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Section Contents

i Executive summary

Assessments run at AFWG provide the scientific basis for the management of cod, haddock, saithe, redfish, Greenland halibut, and capelin in subareas 1 and 2. Taking the catch values provided by the Norwegian fisheries ministry for Norwegian catches and raising the total landed value to the total catches gives an approximate nominal first-hand landed value for the combined AFWG stocks of ca. 20 billion NOK or ca. 2 billion EUR (2018 estimates). NEA cod and coastal cod were benchmarked in 2021. For NEA cod this resulted in updates to the existing SAM assessment model. For coastal cod, the stock has been split into two components. North of 67°N the coastal cod is now assessed with a SAM assessment model, while between 62°N and 67°N the coastal cod is assessed using a category 3 approach based on a CPUE time-series. AFWG is currently working towards running a benchmark (and subsequent HCR evaluation) for Greenland halibut, which is planned for 2022–2023.

The key feature driving the stock assessments this year was that several key surveys (the ecosystem survey, winter survey, and the Lofoten survey) all came in with low totals for the main AFWG stocks. This has led to downward revisions of many of the stocks described here. Several data errors were discovered following the AFWG meeting in April 2021. These had very minor impacts on the NEA cod and haddock assessments (which are not updated in this report), but revised the quota for northern coastal cod from an initial estimate of zero catch to 7865 t (version in this report based on the corrected data).

Stock-by-stock summaries

Cod in subareas 1 and 2 (Northeast Arctic) was assessed using the SAM model following the outcome of the benchmark meeting (WKBARFAR 2021). The biomass is declining, but SSB is still well above B_{pa}. The TAC advice for 2022 is 708 480 tonnes, corresponding to F = 0.50. This is 20% down on the TAC and the advice for 2021. F is above F_{pa}, because the harvest control rule adopted in 2016, limits the annual decrease to 20%. Without this constraint, the advice would have been 604 125 tonnes. The decrease from last year's advice is due to changes in SAM settings and input data at the benchmark, as well as low survey indices in 2021.

Cod in subareas 1 and 2 North of 67°N (Norwegian coastal cod North)—cod.27.2.coastN—is a new ICES stock following a benchmark in 2021 and is the northern part of the previous coastal cod stock. The stock was assessed using the new SAM model developed at the benchmark meeting (WKBARFAR 2021). The spawning-stock biomass increased by 10 000 t in 2020 compared to 2019, but spawning-stock biomass is still below B_{lim} and F increased in 2020. However, the data indicates that the stock is capable of rising above B_{lim} within one year. The catch advice is set to be no more than 7865 t (including all commercial and recreational catches), which is estimated to be the largest catch permitting recovery above B_{lim} in one year.

Cod (Gadus morhua) in Subarea 2 between 62°N and 67°N (Norwegian coastal cod South)—cod.27.2.coastS—is a new ICES stock following a benchmark in 2021 and is the southern part of the previous coastal cod stock. The stock is assessed using the 2-over-3 rule based on a CPUE series from the Norwegian coastal reference fleet (9–15 m, fishing with gillnets in the second half of the year), alongside a LBSPR model to evaluate the necessity of a precautionary buffer. In principle, the CPUE could be used to tune a SPiCT model, however, the time-series needs to be extended before this is practicable. A key uncertainty is the lack of good data on the substantial recreational portion of the overall catch. The current assessment shows a decrease in the spawning potential ratio with a decline in both mean length and mean length of largest 5%. These combine to depict a somewhat depleted and worsening stock status. Given the largely stable CPUE trend in recent years and no adopted reference points, the 2-over-3 rule, including a precautionary buffer, suggests a 6% decrease in next year's catches compared to the last three years average.

Haddock in subareas 1 and 2 (Northeast Arctic) was assessed using the SAM model. The spawning-stock biomass has declined since 2013 but is still well above B_{pa}. The TAC advice for 2022 is 180 003 tonnes, corresponding to F = 0.35. This is 23% down on the TAC and the advice for 2021. The decrease from last year's advice is mainly due to low indices from surveys in autumn 2020 and winter 2021. The retrospective trend indicates that the catch advice given in 2020 for 2021 is likely biased high. The catch in 2020 was 15% lower than TAC and the catch is expected to be below the TAC also in 2021, especially since the TAC in 2021 was higher than the 2020 TAC.

Saithe in subareas 1 and 2 (Northeast Arctic) was assessed using the SAM model. The spawning-stock biomass is well above B_{pa} and has been increasing since 2011, although the increase has been lower in the last years. Considering uncertainty fishing mortality has been below $F_{pa} = 0.35$ since 2015. The TAC advice for 2022 is 197 212 tonnes (corresponding to $F_{mp} = 0.32$) and is very similar to the 197 779 tonnes TAC and advice for 2021. Currently, particularly the strong 2013 (8-year old fish) and the 2016 (5-year old fish) year classes are contributing substantially to the SSB. The retrospective trend indicates that SSB was only slightly overestimated in 2017–2019. In 2020 preliminary catches totalled 169 405 tonnes, corresponding to 99% of the quota allocated.

Redfish (Sebastes mentella, Sebastes norvegicus) in subareas 1 and 2 (Northeast Arctic): is assessed on a two-year cycle, with the next advice in 2022. Interim model results for *S. mentella* indicate that at current levels of exploitation SSB by the end of 2020 is estimated to be 874 727 t with fishing mortality of the plus-group corresponding to $F_{19+} = 0.05$, higher than in 2019 but still below the advised quota. Catches of *S. norvegicus* in 2020 amounted to 9033 t, continuing the trend of increased bycatch since the quota for beaked redfish was raised in 2019. The stock was not assessed in 2021.

Greenland halibut is assessed on a two-year cycle, with advice provided this year. Poor recruitment over the last decade combined with fishing c. 1/3 above advice over the last decade has led to a continued decline in the fishable 45 cm+ biomass, which is currently estimated at 601 kt. The previous precautionary basis for advice was rejected by the Advice Drafting Group (ADG), and an HR_{pa} proposal was requested. Following a delay due to COVID-19, this has now been submitted to ICES for consideration by the ADG.

Anglerfish (Lophius budegassa, Lophius piscatorius) in subareas 1 and 2 (Northeast Arctic): AFWG does not currently give advice on this stock. However, following a recent benchmark, we are now in a position to do so if requested by the managers. Management is based on technical measures rather than a quota. Data-limited model results based on length data from the fishery suggest that the exploitation pattern is appropriate, while the rate is close that which would lead to maximum yield.

Barents Sea capelin: following ToR b), the data on Barents Sea capelin were updated. No assessment is conducted during the spring AFWG meeting, the assessment occurs in autumn following the ecosystem survey[1]. A benchmark will be held in 2022 for this stock together with capelin in the Iceland-East Greenland-Jan Mayen area[2].

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[1] As of October 2021, Section 10 of this report has been updated to reflect the outcomes of the autumn survey and the consequent meeting held online 4–5 October 2021.

[2] The two capelin stocks will be included in the benchmark workshop WKREDCAP 2022, together with beaked redfish (*Sebastes mentella*) in Subarea 14 and Division 5.a, Icelandic slope stock (East of Greenland, Iceland grounds).

ii Expert group information

Expert group name	Arctic Fisheries Working Group (AFWG)
Expert group cycle	Annual
Year cycle started	2020
Reporting year in cycle	1/1
Chair	Daniel Howell, Norway
Meeting venue and dates	14–20 April 2021, online meeting (26 participants)

1 Introduction and ecosystem considerations

Arctic Fisheries Working Group

1.1 Terms of reference

2020/2/FRSG02 The **Arctic Fisheries Working Group** (AFWG), chaired by Daniel Howell, Norway, will meet online 14–20 April 2021 to:

a) Address generic ToRs for Regional and Species Working Groups, for all stocks except the Barents Sea capelin, which will be addressed at a meeting in autumn;

b) For Barents Sea capelin oversee the process of providing intersessional assessment;

c) Conduct reviews as required of time any series computed using the STOX and ECA open source software for use in assessment in the Barents Sea.

The assessments will be carried out on the basis of the Stock Annex. The assessments must be available for audit on the first day of the meeting.

Material and data relevant to the meeting must be available to the group on the dates specified in the 2021 ICES data call.

AFWG will report by 7 May 2021 and 8 October 2021 for Barents Sea capelin for the attention of the Advisory Committee.

Only experts appointed by national Delegates or appointed in consultation with the national Delegates of the expert's country can attend this Expert Group.

1.2 Additional requests

There were no additional requests.

1.3 Responses to terms of reference

Under ToR a (address generic ToRs), the stock assessments and advice were conducted according to generic ToRs c and d, while the generic ToR e benchmark review can be found further down in this introduction and the haddock, NEA cod and coastal cod sections. Work on generic ToRs a and b will be conducted intersessionally as it becomes appropriate.

ToR b is handled in detail by the capelin subgroup of AFWG, held in autumn after the capelin survey. A brief report on the previous capelin assessment is given in this report.

ToR c is to review data changes as required, and this was not required in 2021.

1.4 Benchmarks

A cod benchmark (WKBARFAR 2021) was conducted in early 2021 (ICES, 2021a). This benchmark resulted in a modification of the existing NEA cod SAM assessment model. For coastal cod, the benchmark resulted in the stock being split into two, a category one northern stock (with a SAM stock assessment) and a category three southern stock (2-over-3 rule based on a CPUE series).

Capelin[3] is scheduled to have a benchmark in 2022, with HCR revision conducted at the benchmark. Greenland halibut is scheduled for a benchmark in 2023[4], followed by an HCR evaluation.

1.5 Total catches

In this report, the terms 'landings' and 'catches' are, somewhat incorrectly, used as synonyms, as discards are in no cases used in the assessments. This does not mean, however, that discards have not occurred, but the WG has no information on the possible extent. In contrast, available information indicates low discard rates at present (less than 5% of catch) and it is assumed that discards are negligible in the context of the precision of the advice.

As in previous years, a report from the Norwegian-Russian Analysis group dealing with estimation of total catch of cod and haddock in the Barents Sea in 2018 was available to AFWG. The report presents estimated catches made by Norwegian, Russian and third countries separately. According to that report, the total catches of both cod and haddock reported to AFWG are very close (within 1%) to the estimates made by the analysis group. Thus, it was decided to set the IUU catches for 2017 to zero.

For further information on under- and misreporting, we refer to the 2016 AFWG report.

Discards estimates (1994–2020) of redfish, cod, haddock and Greenland halibut juveniles in the commercial shrimp fishery in the Barents Sea are presented in Figure 0.1. These estimates are obtained with a spatio-temporal model based on a procedure elaborated in Breivik *et al*. (2017). In Breivik *et al.* (2017) an extensive validation study indicates that the new procedure obtains bycatch estimates with approximately correct uncertainty. Previous estimates for the period 1982–2015 are given in earlier reports (e.g. AFWG 2018), and we have not been able to compare these two time-series in detail. Such a comparison should be performed on a relatively fine spatio-temporal resolution. The bycatch estimates illustrated in Figure 0.1 and are available for each quarter in each main statistical area (not shown in report). Note that it is still a work in progress regarding improving the new estimates.

The new time-series in Figure 0.1 are obtained by scaling the estimated bycatch in the Norwegian fishery with the international fishery in each ICES area. The scaling procedure assumes that the Norwegian fishery is representative of the international fishery. This assumption is necessary because the international catch data are available only to a low spatio-temporal resolution. If the international vessels in a relatively high degree trawl at locations not trawled by Norwegian vessels, the bycatch estimates illustrated in figure 0.1 may be biased.

1.5.1 Uncertainty in catch data

For the Norwegian estimates of catch numbers at-age and mean weight-at-age for cod and haddock methods for estimating the precision have been developed, and the work is still in progress (Aanes and Pennington, 2003; Hirst *et al.*, 2004; Hirst *et al.*, 2005; Hirst *et al.*, 2012). The methods are general and can in principle be used for the total catch, including all countries' catches, and provide estimates both at-age and at-length groups. Typical error coefficients of variation for the catch numbers-at-age are in the range of 5–40% depending on age and year. It is evident that the estimates of the oldest fish are the most imprecise due to the small numbers in the catches and resulting small number of samples on these age groups. From 2006 onwards, the Norwegian catch-at-age in the assessment has been calculated using the ECA method described by Hirst *et*

[3] Currently part of benchmark workshop WKREDCAP 2022.

[4] Proposed for a 2022–2023 benchmark together with NWWG Greenland halibut, ghl.27.561214.

al. (2005). The methodology for using ECA to split cod catches into NEA cod and coastal cod is still under development (WKARCT 2015). ECA has now been implemented for saithe, and with partial success for *S. mentella*. A new version of the program (StoX-ECA) is now being tested.

Aging error is another source of uncertainty, which causes increased uncertainty in addition to bias in the estimates: An estimated age distribution appears smoother than it would have been in absence of ageing error. Some data have been analysed to estimate the precision in ageing (Aanes, 2002). If the ageing error is known, this can currently be taken into account for the estimation of catch-at-age described above.

For capelin, the uncertainty in the catch data is not evaluated. The catch data are used, however, only when parameters in the predation model are updated at infrequent intervals, and the uncertainty in the catch data are considered small compared with other types of uncertainties in the estimation.

We note that the SToX survey methodology reviewed by the group is able to produce uncertainty estimates for the survey time-series.

Additional sources of uncertainty arising from sources beyond sampling or age-reading errors have implications for a number of the stocks assessed here. Coastal cod catches, and to a lesser extent catches of the much larger NEA cod stock, have uncertainty issues due to the difficulty of splitting catches between the two stocks. A similar issue applies to small *S. norvegicus* stock and the larger *S. mentella* stock, where species misidentification can be a significant source of error. Finally, there is no agreement between Norway and Russia on an age-reading methodology for Greenland halibut, and such data are not used for tuning the model. The absence of age data creates an important (but unquantifiable) source of error on the GHL stock estimate.

1.5.2 Sampling effort–commercial fishery

Concerns about commercial sampling: The main Norwegian sampling program for demersal fish in ICES subareas 1 and 2 has been port sampling, carried out onboard a vessel travelling from port to port for approximately 6 weeks each quarter. A detailed description of this sampling program is given in Hirst *et al.* (2004). However, this program was, for economic reasons, terminated 1 July 2009. Sampling by the 'reference fleet' and the Coast Guard has increased in recent years. However, the reduction in port sampling of many different vessels seems to have increased the uncertainty in the catch-at-age estimates from 2009 onwards (WD6, 2010). A Norwegian port sampling program was restarted in 2011, although with a lower effort, this improved the basis for the 2011–2019 catch-at-age estimates. From 2014 this program is run by 4-year contracts of a vessel that sails between fish landing sites along the coast from about 66°N to Varanger (70°N, 30°E) three periods a year during the first, second, and fourth quarters, altogether up to 120 days. This is a reduction compared to about 180 days a year before 2009. The catch sampling is done of landed fish, mainly from the fleet fishing in coastal waters, and usually inside the plant, and the rented vessel acts as a transport, accommodation and working (age reading, data work) platform. AFWG recommends that such sampling is also carried out during the third quarter.

Table 0.1–Table 0.4 show the development of the Norwegian, Russian, Spanish and German sampling of commercial catches in the period 2008–2020. The tables show the total sampling effort, but do not show how well the sampling covers the fishery. Indices of coverage should be developed to indicate this. The main reason for the general strong decrease in numbers of Norwegian samples in the first part of this period is the termination of the port sampling program in northern Norway. This program is now up and running again. It should be considered whether catch sampling carried out by different countries fishing by trawl for the same time and area could be coordinated and data shared on a detailed level to a greater extent than is done today.

Cod, haddock and saithe: Available catch-at-age and length data covered the largest portion of catches by the respective fisheries. However, there was a period in spring 2020 when port sampling was at a lower level than usual due to the COVID-19 situation. However, the aggregation level (time and space) used when splitting these catches into Northeast Arctic cod and Norwegian Coastal Cod is also an important issue. Despite the improvement in sampling coverage in 2016–2020, the number of samples should be increased in the coming years, with the aim of covering all quarters and areas contributing the highest catches.

Due to the adopted amendments of the Russian Federal Law "On fisheries and preservation of aquatic biological resources" coming into force, especially concerning the destruction of biological resources caught under scientific research, sampling activities (age sample numbers and length/weight measurements of fish) on board fishing vessels are also reduced, especially in ICES subareas 2.a and 2.b, which may result in greater uncertainty of the stock assessments due to possible biases in the age–length distributions of the commercial catch.

