$ is approximate and valid for large samples, but underestimates the true variance for small samples. Therefore, we use a bootstrapping approach (Efron, 1983) to estimate the sample distributions of $\hat{\hat{Y}}$ and $\hat{Y}$. In other words, the sampled trips are randomly resampled with replacement, forming replicate sets of data. The total quantity is then estimated for each replicate. Repeating this procedure, a large number of times reveals the distribution of the estimates, so their precision can be determined. For the data used in this paper, 1000 replicates suffice to stabilize the percentiles in the distribution.

Only data from trips where the quantity of fish on board is completely documented are used in this approach. Also, we do not make any further assumptions about filling percentages or product types for non-documented trips. Our approach simply uses inspectors' reports of the completely documented trips which, in terms of conversions between product and round weights, are all based on the factors agreed between Russia and Norway for cod and haddock in the relevant areas (Anon., 2003a, b).

Adoption of a common Norwegian–Russian methodology

Based on and to continue and formalize the above methodological procedure, a decision was set out in the protocol of the 36th session of the Joint Norwegian–Russian Fisheries Commission, section 12.6, subsection 9 (Anon., 2007) stating that an analytical group shall "Develop a methodology for analysing satellite tracking data and information about the shipping and landing of fish at ports". The methodology aims to calculate the total Norwegian, Russian, and third-country catches of cod and haddock in the Barents and Norwegian seas, based on a mixed analysis of satellite-tracking data and information on the fish products shipped and landed by the relevant vessels. Catch estimates are based on both empirical and inferred data.

Here, the term "cod and haddock" refers to the joint Norwegian–Russian populations of these species. The methodology covers fishing vessels involved in catching and transhipping fish, and cargo vessels shipping fish products to Russian, Norwegian, or third-country ports. It is applied to fish products of cod and haddock caught in the following areas (Figure 2):

(i) the Norwegian economic zone (including territorial waters);
(ii) the Russian economic zone (including territorial waters);
(iii) the adjacent area (the so-called "greyzone");
(iv) the Fishery Protection Zone around Svalbard;
(v) international waters in the Barents Sea (NEAFC Regulatory Area, referred to as the "loophole").

The analysis is based on reliable information from satellite tracking, catch reports from vessels, landings documentation, and other relevant information from many sources, both national and international. An inventory of these sources is available in the Supplementary Annex S1. All available information is assessed and analysed, including data having legal status to meet the requirements of national fisheries legislation.

For estimating the total catch of cod and haddock, the conversion factors for fish products, and the relevant stowage factor, are specified annually by the Joint Norwegian–Russian Fisheries Commission (Anon., 2003a, b; Sintef, 2006).

In the estimation procedure, each registered cargo is interpreted and classified by category as 0, 1, or 2. Category 0 applies where it is concluded that information about the actual quantities is lacking, that they are underestimated, or that they are based on tracking information only. Category 1 classification means that the final quantities are uncertain, e.g. should an inspection have taken place rather early in the fishing or transhipment process, and category 2 that the final fish load has been determined with certainty. The analysis is based on the average of quantities classified as category 1 or 2 (using individual-trip points to infer averages; see the "Scientific method" described above). This information is then used to raise the quantities on trips classified as 0 and 1. Note that category 1 trips appear twice in this procedure, first in calculating the average quantity, and second being raised to this average per trip. This methodology has been applied by the Norwegian Directorate of Fisheries since 2006 and by the Norwegian–Russian analytical group responsible for these analyses and calculations since 2010.

Conversion factors

All three methods described above assume that for the documented trips and fish loads, the product types are known and the conversion factors (from product to round weight) are correct. For estimating the total fish load on vessels not completely documented, the original method and the adopted common Norwegian–Russian method both make assumptions about products and conversion factors, whereas the scientific method does not. To validate these assumptions, we write the equivalent round weight of fish for each trip as

$$y = kxp, \quad (4)$$

where k is the product conversion factor, x the storage capacity, and p the filling proportion of the vessel for that trip. Rearranging Equation (4) for k gives the conversion factor as a function of the other three parameters. Replacing y with $\hat{\hat{Y}}$ and x with $\bar{X}$, a mean conversion factor $\hat{k}$ is estimated. This approach

