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Review of Greenland halibut deep-water surveys in Northwest Atlantic Fisheries Organization Divisions Subareas 0 and 1 offshore.

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Abstract

Research surveys have been conducted in Northwest Atlantic Fisheries Organization (NAFO) Subarea 1 by Greenland since 1997 and in Subarea 0 by Canada since 1999, using the R/V Paamiut fishing with an Alfredo III bottom trawl. Indices from Divs. 0A-South and 1CD are combined to provide an overall index for the Greenland halibut stock in NAFO 0+1 offshore. The surveys follow a depth stratified random sampling design and until 2003 sets were selected using a random number draw of grid cells within depth strata. In 2004, the independent and random placement of stations was replaced by a buffered random sampling to automatically avoid selecting stations in adjacent cells. The Greenlandic surveys also adopted a variance-based approach to determine the number of stations to allocate to each stratum. This method optimizes set distribution among the depth strata based on variance in Greenland halibut biomass from past surveys, instead of having the same number of stations proportional to the strata area each year. There were no surveys in 2018 and 2020. In 2019, surveys were carried out with a chartered vessel, C/V Helga Maria fishing the Alfredo III trawl, but after examining wing spread and net height data from trawl sensors, it was determined that the gear performance differed substantially from that of the regular survey vessel at depths below 700 m, likely affecting the catchability of Greenland halibut. Therefore, the indices from the two vessels were not considered comparable to the remainder of the time series. In 2021, surveys will be conducted with a new vessel (R/V Tarajoq) and a new trawl gear (Bacalao 476). These changes in vessel and gear provide an opportunity to review past practices and improve the surveys. This research document presents proposed changes in survey design and sampling protocols for review and comment.

Background

Three surveys in Northwest Atlantic Fisheries Organization (NAFO) Subarea 0 and 1 (Figure 1) have been conducted by the R/V Paamiut, a converted shrimp trawler: deep-water survey in Divisions 1CD, deep-water survey in Division 0A-South, and shallow-water Fish and Shrimp survey in Divisions 1A to 1F (Table 1). Results from these surveys form the basis for the assessment of the Greenland halibut (*Reinhardtius hippoglossoides*) 0+1 offshore stock. The deep-water (400-1500 m) survey in 1CD was carried out annually from 1997 to 2017. Surveys at similar depths in 0A-South began in 1999 and were completed every second year between 2004 and 2014, then annually between 2015 and 2017. Surveys in Division 0B were also conducted in 2000, 2001, 2011 and then annually from 2013 to 2016, with the intention of eventually expanding the index to include both 0A-South and 0B. These surveys all used an Alfredo III trawl, with mesh size of 140 mm and a 30 mm mesh liner in the cod-end. The Fish and Shrimp survey (50-601m) in 1A to 1F has been conducted annually since 1991. This survey used a Skjervoy 3000/20 trawl until 2003 and a Cosmos shrimp trawl since 2004. Both trawls had a 20-mm stretched-mesh liner in the cod-end (Nygaard and Nogueira, 2020). Trawl calibration experiments were conducted, and conversion factors were established for the main commercial species (Rosing and Wieland, 2005).

In 2017, the government of Greenland decided that the old vessel R/V Paamiut could no longer be maintained, and it was retired. The construction of a new research vessel was authorized. No surveys were conducted in 2018 and 2020 in 0A-South and 1CD. The 1A to 1F survey was carried out with a chartered commercial vessel C/V Sjurdarberg in 2018. In 2019 all three surveys were carried out using a charter commercial vessel, C/V Helga Maria (Table 1).

Because a different vessel was used for the surveys in 2019, several analyses comparing R/V Paamiut and C/V Helga Maria vessels, gear performance, and catch length frequencies were made (Nogueira and Treble, 2020). Both the 1CD and 0A-South surveys were carried out earlier in the year than usual and this effect was also analyzed using Generalized Additive Models (GAMs) to examine the influence of depth and survey timing on the distribution of Greenland halibut (Wheeland 2020). The NAFO Scientific Council determined there was a vessel effect, with the Alfredo gear working differently at depths below 700 m (Nogueira and Treble 2020). In 2019, Greenland halibut were located shallower than typical for the 0A-South survey, with highest abundance and biomass near the shallowest extent of the survey (400-600m) (Wheeland 2020). This distribution was not characteristic of previous 0A-South surveys, and it suggested that a portion of the stock may have extended beyond the surveyed area in 2019. Given the results of the gear comparison and the distribution changes observed in 0A-South, the 2019 surveys were considered not comparable to previous years and the 1CD and 0A-South index was not accepted as a basis of advice for the Greenland halibut stock in Subareas 0+1 offshore (NAFO 2020). Similar analysis looking at gear performance for the 1A to 1F survey found no differences (Nogueira and Treble 2020) and this survey was accepted as comparable to previous R/V Paamiut surveys (NAFO 2020). The C/V Helga Maria was chartered again in 2020 to conduct the 1A to 1F survey.

A new research vessel, R/V Tarajoq, will be ready to carry out all three surveys in 2021. This change in survey vessel provided an opportunity to improve the gear and a decision was made by the Greenland Institute of Natural Resources (GINR) and Fisheries and Oceans Canada (DFO) to replace the Alfredo III with a Bacalao 476 bottom trawl. These changes in vessel and gear also provide an opportunity to improve the surveys by reviewing past design and sampling practices.

Objectives for the Division 1CD and 0A-South deep-water surveys

The main objective is to conduct a multispecies trawl survey focused on the distribution and abundance of Greenland halibut in relation to depth, temperature, and latitude. Additional biological samples are collected, and specific objectives are:

(1) To collect data to estimate biomass and abundance indices for all commercial and non-commercial fish species.
(2) To collect biological samples to assess length frequency, sex, maturity, age determination and growth (otoliths), and feeding ecology of Greenland halibut (stomachs), and other species as required (e.g., shrimp in the 0A-South survey).
(3) To enumerate and collect biological samples from invertebrate species in order to determine their distribution and assess biodiversity.
(4) To obtain temperature data from each station.

Vessel and Gear

Characteristics of the R/V Paamiut, the C/V Helga Maria and the R/V Tarajoq are provided in Table 2. The Alfredo III trawl was an old design with differences in external dimensions between double and single meshes, and with mesh measured on the inside. This made repairs to the trawl difficult because the outer meshes are of different sizes and require a special sewing ratio. It takes people with special skills to maintain a trawl like the Alfredo, and many of these gear technicians are retired. The Bacalao 476 has the same mesh size on the outside for both single and double meshes, with mesh size varying on the inside (depending on the thickness of the net, single or double net). The benefit is easier maintenance, which minimizes the risk of errors in repair and maintenance of the trawl, and it will also be easier to order a new net, without risking changes in mesh sizes.

The Alfredo III had 60cm chain rigging between the trawl and the 21" rock hopper gear which caused an unknown number of fish and invertebrates to escape. The Bacalao trawl will have the trawl shackled directly onto a steering chain attached to 24" rock hopper gear, reducing the chance of escapement compared to the old Alfredo rigging. With the larger rock hopper gear there will also be less damage to the trawl, and the possibility of more successful sets when fishing on rough bottom.

The difference between both trawls in terms of volume/circumference is not large, and both have a 30 mm cod-end liner. However, the inner mesh size is around 136 mm for the Bacalao 476 compared to 140 mm for the Alfredo III. This slightly smaller mesh size and reduced escapement between the rock hopper bottom gear and the net is expected to increase the catch of juvenile fish and smaller fish species (Table 3, Figure 2).

Evaluation of Survey Designs

Current survey designs for Divisions 1CD and Subarea 0

The 1CD survey extends from 3 nautical miles to the border between Canada and Greenland, at depths between 400 m and 1500 m. The survey area was stratified according to 6 depth strata: 401-600, 601-800, 801-1000, 1001-1200, 1201-1400, and 1401-1500 m (Figure 3 and Table 4). The depth stratification was based on Greenland Geological Survey's 10 m depth contour maps, Canadian Hydrographic Service bathymetric maps and depth soundings made during previous surveys (Nogueira and Estévez-Barcia, 2020).

From 1999 to 2006 the depth stratification scheme for Subarea 0 was based on depths 401-500 m, 501-750, 751-1000, 1001-1250, and 1251-1500 m. In 2008, the depth stratification was updated to facilitate comparison with the 1CD survey and strata covering 401-600, 601-800, 801-1000, 1001-1200, 1201-1400, and 1401-1500 m were established (Treble 2009) (Figure 4). To protect sensitive benthic habitat a decision was made in 2014 not to conduct bottom trawl surveys in Subarea 0 in areas that had been closed to fishing, therefore, strata in 0A with designation B1 were removed (Treble 2016) (Table 5 and Figure 4).