Length measurements of fish and age sampling by Russia have been especially low in ICES subareas 2.a and 2.b in the first half of 2020 due to administrative difficulties in arrangement (stationing) observers onboard fishing vessels (a prolonged procedure via open contest). Available Norwegian data on cod and haddock length measurements onboard Russian vessels made by the Norwegian Coast Guard in the Norwegian economic zone have been used, where possible, in calculations of catch-at-age data by Russia.

Data issues with *S. mentella*: There is still a concern about the biological sampling from the fishery and scientific surveys that may have become critically low, however, there is also a lag of several years between collection of age samples and the processing of them. This is elaborated in the section for this stock.

Data issues with *S. norvegicus*: Despite a recent increase in age-reading for this species, age data are rather poor, and effort in age sampling from the catches is required. The other main source of uncertainty is species misidentification from *S. mentella*, and consequently, careful monitoring that species composition is being reported correctly is required.

Data issues with NEA Greenland halibut: There is still a concern about the biological sampling from the fishery that may have become critically low. Age information is not available, due to disagreements on age reading method, and may affect precision in the assessment which at the moment is length-based. Norwegian landings are split on Greenland halibut by sex for area, gear groups, and quarters. Annual sample level has decreased in the last years and may affect the precision of the catch distribution.

The samples and data basis behind each stock assessment are discussed more in detail under each stock-specific section of this report (e.g. the coastal cod). The number of aged individuals per 1000 t is now well below the standard set by the EU in their Data Collection regulations. For several stocks sampling is inadequate for area/quarter/gear combinations making up considerable proportions of the total catch.

Discontinuation of the Russian autumn survey decreased considerably the biological sampling (age sample numbers, abundance indices evaluations, maturity status of fish definitions, feeding data collections, etc.).

1.5.3 The percentage of the total catch that has been taken in the NEAFC regulatory areas by year in the last year

Generic ToR c-iii asks for the percentage of the total catch that has been taken in the NEAFC regulatory area by year in the last year. In the area where AFWG stocks are distributed, there are two areas outside national EEZs which are part of the NEAFC regulatory area: The International area in ICES Subarea 1 in the Barents Sea (“loophole”, denoted as 1.a or 27_1_A) and the International area in ICES divisions 2.a and 2.b in the Norwegian Sea (“banana hole”, denoted as 2.a.1 and 2.b.1 or 27_2_A_1 and 27_2_B_1). In the table below the WG presents the most likely landings from these areas based on the official reports and discussions within the WG. The text table below shows the percentages for *S. mentella*, Northeast Arctic cod and haddock and Greenland halibut. For the other AFWG stocks, no catches are taken in those areas. The highest precision in these numbers is probably the *S. mentella* figures since these figures have been tabulated each year since 2004, and have been given regular and special attention, also by NEAFC.

	ICES 1.a	**ICES 2.a.1**	**ICES 2.b.1**	**Total**	**%NEAFC**
2020					
NEA cod	1607	9	0	1616	0.23%
Coastal cod	0	0	0	56653	0.0%
NEA haddock	0	0	0	182468	0.0%
NEA saithe	0	3	0	169405	<0.1%
Sebastes mentella	0	5469	0	54686	10.0%
Sebastes norvegicus	0	0	0	9033	0.0%
Greenland halibut	450	0	0	28713	1.5%
Capelin	0	0	0	0	0.0%
Anglerfish	0	0	0	2280	0.0%
2019					
NEA cod	1094	0	0	692609	0.16%
Coastal cod	0	0	0	52807	0.0%
NEA haddock	394	0	0	175402	0.225%
NEA saithe	250	7	0	163180	0.001%
Sebastes mentella	0	6060	0	45954	13.2%
Sebastes norvegicus	0	0	0	8285	0.0%
Greenland halibut	1108	3	0	28832	3.8%
Capelin	0	0	0	0	0.0%
Anglerfish	0	0	0	2809	0.0%
2018					
NEA cod	1724	2	0	778627	0.22%
Coastal cod	0	0	0	36375	0.0%
NEA haddock	24.1	0	0	191276	0.013%

	ICES 1.a	ICES 2.a.1	ICES 2.b.1	Total	%NEAFC
NEA saithe	2.4	0	0	181280	0.001%
Sebastes mentella	3	7823	0	38765	20.2%
Sebastes norvegicus	0	0	0	6647	0.0%
Greenland halibut	798	0	0	28544	2.80%
Capelin	0	0	0	0	0.0%
Anglerfish	0	0	0	1903	0.0%
2017					
NEA cod	1212	12	0	868276	0.14%
Coastal cod	0	0	0	51053	0.0%
NEA haddock	90	0	0	227588	0. 0004%
NEA saithe	70	11	0	145403	0.06%
Sebastes mentella	0	6463	0	31200	20.7%
Sebastes norvegicus	5	0	0	5340	0.1%
Greenland halibut	592	6	0	26380	2.3%
Capelin	0	0	0	0	0.0%
Anglerfish	0	0	0	1478	0.0%
2016					
NEA cod	3619	0	0	849422	0.4%
Coastal cod	0	0	0	54767	0.0%
NEA haddock	7	0	0	233416	0.003%
NEA saithe	81	0	0	140392	0.06%
Sebastes mentella	0	7170	0	35429	20.2%
Sebastes norvegicus	10	0	0	4674	0.2%
Greenland halibut	363	5	0	24972	1.5%
Capelin	0	0	0	0	0.0%
Anglerfish	0	0	0	1435	0.0%
2015					
NEA cod	9	0	0	864384	0.001%
Coastal cod	0	0	0	35843	0.0%

	ICES 1.a	ICES 2.a.1	ICES 2.b.1	Total	%NEAFC
NEA haddock	702	0	0	194756	0.4%
NEA saithe	30	0	0	131765	0.0%
Sebastes mentella	0	4752	0	25856	18.4%
Sebastes norvegicus	13	0	0	3632	0.4%
Greenland halibut	55	0	0	24748	0.2%
Capelin	0	0	0	115044	0.0%
Anglerfish	0	0	0	1043	0.0%
2014					
NEA cod	534	0	0	986449	0.1%
Coastal cod	0	0	0	33660	0.0%
NEA haddock	0	0	0	177522	0.0%
NEA saithe	0	0	0	132005	0.0%
Sebastes mentella	0	4020	0	18780	21.4%
Sebastes norvegicus	0	0	0	4438	0.0%
Greenland halibut	211	0	0	23025	0.9%
Capelin	0	0	0	66000	0.0%
Anglerfish	0	0	0	1657	0.0%

1.6 Uncertainties in survey data

While the area coverage of the winter surveys for demersal fish was incomplete in 1997 and 1998, the coverage was normal for these surveys in 1999–2002. In autumn 2002, 2006 and winter 2003, 2007, 2016 and 2017 however, surveys were again incomplete due to lack of access to both the Norwegian and Russian Economic Zones. This affects the reliability of some of the most important survey time-series for cod and haddock and consequently also the quality of the assessments.

It is very important that the Norwegian and Russian authorities give each other's research vessels full access to the respective economic zones when assessing the joint resources, as was the case for Joint winter surveys (BS-NoRu-Q1 (Btr) and BS-NoRu-Q1 (Aco)) in 2004–2005, 2008–2011 and 2013, for example.

The area coverage in the winter survey was extended from 2014 onwards (Figure 0.2, Table 3.5). With the recent expansion of the cod distribution, it is likely that in years before 2014 the coverage in the February survey (BS-NoRu-Q1 (BTr) and BS-NoRu-Q1 (Aco)) has been incomplete, in particular for the younger ages. This could cause a bias in the assessment, but the magnitude is unknown. The 2014–2021 surveys covered considerably larger areas than earlier winter surveys and showed that cod, haddock and Greenland halibut was distributed far outside the standard survey area. The 2017 and 2018 surveys were restricted by ice Northeast of Hopen Island, and the survey did not extend quite as far as in the years 2014–2016. In 2019 the coverage was almost as extensive as in 2014. Coverage in 2020 and 2021 was less extensive mainly due to increased ice cover in the east. For all stocks except Greenland halibut, mainly younger age groups are found in the northern area. It should however be noted that the survey index from this survey is currently not used in the assessment of Greenland halibut.

The survey estimates within the new, extended area are now used for the tuning data for cod, but with the bottom trawl series split in 2014, as decided at the WKBARFAR 2021 benchmark. For haddock, the new northern area is also included as decided at the WKDEM benchmark in 2020.

There are also other issues with incomplete survey coverage of stocks, e.g. haddock off the Norwegian coast south of Finnmark is not covered in the winter survey and the *S. mentella* survey in the Norwegian Sea does not cover the entire distribution area.

From 2004 onwards, a joint Norwegian-Russian survey has been conducted in August-September. This is a multi-purpose survey termed an "ecosystem survey" because most of the ecosystem is covered; including an acoustic survey for the pelagic species, which is used for capelin assessment, and a bottom trawl survey which includes non-commercial species. The ecosystem survey is now included in both cod and haddock assessments. The survey is also utilized in the assessment of redfish and Greenland halibut.

In 2018, a large area in the eastern Barents Sea was not covered due to technical problems with one vessel, while in 2019, most of the Barents Sea was covered except parts of the International waters and the Northeastern most part. In 2020 the spatial coverage was good, but for COVID-19 related reasons, the survey was less synoptic than usual as the time between the start and end of the survey was 13 weeks while the normal is about 8 weeks (Fig 0.3). Also, one of the vessels used had not previously been used in this type of bottom trawl surveys. The bottom trawl survey indices for cod and haddock from this survey in 2020 were considerably lower than expected, in particular for cod, but it was decided to include them in the assessment. Also, the survey coverage for capelin was not complete at the time assessment and advice had to be provided. Although this did not affect the advice this year, which would have been zero catch even when using the final estimate for the entire area, that may not be the case in future.

It is very important that this survey should be continued with complete spatial coverage and as synoptic as possible. In addition to being the only survey used in capelin assessment and being used in assessment of demersal stocks, it has been shown to be valuable for sampling of synoptic ecosystem information, cover the entire area of fish distribution in the Barents Sea, and provide additional data on geographical distribution of demersal fish, which could prove valuable in future inclusion of more ecosystem information in the fish stock assessments.

The Norwegian coastal survey (NOcoast-Aco-4Q) has in its current design been conducted since 2002. The survey covers the coastal area, including most fjords, and shelf area, including banks, between Kirkenes in northern Norway and Stadt off central Norway. The survey area is divided into seventeen strata, each containing several substrata, and is generally covered by two vessels, which collect acoustic data along defined transects and catch and biological data from both fixed bottom trawl stations and trawl stations identifying acoustic registrations. The coverage of the area has been fairly consistent throughout the time-series. In 2020 bad weather prevented the coverage of three substrata in the southern part of the survey area. Historically the contribution of these areas to the saithe and coastal cod survey index has been low, and it is therefore assumed that the lack of coverage of these areas in the 2020 estimate will not affect the final survey index.

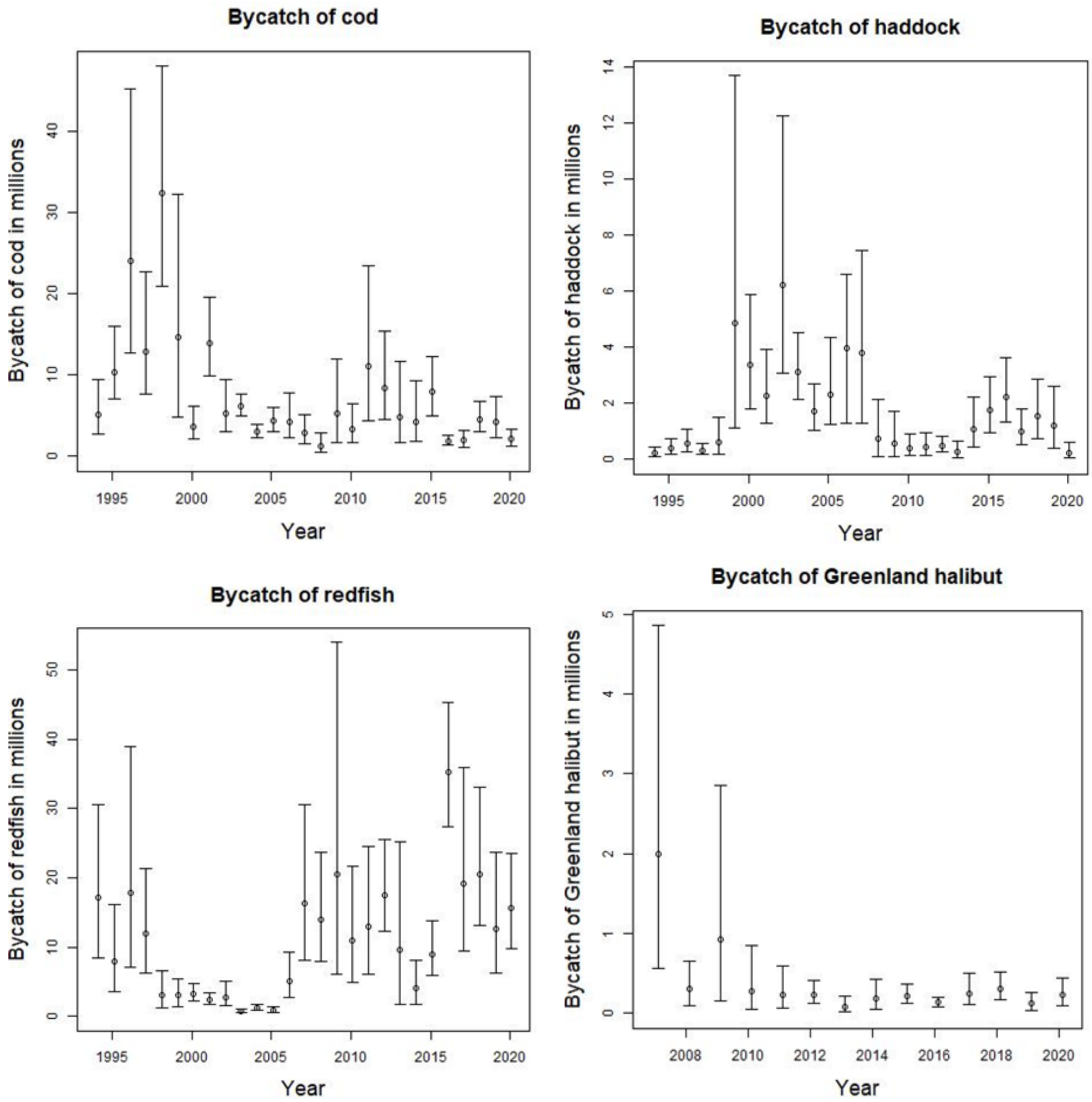

Figure 0.1. Estimated bycatch of cod, haddock, redfish and Greenland halibut in the Barents Sea shrimp fishery. Intervals are 90% confidence intervals.

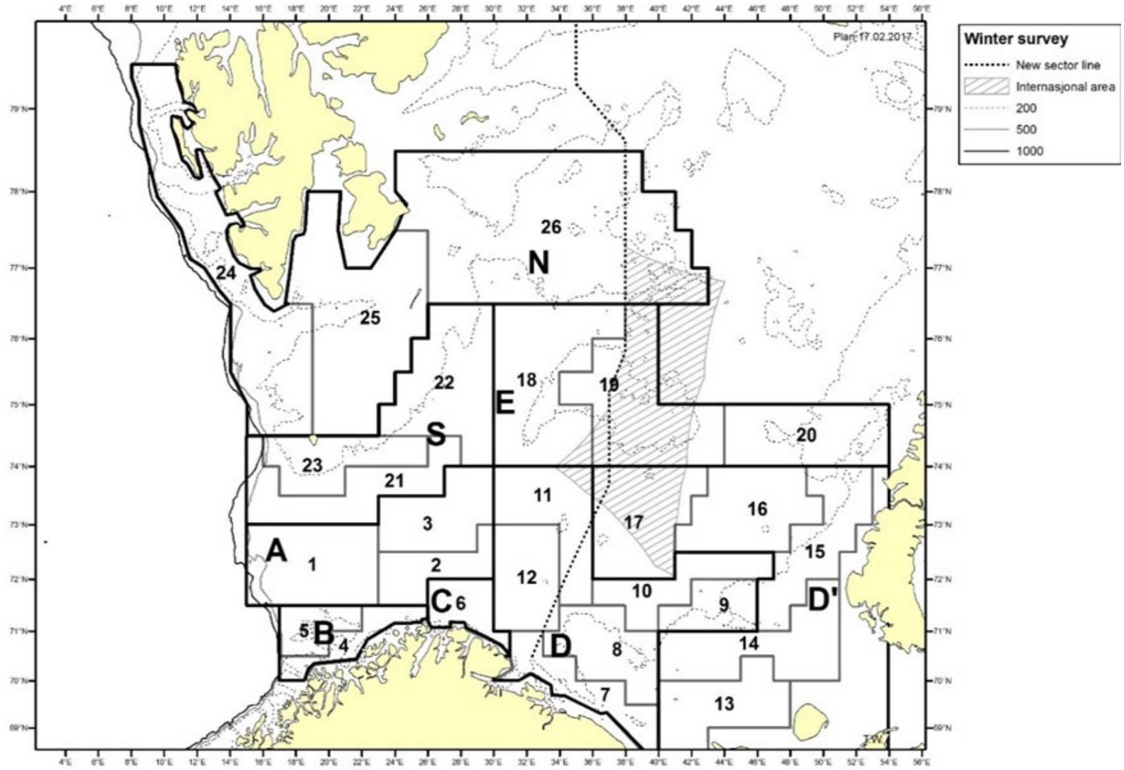

Figure 0.2. Strata (1–26) and main areas (A,B,C,D,D',E and S) used for swept-area estimations and acoustic estimations with StoX. Strata (24–26, main area N) are covered since 2014, and are now included in the standard time-series.