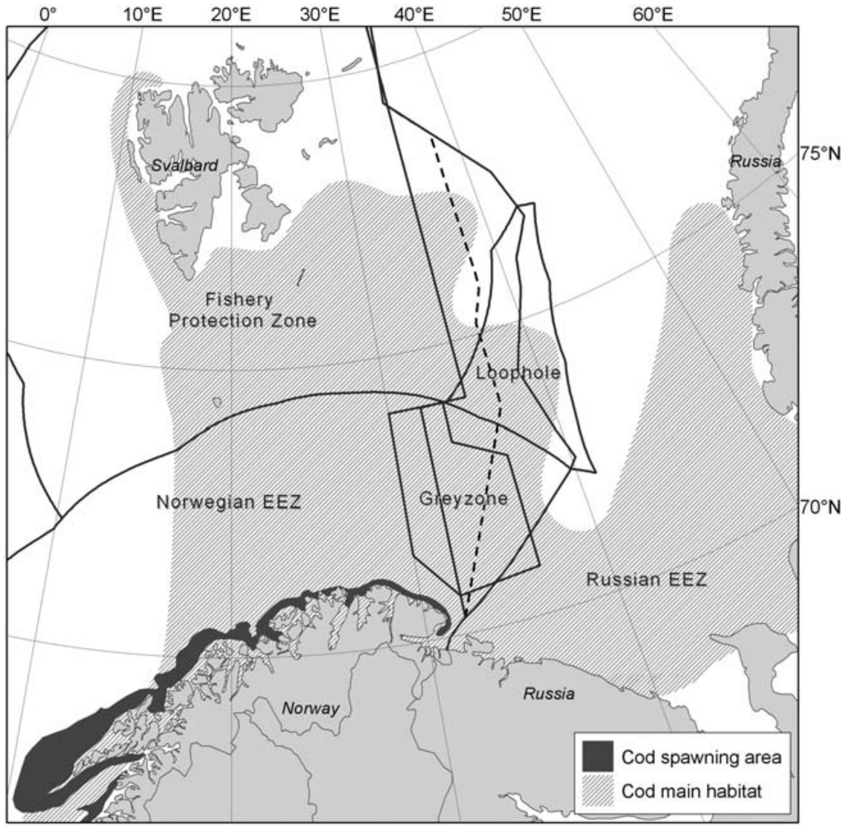

Figure 2. Map of the Barents Sea and the Svalbard area showing the different jurisdiction zones, the distribution of Northeast Arctic cod, and its spawning area. The dashed line shows the new border between Norwegian and Russian waters; when it has been ratified by both countries, the greyzone and loophole areas will be eliminated.

provides some insight into the types of product on board the vessel assuming that the storage capacity and filling percentage are known. As the bootstrap distribution of $\hat{\hat{Y}}$ is available, so also is the corresponding distribution of $\hat{k}$.

Results

Summing all the documented amounts, complete and incomplete, yielded 134 995 t of cod and 31 105 t of haddock.

Fitting least-square linear regressions to the data for each type of vessel and destination, with quantity of fish as the dependent variable and storage capacity as the independent variable, the regression slopes were very different (not shown). Therefore, the analysis for each species was carried out separately for each type of vessel and destination (eight cases in all). Of the 580 trips to EU and Russian ports, 177 samples had complete observations on the quantity of cod and haddock. Cargo vessels made 312 trips with destinations in the EU, yielding 144 samples (Table 2); for those trips, the quantities of cod and haddock have a significant linear relationship with the storage capacity (in both cases $p < 0.01$, and $r^2 = 0.58$ and 0.20 for cod and haddock, respectively), and no deviation from linearity is evident (Figure 3). This shows that the regression estimator is appropriate for determining the amounts of both cod and haddock being shipped from the Barents Sea by cargo vessels with EU destinations. The sample sizes (and the number of

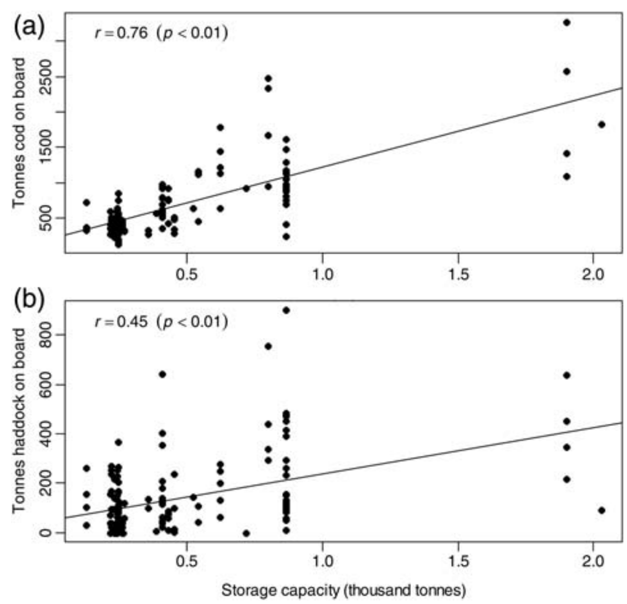

Figure 3. Total round weight of (a) cod and (b) haddock plotted against the storage capacity of cargo vessels for trips with destination EU. Points are observations for individual trips, and lines are linear regressions shown with correlation factor (*r*) and *p*-value.