Both the 1CD and 0A-South surveys are depth-stratified random surveys. The 1CD survey strata are divided into field codes (rectangular blocks containing 12 possible stations). First the field code is selected using a buffered random method developed by Kingsley et al., (2004) (see below for additional details) and then one of the 12 stations is randomly selected. The Subarea 0 survey strata are divided into 6 nm^2 grid cells with the station located at the center of the cell. The grid cells/stations are selected using the buffered random method. A minimum of two randomly placed trawls are conducted per stratum (Bishop, 1994).

In 1CD, the number of hauls were allocated to strata based on the stratum area and inversely to the estimated stratum-specific variance in Greenland halibut biomass from past surveys, with results from the most recent surveys receiving more weight in the estimation. The objective was to optimize the allocation of stations among strata such as to minimize the overall survey index standard error by increasing station allocation in strata with high variability. In 0A-South, the number of stations in each stratum is allocated proportional to the total stratum area (1 station per 750 km^2). The 1CD survey design has had a total of 70 hauls since 1997 (Table 4) and the 0A-South survey has had 77 hauls since 2014 (Table 5).

Buffered random sample selection

In 2004, the spatial placement of stations was changed, in all three surveys, from independent and random to a buffered random placement that aims to avoid spatial clustering of stations (Kingsley et al., 2004).

The buffered random sampling method was developed by the Greenland Institute of Natural Resources (GINR) in order to avoid having to repeat the random selection (re-draw) if two stations were selected too close to one another, or there were clusters of stations that resulted in large spaces without stations. Stations are placed randomly within a stratum, but not closer to one another than a fixed limiting distance or buffered distance that, in 1CD depends on the area of the stratum and the sample size in each stratum (Kingsley et al. 2004). For the 0A-South survey the radius of the buffer around the selected grid cells is 17 km, or approximately one 6 nm^2 grid cell. The buffered set selection method is well described in Kingsley et al. (2004) but it has not been validated for bias (e.g., by simulation). There is no statistical proof that the method remains unbiased or is less biased than random selection or re-sampling (to address a situation where stations are initially selected close together), although in principle a large bias is unlikely. Validation of the method and demonstration of its utility is needed, and K.J. Hedges (DFO) has offered to run a simulation analysis for the 3 surveys.

The algorithm to implement buffered random sampling was coded by its creator in Visual Basic and implemented in Excel and then SAS. Using this software is challenging and ideally the algorithm should be recoded to more modern software, therefore, R -code to run the method will be developed by GINR.

Standard Deviation analysis used to allocate stations in the 1CD survey

The number of stations are allocated to strata based on stratum-specific estimates of the variability (Standard Deviation (SD)) of Greenland halibut biomass from past surveys (Carlsson, 2000). Most of the weight is given to values from the previous year, with decreasing weights as a function of elapsed time, as a temporal correlation is expected. The purpose is to optimize the allocation of stations to strata to minimize the standard error of the total survey estimates. Table 4 shows an example of the allocation of hauls per stratum in 2019.

Optimizing the allocation of stations in this way in surveys with multiple objectives is challenging (e.g., optimizing for a multispecies survey with multiple target size classes for each species) (Miller, 2006). Up to now the 1CD survey has been optimized to reduce the variance (SD) of Greenland halibut biomass but it is not optimized for other species. Furthermore, because biomass over-represents larger Greenland halibut, it is also not optimized for multiple size classes, and small Greenland halibut in particular. This results in potentially insufficient coverage in shallow strata where small sizes of Greenland halibut are found.

It is presently not possible to follow cohorts in length frequency data obtained from the survey (Figure 5). The bulk of the survey catches are individuals from 35 to 60 cm that are found in the deeper depth strata with high number of stations (Table 4).

The impact of using this station allocation program with abundance SD instead of biomass SD was examined (Table 6). This choice resulted in Division 1C stratum 601-800 m receiving one more station and Division 1D strata 1001-1200 m receiving one less station. This is not unexpected as the biomass and abundance indices have similar variance and trend (Figure 6).

A more equitable distribution of stations across strata (e.g., fixed number per km^2) is more likely to be suitable for monitoring multiple species and sizes of fish. Table 7 shows the number of stations in each stratum based on the allocation of one station per 750 km^2 as is used to determine the number of sets in the 0A-South survey. The total number of stations would increase from 70 to 72 in order to have the minimum of 2 stations in 1C stratum 1001-1200 m (C_10-12) and 1D stratum 401-600 m (D_4-6).

Evaluation of Survey Stratification and Coverage

Surveys in Subarea 1

Catch density is typically assumed to be spatially homogenous within strata. In fact, a stratification scheme is optimized when catch density is more homogenous within strata. Where persistent and spatially-structured within-stratum variation in catch density exists, it may make sense to redefine stratum boundaries. In this regard, the catch distribution in 1D stratum 1000-1200 m (D_10-12) was analyzed and found to be spatially heterogeneous (Figure 7). Catches were typically larger in the northwest portion of the stratum, and smaller in the southern arm of the stratum. We propose that the existing stratum could be split into Northwest D_10-12 and South D_10-12. Furthermore, the northwestern portion could in principle be added to the small stratum C_10-12, which is spatially contiguous and contains the same bathymetric contour (Figure 8). The only potential argument against merging those two areas is that the resulting stratum would no longer strictly respect NAFO area boundaries. This would not prevent estimating area-specific indices as it would still be possible to estimate a stratum specific mean density and to apportion it to each area in proportion to the stratum surface area in each NAFO area. This appears as an advisable approach given that currently, the small stratum C_10-12 is allocated a very high station density (1 per 305 km^2).

The 1A to 1F survey is carried out in June- July, with Cosmos gear, covering depths 50 to 600 m, while the 1CD survey will be carried out in October, with Bacalao gear at depths 400 to 1500 m. Therefore, a large part of the Greenland halibut distribution is not covered by any single survey (Figure 9). The deepest strata in 1A and 1B, and the area north of 72° 30' are not surveyed.

Plans for the future would be to expand the 1A to 1F Fish and Shrimp survey to include the depth range from 600 to 900 or 1000 m (the deepest the Cosmos trawl can be fished) in 1AB in the existing survey area (up to 72° 30') (Figure 10).

Surveys were conducted in Baffin Bay (Division 1A 72°30'-76 N) in 2001, 2004 and 2010. However, the strata were not consistent among years and the surveys are not comparable. A new survey could be considered for 1A, from 72°30'-76 N, using the Bacalao 476 trawl at depths 400-1500 m (Figure 10).

Surveys in Subarea 0

An expansion of the Canadian survey, to include 0B and area within 200-400m in both 0A-South and 0B, is being considered (Figure 11). The stratification will use new updated bathymetry (GEBCO 2020). Areas that are proposed to be excluded from the new design are:

1) Portions of strata B2 and A1 (Figure 4 and 11) that fall within the south-west corner of the Disko Fan Conservation Area and were not previously removed;

2) Portions of strata A4 and A5 (Figure 4 and 11) that fall within the Tallurutiup Imanga (Lancaster Sound) National Marine Conservation Area;

3) Portions of most depth strata in 0B that fall within the Davis Strait and Hatton Basin Conservation Areas (Figure 11);

4) Area within 12 nm of the Baffin Island coast that fall within the Nunavut Settlement Area.

The total number of sets planned for 0A-South and 0B would be 79 and 118, respectively (Tables 8 and 9).

There is also a small area at 601-800 m in 0B, near the boundary with 0A, that is currently combined into a single stratum (B1-600) (Table 9). Catches tended to be more similar to adjacent areas in 0A, in the range of 0.5 to 1.5 t/km2 (Treble 2016). Areas at similar depths in southern portions of 0B tended to be larger (Figure 12) suggesting these two areas within 0B are not homogenous and should not be merged into a single stratum. Rather than creating a very small stratum within 0B we might consider merging this area with the associated depth strata in 0A (A1). It is not unusual for survey strata to cross management boundaries. This is being proposed for 1CD above and it also occurs in other Canadian surveys (Rideout et al., 2021).

Dealing With Missing Strata

In 2013, the 1CD survey only covered 1D. Jorgensen (2011) reported that the distribution of biomass has been rather stable with 63-69% found in 1D. Therefore, in 2013 total biomass and abundance in 1C was estimated by a GLM (model: lnbiomass = year*division) using data from 2010-2014.

