Catch Estimates Methodology Study

A Report to the

Northwest Atlantic Fisheries Organization

FINAL REPORT

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Contents

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1 Executive Summary for Non-Specialists

1.1 Background

NAFO's objective of achieving long term conservation and sustainable use of fishery resources is critically dependent on reliable information on catches. Catch information is used in scientific analyses to determine how much can be caught sustainably so that NAFO can set sustainable catch limits, and so that catches can be monitored to assure compliance with those limits. Catch information is needed by species and area fished so that catch can be attributed to different stocks (i.e., fish of the same species, but relatively isolated in terms of reproduction). Information is needed for both retained catch that is brought to port (i.e., landed) and catch that is discarded at sea. Some fish are discarded for various reasons, whether not valuable fish (lack of a market) or regulations that restrict landings (e.g. size limits). The fraction of the catch that is discarded varies widely between fisheries and species (from a trivial amount to a large portion of the catch). Generally, in fisheries where discards account for a substantial fraction of the catch, it is important that the amount of discards be reliably estimated because unaccounted for discards can lead to non-sustainable fisheries.

NAFO Contracting Parties (CP) report several categories of catch information from different, but related, sources. These primary types of data reports are:

1. Port Inspection Reports: Data is collected by inspectors at the fishing vessels' landing sites. Inspectors check fishing vessel reports against evidence on the amount and species of fish landed by the vessel.
2. Daily Catch Reports (CATs): Fishing vessels report daily on the amount (weight) of catch by species. These reports are transmitted electronically from vessels at sea.
3. Logbook Tow x Tow (T x T) catch reports: Fishing vessels record in logbooks the amount caught by species for each time fishing gear is deployed and retrieved back onto the fishing vessel with its catch. For the most common type of fishing operations (trawling), each deployment and retrieval is known as a "tow."
4. Observer Reports: Observers, also known as NAFO observers or NAFO compliance observers, are deployed on fishing vessels to observe at sea fishing operations and collect data on catches independent of catch reporting by fishing vessels (items 2 and 3). The observers collect tow by tow data analogous to data reported in vessel logbooks, depending on the number of tows in a given day would challenge the ability of a single observer to collect data from every tow. The assumption is that the tows for which data are collected are representative of all of the tows, such that the total catch by species for the fishing trip can be reliably estimated.

In addition to the reports described, fishing vessels may be subject to at sea inspections. These inspections are limited to 4 hours, and generally observe only one tow. The data from these inspections are not generally used for scientific purposes or as a direct means of monitoring a Contracting Party's compliance with its allowable catch of a species. These inspections do, however, provide for inspection of fishing operations that applies directly to certain activities, such as directed fishing for which there is no quota, fishing in a closed time, bycatch limits including those for moratoria species, directing for moratoria species. Indirectly, inspections support the same goal by validating estimates generated by the vessels.

Since port inspections (item 1) occur on shore after a fishing trip is complete, they do not generate information about fish that are discarded at sea. Port inspections do include review of logbooks, where discards are reported. Port inspections alone could lead to an underestimate of the total catch; however, under the CESAG method discard weight from CAT reports are used in combination with PSC3 data. The other primary data reports are collected at sea onboard fishing vessels, and should therefore include information on catch discarded at sea. Since daily catch reports (item 2) should reflect data on catch from all tows during the day, the sum of all the daily catch reports for a fishing trip should equal the sum of tow by tow catches recorded in the logbook (item 3) during the trip. Additionally, compliance observer data (item 4) should be representative of the trip, and therefore, the estimate of catch from the trip as provided by compliance observer data should also equal the trip catch estimates from reports submitted by the vessel (items 2 and 3). A fundamental reason for deploying observers is to provide an independent confirmation of catch data reported by fishing vessels. In addition, some contracting parties deploy national scientific observers to collect data for scientific purposes, not for compliance monitoring, although these data can used to estimate catch.

Catch data collection and reporting under the auspice of NAFO, as described above, is comprehensive and it potentially fulfils NAFO needs to achieve its objectives. However, concerns about the reliability of the data were expressed in a 2011 independent performance review[1] of NAFO. Since then, additional studies have reinforced the independent review's conclusion. Concern about the reliability of catch data lead the NAFO Scientific Council to use scientific observer data to estimate catches of some species as an alternative to official reports, although this practice was discontinued several years ago. Potential inaccuracies in reporting of tow by tow data have been mentioned as a key problem with catch data[2].

One response to ongoing concerns about catch reporting was NAFO's adoption of a catch estimation method that relies on port inspection reports (item 1 above), instead of vessel reports (items 2 and 3) or compliance observer reports (item 4). However, the method does rely on vessel CAT reports (item 2) for estimates of discarded catch.

1.2 Study methodology

In effort to ensure NAFO is collecting the most reliable catch information and review tow catch level reporting, NAFO released a request for proposals to conduct a "Catch Estimations Methodology Study". MRAG Americas, Inc. (MRAG) was selected to conduct the study focused on assessing the methodologies in place for estimating tow catches and develop guidance on realistic standard best practices from other fisheries with similar characteristics.

The study included the following elements:

1. Information gathering about the catch estimation methodologies of actors operating in the NAFO Regulatory Area. Information gathering included (a) a review of relevant reporting summarizing catch estimation methods by actor and related reports providing appropriate context for catch data maintained by NAFO, (b) a survey of observers, and (c) interviews with members of the Secretariat, Commission, Scientific Council, enforcement personnel,

[1] NAFO Performance Review, August 5, 2011.
[2] NAFO/GC Doc. 13-4 (Rev.), Assessment of the methodology used by NAFO scientific council to estimate catches for NAFO stocks: 2013 progress report.

and observers. Attempts to interview vessel skippers currently operating in the NAFO Regulatory Area (RA) were not successful.
2. An analysis of sources of error and uncertainty (a) based on the information gathered above, and (b) evaluation of the consistency between sources of data.
3. Guidance on best practices for estimating tow by tow catches based on a review of related practices (for estimation of tow by tow catches) used elsewhere in fisheries similar to NAFO fisheries.
4. An assessment of the resource needs for applying the best practices guidance.

1.3 Study results

Elements of Methodologies

The information gathering element of the study revealed considerable variation in the way that catch data are gathered for individual tows. There may be differences in the methods used between tows, and perhaps between vessel crew (for the purpose of tow by tow reporting in logbooks), observers, and scientific observers, for the same tow. Nevertheless, there are some common elements for estimating the catch from a tow across methods, as follows:

1. <u>Initial estimate of total catch</u>:
   a. One approach is to estimate the total catch based on how full the fishing gear is with fish. For bottom trawling, the portion of the net that contains the catch of fish is referred to as the "codend". It is commonly several meters long. Experienced fishing vessel crew, and perhaps scientists and observers, can judge the weight of the catch based on the fraction of the codend that is full of fish. However, these estimates are for all species combined.
   b. Another approach is to estimate the total catch after it is transferred from the fishing gear to the deck of the fishing vessel. Typically, the catch is transferred to a semi-enclosed area of the deck commonly referred to as a "pond". By knowing how much fish the pond holds when it is full, the weight of the catch from a tow can be estimated based on the fullness of the pond.

   It is unclear if these initial estimates of total catch - based on fullness of the fishing gear or the pond - have much influence on estimates of catch by species for a tow. It is also unclear if estimates of total catch based on fullness are ever verified or "calibrated" by actually weighing the catch.

2. <u>Estimating weight by species:</u> When fish are sorted to species, they are put in containers commonly known as boxes, trays or baskets (we use the term 'box' or 'boxes' in this overview). The weight by species is estimated by multiplying the number of boxes by the average weight of fish for a specific species contained in a box.

   In some cases, boxes contain processed fish, such as boxes of fish fillets. In such cases, it is necessary to adjust the weight of a box of processed fish to the weight of whole fish (known as green weight or wet weight) using what's known as a conversion factor (CF). Conversion factors express the weight of the processed product as a fraction of the green weight.

3. <u>Estimating discards:</u> Discard quantities are estimated visually by the vessel crew.

4. Other estimates: observers may check the amount of processed fish by counting the number of full freezers. They may also consult vessel records of catches.

5. Direct measurement of weight: Scales are used to weigh boxes of fish, of both individual fish (green) weight and process products (e.g., fillet). These weights are used (a) to determine the average weight of a box of fish of a particular species, and (b) to calculate conversion factors by species. The accuracy of box weights and conversion factors depends on the accuracy of the scale used.

   There are a variety of types of scales used. A key distinction between scale types is whether or not they compensate for motion on a moving ship. If not, individual measurements of weight are likely to be inaccurate (high or low depending on ship motion), and it will require averaging a large number of measurements to get a reliable estimate of weight. In some situations, this may not be practical. Another issue with all scales is calibration; scales are calibrated by weighing an object of known weight. However routine recalibration of scales is required to maintain accuracy.

Reliability of Catch Estimation Methodologies

In evaluating methodologies for estimating catch weight and considering the basis for best practices, it is important to investigate the reliability of information by cross referencing between the methodologies and the catch estimates they produce. In the absence of detailed experimental analysis specifically designed to investigate error patterns and reproducibility of results from different methods, data comparisons can provide some understanding of the margin of potential sources of error for tow catch estimates. Similar estimates arising from independent sources may provide assurance that the methodologies are reliable. However, where estimates from various sources demonstrate too little variation, this can be concerning as well because it may indicate a lack of independence. This study made a series of comparisons of catch estimated from various sources to investigate the reliability of catch estimation methods, and identified the following results:

1. Trip catch estimates from observers and vessel reports: Comparisons for 42 trips indicate that trip level estimates are very similar. Most comparisons (for species by trip) were within 2%, and more than a quarter of the comparisons by species within trips were identical. Where trip level estimates of species catches are identical to a high level of precision, this raises concern about the degree to which those estimates are independent.

2. Comparison of conversion factors used by various actors: Conversion factors (CFs) used by observers were compared to those reported by vessels on the same trip, results indicated that CFs used by the two actors are consistent. In the majority of cases there was no difference, which seems to confer that observers often obtain the values for CFs they use from the vessel they are observing.

   The study also compared CFs by species and product type across vessels and observer trip reports. The percent difference between the minimum and maximum CFs reported (for a species and product type combination) often exceeded 5%, and there were a few differences of more than 100%, which would translate into either halving or doubling the estimated wet weight catch.

3. Comparison of trip estimates of catch: Comparisons were made between (a) vessel daily catch reports, (b) vessel logbooks, or (c) compliance observer reports with (d) port

inspection reports.   These comparisons were done for Greenland halibut, cod and American plaice catch reports.

Based on comparisons from trips in 2016 and 2017 where all reporting products were available (total number of trips was in the range 27-40 depending on the comparison), catch estimates from daily catch reports were most consistent with port inspection data (a and d, respectively). Discrepancies tended to be ±10% and centred at approximately zero. Variation in trip estimates was higher for NAFO observer reports (compared with port inspections), as inconsistencies in trip-level reporting exceeding ±20% were common for cod and American plaice, although this pattern was not as apparent for Greenland halibut. For vessel logbook tow by tow reporting, there was evidence of a shift towards negative discrepancies (underreporting), although the pattern was not clear.

4. Comparison of independent observer estimates: The study also considered comparisons of tow by tow catch estimates by NAFO observers and scientific observers (deployed by some contracting parties) on the same fishing trips. It was only practical to make a limited number of comparisons, and as such the results are not conclusive but do offer some initial findings. However, apparent discrepancies between these two sources of catch information were at least partially behind concerns raised about catch estimates that emerged years ago, such that comparisons using more recent data may be indicative of improvements. The results of these limited comparisons (where there were both observers and Scientific observers on a common trip) indicated underestimates by NAFO observers relative to estimates based on Scientific observer data, which aligned with previously reported differences.

Species Catch Estimates

As described above, catch by species is estimated from tow by tow data by counting boxes of processed fish and calculating green weight using both average box weights and conversion factors. This approach can provide reliable (i.e., accurate, reasonably precise) estimates, but there are several potential ways that estimates can go awry. Based on the review conducted during this study, the following potential problems with estimates of tow by tow catch by species are concerns:

1. Average weight of a box of fish: Inaccuracies in the weight of a box of fish translate directly in to bias in estimates of tow by tow weight of catch by species.
2. Conversion factors: Similar to inaccuracies in the average box weight applied, inaccurate CFs result in bias estimates.
3. Representativeness of observations: There is only one NAFO Compliance Observer deployed per vessel, therefore they cannot observe all of the fishing activity during a trip. While working, they still may not be able to observe all boxes. Reliable estimation depends on observations being representative.
4. Independence of data: Observers' estimation of catch should provide independent verification of vessel catch reports. However, if observers depend on crew for inputs to their estimates (e.g., box counts) or they are unduly influenced by the vessel crew, their estimates may not be valid verification.
5. Reliable scales: Reliable scales are essential to accurately estimate box weight and conversion factors. Scales that do not compensate for motion or are not routine calibrated raise concerns and contribute to the biases indicated in items 1 and 2.

Best Practices

The need for estimates of tow by tow species catches is not unique to NAFO; fishery management organizations worldwide deploy at sea observers analogous to the NAFO Compliance Observer program to fulfil their needs. This study reviewed procedures employed by the following organizations and fisheries to identify practices that have the applicability to improve the reliability of catch estimates:

1. US Alaska Groundfish Fishery
2. US At-sea Hake Fishery
3. Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Krill Fishery
4. UK North Sea Cod Fishery
5. Norwegian Spring Spawning Herring Fishery
6. UK Marine Management Organisation

Based on the identification of potential problems with catch estimates in NAFO fisheries and review of practices by the identified fishery management organizations and fisheries worldwide, the NAFO should consider establishing best practice guidelines or standards (we note that some of these have already been implemented with the review of the Observer Program in 2018, details are provided in the full report) for the following:

1. Independence of Observers: Some steps have already been taken to improve independence, but they may not be sufficient.
2. Independent communication capability: Providing observers with the ability to communicate independently from vessel communication equipment may enhance their independence, as well as having other benefits (e.g., safety).
3. Common training of Observers: Training is now conducted by individual contracting parties; the amount and content of training varies.
4. Regular and independent checks on box weights and conversion factors: It is unclear how often and how independently (from vessel crew influence) these determinations are made currently. Reliable determinations require scales that are motion compensated and routinely calibrated.
5. Discard estimation: It is unclear what the current practice is for estimating discards, but the lack of estimates for many trips is reason enough to establish best practices for estimating discards in the future. Estimating discards is more difficult than estimating retained catch, but it is a routine function of at sea observers worldwide.
6. Use of visual image technology: Date/time stamped photographs taken of the cod end and holding ponds (anything that is part of a volumetric analysis) are a very useful means of documenting total tow catch. Video technology may also be useful to address the problem of estimating discards.
7. Data verification based on fish species distribution patterns: Depending on when and where fishing occurs, the approximate mix of species caught can be predicted based on past data. Comparison of reported species composition to expected patterns could help to verify the reasonableness of the reports.

This study also identified the potential for application of new technologies to improve or enhance catch data collection. For example, there is now technology to directly measure the weight of the codend of a trawl net rather than depend on estimates of fullness.

In some situations, electronic (i.e., video) monitoring has been applied as an alternative to human observers (or at least to substantially reduce dependence on them). Doing so may require rules on handling and retaining catches that have an impact on fishing practices and procedures on fishing vessels.

The costs of implementing best practices as described above is addressed qualitatively in terms of human resource, technology, procedural and monetary needs. For some practices, the costs are potentially substantial, but they are probably small compared to the costs of current catch estimation programs and the importance of reliable catch estimates.

2 Introduction

2.1 Purpose and need

NAFO receives catch data from its Contracting Parties to monitor compliance with NAFO regulation of catches. If the data are reliable, they are valuable as a basis for analyses leading to the development of scientific advice by Scientific Council to support the decision making of the Commission. When catch data are unreliable, there are various scientific "work arounds" that scientists use to generate best catch estimates for scientific purposes. Such scientific work arounds to generate catch estimates have been used by NAFO, ICCAT, CCSBT, ICES and other organizations at various times past or present. As stated on the NAFO web site: "The NAFO Scientific Advice is generated through a joint effort by NAFO Members and makes use of different data sampling programs carried out by Members states. Additionally, available statistics on the resources and their environment are also used when producing the advice." However, the NAFO Scientific Council has expressed the view that it is not its responsibility to develop its own "best catch figures". Instead, it would prefer to receive accurate official catch data to conduct its work, rather than have to use unofficial estimates. There are clear difficulties arising from the use of unofficial estimates of catch in conducting stock assessments of NAFO stocks, particularly when there are substantial discrepancies between these and the official data[3].

Fishing vessels and Contracting Parties are required by the NAFO Conservation and Enforcement Measures (NCEM) to submit catch data to the Secretariat, where they are collectively referred to as STATLANT 21 catch data. The primary data sources are: the Inspection Reports, Compliance Observer Reports, Daily Catch Reports (CATs), and Logbook Tow x Tow (T x T) catch data. In addition, data from national scientific observers have been used in the past in an ad-hoc catch estimation process.

Discrepancies between catch estimates can result in a range of ways, including measurement or observational error (when the method of measuring the catch is not accurate) and sampling error (when the catch is estimated from a sample of the total catching population – as is often the case with observer data). They can also arise from deliberate misreporting. Errors may be random (resulting in reduced precision in the estimate) or systematic (resulting in biased estimates). Previous studies[4] have identified where the errors may lie within some of these measurements or estimations.

Studies have identified tow by tow catch estimates as a primary issue. A 2011 NAFO Performance Review[5] provided important context for this study, as outlined in the call for tender, identifying concerns over the accuracy and quality of data submitted to NAFO, particularly those used by the Scientific Council in estimating catch. In response to the 2011 Performance Review, actions have been taken by NAFO including the establishment of a focused working group and adoption of a catch estimation strategy; additionally a second performance review was undertaken while this project was being conducted. Subsequently, a peer-review panel concluded that observed catch discrepancies are due to differences in estimates of tow catch from four distinct sources[6] (Figure 1), and that it is important to understand the relationship of these estimates to vessel logs and the accuracy of vessel logs:

[3] NAFO SCR Doc. 13/051 (W. Brodie)

[4] SC-CCAMLR-XXXII, Annex 5. Report of the Working Group on Ecosystem Monitoring and Management. Bremerhaven, Germany, 1 to 10 July 2013.

[5] NAFO Performance Review, August 5, 2011.

[6] NAFO/FC-SC Doc. 14/01

- Vessel skippers complete fishing log books that provide information by tow (NAFO Conservation and Enforcement Measures (NCEM) - Annex II.N) and submit these data to NAFO;
- NAFO observers record catch for each tow in accordance to the NCEM Article 30 item 2(c) and based on the training and instruction from their observer provider, reports are submitted to the state contracting party, which then submits completed reports to NAFO;
- Scientific observers are deployed on some CP's vessels to provide independent fisheries data for research purposes; these data are not provided to NAFO but have been used to derive catch estimates in the past by scientists at the Scientific Council; and
- NAFO at-sea inspectors inspect on-board catch and verify species and volumes against logbook records according to NCEM Article 34 (NCEM Annex IV.B); these reports are submitted to NAFO by the CPs.

In reviewing methodologies employed, each of the tow by tow catch records presents opportunities for error in catch estimation and discrepancy between estimates. Observed catch discrepancies, as pointed out by a Peer review Expert Panel (PREP)[7], are due to differences in estimates of the tow catch found in these different sources. Given the concerns over the tow by tow data sources, the presently approved CDAG Catch Estimation Strategy relies on catch weight recorded by port inspections (PSC3) with the addition of discard weights from daily catch reports (CAT) reported to the Secretariat by the vessel masters. If PSC3 data are not available for a particular trip, the sum of the CAT data for the trip is used, but this is scaled using the PSC3 data from other trips by the same vessel. This reduces the influence of vessel reports on catch estimates by scaling them to match the port inspection reports.

Our report addresses primarily the methodology behind the individual tow catch estimates from the sources described above, undertaking the following specific activities:

1. **Review of Current Relevant Reporting**: Interviews with key contacts at the Secretariat, Commission, Scientific Council, observer program providers, observers, surveillance and enforcement personnel, along with review of related NAFO meeting summaries, reports and working papers provided important background, perspective and context to the study and described the catch data supply chain necessary to isolate potential opportunities for error.
2. **Analysis of sources of error and uncertainty:** Review of compliance observer reports, potential opportunities for error in observer and vessel catch estimation, scientific observer data, administered survey of compliance observer activities, and review of observer program practices and training that direct on-board activities.
3. **Guidance on Best Practices to Estimate Tow Catches:** Review and analysis of the tow catch estimate methodologies used in fisheries with similar characteristics to those in NAFO to provide guidance on best practices to estimate tow catches, the potential for standardizing these practices.
4. **Assessment of resources needs:** Identification of the technical, human and/or methodological resources needed to implement best practices given the characteristics of the fleets, fishery operations and regulatory restrictions.

[7] NAFO/FC-SC Doc. 14-01, Report of the Fisheries Commission and Scientific Council Ad hoc Working Group on Catch Reporting 3-4 February 2014.

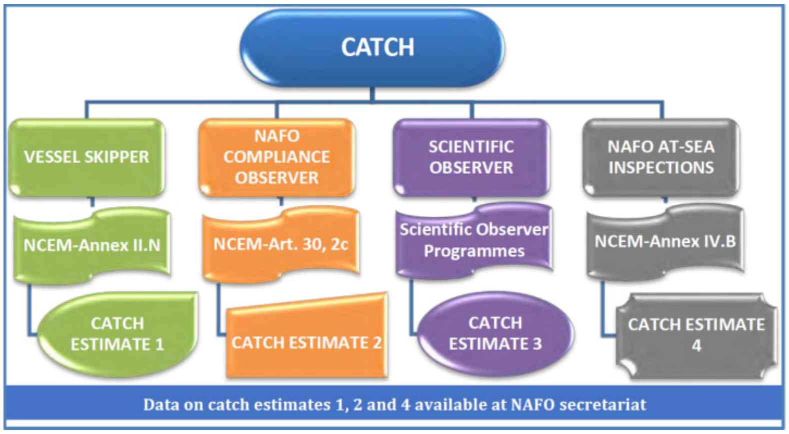

Figure 1. Catch estimate data sources considered in this analysis (source: FC-SC CR-WP 17-01 revised).

2.2 Structure of the report

Section 3 of the report sets out in detail the data gathering activities undertaken in the first part of the project. This includes:

- contacts with the NAFO Secretariat and the various background reports and other NAFO data that were made available;
- contacts with members of the Contracting Parties' delegations to STACTIC and the Scientific Council, including interviews;
- contacts with NAFO observers and the observer providers, including the development of a questionnaire, and investigation of the various observer manuals in use;
- contacts with NAFO inspectors; and
- contacts with vessel captains operating in the NAFO Regulatory Area were attempted but unsuccessful;

Sections 4 to 7 present the four main deliverables of the project:

- Methods in place by actor;
- Identification of margin of potential sources of error for tow catch estimates;
- Guidance on realistic standard best practice to estimate tow catches based on the results of this study and a series of case studies of fisheries with similar characteristics to NAFO fisheries; and
- Assessment on catch estimates resource needs

3 Project Activities

This section documents the activities of the project team to engage the various actors, understand their roles in the catch estimation process and their methods for tow catch estimation.

3.1 NAFO Secretariat

The project team discussed the project with the Secretariat staff at multiple instances both by phone and in person. Inception calls were held on April 6th and April 27th 2018. Project team members visited the NAFO Secretariat at the time of the STACTIC meeting May 7th-8th and the Scientific Council Meeting June 1st-5th 2018.

These interviews were critical to building our collective understanding of data collections and management, previous reports and analyses of catch estimation issues, the roles of the various players, data access for delegates and others, regulatory measures for managing the fishery, and the role and process of science. These conversations also helped us to identify and meet with key members of Contracting Party delegations and other key players, including observer providers and NAFO Inspectors and directed us to valuable reports and helped us understand the issues with catch estimates that have persisted for years.

The Secretariat receives NAFO compliance observer reports submitted by CPs in accordance with Article 30 (which was subsequently amended for 2019) of the NAFO Conservation and Enforcement Measures[8] and these reports were made available to our project team. A new standardized reporting template was adopted in 2013 for use starting in 2014 (Annex II.M of the NAFO Conservation and Enforcement Measures). Among other things, these reports contain tables of tow by tow catch estimates showing amounts retained and discarded by species and product type. They also show the conversion factors used to convert back from processed totals to whole ("green" or "round") weight. The reports in the standardized template are received by the Secretariat in either a spreadsheet format or PDF files (Table 1). In the period 2017-2018 compliance observer reports were required to be submitted to the Secretariat in Excel spreadsheets[9] (the reports format is essentially a series of data tables). In 2018, there was a significant reduction in the proportion of observer reports submitted as PDFs, but still more than one third were PDFs. (Table 1). In the period 2016 to 2018, all but one CP submitted their observer reports as Excel spreadsheets.