Table 3. Estimated total round weight (t) of cod and haddock from Norwegian waters in 2005 per type of vessel and its destination, 95% confidence intervals (in parenthesis) estimated using bootstrapping with 1000 replicate datasets.

Species	Vessel type	To the EU	To Russia	Total to the EU and Russia	To Norway	Total
Cod	Cargo	243 348 (218 017 – 260 832)	10 843 (4 425 – 18 022)	254 191 (227 380 – 270 219)	1 021	255 212 (228 401 – 271 240)
Cod	Fishing	36 339 (21 648 – 42 817)	4 393 (1 988 – 4 523)	40 733 (24 706 – 45 971)	70 979	111 712 (95 685 – 116 950)
Cod	Total	279 687 (248 399 – 293 387)	15 237 (6 704 – 20 965)	294 924 (258 956 – 307 231)	72 000	366 924 (330 956 – 379 231)
Haddock	Cargo	48 494 (40 291 – 57 571)	29 320 (424 – 72 553)	77 813 (44 057 – 118 921)	125	77 938 (44 182 – 119 046)
Haddock	Fishing	4 531 (2 045 – 5 966)	2 693 (1 152 – 2 741)	7 223 (3 771 – 7 964)	26 475	33 698 (30 246 – 34 439)
Haddock	Total	53 024 (43 935 – 61 612)	32 012 (2 223 – 74 344)	85 037 (49 561 – 123 825)	26 600	111 637 (76 161 – 150 425)

Table 4. Estimate of 2005 landings (t) of cod and haddock from Norwegian waters compared with the fleet's quota, reported landings, and the amount adopted by ICES as surplus landings in the stock assessment.

Species	Total estimate (t)	Total quota (t)	Total reported (t)	Additional to quota (t)	Additional to reported (t)	Adopted by ICES as surplus (t)
Cod	366 924	213 700	200 077	153 224	166 847	166 000
Haddock	111 637	51 300	50 012	60 337	61 625	40 283

trips) are less for vessels with Russian destinations and for fishing vessels with EU destinations (Table 2). For those groups, there was no significant correlation between quantity and storage capacity (results not shown), so the simple mean estimator was used to analyse these groups.

The estimated total quantities of cod and haddock are summarized in Table 3. For cod, the result is 294 924 t, with 95% confidence intervals (258 956–307 231 t), mostly in the cargo vessels with destination EU, which accounted for some 83% of the total. The smallest quantity is in fishing vessels with destination Russia, i.e. 4393 t, with 95% confidence intervals (1988–4523 t). The estimated total quantity of haddock was 85 037 t, with 95% confidence intervals (49 561–123 825 t). Although this is much less than the total quantity of cod, the proportional distributions across destinations and types of vessel are similar, except that the haddock proportion on cargo ships with destination Russia is relatively high.

In addition to the results of the analyses above, we fully documented the quantities landed by the fleet in Norway. These were 72 000 t of cod and 26 600 t of haddock.

In 2005, the total reported landings from this fleet were 200 077 t of cod and 50 012 t of haddock (Table 4). Our documentation and estimation procedures therefore revealed that 166 847 t (95% *CI* 130 879–179 154 t) of cod and 61 625 t (95% *CI* 26 149–100 413 t) of haddock additional to the reported quantities were landed that year. ICES accepted the estimates and included 166 000 t as surplus landings in the stock assessment for Northeast Arctic cod, and 40 283 t for Northeast Arctic haddock. The reason for the difference is the precision of the haddock estimate, which is much poorer than that of cod. The ICES Arctic Fisheries Working Group therefore decided to use the proportions of cod and haddock in the international reported landings (i.e. those from ICES Subarea I and Division IIb for 2002–2005) to partition the unreported landings between the two species (ICES, 2006). This resulted in the above value for surplus landings of haddock.

By comparison, the Norwegian Directorate of Fisheries (Anon., 2006a) reported minimum landing estimates of 315 000 t (cod) and 87 600 t (haddock), respectively, 14 and 21% lower than the estimates obtained in the analyses presented here.