In years 1999-2004, 2007 and 2017, some strata were not surveyed due to bad weather or lack of time (Table 10). Missing strata has also been a problem for the 0A-South survey, in particular 2006 was considered incomplete and is not used in the assessment. No attempt has been made to correct the total index or estimate biomass/abundance in these missed strata, and it has been assumed that the missed strata biomass was zero.

In the 1A to 1F Fish and Shrimp Survey, when a stratum has been missed, an "area correction" is included. The area of the missing stratum is added to the next stratum of similar depth, and that “corrected area” is the one used for the biomass and abundance indices estimation.

The NAFO Scientific Council has also observed problems with survey coverage over the years and in 2019 STACREC **recommended** the *following actions for future years whenever survey coverage issues arise*:

• The STACREC report should contain, after the general survey presentation, a summary of the decisions and conclusions stock by stock regarding whether the survey can be used as a stock index for that year.

• The mean proportion (over time) of total survey biomass in the survey strata missed that year should be calculated.

• At this time, the following may be used as initial (“preliminary”) guidelines based on the value of the mean proportion of total survey biomass in the survey strata missed in that year:

o If it is <10% : the survey index of that year is most likely acceptable.

o If it is between 10% and 20% : the survey index of that year is questionable and needs to be examined carefully before deciding whether it is acceptable.

o If it is >20% : the survey index of that year is most likely not acceptable. Any decision to accept it would require a clear and well justified rationale.

These are preliminary guidelines and sampling biases may also be relevant in the considerations for each specific stock and survey. In particular, the finer structure of the indices needs to be considered if they are used disaggregated by age or length in stock assessments.

It has been suggested that an added guideline might be: For age groups where there is a greater than 10% difference between total survey biomass in the survey strata missed that year in the index used (total or mean numbers), then it should be excluded from the model, if the model can handle missing values. However, there was no time to discuss this at the June 2020 meeting and therefore this discussion will be deferred to June 2021.

An approach to dealing with missing strata should be determined and defined for both deep-water surveys. It is suggested that the same method used in the 1A to 1F Fish and Shrimp Survey could be considered. However, some guidance around this approach may be needed. For example, it might be acceptable in cases where <10% of the survey strata are missed but becomes less so as the proportion of missed strata increases.

Sampling Protocols

Divisions 1CD survey

The sampling protocol separates length measurements from other biological parameters:

- Length measurements - Length is recorded for all individuals caught. If the catch is larger than 250 individuals, a random sample is taken. No sex information is recorded.
- Biological samples **-** A random sample is taken at each station to ensure that X number of individuals in each length class are sampled during the survey (e.g., 10 per 1 cm group for Greenland halibut). Sampling includes sex, maturity and otoliths for age determination. The number of individuals has varied from year to year.

This approach is assumed to be representative of the whole survey area. However, estimates of Greenland halibut sex and maturity are likely to be biased using this method, unless these properties are spatially homogenous, which is unlikely. For example, sex is determined only when biological data are collected (10 individuals per length class in the whole survey) and given the sexual dimorphism of Greenland halibut this could result in biased estimates. To examine this question, sex information was collected from all length measurements during the 2019 survey. Male and female proportions for the fully sampled catch were compared with proportions based on the biological sub-samples. In some length ranges, the proportion of males and females changed considerably (Table 11).

Also, since the biological data are not collected from all sets in the whole survey some sizes are preferentially sampled at some sites compared to others. Sampling is not representative, and it is very likely that the estimated sex, maturity and age composition for the survey are biased and this could compromise assessment and spatial models. Simulation studies of Canadian surveys (Regular et al., 2020), Norwegian surveys with North Sea cod (Jourdain et al., 2020), and Northeast Arctic cod (Aanes and Volstad, 2015) determined that the strategy of taking small age samples from as many sets as possible is better than taking more age samples from fewer sets. When otoliths are sample from every set the bias disappears.

The proposal for a new 1CD survey protocol is to:

1) Obtain an observation of sex for each measured individual above a certain length at which sex can easily be determined macroscopically (> 20 cm). This will allow for the estimation of sex-specific length frequencies, which is important for sexually-dimorphic fish such as Greenland halibut. Given that it is also unlikely that sex distribution is homogeneous this improvement in sampling could provide opportunities to apply different assessment models in the future (e.g., females only to assess potential for differential harvesting pressure).

2) Collect maturity and otoliths following a length-stratified protocol, i.e., for the first fish measured in a length (per 1 cm) or length-sex bin (per 5 cm length group) in each set.

Subarea 0 surveys

The sampling protocol separates length, sex and maturity measurements from age (otoliths) and other biological parameters:

•Length, sex and maturity are recorded for all individuals caught in a typical set. If the catch is too large (this is not defined currently), a sub-sample is taken, and these are sampled for length, sex and maturity.

•Otolith samples are collected in a way that is similar to that done for the biological sampling in the 1CD survey. The target sample is otoliths from 10 fish per cm per sex for the entire survey (e.g., 0A-South or 0B). Technicians are asked to spread the sampling out across sets using their judgement as to how many samples to take from each set. The computer keeps track of the running total. Once the sample is full for a particular sex/size class then sampling stops, whether the survey is complete or not.

This approach is assumed to be representative of the whole survey area. However, as described above, there is likely bias in the otolith sampling protocol, therefore, it is proposed that samples be collected from each set. We are considering 1 fish/cm/sex/set. This will likely result in larger samples of the most abundant sizes but a structured sub-sampling of this otolith collection can be made during the actual age reading.

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Table 1. Surveys carried out in Divisions 1CD and 0A-South with R/V Paamiut and C/V Helga Maria.

Survey	R/V Paamiut	C/V Sjurdarberg	C/V Helga Maria
0A-South	1999, 2001, 2004, 2006, 2008, 2010, 2012, 2014, 2015-17, 2019	-	2019
GHL 1CD	1997-2017	-	2019
Fish and Shrimp 1A-F	1991 - 2017	2018	2019-2020

Table 2. Vessel characteristics for R/V Paamiut , C/V Helga Maria and R/V Tarajoq.

Name	R/V Paamiut	C/V Helga Maria	R/V Tarajoq
Vessel type- generic	Research (former Fishing)	Fishing	Reaserch
Vessel type -detailed	Trawler	Trawler	Trawler
Status	Stopped	Active	In construction
Call sign	OYZC	TFDJ	OYLD
Flag	Greenland	Iceland	Greenland
Gross tonnage (t)	1084	1470	2860*
Net tonnage (t)	325	441	**
Machinery power (Kw)	1471	2200	2900/3600
Length overall (m)	58.61	56.88	61.4
Maximum breadth (m)	11.21	12.62	16
Maximum draught (m)	4.2	6	6.4
Propulsion (BHP)	2000	2992	3943/4896
Fuel type and capacity (m3	Diesel 257	Diesel 238.4	Diesel 475
Year built	1971	1988	2021

* to be confirmed

** not determined yet

Table 3. Gear and door specifications for the Alfredo III and Bacalao 476 trawl gear (note the door change in 2004). In the formula used to calculate wing spread, t is the length of the trawl (m), L is the distance between doors (m), and s is the length of the bridles (m).

Gear	Alfredo III	Bacalao 476
Vertical trawl opening (m)	5.6	4.5*
Distance between doors (m)	120 -145	151.8*
Wing spread (m)	V = 10.122 + L * 0.142.	$V = (t_l * L) / (t_l + s_t)$
Inside mesh size (mm)	140	136
Door (cm)	Pre-2004: Greenland Perfect (370*250) Post- 2004: Shark injector (353*273)	Shark injector (353*273)
Door type (kg)	Pre- 2004: 2400 with extra 20 kg Post- 2004: 2850	2850
Cod-end mesh size (mm)	44	44
Mesh-liner in the cod-end (mm)	30	30
Rock hopper (inches)	21	24

* gear simulations at 360 m depth

Table 4. Divisions 1CD depth strata and areas and set allocations for the 2019 survey.

Division	Stratum	Depth range (m)	Area (km2)	Num Stations in 2019	Prop. Area Surveyed km2
1C	C4-6	401-600	3366	2	1683
1C	C6-8	601-800	16120	10	1612
1C	C8-10	801-1000	6066	13	467
1C	C10-12	1001-1200	611	2	306
1D	D4-6	401-600	903	2	452
1D	D6-8	601-800	1940	2	970
1D	D8-10	801-1000	3874	4	969
1D	D10-12	1001-1200	10140	19	534
1D	D12-14	1201-1400	6195	12	516
1D	D14-15	1401-1500	3091	4	773
		Total	**52306**	**70**	

Table 5. 0A-South survey stratification (2008-2019) with area and set allocation based on a coverage of 1 set per 750 km^2.