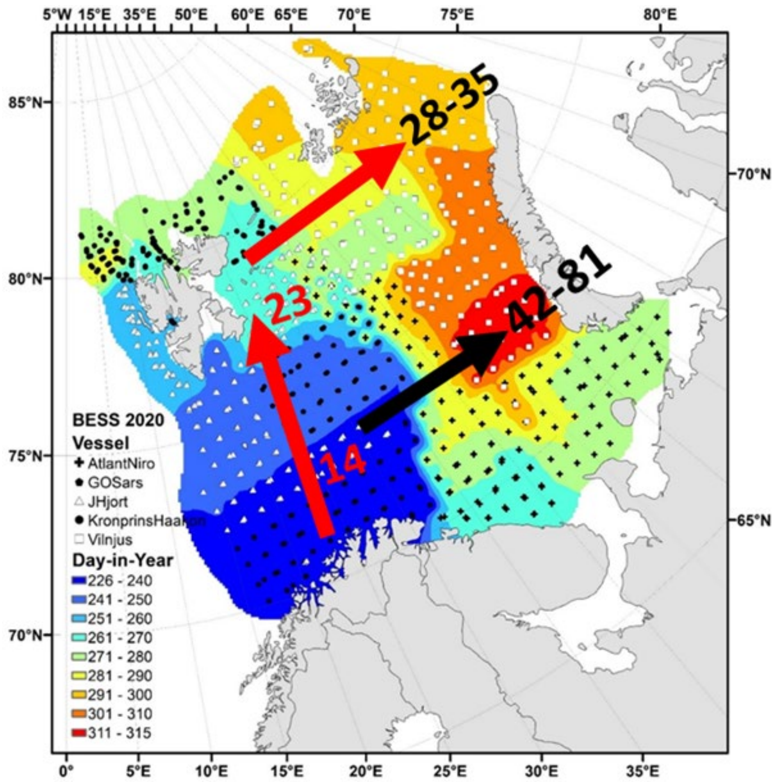

Fig 0.3. Barents Sea Ecosystem Survey (BESS) 2020, area coverage and trawl stations.

After AFWG 2021 minor errors were discovered in the Norwegian SToX dataseries for 2021 for NEA cod and haddock. The advice has been updated and reflects the corrected data. However the values presented in this report are prior to the correction. More detail is given in the relevant stock sections.

1.7 Age reading

In 1992, PINRO, Murmansk and IMR, Bergen began a routine exchange program of cod otoliths in order to validate age readings and ensure consistency in age interpretations (Yaragina *et al.*, 2009b, AFWG 2008, WD 20). Later, a similar exchange program has been established for haddock, capelin and *S. mentella* otoliths. Once a year (now every second year, no exchanges of redfish age readers so far) the age readers have come together and evaluated discrepancies, which are seldom more than 1 year, and the results show an improvement over the period, despite still observing discrepancies for cod in the magnitude of 15–30%. An observation that is supported by the results of an NEA cod otolith exchange between Norway, Russia and Germany (Høie *et al.*, 2009; AFWG 2009, WD 6). 100 cod otoliths were read by three Norwegian, two Russian and one German reader, reaching nearly 83% agreement (coefficient of variation 8%). The age reading comparisons of these 100 cod otoliths show that there are no reading biases between readers within each country. However, there is a clear trend of bias between the readers from different countries, Russian age readers assign higher ages than the Norwegian and German age readers. This systematic difference is a source of concern and is also discussed in Yaragina *et al.* (2009b). This seems to be a persistent trend and will be revealed in the following annual otolith and age reader exchanges.

From 2009 onwards, it was decided to have meetings between cod and haddock otolith readers only every second year. The overall percentage agreement for the 2017–2018 exchange was 87.7% for cod (WD 08), which was a little lower than at the previous meeting. The general trend is that the Russian readers assigned slightly higher ages than the Norwegian readers compared to the modal age for age group 7 years and older. The main reason for cod ageing discrepancies between Russian and Norwegian specialists was still a result of different interpretations of the false zones. This can partly be caused by different reading techniques, i.e. IMR reading opaque zones and PINRO reading translucent zones. For haddock, the main reason for discrepancies between PINRO and IMR readers was a different interpretation of the otolith summer structures in the first and second year of fish, life due to false zones. Sometimes discrepancies were caused by a different interpretation of the latest increments that were very thin in some cases.

For both species, the samples collected in autumn appeared to be the hardest to interpret. The main reason for that seems to be difficulties in determining if the marginal increment represents summer (opaque) or winter (translucent) growth.

A positive development is seen for haddock age readings showing that the frequency of a different reading (usually ±1 year) has decreased from above 25% in 1996–1997 to about 10% at present. The discrepancies are always discussed and a final agreement on the exchanged cod and haddock otoliths is achieved for all otoliths at present, except ca. 2–5%. For haddock, the overall percentage agreement for recent data (2017–2018) was 88.1% and the precision CV was 3.0%, the same values for cod totalled 87.7% and 3.7% accordingly and considered to be satisfactory.

The next workshop on cod and haddock otolith reading will be held in May–June of 2021.

As the EU catches only make up a few percent (<10%) of the total, the German and Spanish length and age data do not have a major impact on the assessment of the relevant stocks. But in order to use consistent datasets, regular age-reading comparisons should be made. EU age readers could be invited to the NOR-RUS exchanges and workshops.

To determine the effects of changes in age reading protocols between contemporary and historical practices, randomly chosen cod otolith material from each decade for the period 1940s–1980s has been re-read by experts (Zuykova *et al.,* 2009). Although some year-specific differences in age determination were seen between historical and contemporary readers, there was no significant effect on length-at-age for the historical period. A small systematic bias in the number spawning zones detection was observed, demonstrating that the age at first maturation in the historic material as determined by the contemporary readers is younger than that determined by historical readers. The difference was largest in the first sampled years constituting approximately 0.6 years in 1947 and 1957. Then it decreased with time and was found to be within the range of 0.0–0.28 years in the 1970–1980s. The study also shows that cod otoliths could be used for age and growth studies even after long storage.

For capelin otoliths, there is a very good correspondence between the Norwegian and Russian age readings, with a discrepancy in less than 5% of the otoliths. This was confirmed at the Norwegian-Russian age reading workshop on capelin in October 2011 (WD 13, 2012).

For some of the samples, a very high agreement was reached after the initial reading by the different experts. In other cases, some disagreement was evident after the first reading. After the initial reading, the results were analysed. The otoliths that caused disagreement were read again and discussed among the readers. After discussions about the reasons for disagreement, some readers wanted to change their view on some of the otoliths. When the samples were read once more, the agreement was 95%.

It was concluded that experts from all laboratories normally interpret capelin otoliths equally. Difficult otoliths are sometimes interpreted differently, but these samples are few, and should not cause large problems for common work on capelin biology and stock assessment. All participants noted the great value of conducting joint work on otolith reading, and it was decided to continue the programme of capelin otolith exchange and to involve the labs at Iceland and Newfoundland in the exchange program. Readers from Norway and Russia should continue to meet at Workshops every second year. A capelin age reading Workshop was held in Murmansk in April 2016, and the report from that meeting was presented to the capelin assessment meeting in October 2016. An age reading Workshop for capelin was held in Murmansk in October 2019.

In order to achieve the most accurate age estimates, ICES recommends methods and best practices for age reading of both redfish and Greenland halibut. Still there continue to be differences in opinion between PINRO and IMR regarding age reading methods for these species. It is recommended to start an annual or biannual exchange of otoliths and age reading experts on these species in order to identify the differences in interpretation and to discuss possibilities for a common approach.

The report from the Workshop on Age Reading of Greenland Halibut (WKARGH; ICES CM 2011/ACOM:41) described and evaluated several age reading methods for Greenland Halibut. A second workshop (WKARGH 2) was conducted in August 2016 and worked on further validation on new age reading methods. The workshop recommended that two new methods can be used to provide age estimations for stock assessments. Further, recognizing some bias and low precision in methods, the WKARGH2 recommends that an ageing error matrix or growth curve with error be provided for use in future stock assessments (WKARGH2 report 2016, ICES CM 2016/SSGIEOM:16). WKARGH2 recommends regular inter-lab calibration exercises to improve precision (i.e. exchange of digital images between readers for each method and between methods). The new age readings are not comparable with older data or the Russian age readings, and the new methods show that the species is more slow-growing and vulnerable than the previous age readings suggest. AFWG suggests that Russian and Norwegian scientists and age readers meet to work out issues of disagreements on Greenland halibut aging.

From 2009 onwards, an exchange of *Sebastes mentella* otoliths is conducted annually between the Norwegian and Russian laboratories (see section 6.2.2). In 2011 ICES/PGCCDBS identified differences in the interpretation of age structure by different national laboratories and recommended that international exchanges of otoliths be conducted (ICES C.M. 2011/ACOM:40). The work was conducted during 2011 (Heggebakken, 2011) with participation from Canada, Iceland, Norway, Poland and Spain. Unfortunately, Russia did not respond to the invitation to participate. The agreement in age determination was 79.2% (with allowance for ±1 years) for all ages combined, but 38.6% when only fish older than 20 years were considered. It is recommended that 1) future exchanges be conducted every 3–5 years, 2) that these should primarily focus on 20+-year-old fish and 3) that Russian scientists contribute to future exchanges. A meeting between *S. mentella* age readers from Norway and Russia was held in 2013. Otolith exchanges took place in 2014. It is recommended that such meetings and otolith exchanges be conducted regularly in future.

1.8 Assessment method issues

For coastal cod, the benchmark has resulted in a split into two stocks. For the northern (north of 67 degrees) part there is now a SAM assessment model. However there is no Fmsy (since we have no data above B_{lim}), and there is a need for a rebuilding plan for this stock. In addition, since this is the first assessment model it is likely that there will be a need for a revision once we accumulate some years' experience running the model. The southern (between 62 and 67 degrees north) now gives advice based on a 2-over-3 rule. A surplus production, based on the reference fleet CPUE, was developed. However, the CPUE time-series was too short to adequately tune the model. This should be investigated further as the time-series is extended, with a view to an eventual benchmark and adoption of the production model for assessment purposes.

Work is in progress on revising the capelin assessment methodologies, with a planned benchmark (in conjunction with Iceland) in 2022. Greenland halibut also has a benchmark (again jointly with Iceland) in 2022, planned to be followed by an HCR evaluation. For Greenland halibut the target F is the key issue, with the previous F_{pa} being rejected by the Advice Drafting Group. A revised F_{pa} has therefore been submitted.

1.9 Environmental information included in the advice of NEA cod

For the fourteenth time, environmental information has been applied in the advice from AFWG. In this year's assessment ecosystem information was directly used in the projection of NEA cod. A combination of regression models, which is based on both climate and stock parameters, were used for the prediction of recruitment-at-age 3, see section 1.11.4.

In addition, the temperature is part of the NEA cod consumption calculations that goes into the historical back-calculations of the amount of cod, haddock, and capelin eaten by cod.

1.10 Proposals for status of assessments in 2021–2022

For anglerfish there is currently no advice, however following the benchmark in 2018 we are now in a position to conduct an assessment and provide advice if requested to do so. Greenland halibut is assessed this year and will be benchmarked next year in time for the next advice in 2023, the two redfish stocks will get an update assessment in 2022.

Table 0.1. Age and length sampling by Norway of commercial catches in 2008–2019. Number of samples and average number of fish per sample. Also, number of age samples and aged individuals per 1000 t caught. For comparison, also the EU DCF requirements are shown.

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of unique vessels (***)	No of age samples	No of aged individuals	Landing tonnes	Length-samples per 1000 t	Age samples per 1000 t	Aged individuals per 1000 t	EU DCF for comparison per 1000 t
NEA-cod + coastal cod												
	2008	336	2526	51263		464	16026	196067	12.9	2.4	81.7	125
	2009	272	2669	53350		417	14170	224816	11.9	1.9	63.0	125
	2010	175	2542	39733		338	7671	263816	9.6	1.3	29.1	125
	2011	273	2305	46227		434	10043	331535	7.0	1.3	30.3	125
	2012	356	3132	57954		618	14710	363207	8.6	1.7	40.5	125
	2013	266	2917	81583	84	1275	13940	464258	6.3	2.7	30.0	125
	2014	556	2063	254627	306	1170	14815	465554	4.4	2.5	31.8	125
	2015	498	1654	130514	89	1392	16500	413741	4.0	3.4	39.9	125
	2016	482	2500	91590	401	1398	17027	403907	6.2	3.5	42.2	125
	2017	413	2615	91366	348	1458	15471	408423	6.4	3.6	37.9	125
	2018	873	3163	122788	346	1545	15535	369897	8.6	4.2	42.0	125
	2019	842	3093	135375	337	1457	12519	322233	9.6	4.5	38.9	125
	2020	389	1869	53587	259	653	12431	334773	5.6	2.0	37.1	125

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of unique vessels (***)	No of age samples	No of aged individuals	Landing tonnes	Length-samples per 1000 t	Age samples per 1000 t	Aged individuals per 1000 t	EU DCF for comparison per 1000 t
NEA-haddock												
	2008	285	2177	45038		281	9474	72553	30.0	3.9	130.6	125
	2009	233	2255	41481		206	6010	104882	21.5	2.0	57.3	125
	2010	154	2155	38045		232	5458	123517	17.4	1.9	44.2	125
	2011	227	2028	39663		312	7225	158293	12.8	2.0	45.6	125
	2012	258	2609	47995		386	8191	159008	16.4	2.4	51.5	125
	2013	89	2142	62193	86	965	5718	99127	21.6	9.7	57.7	125
	2014	425	1479	114560	126	825	7297	91333	16.2	9.0	79.9	125
	2015	397	1380	76574	47	967	8394	95086	14.5	10.2	88.3	125
	2016	237	1986	47032	208	391	8202	108718	18.3	3.6	75.4	125
	2017	215	2108	57461	150	1084	8805	113206	18.6	9.6	77.8	125
	2018	536	2435	85303	130	1088	8397	93839	25.9	11.6	89.5	125
	2019	497	2269	83378	123	1003	7652	93860	24.2	10.7	81.5	125
	2020	142	1055	32009	70	342	6589	88108	12.0	3.9	74.8	125
NEA-saithe												
	2008	252	1327	19419		160	5262	165998	8.0	1.0	31.7	125
	2009	182	1337	13354		113	2981	144570	9.2	0.8	20.6	125