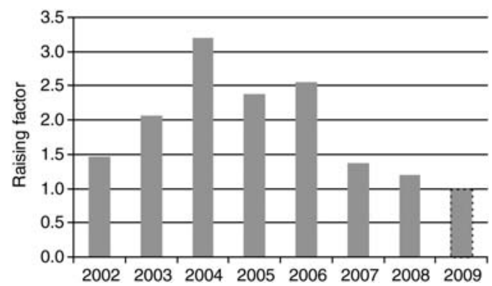

Figure 4. Relationship between documented quantities of cod (based on inspections, landings in Norway, and the NEAFC database) and calculated quantities for all trips by year. The raising factor (the ratio of calculated and documented quantities) has declined considerably in recent years as the volume of documented data has increased. The apparently complete documentation in 2009 is still in question.

Figure 4 shows the relationship between documented quantities of cod (based on inspections, landings in Norway, and the NEAFC database) and our calculations. The raising factor has been reduced considerably in recent years, from 3.2 in 2004 to 1.2 in 2008, as the quantity of documented data increased. The apparently complete documentation in 2009 is, however, still open to question.

The unreported overfishing (i.e. additions to the reported landings) of cod (Figure 5a) and haddock (Figure 5b) during the years 2002–2009 decreased rapidly after peaking in 2005, based on the adopted Norwegian–Russian estimation procedures described above, and the results have been accepted by the ICES Advisory Committee (ICES, 2010). The estimated mean product-conversion factor as a function of the mean filling proportion, for the summed quantities of cod and haddock (Table 3), is shown in Figure 6. For example, cargo vessels with destination EU are typically assumed to be on average 90% filled (Anon., 2006a). The average conversion factor for the summed cod and haddock is then 1.87, with 95% confidence intervals of (1.67–2.00; Figure 6b). This is considerably higher than the factors used by the Norwegian Directorate of Fisheries (Anon., 2006a), i.e. 1.5 for cod and 1.4 for haddock, indicating the presence of

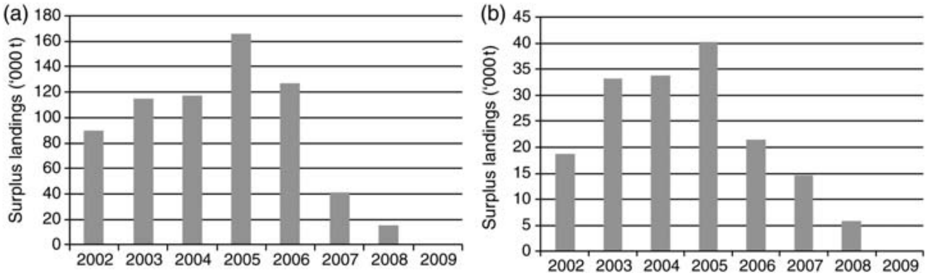

Figure 5. Registered overfishing (in addition to reported landings) of (a) cod and (b) haddock by year, 2002–2009, based on data and estimation procedures described in the text. These figures have been adopted by the ICES Advisory Committee (ACOM; ICES, 2010).