Submitting the reports as PDFs is in accordance with Article 30, 13(g): the duty of the observer is to "submit the observer report, in a computer readable form". But for the data to be used in any kind of analysis, including checks for data quality and comparisons with logbooks etc., they have to be extracted from the PDF into a useable format (spreadsheet or database). While it is relatively straightforward to extract the data from a single PDF file into a spreadsheet, due to the structure of the tables, significant additional manual formatting is required to convert them to a useable database format. This is a significant constraint to the utility of these data for routine analysis by the Secretariat and the Scientific Council. Given it seems highly likely that the PDF files are themselves generated from original data files (probably spreadsheets), it should not be a significant burden for them to be submitted as Excel spreadsheets.

To facilitate potential future analysis (and not specifically relating to the methodology of conducting catch estimates), we strongly recommend that NAFO receives complete observer reports and data directly and in a format that enables their routine and efficient use in compliance and scientific analyses, including data quality screening procedures. Furthermore, we recommend that NAFO invest in modern database architecture and require that all data be submitted in an appropriate electronic format.

[8] As amended through September 2018 NAFO/COM Doc. 18-14
[9] Information provided by the NAFO Secretariat

Table 1. Number of observer reports received by the Secretariat by type since the new reporting template was adopted in 2013 for use starting in 2014

Year	Total Observer Reports Received by NAFO	Number of Reports in Excel	Number of reports in PDF	% of Reports in PDF
2014	92	55	37	40.2
2015	99	58	41	41.4
2016	99	48	51	51.5
2017	91	44	47	51.6
2018	88	58	30	34.1

3.2 Contracting Parties

Interviews with members of Contracting Party delegations were conducted on the margins of the regular meetings of STACTIC and the Scientific Council in 2018. Two project team members travelled to NAFO headquarters and made a brief presentation of the project to the STACTIC intersessional meeting in May 2018. On the margins of the meeting, interviews were conducted with over 15 delegates. In early June three project team members travelled to Halifax to conduct interviews with delegates at the annual meeting of the Scientific Council. We made a brief presentation to the plenary meeting and the Council discussed the key issues in NAFO catch estimation procedures. We met with nine current members of the Scientific Council to discuss their thoughts regarding tow level catch estimation and gave opportunities to provide feedback on our approach to the project.

Following discussions with Contracting Party members on the margins of the STACTIC meeting in May 2018, in person and telephone interviews were conducted with five NAFO Inspectors from two CPs.

Several members of the NAFO Scientific Council interviewed during the study made reference to comparisons of official NAFO catch data with catch estimates based on data from national scientific observers deployed by some CPs (González-Costas (2013) [10] and Alpoim (2013) [11]).

The scientific observer data from several years leading up to 2010 were used in the context of work undertaken by members of the Scientific Council to establish the best possible catch data for the purposes of stock assessment. While an essential part of the scientific process at the time, the catch estimation was conducted in the margins of stock assessment meetings without transparent well documented methods. This raised concerns regarding the *ad-hoc* nature of the process and the need for a more formally recognised and routinely implemented catch estimation procedure.

Since 2013 the Scientific Council has used official catch reports as an input to an agreed protocol for estimating catch (CDAG Revised Catch Estimation Strategy[12]). This strategy relies principally on data from port inspections for landings estimates and on daily vessel reports for estimates of discards (there is no discard information in port inspection reports).

[10] NAFO SCR Doc. 13/052
[11] NAFO SCR Doc. 13/053
[12] NAFO COM-SC Doc. 17-08

3.3 NAFO Observers

3.3.1 Observer questionnaire

A questionnaire (see Appendix 2: Observer) was designed and distributed to NAFO observers either via the observer providers, or directly, to collect information directly from them regarding catch estimation on the vessels that they had worked on, how errors could occur and what improvements could be made. The questionnaire was confidential and observers were given the option of answering anonymously. It was available both as a hard copy that could be completed through an interview and via a secure online web site.

The questionnaire was split into five sections:

Section 1: Asked about the observer and was designed to give a brief background of their experience, when they had worked in NAFO, how long they have worked there and any other fisheries they may have worked on.

Section 2: Was more specific to their experience in NAFO looking at the number and type of vessels they had worked on and what species they had been targeting. Again, this was to gauge the observer's level of experience and how this may have affected their answers and the way that they may estimate or record weights.

Section 3: Asked how the vessel handled the fish once on-board the vessel. In order to simplify it, this was limited to the last vessel on which the observer had worked in NAFO and was intended to give a very broad description of whether fish were sorted by species or size, the use of conversion factors and whether discards were recorded. Limiting questioning to the observers most recent experience was important for focusing the questions, but has the potential to introduce bias in the event that the last vessel/experience was atypical.

Section 4: Looked at how catch weights were estimated or measured on the vessel by both the vessel and the observer, if differences existed and if they did exist, the observer's view of why this was the case.

Section 5: Allowed to the observer to give their opinion as to whether estimation techniques within the fishery could be improved, what obstacles exist to making these improvements and any other comments they may have.

The questionnaire used a combination of yes / no answers, multiple choice, ranking and free form text to allow further explanation where necessary. Informal interviews were also conducted with several observers, once the questionnaire had been completed and a summary of these interviews is provided in Section 3.3.2. Although the answers provide some indication of the practices on-board the vessels they are not necessarily representative of NAFO as a whole, providing the opinions of the observers on some of the vessels on which they have worked.

With respect to the handling of fish and catch estimation methodology, observers were asked to comment only on the vessel/trip on which they had most recently observed. They covered experiences from 24 trips, 21 on demersal trawlers targeting finfish, one trawler targeting northern prawns and two longliners targeting cod.

There were 24 responses to the survey, with 10 being completed through direct interviews and the rest through the online portal. Although this is a relatively small sample compared to the number of observer reports received annually, (89 received in 2017), it was from a selection of mostly experienced observers who had worked at different times and in different fisheries. The experience of the observers varied between about 2 months up to 28 years with an average time of around 10 years. Most of the responders had over 5 years' experience.

Most of the observers had a high degree of fisheries experience, with all but two having also worked outside of NAFO, including other RFMOs such as IOTC, ICCAT, SIOFA and NEAFC. Most had also worked with a wide variety of different types of fishing gear in addition to the trawls and longlines used in NAFO, including purse seines, pots and pole and lines.

This survey sought information to describe observer methodologies and experiences, but was not expected to provide a statistically representative sample. By definition the responses were based on the period during which they were employed as a NAFO observer. Seven observers were active in the early stages of the program in the 1990s; most respondents (17) were active observers between 2000 and 2009; a further nine were active between 2010 and 2014. Attempts were made to contact current observers, including through the provider companies, but responses were received from only five observers who were recently or currently active in NAFO (2015 to present). Over this recent period, the number of observers deployed annually has ranged between 53 and 65. As of the end of July, 19 observers have been deployed in 2019. Data on the number of individual observers deployed is not readily available for years prior to 2015. For deployments prior to 2004, observer reports only exist in archived paper versions. While the responses of observers from the early stages may not reflect current practice, they provide an opportunity to explore how methods have changed over time. Four of the observers had also worked in NAFO in other roles, two as national scientific observers, one as an engineer on fishing vessels, one as an European Fisheries Control Agency (EFCA) Coordinator for NAFO and one as a NAFO inspector.

Observers were asked to comment on their experience on different types of vessels in NAFO fisheries. The full group of responders had completed 138 trips, of which 130 (94%) were on demersal trawlers. Seven trips were on longliners (or a combination of gillnets and longlines). Most vessels targeted Greenland halibut (GHL) or redfish (RED) but cod (COD), Atlantic halibut (HAL), skate (SKA) yellowtail flounder (YEL) and prawns (PRA) were also targeted.

3.3.2 Observer interviews

Although the questionnaire asked observers to report only on their most recent deployment, some of them were reluctant to provide specific details on their experience with the practices of vessel owners, fishing captains and crew. They were, however, more willing to discuss some of their experiences in a more informal and less structured interview. We conducted informal interviews with eight of the observers who had previously completed the questionnaire. The information provided was by definition anecdotal, and should be treated as such. Nevertheless, it was helpful in the context of understanding some of the challenges associated with catch estimation on board vessels in NAFO.

3.3.3 Observer providers

STACTIC and Scientific Council members provided information on how the observer programs are run in their various countries and facilitated contacts with several third party observer providers. In addition to providing background information on how the observers are recruited, trained, employed and deployed onto vessels, these contacts also enabled us to contact the observers themselves.

For additional comparison of compliance observer training and operations, we reviewed the observer training manuals used by various observer providers. We obtained training and methodological instruction for NAFO observers from six countries. The goal was to explore the range of instructions for catch estimation under which observers operate and whether these reflect best practice. The summary of comparisons is provided in Appendix 1. Observer Manual Comparison.

3.4 Vessel Masters

We aimed to conduct interviews with vessel masters to understand their views on catch estimation and reporting in NAFO fisheries. Efforts were made to contact masters from a range of NAFO Contracting Parties, vessel types and target species. Vessel captains are a difficult group to reach. They are often at-sea, complicating the scheduling of any contact. We worked with STACTIC members and observer provider contacts to identify willing vessel captains for interview. Despite considerable effort to reach this group, we were largely unsuccessful. We did have opportunity to contact two vessel captains from one CP that had previously operated in the NRA, but did not receive reply on our requests to communicate with any other captains. A fully documented description of the methodologies in place by vessel masters could not be completed.

4 Methodologies in Place by Actor

In this section we provide a description of the methodologies in place by all actors involved in the process of obtaining tow catch estimates (Figure 1).

4.1 NAFO Observers

In this section we describe the methods used by NAFO observers based on information provided in response to the observer questionnaire, interviews with observers, interviews with observer providers and a review of observer manuals from several countries. The catch estimation methods used by observers fall into two main categories: estimation and measurement, although in practice there is often a combination of both. Catch weight is estimated through some means of volumetric estimation or counting of standard pre-weighed units (baskets, trays, boxes etc.). Catch weight is measured directly on board using some type of scale.

The way in which the fish are handled on-board, both before and after processing, has an effect on how accurately catch weights can be estimated overall and particularly by species. In responding to the questionnaire, all observers stated that the retained catch was separated by species, enabling tow catch weights to be estimated by species in real time. In all but one case the target species were also graded by size; all secondary species were generally frozen without grading. Prawns were automatically size graded while on-board and in this case there was very little bycatch; mostly just juvenile fish.

4.1.1 Estimation of catch weights

The estimation methods used by observers are listed below. Generally a combination of methods is used, involving an initial estimation of the whole catch when the net is first hauled, followed by more refined estimations by species once the catch is on board. Figure 2 shows the frequency of occurrence of these methods according to the observer questionnaire results. Figure 3 provides a ranking of these methods by the observers in terms of accuracy with 1 being this highest and 4 being lowest. The counting of boxes was the highest ranked by some margin.

1. Net:

Observers estimate the total weight of the catch (all species) based on the fullness of the net or cod end. This may be done by counting the number of 'rings' (bindings around the net spaced at a certain distance apart) in the part of the cod end that is full of fish. There are also several formulae available for calculating the volume of the net filled with fish and the weight of fish in it. The formulae used depend on the shape of the cross section of the net, although in most cases it is circular or oval (Box 1).

Box 1. Formulae for calculating the weight of fish in a net.

- Rectangle cross section = L x W x H x ρ
- Circular cross section = πr2 x L ρ
- Oval cross section = π x (short r) x (long r) x L x ρ
- Wedge cross section = ½ x (L x W x H) x ρ

  Where:
  W = Width (constant)
  r = radius (constant)
  π = pi (constant)
  L = Length of net with fish (haul specific)
  H = Height of fish in net (haul specific)
  ρ = volume-to-mass factor (kg/m^3) (variable)

Once the volume of the net has been calculated it is converted to a weight using a volume to mass conversion factor for the species or species mix being caught (kg/m^3). Ideally this is checked on a regular basis by taking a known volume from the cod end (e.g. 20 m^3), allowing it to drain and then weighting it. This enables calculation of an accurate value for the green weight caught per m^3. However, in practice this is normally just estimated based on the previous experience of the crew. Pre-calculated values have been given by the FAO for some species (Table 2). These are not species caught in NAFO but provide an example of typical values. Observer manuals used in NAFO also provide instructions for calculating density on board.

Observers reported that estimating the overall catch from the net fullness was not used as the primary method of catch estimation due to its relative inaccuracy; instead it was used to obtain an initial estimate that was then refined by using other methods once the catch was on board.

Table 2. Density and stowage rate of some selected fish species (Source adapted from FAO[13])

Fresh Fish	Density (lb/ft^3)	Density (kg/m^3)	Stowage Rate (ft^3/ton)
Whole fresh herring in bulk	58.2	932.4	38·5
Whole fresh mackerel in bulk	50.0	851	45
Whole fresh sprats in bulk	53.2	958.7	42
Whole fresh capelin in bulk	62.5	1188.8	36

2. Pond:

Similar to the fullness of the cod end, the total catch can be estimated with more accuracy once it is on board from the volume of the fish pond. By knowing the weight of fish that can be held in the

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[13] Waterman J. J. Measures, Stowage Rates and Yields of Fishery Products. Torry Advisory Note No. 17 from http://www.fao.org/3/x5898e/x5898e01.htm#Densities%20and%20stowage%20rates

pond when full, observers derive a catch estimate from the proportion of the pond that is full after each haul. Alternatively, they can calculate the volume of fish in the pond and apply a volume-to-mass factor to calculate the weight. The formula for deriving this is given in Box 2. As with the fullness of the cod end, this method of catch estimation is not normally used by itself and errors can occur where new hauls are emptied into the pond before the previous haul has been emptied, however, it may be used to refine the initial estimate taken from the net. The same comments regarding the verification of the volume to mass conversion factor apply here (see above).

Box 2. Formula for calculating the weight of fish in the pond

- Pond volume = L x W x H x ρ
  Where:
  L = Pond length (constant)
  W = Pond width (constant)
  H = Height of fish in pond (haul specific)
  ρ = volume-to-mass factor (kg/m^3) (variable)

3. Boxes:

The most common method of estimating the total catch is counting the numbers of boxes, trays or baskets of catch (for convenience we will refer to all these variations as boxes) and multiplying the total by an average weight per box, accounting for the weight of the box. An example formula is given in Box 3. This is done after the catch has been processed and put into freezers and sorted into species on board. The average weight per box is normally provided to the observer by the crew / officers on the vessel based on weighing of a sample of boxes. Different vessels use different sized boxes. Standard box weights when full are 12kg, 14kg or 20kg. The captain tells the observer what the standard weight is, and it is generally assumed to be correct. Observers reported that the average weight was checked, although not always. The frequency of checking varied between daily to once at the beginning of a trip. The vessel and/or the observer used scales of varying types to check the average weight (see Section 4.1.2 for information regarding the use of scales on board). When it was the latter, the observer was not present when the sample boxes are measured. No specific information was available on the accuracy of the standard box weights for different species and the variation across different vessels. Weights of the boxes should be checked on a regular basis to account for possible variations throughout the season and in different areas, ideally though weighing a selection and calculating the average weight and standard deviation.

Box 3. Formula for calculating the weight of fish from boxes.

- Box numbers = $(M-M_{tray})*N$
  Where:
  M_{tray} = Mass of the tray (constant)
  M = Mass of fish and tray combined (variable)
  N = Number of trays (haul specific)

The boxes contain processed fish (e.g. headed, gutted and tailed, or fillets) ready for freezing. A conversion factor is applied by species and product type to convert the total weight of product from the tow (calculated using the formula in Box 3, or similar) to an estimate of the green (unprocessed) catch weight. Like the standard weight, the conversion factor is also usually provided by the captain. Conversion factors may be changed from time to time, but generally they are standard for a vessel and potentially across multiple vessels (see Section 4.1.3 for detailed information on conversion factors). This description is typical of the procedure followed by NAFO observers and is used by all observers where catch is estimated, either as the only method, or in combination with other methods to cross-check their estimation (e.g. net and pond).

4. Other:

Another method used by observers was counting the number of filled freezers and/or freezer compartments, which have a known capacity of processed fish. Counting the number of filled freezers can be used as a means of verifying the estimates of net fullness. Some observers also checked their estimates with the vessel recorded catch figures. However, to ensure complete independence of observer figures, observer catch figures should be estimated separately to that of the vessel.

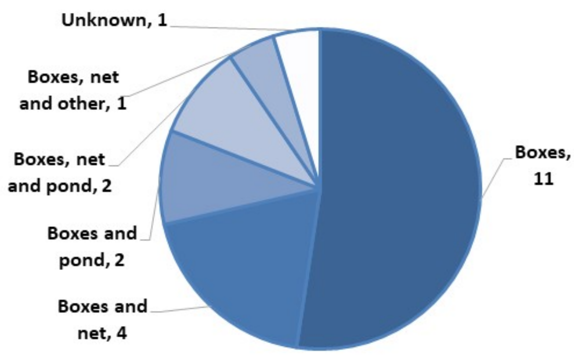

Figure 2. Techniques used by observers to estimate catch (frequency of occurrence in the questionnaire results).

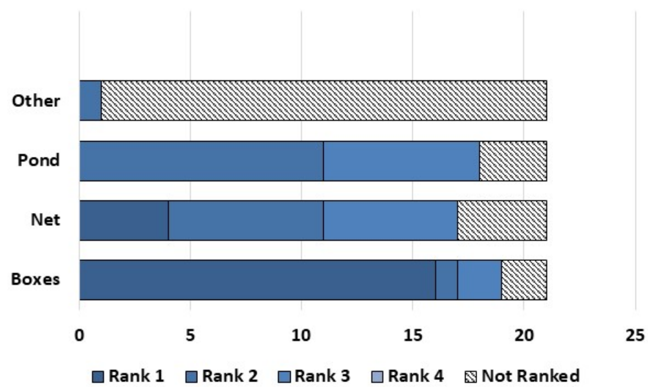

Figure 3. Accuracy of catch estimation techniques ranked by observers in the questionnaire.

4.1.2 Direct measurement of catch weights

Some observers have been able to weigh the catch directly using various types of scales on the vessels, although two out of the five observers most recent deployed reported they had never been on a vessel where scales were available. Where scales were available they were normally used in conjunction with verifying average box weights for catch estimation rather than weighing the whole catch. The types of scales used on a vessel will be largely dependent on the volume of the catch, the catch value and the requirements of the management system in place. For the purpose of the questionnaire they were divided into four categories:

1) **Electronic motion compensated (MC) –** The most expensive but most accurate of the used at sea scales; these compensate for the movement of the vessel. In common with all scales the precision depends on the required maximum capacity and the budget available.
2) **Electronic non-motion compensated (Non-MC) –** These scales can weigh to high precision but do not compensate for the roll of the vessel. They are better in calm weather but can be used to calculate average box weight if conditions are suitable.
3) **Mechanical –** Cheaper than electronic scales also not as precise they have the advantage of being more reliable than electronic scales and less likely to break down. A mechanical balance also has an element of motion compensation built into its design because it is comparing two weights. They cost under $1,000.

The frequency of occurrence of these scale types in the observer questionnaire results are shown in Figure 4. On most vessels the compliance observer had access to electronic non-MC scales.

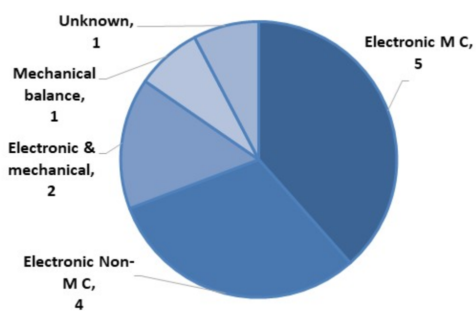

Figure 4. Type of scale available on-board for observers.

4.1.3 Product conversion factors

Both observers and vessels use species/product conversion factors (CFs) to estimate catch weights on board (e.g. see Section 4.1.1). The CFs in use have a significant effect on catch estimation and should be checked on a regular basis. Variations in CFs can arise due to a number of factors, ranging from the area and time of year to the individual and/or machines processing the fish or product.

CFs used by observers come from various sources, including:

- **Vessel:** The CFs were calculated by a member of the vessel crew (usually fishing master or captain).
- **Contracting Party:** The CFs were provided to the vessel by its CP, or through NAFO.
- **On-board Analysis:** The CFs were calculated by the observer and provided to the vessel.
- **Unknown:** The observer did not know where the CFs in use had come from.
- **Not used:** No CF was used (the product was frozen whole).

The questionnaire results are shown in Figure 5. In practice there is some overlap between these categories. For example, in most cases the observer recorded that the CFs were provided by the vessel, but in some of those cases they were likely provided to the vessel by their CP. In only two cases the observers stated that an analysis had been undertaken on board to calculate the CFs. In one of these cases the observer outlined the protocol used: 100 individual fish of different sizes were collected and weighed together; the fish were then processed and weighed again. The CF was calculated as the live weight / processed weight.

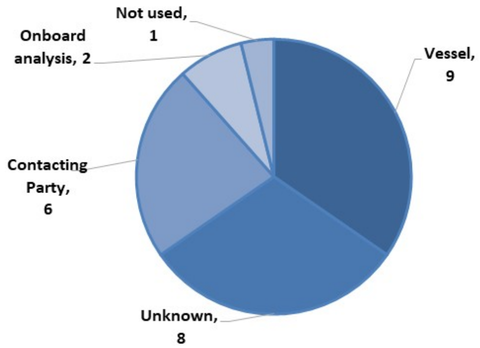

Figure 5. Source of conversion factors.

Regarding updating of conversion factors, three observers reported that the conversion factors did not change from trip to trip; four stated that they were changed from trip to trip and that different conversion factors were calculated depending on species, weight and the final product. Another observer stated that all the conversion factors used by the vessel were provided in a manual.

4.2 Vessels

Attempts to contact vessel masters operating in the NAFO Regulatory Area were unsuccessful. We therefore had no direct information on catch methodologies used by the vessels. According to the observers who responded to the questionnaire, tow catches by species were estimated on board the vessels using the same methods reported by the observers (Section 4.1.1), but we do not know the degree to which this represents common practice. Observers also commented on the recording of discards with the results shown in Figure 6. Some observers were unsure of whether the vessel recoded discards for the whole trip, although it can be assumed that if they were recorded on a haul be haul basis then they were also recorded for the trip. The results showed that where vessels did record discards, they did so on a tow by tow basis. Discard weights were either estimated visually by the vessel crew from the factory or, in some cases, through observing the discard belt for a period of time, estimating the weight discarded over that period and extrapolating it to the entire haul.

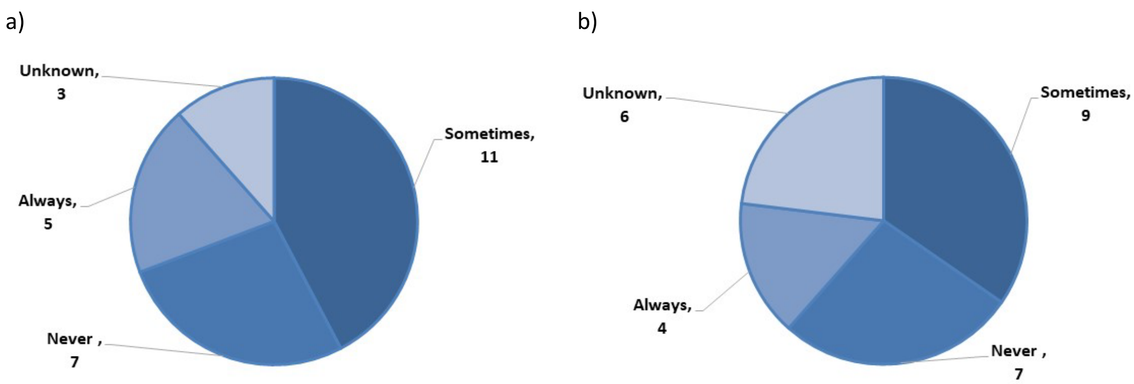

Figure 6. How vessels recorded discards on a tow by tow basis (a) and over the entire trip (b).

4.3 National Scientific Observers

Several CPs deploy scientific observers onto vessels operating in NAFO waters on a routine basis. In some cases a single observer carries out the functions of both a NAFO observer and a scientific observer, but the majority of deployments were separate from the NAFO observers (although on the same vessels). The main objective of scientific observers is to collect scientific information, including biological samples and representative length frequency of the catch. The background of the scientific observers is variable. Some have a degree in biology, or marine sciences and before they go on-board they attend a training course covering all the tasks they are required to perform, including catch estimation, biological sampling and how to take biological samples (otoliths, gonads, etc.). Some scientific observers are crew members who have gone through this training, but they do not necessarily have a university level scientific background.

In order to raise length frequency samples up to the total catch, scientific observers must collect catch and effort data from sampled hauls. The scientific observers are instructed to collect these data independently, but they still must rely on the cooperation of the captain and the crew. Scientists involved in the deployment of scientific observers in NAFO have noted that they are enabled to undertake their studies through a collaborative arrangement with the vessels, with the understanding that their data are collected for scientific studies and not for compliance purposes.