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of unique vessels (***)	No of age samples	No of aged individuals	Landing tonnes	Length-samples per 1000 t	Age samples per 1000 t	Aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2010	138	1316	15998		151	3667	174544	7.5	0.9	21.0	125
	2011	152	1210	17412		215	4843	143314	8.4	1.5	33.8	125
	2012	209	1474	19191		204	4113	143104	10.3	1.4	28.7	125
	2013	87	1570	69469	69	788	5507	111981	14.0	7.0	49.2	125
	2014	192	697	54365	94	575	5390	115880	6.0	5.0	46.5	125
	2015	206	839	69375	43	614	6484	114830	7.3	5.3	56.5	125
	2016	226	1448	52376	151	737	7278	121710	11.9	6.1	59.8	125
	2017	195	1416	42812	141	788	6348	128651	11.0	6.1	49.3	125
	2018	388	1665	43938	148	823	6937	162454	10.2	5.1	42.7	125
	2019	380	1629	43503	136	817	6552	144133	11.3	5.7	45.5	125
	2020											
S. Norvegicus												
	2008	104	1093	18305		98	2281	6180	176.9	15.9	369.1	125
	2009	66	1131	17386		96	2302	6215	182.0	15.4	370.4	125
	2010	49	1050	19339		97	2164	6515	161.2	14.9	332.2	125
	2011	75	1064	16347		106	2310	4645	229.1	22.8	497.3	125
	2012	78	993	12994		76	1297	4250	39.1	3.1	56.7	125

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of unique vessels (***)	No of age samples	No of aged individuals	Landing tonnes	Length-samples per 1000 t	Age samples per 1000 t	Aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2013	35	654	627	17	74	1122	4244	154.1	17.4	264.4	125
	2014	24	66	919	24	24	365	3053	21.6	7.9	119.6	125
	2015	28	121	3497	22	405	1281	2492	48.6	162.5	514.0	125
	2016	54	642	2376	36	517	1585	4606	139.4	112.2	344.1	125
	2017	69	695	6177	44	571	1633	3354	207.2	170.2	486.9	125
	2018	64	778	7354	32	629	1252	4287	181.5	146.7	292.0	125
	2019	47	810	9828	17	206	958	5667	142.9	36.4	173.8	125
	2020	47	761	9631	15	172	0	5902	128.9	29.1	0	
*S. mentella ** *												
	2008	13	178	1038		0	0	2214	80.4	0.0	0.0	125
	2009	12	319	1841		2	40	2567	124.3	0.8	15.6	125
	2010	11	284	3664		11	320	2245	126.5	4.9	142.5	125
	2011	9	255	3210		11	298	2690	94.8	4.1	110.8	125
	2012	13	166	2187		13	241	2098	79.1	6.2	114.9	125
	2013	14	184	383	5	13	390	1361	135.2	9.6	286.6	125
	2014	11	36	4664	12	49	5	13402	2.7	3.7	0.4	125
	2015	21	166	23794	10	21	184	19700	8.4	1.1	9.3	125

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of unique vessels (***)	No of age samples	No of aged individuals	Landing tonnes	Length-samples per 1000 t	Age samples per 1000 t	Aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2016	23	285	5470	9	22	169	19083	15.0	1.2	8.9	125
	2017	30	256	3196	24	211	24	17280	14.8	12.2	1.4	125
	2018	39	409	8782	20	364	25	19287	21.2	18.9	1.3	125
	2019	21	345	5884	5	24	0	24141	14.3	1.0	0	125
	2020	29	475	10796	8	65	0	33997	14.0	1.9	0	
Greenland halibut												
	2008	53	580	9074		0	0	7394	78.4	0.0	0.0	125
	2009	36	922	12853		0	0	8446	109.2	0.0	0.0	125
	2010	26	519	8395		0	0	7685	67.5	0.0	0.0	125
	2011	29	463	8204		0	0	8273	56.0	0.0	0.0	125
	2012	34	610	7716		0	0	10074	60.6	0.0	0.0	125
	2013	26	597	4930		0	0	12613	47.3	0.0	0.0	125
	2014	33	236	2559	10	0	0	10876	21.7	0.0	0.0	125
	2015	31	273	8769	11	0	0	10704	25.5	0.0	0.0	125
	2016	83	384	2304	60	0	0	12573	30.5	0.0	0.0	125
	2017	67	556	10022	43	317	0	13194	42.1	24.0	0.0	125
	2018	96	582	11720	63	342	0	14876	39.1	23.0	0.0	125

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of unique vessels (***)	No of age samples	No of aged individuals	Landing tonnes	Length-samples per 1000 t	Age samples per 1000 t	Aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2019	61	394	9286	47	80	0	14813	26.6	5.4	0.0	125
	2020	80	429	9110	52	80	0	14532	29.5	5.5	0.0	
*Anglerfish (Monk)*******												
	2013	8	55	1551	0	0	0	2988	18	36.5	0.0	125
	2014	8	33	836	0	0	0	1655	19	18.1	24.8	125
	2015	8	74	2054	0	0	0	933	82	35.3	0.0	125
	2016	8	57	1339	0	0	0	1355	41	17.9	0.0	125
	2017	8	88	3604	0	0	0	1473	59	23.8	0.7	125
	2018	8	94	3233	0	0	0	1884	49	24.4	1.1	125
	2019	8	68	3223	0	0	0	2750	24	22.5	0.0	125
	2020	8	89	4129	0	0	0	2258	39	0	0.0	
Capelin												
	2008	4	3	150		0	0	5000	0.6	0.0	0.0	125
	2009	18	97	7039		39	1039	233000	0.4	0.2	4.5	125
	2010	75	230	6191		47	1291	246000	0.9	0.2	5.2	125
	2011	115	315	8346		48	1313	273000	1.2	0.2	4.8	125
	2012	84	308	9337		29	843	181328	1.7	0.2	4.6	125

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of unique vessels (***)	No of age samples	No of aged individuals	Landing tonnes	Length-samples per 1000 t	Age samples per 1000 t	Aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2013	12	213	12215	47	47	773	156340	1.4	0.3	4.9	125
	2014	27	113	9054	1	8	1086	40021	2.8	0.2	27.1	125
	2015	65	722	83776	65	722	5393	71435	10.1	10.1	75.5	125
	2016	7	27	1863	7	27	649					125
	2017	21	43	2294	14	25	305					125
	2018	68	207	15022	33	76	823	123461	1.7	0.6	6.7	125
	2019	4	26	260	2	13	0	0				125
	2020							0				

***) In addition to age the otoliths are also used for identification of coastal cod.**

****) Age samples from surveys with commercial trawl come in addition.**

*****) From 2013 No of unique vessels are split by length and age samples.**

******) Only from large meshed gillnets as basis for assessment**

Table 0.2. Age and length sampling by Russia of commercial catches and age sampling of surveys in 2008–2020. Also length-measured individuals and aged individuals per 1000 t caught. For comparison also the EU DCF requirements are shown.

Stock	Year	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
NEA-cod*										
	2008	380592	3097	7565	10662	190225	2001	16.3	56.0	125
	2009	178038	1075	7426	8501	229291	776	4.7	37.1	125
	2010	126502	1828	7670	9498	267547	473	6.8	35.5	125
	2011	122623	2376	5783	8159	310326	395	7.7	26.3	125
	2012***	140028	2040	7742	9782	329943	424	6.2	29.6	125
	2013	131455	1999	8103	10102	432314	304	4.6	23.4	125
	2014	114538	3110	7154	10264	433479	264	7.2	23.7	125
	2015***	105721	2486	6095	8581	381188	277	6.5	22.5	125
	2016	158006	5090	2704	7794	394107	401	12.9	19.8	125
	2017	161192	4918	6121	11039	396195	407	12.4	27.9	125
	2018	157048	3129	1982	5111	340364	461	9.2	15.0	125
	2019***	83018	2093	3737	5830	316813	262	6.6	18.4	125
	2020***	112950	3105	3858	6963	312683	361	9.9	22.3	125

Stock	Year	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
NEA-haddock										
	2008	216959	2498	5677	8175	68792	3154	36.3	118.8	125
	2009	43254	489	5421	5910	85514	506	5.7	69.1	125
	2010	85445	834	5060	5894	111372	767	7.5	52.9	125
	2011	61990	1570	3584	5154	139912	443	11.2	36.8	125
	2012***	87880	1545	5034	6579	143886	611	10.7	45.7	125
	2013	42927	1205	4021	5226	85668	501	14.1	61.0	125
	2014	45447	899	3796	4695	78725	577	11.4	59.6	125
	2015***	31009	914	2972	3886	91864	338	9.9	42.3	125
	2016	55598	2691	1884	4575	115710	480	23.3	39.5	125
	2017	74297	3554	2614	6168	106714	696	33.3	57.8	125
	2018	61360	2274	1136	3410	90486	678	25.1	37.7	125
	2019***	44728	1923	1778	3701	76125	588	25.3	48.6	125
	2020***	69301	2356	1575	3931	89030	778	26.5	44.2	125
NEA-saithe										
	2008	8865	479	175	654	11577	766	41.4	56.5	125
	2009	5279	7	68	75	11899	444	0.6	6.3	125

Stock	Year	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2010	422	112	249	361	14664	29	7.6	24.6	125
	2011	88	9	27	36	10007	9	0.9	3.6	125
	2012	4062	145	104	249	13607	299	10.7	18.3	125
	2013	17124	402	76	478	14796	1157	27.2	32.3	125
	2014	2302	278	26	304	12396	186	22.4	24.5	125
	2015	1505	104	131	235	13181	114	7.9	17.8	125
	2016	4233	272	16	288	15203	278	17.9	18.9	125
	2017	1762	228	110	338	14551	121	15.7	23.2	125
	2018	4758	454	9	463	14171	336	32.0	32.7	125
	2019	4528	94	0	94	13990	324	6.7	6.7	125
	2020	83	17	96	113	14082	6	1.2	8.0	125
S. marinus (norvegicus)										
	2008	1196	45	17	62	749	1597	60.1	82.8	125
	2009	241	2	27	29	698	345	2.9	41.5	125
	2010	486	25	199	224	806	603	31.0	277.9	125
	2011	885	77	62	139	919	963	83.8	151.3	125
	2012	1564	58	54	112	681	2297	85.2	164.5	125

Stock	Year	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2013	770	22	142	164	797	966	27.6	205.8	125
	2014	589	25	33	58	806	731	31.0	72.0	125
	2015	120		20	20	664	181	0.0	30.1	125
	2016	1113	147	34	181	776	1434	189.4	233.2	125
	2017	1426	86	101	187	1131	1261	76.0	165.3	125
	2018	1877	30	21	51	1546	1214	19.4	33.0	125
	2019	1015	150	0	150	1804	563	83.2	83.2	125
	2020	2107	47	31	78	2492	846	18.9	31.3	125
S. mentella										
	2008	21446	471	3379	3850	7117	3013	66.2	541.0	125
	2009	29435	761	1447	2208	3843	7659	198.0	574.6	125
	2010	2776	100	2295	2395	6414	433	15.6	373.4	125
	2011	917	7	640	647	5037	182	1.4	128.4	125
	2012	7802	422	1146	1568	4101	1902	102.9	382.3	125
	2013	19092	1253	1625	2878	3677	5192	340.8	782.7	125
	2014	817	25	1297	1322	1704	479	14.7	775.8	125
	2015	771		1818	1818	1142	675	0.0	1591.9	125

Stock	Year	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2016	27765	1076	85	1161	8419	3298	127.8	137.9	125
	2017	958	99	1000	1099	4952	193	20.0	221.9	125
	2018	21004	845	39	884	10497	2001	80.5	84.2	125
	2019	6881	400	469	869	13164	523	30.4	66.0	125
	2020	8718	340	612	952	13997	623	24.3	68.0	125
Greenland halibut										
	2008	106411	1519	3366	4885	5294	20100	286.9	922.7	125
	2009	77554	819	2282	3101	3335	23255	245.6	929.8	125
	2010	32090	416	2784	3200	6888	4659	60.4	464.6	125
	2011	9892	115	1541	1656	7053	1403	16.3	234.8	125
	2012	82943	2140	2506	4646	10041	8260	213.1	462.7	125
	2013	12608	555	2756	3311	10310	1223	53.8	321.1	125
	2014	24346	633	2106	2739	10061	2420	62.9	272.2	125
	2015	22116	575	2489	3064	12953	1707	44.4	236.5	125
	2016	11818	574	221	795	10576	1117	54.3	75.2	125
	2017	24061	1205	1579	2784	10713	2246	112.5	259.9	125
	2018	21893	954	308	1262	12072	1814	79.0	104.5	125

Stock	Year	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2019	861	125	1552	1677	12198	71	10.2	137.5	125
	2020	1387	165	1853	2018	12266	113	13.5	164.5	125
Capelin										
	2008**	82625	1644	2341	3985	5000	16525	328.8	797.0	125
	2009	94541	900	2511	3411	73000	1295	12.3	46.7	125
	2010	67265	1072	4043	5115	77000	874	13.9	66.4	125
	2011	63784	1273	2271	3544	86531	737	14.7	41.0	125
	2012	20023	1130	1783	2913	68182	294	16.6	42.7	125
	2013	54708	1565	1007	2572	60413	906	25.9	42.6	125
	2014	13206	850	1249	2099	25720	513	33.0	81.6	125
	2015	27200	1000	1004	2004	115				125
	2016	8669	3954	1047	5001	0				125
	2017			4115	4115	6				125
	2018	14491	250	1050	1300	65934	220	3.8	19.7	125
	2019			1498	1498	34				125
	2020			1245	1245	19				125

***) In addition also used long-term mean age–length keys.**

****) Age samples from surveys with commercial trawl come in addition.**

*****) In addition used samples from Russian vessels, sampled by the Norwegian Coast Guard in 2012, 2015, 2019 and 2020.**

Table 0.3. Age and length sampling by Spain[5] of commercial catches and length sampling of surveys in 2008–2020. Also length-measured individuals and aged individuals per 1000 t caught. For comparison also the EU DCF requirements are shown.

Stock	Year	No of vessels	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
NEA-cod											
	2008	2	10108	610		610	9658	1047	63	63	125
	2009	2	8733	1834		1834	12013	727	153	153	125
	2010	2	28297	1735		1735	12657	2236	137	137	125
	2011	2	11633	964		964	13291	875	73	73	125
	2012	2	9849	998		998	12814	769	78	78	125
	2013	2	30295	2381		2381	15041	2014	158	158	125
	2014	2	27828	2306		2306	16479	1689	140	140	125

[5] The onshore and the at-sea sampling programs coordinated by the IEO were suspended in most of 2020, due notably to administrative problems and to a lesser extend to COVID-19. This affected all stocks. Both sampling programmes are hired by IEO through call for tenders addressed to specialized companies. The public tender launched in 2019 (to start in 2020) was declared void, having to be re-launched again. This second launch was delayed as a result of the paralysis of public activity during the state of alarm due to the COVID-19 pandemic, and could only be reopened in June-July. Given that the process of awarding the contract by public tender takes three-four months under normal conditions, it was finally resolved in December 2020 and signed in January 2021. Since then all activities have been resumed. The sampling to obtain the biological variables of the population (mainly reproduction and growth) is normally carried out in the IEO laboratories. This activity has also faced problems in 2020. On the one hand the administrative and financial difficulties of the IEO prevented the purchasing of samples in the market and on the other hand the three months closure of the labs (15 March to 21 June) due to COVID-19 did not allow for a normal activity.

Stock	Year	No of vessels	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2015	2	18568	1445		1445	18772	989	77	77	125
	2016	2	27937	1246		1246	14640	1908	85	85	125
	2017	2	33984	2018		2018	14414	2358	140	140	125
	2018	1	25933	911		911	14415	1799	63	63	125
	2019	1	5781	1117		1117	13939	415	80	80	125
	2020						11403				125
NEA-haddock*											
	2009	1	2561				240				
	2010	1	3243				379				
	2011	1	1796				408				
	2012	2	3198				647				
	2013	1	660				413				
	2014	1	2460				370				
	2015	1	702				418				
	2016	2	701				357				
	2017	1	710				156				
	2018	1	154				169				

Stock	Year	No of vessels	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2019						280				
	2020						45				
NEA-saithe											
	2009	1	123				2				
	2013	1					5				
	2014	1					13				
	2015	1					33				
	2016						25				
	2017						85				
	2018						60				
	2019						199				
	2020						0				
S. mentella											
	2008**	1	2275	28			987	2304	28	0	125
	2011*	1	86				1237				
	2012**	2	11579	476			1612	7183	295	0	125
	2014**	1	6177				1146	5390			

Stock	Year	No of vessels	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2015**	1	6117				2371	2580			
	2016**	1	11806				3133	3768			
	2017**	1	5015				2624	1911			
	2018**	1	11638				2399	4851			
	2019**	1	11952				1908	6265			
	2020**						737				
	2018		21004	845	39	884	10497	2001	80.5	84.2	125
	2019		6881	400	469	869	13164	523	30.4	66.0	125
	2020		8718	340	612	952	13997	623	24.3	68.0	125
Greenland halibut											
	2008	2	11662				112	103826			
	2009	1	3383				210	16143			
	2010	1	5783				182	31800			
	2011	1	8541				169	50600			
	2012	1	4809				186	25907			
	2013	1	11988				190	63019			
	2014	1	12002				206	58262			

Stock	Year	No of vessels	No of length-measured individuals (commercial catches)	No of aged individuals (commercial catches)	No of aged individuals (surveys)	Total no of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Aged individuals per 1000 t (commercial catches)	Total aged individuals per 1000 t	EU DCF for comparison per 1000 t
	2015	1	17552				111	158126			
	2016	1	15031				218	68837			
	2017										
	2018										
	2019	1					49				
	2020						96				

***) Sampling from bycatch in cod fishery.**

****) Sampling from pelagic redfish fishery.**

*****) Sampling from Spanish Greenland halibut survey.**

Table 0.4. Age and length sampling by Germany of commercial catches and age sampling of surveys in 2008–2020. Also length-measured individuals and aged individuals per 1000 t caught. For comparison also the EU DCF requirements are shown.