Stratum	Depth (m)	Area (km^2)	Set Allocation
A1-4	400-600	2152	3
A2-4	400-600	4649	6
A3-4	400-600	785	2
A4-4	400-600	1922	3
B2-4	400-600	2519	3
	Sub-total	12027	17
A1-5	600-800	795	2
A2-5	600-800	2250	3
A3-5	600-800	760	2
A4-5	600-800	2483	3
B2-5	600-800	5108	7
		11396	17
A1-6	800-1000	604	2
A2-6	800-1000	1145	2
A3-6	800-1000	1020	2
A4-6	800-1000	1376	2
B2-6	800-1000	2656	4
		6801	12
A1-7	1000-1200	745	2
A2-7	1000-1200	1873	2
A3-7	1000-1200	1307	2
A4-7	1000-1200	1636	2
B2-7	1000-1200	1789	2
		7349	10
A1-8	1200-1400	813	2
A2-8	1200-1400	2151	3
A3-8	1200-1400	1146	2
A4-8	1200-1400	1072	2
B2-8	1200-1400	1779	2
		6961	11
A1-9	1400-1500	498	2
A2-9	1400-1500	1153	2
A3-9	1400-1500	684	2
A4-9	1400-1500	710	2
B2-9	1400-1500	346	2
		3390	10
Total		47924	77

Table 6. Number of stations allocated in each stratum based on abundance Standard Deviation (a) vs biomass Standard Deviation (b).

(a)

Year	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005
Stratum	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers	Stations by numbers
1C 0401-0600	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1C 0601-0800	13	13	13	12	11	9	9	9	8	8	8	7	7	8	8	10
1C 0801-1000	14	13	13	13	13	14	15	14	14	15	13	13	12	11	11	13
1C 1001-1200	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1D 0401-0600	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1D 0601-0800	3	3	3	3	4	4	4	5	2	2	2	2	2	2	2	2
1D 0801-1000	4	5	5	5	5	5	5	5	6	6	6	6	6	7	7	8
1D 1001-1200	17	17	17	17	17	16	16	16	17	16	17	18	18	15	15	15
1D 1201-1400	9	10	10	10	10	11	11	11	12	12	13	13	14	15	15	11
1D 1401-1500	4	4	4	4	4	5	4	4	5	5	5	5	5	6	6	5
CV	7.346	7.478	7.478	7.626	7.936	7.687	7.773	7.751	7.43	7.751	7.862	8.149	8.557	7.977	8.201	7.715
SE predicted	4431949	4439443	4439443	4535677	4743869	4583067	4881831	5014720	4979904	5120236	5247107	5552516	5792333	5437808	5584476	5206483

(b)

Year	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005
Stratum	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass	Stations by biomass
1C 0401-0600	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1C 0601-0800	12	12	12	11	10	7	6	6	6	6	6	5	5	5	5	7
1C 0801-1000	14	13	13	13	13	13	14	14	14	14	12	13	11	10	10	12
1C 1001-1200	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1D 0401-0600	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1D 0601-0800	3	3	3	3	3	4	4	4	2	2	2	2	2	2	2	2
1D 0801-1000	4	4	4	5	5	5	5	5	5	6	6	6	6	7	7	9
1D 1001-1200	18	18	18	18	18	18	18	18	19	18	19	19	20	16	16	16
1D 1201-1400	9	10	10	10	11	12	12	12	13	13	14	14	15	17	18	13
1D 1401-1500	4	4	4	4	4	5	5	5	5	5	5	5	5	7	6	5
	7.387	7.231	7.231	7.364	7.593	7.363	7.494	7.46	7.179	7.528	7.731	8.026	8.471	7.884	8.054	7.293
	5410160	5161258	5161258	5177217	5281196	4999056	5244719	5362840	5279642	5387130	5514764	5804754	5974768	5524035	5559484	4865713

Table 7. Division 1CD strata, area, number of stations allocated in 2019 using the method of the Standard Deviation optimization and number of stations proportional to the total area (1 station per 750 km^2).

Division	Stratum	Depth range (m)	Area (km2)	Numb. stations (SD analsysis in 2019)	New allocation (1station/750km2)
1C	C4-6	401-600	3366	2	4
1C	C6-8	601-800	16120	10	21
1C	C8-10	801-1000	6066	13	8
1C	C10-12	1001-1200	611	2	2*
1D	D4-6	401-600	903	2	2*
1D	D6-8	601-800	1940	2	3
1D	D8-10	801-1000	3874	4	5
1D	D10-12	1001-1200	10140	19	14
1D	D12-14	1201-1400	6195	12	8
1D	D14-15	1401-1500	3091	4	4
			Total	**70**	**72**

* Those strata would have only 1 station per 750 km^2 but they need a minimum of 2.

Table 8. The 2021 Division 0A-South stratification scheme revised based on updated bathymetry, removal of area falling within fishery closures (Strata A1 and B2) and marine conservation areas (Strata A4 and A5), merging of the remainder of strata B2 into A1, and addition of depths 200 m to 400m up to 12 nm from the Baffin Island coast. Set allocation is based on 1 set per 750 km^2.

Stratum	Depth (m)	Area (km^2)	Set Allocation
A1-200	200-400	939	2
A2-200	200-400	3060	4
A3-200	200-400	1826	2
A4-200	200-400	2156	3
	Sub-total	7981	11
A1-400	400-600	3458	5
A2-400	400-600	2703	4
A3-400	400-600	834	2
A4-400	400-600	954	2
		7949	13
A1-600	600-800	4105	5
A2-600	600-800	1821	3
A3-600	600-800	705	2
A4-600	600-800	1972	3
		8604	13
A1-800	800-1000	4051	6
A2-800	800-1000	1234	2
A3-800	800-1000	1009	2
A4-800	800-1000	1463	2
		7758	12
A1-1000	1000-1200	3475	5
A2-1000	1000-1200	2109	3
A3-1000	1000-1200	1209	2
A4-1000	1000-1200	1415	2
		8208	12
A1-1200	1200-1400	1984	3
A2-1200	1200-1400	2344	3
A3-1200	1200-1400	1197	2
A4-1200	1200-1400	1242	2
		6767	10
A1-1400	1400-1500	558	2
A2-1400	1400-1500	1327	2
A3-1400	1400-1500	695	2
A4-1400	1400-1500	814	2
		3394	8
Total		50660	79

Table 9. The 2021 Division 0B stratification scheme revised based on updated bathymetry, removal of area falling within fishery closures and addition of depths 200-400m up to 12 nm from the Baffin Island coast. Set allocation is based on 1 set per 750 km^2.

Stratum	Depth (m)	Area (km2)	Assigned Sets (1/750km2)
B1-200	200-400	18016	24
B2-200	200-400	29003	39
	Sub-total	47019	63
B1-400	400-600	12604	17
B1-600	600-800	7467	10
B1-800	800-1000	8212	11
B1-1000	1000-1200	6672	9
B1-1200	1200-1400	4446	6
B1-1400	1400-1500	711	2
		87131	118

Table 10. Number of stations per stratum from 1997 to 2019. Years 1999-2004, 2007 and 2017 have strata without stations. In 2013 a whole division was not surveyed.

Div	Depth (m)	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2019
1C	400-600	3	4	2	0	4	0	2	1	2	2	1	3	2	2	1	2	0	1	2	2	0	2
1C	600-800	11	14	7	3	8	4	4	5	8	6	4	5	5	4	5	3	0	5	6	9	6	10
1C	800-1000	8	8	6	4	3	4	4	10	11	9	10	11	13	12	14	11	0	12	13	13	7	13
1C	1000-1200	2	2	0	2	2	1	2	2	2	2	2	2	2	2	2	2	0	2	2	2	2	2
1D	400-600	2	1	0	0	0	0	0	0	2	3	2	2	2	2	2	2	1	1	2	2	2	2
1D	600-800	2	2	1	0	0	0	0	2	1	2	0	2	2	2	2	1	1	2	2	3	2	2
1D	800-1000	4	4	2	2	3	4	2	3	3	4	5	4	4	5	5	3	4	3	4	4	4	4
1D	1000-1200	18	11	11	11	13	12	10	12	14	13	12	18	18	19	17	14	11	15	20	19	16	19
1D	1200-1400	8	8	7	7	10	7	7	12	12	14	9	16	15	13	14	9	7	13	11	12	10	12
1D	1400-1600	5	2	2	2	3	3	4	4	6	6	5	7	5	5	5	3	3	4	5	4	4	4

Table 11. Proportion of females (F) and males (M) from the fully sampled catch (sample size = 6649 ind.) in 2019, compared to the proportion from the biological sub-sample (sample size = 1003 ind.).