As with the observers, scientific observers must collect information on the amount of processed fish before it is transferred to the freezer hold. The weight of processed fish is converted back to live weight by using the appropriate conversion factor for the product type (fillet, headless fish, gutted fish, etc.) and species. The primary source of data on the amount of processed fish is the notes recorded by the crew in the factory. However, if there appear to be deviations between these data and the real catch (by species and/or total weight), the scientific observers are instructed to make corrections based on a visual estimation of the catch volume, i.e. observation of freezer tunnels, number of trays with frozen fillets etc. This description was provided by the scientists overseeing the scientific observer work and is essentially similar to the methods used by the observers. While they work independently of each other, key parameters, such as the average box weights and conversion factors would come from the same sources. Scientific observers also estimate the weight of discarded fish by counting the number of boxes of discards, multiplied by the mean weight of boxes.

4.4 NAFO At-Sea Inspectors

During at-sea inspections, inspectors have about 4 hours to complete their tasks under the NAFO CEM (or the time required for the net to be hauled in and both the net and the catch to be inspected, whichever is the longer). If issues are identified during the inspection then additional time can be taken[14]. Generally one tow and catch is monitored on board the vessel, including gear inspection, catch estimate, species, and length of fish. Inspectors look at the record of tow catches and identify any discrepancies particularly regarding species composition and compare with other vessels in the area. During interviews, inspectors mentioned that it is challenging to obtain a proper analysis of catch on board during an at-sea inspection, particularly if the vessel is almost full (making a count of boxes/cartons practically impossible).

4.4.1 Estimates of tow catch based on net fullness

In estimating catch from the net, inspectors generally apply two methods, which can be used in conjunction with each other, or separately. Firstly, using their knowledge and experience an inspector, they estimate the total catch based on a visual inspection of the net as it is recovered, relying on working experience and knowledge of trawling, species densities, familiarization of the specific vessel, and in-depth working knowledge of bottom trawls. According to inspectors, these estimates can be very accurate. Secondly, they apply a volumetric formula to the shape and fullness of the net. A range of shape-based formulae are shown in Figure 7. Of those shown, the cylinder and

[14] NAFO CEM Article 34 (g)

ellipsoidal are the most commonly used by inspectors, because they most closely represent the shape of a trawl with different species.

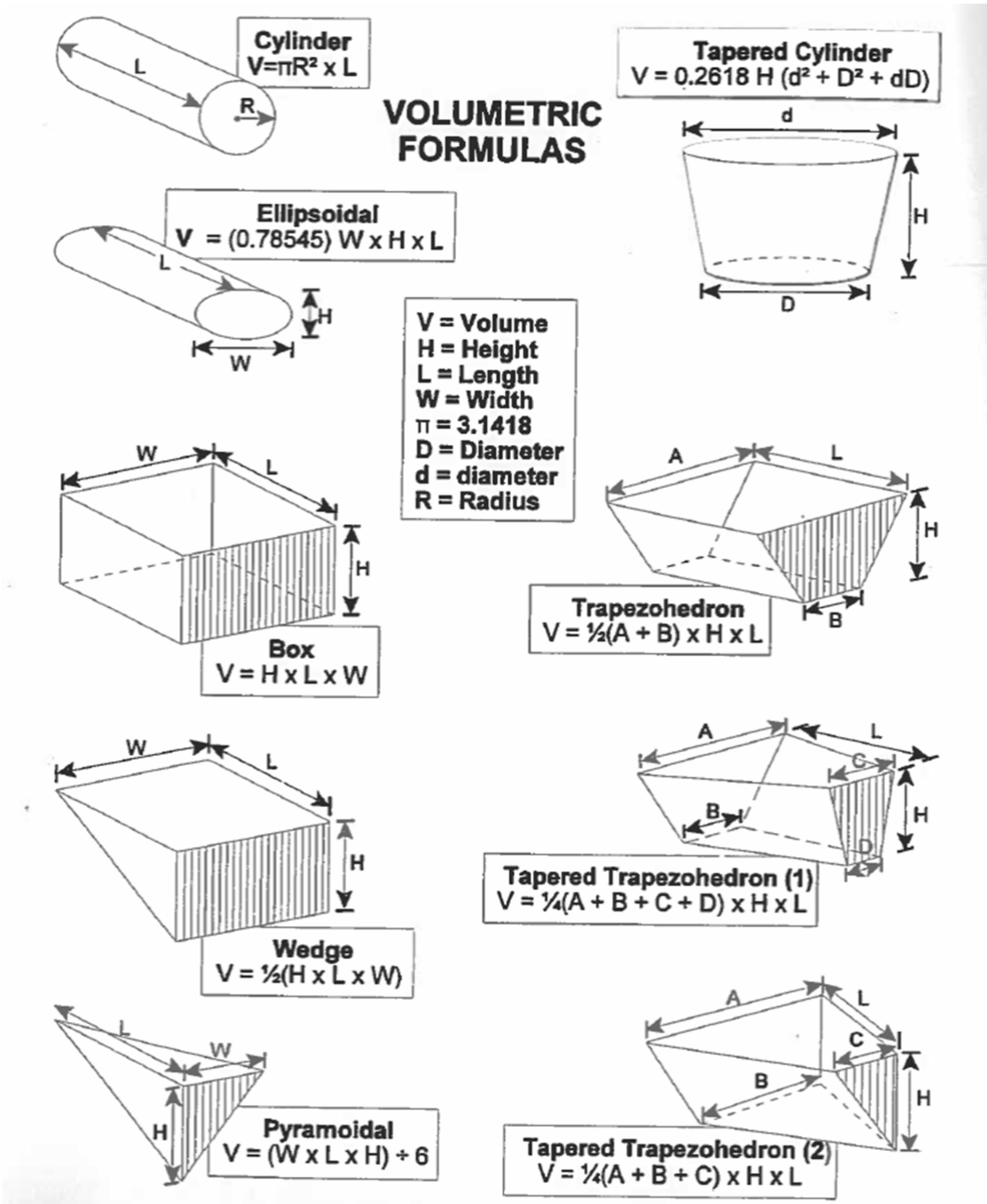

Figure 7. Volumetric formulae applied by NAFO Inspectors in estimating the size of the total catch by tow during at-sea inspections.

4.4.2 Estimates of catch onboard

Inspectors use three methods for estimating catch onboard a vessel at the time of an inspection:

i. Count of the total number of cartons in the fish hold and multiply by the nominal stamped box weight. Inspectors weigh random cartons in the hold to verify the stamped weight and open them to confirm the species. This method is only used where there is a smaller quantity of product in a fish hold.
ii. Measure the empty space in the fish hold. This method is used when there is a large amount of product occupying a fish hold. Each vessel fishing in NAFO must carry on board an accurate and up to date capacity plan that has been certified by a competent authority or recognized by its flag state within the preceding two years[15]. Among other things, the capacity plan specifies the shape, dimensions and capacity of each fish storage space in cubic meters. Each vessel must also maintain a stowage plan[16] that shows the location and quantity, expressed as product weight in kg, of each species within each fish hold. The inspector measures the volume of empty space that is not occupied by fish product, which is subtracted from the overall volume of the fish hold. The resulting product volume is multiplied by a density value (weight/volume) to determine the estimated weight of product in the hold.
iii. Measure the volume of product in the fish hold. This is usually done only when the "cube" of product can be measured easily. The inspector measures the length, width and height of the cube of product to determine its volume (m^3). Once that volume is measured, the inspector follows the same procedure as in (ii), multiplying by the density value.

The volumetric assessment is more common, requiring the application of and average conversion factors where there are multiple species and product types. The inspector may not have access the whole storage area to assess conformance with the stowage plan. Aerial surveillance has also been used to estimate total tow catches based on the shape and fullness of the cod end assessed from photographs.

[15] NAFO CEM Article 25 (9,10,11)
[16] NAFO CEM Article 28 (5)

4.5 Matrix of limitations and opportunities for errors from each methodology and actor

In this section we present a summary matrix by methodology and actor showing commonalities, differences, limitations and opportunities for errors resulting from our desktop review. Further analysis and guidance on best practices is provided in Section 5 and Section 6 respectively.

	(NAFO Compliance) Observer	Vessel	Scientific Observer	At-Sea Inspector
Estimation of tow catch weight and catch on board				
Net: Estimation of catch from the fullness of the cod end	Accessible to the observer with little or no involvement of the crew; photographic evidence easily taken; no species breakdown and imprecise; estimation by eye depends on observer experience; formulae for volume can be applied.	Part of the vessel routine; skippers and crew have significant experience in estimating catches from eyeballing the cod end; likely don't use volumetric formulae.	Same as for compliance observer.	Accessible to the Inspector both on board and remotely (including from aerial surveillance); photographic evidence easily taken; no species breakdown and accuracy depends on inspector's experience; formulae for volume can be applied
Pond: volumetric measure met of a (preferably) demarcated holding pond on deck	If available, provides a more accurate version of the net estimation; no species breakdown, but can be used for separating and estimating discards before they are discarded.	Part of the vessel routine; skippers and crew have significant experience in estimating catches from the fullness of holding ponds.	Same as for compliance observer.	If available provides a more accurate version of the net estimation; may not be much better than cod end estimation for experienced inspectors.
Boxes: counting of boxes of sorted and processed fish; multiply by average weight and conversion factor	Relies on cooperation of the crew to make an accurate count of the boxes by species; relies on accurate average weights and conversion factors; if all is correct then estimation of catch is good.	Part of the vessel routine; relies on accurate average weights and conversion factors; results can be biased either inadvertently or deliberately.	Similar to compliance observer; only needed on sampled tows.	Less available to the Inspector. Takes time for the catch to be processed and may not be completed while the inspection is going on (four hour limit in CEM). Inspector only has a single snapshot (tow).
Logbook and hold Inspection for catch on-board	Not applicable	Part of the vessel routine	Not applicable	Part of inspection process; Inspector can use capacity plan and stowage plan to estimate catch on board, but may not have access the whole storage area to assess conformance with the

	(NAFO Compliance) Observer	Vessel	Scientific Observer	At-Sea Inspector
				plan. Challenging to obtain a proper analysis of catch on board during an at-sea inspection, particularly if the vessel is almost full.
Tools for Direct Measurement				
Mechanical scale	Generally accessible to the observer; depends on design, but mechanical balance is useful for measuring small quantities and is motion compensated; useful for checking conversion factors.	Depends on design, but mechanical balance is useful for measuring small quantities and is motion compensated; useful for checking conversion factors.	Same as for compliance observer.	Not applicable
Electronic platform scales	Useful for weighing boxes, but without motion compensation accuracy and precision is significantly impacted by the movement of the vessel.	Useful for weighing boxes, but without motion compensation accuracy and precision is significantly impacted by the movement of the vessel.	Same as for compliance observer.	Provides an opportunity for Inspectors to check individual and average box weights in use; but significantly impacted by movement of the vessel.
Electronic platform scales (motion compensated)	Best way to weigh boxes at sea; good for checking average weights and conversion factors. May not be readily available to the observer unsupervised.	Best way to weigh boxes at sea; good for checking average weights and conversion factors.	May have more independence than the compliance observer	Provides an opportunity for Inspectors to check individual and average box weights.
Flow scales	Observer can verify calibration of the scale; provides accurate measure of entire catch passing along the conveyor; could help with verification of catch estimates	Not widely used in NAFO; Accurately measures entire catch on the conveyor; may not be separated into species;	Same as for compliance observer.	Inspector could participate in verification of calibration.

5 Margin of potential sources of error for tow catch estimates

In this section we explore a range of potential sources of error in tow catch estimates. We begin with a comparison of catch reports from observers and vessels to see what margins of difference are evident in the data. We also asked observers through the questionnaire what factors they considered had most impact on the accuracy of their catch estimates. This is followed by an analysis of differences in reported conversion factors and a comparison of trip level catch reports, again with a view to exploring the potential margin of errors. Finally, we discuss the outputs from the scientific observers deployed by some CPs and how these can be compared to those of the observers.

5.1 Comparison of observer and vessel tow catch estimates

In Part 3 of the observers' reports to NAFO (Compliance Information) the observers provide a summary of discrepancies in trip level total catch between the captain's logbook entries and observer´s catch estimates (total catch estimate for the trip and/or percentage difference). To explore the possible magnitude of these differences we extracted these data from 42 observer reports spanning 2014 to 2017. These data are summarized in Figure 8. These scatterplots show that the observers' total catch by species/trip are routinely very similar to the captains' figures. 26% of the observers' species totals in this sample were identical to the captains' figures. The majority of these instances were for relatively small catches (less than 10 tonnes/trip), but there were some trips with substantial catches where there was zero difference between the two. For example there were six trips where the catch of Greenland halibut catches were the same, with catch totals ranging from 14 tonnes to 175 tonnes. Of the 74% not identical, 70% were within ±0.5% and 52% were within ±2%. These differences are within generally accepted margins of tolerance for catch estimates recorded in fishing logbooks when compared to actual amounts of fish retained on-board as verified, for example, through port inspection. The full range of percentage differences for a single species across these trips was -10.04% (a 6.4 tonne catch of redfish) to +20.0% (a 115 tonne catch of skate); a positive percentage means the observer's total was higher.

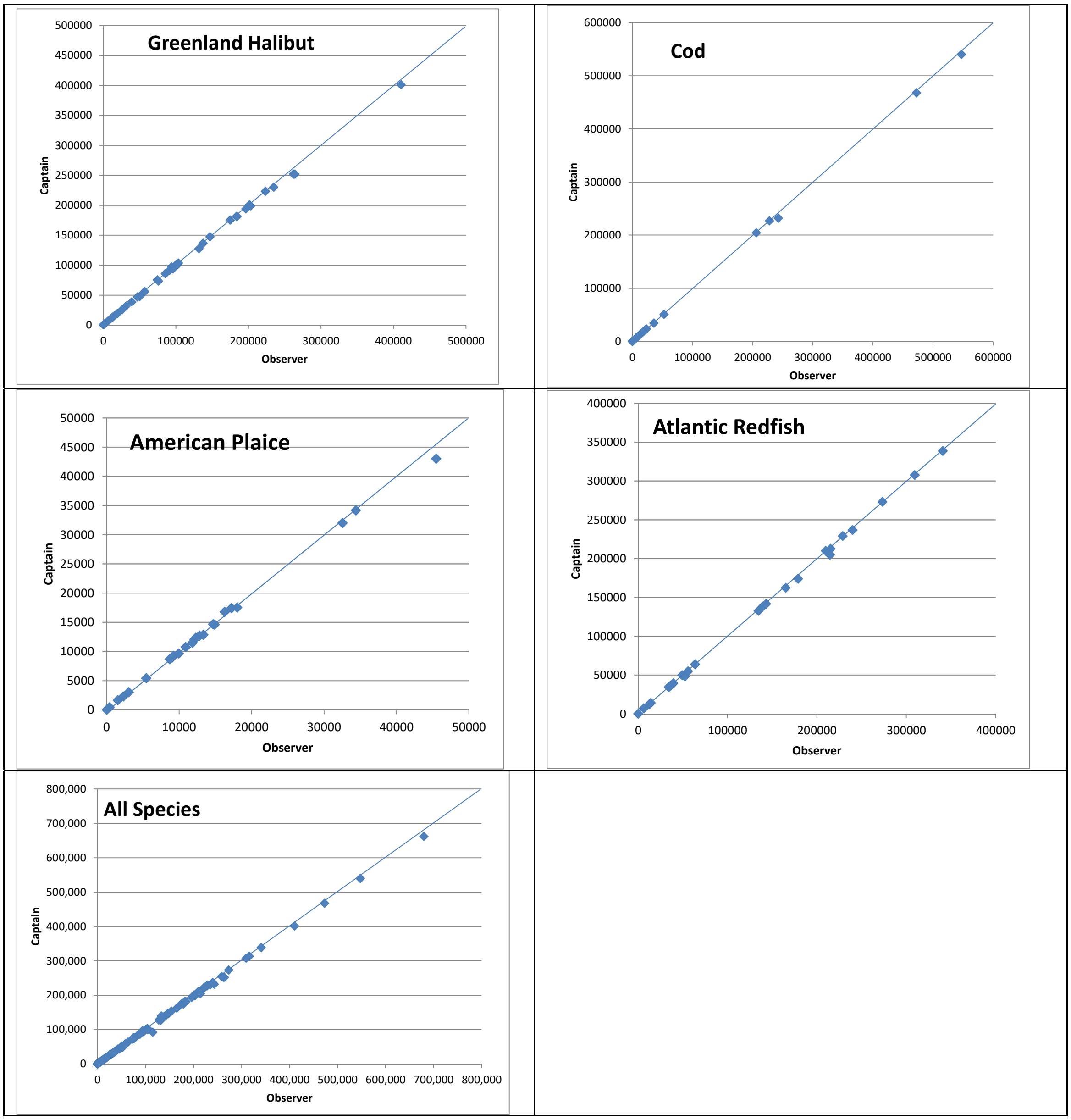

Figure 8. Scatterplot comparisons of NAFO Compliance Observer catch totals (kg) by trip with Captain's totals for 42 trips spanning 2014-2017.

In addition to analysing the data from the observer reports, we asked observers in the questionnaire whether their catch estimates were different to the vessels and approximately what proportion this difference was. The results are plotted in Figure 9. In most cases observers estimated that the overall difference was less than 10% and in one case that there was no difference at all. Five observers estimated that the difference was 10-20%.

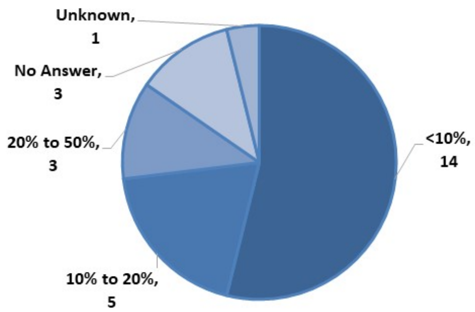

Figure 9. Estimated difference in total catch at the end of each trip as estimated by the observer.

In the observer questionnaire, observers were ask to rank a number a factors that could influence the accuracy and/or precision of their catch estimations and catch measurements (using the methods described in Section 4.1); 1 being most likely to have an effect and 4 being least likely. Leaving the choice blank indicated it would have no affect at all. The choices were:

- **Weather** – Estimation is generally more difficult in rough weather due to the movement of the vessel / net / fish in pond and it is likely that processing and sorting the fish will be slower resulting in a mix of hauls in the fishpond. Unless the scales are motion compensated it is unlikely that they can be used effectively in rough weather.
- **Volume of the catch** – The volume of the catch can affect estimation in different ways. Where estimations are made using a standard average box weight, the actual box weight is likely to be different (more or less). Assuming the average weight is well estimated and the differences are normally distributed, the greater the number of boxes the more likely it will be that those differences will cancel each other out and the total catch weight will be well estimated. If the catch is smaller, filling only a few crates then errors in estimation may be greater, particularly if the estimated weight includes partially full crates. Conversely, where fish pond fullness is used, estimations may become inaccurate when the volume of catches is high or when one haul is added to the pond before the other has been fully processed. Increased pressure in the crew to process the catch in time may lead to unevenness in the packing of the crates or irregularities in the processing of the fish.
- **Crew** – The experience of the crew can affect how the fish are graded, processed and packed, leading to box weights that vary from the standard average in a non-normal way (they may be lighter or heavier on average). With regards to vessel reporting, different crew members may estimate the fullness of the net or hold differently and there may also be a problem with consistent identification of species leading to unintentional misreporting.
- **Other** – Other factors included scales not functioning properly, could not measure larger weights, or were not located in a position where the observer could use them.

The results are shown in Figure 10 and Figure 11. In the case of catch estimation, the category most often ranked highest was nothing, i.e. nothing had a direct effect on catch estimation. Some observers ranked other categories the highest and more than half the observers responded that weather or the crew had some effect. The volume of the catch may have some impact on an observer's ability to estimate the catch accurately, although the specific reasons were not given in the responses received.

In the case of catch measurement using scales on board, the results were clearer, with weather being regarded as having the greatest impact. The majority of observers considered that weather had an effect on the accuracy of the weighing equipment used and most thought that this was the most influential. Of the three that did not rank it, two were from vessels with motion compensated scales on board and one could not recall. The "crew" influence on catch measurement related to the crew's experience, ability to use the weighing equipment and record the measurements. Less than half considered that this was an important factor, although one observer responded that this had the strongest influence. Other factors included the condition of the scales themselves, which did not always work or were difficult to reach in the factory. Observers with access to electronic motion compensated models were less likely to cite anything as having an impact.

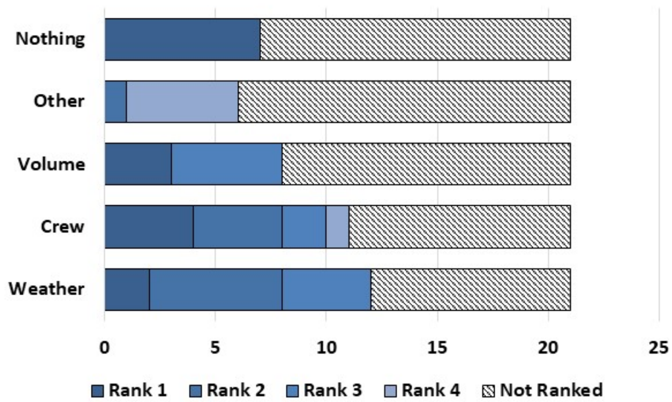

Figure 10. Factors affecting the accuracy of catch estimation as ranked by the observers.

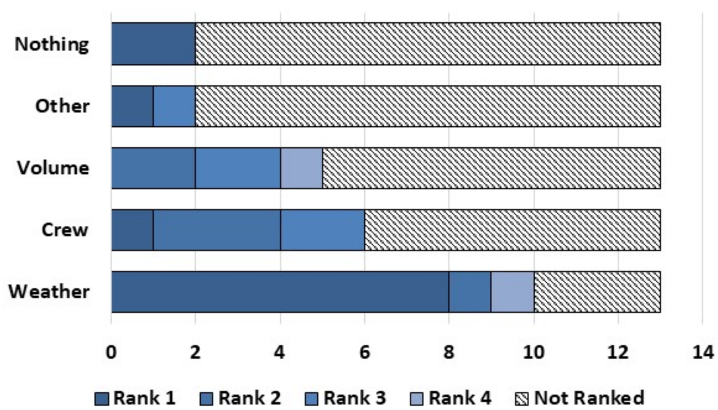

Figure 11. Factors affecting the accuracy of scales used for measuring catch weights ranked by observers.

5.2 Consistency in conversion factors

As mentioned in Section 4.1.3, CFs are an important part of catch estimation and a potential source of error if they do not reflect the true differences between processed and whole weights. We examined consistency in the use of CFs in three ways:

- First, we compared CFs between vessels using data reported during port inspections in 2017. Data for this analysis (n=64 port inspections) were provided by NAFO Secretariat staff. For each combination of stock and product type, the range of values used (i.e., minimum and maximum values) were converted to a percent difference as $(\max value - \min value)/$

$\min value \times 100$. Thus, by calculating variation in CF usage on the same relative scale, product types with large discrepancies could be identified.

- Second, we compared CFs reported in NAFO compliance observer reports. CFs were extracted from observer reports consisting of n=25 trips between 2014 and 2017. Like the first analysis, for each combination of stock and product type, the range of values used (i.e., minimum and maximum values) were converted to a percent difference as $(\max value - \min value)/ \min value \times 100$. Observers also routinely compared the CFs they used in catch estimation with those used by the captain. From the observer reports examined during this study, the differences for the four main target species (Greenland halibut, cod, American plaice and Atlantic redfish) were less than 5% and in the majority of cases there was no difference (reflecting the practice described in Section 4.1.3 of the observer obtaining the CF from the skipper).

- Third, it was desirable to compare the use of CFs at the trip level between reporting provided by the vessel and reporting provided by NAFO observers. Data available to conduct such an analysis was sparser because during the study it was pointed out that no unique identifier was available to match these reporting types. However, using information from vessel logbook entries and NAFO observer´s estimates, a comparison was made (n=8 trips). The sparsity of these data prevented meaningful analysis for each stock-CF combination, but instead results summarize percent difference pooled across all stocks/products. In this case, percent difference between NAFO observers and vessel logbooks is calculated $(NAFO\ observer - logBook)\ /logBook \times 100$.