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Age-sampled individuals per 1000 t	EU DCF for comparison
NEA cod									
	2008	5	3	65800	2033	4955	13280	410	125
	2009	5	2	43107	2419	8585	5021	282	125
	2010	5	2	51923	3075	8442	6151	364	125
	2011	4	1	7318	769	4621	1584	166	125

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Age-sampled individuals per 1000 t	EU DCF for comparison
	2012	4	2	16315	1924	8500	1919	226	125
	2013	4	2	29281	2043	7939	3688	257	125
	2014	4	1	23137	1291	6225	3717	207	125
	2015	4	1	39335	886	6427	6120	138	125
	2016	3	1	22109	1060	6636	3332	160	125
	2017	4	1	19942	785	5969	3341	132	125
	2018	4	2	43371	2283	7774	5579	294	125
	2019	2	1	17954	1444	8535	2104	169	125
	2020	2	1	21716	1021	9786	2219	104	125
NEA haddock									
	2008	5	3	5548	442	535	10370	826	125
	2009	5	2	23348	958	1957	11931	490	125
	2010	5	2	54704	1039	3539	15457	294	125
	2011	4	1	1925	160	1724	1117	93	125
	2012	4	2	4088	502	1111	3680	452	125
	2013	4	1	7040	478	501	14052	954	125
	2014	4	1	3113	261	340	9156	768	125
	2015	4	1	616	325	124	4968	2621	125

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Age-sampled individuals per 1000 t	EU DCF for comparison
	2016	3	1	4807	544	170	28276	3200	125
	2017	4	1	3464	527	155	22348	3400	125
	2018	4	2	4345	497	391	11113	1271	125
	2019	2	1	5031	393	208	24188	1889	125
	2020	2	1	2979	356	283	10527	1258	125
NEA saithe									
	2008	5	3	10210	605	2263	4512	267	125
	2009	6	2	8667	1091	2021	4288	540	125
	2010	7	2	11424	1001	1592	7176	629	125
	2011	4	1	4863	530	1371	3547	387	125
	2012	7	2	14193	1202	1371	10356	877	125
	2013	4	1	1190	414	1212	982	342	125
	2014	3	1	25	0	259	97	0	125
	2015	4	0	0	0	424	0	0	125
	2016	3	1	13981	909	951	14701	956	125
	2017	4	1	15734	603	1154	13634	523	125
	2018	4	1	19718	473	1651	11943	286	125
	2019	2	1	9465	1521	1387	6824	1097	125

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Age-sampled individuals per 1000 t	EU DCF for comparison
	2020	2	1	11900	745	1573	7565	474	125
Redfish									
	2008	5	3	330	0	46	7174	0	125
	2009	8	2	0	0	100	0	0	125
	2010	6	2	0	0	52	0	0	125
	2011	6	1	7937	0	844	9404	0	125
	2012	9	2	4036	0	584	6911	0	125
	2013	4	1	1315	0	81	16235	0	125
	2014	4	1	571	0	451	1266	0	125
	2015	4	1	76	0	266	286	0	125
	2016	3	1	6095	0	497	12264	0	125
	2017	4	1	977	0	770	1269	0	125
	2018	4	2	3438	0	2508	1371	0	125
	2019	2	1	8958	0	1741	5145	0	125
	2020	3	1	4248	0	1998	2126	0	125
Greenland halibut									
	2008	5	2	0	0	5	0	0	125
	2009	3	2	0	0	19	0	0	125

Stock	Year	No of unique vessels	No of length samples	No of length-measured individuals	No of aged individuals	Landings tonnes	Length-measured individuals per 1000 t	Age-sampled individuals per 1000 t	EU DCF for comparison
	2010	2	2	0	0	14	0	0	125
	2011	3	1	0	0	81	0	0	125
	2012	4	2	0	0	40	0	0	125
	2013	3	1	1298	0	49	26544	0	125
	2014	4	1	1076	0	34	31647	0	125
	2015	4	1	658	0	32	20563	0	125
	2016	3	1	365	0	9	40556	0	125
	2017	4	1	0	0	21	0	0	125
	2018	4	1	257	0	52	4942	0	125
	2019	2	1	511	0	45	11356	0	125
	2020	2	1	305	0	74	4122	0	125

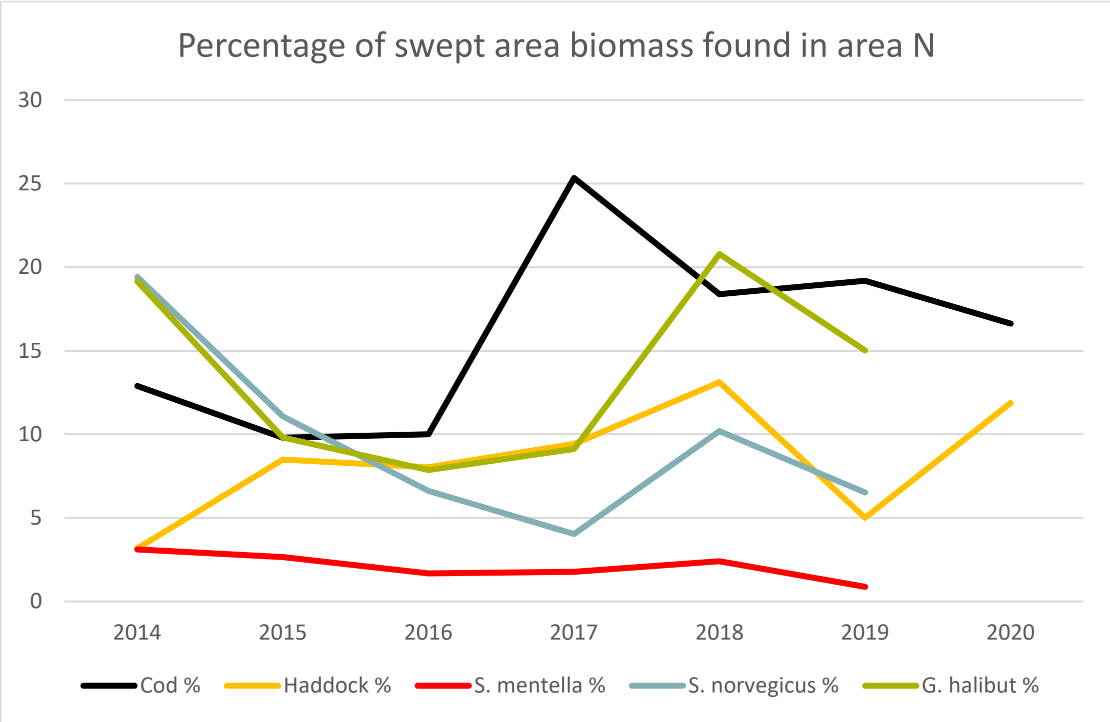

Figure 0.4. Proportion of swept-area biomass in the Joint winter survey found in the new northern area (N), by year and species. For 2020 the indices for redfish and Greenland halibut have not yet been calculated.

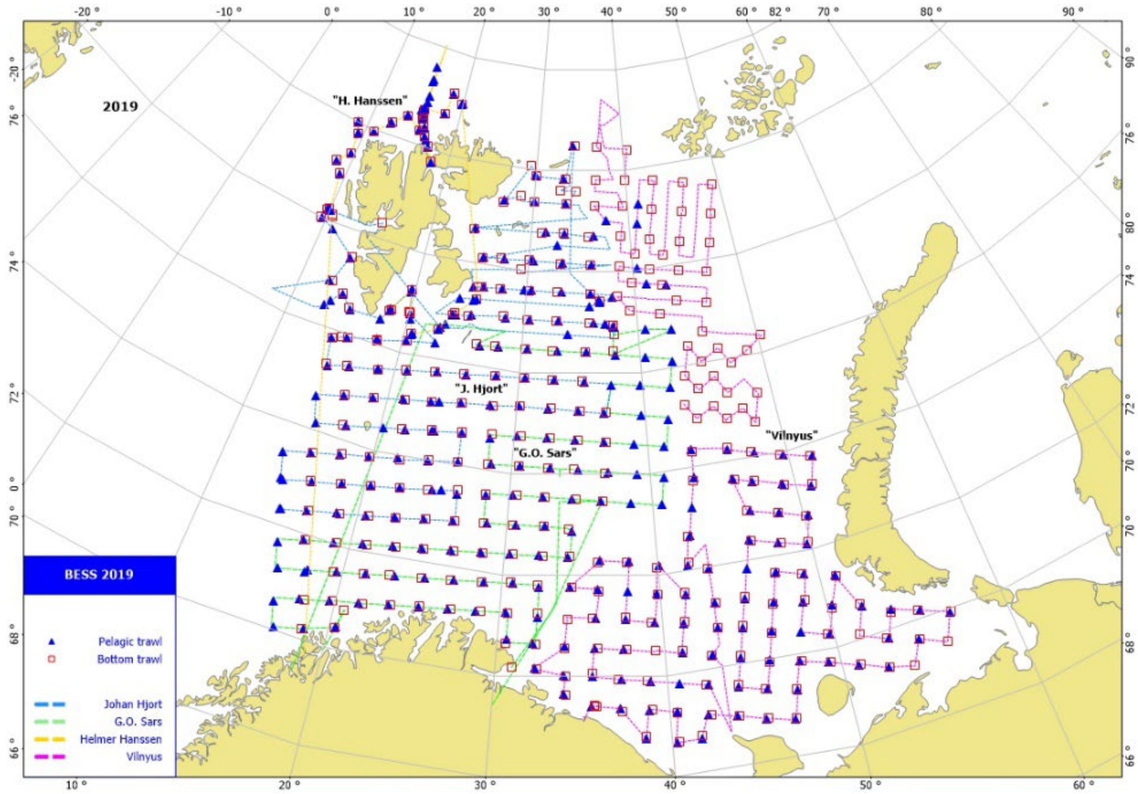

Figure 0.5. Barents Sea Ecosystem survey (BESS) 2019, realized vessel tracks with pelagic and bottom trawl sampling stations.

1.11 Ecosystem information

The aim of this section is to collect important ecosystem information influencing the assessment of fish stocks handled by AFWG. In general, such information is collected and updated by the ICES WGIBAR group, here we only provide information that is directly relevant to the assessment of the AFWG stocks as well as information that is updated after the 2021 WGIBAR report was finished.

1.11.1 0-group abundance

The recruitment of the Barents Sea fish species measured as 0-group has shown a large year-to-year variability. The most important reasons for this variability are variations in the spawning biomass, hydrographic conditions, changes in circulation pattern, food availability and predator abundance, and distribution. In 2018 and 2020, 0-group indices were strongly affected by incomplete area coverage in the Barents Sea, but attempts have been made to correct for this (Prozorkevitch and Van der Meeren, 2021).

1.11.2 Consumption, natural mortality, and growth

Cod is the most important predator among fish species in the Barents Sea. It feeds on a wide range of prey, including larger zooplankton, most available fish species, including own juveniles and shrimp (Tables 1.1–1.2). Cod prefer capelin as a prey, and fluctuations of the capelin stock may have a strong effect on growth, maturation, and fecundity of cod, as well as on cod recruitment because of cannibalism. The role of euphausiids for cod feeding increases in the years when capelin stock is at a low level (Ponomarenko and Yaragina, 1990). Also, according to Ponomarenko (1973; 1984), interannual changes of euphausiid abundance are important for the survival rate of cod during the first year of life.

The food consumption by NEA cod in 1984–2020, based on data from the Joint Russian-Norwegian stomach content database, is presented in Tables 1.1–1.2. The Norwegian (IMR) calculations are based on the method described by Bogstad and Mehl (1997). The main prey items in 2020 were capelin (about 2 million tonnes), followed by krill, amphipods and polar cod of which the consumption was about 500 thousand tonnes of each category. Shrimp, long rough dab, cod, herring, haddock and snow crab were all less important (between 90 and 180 thousand tonnes for each species). The increase in consumption of polar cod from 2019 to 2020 is consistent with the markedly increased abundance of this species. The decrease in consumption of young cod and haddock is consistent with the low abundance of age 0 and 1 of these species in 2020. The consumption calculations made by The consumption per cod by cod age-groups are shown in Tables 1.3–1.4 (IMR and PINRO estimates), while the proportion of cod and haddock in the diet by cod age-group (IMR estimates) is given in Tables 1.5 and Table 1.6. IMR show that the total consumption by age 1 and older cod in 2020 was 5.2 million tonnes. For technical reasons, PINRO estimates (Table 1.2 and 1.4) were not updated this year.

Growth of cod as calculated from weight at age in the winter survey has shown a declining trend in the last years, but this decline has now been halted, and for age 6 and older the trend seems to have been reversed. However, weight at age 3 and 4 was the lowest in this survey series from 1994–present, and for ages 3 and 6–8 it was among the three lowest values in the same period. The trends in consumption per cod by age-group in recent years seem consistent with the trends in size at age.

Weight at age in the Lofoten survey was stable from 2019 to 2021, while weight-at-age in catch of cod decreased slightly for ages 3–9 from 2018–2020.

How is the outlook for cod food abundance in 2021? Total abundance of pelagic fish stocks is at an average level, for the most important pelagic species, capelin, the abundance of immature capelin in 2020 was intermediate due to a very strong 2019 year class (the strongest since 2000). Polar cod abundance in 2020 was close to the highest value observed in the 35-year time-series due to the 2019 year class being the strongest ever observed. However, the herring abundance in the Barents Sea is now low as the strong 2016 year class has left the Barents Sea and the following year classes, which still are found in the Barents Sea, are weak. Also, age 1–2 cod and haddock abundance in 2021 is low. On the positive side, shrimp abundance is high, while the abundance of other prey species is around average. Altogether there seems to be reasonable consistency between growth, consumption and feeding data.

One direct application for the management of results from the trophic investigations in the Barents Sea is the inclusion of predator's consumption into fish stock assessment. Predation on cod and haddock by cod has since 1995 been included in the assessment of these two species. These data, summarized in Tables 1.1, 1.3 and 1.5, are used for estimation of cod and haddock consumed by cod and further for estimation of their natural mortality within the SAM model (see sections 3.3.3 and 4.5.5). The average natural mortality for the last years is used as predicted M for the coming years for cod and haddock.

Cod consumption was used in capelin assessment for the first time in 1990, to account for natural mortality due to cod predation on mature capelin in the period January–March (Bogstad and Gjøsæter, 1994). This methodology has been developed further using the Bifrost and CapTool models (Gjøsæter *et al*., 2002; Tjelmeland, 2005; ICES CM 2009/ACOM:34). CapTool is a tool (in Excel with @RISK) for implementing results from Bifrost in the short term (half-year) prognosis used for determining the quota.

In recent years the abundance of large cod and haddock has been very high, and it is still at a high level for cod. There are a limited number of predators on such large fish. As predation is likely to be a major source of natural mortality, it could thus be considered whether the natural mortality in older age groups should be reduced in such a situation. The assumption of reduced natural mortality on older cod was explored by IBPCOD 2017, but no evidence of this was found based on available catch and survey data. To investigate this further, analyses on predator consumption and biomass flow at higher trophic levels like those done by Bogstad *et al.* (2000) should be updated, and such work is ongoing for marine mammals. For cod, in particular, the fishing mortality since 2008 has been so much lower than before that the relative impact of the natural mortality on the survival of older fish has increased considerably.