2019 Length	Real samples		Estimation from bio data	
	% F	% M	% F	% M
38	26.3	73.7	41.2	58.8
39	26.3	73.7	17.6	82.4
40	33.3	66.7	31.8	68.2
41	33.8	66.2	30.4	69.6
42	29.6	70.4	23.8	76.2
43	24.7	75.3	26.1	73.9
44	15.5	84.5	18.2	81.8
45	15.9	84.1	22.7	77.3
46	16.1	83.9	19.0	81.0
47	9.0	91.0	9.5	90.5
48	9.8	90.2	5.0	95.0
49	12.6	87.4	18.2	81.8
50	12.5	87.5	15.0	85.0
51	10.4	89.6	4.8	95.2
52	8.5	91.5	4.8	95.2
53	11.8	88.2	13.6	86.4
54	12.7	87.3	33.3	66.7
55	15.1	84.9	15.0	85.0
56	15.7	84.3	20.0	80.0
57	15.7	84.3	20.0	80.0
58	23.8	76.2	30.0	70.0
59	34.4	65.6	50.0	50.0
60	33.3	66.7	40.9	59.1
61	33.7	66.3	40.0	60.0
62	42.0	58.0	35.0	65.0
63	58.6	41.4	72.7	27.3
64	65.1	34.9	65.2	34.8
65	55.6	44.4	69.6	30.4
66	51.1	48.9	60.7	39.3
67	52.8	47.2	60.9	39.1
68	43.3	56.7	40.0	60.0

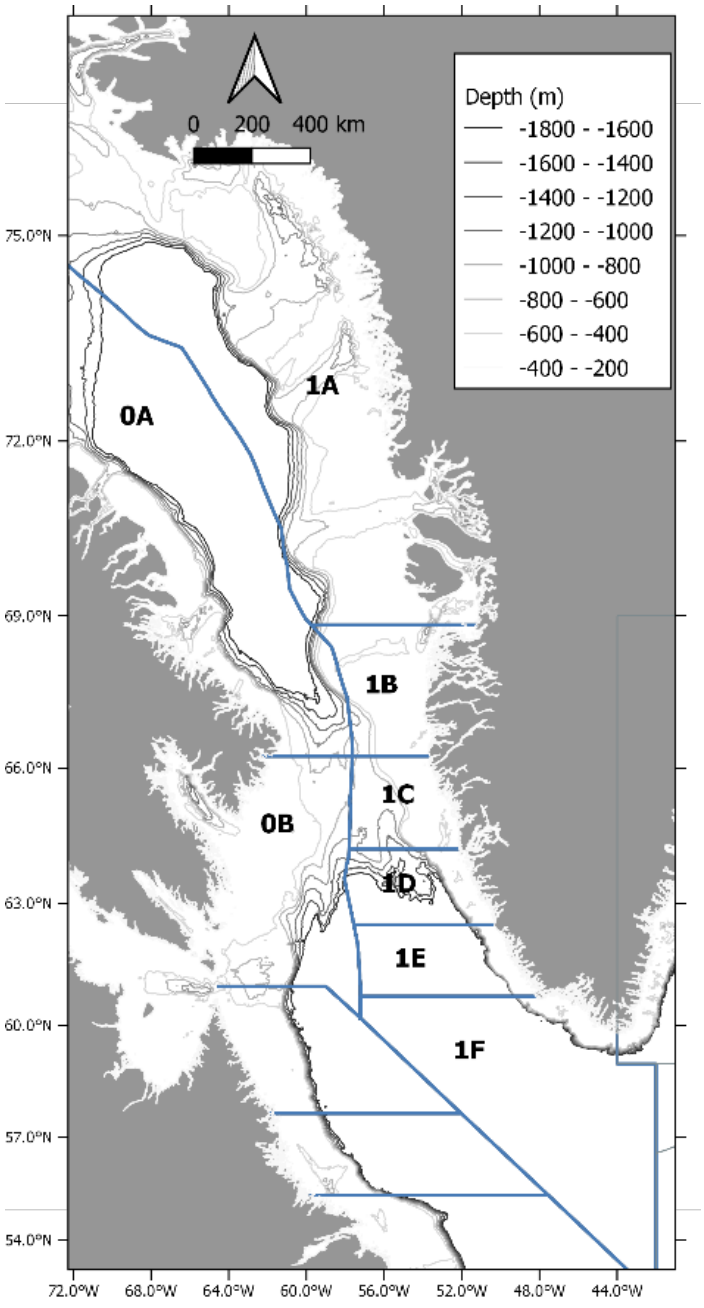


Figure 1. Northwest Atlantic Fisheries Organization Subarea 0+1.

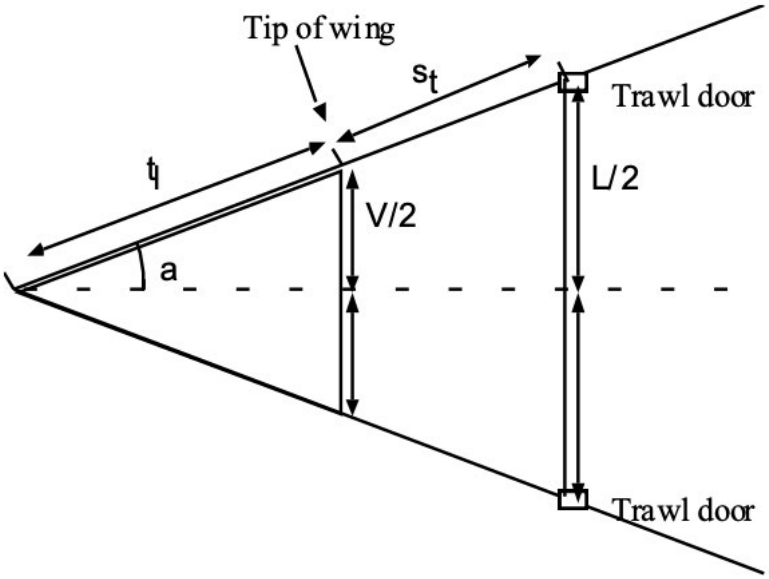


Figure 2. Wing spread is estimated as $V= (t_l *L) / (t_l + S_t)$, where t_l is the length of the trawl, S_t is the length of the bridles and L is the distance between the doors.

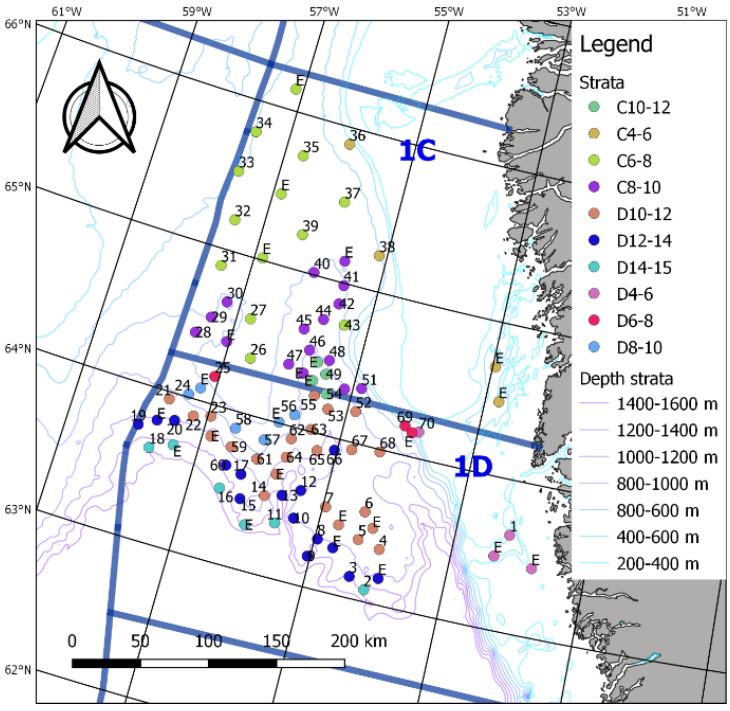


Figure 3. Set locations for the 2019 1CD survey.