Comparison between vessels revealed, in many instances, differences in use of CFs that exceeded 5% (Table 3). The magnitudes of these differences, if they do not reflect reliable calculations of CFs, have considerable potential to bias total catch estimates. Conversion factors that exceeded 5% difference were typically those associated with gutted products (GHT, GUH, GUT), with discrepancies occurring for these product types across a variety of species. In the comparison of CFs reported by observers, similar patterns were found in that variation in CFs was highest for gutted products (Table 4). The third comparison, of available matched vessel and NAFO observer data, showed consistent use of CFs within trips by both parties, as 69% of species-CF combinations were identical between reporting products. Other non-zero differences were small with a range of -5.7% to 6.8% (Figure 12). It was subsequently noted that in their trip reports, observers routinely list the CFs they used in catch estimation compared to those used by the captain. Seven observer reports were examined; the differences in CFs for the four main target species (Greenland halibut, cod, American plaice and Atlantic redfish) were less than 5%, and in the majority of cases there was no difference (reflecting the common practice described in Section 5.1.3 and Figure 5 of the observer obtaining the CF from the vessel, or both observer and vessel receiving the CFs from the vessel's CP).

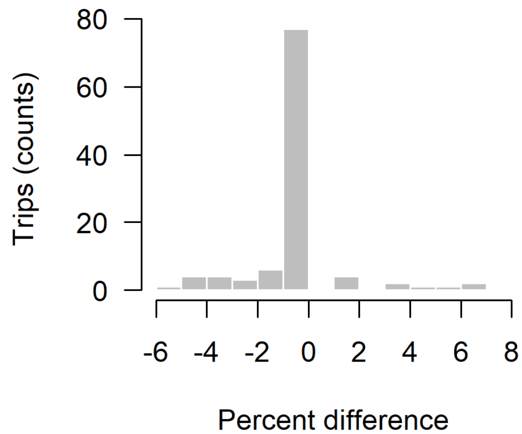

Figure 12. Percent difference in use of conversion factors between vessel reporting and NAFO observers (n=8 trips).

Table 3. Between vessel comparison of the use of product conversion factors. Entries are percent difference between minimum and maximum reported conversion factors for each combination of species and product type. Rows are species (3-alpha codes) and columns are product type (3-alpha codes). Blue highlighted entries are those >5% difference between minimum and maximum values reported. Some between-vessel differences in CFs may result from market preferences for specific cuts of fish; no information on this was available.

	FIL	FIS	FSB	FSP	GHT	GHT+SKI	GUG	GUH	GUH/GHT	GUH/OTH	GUL	GUS	GUT
ALC		0											
ALF													
ANG					31.6			0			0	1.3	31.1
BSF													
CAB								0					
CAT		0		0	0			3.1					
COD	0		0					21.4		0			
DGX												0	
GDE								0					
GHL					4.3							0.7	
GPE								0					
HAD		0			88.4			16.4					
HAL		0			19.2		0	7.7	0				14.3
HKR					0								
HKS					19.3			0					
HKW		0		0	78.1			100					
HPR													
MZZ													
OIL							0						
ORY													0
PLA		0			24.2	0		0.7					
RED								4.4					
RHG					35.4	0						60	0
RNG					38.1	0						30	0
SKA													
SQI													
WIT					16.7							100	3.8
YEL					13.3	16.7		0				1.5	

Table 4. Continued

	HEA	JAP	JAP/WHL	JAT	OTH	OTH-SKIN	TAL	TAS	TLD	WHL	WHL/GHT	WNG	WNG+SKI
ALC													
ALF		17.6								0			
ANG					0		0	0					
BSF				0									
CAB													
CAT					0								
COD					23.2					0			
DGX													
GDE													
GHL		0		0	0					50			
GPE													
HAD					5.8					0			
HAL	0				11.9					0	0		
HKR													
HKS										0			
HKW													
HPR										0			
MZZ					0								
OIL													
ORY													
PLA				16.7	10.3					0			
RED		25	0							0			
RHG		0			30								
RNG					0	0							
SKA					194.1				0			48.1	33.3
SQI										0			
WIT				8.3	0					0			
YEL				8.3	0					0			

Table 4. Between observer comparison of the use of product conversion factors. Entries are percent difference between minimum and maximum reported conversion factors for each combination of species and product type. Rows are species (3-alpha codes) and columns are product type (3-alpha codes). Blue highlighted entries are those >5% difference between minimum and maximum values reported.

	FIL	FIS	FSB	GHT	GHT-SKI	GUH	GUS	GUT	JAP	JAT	OTH	OTH3P	TAL	TAS	WHL	WNG
ANG				0			33.3						0	0		
BYS						0										
CAT		0		60		56.2										
COD	0		0	17.2		0					35.4	0				
CUX								0								
DGX				0	0											
GHL				6.5											0	
HAD	0	0		0		0.7					15.4	0				
HAL				48.2		27.3		42.2			0				0	
HKR						0										
HKS				19.3		0									0	
HKW				28.5		21.4										
PLA				25			0									
RED				0		11.2	NA		12.5	0					0	
RHG				34.8		0	66.7									
RNG					0		4.2									
SHX						0										
SKA															0	91.4
SQI															0	
WIT				16.7			0	3.8							0	
YEL				16.7			16.7									

5.3 Comparison of trip level catch reports received by NAFO

To explore potential magnitude of errors in catch estimates, we compared catch data from daily catch reports, port inspections (PSC3), NAFO observers, and tow by tow logbooks summed over entire trips for 2016 and 2017. Reported trip-level catches were obtained from FC-SC CDAG 17-01 (Rev. 2) and from COM-SC CESAG-WP 18-04 Supplementary Information. While both information sources contained comparisons of reporting products, those comparisons were made through summation of catches across trips, comparing reporting consistency of aggregated catch. Here, we make comparisons between reporting products for each trip (trip level). Given that CDAG catch estimation considers port inspection (PSC3) to be the most accurate (COM-SR CR/CDAG, April, May, August 2017), percent differences between reporting products are presented relative to PSC3. Percent difference is calculated as $(reporting\ product - PSC3)/PSC3\ \times 100$. Comparisons are made for 3LMNO Greenland halibut (GHL), 3M cod (COD), 3LNO American plaice (PLA) using trips where all four reporting products were available.

Similar patterns in reporting behaviour were found across all three stocks (Figure 13, Figure 14, and Figure 15). Most consistent were daily catch reports, as discrepancies between daily catch reports and port inspections tended to be ±10% and centered at approximately zero. Variation in discrepancies was higher for NAFO observer reports, as inconsistency in trip-level reporting exceeding ±20% was common for COD and PLA, although this pattern was not observed for GHL. For tow by tow reporting, there is evidence of a shift towards negative discrepancies (underreporting), although the pattern may not be indicative of all trips. Since daily catch reports and tow by tow reporting are obtained from vessel records, it is peculiar that daily catch reports maintained greater consistency with port inspections than did tow by tow records. This pattern can be seen by comparing (A) versus (E) or (B) versus (F) in Figure 13, Figure 14, and Figure 15. Collectively, these results appear to highlight the need to improve the reliability of observer and logbook data collection. While the summaries reported here are provided for the entire trawl fleet, trends were also examined according to flag state.

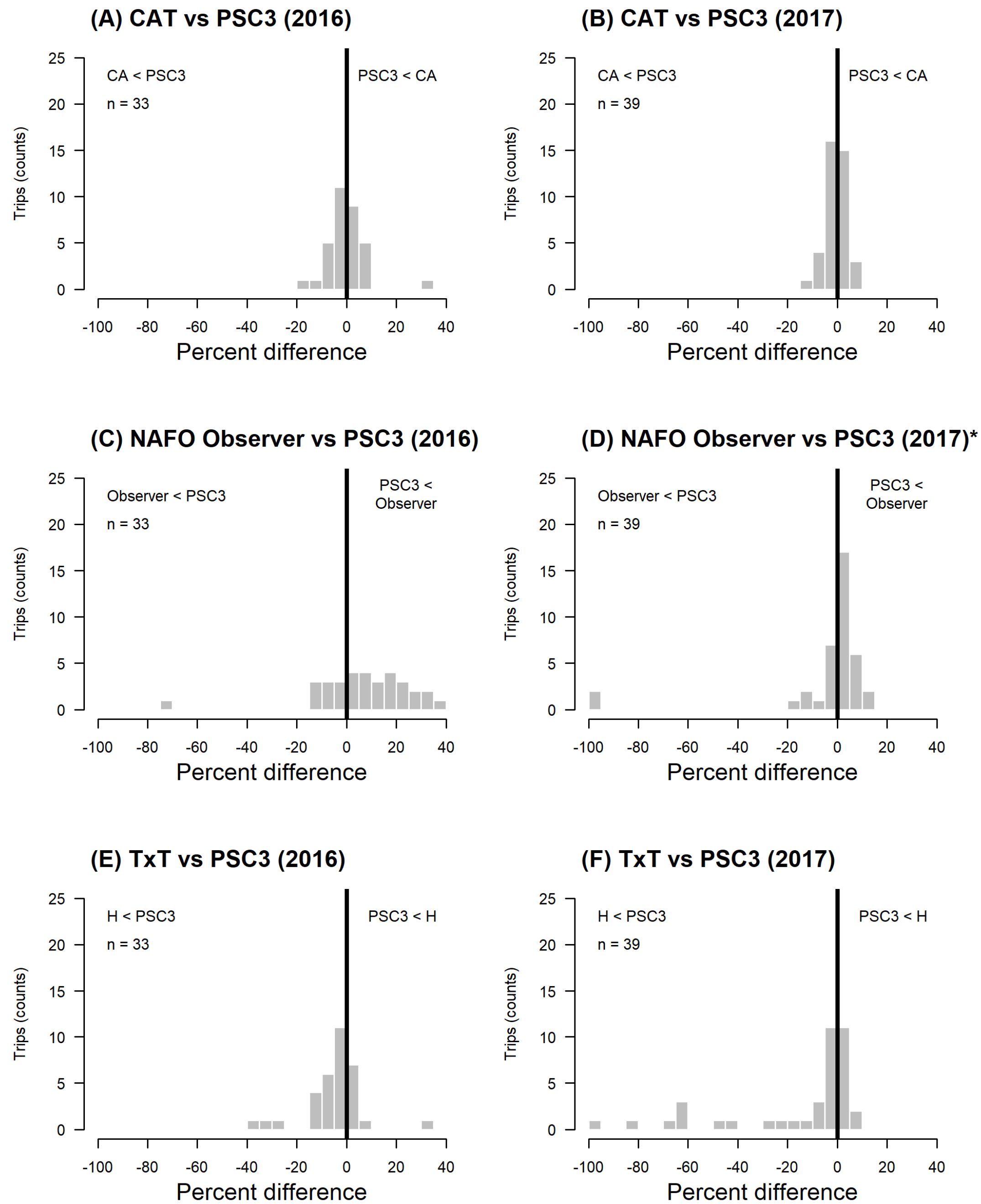

Figure 13. Discrepancies among reporting types for 3LMNO Greenland halibut from trips reported 2016 and 2017. Percent difference is calculated as $(reporting\ product - PSC3)/PSC3\ \times 100$, always using port inspections (PSC3) as the reference catch. Observations are trips where all four reporting products were reported (n); CAT is daily catch reports; NAFO observer refers to NAFO compliance observer program; TxT is tow by tow logbook data; all data was reporting in kg live weight.

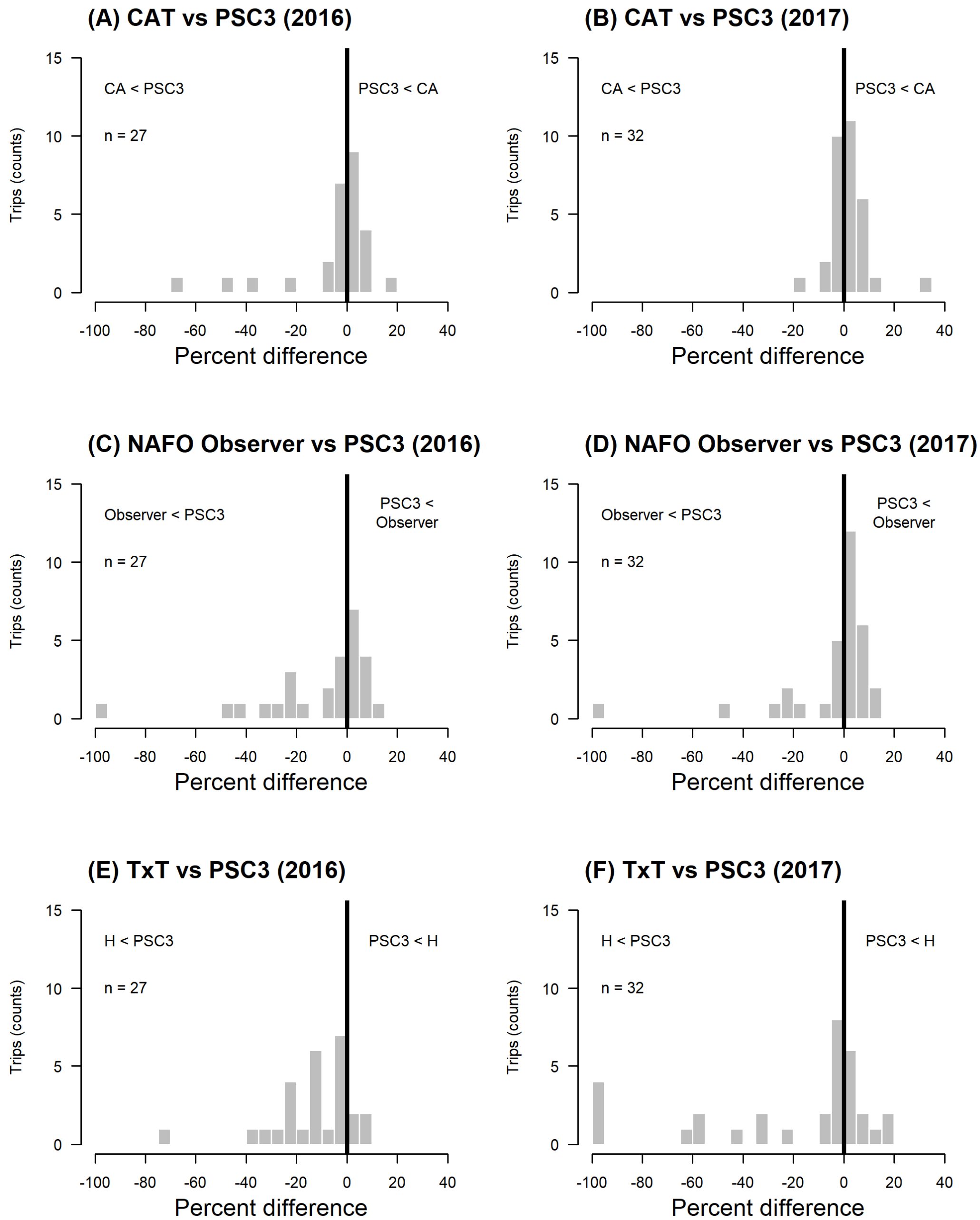

Figure 14. Discrepancies among reporting types for 3M cod from trips reported 2016 and 2017. Percent difference is calculated as $(reporting\ product - PSC3)/PSC3\ \times 100$, always using port inspections (PSC3) as the reference catch. Observations are trips where all four reporting products were reported (n); CAT is daily catch reports; NAFO observer refers to NAFO compliance observer program; TxT is tow by tow logbook data; all data was reporting in kg live weight.

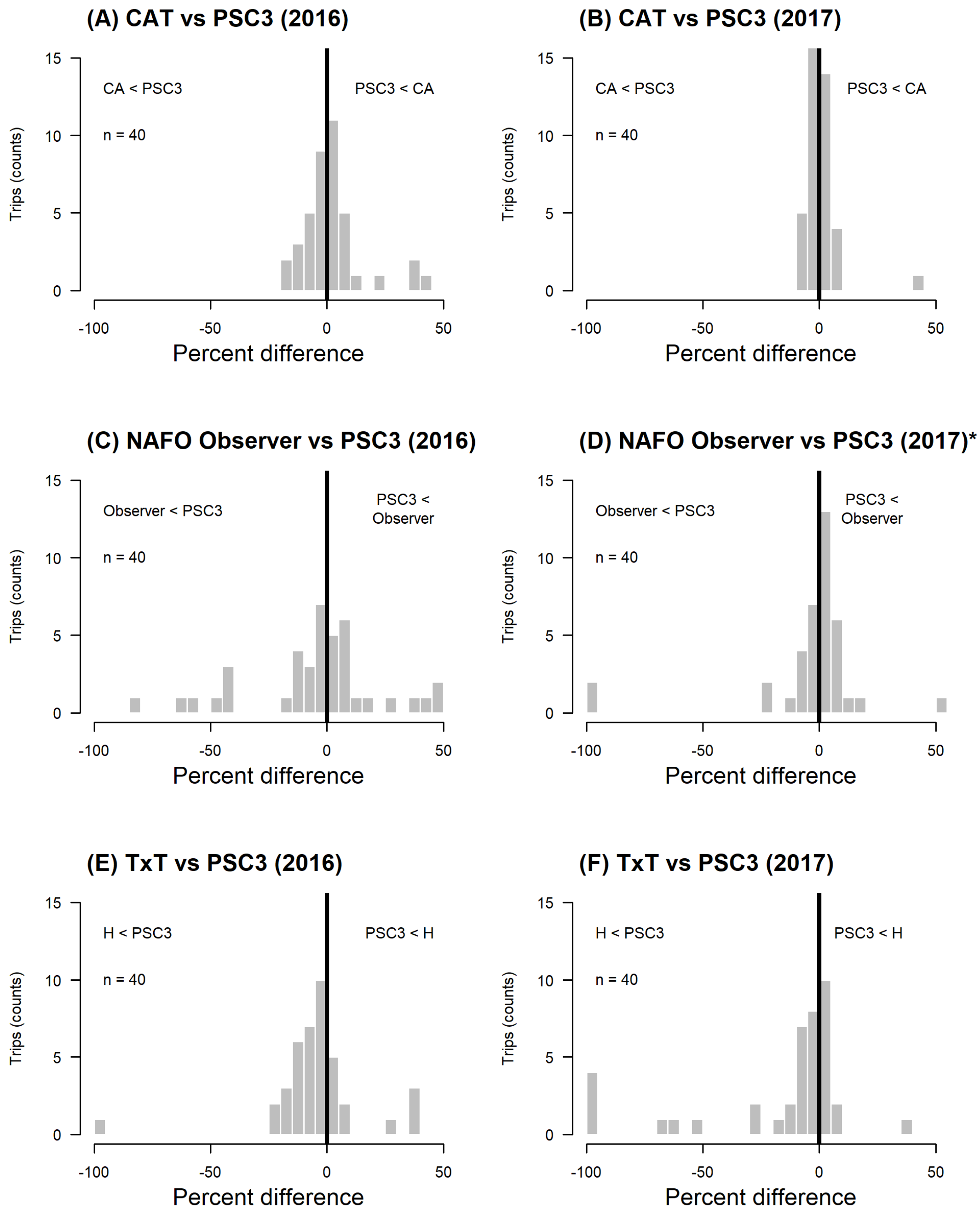

Figure 15. Discrepancies among reporting types for 3LNO American plaice from trips reported 2016 and 2017. Percent difference is calculated as $(reporting\ product - PSC3)/PSC3 \times 100$, always using port inspections (PSC3) as the reference catch. Observations are trips where all four reporting products were reported (n); CAT is daily catch reports; NAFO observer refers to NAFO compliance observer program; TxT is tow by tow logbook data; all data was reporting in kg live weight.

5.4 Scientific Observer data

The primary purpose of deploying scientific observers in NAFO is the collection of scientific information on the catch, including length frequencies and other biological data, rather than catch estimation for stock assessment or other purposes. Nevertheless, these observers must still make accurate tow catch estimates on sampled tows to obtain distributions that are representative of the catch. They may not have an accurate total catch for the trip because they may not sample all tows (and such data cannot be used for compliance purposes, or example monitoring quota uptake). Hence the approach adopted by González-Costas (2013) and Alpoim (2013) for comparing overall catch estimates by calculating CPUE rather than catch totals directly.

Where scientific observers and NAFO observers are collecting data on the same trip, it becomes possible to compare catch estimates from individual tows where those tows exist in both data sets. Given the two observers are using essentially the same methods for estimating tow catches (Section 4), but operating independently, any significant differences between the two would suggest a need to investigate the possible reasons for those differences to understand the margin of potential sources of error for tow catch estimates.

Matching the tows between the scientific and compliance observer datasets is a non-trivial exercise. There is no unique identifier that matches these data at the tow level, thus making tow by tow comparisons more difficult. We note that the compliance observer data are also not automatically aligned at the tow level with the tow by tow logbook data. Best practice would be that all data collected on trips in NAFO waters have unique identifiers by CP, vessel, trip, and tow as part of a modern database architecture. This would greatly assist routine auditing of the data for quality assurance and quality control. Consultation with other Regional Fisheries Bodies regarding their fisheries database structures would likely be a useful part of this process.

To investigate the potential for comparing the scientific and compliance observer catch estimates at the tow level, the project team obtained a sample of scientific observer data from NAFO trips between 2014 and 2017. The equivalent compliance observer reports were provided by the NAFO Secretariat. Due to the time needed to prepare the NAFO compliance observer data for analysis (essentially extracting data from PDF files; see Section 3.1) it was not possible to compare all of the available scientific observer data with all of the equivalent compliance observer data. Nevertheless, it was possible to explore the feasibility of matching the data at the tow level, and undertake a preliminary investigation of the observed magnitude of differences in tow catch estimates.

The matching of individual tows within trips was complex and required close scrutiny of the data. An initial comparison to match the trips based on dates and other information was followed by a more precise pairing on the basis of the locations of the hauls and other tow level information. Tow level data from nine trips undertaken by scientific observers were matched to tow level data from observers. Given the relatively small number of trips being compared, the matching was done visually in spreadsheets rather than using a database algorithm. As discussed above, a unique identifier for trips and tows common to all datasets on NAFO trips would greatly simplify this process and enable more data to be compared more quickly.

Seventy-nine percent of the tows from the trips analysed in this study were matched between the two datasets; for the majority of trips, the match was 85% or higher, showing that even without unique identifiers it is possible to undertake this type of analysis. One way to verify the matching of tows was through the alignment of shifts in tow species composition when a vessel switches from one target species to another. For example it was possible to see clusters of hauls targeting a key species like Greenland halibut; If the tows are well matched, these clusters must align between the two sets of data. Similar alignments occurred with other species.

The tow catch estimation methods used by the two kinds of observers are similar, hence if those methods are reliable there should be a high degree of congruence in the estimates. Within the limited dataset we were able to analyse we saw good correspondence in estimates for some species on some trips, meaning it is clearly possible for the observers to arrive at similar results. However, we also saw significant differences in the tow catch estimates in many cases. The biggest differences were observed in the catch estimates for Greenland halibut which were significantly lower in the compliance observer data than in the scientific observer data. This aligns with the results presented previously by González-Costas (2013) and Alpoim (2013). The methodologies used for their comparisons focus not on tow catch estimates, but on the calculation of a stratified mean catch per unit effort (cpue) from the scientific observers' tow by tow catch and effort data which is then raised up to total catch using total effort from either the NAFO compliance observer data (González-Costas, 2013) or the Fisheries Directorate (Alpoim, 2013). González-Costas (2013) describes a bootstrap procedure used to analyse the uncertainty in the catch estimates from the scientific observer data and also presents a comparison of results by year with the NAFO compliance observer data for the same vessels and days when both observers were on-board.

The sample size in our analysis is limited and additional analysis would be needed to reach conclusions about the reliability of the observers' tow catch estimates, but given the history of problems with catch estimation, it does raise some concerns. What our analysis shows clearly is the feasibility of tow-level data comparisons, even in the absence of unique record identifiers. More data are already available on which similar comparisons could be undertaken, and additional scientific observer data exist to which the project team did not have access. Routine analysis and comparison of these data from different sources would represent best practice with respect to data auditing and QA/QC. In the following section we provide guidance on best practices for estimating tow catches, some of which would, among other thigs, contribute towards a better understanding of the possible reasons for differences between estimates made by observers and scientific observers.

6 Guidance on realistic standard best practices to estimate tow catches

The methods used to estimate tow caches in NAFO fisheries are described in Section 4. In essence, they center on the counting of boxes of processed fish and calculation of green weight using average standard box weights and CFs. There is some cross checking with volumetric measurements of total catch, either of the cod end or holding ponds on board, but it is unclear how often any corrections are applied. In principle, if the average standard box weights and CFs are well estimated and representative and the box counts are accurate then this approach should provide reasonably accurate results. However, if the standard box weights and CFs are not well estimated, or the box counts are wrong, then these are potential sources of error that could lead to inaccuracies in recording of green-weight totals.

Section 5 discusses potential sources of error for tow catch estimates and there are some areas of concern for tow level catch estimates. For example, the comparison of CFs between vessels presented in Section 5.2 revealed differences in use of CFs that exceeded 5%. A comparison of trip level catch reports received by NAFO showed that daily catch reports maintained greater consistency with port inspections than tow by tow records. In addition, a provisional comparison of compliance observer and scientific observer catch estimates suggested that there are some significant differences at the tow level. In this section we provide guidance on realistic standard best practices to estimate tow catches that is relevant to NAFO. This is based in part on a series of case studies of similar fisheries with a view to developing common standard protocols that should lead to improvements.