The amount of commercially important prey consumed by other fish predators (haddock, Greenland halibut, long rough dab, and thorny skate), has also been calculated (Dolgov *et al*., 2007), but these consumption estimates have not been used in assessment for any prey stocks yet. Marine mammals are not included in the current fish stock assessments. However, it has been attempted to extend the stock assessment models of Barents Sea capelin (Bifrost) by including the predatory effects of minke whales, and harp seals (Tjelmeland and Lindstrøm, 2005).

1.11.3 Maturation, condition factor, and fisheries–induced evolution

Data on maturity-at-age are one of the basic components for spawning-stock biomass (SSB) estimates. There have been substantial changes observed in maturity-at-age of NEA cod over a large historical period (since 1946) showing an acceleration in maturity rates, especially in the 1980s. They are thought to be connected both with compensatory density-dependence mechanisms and genetic changes in individuals (Heino *et al*., 2002; Jørgensen *et al*., 2008; Kovalev and Yaragina, 2009; Eikeset *et al*., 2013; Kuparinen *et al*., 2014) resulted from strong fishing pressure.

Studies on possible evolutionary effects for this stock should be updated with data for recent years to investigate the effects on population dynamics, including growth, maturation and evolutionary effects, of a prolonged period with low fishing mortality and high stock size.

Recent laboratory and fieldwork have shown that skipped spawning does occur in NEA cod stock (Skjæraasen *et al.*, 2009; Yaragina, 2010). Experimental work on captive fish has demonstrated that skipped spawning is strongly influenced by individual energy reserves (Skjæraasen *et al.*, 2009). This is supported by the field data, which suggest that gamete development could be interrupted by a poor liver condition especially. Fish that will skip spawning seem to remain in the Barents Sea and do not migrate to the spawning grounds. These fish need to be identified and excluded when estimating the stock–recruitment potential as currently they are included in the estimate of SSB. However, more work needs to be undertaken to improve our knowledge of skipped spawning in cod (e.g. comparisons and intercalibration of Norwegian and Russian databases on maturity stages should be done) and other species in order to quantify its influence on the stock reproductive potential.

1.11.4 Recruitment prediction for northeast Arctic cod

Prediction of recruitment in fish stocks is essential to harvest prognosis. Traditionally, prediction methods have been based on spawning-stock biomass and survey indices of juvenile fish and have not included effects of ecosystem drivers. Multiple linear regression models can be used to incorporate both environmental and parental fish stock parameters. In order for such models to give predictions, there need to be a time-lag between the predictor and response variables. In this section, a model for Northeast Arctic cod which is in use in assessment is presented. Note that a recruitment model for Barents Sea capelin with similar features also was presented to the group (WD 13).

1.11.5 Historic overview

Several statistical models, which use multiple linear regressions, have been developed for the recruitment of northeast Arctic cod. All models try to predict recruitment-at-age 3 (at 1 January), as calculated from the assessment model, with cannibalism included. This quantity is denoted as R3. A collection of the most relevant models previously presented to AFWG is described below.

Stiansen *et al.* (2005) developed a model (JES1) with 2-year prediction possibility:

JES1: R3~ Temp(-3) + Age1(-2) + MatBio(-2)
JES2: R3~ Temp(-3) + Age2(-1) + MatBio(-2)
JES3: R3~ Temp(-3) + Age3(0) + MatBio(-2)

Temp is the Kola annual temperature (0–200 m, station 3–7), Age1 is the winter survey bottom trawl index for cod age 1, and MatBio the maturing biomass of capelin on 1 October. The number in parentheses is the time-lag in years. Two other similar models (JES2, JES3) can be made by substituting the winter index term Age1(-2) with Age2(-1) and Age3(0), giving 1 and 0-year predictions, respectively.

Svendsen *et al.* (2007) used a model (SV) based only on data from the ROMS numerical hydrodynamical model, with 3-year prognosis possibility:

SV: R3~ Phyto(-3) + Inflow(-3)

Where Phyto is the modelled phytoplankton production in the whole Barents Sea and Inflow is the modelled inflow through the western entrance to the Barents Sea in autumn. The number in parentheses is the time-lag in years. The model has not been updated since 2007.

The recruitment model (TB) suggested by T. Bulgakova (AFWG 2005, WD14) is a modification of Ricker's model for stock–recruitment defined by:

TB: R3~ m(-3) exp[-SSB(-3) + N(-3)]

Where R3 is the number of age 3 recruits for NEA cod, m is an index of population fecundity, SSB is the spawning-stock biomass and N is equal to the number of months with positive temperature anomalies (TA) on the Kola Section in the birth year for the year class. The number in parentheses is the time-lag in years. For the years before 1998 TA was calculated relative to monthly average for the period 1951–2000. For intervals after 1998, the TA was calculated with relatively linear trend in the temperature for the period 1998–present. The model was run using two-time intervals (using cod year classes 1984–2000 and year classes 1984–2004) for estimating the model coefficients. The models have not been updated since 2009.

Titov (Titov, AFWG 2010, WD 22) and Titov *et al.* (AFWG 2005, WD 16) developed models with 1 to 4-year prediction possibility (TITOV0, TITOV1, TITOV2, TITOV3, TITOV4, respectively), based on the oxygen saturation at bottom layers of the Kola section stations 3–7 (OxSat), air temperature at the Murmansk station (Ta), water temperature: 3–7 stations of the Kola section (layer 0–200 m; Tw), ice coverage in the Barents Sea (I), spawning-stock biomass (SSB), annual values of 0-group cod abundance index, corrected for capture efficiency (CodC0) and the bottom trawl swept-area abundance of cod at the age 1 and 2, 3 derived from the joint winter Barents Sea acoustic survey (CodB1, CodB2, CodB3). At the 2010 AFWG assessment it was suggested (Dingsør *et al.*, 2010, WD 19, and related discussions in the working group to try to simplify these models).

Hjermann *et al.*, (2007) developed a model with a one-year prognosis, which has been modified by Dingsør *et al.* (AFWG 2010, WD19) to four models with 2-year projection possibility.

H1: log(R3)~ Temp(-3) + log(Age0)(-3) +$BM_{cod3\text{-}6}$ /$ABM_{capelin}$(-2,-1)
H2: log(R3)~ Temp(-2) +I(surv)+ Age1(-2) + $BM_{cod3\text{-}6}$ /$ABM_{capelin}$ (-2,-1)
H3: log(R3)~ Temp(-1) + Age2(-1) + $BM_{cod3\text{-}6}$ /$ABM_{capelin}$ (-1)
H4: log(R3)~ Temp(-1) + Age3(0)

Temp is the Kola yearly temperature (0–200 m), Age0 is the 0-group index of cod, Age1, Age2 and Age3 are the winter survey bottom trawl index for cod age 1, 2 and 3, respectively, $BM_{cod3\text{-}6}$ is the biomass of cod between age 3 and 6, and ABM is the maturing biomass of capelin. The number in parentheses is the time-lag in years. The models were not updated this year.

At AFWG 2008, Subbey *et al.* presented a comparative study (AFWG 2008, WD27) on the ability of some of the above models in predicting stock–recruitment for NEA cod (Age 3). At the assessment in 2010, a WD by Dingsør *et al.* (AFWG 2010, WD19) was presented, which investigated the performance of some of the mentioned recruitment models. It was strongly recommended by the working group that a Study Group should be appointed to look at criteria for choosing/rejecting recruitment models suitable for use in stock assessment.

The "Study Group on Recruitment Forecasting" (SGRF; ICES CM 2011/ACOM:31, ICES CM 2012/ACOM:24, ICES CM 2013/ACOM:24) have had three meetings (in October 2011 and 2012, and November 2013). Their mandate is to give a "best practice" (Standards and guidelines) for choosing recruitment models after their next meeting, which may be implemented at the next AFWG.

The SGRF 2012 report addressed the problem of combining several model predictions to obtain a recruitment estimate with minimum variance. The method (involving a weighted average of individual model predictions) was proposed as a replacement for the hybrid method of Subbey *et al.* (2008). One major issue not addressed in ICES SGRF (2012) was how to choose the initial ensemble of models, whose weighted average is sought. There are practical constraints (with respect to time and personnel), which stipulates that not all plausible models can be included in the calculation of the hybrid recruitment value. A methodology for choosing models to include in the calculation of a hybrid, representative recruitment forecast was addressed in SGRF 2013. Details can be found in the SGRF 2013 ICES report.

1.11.6 Models used in 2021

The model approach taken in 2021 was the same as in 2018–2020. Some changes were made in 2018, they are described below.

In 2018 at the meeting of the AFWG, the correction and simplification of models were continued. Due to the fact that in 2017–2018 there was a significant correction of the initial biological data, which caused significant changes in the results of the prognostic models, in 2018 a complete audit of both prognostic models and the hybrid model combining the results of their work was carried out. The main purpose of the model revision was to increase the stability of the models, that is, to reduce the possibility of potential correction of the models due to correction of the biological data included in the model. The solution to the problem was found by increasing the retrospective database backwards in time, that is, from the beginning of the 1980s to the beginning of the 1960s. Accordingly, sets of predictor sets have been revised. The number of models was reduced from 5 to 2 and the names of the models were changed from Titov0(1,2,3,4) to TitovES (environment, short prediction) and TitovEL (environment, long prediction).

This has been conducted and has improved the statistical performance (details are shown in Titov, AFWG 2018, WD23):

TitovES: R32 ~ DOxSat2(t-13) + ITw(t-43) + expIce(t-40) + Ice(t-15)
TitovEL: R34 ~OxSat(t-39)+ ITw(t-43)

Where DOxSat(t-13)~ expOxSat(t-13) + OxSat(t-39), ITw(t-43) ~ I(t-43) +Tw(t−46). The number in parentheses is the time-lag in months, relative to April in the year when the prediction is carried out.

At the 2018 AFWG assessment, a hybrid model (i.e. an average combination) of the best functioning statistical recruitment models were repeated. A statistical analysis of the accuracy of the model's work was carried out, which consisted in estimating the errors in the recovery of data on the number of NEA cod recruitment. Accuracy of the model's work was verified by calculation of standard deviations of the NEA cod recruitment predicted values from the SAM values for the period 2005–2015 when the model was adjusted for data from 1983 to 2004, which consisted in estimating the errors in the recovery of data on the number of NEA cod recruitment.

Figure 1.1 shows the standard deviations of the NEA cod recruitment prediction. It can be seen that the addition of biological parameters (CodB1, CodB2, CodB3, CodC0, SSB) to environmental models (TitovES, TitovEL) substantially increases the error.

Based on these calculations, after comparing the results of constructing independent retrospective forecasts using the methodology previously used in ICES SGRF (ICES CM 2013/ACOM:24), it was decided to abandon the use of biological predictors and to use only environmental data in the NEA cod recruitment forecasting models. It was also found that all models (TitovES, TitovEL, RCT3) satisfy the quality conditions with respect to the forecast for the mean values accepted as the criterion for entering into the calculation of the hybrid model adopted earlier (ICES CM 2013/ACOM:24). It was decided that all biological data will be included in calculations based on the RCT3 model, and the remaining two models (TitovES, TitovEL) will be used only to account for the effect of environmental conditions on NEA cod recruitment.

In AFWG 2021 the procedure for estimating weights for various models (TitovES, TitovEL, RCT3) was repeated using the same method as was made on Study Group on Recruitment

Forecasting (SGRF) in 2013. The input data for the models are given below in Tables 1.7 (TitovES, TitovEL) and 1.8 (RCT3).

In summary, the SAM estimate for age 3 from the AFWG 2021 assessment was used as historical R3. The recruitment forecast for 2021–2024 are based on a hybrid model with weighting estimated at AFWG 2021. The weights and forecasts for the 2021 AFWG assessment can be found in Table 1.9.

It was noted that the oceanographic dataset for the Titov ES and EL models cover the year classes from 1959 onwards, while the survey data used in the RCT3 model only cover the year classes from 1991 onwards, although those survey dataseries started in 1981. Further, the area covered in the surveys was extended in 2014, which is accounted for in the cod assessment by splitting the bottom trawl survey series in that year, while no such split was made in the RCT3 model. It should be investigated how this area expansion in the survey best could be accounted for in the recruitment model.

New software in R was presented during AFWG 2021 for predicting cod recruitment using the hybrid model (WD 20) including the automatic procedure for the submodel's weight estimation. A comparison of predicted values with "old" software (WD 21) was done and the results were identical.

Table 1.1. The North-east arctic COD stock's consumption of various prey species in 1984-2020 (1000 tonnes) based on Norwegian consumption calculations

Year	Other	Amphipods	Krill	Shrimp	Capelin	Herring	Polar cod	Cod	Haddock	Redfish	G. halibut	Blue whiting	Long rough c	Snow crab	Total
1984	494	27	119	447	739	82	16	23	52	374	0	0	25	0	2398
1985	1252	188	64	179	1780	214	3	31	54	244	0	2	48	0	4058
1986	679	1426	133	165	961	162	156	74	110	340	0	0	66	0	4273
1987	813	1372	89	233	295	38	225	26	6	340	1	0	11	0	3449
1988	447	1419	337	151	382	8	99	11	2	259	0	5	6	0	3126
1989	679	823	245	123	589	3	37	8	10	222	0	0	67	0	2805
1990	1149	123	80	162	1409	7	5	16	14	188	0	81	86	0	3320
1991	688	63	71	164	2441	7	10	22	16	264	7	8	240	0	4002
1992	826	97	154	354	2266	275	92	46	88	172	23	2	94	0	4487
1993	709	242	669	305	2873	155	269	261	69	92	2	2	27	0	5674
1994	611	552	693	506	1060	146	599	223	48	76	0	1	43	0	4558
1995	827	972	527	358	607	117	245	367	114	194	2	0	36	0	4366
1996	604	620	1166	345	548	46	101	536	67	95	0	10	37	0	4173
1997	466	404	545	350	978	5	115	350	44	33	0	34	15	0	3340
1998	448	411	513	375	836	104	174	163	36	9	0	14	18	0	3100
1999	422	166	306	300	2047	151	258	67	30	18	1	35	9	0	3808
2000	427	188	492	503	1935	61	218	83	58	8	0	41	21	0	4035
2001	721	176	382	291	1836	76	264	68	51	6	1	157	32	0	4060
2002	376	96	260	241	2004	86	280	108	127	1	0	239	16	0	3834
2003	545	285	545	238	2152	216	275	110	166	3	0	74	53	0	4662
2004	626	560	347	246	1253	216	358	126	198	3	11	56	65	1	4065
2005	781	579	527	274	1399	132	388	118	324	2	5	115	53	0	4697
2006	870	225	1078	353	1737	170	108	80	361	12	2	163	130	0	5287
2007	1259	310	1091	428	2140	285	266	88	378	46	0	44	75	0	6411
2008	1578	160	931	385	2865	105	514	187	293	59	13	18	93	0	7201
2009	1495	243	635	265	3978	123	730	196	252	28	3	5	115	2	8072
2010	1616	415	1049	281	3900	52	334	241	267	142	10	14	133	7	8462
2011	1556	254	902	221	4120	84	424	286	279	115	0	26	122	9	8398
2012	1975	316	842	345	3641	51	519	373	220	51	34	8	125	7	8506
2013	1774	261	566	267	3660	51	137	380	200	111	1	21	167	15	7612
2014	1409	326	475	202	3713	72	31	358	88	31	11	18	106	9	6849
2015	1595	619	637	243	3278	126	147	213	178	140	43	59	85	33	7396
2016	1691	530	745	299	2210	95	346	198	222	57	6	87	120	10	6617
2017	1053	126	582	251	2950	193	88	315	272	45	4	24	139	53	6097
2018	1032	267	644	180	2886	203	246	246	276	34	70	47	52	44	6227
2019	779	212	415	308	2600	181	168	188	212	44	0	2	99	50	5258
2020	919	523	535	172	2021	107	467	115	92	30	14	13	150	90	5247

Table 1.2. The North-east arctic COD stock's consumption of various prey species in 1984-2020 (1000 tonnes) based on Russian consumption calculations (Dolgov, WD 07 AFWG 2020)