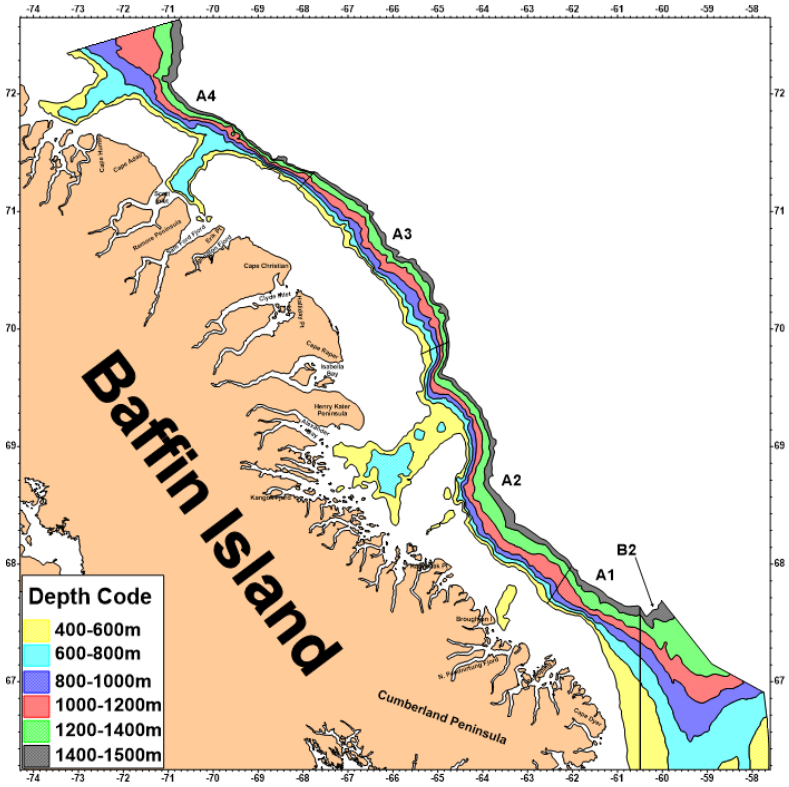


Figure 4. Stratification scheme the 0A-South survey, 2008 to 2019, 66° N to 72° N.

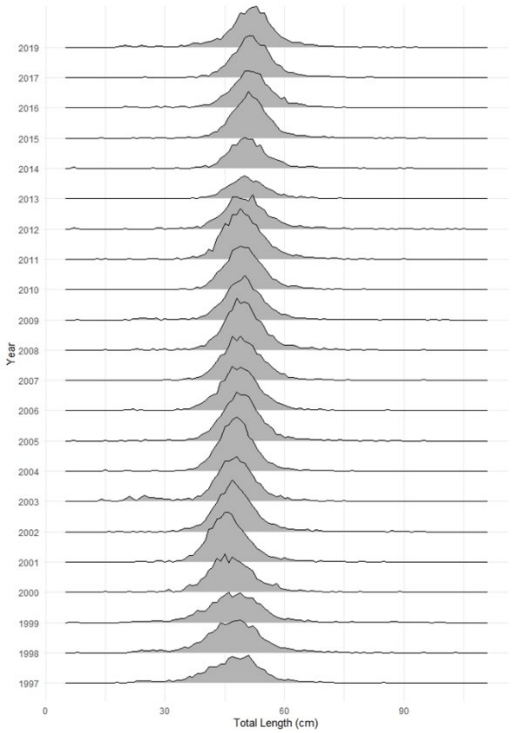
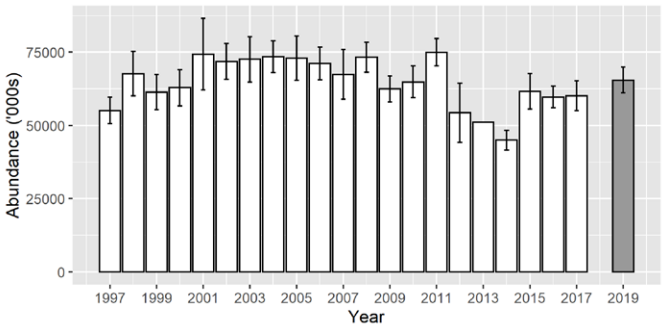


Figure 5. Greenland halibut length distribution for the 1CD survey.

a)



b)

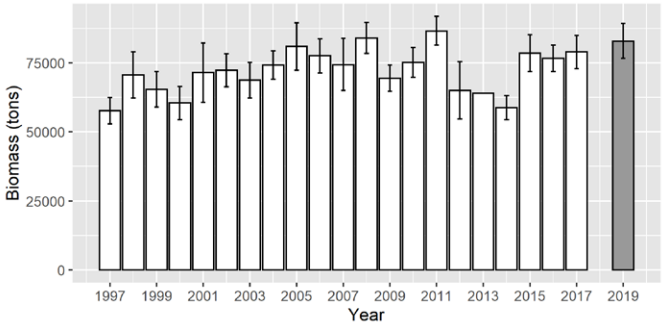


Figure 6. Abundance (a) and biomass (b) indices (with one standard error) of Greenland halibut in the 1CD survey from 1997 -2018 with R/V Paamiut and in 2019 with C/V Helga Maria.

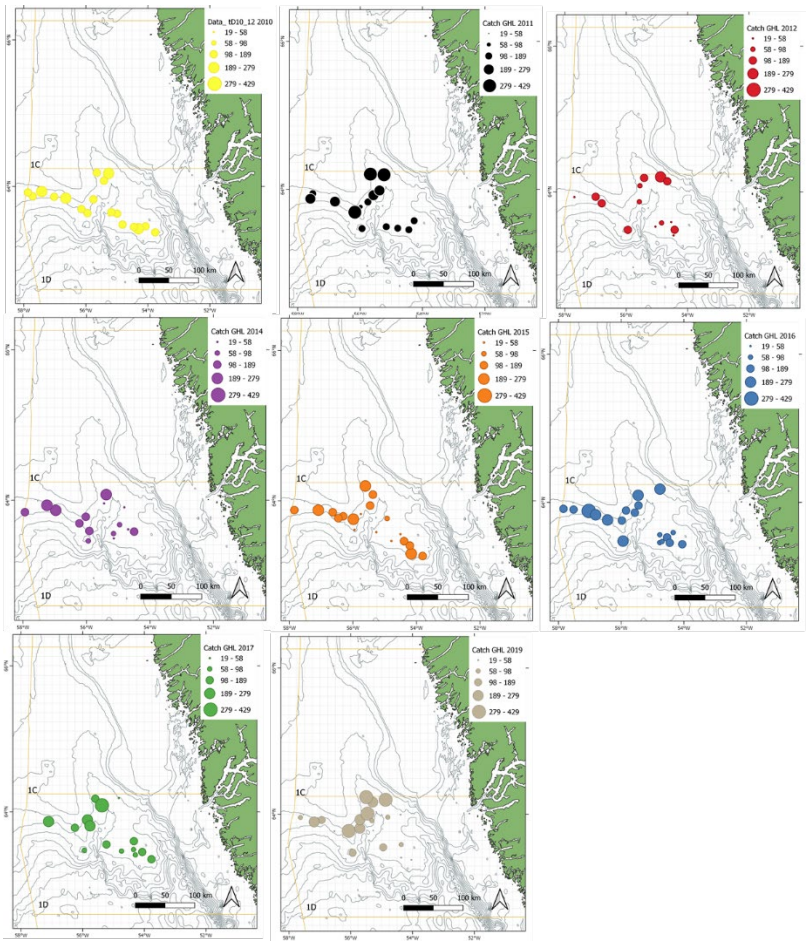


Figure 7. Greenland halibut catch distribution for stratum 1001-1200 m in Division 1D, 2010 to 2019.