6.1 Case study fisheries for best practices.

Catch weight estimation protocols in fisheries require a clear structure, with well-defined goals and responsibilities. We have reviewed best practices in several case study fisheries to determine which elements could be applicable to fishing operations in the NAFO RA. The case studies and their selection rationale are summarized in Table 5. The detailed case studies are provided in Appendix 3. The Best Practices that stem from these case studies and other sources are discussed in Section 6.2

Table 5. Criteria for selecting case studies.

Case Study Fishery	Summary and Selection Rationale
US Alaska Groundfish Fishery	The Alaska groundfish fishery is a diverse multispecies fishery operating in the Gulf of Alaska (GOA), the Bering Sea/Aleutian Islands (BSAI) and in many bays, sounds and straits that bisect the coastline and constitute the internal waters of Alaska. A component of the fishery (Pacific cod, Alaskan flatfish and pollock) has been certified sustainable against the Marine Stewardship Council's standard. Regulatory requirements to use certified, motion compensated flow scales to measure catches directly were first introduced in 1998 and the requirement has since expanded to other fisheries in the area, including longline caught cod. The scales are checked daily in the presence of independent observers, the checks are logged by the scales themselves and the whole area around where the scales are installed on board is monitored through video surveillance. There is also a robust traceability scheme in place for products from both shore and at sea processors.
US At-sea Hake Fishery	The US at-sea hake fishery operates in the Pacific Ocean off the coasts of Washington and Oregon. Processing vessels target Pacific hake using pelagic trawls. Similar to the BSAI pollock fishery (within the Alaska groundfish fishery), the at-sea hake fishery uses flow scales that are checked on a regular basis by on-board observers to measure catch. Observer tasks and sampling protocols are clearly laid out in the observer manual, which serve as best practice procedures for this type of sampling. Electronic Monitoring (EM) has also been successfully used in this fishery to support the observer's role
CCAMLR Antarctic Fisheries	The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is an international conservation organisation comprised of 24 Member States and the EU[17]. It is the body responsible for the conservation of marine life in the Southern Ocean which includes management of the fisheries; the current active fisheries are trawl for krill, icefish and toothfish and longline, also for toothfish. CCAMLR operates an observer program administered by the Secretariat and implemented by the Member States through bilateral agreements between designating and receiving states. CCAMLR observers use standardised data collection protocols and forms and the Secretariat is in the process of developing a system for accrediting Member States' training programs to ensure harmonised training standards are in place. The system requires 100% coverage for both toothfish and icefish fisheries using international observers from a different flag state to that of the vessel to ensure

[17] CCAMLR has many of the characteristic of an RFMO with respect to the management of fisheries in the Southern Ocean, but as a component of the Antarctic Treaty System with responsibility for all living marine resources within its Area, is generally not referred to as an RFMO.

Case Study Fishery	Summary and Selection Rationale
	independence. For various logistical reasons, vessels in the krill fishery can use either national or international observers, although the data are collected using the same protocols and submitted using the same reporting formats. Coverage requirements for krill have been increasing since the observer program was first made mandatory in 2009 and currently (2018/19) stands at 75%, 100% coverage will be mandatory after 2020. The krill fishery also employs a variety of different techniques to weigh or estimate catch weights. As with NAFO, the importance of accurate catch recording for the management of this fishery has been highlighted by the Scientific Committee and vessels are required to notify CCAMLR, prior to the start of the season, on how they will estimate the green weight of krill caught and record the parameters by which the estimations are made. In addition, the toothfish fishery operates under a strict area quota system which relies on near real time accurate reporting of catches to effectively manage area closures. A number of the toothfish fisheries are also MSC certified and operate under a strict chain of custody regime which also requires an accurate reporting of catch weights which are verified up the chain. Observers calculate conversion factors on a sample of fish daily which are used establish the conversion factor for the vessel for the next season, or in some areas during the season..
UK North Sea Cod Fishery	North Sea cod is one of several important species fished in the North Sea and has recovered from years of depletion. The vessels that operate under the Scottish Fisheries Sustainable Accreditation Group (SFSAG) which in 2017 received MSC certification, provide a best practice example of accurate and near real time catch reporting. The North Sea cod stocks have been subject to a multiannual recovery plan since stocks reached an all-time low in 2006. This plan has required, among other regulations, accurate recording of catches and reporting in near real time to inform area closures. This multispecies fishery has recently been obliged to comply with the EU Landing Obligation (LO) which requires careful monitoring of catches for quota uptake for all managed species. The use of electronic monitoring and electronic logbooks has given a greater confidence of accurate catch reporting.
Norwegian Spring Spawning Herring Fishery	The Norwegian spring spawning herring fishery targets this highly migratory species using purse-seine and pelagic (mid-water) trawl during its spawning off the Norwegian west coast between February and March. On-board observers use probability-based catch sampling that could be applied to NAFO sub-areas and divisions for both target and bycatch species. The model is considered to provide near optimal sampling and could be used to provide near real-time data for monitoring purposes.
UK Marine Management Organisation (MMO) - Fully Documented Fisheries (FDF) Scheme	This example presents the study of a scheme rather than a fishery. The UK MMO trials are one of many trials of Remote Electronic Monitoring (REM) being used to provide greater coverage of at sea operations of various fisheries. This particular scheme has been in operation since 2011 on a voluntary basis in three fisheries out of England: North Sea cod and the Western English Channel dover sole and haddock. The scheme has achieved its main goal: to monitor and reduce discards, and was shown to reduce discarding to below 1% of the catch on vessels that deployed REM compared to an estimated 41% in non-participating vessels.

6.2 Guidance on realistic standard best practices to estimate tow catches

Our guidance on realistic standard best practices to estimate tow catches is organized in two main categories:

- Guidance for the NAFO compliance observer program, and
- Guidance for vessel practices.

These practices and their applicability to fishing activities in NAFO are described in the following sections and summarized in Table 6, which includes an assessment of the strengths, weaknesses, opportunities and threats (SWOT).

An analysis of resources that may be required, either technical, human or methodological, is provided in Section 7.

6.2.1 Best practice guidance for the NAFO Observer Program

6.2.1.1 Observer independence

Paragraph 2 of Article 30 of the NAFO CEM states that observers shall be free from undue influence or benefit linked to the fishing activity of the vessel [on which they are deployed]. A lack of arm's length between observers and the vessels on which they observe can be a significant impediment to achieving reliable and independent catch estimates, irrespective of the precise methodology used for estimating tow catches. This is widely acknowledged across domestic and international fisheries observer programs and has been addressed in a variety of ways. It is very common, for example, to include a requirement that individual observers are not deployed on consecutive trips on the same vessel. This is particularly important in fisheries where the observer trips are of several weeks duration as they are in NAFO. This requirement is included in the amended Article 30 (NAFO Observer Program) adopted in September 2018. This is a good provision, but it is not sufficient by itself to ensure catch estimation is not being impacted by the issue of observer independence. During our interviews with observers, some stated that they came from the same village as the vessel owners or crew of the vessel on which they were observing and this impacted the degree to which they could maintain independence on board, particularly if (for example) their estimates of tow catch weights varied from those of the vessel. Coming from the same village may be an extreme example, but it is currently common practice for observers to be from the same country as vessels on which they are deployed and the relationship between the vessels and the observer providers appears to be relatively close.

Under Article 30, it is the Flag State Contracting Parties' responsibility to ensure that at least one compliance observer is deployed in its vessels fishing in the NAFO RA. Currently, CPs typically have national observers deployed on their own vessels. This may be because their observers are deployed as an extension to a domestic observer program in which is it common, if not an actual requirement, to use nationals due to immigration laws and restriction on foreign workers. It is also typical practice in NAFO for a CP to meet its observer requirements by contracting with an observer provider that employs predominantly nationals for reasons of convenience and language requirements. Previously, some NAFO CPs have required observers on their vessels to be from a flag state other than the vessel's flag state (e.g. in the mid 1990s). National observers have been deployed predominantly since about 2002.

Best practice among RFMO observer programs to reduce the risk of insufficient independence in catch estimation and other observer data is for the observer program to be international; i.e. the observer cannot be from the same flag state as the vessel. For example, in CCAMLR fisheries there is a requirement for 100% coverage by an international observer. Designated scientific observers operate in accordance with bilateral arrangements concluded between the Designating and Receiving Members (the former being the Member wishing to place scientific observers on board a vessel of another Member and the latter being the Member who accepts a scientific observer on board its vessel). Scientific observers in the CCAMLR scheme are nationals of the Designating Member. This international status of the program automatically raises the profile of the observer because the terms of their deployment are held under a bilateral agreement. Protections for observers and vessels are set out in a clearly defined memorandum of understanding (MOU) between the Designating and Receiving Members. A good extension of this is for the same protections to be agreed in an MOU between the observer provider and vessel operator (as is the case in the transhipment observer programs of IATTC, IOTC and ICCAT). Vessels must then be held accountable for not complying with the conditions of the MOU.

There are examples of international observer deployments in NAFO fisheries. During interviews with CPs we were informed that when quota is transferred between NAFO CPs, this can include a requirement for the receiving vessel to carry an observer from the CP from which the quota was transferred. When this happens there are two NAFO observers working on a single vessel.

Added independence, security and performance can be also achieved through placing two observers on one vessel. This is the practice in US Alaska groundfish fisheries to reduce the pressure on a single observer and allow more independence from the crew and officers.

6.2.1.2 Common training standards for observers

For an observer program to succeed it is important that the observers receive good and consistent training to carry out their tasks to the required standards and that this is well recognized. All NAFO observers received training prior to deployment. Observers are currently trained and supplied through the flag state of the vessels on which they observe. There is a variety of training programs and manuals which can result in variation in training standards.

We reviewed training manuals used by several programs to train NAFO observers to explore the whether they reflected best practice in catch estimation. To review these manuals systematically, we developed a list of questions, informed by our collective experience with observer programs and responses to the observer questionnaire and interview comments. These questions pertained to the areas of weight of target and bycatch, weight of discards, conversion factors, reporting differences, standards and training, and equipment. The detailed results for those manuals we were able to access are shown in Appendix 1. Observer Manual Comparison. This review of the manuals was not a review of the observer training as a whole and many of the items covered are also covered in the training course itself or in supplementary guides. It was apparent, however, that there were some differences between the content of the manuals, with some informing the observer what they were required to do but not how to do it. From the questionnaire it also appeared that there were differences between the training observers received prior to going to sea. Standardisation of the training program and manual for use across all NAFO CPs would help to improve the consistency and accuracy of catch weight estimation. This includes ensuring observers are fully trained in scientific methodologies, including randomised sampling protocols, weighing and volumetric estimation protocols, and biometric analysis. This process is underway with relevant proposals included in STACTIC OPR-WP 18-05 and STACTIC OPR 18-07. Accreditation of CPs training programs to a common standard is a means of ensuring consistency and quality control.

In 2009 CCAMLR initiated the development of an accreditation scheme (COTPAS – CCAMLR Observer Training Programme Accreditation Scheme) with the objective of improving the quality and consistency of observer data and reports by ensuring that all certified courses covered the same basic components up to a minimum standard. The components and standards were finalised in 2010[18] and Member States or their observer providers have been encouraged to submit their course outlines and materials for review, both by the Secretariat and by an external expert panel. Although originally intended to be mandatory and only individuals who had been trained through an accredited course could operate as CCAMLR observers, currently it is voluntary, following objections from some Members. Despite this, two Members have submitted their courses and had them accredited.

6.2.1.3 Regular, independent checking of CFs and box weights

As described in Section 4, two of the most important parameters in the estimation of tow level catches in NAFO fisheries are the average box weight and the conversion factor. Both of these are key in the calculation that is at the center of most of the catch estimation. Any inaccuracies in these parameters can give rise to significant bias in catch estimates.

In both cases there should be regular and independent checking by the observer. Independence is essential. The Observer must be able to undertaken the analysis without interference, although some assistance may be needed from the crew for practical purposes. Cooperation must therefore be required. The observer will also have to rely on equipment on board to complete the necessary measurements. In section 4.1.2 we discussed direct measurement of catch weights on board and how this occurs principally for the purpose described in this section. Most observers have access to electronic scales on board, but best practice would be for these to be motion compensated. Motion compensated scales must also be calibrated regularly using standard weights to ensure they are giving accurate readings.

In terms of experimental design, sample size both in terms of how many boxes/fish should be sampled and how often the process should be repeated depends on the on the variability in the results. For standard box weights, at least 20 boxes would be a good starting point. Best practice guidelines for storage and weighing at sea have been developed for demersal fishermen by Seafish and Seafood Scotland[19] and are summarised below:

- Fish should preferably be weighed in the fish hold where they are less likely to be disturbed, otherwise they should be located on deck;
- Scales should be correctly tared accounting for the box or container the fish are weighed and stored in;
- Scales should be calibrated on a regular basis, preferably daily (see the US Alaska Groundfish Fishery case study), using a calibration weight. Where possible, record details of each calibration check;
- Fish should be allowed to stand for a suitable time before weighing to allow excess water to drain off; and,
- The recorded weight should take into account the 'drip loss' that will occur between the fish being caught and the fish being landed.

[18] See CCAMLR XXX Annex 7. Report of the Ad Hoc Technical Group for At Sea Operations. Hobart, Australia, 11 to 15 October 2010.
[19] Seafish and Seafood Scotland. The Good Practice Guide for Demersal Fishermen. Available from https://www.seafish.org/media/Publications/DemersalGPG_0505.pdf

Drip loss is the reduction of weight due to loss of liquid during storage and transport, this will vary according to a number of factors both within and outside the control of the fishermen, summarised below:

Outside the control of fishermen.

- Species;
- Condition of the fish (dependent on the season); and,
- Ambient temperature.

Within control of the fishermen.

- Fishing method – longer trawls will soften or bruise the fish leading to higher drip loss;
- Exposure to the elements – minimise time in the open where it will be vulnerable to drying and temperature fluctuations;
- Time taken from net to box – fish should be processed quickly
- Method of packing and ratio of fish to ice (where used);
- Weight of fish in box – overfilling boxes will crush fish leading to high weight loss; and,
- Length of fishing trip – Longer trips a liable to higher weight losses.

As previously mentioned, the drip loss will vary according to the species of fish, Seafood Scotland recommend using a figure of 3.5% to account for this in whitefish, however this can be as high as 11.5% on other species, such as monkfish.

If using fullness of net or fish pond measurements then the volume to mass ratio should be checked on a regular basis particularly when moving between areas. A known volume of fish should be taken, excess water be allowed to drain, and the weight of the fish taken afterwards.

For conversion factors, some current protocols require 100 individual fish of different sizes to be collected and weighed together; then processed and weighed again. How often this should be done will depend on the variability in the results. Initially measurements should be taken at least once a week, but if there is little variation, then the time interval could be increased.

6.2.1.4 Independent communications

The amended NAFO observer program requires flag state CPs to ensure that NAFO observers are equipped with an independent two way communication device at sea[20]. Since such devices have become widely available at reasonable cost, their use has become a best practice standard in international observer programs around the world, particularly those with extended trip lengths and remote locations. A good example is the inReach[21], a satellite communication device which is used in many RFMO observer programs, including the longline transhipment programs of IATTC, ICCAT and IOTC. This device has two-way text messaging, live tracking and interactive SOS capabilities. A compliance observer could use it (for example) to report basic total tow catch amounts in real time, and within-trip reporting of catch totals prior to vessels moving between Divisions.

[20] NAFO CEM Article 30 paragraph 7(e)
[21] https://explore.garmin.com/en-US/inreach/

6.2.1.5 Photographs and video

The amended NAFO observer program refers to images and video that the compliance observer may take during their observations, in the context of (i) confidentiality[22], (ii) the content of the observer report submitted at the end of a trip[23], and (iii) maintaining records of discrepancies with the NAFO CEM[24]. Date/time stamped photographs taken of the cod end and holding ponds (anything that is part of a volumetric analysis) routinely in a systematic way are a very useful means of documenting total tow catch and discards. Photographs can also be taken of the production logbook. Over time a comparison of photographs and tow catch estimates builds into a valuable database that can be used for data verification and also training for new observers. Video can also be very useful for the same purpose.

6.2.1.6 Catch data verification using distribution patterns

Species composition varies by location, depth and other factors. Fishing operations in certain areas target specific species. For example, when fishing at deeper depths (e.g. 800m) a vessel is likely to catch a high proportion of Greenland halibut (GHL) and no American plaice (PLA). Conversely, when operating at shallower depths (e.g. 300m), a vessel is likely to catch a much higher proportion of PLA and very few GHL. The catch of other species that are discarded may vary in similar ways. Data analysis protocols for verification of species composition can take these patterns into account.

6.2.2 Best practice guidance for vessels

In this section we describe practices on vessels and by crews that can lead to improvements in tow catch estimation.

6.2.2.1 Direct measurement of catch weight

Direct measurement of catch weight is a means of verifying indirect methods, and/or mitigating the potential inaccuracies inherent with the volumetric and box count/conversion factor methods of measuring catch. Weighing equipment is becoming increasingly common on board vessels as fisheries managers require greater accuracy of catch weights to ensure proper implementation of catch limits and to support reliable stock assessments. A range of products is available for an array of different vessel/gear types, configurations and fish products. The more accurate and sensitive the weighing equipment needs to be, and the more robust it is, the higher the cost. Aside from cost, the type of weighing equipment used by vessels depends on a number of factors, including:

- typical volume of catch per fishing effort
- fish handling procedures;
- catch value; and,
- management system in place (i.e. catch reporting requirements).

Several methods have been devised for making direct measurements of tow catches, including (in order of application to an individual tow catch) cod end weighing, in-line flow scales, hopper scales and standing (floor) scales. Cod end weighing has not seen widespread commercial application following testing in 2009[25] but could be applicable in certain circumstances where catches per haul

[22] NAFO CEM Article 30 paragraph 7(g)
[23] NAFO CEM Article 30 paragraph 13(g)
[24] NAFO CEM Article 30 paragraph 13(i)ii
[25] Caslake, R. 2009. Seafish Research and Development, UK. 14pp.
https://www.seafish.org/media/Publications/SR616_CodendWeigherFinal.pdf,

are low. Flow scales have seen widespread use at sea, for example in Alaska groundfish fisheries, since their first introduction in 1998.

The cod end weigher, as its name implies, is designed to weight the whole of the cod end as it is hauled. The advantage is this provides a direct measurement of the whole catch, which can therefore provide an estimate of the discard total, once the retained catch estimates have been calculated and subtracted. The codend weigher is fixed in-line with a suitable part of the rigging so that it hangs vertically when lifting the codend and it is designed to compensate for the motion of the vessel so accurate weights can be recorded. Information is transmitted from the weigher to a computer system that houses software for processing the recorded weights. Once the weight of the retained catch has been recorded, the difference between the two (catch weight less the retained weight) is the discarded weight.

Certified, motion-compensated flow scales are used to weigh a continuous flow of material moving on a conveyor. They were introduced in Alaska fisheries in the late 1990s to improve the accuracy and reliability of catch weight estimates in fisheries which processed catch at sea. They were first established as a requirement to weigh total catch aboard Bering Sea and Aleutian Islands (BSAI) pollock catcher processors (CPs) and motherships in 1998. Specific flow scale models are certified for use in these fisheries to ensure that they are installed correctly and functioning properly. This requires an initial inspection and annual re-inspections. The scales must be calibrated daily while in use and checked for performance. Observers witness and document daily calibrations and the scales are required to weigh with an accuracy of +/- 3% when compared with weighing on a motion-compensated platform scale.

Flow scale regulations in Alaska were updated in 2014, requiring enhancements of daily scale testing. Vessels are required to have electronics capable of logging and printing the frequency and magnitude of scale calibrations, and must have video to monitor the flow scale and the area around the scales. The requirement to use flow scales in Alaska fisheries has been expanded to include CPs and motherships in AFA (American Fisheries Act), CDQ (Community Development Quota), Amendment 80 (BSAI multispecies bottom trawl), and Central GOA Rockfish fisheries. These are all Limited Access Privilege Programs (LAPPs). Flow scales are also a requirement in the US At-Sea Hake Fishery and the CCAMLR Antarctic krill fishery. On trawlers the entire unsorted catch is weighed on the flow scale. On longliners targeting Pacific cod, only the target species is weighed on the flow scales.

Examples of flow scales include the Marel M2200/M1100 or Pol S-185, supplied by Lorrimar for smaller vessels. Costs vary according to the specifications required but are typically between $6,800 and $10,100. Most can also be integrated with the vessel's GPS, electronic logbook and PC which can in turn be connected to a printer so boxes / batches can be individually labelled. They can also be retro fitted to older vessels. By comparison, non- motion compensated scales typically cost between $1,200 and $2,400. As with motion compensated scales, they can integrated with other instruments and can also be retro-fitted.

Hopper scales are another means of weighing a continuous product flow, but in this case the weighing is done in batches just prior to packing or other purposes. Hopper scales can be used at sea, but they are used more commonly in land based processing plants currently. Their use would

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Dolder P. et al Scoping Industry Approaches to Fully Documented Fisheries. Fisheries Science Partnership: 2012/13, NFFO.
http://nffo.org.uk/uploads/attachment/102/scoping-industry-approaches-to-fully-documented-fisheries-final-report.pdf

need to be governed under a calibration and verification procedure similar to that described above for flow scales in Alaska.

Weighing equipment can be integrated within the processing system such that fish arrives at in-line scales via conveyors/chutes and is automatically weighed before being boxed. The most advanced integrated systems have scales installed on a shelter deck, interfaced with global positioning system (GPS), the bridge PC, a label printer, with a satellite data connection. The system allows recording of every batch number, which is individually labelled. The record can be displayed on the bridge PC, so the vessel master can manage his catch on net weight, live weight, or wet weight. The system can also record the number of crates, full or empty and location in fish hold (stowage management).

Accurate weighing of catches on board using in-line weighers like flow and hopper scales can be impacted by the amount of water accompanying the fish. This can be mitigated using a dewatering box/grid prior to the fish reaching the conveyor. Flow scales are also used in the Antarctic krill fishery in which the catch is pumped though the factory in pipes with added seawater. The fraction of water mixed in with the krill is accounted for by calculating the weight of water that drains off a sample after a two-hour period and typically accounts for 8-12% of the sample weight.

6.2.2.2 Discards

A volumetric measure of the contents of the fish pond can be taken to provide a preliminary estimate of the total catch weight. This should be conducted by the compliance observer. All catches from the pond/ponds then pass over electronic flow scales (calibrated daily and verified by the compliance observer) to provide a measure the total catch weight of the haul, recorded by the vessel (this can be compared to the volumetric estimate by the observer). From this, retained catches can be separated, processed and sorted in to trays by species. Trays would be weighed on motion compensated scales (or trays of a known average weight counted) to give the total processed weight for each species, then scaled up using conversion factors to give a total green weight by species for the retained portion of the haul. From this figure, the total weight of discards is calculated. Discards can be sorted in to trays by species and weighed on motion compensated scales in a similar manner, or counted by trays of a known average weight, to give a total estimated weight by species.

Discards can also be estimated through random sampling by observers. The observer removes all discards for a proportion of the haul, as they pass over the flow scales (start weight and end weight is recorded), would yield data on numbers and proportions of each species .This would be particularly applicable when there are a large number of species, such that placing fish into trays for each species becomes impractical. These data can then be scaled up as proportions of the total green weight of the haul. Samples of length and weight can be used to provide estimates of total numbers for each species.

6.2.2.3 Electronic monitoring

Remote Electronic Monitoring (REM) of fishing operations entails the installation of (usually) high definition (HD) tamper proof cameras onto fishing vessels to record various aspects of fishing operations. REM systems store pictures and video footage on secure storage unit on board and these are then recovered and replaced at the end of a trip and sent for review. Pictures and video can also by automatically uploaded to the monitoring centre once the vessel comes within range of shore-based communications, either the GSM cellular system or a purpose-built stations. Most systems also have the capacity to send images and/or video in real time via satellite to the monitoring centre on land. This capacity is generally not used for the review and estimation of actual fishing events but rather as a shore-based check that the system is working properly.

When the pictures and video have been received by the REM provider, bespoke software is used to filter the material so that the reviewer only needs to monitor selected fishing events rather than watch the entire record. This is done in a variety of ways depending on the specifics of the fishery. Some systems apply a variety of filters such as vessel speed to identify likely fishing events; these are then checked by the reviewer for false positives and then the actual fishing events are reviewed at normal speed or below and the required data collected. Most REM providers use machine learning to further increase the accuracy of these filters and rapid progression is also being made with using image recognition for species identification in the catch. Some systems also have inbuilt tools that enable recording of length frequency. These data can be used to extrapolate catch weight using conversion factors. The successful application of REM is dependent on having reviewers that are experienced in that particular fishery and an automated system that can reliably reduce the ratio of time spent fishing relative to review time.