	NOT UPDATED THIS YEAR														
Year	**Other**	**Amphipods**	**Krill**	**Shrimp**	**Capelin**	**Herring**	**Polar cod**	**Cod**	**Haddock**	**Redfish**	**G. halibut**	**Blue whiting**	**Long rough**	**Snow crab**	**Total**
1984	560	31	94	353	593	34	18	14	50	197	0	5	52		2000
1985	767	441	31	211	1041	26	0	89	36	100	0	18	22		2779
1986	615	949	66	159	855	51	169	26	99	166	1	3	26		3186
1987	541	593	79	233	175	9	118	23	2	119	1	10	5		1908
1988	544	196	239	146	348	21	0	21	76	133	0	0	22		1745
1989	496	324	190	117	767	4	37	35	2	178	0	0	64		2213
1990	278	31	105	266	1264	65	8	24	15	237	0	39	79		2409
1991	289	81	55	277	3204	25	45	52	22	141	5	6	46		4248
1992	788	38	211	258	2021	335	196	82	37	117	1	0	42		4125
1993	563	174	184	220	2743	170	170	144	148	40	5	4	47		4611
1994	447	296	359	458	1276	102	486	383	72	55	0	1	40		3976
1995	502	455	396	533	670	192	191	541	130	110	3	0	52		3775
1996	674	346	957	195	469	74	74	451	57	67	0	9	45		3415
1997	463	134	510	257	511	52	111	383	35	29	2	17	17		2520
1998	311	220	645	286	916	73	134	131	23	15	0	24	20		2797
1999	179	81	458	268	1540	80	177	49	16	14	0	27	9		2898
2000	243	122	437	394	1800	53	167	59	32	4	0	28	21		3360
2001	384	75	411	322	1522	93	148	62	52	4	2	145	31		3250
2002	225	45	286	202	2400	55	302	100	80	4	0	110	17		3825
2003	400	171	547	227	1219	153	221	132	331	2	0	28	51		3481
2004	496	393	478	256	1097	129	369	86	144	7	16	48	62		3583
2005	620	163	688	244	1023	168	320	112	271	7	2	67	47		3731
2006	786	86	1547	274	1341	268	125	95	285	17	1	103	148		5076
2007	831	192	1340	420	1881	275	289	68	329	29	1	32	73		5760
2008	1021	51	1005	345	3278	122	664	156	331	60	13	17	121		7184
2009	1048	189	938	284	3360	229	828	142	347	28	0	8	285		7687
2010	973	330	1843	255	4120	143	512	181	246	163	1	16	136		8918
2011	1251	202	831	226	4473	85	422	259	359	143	2	57	170		8479
2012	1771	164	600	273	2986	97	439	291	415	41	7	33	133		7251
2013	1366	210	648	334	3676	45	146	447	272	178	2	40	216		7581
2014	1391	121	744	208	3340	56	98	390	170	20	7	27	154		6726
2015	1122	301	1160	442	2675	69	159	175	180	87	14	39	117		6539
2016	1542	654	775	216	2221	86	248	239	158	48	3	51	328		6568
2017	1042	85	681	316	2709	99	75	271	315	188	3	26	249		6060
2018	1153	146	1541	178	1624	271	117	352	479	41	41	41	121		6105
2019	751	97	498	189	2103	379	131	415	292	47	0	15	159		5075

Table 1.3		**Consumption per cod by cod age group (kg/year), based on Norwegian consumption calculations.**									
Year/Age	1	2	3	4	5	6	7	8	9	10	11+
1984	0.247	0.815	1.683	2.521	3.951	5.208	8.009	8.524	9.180	9.912	9.954
1985	0.304	0.761	1.833	3.105	4.675	7.360	11.246	11.972	12.497	13.751	13.869
1986	0.161	0.498	1.343	3.152	5.669	6.884	11.018	11.944	12.749	13.513	13.768
1987	0.219	0.602	1.290	2.051	3.532	5.489	7.077	8.107	8.923	9.343	9.301
1988	0.164	0.702	1.150	2.149	3.743	5.877	10.098	11.222	12.575	13.127	13.373
1989	0.223	0.715	1.606	2.714	3.980	5.611	7.678	8.499	9.597	10.198	10.628
1990	0.363	0.906	1.909	3.058	4.218	5.447	6.527	6.877	7.075	7.455	7.955
1991	0.293	0.972	2.178	3.536	5.318	7.073	9.470	10.238	11.292	12.339	12.037
1992	0.215	0.665	2.100	3.135	4.142	5.093	7.868	9.023	9.402	10.124	10.156
1993	0.112	0.529	1.548	3.045	4.823	6.292	9.413	11.272	11.798	12.288	12.880
1994	0.130	0.406	0.924	2.523	3.508	4.544	6.404	8.844	9.716	9.988	10.232
1995	0.103	0.299	0.918	1.824	3.359	5.261	7.726	10.425	12.300	12.770	13.191
1996	0.108	0.359	0.938	1.855	3.055	4.434	7.409	11.124	14.591	15.048	15.432
1997	0.140	0.327	0.952	1.778	2.717	3.537	5.261	8.128	12.659	13.389	13.205
1998	0.117	0.400	0.991	1.953	2.922	4.188	5.751	8.078	11.375	12.071	12.113
1999	0.163	0.505	1.095	2.720	3.719	5.444	6.975	9.193	10.953	12.063	12.181
2000	0.170	0.499	1.239	2.467	4.262	5.650	7.975	9.405	12.679	13.401	13.542
2001	0.171	0.448	1.308	2.435	3.688	5.305	7.550	11.238	13.477	14.400	14.674
2002	0.199	0.553	1.163	2.443	3.382	4.721	6.366	9.069	10.301	11.513	11.098
2003	0.207	0.648	1.316	2.391	4.002	5.958	8.438	10.435	12.903	13.576	14.443
2004	0.222	0.476	1.298	2.285	3.339	5.568	7.444	11.468	17.366	19.237	18.956
2005	0.203	0.659	1.380	2.746	4.247	6.365	7.670	10.284	13.851	14.895	15.610
2006	0.204	0.626	1.584	2.811	4.241	6.316	7.868	11.626	14.023	15.100	15.929
2007	0.256	0.653	1.738	3.092	4.471	6.237	8.277	10.287	12.786	13.554	13.988
2008	0.204	0.724	1.469	2.877	4.082	7.111	8.407	11.463	15.655	16.348	16.617
2009	0.192	0.618	1.494	2.769	4.434	5.759	8.470	11.487	12.793	13.632	13.821
2010	0.203	0.635	1.357	2.504	3.989	5.709	8.447	12.078	15.363	16.040	16.394
2011	0.219	0.663	1.419	2.627	4.033	5.351	7.272	9.663	15.139	16.314	16.304
2012	0.231	0.763	1.503	2.688	4.103	5.077	7.312	10.038	15.400	16.594	16.518
2013	0.182	0.674	1.447	2.531	3.908	4.999	5.954	7.582	11.489	12.510	13.450
2014	0.224	0.648	1.308	2.549	3.763	4.253	5.837	8.010	10.796	11.514	12.026
2015	0.218	0.662	1.426	2.528	4.254	5.695	7.376	8.628	13.081	13.892	15.034
2016	0.252	0.722	1.578	2.769	3.919	5.514	7.201	8.040	12.056	12.652	14.479
2017	0.248	0.791	1.529	2.653	3.977	5.628	7.031	8.143	11.271	14.168	16.982
2018	0.194	0.775	1.566	2.813	4.391	5.208	6.811	10.602	12.879	17.074	15.980
2019	0.191	0.515	1.343	2.288	3.517	4.417	6.219	8.963	12.186	11.715	12.973
2020	0.175	0.465	1.086	2.461	3.503	4.926	6.796	10.080	11.988	13.655	15.837
Average	**0.201**	**0.613**	**1.406**	**2.590**	**3.969**	**5.500**	**7.639**	**9.785**	**12.275**	**13.221**	**13.647**

Table 1.4		Consumption per cod by cod age group (kg/year), based on Russian consumption calculations.											
		NOT UPDATED THIS YEAR											
Year/Age	1	2	3	4	5	6	7	8	9	10	11	12	13+
1984	0.262	0.895	1.611	2.748	3.848	5.486	6.992	8.561	10.572	13.166	13.200	15.547	17.153
1985	0.295	0.753	1.658	2.681	4.264	6.599	8.241	9.745	10.974	14.448	17.327	17.391	19.186
1986	0.179	0.526	1.455	3.455	5.001	5.991	6.458	8.157	9.766	11.457	13.188	14.621	16.134
1987	0.145	0.432	0.852	1.558	3.073	4.380	7.357	9.667	12.705	14.481	15.899	16.616	18.318
1988	0.183	0.704	1.075	1.628	2.391	4.386	8.207	9.978	10.868	16.536	14.639	16.046	17.000
1989	0.282	0.909	1.465	2.207	3.243	4.798	6.578	8.725	11.134	15.798	16.313	18.436	18.041
1990	0.288	1.006	1.694	2.693	3.278	3.833	5.583	6.870	10.715	11.426	13.555	15.964	17.595
1991	0.241	0.936	2.670	4.472	6.037	7.844	9.590	11.543	14.969	19.292	18.590	21.720	23.960
1992	0.178	0.969	2.475	2.866	3.995	5.137	6.723	7.414	8.755	12.303	14.288	15.184	16.745
1993	0.133	0.476	1.512	2.865	3.944	5.108	7.372	8.945	10.343	11.600	14.835	16.536	18.249
1994	0.180	0.512	1.212	2.402	3.517	5.359	7.560	10.001	11.818	12.896	14.499	17.656	19.469
1995	0.194	0.497	0.962	1.801	3.204	4.847	7.332	9.688	13.835	15.247	16.899	19.273	21.254
1996	0.170	0.498	1.028	1.916	3.059	4.189	6.987	10.212	12.185	13.614	14.529	16.275	17.945
1997	0.119	0.341	0.992	1.908	2.668	3.503	4.954	7.980	12.174	16.762	16.710	18.410	20.308
1998	0.232	0.528	1.081	2.016	2.823	4.089	5.469	7.346	9.586	13.012	14.404	15.640	17.243
1999	0.261	0.431	1.128	2.490	3.676	5.222	6.398	8.220	9.194	13.364	15.268	16.990	18.727
2000	0.186	0.545	1.288	2.551	4.387	6.559	8.833	10.483	11.522	15.132	17.090	19.793	21.822
2001	0.150	0.413	1.163	2.110	3.430	5.571	6.835	10.233	12.457	15.130	17.341	19.307	21.345
2002	0.252	0.677	1.303	2.699	3.847	5.591	7.846	10.796	13.238	18.787	17.836	20.278	22.359
2003	0.228	0.618	1.296	2.028	3.547	4.716	6.684	8.905	13.418	14.492	19.480	19.309	21.292
2004	0.250	0.654	1.412	2.567	3.857	5.660	7.730	11.126	15.907	20.770	21.607	24.940	27.503
2005	0.255	0.687	1.514	2.504	3.896	5.264	7.192	9.395	13.163	15.981	20.628	21.448	23.639
2006	0.354	0.925	1.881	2.813	4.019	5.332	7.450	10.328	13.111	17.759	19.488	22.322	24.609
2007	0.234	0.681	1.874	3.128	4.459	5.893	7.563	9.178	12.032	15.919	19.961	21.644	23.863
2008	0.223	0.719	1.697	2.959	4.194	6.073	7.809	10.464	13.627	17.254	21.590	23.373	25.779
2009	0.217	0.624	1.495	2.526	4.304	5.623	7.855	11.490	13.341	15.988	18.770	21.866	24.111
2010	0.235	0.651	1.401	2.577	4.065	5.757	8.312	11.805	16.090	16.844	20.129	23.023	25.387
2011	0.248	0.721	1.497	2.513	3.859	4.963	6.848	9.213	13.799	19.074	20.784	23.791	26.241
2012	0.207	0.588	1.203	2.292	3.266	4.461	5.862	7.629	11.713	16.211	19.345	21.032	23.190
2013	0.190	0.656	1.641	2.552	3.809	4.952	5.791	7.757	10.881	14.989	19.785	22.386	24.691
2014	0.242	0.622	1.321	2.340	3.608	4.387	5.560	7.447	9.017	12.547	16.044	18.854	20.781
2015	0.234	0.745	1.390	2.406	3.915	4.922	5.960	7.505	10.265	12.116	16.245	19.978	22.023
2016	0.307	0.870	1.722	2.813	3.474	4.740	6.754	9.117	10.665	14.810	19.921	24.195	26.683
2017	0.244	0.779	1.582	2.531	3.748	4.943	6.601	9.180	11.302	16.016	20.086	23.464	25.870
2018	0.316	0.867	1.846	2.699	3.736	5.000	6.489	9.170	11.166	14.577	18.672	21.848	24.091
2019	0.269	0.655	1.383	2.204	3.316	4.500	6.415	9.078	13.251	15.509	19.423	22.635	24.958
Average	**0.227**	**0.670**	**1.466**	**2.514**	**3.743**	**5.158**	**7.005**	**9.260**	**11.932**	**15.147**	**17.455**	**19.661**	**21.599**

Table 1.5 Proportion of cod in cod diet, based on Norwegian consumption calculations

Year/age	1	2	3	4	5	6	7	8	9	10	11+
1984	0.0000	0.0000	0.0032	0.0000	0.0432	0.0262	0.0332	0.0361	0.0371	0.0392	0.0394
1985	0.0015	0.0009	0.0014	0.0017	0.0312	0.0074	0.0822	0.0826	0.0833	0.0835	0.0840
1986	0.0000	0.0022	0.0015	0.0004	0.0130	0.1743	0.1760	0.1761	0.1758	0.1749	0.1745
1987	0.0000	0.0000	0.0007	0.0050	0.0103	0.0244	0.0383	0.0395	0.0412	0.0409	0.0443
1988	0.0000	0.0000	0.0000	0.0002	0.0059	0.0014	0.0037	0.0036	0.0031	0.0035	0.0031
1989	0.0000	0.0006	0.0016	0.0019	0.0027	0.0039	0.0036	0.0036	0.0039	0.0038	0.0040
1990	0.0000	0.0000	0.0000	0.0007	0.0010	0.0010	0.0165	0.0172	0.0181	0.0179	0.0178
1991	0.0000	0.0005	0.0000	0.0003	0.0032	0.0020	0.0222	0.0227	0.0230	0.0231	0.0231
1992	0.0000	0.0021	0.0037	0.0129	0.0248	0.0475	0.0119	0.0160	0.0232	0.0232	0.0231
1993	0.0000	0.0410	0.0370	0.0515	0.0541	0.1135	0.0498	0.0795	0.0797	0.0796	0.0802
1994	0.0000	0.0037	0.0927	0.0349	0.0285	0.0785	0.1248	0.1330	0.2659	0.2674	0.2668
1995	0.0069	0.0812	0.0747	0.0803	0.0923	0.1118	0.1387	0.2526	0.2542	0.2539	0.2545
1996	0.0000	0.1500	0.2566	0.2051	0.1321	0.1263	0.1874	0.2091	0.2436	0.2447	0.2437
1997	0.0000	0.0687	0.0762	0.1137	0.1558	0.1555	0.2315	0.2269	0.2919	0.2850	0.2916
1998	0.0000	0.0134	0.0272	0.0418	0.1037	0.0978	0.1090	0.1498	0.2722	0.2741	0.2718
1999	0.0000	0.0000	0.0048	0.0136	0.0147	0.0338	0.0618	0.1114	0.1902	0.1907	0.1843
2000	0.0000	0.0000	0.0287	0.0148	0.0134	0.0266	0.0497	0.0570	0.2682	0.2699	0.2594
2001	0.0000	0.0160	0.0116	0.0082	0.0131	0.0241	0.0498	0.0375	0.3250	0.3233	0.3268
2002	0.0000	0.0385	0.0597	0.0142	0.0187	0.0284	0.0357	0.0623	0.1582	0.1560	0.1555
2003	0.0000	0.0190	0.0198	0.0199	0.0206	0.0188	0.0451	0.1030	0.2194	0.2219	0.2228
2004	0.0081	0.0234	0.0280	0.0269	0.0296	0.0319	0.0380	0.0663	0.1062	0.1062	0.1077
2005	0.0000	0.0266	0.0230	0.0266	0.0145	0.0277	0.0436	0.0779	0.1484	0.1462	0.1437
2006	0.0000	0.0103	0.0007	0.0128	0.0288	0.0158	0.0392	0.0368	0.0810	0.0821	0.0820
2007	0.0000	0.0000	0.0011	0.0117	0.0119	0.0304	0.0282	0.0901	0.1407	0.1413	0.1383
2008	0.0000	0.0559	0.0257	0.0101	0.0157	0.0098	0.0764	0.0873	0.0975	0.0959	0.0981
2009	0.0116	0.0225	0.0262	0.0251	0.0152	0.0139	0.0219	0.0945	0.1078	0.1082	0.1076
2010	0.0000	0.0327	0.0580	0.0270	0.0243	0.0243	0.0203	0.0383	0.1367	0.1369	0.1353
2011	0.0129	0.0152	0.0492	0.0170	0.0361	0.0300	0.0238	0.0575	0.1279	0.1279	0.1278
2012	0.0274	0.0608	0.0640	0.0618	0.0274	0.0432	0.0410	0.0373	0.0685	0.0691	0.0681
2013	0.0214	0.0303	0.0459	0.0389	0.0276	0.0224	0.0478	0.0538	0.1166	0.1171	0.1335
2014	0.0824	0.0363	0.0450	0.0342	0.0213	0.0456	0.0661	0.0787	0.0658	0.0658	0.0752
2015	0.0000	0.0088	0.0308	0.0283	0.0266	0.0192	0.0233	0.0281	0.0555	0.0553	0.0539
2016	0.0157	0.0192	0.0063	0.0393	0.0146	0.0172	0.0266	0.0137	0.0906	0.0914	0.0910
2017	0.0419	0.0354	0.0386	0.0470	0.0436	0.0400	0.0560	0.0913	0.0686	0.1015	0.1409
2018	0.0000	0.0186	0.0680	0.0480	0.0351	0.0378	0.0567	0.0310	0.0243	0.0076	0.0252
2019	0.0000	0.0000	0.0328	0.0296	0.0339	0.0228	0.0366	0.0741	0.0934	0.0252	0.0792
2020	0.0000	0.0227	0.0013	0.0041	0.0110	0.0177	0.0311	0.0504	0.0683	0.0649	0.1118