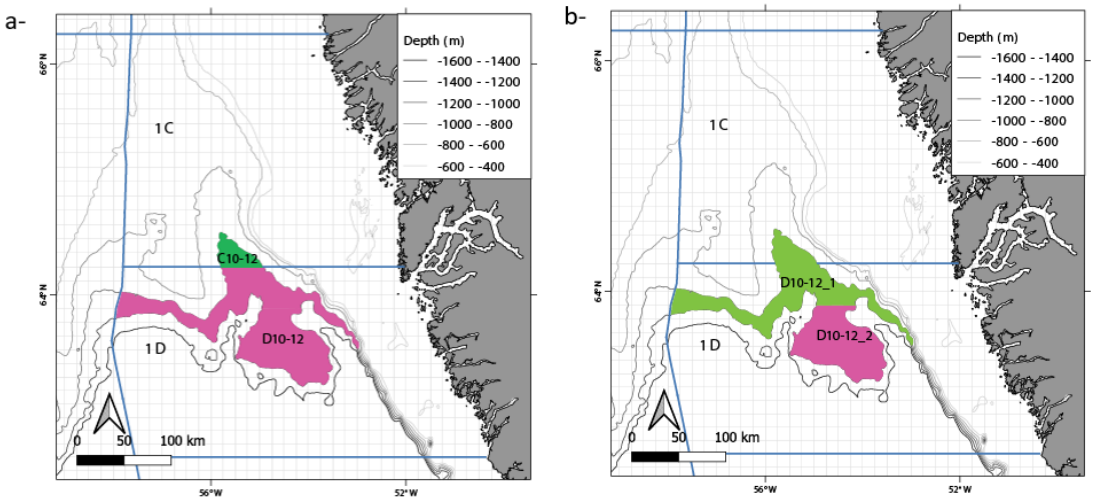


Figure 8. New stratification proposal: a- Current stratification: Strata C10-12 and D10-12 b- Proposal: D10-12 split in D10-12_1 and D10-12_2 and D10-12_1 combined with C10-12.

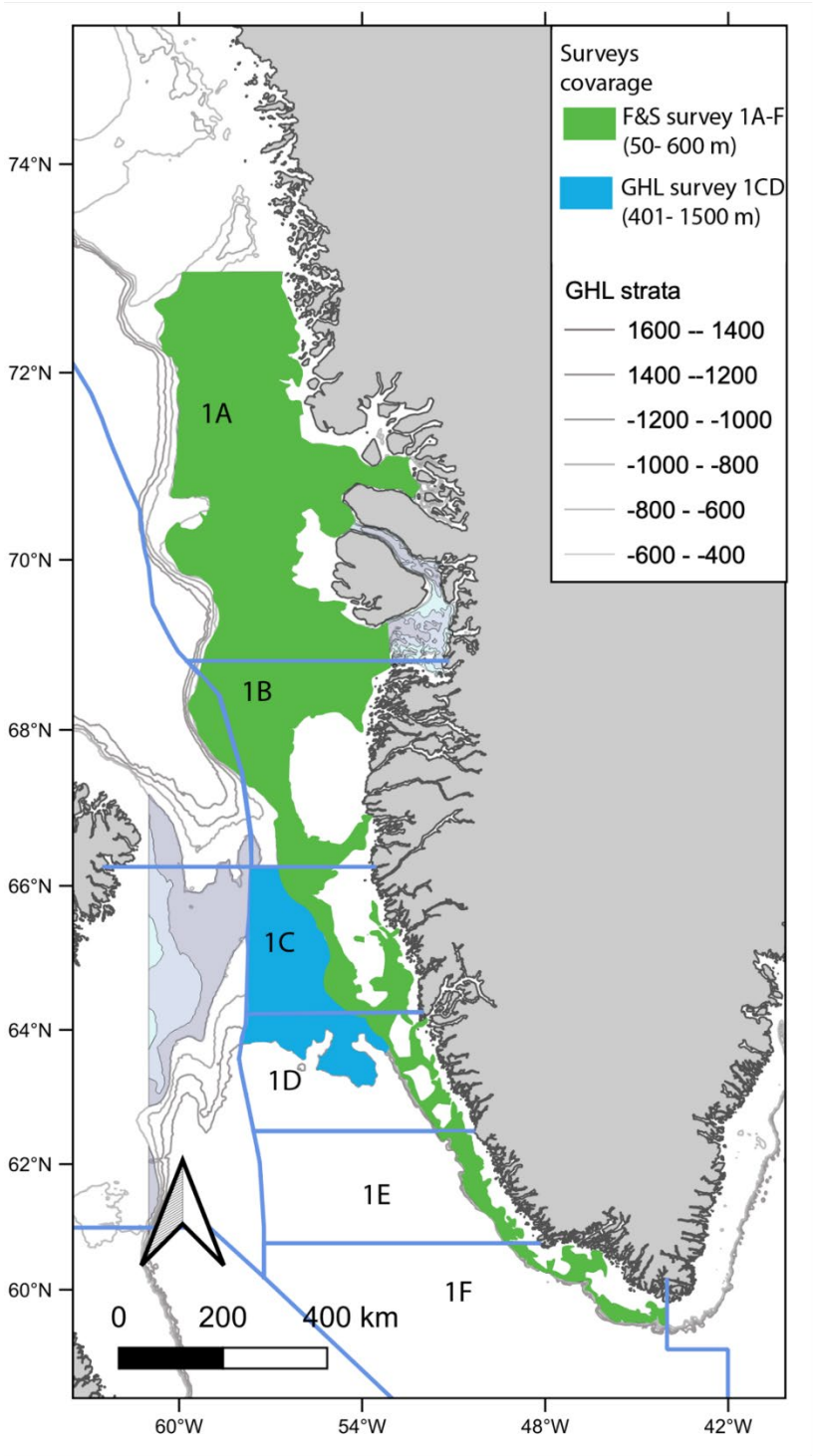


Figure 9. Area covered by the Greenlandic surveys: 1A to 1F (F&S survey) (green) and 1CD (GHL survey) (blue).

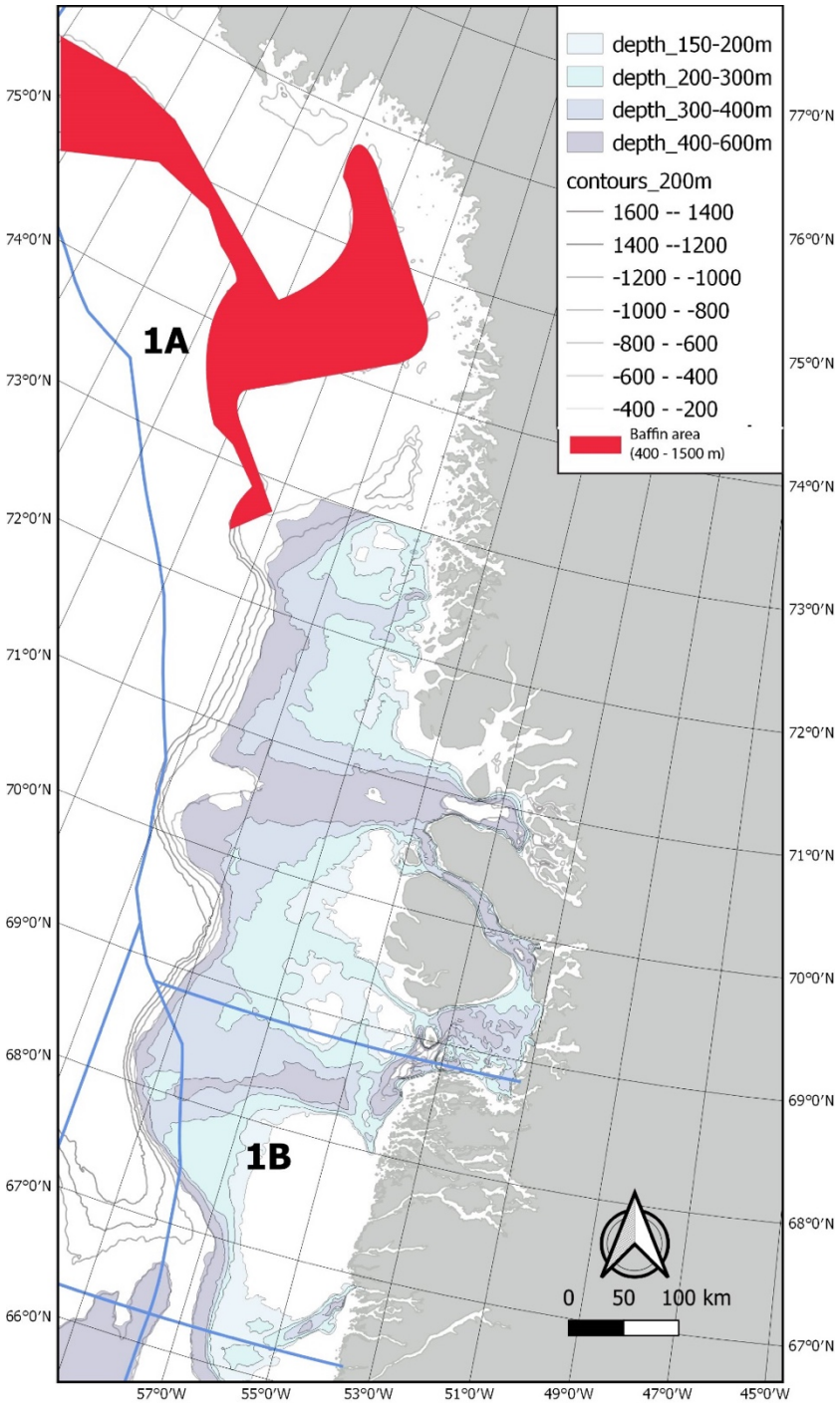


Figure 10. This map shows the area in 1AB included in the Fish and Shrimp survey (150 m to 600 m) (up to 72°30' N), the deep area from 601-1000 m below 72°30' N that could be included in the survey using Cosmos bottom trawl, and the area of 1A between 400 m and 1500 m that is currently not included in any surveys (red) (72°30'N to 76°N) that could be considered for a future survey with Bacalao 476 bottom trawl.