REM may be used as an alternative for comprehensive observer coverage, but it generally is not regarded as a viable replacement for all observer coverage. It can monitor catch amounts and/or catches of ETP species, particularly on small vessels that make observer deployment difficult. In larger scale fisheries like NAFO, it can complement the tasks undertaken by observers. It can also be used to verify scale calibration and counts of boxes of fish etc. In the case of US Alaskan groundfish fishery, for example, vessels use cameras to monitor both the flow scales themselves and the areas around the scales.

REM can be interfaced with other sensors, for example a vessel's winch, to detect when a fishing event is taking place and an independent GPS system to detect where it is taking place. This is a step towards achieving the goal of a fully documented fishery (FDF). This has been trialled in a number of fisheries, most notably in the UK to help implement the EU landing obligation, and has been shown to significantly reduce discards through vessels modifying their behaviour and gear (see for example, the UK Marine Management Organisation (MMO) – Fully Documented Fisheries (FDF) Scheme – see Appendix 3).

Within NAFO, REM could help to provide an independent verification of tow catch estimation, alongside flow scales. It can generate a real-time record of codend bag sizes and catch handling in the factory for an individual tow and can provide a verification of fishing effort and total catch independent of the crew and the observer. Properly sited cameras can provide catch weight estimation of the codend as well as monitoring the factory throughput, freezer storage and species discarded.

Table 6. Guidance on Best Practices for tow catch estimation in NAFO fisheries

Best Practice	Application to NAFO	Benefits	Challenges
Guidance for the NAFO Observer Program			
International observer program	Observers deployed from a different flag state to the vessel, either through a central provider or through a bilateral agreement or MoU between designating and receiving CPs.	• Provides greater independence for observers, reduced risk of influence. • Successfully managed in other RFMOs, e.g. CCAMLR, tRFMOs.	• Likely more expensive to run an international observer program. • Potential language issues on the vessels if observers from different Flag State.
Common Standards and program accreditation	Observer program standardised across providers and only accredited bodies provide training. CCAMLR is going through a similar process of accreditation for their observer training programs.	• Referenced in EU proposal to revise Article 30 and introduce training standards (STACTIC OPR-WP 18-05) and proposal to improve data quality management through standardisation of training programs and forms (STACTIC OPR 18-07). • Standardise the protocols for observers catch estimation of target and bycatch species, conversion factor calculations, estimating discards. • Using standard electronic forms, for example excel, to record and submit data. • Member States will still be responsible for supplying and training their own observers but using standardised training and accredited trainers.	• Added cost of accreditation and maintenance of program • May require some changes to established programs. • Accreditation of Members courses is a time consuming and lengthy process ideally involving external, independent experts.
Regular verification of average box weights.	Most common method of tow catch weight estimation by observers in NAFO (to count the number of boxes of each species and multiply by the weight of box); it is important to have regular and independent checking of box weights.	• Trials have shown use of motion compensated scales on vessels give significantly more accurate assessment of weight than vessel's estimate alone (5% error compared to 23%)[26]. • Weigh a random sample of boxes on a regular basis, verified by the observer. • Regular checks will account for any changes over time. • Some vessels already currently verify average the box weights.	• Not all vessels carry suitable motion compensated scales. • motion compensated scales must be calibrated regularly. • Additional pressure on observers to verify weights.
Regular verification conversion factors.	Conversion factors should be checked on a regular basis to account for seasonal and spatial changes as well as changes in the crew members undertaking the processing.	• Calculation of conversion factors and reporting can be a standard daily task for observers. • Observer calculated conversion factor can be compared to the standard conversion factors used by the vessel.	• Conversion factors are often supplied by the Flag State. • Catch verification can be difficult where conversion factors are changed mid -season. • Requires access to motion compensated scales and/or accurate mechanical balance.

[26] Seafish (2011). Weighing at Sea Trials. Research and Development Factsheet, February 2011. https://www.seafish.org/media/Publications/FactsheetWeighingatSeaTrials_FS54_201102.pdf

Best Practice	Application to NAFO	Benefits	Challenges
Regular verification of volume to mass ratio.	Where fish pond volumes are used for weight estimations the volume to mass ratio should be established and checked on a regular basis accounting for any water content (e.g. CCAMLR krill fishery).	• Would account for any water content mixed in with the fish when stored in the fishpond. • Recognised issue with flow scales resulting in recommendation of the installation of 'dewatering' box to drain excess water before weighing fish.	• Requires development of handling protocols for target species in NAFO (protocol used for krill may not be appropriate). • Process can be time consuming and vessels may be reluctant to conduct tests.
Observers provided with independent means of communication.	NAFO observer trips are offshore and of long duration. This has been adopted by a number of RFMOs, including tRFMOs for transhipment observers and CCAMLR.	• Equipment is readily available • Would allow 2-way communication between observer and their provider, independent of the vessel. • Has been successfully adopted in a number of regional and international observer programs (e.g. CCAMLR, IOTC, ICCAT, IATTC, PNG program) for enhancing observer independence and safety. • Can also be used to report daily catch data or to give daily positions, independent of vessel. • Enhances observer morale.	• Would require extra training for observers and observer providers. • Cost of purchase, maintenance and data transmission (depending on data reporting usage).
Photos and Video	Regular time-stamped photographs and/or video of hauls; already part of the amended NAFO observer program.	• Provides independent verification of total catches by tow. • Builds up library of cod end and other images for observer training and QA/QC of catch data	• Standard protocol for taking photos and videos must be developed and strictly adhered to. • Data volumes for reporting increase.
Catch data verification.	Recommendation from STACTIC OPR-WP 18-11 that vessel daily CAT messages can be compared with observer daily OBR messages for real time verification of catch reports.	• Potential to verify catches in real time by comparing the two data sets has already been recognised by STACTIC and process in underway to make OBR message comparable to CAT. • Feasibility study being undertaken to examine practicality of observers entering their data into offline application and submitting when online directly into central database. as used in Iceland's domestic program (STACTIC OPR-WP 18-11).	• To be effective, OBR message would need to be sent independently to vessel CAT message (e.g. through observers' InReach (or similar) device).
Guidance for Vessels			
Vessels submit documentation on how catches are estimated on-board.	Prior to each season vessels should be asked to submit details of how catch weights are estimated on-board as part of their notification application under Article 25.	• Would allow STATIC to review regularly the mechanisms in place to record catch weights and compare t best practices. • May incentivise flag states to examine the way their vessels record catches and improve if necessary. • Observers can confirm that methods submitted are used in practice.	• Scales would need to be of a make / model approved by the Secretariat. • May not be possible to arrive at standard methods. • Obtaining results may not actually lead to improved catch estimates.

Best Practice	Application to NAFO	Benefits	Challenges
Motion compensated flow scales.	Flow scales will provide a more accurate method of recording catches and are used successfully in number of trawl fisheries.	• Provides an accurate measurement of the total retained catch; scales used in the Alaska groundfish fishery and US hake fisheries are certified to weigh within +/- 3%. • Can incorporate a computer monitoring system to control production and monitor data. • Information can be stored electronically for reporting purposes or incorporated into an electronic logbook. • Scales can be certified and checked regularly for accuracy; observer can verify this process. • Scales can be monitored by video.	• Scales are expensive. • Scales require continual monitoring and maintenance while at sea and require crew experienced in mass-processing facilities. • Scales must be tamper-proof • Strict protocol required for verification, as in the Alaska fishery where they are checked daily in the presence of an observer and the scales themselves are monitored by video. • Vessel modifications are required; factory space can be an issue, depending on the model they can be up to 6 feet long and 3 feet wide. They also require a dewatering box prior to the fish reaching the conveyor to ensure an accurate reading. • The scales are bolted to floor to prevent movement and are therefore not portable. • Processing rate may slow down on some vessels.
Codend weigher	Developed to measure discards in a fishery; scale measures total weight of the codend as it is hauled in and compare to the weight of the retained catch. The difference is the discarded catch.	• Compact and east to handle and install, trials showed it to be more accurate that a vessel captain's estimation and within 3% of the true weight. • Less expensive that flow scales.	• Vessel must have capacity to lift net vertically off the deck for it to work effectively. • Only tested on weights up to 300kg. • Tested model had a number of technical issues. • Not widely used to date. • Despite the apparent success of the initial trials, there do not appear to have been any tests or revised models built since 2009.
Discard estimation	Vessels should be required to separate retained catches and discards into separate holding ponds prior to discarding to enable routine estimation of discards.	• Practice is undertaken already by most vessels in NAFO. • Makes it easier to estimate weights of retained and discarded fish.	• For vessels not already using holding ponds may require some redesign of vessel layout prior to implementing. • May not be a practical option on some vessels due to size.

Best Practice	Application to NAFO	Benefits	Challenges
Remote electronic monitoring (REM)	Monitoring of fishing activity and catch on fishing vessels through installation of cameras, GPS and sensors, has already been tested and is in use in a number of fisheries worldwide. Existing applications within NAFO incorporate recording of discards and/or verification of total catch.	• REM has been successfully deployed in other fisheries for a range of purposes, including monitoring of discards and ETP interactions; it is flexible enough to be tailored to the requirements of a particular vessel. • Studies show it to be cheaper than other forms of monitoring, specifically high coverage observer programs; once installed operational costs are low. • Can provide 100% coverage of fishing operations and opportunity to resample recordings for different purposes. • If used for compliance purposes has the potential to replace observers for some functions; can solve some aspects of the independence requirement. • Has been shown to alter fisher's behaviour beneficially; for example a reduction in discarding.	• For catch estimation most trials or applications have been for fisheries where individual fish are easy to identify, or single species fisheries. In a multispecies trawl fishery such as NAFO it may have limited applications. • In most fisheries trials have required some incentive (e.g. compensation for time etc.) • The trust issue needs to be addressed; fishers do not want the data to be used against them[27]. • Systems are not tamper proof; various methods can be used to spoil the data e.g. operating out view, or smearing lenses. • REM cannot collect most biological data such as sex and maturity, or collect samples such as otoliths. • Reviewers require training and auditing. • Problematic on longer trips (several months) with respect to data storage. • Requires technical support to install, maintain and manage.

[27] Stephen C Mangi, Paul J Dolder, Thomas L Catchpole, Dale Rodmell & Nathan de Rozarieux (2013). Approaches to fully documented fisheries: practical issues and stakeholder perceptions. Fish and Fisheries.

7 Assessment of catch estimates resources needs

Table 7 and Table 8 provide summaries of the resource needs associated with the best practices described in Section 6.

Table 7. Summary of Best Practices and Related Resource Needs

Best practice	**Example Source Fishery**	**NAFO / Fleet / CP**	**Resource Needs**			**Program Needs**			**Time Requirement**
			Technical	Human	Methodological	Observer Program	Catch Estimation	Sampling Methodology	
International Observer Program	CCAMLR fisheries**	NAFO				+	+	—	
Common Standards and Program Accreditation	Alaskan groundfish fishery	NAFO				+	+	+	
Regular verification of average box weight	CCAMLR Antarctic krill fishery	Fleet				++	++	++	
Regular verification of conversion factors	CCAMLR Antarctic krill fishery	NAFO/Fleet				—	++	—	
Regular verification of volume to mass ratio	CCAMLR Antarctic krill fishery	Fleet				++	++	++	
Observers provided with independent means of communication	CCAMLR Antarctic krill fishery	NAFO				+	—	—	
Photos and video	NAFO	NAFO							
Use of observer data to verify vessel reports	US At-sea hake fishery	NAFO/MS				++	++	++	
Submission of documentation on how catches are estimated on board	CCAMLR Antarctic krill fishery	Fleet				—	++	++	
Installation of motion compensated flow scales	Alaskan groundfish fishery	Fleet				++	++	—	
Installation of codend weigher	UK North Sea cod fishery*	Fleet				—	++	—	
Catch separation for discard estimation	Several	Fleet				++	++	++	
Remote electronic monitoring (REM)	MMO UK Fleet***	Fleet / MS				++	—	—	
Electronic Reporting Scheme (ERS)	Norwegian spawning spring herring	NAFO				—	++	—	

Key

Technical Needs

None, current resources can be used
Some technology & training
Comprehensive technology & training

Human Needs

None, current resources can be used
Some additional human capacity
Additional Capacity likely to add cost

Methodological Needs

None
Some
Additional

Time considerations

Could be implemented <1 year with dedication
Longer term practice

Program Needs

Strong practices to meet this need	++
Will meet this need	+
Weak/won't meet this need	—

*As trial only

**Applies to all CCAMLR fisheries apart from krill

*** Voluntary trial only

Table 8. Assessment of catch estimates resources needs

Best Practice	Additional Resources Required
Guidance for the NAFO Observer Program	
International Observer Program	• Additional costs to vessels / Member States for observer deployments and observer salaries. • NAFO Protocol for CPs to arrange deployment of observers at international level. • Development of Standardised MoU by the Secretariat to be approved by Members.
Common Standards and Program Accreditation	• Requires a standardised set of observer sampling protocols and training standards. • Development and agreement of minimum standards for accreditation program, e.g. using STACTIC OPR-WP 18-05 as a basis. • Establishment of an expert working panel to review training programs and award accreditation.
Regular verification of average box weights.	• Protocol for calculating average box weights. • Vessel to obtain motion compensated scales of sufficient precision and accuracy (estimated to be between $4,500 to $6,000). • Addition to logbooks enabling observers and vessels to record frequency and accuracy of tests. • Augmentation of observer training
Regular verification conversion factors.	• Protocol for assessing conversion factors for key target species. • Vessels must have scales to accurately measure whole and processed fish. • Format for recording data. • Augmentation of observer training
Regular verification of volume to mass ratio.	• Protocol for calculating volume to mass ratio. • Vessels may need to install specialist equipment (e.g. dewatering box) to calculate volume to mass ratio. • Format for recording data. • Augmentation of observer training
Observers to be provided with independent means of communication.	• Purchase and operation of communications units (e.g. Garmin inReach units, currently used in ICCAT, IOTC and IATTC transhipment programs) cost between $370 and $540 for the unit. Operation costs depend on data volumes. For simple text only, typical cost is $20 per month. • Message monitoring protocol and staff allocation • Handle of catch reports, including data storage mechanism.
Photos and Video	• Camera and video equipment • Protocol for recording (including sate stamp), storing and transmitting data • Augmentation of observer training
Catch data verification.	• Staff required to monitor daily submissions and generate reports. • Development costs to set up secure server and database. • Additional costs of data transmissions from vessel. • Costs of equipping observers with independent means of communication.
Guidance for Vessels	
Vessels submit documentation on how catches are estimated on-board.	• Format for submission of information. • Protocol for observers to verify methods in practice.

Motion compensated flow scales.	• Reported costs of scales vary: a report from 2010[28] estimated a cost of between $50,000 and $70,000 with an installation cost of up to $6,000. Maintenance package $15,000.
	• In 2014 Marel quoted $30,400 per flow scale to replace all the scales that were operating in the Alaska groundfish fishery, with software costing an additional $2,000.
	• Additional costs and resources are related verifying the readouts on the scales. This would involve:
	  • Developing a set of standards by which to certify the scales;
	  • Developing protocols for checking accuracy of scales while at sea.
	  • Verifying the at sea checks have been undertaken.
	  • Purchase and installation of video monitoring system (estimated to be between $4,000 and $17,000 depending on the system).
	  • Review of video footage by independent reviewer.
	• Protocol for observers to verify operation of scales
	• Observer training
	• REM to monitor tamper-free scale operation

[28] Discussion Paper: Potential Applicability of Flow Scales, Hopper Scales, Truck Scales and Volumetric Measurement in the Atlantic Herring Fishery. Prepared by Council Staff for the Herring Committee July 2010.

Best Practice	Additional Resources Required
Codend weigher	• Additional texting to verify utility of system in NAFO fisheries • Personnel to operate laptop during hauling. • Projected cost of system under $5,500 per vessel. • Reporting protocol
Discard estimation	• Some vessels may require modification for installation of ponds • Catch sorting protocol.
Remote electronic monitoring (REM)	• Purchase of the equipment, installation, annual maintenance and monitoring of the footage for each trip. • A 2013 report estimated the cost to be about $11,500[29] for Danish vessels in 2011. • More recent estimate: $6,800 for equipment and installation in 2016[48]. • The annual cost of running the equipment was estimated in 2017 to be around $7,500 per year based on a system comprising 4 digital cameras, GPS assembly, hydraulic pressure sensor assembly, POE switch, software, 300m Cat5 cable, power cables and two 1TB hard drives. It also includes the salary of a reviewer covering 10% for the footage[46]. • A report from 2012[30] estimated the cost to be around $33,000 per year, although this included the use of a full-time analyst working 225 days per year.

[29] Dolder, P. J., Mangi, S.C., Catchpole, T.L., Rodmell, D., Deas, B. and de Rozarieux, N. Scoping Industry Approaches to Fully Documented Fisheries. Fisheries Science Partnership 2012-2013. Final report. 76 pp.

[30] Needle, C. L., Dinsdale, R., Buch, T. B., Catarino, R. M. D., Drewery, J., and Butler, N. Scottish science applications of Remote Electronic Monitoring. – ICES Journal of Marine Science, 72: 1214–1229.

Appendix 1. Observer Manual Comparison

The following table summarises the content of the observer manuals from different Member States that were reviewed as part of the project to assess the uniformity between programs with regard to recording catch weight data at sea.

Table 9. Comparison of the content of Compliance Observer Manuals.

	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6
WEIGHT OF TARGET AND BYCATCH						
Are observers instructed to record the catch weight?	Y	Y	Y	Y	Y	Y
Is catch weight disaggregated by species?	Y	Y	Y	Y	Y	y
For what species?	ALL	ALL	ALL	ALL	ALL	ALL
Is catch weight recorded by haul/day/period?	HAUL	HAUL	HAUL	HAUL	HAUL	HAUL
Do observers accurately weigh samples using scales at any stage?	Y	Not mentioned in the manual.	Y	Y	Not mentioned in the manual	Y – Discards only.
Is the entire catch weighed?	N	All species must be recorded and the weights must be converted using conversion factors provided by the captain.	Y (if possible)	Y (if possible)	Not mentioned in the manual	N
Is catch weight estimated based on sample weights (e.g. average weight of sampled trays x total number of trays)?	Y	Not mentioned in the manual.	Y	Y	Not mentioned in the manual	Y – Vessel's weights
Is the catch weighed directly using scales?	Y	Not mentioned in the manual.	Y	Y	Not mentioned in the manual	Y – Discards only.
Is the catch weight estimated from volumetric measurements?	N	Not mentioned in the manual.	Y	Y	Not mentioned in the manual	N
Other method?	N	Not mentioned in the manual.	Tally, Basket count, catch composition extrapolation	Counting	Not mentioned in the manual	Basket count, catch composition extrapolation
Or a combination?	N	Not mentioned in the manual.	Y	Y	Not mentioned in the manual	Y
If a combination, is there	N	Keep using CF given	Y	Y	Not mentioned in	Keep tray counts,

	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6
instruction regarding the choice of method?		by vessel to give live weight. Discard is Observer's wt. (no method named).			the manual	discarded weights are estimated through catch composition extrapolation.
Do the instructions for weighing the catch vary under different conditions/access to catch?	N	Not mentioned in the manual.	Y	Y	Not mentioned in the manual	
WEIGHT OF DISCARDS						
Are observers instructed to record discards?	Y	Y	Y	Y	Not mentioned in the manual	Y
Does the manual direct the observer to make independent estimates of discards?	Y	N – It doesn't specify either "independent" nor "estimates".	Y	Y	Not mentioned in the manual	Y
Is discard catch weight estimated?	Y - always	Not mentioned in the manual.	Y	Y	Not mentioned in the manual	Y – Weigh ½ of catch (one side of vessel), then multiply by 2.
Is discard weight measured directly using scales?	Y (periodically to verify estimates)	Not mentioned in the manual.	Y	Y	Not mentioned in the manual	Y
Is the discard weight estimated from volumetric measurements?	N	Not mentioned in the manual.	Y	Y	Not mentioned in the manual	N
Other method?	When not present to Observer: calculate from the mean of the discarded quantities of each species in the previous sets and later (if there are no large	Not mentioned in the manual.	Tally, Basket count, catch composition extrapolation	Counting	Not mentioned in the manual	Basket counts.

	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6
	differences in area and depth), calculating the amount discarded as a proportion of the catch of the dominant species.					
Or a combination?	-	Not mentioned in the manual.	Y	Y	Not mentioned in the manual	N
Is discard weight recorded by haul/day/period?	HAUL	HAUL	HAUL	HAUL	HAUL	HAUL
Do the instructions for weighing the discards vary under different conditions/access to catch?	Y	Not mentioned in the manual.	Y	Y		N
CONVERSION FACTORS						
Does the manual give instructions on the use of conversion factors?	Y	Y	N	Y	Not mentioned in the manual	Not mentioned in the manual
Does the observer make an independent estimate of conversion factors?	Y	N	N	Y	Not mentioned in the manual	N
If the observer makes an independent estimate, give a brief description of how they are instructed to calculate the conversion factor.	The conversion factor is found by dividing the live weight between the processed weights.	Not mentioned in the manual.	-	Collect random sample. Count and weigh sample. Process fish normally. Re-count and re-weigh sample. CF= round wt./product wt.	Not mentioned in the manual	-
Are conversion factors agreed with the captain?	N	Y	N	Y	Not mentioned in the manual	Y
Are conversion factors	N	Y	N	N	Not mentioned in	Y

	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6
provided by the captain?					the manual	
REPORTING DIFFERENCES						
Is the observer instructed to record the catch data from the vessel's logbook?	N	Y	N	N	N	Y – Kept catch.
Is the observer instructed to record discrepancies in catch estimates between the logbook and their own figures?	N – must always reconcile differences in weights.	Yes. The observer is instructed to record discrepancies in catch estimates between the logbook and their own figures.	N	Y	N –"Comparison always the ship's logbook with the production log." No mention of recording differences.	N – No discrepancies since wts. Are taken from logbooks.
If so, what are the allowable differences?	-	No mention in the manual.	-	Not defined specifically. In terms of reporting it: "Observer should be flexible on clerical errors and minor omissions in logbooks".	-	-
Are observers required to share their data with the vessel if requested?	Y	N	Y	N	Y – If instructed to do so. "non-confidential documents must be displayed to third parties; but only to the ship management".	Not mentioned in the manual
What frequency are observers expected to submit reports to NAFO? In what form?	Not mentioned in the manual	Not mentioned in the manual	Not mentioned in the manual	Not mentioned in the manual	Not mentioned in the manual	Not mentioned in the manual
STANDARDS AND TRAINING						
Is there a minimum educational standard for	Not mentioned in the manual	Not mentioned in the manual	Y	Y	Not mentioned in the manual	N

	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6
observers?						
Is there a minimum experience requirement for observers?	Not mentioned in the manual	Not mentioned in the manual	N	N	Not mentioned in the manual	N – Crew member of one of vessels.
Are observers trained in catch weight estimation using protocols?	Not mentioned in the manual	Not mentioned in the manual	Y	Y	Not mentioned in the manual	Not mentioned in the manual
What protocols are used when estimates or weights cannot be obtained?	Calculate from the mean of the discarded quantities of each species in the previous sets and later (if there are no large differences in area and depth), or calculating the amount discarded as a proportion of the catch of the dominant species.	Not mentioned in the manual	Captain's estimates or deemed an unobserved haul.	Sometimes Observers have to rely on logbook entries to collect catch and effort data. When Observers record set information based on logbook figures it is referred to as a *logged* set.	Not mentioned in the manual	Not mentioned in the manual
Are there any practical exercises outlined in the manual?	Y	N	Y	Y	Not mentioned in the manual	Not mentioned in the manual
Is there a final exam or test the observers are required to undertake before carrying out the work?	Not mentioned in the manual	Not mentioned in the manual	Y	Y	Not mentioned in the manual	Not mentioned in the manual
Is observer performance assessed/reviewed?	Y	Not mentioned in the manual	Y	Y	Not mentioned in the manual	Not mentioned in the manual
How is observer performance assessed/reviewed?	Post trip interview with key personnel.	Not mentioned in the manual	Each trip is edited and bi-annual performance	Post trip de-briefing.	Not mentioned in the manual	Not mentioned in the manual

	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6
			reports are completed by NMFS. These are sent to Observers and their providers. Observers must do an in-person debriefing with NMFS every 6 months. Providers do captain interviews and track deliverables.			
Are observers re-trained at any point? If so, how?	Not mentioned in the manual	Not mentioned in the manual	Y- ASM Observers are required to attend a yearly recertification training. If a NEFOP Observer did not actively observe 12 months from their certification date on that gear, the Observer must attend an approved refresher course. Safety - observers are required to complete a two-day safety refresher training course ("Safety II") every 18	N	Not mentioned in the manual	Y – A 1 day de-briefing 2 times/year.