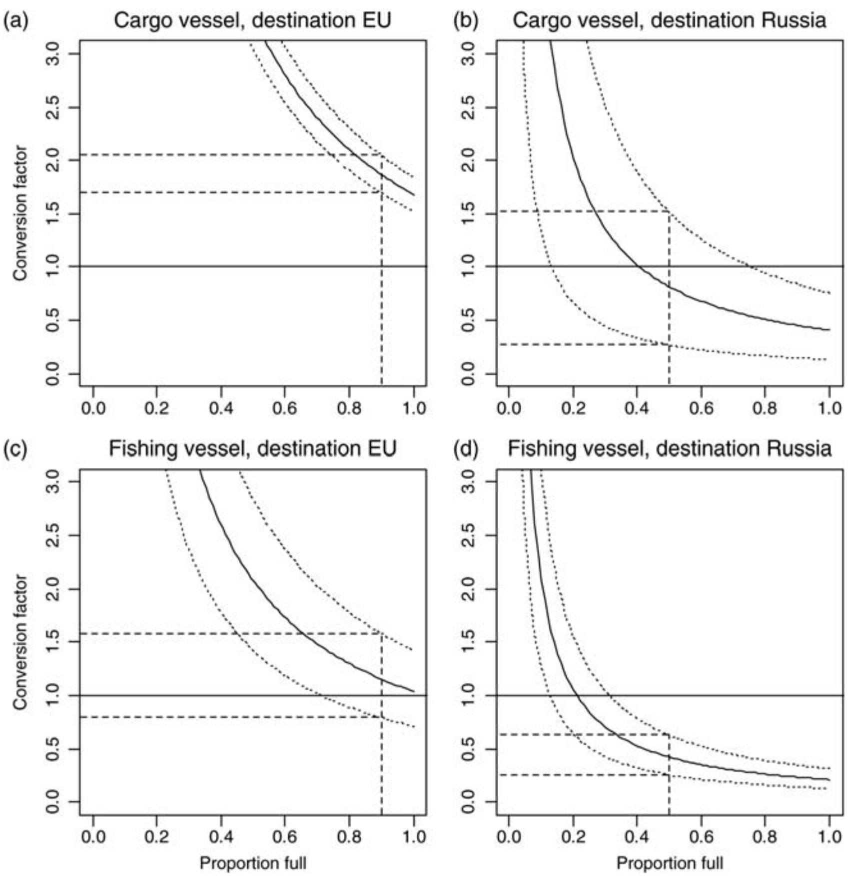

Figure 6. Mean conversion factors between product and round weights as a function of the filling proportions of vessels, based on the estimated combined quantities of cod and haddock in 2005 (solid line). Dotted lines show the corresponding 95% confidence intervals. Examples are shown for filling proportions 0.9 and 0.5 for trips with destinations EU and Russia, respectively.

other fish products than headless and gutted fish. Fishing vessels with destination Russia are usually assumed to be less full than cargo vessels with destination EU. If their filling percentage is set to 50% (again a typical assumption by the authorities), the estimated conversion factor is significantly <1.0 (Figure 6d).

Discussion

Adding the estimated quantity of fish transported out of the NEZ to that reported as landed in Norway indicates the total quantity of fish caught. Using the landings reported in Norway by the Norwegian Directorate of Fisheries (Anon., 2006a), i.e. 72 000 t of cod and 26 600 t of haddock, the estimated catches were 366 924 t of cod and 111 637 t of haddock. The 2005 quotas for Russia were 213 700 t for cod and 51 300 t for haddock, so the estimates exceed the quotas by 153 224 and 60 337 t for cod and haddock, respectively.

The choice of estimator was based on the significance of correlations between the quantities and the storage capacity. Therefore, for both cod and haddock, we used the linear-regression estimator for cargo vessels with destination EU (Figure 3), and otherwise the simple mean estimator. Note again that the original method (Anon., 2006a) was based on roughly estimated filling percentages and that we assumed that the product was always headless and gutted fish. This method also included data from trips with incomplete documentation, i.e. it is known that the vessels might eventually have carried more fish simply because they were inspected and the documentation gathered some time before the trip ended. In such cases, the filling percentage and the total catch could well have been underestimated. In addition, the fish on board a vessel could well be a mix of different product types, including fillets. With no information available on product type, and the assumption that all fish products were headless and gutted, the method in Anon. (2006a) could theoretically produce estimates of filling percentages exceeding 100%. This is confirmed by the data from cargo vessels with destination EU, because our approach to estimating conversion factors implies values notably >1.5 for plausible ranges of filling proportion (Figure 6). Moreover, a conversion factor <1 is not realistic and implies that the filling proportion is set too high, a major part of the load consists of by-product such as fish heads and livers, or the total amount of fish transported to Russia has been underestimated. This is illustrated for both cargo and fishing vessels with destination Russia, where the fillings must be less than some 50 and 20%, respectively (Figure 6), to produce conversion factors exceeding 1. This explains most of the discrepancies between the lower estimates reported by the Norwegian Directorate of Fisheries (Anon., 2006a) and the higher ones presented here.

Unreported landings will reduce the effect of management measures and will undermine the intended objectives of harvest control rules. It is therefore important that management agencies ensure that all catches are counted against the TAC.

There is some disagreement between the Contracting Parties in the analytical group concerning the interpretation of the mandate and the approach to be used. For instance, there have been no reciprocal inspections of the other Party's data. From the perspective of a stock assessment, this is necessary to improve data reliability. Norway and Russia, as the countries responsible for managing these stocks, need to continue the annual programme of analytical work to secure the necessary quality and accuracy of the catch statistics. Inspections at sea are an important part of this work. VMS data and all at-sea observations must continue to be checked against landings documentation in all countries involved, not merely relying on the NEAFC Port State Control (which inspects just 15% of the annual landings in a port), and/or the cross-checking of erroneous documents. It is suggested that checkpoints be deployed in strategic areas, e.g. in the Svalbard fishery protection zone, and that the mutual exchange of satellite-tracking (VMS) data from each Party's vessels be made possible, whether the vessels are operating within economic zones or international waters.

Supplementary material

Supplementary material is available at the *ICESJMS* online version of the paper as the sources of information used to calculate catch levels of cod and haddock.

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