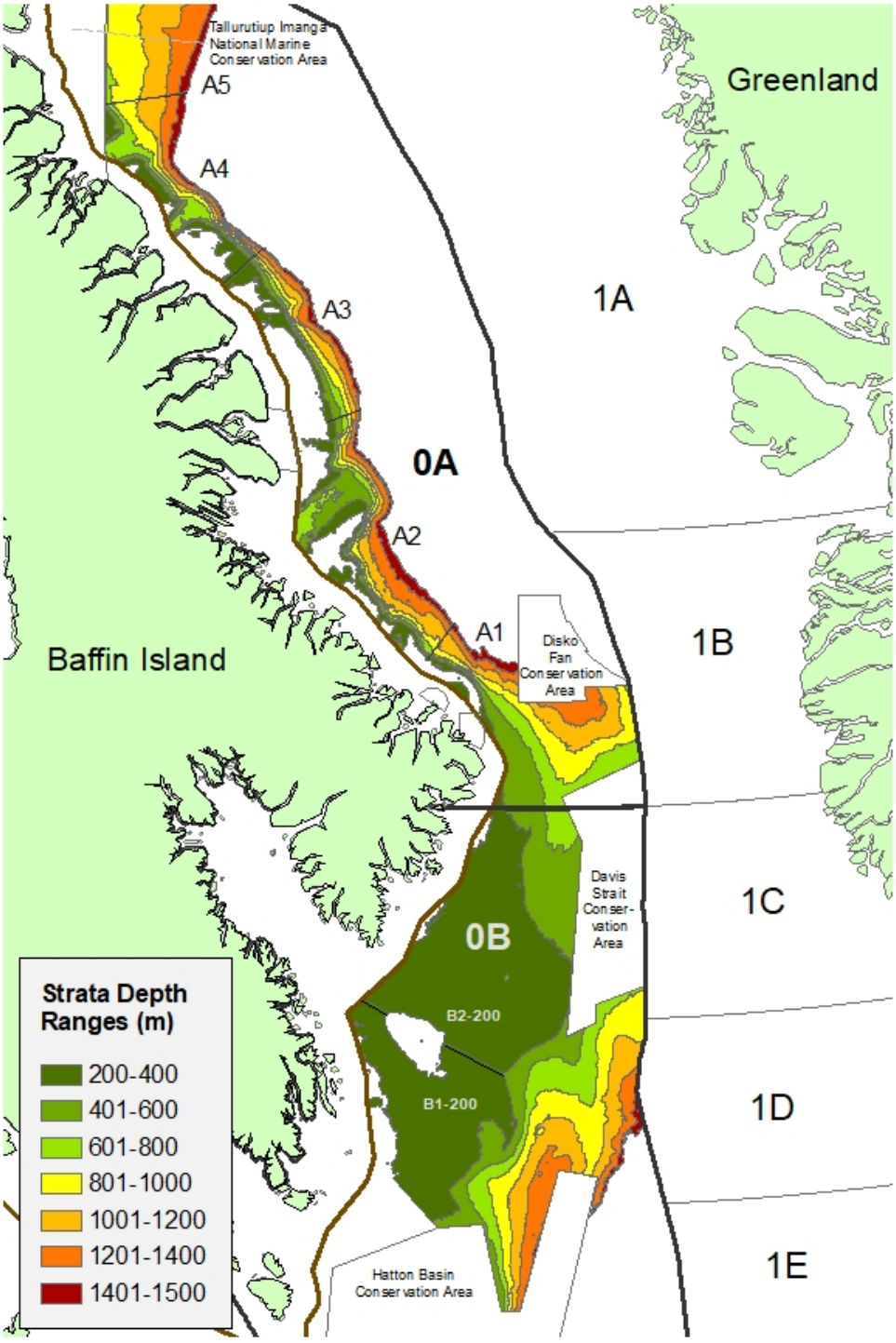


Figure 11. New stratification scheme for Division 0A-South and 0B.

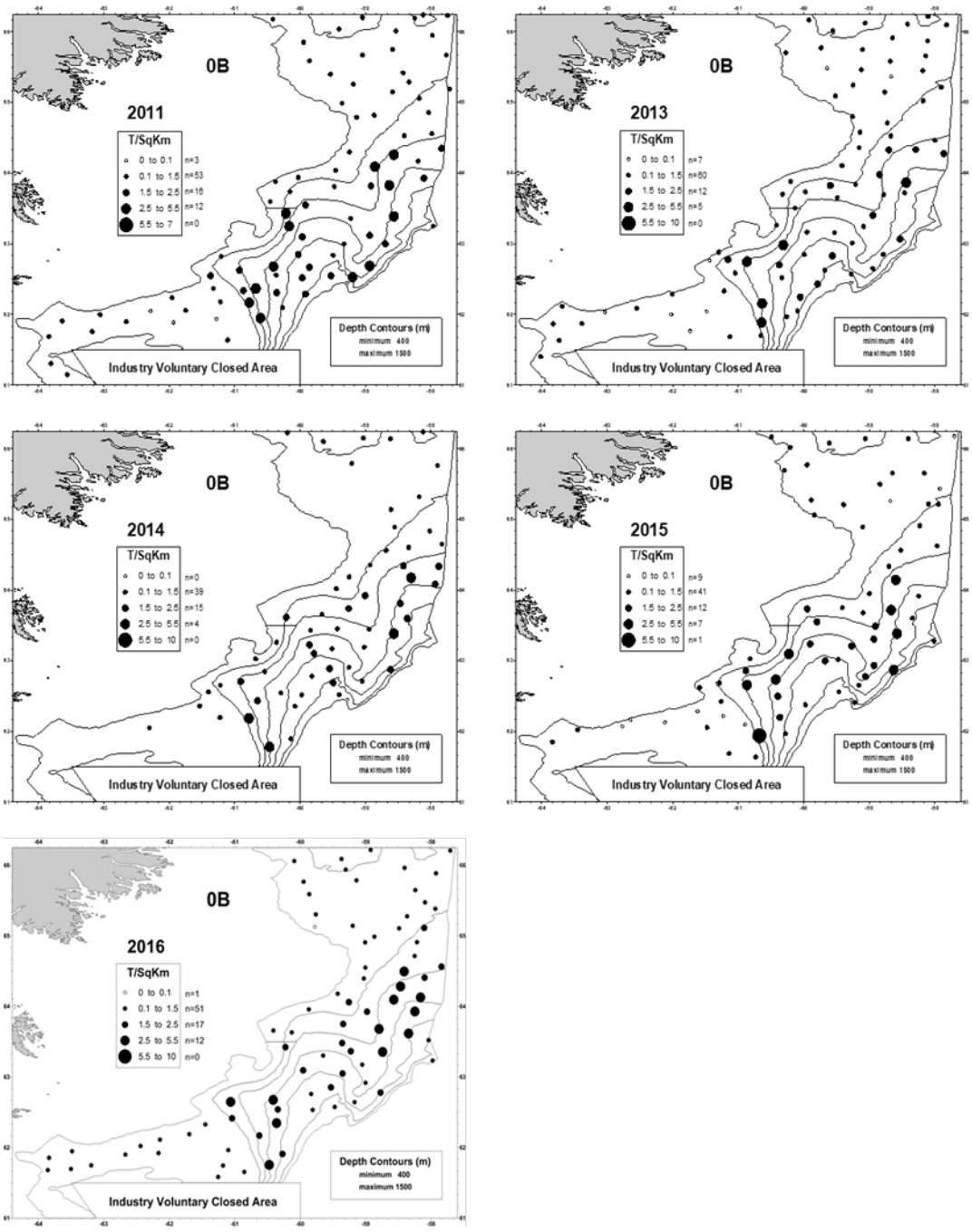


Figure 12. Greenland halibut catch distribution for 0B.