	Country 1	Country 2	Country 3	Country 4	Country 5	Country 6
			months.			
EQUIPMENT						
What equipment are observers provided with?	Not mentioned in the manual	Not mentioned in the manual	Detailed list of equipment available in separate documents	Not mentioned in the manual	Not mentioned in the manual	Not mentioned in the manual
OTHER						
Any other comments on how catch weight estimation is outlined in the manual?	-	The manual outlines what the observer has to do on the vessel and gives a good background to the fishery, however there is no instruction on how to do it.	Basket or tote counts.	-	-	-

Appendix 2: Observer Questionnaire

CONFIDENTIAL

Catch Estimates Methodology Study

NAFO Compliance Observer Questionnaire

The Northwest Atlantic Fisheries Organisation (NAFO) is seeking to improve the recording of catch weights on a tow-by-tow basis for vessels operating within the NAFO Convention Area.

This study aims to provide NAFO with accurate, up-to-date information on the various methods used to measure catch weights on board by the vessels, NAFO compliance observers, national scientific observers, and NAFO inspectors. The results of the study will be used by NAFO to evaluate options for improving and optimizing catch estimation techniques for NAFO-managed fisheries.

This questionnaire is for NAFO Compliance Observers. It should take approximately 15 minutes to complete. The questions are split into different categories which relate to different components of the vessels' and observers' reporting duties and operations. We are also interested in your opinions, as a NAFO compliance observer, on the subject of improving catch weight measurement on board.

Unless otherwise directed, please answer all questions. If you are unsure or do not know an answer, please write 'Unknown'. If a question is not relevant, please write 'N/A'. If you need more room for your answer please use the space at the end of the questionnaire (or a separate sheet if needed). All answers are confidential and your name will not be used in the study.

Please send you completed questionnaire to James Moir Clark at:
MRAG Ltd.
18, Queen Street,
London
W1J 5PN
United Kingdom

Or email to: j.clark@mrag.co.uk cc a.watson@mrag.co.uk
Telephone +44 (0)207 2557790/7787

Thank you for participating in this study. If you would be comfortable with us following up with you for any clarifications, please provide your email address.

1 About yourself

1.1 Name (optional): ____

1.2 What is your nationality? ________________________________

1.3 How long have you been working as an observer (in all fisheries)?

_________Years ________Months

1.4 In what fisheries have you worked as an observer?

____

____

____

1.5 How many observer trips have you completed in NAFO and how many different vessels have you worked on?

Trips _________ No vessels: _________

1.6 When did you work as an observer in NAFO? (check all timeframes that apply)

__ 1990 - 1999 __ 2010 - 2014

__ 2000 -2009 __ 2015 - current

1.7 Did you receive training on estimating catch weights prior to working as a NAFO observer?

__ Yes (please give details)_____________________________ __ No

____

1.8 Have you worked in NAFO in any other capacity (e.g. inspector, scientific observer, fisherman)?

__ Yes, (please give details) _____________________________ __ No

2 Vessel Details: The following sections apply to vessels you have worked on as a NAFO compliance observer only.

2.1 How many trips have you completed on each type of vessel (enter a number)?

__ Demersal Trawler __ Other (please give details)____________________

2.2 How many trips have you completed on vessels from different flag states (enter a number)?

Flag State	Trips

2.3 What was the approximate average fishing trip length (in days) for each type of vessel - please complete the table below?

	Vessel type	
Flag	Demersal	Other
1		
2		
3		

2.4 What were the main target species for each type of vessel – please complete the table below using the species codes supplied?

	Vessel type	
Flag	**Demersal**	**Other**
1		
2		
3		

Species codes – Reference only

Species	Code	Species	Code
Cod	COD	Witch flounder	WIT
Redfish	RED	Greenland halibut	GHL
American plaice	PLA	Atlantic halibut	HAL
Yellowtail flounder	YEL	Northern prawn	PRA

3 On board Handling of Fish on the Vessel: This section refers to the most recent vessel you worked on as a NAFO observer.

3.1 What was the flag and vessel type of the last vessel you worked on as a NAFO observer? (you will complete the following questions based on this)

Flag ________________ Vessel Type ________________________

3.2 Was the catch separated into different species?

__ Always __ Sometimes (please give details)_________________________

__ Never __ Unknown

3.3 Was the catch separated into different size groups?

__ Always __ Sometimes (please give details)_________________________

__ Never __ Unknown

3.4 Did the vessel use a Conversion Factor to convert processed weight to live / green weight?

__ Always __ Sometimes (please give details)_________________________

__ Never __ Unknown

What method was normally used to calculate the Conversion Factor and how often was it reviewed and updated?

____

____

3.5 Did the vessel estimate amounts of discarded catch?

__ Always __ Sometimes __ Never __ Unknown

3.5.1 How were discard weights estimated?

____

____

4 Observer recording of catch weights for Target Species ONLY: This section refers to the most recent vessel you worked on as a NAFO compliance observer.

4.1 Did you give an independent measurement / calculation / estimate of the catch weights?

__ Yes

__ No [go straight to **Section 5]**

4.2 How did you normally measure/calculate the catch weight?

__ Weighed [if only weighed, go to question **4.3**]

__ Estimated [if only estimated, go to questions **4.4** and sub-question]

__ Both

__ Other ____

4.3 If used, what types of scales were on board for the observer to use?

__ Mechanical balance

__ Spring balance

__ Electronic–non-motion compensated

__ Electronic -motion compensated

__ Other (please detail) ____

__ ____

4.4 For scales, rank (1 highest and 5 lowest) the following factors that influenced the accuracy or precision of the weighing equipment in order of influence.

__ Weather conditions

__ Experience of crew

__ Volume of catch

__ Other (give details) ____________________________

__ Nothing influenced the accuracy or precision of the weighing equipment

__ The observer has not been on a vessel with scales on

4.5 If catch weight was estimated what method(s) was/were normally used?

__ Counting boxes/baskets & multiplying by a factor

__ From the fullness of the net

__ Weighing each box/basket or fish

__ Fullness of fish pond / hold

__ Other, (please detail)_________________
____

4.5.1 How was this method checked and how often was it done?

____

____

4.5.2 If the method omitted discards (e.g. if counting/weighing boxes) how were discard weights estimated?

____

____

____

____

4.6 Rank (1 highest and 5 lowest) the following methods of estimating catch weight on board fishing vessels in order of accuracy (with).

__ Counting boxes/baskets & multiplying by a factor

__ From the fullness of the net

__ Weighing each box/basket or fish

__ Fullness of fish pond / hold

__ Other, (please detail)_________________
____

4.7 For estimations, rank (1-5) the following factors which influence the accuracy or precision of the weight estimations (with 1 highest and 5 lowest).

__ Weather conditions

__ Experience of crew

__ Volume of catch

__ Other (give details) _____________________________

__ Nothing influenced the accuracy or precision of the estimation method

4.8 Were there differences of over 10% between the observer's recorded catch weights and those recorded by the vessel on a <u>tow by tow</u> basis?

__ Yes, there were differences for more than 10% of tows (please detail) ____________
____

__ Differences occurred in less than 10% of tows and those differences were minor and random

__ Unknown

4.9 What was the difference, if any, between the observer's total recorded catch weight (all species) and the catch weight recorded by the vessel?

__ <10%

__ >10% but <20%

__ >20% but <50%

__ >50% but <100%

__ >100%

4.9.1 Please give details as to why these differences occurred.

____

____

____

____

4.10 Was there a difference in over 10% in the observer's recorded catch weight and the vessels recorded catch weight for any <u>single species</u>?

__ Yes

__ No

4.10.1 Please give details as to why these differences occurred.

____

____

____

4.11 Did the observer's working relationship with either the captain or crew have an influence on the catch weight estimation by either party?

__ Yes

__ No

4.11.1 Please explain your choice of answer

____

____

____

4.12 Are there ways in which the observer's abilities to perform his/her duties while on board the vessel could be improved?

__ Yes __ No

4.12.1 Please explain your choice of answer

____

____

____

5 General

5.1 Could measurement of tow by tow catch on vessels be improved in this fishery?

__ Yes __ No

5.1.1 Please explain your answer?

____

____

____

____

____

____

5.2 What obstacles exist, that would/could hinder improvements being made?

____

____

____

____

____

Space for continuation of answers (please identify question(s))

Appendix 3: Case Study Fisheries

Case Study: US Alaska Groundfish Fisheries	
Area	Gulf of Alaska (GOA) and Bering Sea and Aleutian Islands (BSAI) – FAO Area 67
RFMO	North Pacific Fishery Management Council (NPFMC) & National Marine Fisheries Service
Gear	Multiple gears (bottom and midwater trawl, pot, longline)
Stock	Multiple stocks (walleye pollock, Pacific cod, sablefish, shallow and deep water flatfish, rex sole, flathead sole, arrowtooth flounder, Pacific ocean perch, shortraker/rougheye rockfish, northern rockfish, "other slope" rockfish, pelagic shelf rockfish, demersal shelf rockfish, thornyhead rockfish, Atka mackerel, sculpin, octopus, shark, squid, and skate.)
MSC status	Three fisheries have achieved MCS status, pollock in 2005, Pacific cod and Alaska flatfish in 2010. All have been recertified since.
Quota	Multiple species, multiple quotas
Applicability to NAFO catch weight recording	• These are large-scale multispecies fisheries that include pelagic and demersal trawlers. • All catches are weighed using preapproved flow scales to an accuracy of within +/- 3%. • The scales are checked on a daily basis in the presence of an independent observer. The scales must also be able to log the frequency and magnitude of the calibrations and vessels should use video to monitor the area around the scales. • Robust traceability system in place. Once processed products will be packaged and labelled with species, product weight, vessel and date of capture and will go through the supply chain unopened until purchased.
Monitoring and Regulation	Groundfish fisheries off Alaska are conducted in accordance with the requirements of two Fishery Management Plans (FMPs); Groundfish of the Gulf of Alaska[31] (GOA) and Groundfish of the Bering Sea and Aleutian Islands Management Area[32] (BSAI). These fisheries target a range of species and utilize multiple gear types (bottom trawl, midwater trawl, pot, longline). These FMPs have been in place since the 1970s and each has been amended may times in response to changes in resource status, management approach, allocation, monitoring, etc[33]. Among the stipulations laid out in these plans are requirements for observer coverage, reporting of discard, retained catch and production, and provision of additional information necessary for accurate and timely reporting of catch. The Alaska Groundfish Catch Accounting System (CAS) receives data from various sources and provides estimates of catch quantity and composition at the haul and fishery level (refs). The system relies heavily on data collected by observers. Data

[31] NPFMC. 2018a. Fishery management plan for groundfish of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, Alaska 99501. 130 p. (https://www.npfmc.org/wp-content/PDFdocuments/fmp/GOA/GOAfmp.pdf)

[32] NPFMC. 2018b. Fishery management plan for groundfish of the Bering Sea and Aleutian Island management area. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, Alaska 99501. 152 p. (https://www.npfmc.org/wp-content/PDFdocuments/fmp/BSAI/BSAIfmp.pdf)

[33] See for example https://www.npfmc.org/wp-content/PDFdocuments/fmp/BSAI/BSAIGFAmActionSumm.pdf

	sources and estimation methodologies were initially described by (Cahalan et al. 2010)[34] and updated in 2014 (Cahalan et al. 2014)[35] following changes in observer coverage requirements and deployment strategies and additional changes in data collection and submission requirements. The changes in the observer program that were implemented in 2013 (the restructured program) divided the GOA and BSAI groundfish fleet into two non-overlapping deployment categories: the full coverage category that requires at least one observer to be present while a vessel is fishing and, under certain management programs, two at-sea observers; and the partial coverage category that gives NMFS the discretion of placing observers on vessels and at shoreside processing plants. In general, the full coverage category consists of vessels that process catch at sea (catcher/processors (CPs) and motherships), catcher vessels (CVs) fishing for pollock in the Bering Sea, vessels fishing with trawl gear for groundfish for a community development quota program entity, and vessels participating in the Central GOA Rockfish Program. Vessels in the partial coverage category that participate in the BSAI Pacific cod trawl fishery are also currently required to carry an observer on each fishing trip, Shoreside processing plants accepting deliveries from vessels participating in the directed BSAI pollock fishery are required to have shoreside observer coverage for those pollock deliveries. The partial coverage category consists of federally permitted vessels not in the full coverage category, including catcher vessels fishing for Pacific halibut and shoreside plants not in the full coverage category. The CAS relies solely on data collected by observers or industry-submitted data that is verified (e.g. industry discard reports from the partial coverage category are not used; discard from unobserved hauls and trips in this category is estimated from observe data). Sampling methods used by observers are specific to the type of gear being deployed. On trawl vessels, the entire weight of the catch taken on observed hauls is either estimated by the observer or directly measured when on-board flow scales are available. A portion of the total haul is selected randomly and the weight of each species in the sample is recorded. The species-specific weight is expanded by the sampling fraction (size of sample divided by size of haul) to estimate the total catch of that species. Further details regarding catch estimation methods can be found in the 2018 Observer Sampling Manual (AFSC 2018)[36].
Catch recording	Requirements to use certified, motion-compensated flow scales to weigh total catch aboard BSAI pollock catcher processors (CPs) and motherships were first promulgated in 1998 and implemented soon thereafter. The flow scale program was introduced to improve the accuracy and reliability of catch weight estimates in fisheries which processed catch at sea and, thereby, improve accountability in these limited-access fisheries. During development of the program, it became apparent that a comprehensive approach was necessary

[34] Cahalan, J., J. Mondragon, and J. Gasper. 2010. Catch sampling and estimation in the Federal groundfish fisheries off Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-205, 42 p.
[35] Cahalan, J., J. Gasper, and J. Mondragon. 2014. Catch sampling and estimation in the federal groundfish fisheries off Alaska, 2015 edition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-286, 46 p
[36] Alaska Fisheries Science Center (AFSC). 2018 Observer Sampling Manual. Fisheries Monitoring and Analysis Division, North Pacific Groundfsh Observer Program. AFSC, 7600 Sand Point Way N.E., Seattle, Washington, 98115. (https://www.afsc.noaa.gov/FMA/Manual_pages/MANUAL_pdfs/manual2018.pdf)

	to certify specific flow scale models for use in these fisheries, ensure that they were installed correctly and functioned properly (this required an initial inspection and annual re-inspections) and that the scales were calibrated daily while in use and checked for performance. Observers were required to witness and document daily calibrations (materials tests). Flow scales were required to weigh with an accuracy of +/- 3% (when compared with weighing on a motion-compensated platform scale). Even with all these safeguards in place, compliance concerns arose. NOAA served notices of violation to American Seafoods (a company operating pollock CPs in the BSAI) which accused the company of manipulating flow scales measuring Bering Sea pollock catches in numerous hauls of fish in between 2007 and 2012, causing the scales to register lower weights[37]. The company eventually paid a $1.75M civil penalty. Partially in response to compliance and enforcement issues, but also to update flow scale requirements by adding additional fisheries and recognizing technological advances, flow scale regulations were updated in 2014. These new regulations require enhancements of daily scale testing for flow scales, that vessels required to use flow scales have electronics capable of logging and printing the frequency and magnitude of scale calibrations, and that vessels use video to monitor the flow scale and the area around the scales. The requirement now applies to CPs and motherships in AFA (American Fisheries Act), CDQ (Community Development Quota), Amendment 80 (BSAI multispecies bottom trawl), and Central GOA Rockfish fisheries. These are all Limited Access Privilege Programs (LAPPs)[38]. Note that under these new regulations, flow scales are now required in some longline fisheries for Pacific cod. However, unlike trawlers where the entire unsorted catch is weighed on the flow scale, only Pacific cod are weighed on longliner flow scales.
Issues for consideration	• Flow scales are complex instruments which require careful maintenance and monitoring. Defining and implementing requirements for scale certification, inspection following installation, and daily calibration are essential components of a successful system. Furthermore, given the potential for tampering and the stakes involved, calibrations should be monitored by an independent observer have electronics capable of logging and printing the frequency and magnitude of scale calibrations, and vessels should use video to monitor the flow scale and the area around the scales. • Properly used, flow scales can provide accurate and precise measurement of total catch. However, if catch composition by weight is required, catches should be sampled for composition after total weight has been obtained, according to a properly designed sampling plan. This sampling should be carried out by certified observers. • For expansion from weighed and sampled hauls to unsampled hauls, and for estimating total fishery catch by species, a comprehensive catch accounting system is required and all data should be verified (or verifiable). • Costs associated with implementing and maintain a flow scale system can be

[37] See https://www.seafoodsource.com/news/supply-trade/american-seafoods-settles-scale-tampering-cases
[38] see https://alaskafisheries.noaa.gov/rules-notices/search?search_api_views_fulltext=scales for regulatory history

	high. In addition to the scales themselves, agency staff are required for scale inspection and compliance monitoring, and independent observers are required to ensure that daily calibrations are conducted and to carry out species composition sampling. Approximate costs are given below[39]: • New flow scales cost approximately $30K; • Installation costs would vary depending on vessel configuration; • Individual vessel costs to meet scale video monitoring requirements range between $5K and $20K; • The fleet already covers observer costs under different regulations; and • Agency costs include (for Alaska), 2 full time scale installation inspectors, 1.5 new compliance/enforcement officers. • Catcher / processor vessels that use flow scales in the groundfish fishery tend to be large (65-115 meters) which may them more suited to flow scales than vessels in NAFO. • If not already fitted, NAFO vessels would need to be retro-fitted which would increase costs. • Unless strictly monitored and regulated it has been demonstrated that flow sales can be manipulated.

US At-Sea Hake Fishery	
Area	US West Coast from US/Canadian border to Oregon/California border
RFMO/ National Fisheries	Season runs from mid-May each year. Fishery is managed in the US by the National Marine Fisheries Service (NMFS) West Coast Regional Office and Pacific Fishery Management Council. Management in Canadian waters is by the Department of Fisheries and Oceans Canada (DFO) Pacific Region. Bi-lateral Pacific whiting management agreement between the US and Canada was implemented 2012.
Gear	Midwater trawl (pelagic and off-bottom)
Stock	Pacific Hake is a migratory semi-pelagic stock distributed along the west coast of North America; currently the most abundant groundfish population in the California current system. Several distinct populations divided in to coastal (at-sea fishery) and inshore (shore-based whiting fishery). Fish migrate from spawning grounds on the Southern California Bight northwards in spring along the continental shelf to summer feeding grounds off Northern California to Vancouver Island. Range of migration varies from year to year according to age and oceanographic conditions. Spawning occurs December to March; current biomass estimated at 1.357 million mt. Stock relies on high recruitment from above average year classes: long period of decline from mid-80's to 2000, rise peaking in 2003 from 1999-year class. Low recruitment levels thereafter resulted in a time-series low of 0.568mt in 2010. Very large recruitment from 2010-year class. Assessments have provided estimates showing relatively constant biomass since 2013.
MSC status	MSC certified in 2009; re-certified 2014

[39] From: Alaska Regional Office 2014 Rule to provide for more effective monitoring of at-sea flow scales. https://alaskafisheries.noaa.gov/sites/default/files/analyses/scalesdraftrir012014.pdf

Contracting Parties	US, Canada
Quota	TAC in 2018 was 597,500mt. Allocation of TAC under current management agreement is 26.12% Canada, 73.88% to US (2018 US allocation was 441,433mt). The at-sea hake fishery consists of three sectors: Motherships, Catcher/Processors, and Tribal. The TAC is allocated to each sector as a percentage of the annual quota. Due to declines in some species along the West Coast, the fishery is subject to bycatch quotas for specific species. The fishery operates a trawl rationalisation system based on the allocation of shares to cooperatives (catch share program), allowing greater flexibility to share owners. This generates the opportunity for regulatory relief through greater individual and collective responsibility for staying within allowable catch limits imposed by the rationalisation plan.

Applicability to NAFO observer scheme	• The fishery has many similarities to NAFO, both in type of gear and division by areas. Several practices employed in this fishery could apply to NAFO operations.
	• The introduction of flow scales provides a means to provide accurate figures on total catch weight. All catch is required to pass across the scales pre-sorting. This is an essential element of the program:
	    • With appropriate checks in place, provided by the use of flow scales, it could remove the need for observers to estimate total catches;
	    • These tools would enable observers to use random sampling designs to sample catches for bycatch effectively; and
	    • This would increase the reliability and accuracy of data which could be fed in to quota monitoring programs.
	• Random sampling designs would be easy to apply and could remove the potential issue of conflict with the crew of the vessel.
	Training is a key element in the observer program employed in the Hake fishery, and mimicking that practice in NAFO will improve the reliability and applicability of observer data as a management tool.
	• Elements of the observer's tasks are supported by clear protocols, support within regulations, and through contact with observer program advisors.
	• Electronic monitoring has been used successfully within this fishery and provides additional support to the observer's tasks.
	• The hake fishery requirement to report data on all catches at least once a day using NOAA's ATLAS World Ocean Database provides near real-time information. Accurate bycatch data by NAFO divisions and sub-areas could be obtained through this system.
	• The catch share program, as implemented in the Hake fishery, could be considered as a means of reducing regulatory requirements.

Monitoring and Regulation	Managed under the At-sea hake (Pacific whiting)/Pacific Coast Groundfish Fishery Management Plan by Pacific Fishery Management Council (PFMC). Active management of the fishery started in the early 1980's. The PFMC maintains a standardised reporting methodology to assess the amount and type of bycatch occurring within the fishery in addition to being required by the Magnuson-Stevens Act (16 U.S.C. 1853(a) (11), MSA). The MSA also sets out guidelines for federal observer programs.

	Electronic monitoring has been successfully implemented in the Canadian component of the fishery and the US fishery began testing electronic monitoring equipment in 2004 in the shore-based hake fishery and is now in use on several at-sea vessels. Electronic monitoring has the ability to collect data and provide catch accounting. The US fishery presently employs observers on 100% of fishing effort. The at-sea observer program is one of two main components of the fishery's total catch accounting methodology: Observers record bycatch estimates and all landings are monitored. Landings are also sampled by state personnel who collect species composition data, ageing samples (otoliths), lengths and other biological data. Landings, logbook data and port sampling data are reported in-season to the PacFIN data management authority, which is managed by the Pacific States Marine Fisheries Commission. Total catch estimates are tracked using the management of Quota Species Monitoring (QSM) reports.
Catch Recording and Observer Program details	Observers monitor and record catch data, including species composition of retained and discarded catch, along with biological data. NOAA produced a comprehensive At-Sea Hake Observer Program sampling manual for observers as a supplement to the North Pacific Observer Program Manual. All observers go through a 3-week training program. Observer priorities are clearly defined. Observer's report catch data at least once daily via the ATLAS communication software database. Observers monitor between 10 and 20% as a proportion of total landings. If there are 2 or more observers on-board, 100% of hauls are sampled. Otherwise, observers use random sampling protocols and either follow a random sample table or a random break table; break tables are designed to give the observer a six-hour break each day. Sampling units are defined on a haul-by-haul basis following a random sampling design/plan. This follows a stepwise process: (a) Define the population (every fish in haul), (b) Define sample units; (c) Number all sample units; and (d) Randomly select units to sample (random number tables). In the hake fishery, sampling 50% of the haul for species composition is the norm. Subsamples of the catches are randomly collected, weighed and measured. Estimates of total bycatch are then extrapolated from the observer's sampling data. Protocols are well defined for individual species of concern. All data is checked and entered on to ATLAS. Gear checks are performed periodically and observers have access to land-based support from observer program monitors and advisors. A number of vessels now have at-sea electronic monitoring (EM) which includes video footage at various stages of the hauling and processing of the catch. Captain's are required to record haul information in a generic logbook, notebook, or an electronic logbook (ELB). Observers are required to make copies of the vessel's haul information. All vessels are required by regulation to have flow scales and must test them daily; everything in the catch must pass over the flow scale to be weighed. If large species are extracted on deck (e.g. large sharks) the observer must be informed and allowed time to measure the total length which is then applied to species-

	specific length/weight tables to estimate weight. No pre-sorting is permitted on deck. Flow scales must be tested daily by the vessel and must be verified and witnessed by the observer for the test to be valid. It is the vessel's responsibility to conduct the test when the observer is present. The vessel must complete a daily flow scale test record form. Observers use the flow scales to record species composition from random samples. This is done in cooperation with the crew. Recording catch weight across the flow scales pre and post sampling provides the total weight of each sample. All bycatch species within each sample must be recorded.
Issues for consideration	• The cost of fitting flow scales may be expensive to individual vessel companies: there may be a need to support this process over a time-defined period. • Observer operations require cooperation from vessel crews in assisting with observer tasks. • The introduction of an effective sampling protocol may be able to reduce observer coverage needed and thus expense. • These changes would represent a shift away from observers providing a purely compliance role to a more scientific role. This may improve the perceptions of the utility of the observer's role both within the industry and by the observer and may improve morale.