Table 1.6 Proportion of haddock in cod diet, based on Norwegian consumption calculations

Year/age	1	2	3	4	5	6	7	8	9	10	11+
1984	0.0443	0.0175	0.0053	0.0225	0.0455	0.0215	0.0022	0.0020	0.0019	0.0018	0.0017
1985	0.0205	0.0227	0.0052	0.0076	0.0207	0.0109	0.0000	0.0000	0.0000	0.0000	0.0000
1986	0.0000	0.0187	0.0015	0.0866	0.0005	0.0530	0.0249	0.0248	0.0257	0.0286	0.0301
1987	0.0000	0.0052	0.0003	0.0025	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1988	0.0000	0.0000	0.0000	0.0000	0.0003	0.0034	0.0034	0.0034	0.0039	0.0035	0.0039
1989	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0339	0.0338	0.0349	0.0347	0.0356
1990	0.0000	0.0000	0.0000	0.0024	0.0021	0.0007	0.0130	0.0124	0.0117	0.0118	0.0119
1991	0.0000	0.0000	0.0098	0.0079	0.0045	0.0051	0.0031	0.0030	0.0029	0.0028	0.0028
1992	0.0000	0.0000	0.0014	0.0683	0.0208	0.0271	0.0278	0.0317	0.0462	0.0462	0.0461
1993	0.0000	0.0000	0.0204	0.0073	0.0149	0.0144	0.0278	0.0261	0.0261	0.0261	0.0263
1994	0.0000	0.0000	0.0065	0.0131	0.0069	0.0141	0.0298	0.0491	0.0456	0.0452	0.0453
1995	0.0000	0.0354	0.0030	0.0429	0.0260	0.0241	0.0393	0.0956	0.1617	0.1615	0.1619
1996	0.0000	0.0000	0.0592	0.0155	0.0098	0.0170	0.0376	0.0485	0.0925	0.1016	0.0981
1997	0.0000	0.0000	0.0242	0.0189	0.0245	0.0158	0.0127	0.0175	0.0561	0.0569	0.0539
1998	0.0000	0.0000	0.0115	0.0120	0.0227	0.0192	0.0106	0.0323	0.0161	0.0166	0.0160
1999	0.0000	0.0000	0.0028	0.0078	0.0158	0.0124	0.0120	0.0139	0.0224	0.0225	0.0217
2000	0.0000	0.0000	0.0233	0.0102	0.0178	0.0116	0.0158	0.0525	0.0286	0.0285	0.0287
2001	0.0000	0.0081	0.0052	0.0163	0.0147	0.0171	0.0194	0.0198	0.0337	0.0330	0.0345
2002	0.0000	0.0000	0.0185	0.0339	0.0353	0.0471	0.0747	0.0761	0.1830	0.1793	0.1785
2003	0.0000	0.0000	0.0145	0.0311	0.0595	0.0436	0.0553	0.1215	0.1079	0.1078	0.1078
2004	0.0044	0.0418	0.0745	0.0388	0.0575	0.0501	0.0564	0.0996	0.0910	0.0911	0.0924
2005	0.0000	0.0853	0.1047	0.0595	0.0621	0.0646	0.1038	0.1082	0.1115	0.1101	0.1085
2006	0.0000	0.0409	0.0829	0.0872	0.0604	0.0897	0.0716	0.1063	0.0962	0.0957	0.0958
2007	0.0000	0.0035	0.0462	0.0415	0.0833	0.0980	0.1335	0.1152	0.1631	0.1627	0.1648
2008	0.0000	0.0045	0.0106	0.0156	0.0383	0.0753	0.1148	0.1327	0.2329	0.2346	0.2321
2009	0.0000	0.0218	0.0241	0.0182	0.0142	0.0362	0.1090	0.0595	0.1881	0.1868	0.1891
2010	0.0000	0.0031	0.0279	0.0182	0.0178	0.0217	0.0362	0.1420	0.1819	0.1806	0.1810
2011	0.0000	0.0049	0.0362	0.0285	0.0087	0.0204	0.0411	0.0924	0.1633	0.1630	0.1625
2012	0.0000	0.0000	0.0113	0.0282	0.0337	0.0271	0.0368	0.0335	0.0859	0.0848	0.0872
2013	0.0000	0.0073	0.0309	0.0112	0.0314	0.0233	0.0147	0.0363	0.0615	0.0615	0.0916
2014	0.0000	0.0089	0.0037	0.0255	0.0080	0.0047	0.0022	0.0340	0.0143	0.0143	0.0194
2015	0.0000	0.0175	0.0409	0.0254	0.0172	0.0166	0.0258	0.0197	0.0384	0.0385	0.0399
2016	0.0000	0.0051	0.0799	0.0771	0.0265	0.0259	0.0323	0.0420	0.0342	0.0343	0.0339
2017	0.0106	0.0429	0.0153	0.0450	0.0462	0.0568	0.0466	0.0528	0.0795	0.0677	0.0867
2018	0.0000	0.0000	0.0434	0.0365	0.0590	0.0661	0.0551	0.0588	0.0821	0.0304	0.1164
2019	0.0000	0.0000	0.0284	0.0564	0.0422	0.0491	0.0513	0.0401	0.0345	0.0644	0.2709
2020	0.0000	0.0000	0.0011	0.0063	0.0037	0.0096	0.0257	0.0707	0.0514	0.0816	0.0287
Average	**0.0022**	**0.0107**	**0.0236**	**0.0277**	**0.0257**	**0.0296**	**0.0378**	**0.0516**	**0.0706**	**0.0706**	**0.0785**

Table 1.7. Parameters of TitovES and TitovEL models (subscripts correspond to the time-lag in months before the start of the year to which the value Cod3 is attributed).

Year	Cod3	$OxSatt_{39}$	$DOxSatt_{13}$	$ITwt_{43}$	$Icet_{15}$	$expIcet_{40}$
1962	1252375	−0.19	−6.6	1.86	0.5	0
1963	900621	−0.94	−2.37	1.59	1.5	0
1964	468028	1.63	1.23	2.47	9	0
1965	870506	0.88	−0.2	3.91	15.7	0
1966	1842715	−1.09	−3.98	7.97	5.3	0
1967	1311586	−0.23	−2.84	8.23	5	9.3
1968	183717	1.5	−0.13	3.78	15.5	0
1969	110450	0.85	0.63	1.77	15.9	0
1970	205641	−0.17	−0.23	3.51	19.8	7.9
1971	402577	0.06	−0.12	−0.13	18.8	2.7
1972	1045979	−3.32	−6.59	14.55	−0.6	428.9
1973	1723668	−2.1	−10.37	19.14	1.8	768.6
1974	568211	1.06	−1.73	2.4	2	0
1975	608710	1.9	0.78	−2.64	−1.2	0
1976	607084	1.33	−1.28	−3.07	−1.9	0
1977	372778	−0.07	−1.84	−2.44	2.5	0
1978	622679	1.19	0.1	1.05	−1	0
1979	202675	0.5	−1.48	−0.12	3.5	0
1980	130292	−0.31	−2.72	1.98	12.9	0
1981	143781	0.76	−0.18	1.94	14.7	0
1982	183737	0.8	0.61	−3.15	8	0.1
1983	141514	0.78	0.22	1.87	12.2	8.5
1984	442251	−2.21	−2.35	−3.08	12.9	0
1985	534310	−0.1	−1.17	3.59	−1.2	0.1
1986	1374917	−2.14	−4.39	1.39	−8.5	2.9
1987	360087	−0.33	−1.69	2.12	0.6	0
1988	335536	0.87	−1.4	−2.34	3.8	0
1989	157635	0.32	−3.42	−5.17	10.5	0

Year	Cod3	$OxSatt_{39}$	$DOxSatt_{13}$	$ITwt_{43}$	$Icet_{15}$	$expIcet_{40}$
1990	130130	1.11	−1.32	−4.21	10.5	0
1991	295846	0.88	0.7	2.42	6.5	0
1992	715916	1.34	0.48	1.37	−0.9	0
1993	988150	−1.98	−3.86	6.12	−0.6	0
1994	752473	−0.5	−2.26	8.25	−4.9	0
1995	539384	0.83	−2.42	4.36	1.8	0
1996	407389	0.86	−0.08	0.55	0.7	0
1997	785420	0.88	0.17	3.11	−7.3	0
1998	1063528	0.3	−6.08	−2.32	−2.5	0
1999	632034	−0.72	−2.4	−6.81	2.9	0
2000	749727	1.86	1.55	−2.29	13.6	0
2001	593152	0.62	0.05	−6.04	2.3	0
2002	374202	−0.88	−0.98	3.63	−9.9	0.8
2003	756675	−0.39	−0.64	8.5	−5.8	0
2004	242069	−2.2	−2.53	−4.62	−1.4	0
2005	693264	−1.65	−1.82	−1.45	4.9	0
2006	536630	−1.18	−1.65	−4	−6	0
2007	1243906	−1.39	−4.42	7.42	−12.3	0
2008	1002761	−1.14	−1.59	3.39	−18	0
2009	581758	0.79	−1.83	−1.61	−17.5	0
2010	201832	−0.38	−2.6	−8.94	−9	0
2011	358117	0.83	−0.07	−5	−4.3	0
2012	503017	0.91	−0.13	−5.05	−4.3	0
2013	464921	0.04	−0.09	1.44	−10.5	0
2014	852202	−0.46	−1	1.43	−17.8	0
2015	452019	−1.26	−1.62	−2.22	−10.5	0
2016	286334	−1.31	−1.92	−7.52	−5.8	0
2017	781901	−0.33	−0.64	−1.69	−14.4	0
2018	508296	−1.24	−1.41	0.1	−20.9	0

Year	Cod3	$OxSatt_{39}$	$DOxSatt_{13}$	$ITwt_{43}$	$Icet_{15}$	$expIcet_{40}$
2019	659091	−0.63	−1.08	−1.71	−13.2	0
2020	572413	−2.02	−2.19	−6.35	−13.6	0
2021	NA	−0.8	−1.08	−1.33	−9.2	0
2022	NA	−1.55	−2.1	−2.47	−12.8	0
2023	NA	−1.52	NA	−4.18	NA	0
2024	NA	−0.31	NA	−5.63	NA	0

Table 1.8 Initial data for RCT3 model.

year class	recruitment	BST1	BST2	BST3	BSA1	BSA2	BSA3
1982	534	NA	NA	NA	NA	NA	NA
1983	1375	NA	NA	NA	NA	NA	NA
1984	360	NA	NA	NA	NA	NA	NA
1985	336	NA	NA	NA	NA	NA	NA
1986	158	NA	NA	NA	NA	NA	NA
1987	130	NA	NA	NA	NA	NA	NA
1988	296	NA	NA	NA	NA	NA	NA
1989	716	NA	NA	NA	NA	NA	NA
1990	988	NA	NA	NA	NA	NA	NA
1991	752	NA	NA	294	NA	NA	324
1992	539	NA	557	283	NA	624	138
1993	407	1044	541	163	903	212	99
1994	785	5356	792	318	2175	272	159
1995	1064	5899	1423	355	1826	565	391
1996	632	5044	496	188	1699	475	148
1997	750	2491	350	246	2524	232	295
1998	593	473	242	183	365	263	177
1999	374	129	78	118	153	52	61
2000	757	713	419	377	364	209	307
2001	242	34	66	64	19	53	33
2002	693	3022	243	249	1505	117	125

year class	recruitment	BST1	BST2	BST3	BSA1	BSA2	BSA3
2003	537	323	217	116	161	139	65
2004	1244	853	289	361	500	158	59
2005	1003	674	370	194	411	47	200
2006	582	595	102	126	85	94	108
2007	202	69	36	37	51	26	23
2008	358	389	95	85	205	44	40
2009	503	1028	226	76	620	91	83
2010	465	617	100	69	266	40	61
2011	852	703	143	227	497	89	287
2012	452	436	191	144	313	211	139
2013	286	1246	343	99	1759	211	56
2014	782	1642	306	179	1904	202	112
2015	508	312	129	139	241	73	109
2016	659	645	501	282	439	280	204
2017	572	2714	559	238	2058	362	117
2018	NA	1791	274	115	1437	158	70
2019	NA	165	33	NA	93	17	NA
2020	NA	88	NA	NA	44	NA	NA

Table 1.9. Overview available prognoses of NEA cod recruitment (in million individuals of age 3) from different models.

Model	Parameter	Years of prediction	2021 Prognosis	2022 Prognosis	2023 Prognosis	2024 Prognosis
TitovEL	R at age 3	4	590	614	548	386
	Model weight		0.34	0.47	1	1
TitovES	R at age 3	2	559	627		
	Model weight		0.42	0.53	0	0
RCT3	R at age 3	3	525	301	384	
	Model weight		0.24	0	0	
Hybrid	R at age 3	4	561	621	548	386

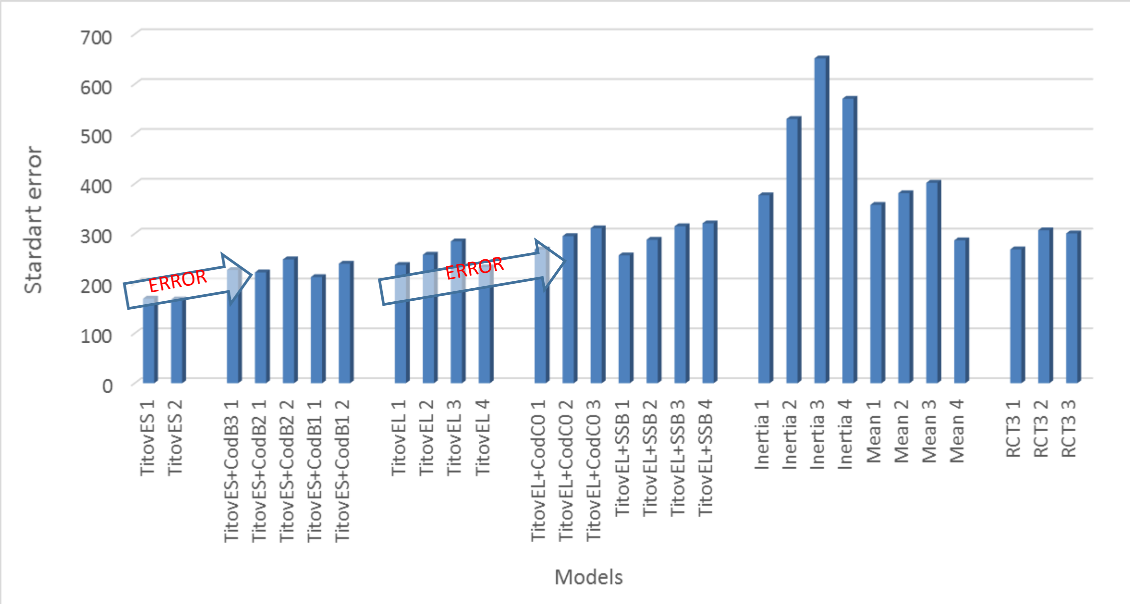

Figure 1.1. Standard errors of the NEA cod recruitment predicted values from the SAM values.