CCAMLR Fisheries	
Area	Southern Ocean, FAO Areas 48 and 58
RFMO	Managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), with the characteristics of an RFMO with respect to fisheries management, but with additional responsibility for the conservation of marine life in the Southern Ocean under the Antarctic Treaty System.
Gear	Pelagic trawl, both traditional and continuous. Currently two vessels employ the continuous method (where the net stays in the water for an extended period and the catch is pumped on-board).
Stock	Antarctic krill (*Euphausia superba*). Although fisheries have occurred in Area 58, and a small amount still is taken from there, the main fishery occurs in Area 48. The current stock estimate for Area 48 is 60.7 million tonnes, based on the last survey conducted in 2000. An updated survey and assessment is planned from 2019.
MSC status	Currently two companies, covering 4 of the 10 vessels currently authorised to fish, have achieved MSC certification, Aker Biomarine in 2010 and Pesca Chile in 2018.
Contracting Parties	There are currently 24 acceding states to CCAMLR and the EU. Not all are fishing nations and only five fish for krill: Chile (2 vessels), China (2 vessels), Korea (3 vessels), Norway (2 vessels) and Ukraine (1 vessel).
Quota	CCAMLR follows the precautionary principle and the current quota for Area 48 is set at 5.61 million tonnes (just over 9% of the estimated biomass). The catch is further limited to 620,000 tonnes, which is defined as a 'trigger level', if reached then further interim management measures will be put in place.
Applicability to NAFO catch weight recording	• A pelagic trawl fishery which is monitored and managed through real time closures based on catch reporting. • Some of the catch estimation methods are similar to those used in NAFO (and other trawl fisheries) and issues with the accuracy of catch reporting has previously been identified.

	• To assess the level of uncertainty in catches, vessels are required to record in their logbooks the estimation method used and the variables that have gone into making that estimation, some of which will change on a tow by tow basis, other will change throughout the season. This involves constantly checking the estimation method. • CCAMLR have standardised data collection and submission formats used by all member states. They are also in the process of accrediting observer training courses throughout their member states to ensure minimum training standards are in place.
Monitoring and Regulation	All fisheries in CCAMLR are managed through a series of Conservation Measures (CMs), which are binding on all parties. The CMs are reviewed annually by the Commission, based on advice from the Scientific Committee and its Working Groups, who set the quotas and assess decision rules that manage the fishery (akin to the process employed by NAFO). The quota is set for the area, not for individual vessels of flag states. Although the quota is set at 5.61 million tones, the management of the fishery is based on the 'trigger level', when reached the fishery will in effect be closed for the season until interim management measures (as yet undefined) are put in place. To prevent all the catch being taken from one area, the 'trigger level' is divided between four Subareas[40] (48.1, 48.2, 48.3 and 48.4), when the trigger level is reached in any one area it will be closed for the rest of the season and the vessels must move on to another. To effectively monitor catches within each area, vessels are required to report their catches to the CCAMLR Secretariat on a monthly basis[41]. The Secretariat will then compile the catch statistics and inform the vessels of what proportion of the trigger level has been taken, should the catches reach 80% of the trigger level then the frequency of catch reporting increases to every 5 days to ensure there is no overshoot of the trigger level. There is a system of observation in place, although prior to 2009 this was only done on a voluntary basis. Since 2009 it has been phased in with a target of 100% coverage (of vessels) by 2010. Observers are deployed for scientific purposes, , although the information they collect may be used later in assessing compliance with certain measures such as the design and deployment of bycatch mitigation devices. Their main role is to collect biological information on the target species and bycatch species (which may otherwise be missed) and monitor for any incidental mortalities. They do not give independent estimates of catches of target species, bycatch or discards although they can assist vessels in completing their logbooks and undertaking their reporting requirements, for example through identifying certain bycatch species. They also record to method by which catches are recorded compared to the method that was notified to CCAMLR.
Catch recording	As well as ensuring that area-based catch limits are not exceeded, accurate information on total removal of krill is important to track the dynamics of the stock and impact of the fishery and feed into the feedback management system that is being developed for the fishery. There has been concern regarding potentially large variation between reported green weight and actual green weight being removed, largely due to variety of conversion factors being reported

[40] CCAMLR Conservation Measure 51-07
[41] CCAMLR Conservation Measure 23-06

	(although in reality, conversion factors are rarely used to calculate green weight in the krill fishery). Therefore, as part of their annual notification to fish[42], vessels are required to submit details of how they estimate or measure the green weight that is reported to CCAMLR. The methods used were split into six categories: • Flow meter: Pipes into the factory measure the volume of krill passing through, which is then converted to weight using a volume to mass multiplier that accounts for the added volume from seawater. • Flow scale: A conveyor weighs the amount of krill as it is transported from the holding tank into the factory. The fraction of water mixed in with the krill is accounted for by calculating the 'drip loss'. This is the weight of water that drains off a sample after a two-hour period and typically accounts for 8-12% of the sample weight. • Holding tank volume: Uses the height to which the holding tank is filled after each haul and applies a volume to mass multiplier. • Plate tray: Where krill are packed into trays, the mean mass of krill per tray is multiplied by the number of trays, accounting for the mass of the tray itself. • Codend volume: This method builds from recognizing that most codends have a regular shape and volume. The volume of krill in each catch can therefore be calculated where the length of the codend filled with krill is known (through counting the number of equidistant rope rings used to strengthen it). Weight is determined through a volume to mass multiplier. • Conversion factor: Use of a conversion to convert the product into the green weight. For all methods there are a number of variables, some of which are constant, some haul specific, and some variable depending on time of year and area, among other things. To assess the level of uncertainty around each of these methods, vessels are required to record in their logbooks, on a tow by tow basis, the variables and associated values appropriate to their estimation method[43]. A full description of the variables used for each method is given in Table 10. CCAMLR observers do not give any independent estimate of the catch but they do document how vessels record their catch weights. Their role is mainly scientific, along with collecting biological data on the target species they also subsample the catch for bycatch, larval or smaller fish. Data collection forms, protocols and priorities are decided by the Scientific Committee and standardised through all the Member States. Since 2009, CCAMLR have been developing an accreditation system for all training courses run by Member States or their providers (COTPAS – CCAMLR Observer Training Programme Accreditation Scheme), although it is currently only voluntary, following resistance from some Members to fully adopt it. Since 2019 it has also been mandatory for observers to carry '…personal locator beacons and two way satellite communications devices' to enhance observer safety and welfare.

[42] CCAMLR Conservation Measure 21-03

[43] SC-CCAMLR-XXXI, Annex 6. Report of the Working Group on Ecosystem Monitoring and Management. Appendix D. Santa Cruz de Tenerife, Spain, 2 to 13 July 2012.

Issues for consideration	• There are fewer vessels in this fishery (compared to those operating in the NRA) making it easier to monitor and manage. • As a target species krill will be very different to finfish species so not all the estimation methods will be appropriate. Although prawns are targeted in NAFO, they are taken in a demersal fishery and fewer problems with catch weight estimations have been identified against them. • The observer program is scientific only and does not give independent estimates of catches of target or bycatch species. • While quotas are set for the various management areas, until recently they have not been reached and there is little incentive to misreport. Catches in the Area as a whole have not exceeded 300,000 tonnes since the early 1990s, less than half the 'trigger level' currently in place.

Table 10. Examples of parameters on which uncertainty estimates are needed. V – volume of krill; W – width; L – length; H – height; ρ – volume-to-weight conversion factor; A – product weight; β – product-to-green weight conversion factor; sub-index 'h' indicates haul-by-haul estimation[44].

Method	Equation (kg)	Parameter			
		Description	Type	Estimation method	Unit
Holding tank volume	$W*L*H*\rho*1\,000$	*W* = tank width	Constant	Measure at the start of fishing	m
		L = tank length	Constant	Measure at the start of fishing	m
		ρ = volume-to-mass conversion factor	Variable	Volume-to-mass conversion	kg/litre
		H = Tank height	Haul specific	Direct observation	m
Flow meter	$V*F_{krill}*\rho$	*V* = volume of krill and water combined	Haul-specific	Direct observation	litre
		F_{krill} = fraction of krill in the sample	Haul-specific	Flow meter volume correction	-
		ρ = volume-to-mass conversion factor	Variable	Volume-to-mass conversion	kg/litre
Flow scale	$M*(1–F)$	*M* = mass of krill and water combined	Haul-specific	Direct observation	kg
		F = fraction of water in the sample	Variable	Flow scale mass correction	-
		M_{tray} = mass of empty tray	Constant	Direct observation prior to fishing	kg
Plate tray	$(M–M_{tray})*N$	*M* = mean mass of krill and tray combined with water drained	Variable	Direct observation, prior to freezing	kg
		N = number of trays	Haul-specific	Direct observation	-
Meal conversion	$M_{meal}*MCF$	M_{meal} = mass of meal produced	Haul-specific	Direct observation	kg
		MCF = meal conversion factor	Variable	Meal to whole krill conversion	-
Codend volume	$W*H*L*\rho*\pi/4*1\,000$	*W* = codend width	Constant	Measure at the start of fishing	m
		H = codend height	Constant	Measure at the start of fishing	m
		ρ = volume-to-mass conversion factor	Variable	Volume-to-mass conversion	kg/litre
		L = codend length	Haul-specific	Direct observation	m

[44] Taken from CCAMLR Conservation Measure 23-06.

UK North Sea Cod Fishery	
Area	ICES Division IVa & IVb and 2a.
RFMO	ICES (International Council for the Exploration of the Sea)
Gear	Trawl (single and pair trawling) and Danish Seine.
Stock	North Sea cod stock SSB has increased since its historical low in 2006 but is forecast to be 116,380 tonnes in 2019, below the MSY $B_{trigger}$ level of 150,000 tonnes.
MSC status	The fishery achieved MSC status in 2017. The Scottish Fisheries Sustainable Accreditation Group (SFSAG) fishery for North Sea cod is made up of a number of different producer organisations representing 232 vessels.
Contracting Parties	SFSAG is made up of all the Scottish Producer Organisations (POs) and a number of fishermen associations.
Quota	In addition to its share of UK quota, the Scottish fleet also swaps quota with other EU Member States. In 2017 the quota was 32,53 tonnes, 18,730 tonnes of which was the final allocation for the Scottish fleet.
Applicability to NAFO catch weight recording	• The fishery includes a demersal trawl fishery targeting a mix of species. • Vessels have taken part in voluntary trials using Remote Electronic Monitoring (REM) as part of the Marine Management Organisation's (MMO) Fully Documented Fisheries Scheme to monitor discarding (described in a separate case study in more detail). • Target species was part of the EU cod recovery plan following the reduction in stocks to 44,000 tonnes in 2006 from a peak of 270,000 tonnes in the 1970's. This included developing a system of electronic monitoring using CCTV on-board vessels to monitor catches and discards. The fishery went from being a stock in recovery to receiving MSC status in 2017. • Use of electronic logbooks (e-logbook) has standardised the recording and reporting of catches.
Monitoring and Regulation	The North Sea stock is shared jointly between Norway and the EU, the majority of the Unit of Certification (UoC) stock is taken within EU waters with a small part being taken within the Norwegian EEZ. As a result of declining stocks, it become subject to an EU multiannual recovery plan initiating in 2004 and revised as a two-stage plan in 2008 with a recovery phase and a long-term management phase which was initiated in 2016 and is currently in force. The majority of the Monitoring, Control and Surveillance (MCS) activities are undertaken by Marine Scotland Compliance (a small amount is also undertaken by the Norwegian Directorate of Fisheries) in conjunction with enforcement authorities at the UK and EU level. They also exchange information with the Norwegian authorities and using a risk-based framework identify areas where enforcement activities can best be put in place to ensure compliance. The system for fisheries control is laid out in the Control Regulation which has been in place since 2010. Among other things it requires that all vessels over 12 meters are fitted with a VMS system and use electronic logbooks (e-logbooks). Member states are required to carry out monitoring of their fleet and follow up on any infringements detected, this includes misreporting of catches by more than 500kg or 10% of what is recorded in the logbook. A system for the registration of all buyers and sellers has also been in place since 2005 and all auction sites must be

	officially designated to reduce the opportunity for any IUU fish to pass though the market. Compliance in the fishery is thought to be high, with no infractions being reported in 2015 and 2016. The phased introduction of the EU Landing Obligation (LO) between 2015 and 2019 has highlighted the need to carefully monitor catches of all managed species to ensure individual vessels do not overrun their quota allocations. As well as innovations in gear technology this also led to an industry driven scheme for the spatial and temporal reporting of unwanted catches through observer programs, self-reporting and Remote Electronic Monitoring (REM).
Catch recording	Vessels in this fishery are required to use an electronic logbook (e-logbook) and are tracked via VMS. There is also robust chain of custody system in place, governed by the EU and UK Government, to ensure traceability of all the products. After each haul fish are brought on-board and graded according to length and marketplace demand, and placed into open containers based on their grade. The containers are labeled with the species, weight and date of capture and, in the case of cod, are marked as MSC certified provided they are caught within the certification area (this can be verified through linking the date of capture to the e-logbook which records exactly where the vessel was fishing at that time). Fish are not processed or frozen on-board but are covered with ice to maintain their temperature and landed fresh. Once landed the labelled boxes remain separated by fishing area and are either sold directly by the fishing company to a processor at point of landing or through an auction. EU traceability legislation means that fish bought at auction must also be labelled with the vessel name, fishing gear used and ICES catch area prior to the sale so the buyers can make more informed decisions. Traceability up to the point of first sale is maintained by the vessel skipper, any subsequent change of ownership after this requires additional chain of custody certification. Fish are either landed at ports in the UK or in northern Denmark. Buyers and sellers are required to be registered (under the Registration of Fish Buyers and Sellers and Designation of Fish Auction Sites Regulations 2005) and all transactions at first point of sale must be fully recorded. This, combined with the use of e-logbooks and normal customs and practices mean that there are a number of measures in place to ensure that any mis-reporting is detected. In addition, each vessel in the unit of certification is required to sign a terms of membership that any product under that unit of certification shall be segregated and traceable through logbooks and other mechanisms, for example GPS linked weighing records.
Issues for consideration	• All vessels are registered to a single Member State and the majority of monitoring is undertaken by single entity (Marine Scotland) with small amounts undertaken by Danish authorities. • All products are landed fresh and trip are generally short (2-3 days) compared to NAFO.

	• Low level of observer monitoring (<1% of trips monitored).

Norwegian Spring Spawning Herring Fishery	
Area	North-east Atlantic, EEZ's of Norway, Russia, Iceland, EU and Faroe Islands
RFMO	North-East Atlantic Fisheries Commission (NEAFC) provides recommendations, conservation and management measures, although these measures are not binding. International Management Plan advised by ICES in place. Employs Port State Measures (PSMs) for catch monitoring.
Gear	Purse-seine, pelagic (midwater trawl)
Stock	Highly migratory stock, spawning off the Norwegian west coast between February and March, when they are targeted. The general trend is downwards, however, 2016 recruitment year numbers are very high.
MSC status	MSC certified in 2009, recertified 2014. Expedited Assessment carried out May 2018 – assessment identified that management needs to improve, new condition have been put in place to develop precautionary harvest control strategy.
Contracting Parties	Norway, Iceland, Faroe Islands, European Union, Russian Federation
Quota	Norway has approximately 60% of the quota. In 2019, the quota is 588,562 tonnes, an increase of 53% recommended by ICES, based on the 2016 year class being the strongest since 2004, signalling an upturn in stocks. In 2018, the quota was 384,197 tonnes; there was no international agreement on quota in 2018: sum of quotas set by contracting parties was 546,448 tonnes.
Applicability to NAFO observer scheme	• The method of probability-based catch sampling could potentially provide a framework for directing observers in biological sampling of catches within NAFO sub-areas and divisions. • It potentially has a number of applications both for sampling of target species and sampling bycatch and could be used to provide real-time data for monitoring purposes since the model is considered to provide near optimal sampling. This data can then be scaled up to provide an estimate of all catches.
Monitoring and Regulation	Predominantly through the use of 'live' self-reporting of information on fishing activities reported through NEAFC's Electronic Reporting System (ERS). Each contracting party is responsible for monitoring their vessels according to the recommendations of NEAFC.
Catch Recording	Catch monitoring aims to establish the number of fishes caught per year class within the fishery and for each defined area. Data on catches are used in conjunction with surveys and acoustic data for stock biomass assessment. Length/weight and age at length are determined in order to achieve this. For length and weight data, fish are self-sampled by fishermen at sea for every catch, who then report the data using the ERS daily to Norges Sildesalgslag (prize reward system): Norway uses the Norwegian fisherman's sales organisation Norges Sildesalgslag for catch figures sold in all sales and electronic auctions. Landed catches are recorded and traceability management procedures in place. For age at length composition for total catches, a probability-based catch

	sampling protocol is in place. Data is based on analysed samples and landings statistics. Sampling is conducted in 'real time' using the vessel's Electronic Recording System (ERS) to 'order' samples from fishing operations (PSUs; primary sampling units): age at length is determined from fish scales: fish must be sampled from catches at sea and frozen to ensure scales of sufficient quality for age-reading. The fish are selected as samples at sea using a catch sampling strategy called the 'Herring Lottery'. The Herring Lottery operates by requesting all vessels >15m with ERS (a requirement of licence) to report estimated catches immediately when a set is successful, directly to the Norwegian Directorate of Fisheries. Vessels are put in to a 'lottery' and selected probabilistically based on criteria set in terms of catch fraction of quota, time, area, gear and across vessels in order to achieve an optimal sampling regime. Vessels are then notified within minutes (max. 1 hour) if selected to retain a sample of the catch for freezing and later submission to Norges Sildesalgslag on landing. Frozen boxes are then shipped to the Norwegian Institute of Marine Research. Feedback is then provided to the Directorate of Fisheries and the fishing industry.
Issues for consideration	• Use of the ERS requires IT support and programming based on robust statistical model. • The system is voluntary and in order to work effectively, requires strong support from industry. • Monitoring and self-regulation of landed catches are a major contributor to data outputs. • Self-regulation on-board vessels requires a high degree of trust and some training. • Sampling protocol and data collection relies heavily on vessel's Electronic Recording and Reporting System (ERS).

UK Marine Management Organization (MMO) – Fully Documented Fisheries (FDF) Scheme	
Area	ICES Division IVa & IVb VIIe.
RFMO/ Management organisation	Marine Management Organisation (MMO)
Gear	Multiple
Stock	Within the UK fleet there are three schemes in place – North Sea cod, Western English Channel focusing on haddock and dover sole, fishing multiple stocks.
MSC status:	N/A
Quota:	N/A
Contracting Parties	English fleet
Background	The use of Remote Electronic Monitoring (REM) as a tool towards achieving the goal of a Fully Documented Fishery (FDF) has been trialled in a number of countries including Canada, the US, Australia, New Zealand, Denmark, the Netherlands and Germany. For the most part these have shown REM to be reliable, although they have tended to be in fisheries where individual fish have

	been easy to identify in the catch, such as hook and line fisheries, or that have concentrated on a single species in a mixed fishery, such as cod. The MMO FDF scheme has been organised in cooperation with industry as a voluntary scheme since 2011 to monitor a multispecies fishery with the primary aim of reducing the catch and discarding of unwanted and undersized fish. The phased introduction of the Landing Obligation in 2015 (completed in 2019) has meant that all managed fish species caught by EU vessels must be landed and are subsequently counted against quota, it is therefore important to ensure that catches are accurately monitored so the obligation can be met. The trails have shown that it has significantly reduced the amount of quota species being discarded at sea – in 2015 discards of cod by vessels taking part in the North Sea scheme were below 1% of the total catch compared to an estimated 41% for non-participating vessels. This is due primarily to vessels modifying their behaviour of gear to reduce catches of small or untargeted fish. Despite this the participation is still low, estimated to be around 1%, despite the fact that it has worked out to be cheaper when compared to other independent monitoring schemes, such as observer programs. The scheme will continue in 2019 on a voluntary basis.
Applicability to NAFO catch weight recording	• Uses Remote Electronic Monitoring (REM) to record vessel activity, including species caught, retained and discarded. • Cameras monitor fish processing and discarding, GPS tracks where vessel is fishing and sensors detect when the fishing net is deployed. • Introduced primarily to monitor discarding and incentivises vessels to reduce discarding by using more selective gear and fishing practices (for example avoiding areas where juvenile fish are likely to be caught). From 2015 vessels taking part in North Sea scheme were shown to have had less than 1% of cod catch discarded compared to estimates of 41% for non-participating vessels[45]. • Improved technology has meant reduced costs in recent years within UK fleet estimated to be approximately $5,000[46][47] per year which is lower than the cost of deploying an observer.
Catch recording	While there is no current accepted definition of FDF, and in many cases the term is interchangeable with Remote Electronic Monitoring (REM), in the case of the MMO trials it refers to a system that uses sensors to detect when the net is being deployed and recovered, a GPS to record where the net is being deployed and recovered and CCTV footage to record what is being caught and confirm that no discarding is taking place (for managed species). Weights of species can be recorded as they come on-board through cameras

[45] MMO (2017). Fully Documented Fishery scheme helping to reduce discards of quota species. Sourced from https://marinedevelopments.blog.gov.uk/2017/03/20/fully-documented-fishery-discards-quota-fish-cctv/

[46] WWF UK (2017). Remote Electronic Monitoring. Why camera technology is a cost effective and robust solution to improving UK fisheries management.

[47] This 2017 figure includes a 90% contribution from the European Maritime and Fisheries Fund (EMFF) for hardware and installation costs. Without this, annual costs would be closer to $7,500 assuming a five year lifespan.

	trained on scales or the conveyor once species have been separated. Any discards can be monitored through cameras directed towards the discard chute. Information is stored on hard drives to be reviewed on return to shore by trained reviewers. In other programs, initiated in Denmark, footage is transferred live, or near live, via 3G. Although this technology has been trialled in a number of different fisheries and is useful for monitoring some compliance issues such as the monitoring of discards, studies have shown that there can be a tendency for video inspectors to underestimate discards by 32%[48] when compared to fishermen or on-board observer estimates where a mixed fishery is involved.
Issues for consideration	• Scheme is currently voluntary and the take up is relatively low despite the incentives of additional quota or days at sea. • Most fishermen who have not experienced it before see REM as intrusive. • Without incentive, it is unlikely that fishermen will take it on a voluntary basis, as it can leave them at a commercial disadvantage compared to those who do not have it. • Technical problems still exist, for example with formatting of hard drives that store data. • While it could be used as a tool to replace observers at sea for compliance purposes, all footage must still be reviewed to provide 100% coverage which would be time consuming. • Some evidence of potential camera tampering has been identified such as bypassing the field of view or smearing the camera lens.[49]

[48]Mortensen, L, O, Ulrich, C, Jakob Olesen, H, Bergsson, H, Casper W. Berg, C, W, Nikolaos Tzamouranis, N, Dalskov, J. (2017) Effectiveness of fully documented fisheries to estimate discards in a participatory research scheme. Fisheries Research 187. 150–157

[49] See https://www.seafish.org/media/1807738/dag_oct2018_mmo.pdf

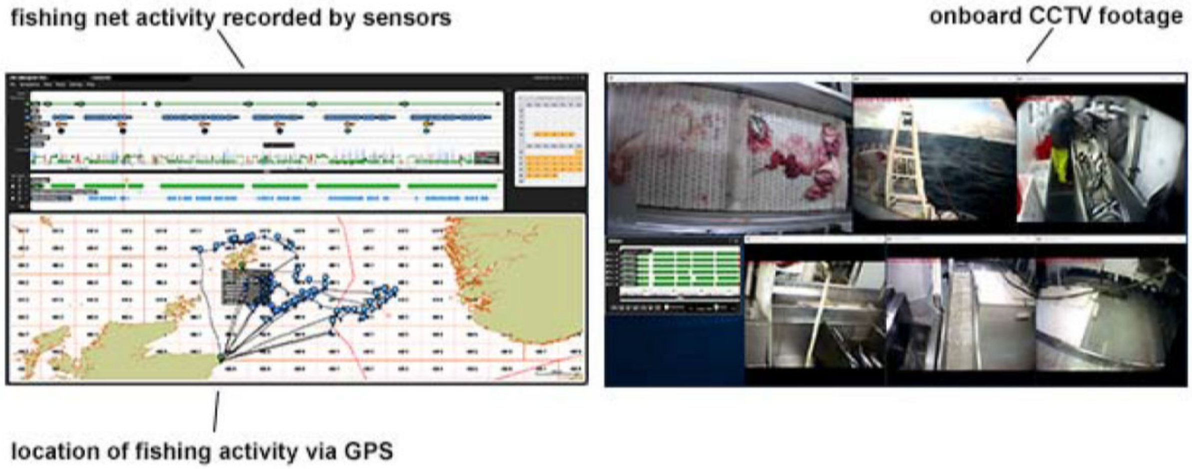

Figure 16. Screen set up of an MMO Analyst looking at data and footage from a catch quota trial vessel[45].