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Assessment of the Greenland Halibut Stock Component in NAFO Subarea 0 + 1 (offshore)

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Abstract

The paper presents information used in the stock assessment of Greenland halibut in Northwest Atlantic Fisheries Organization Subarea 0 and 1 (offshore). Since 1995 catches have been near the TAC, increasing in step with increases in the TAC, reaching a high of 36,436 t in 2021. Greenland and Canada have conducted buffered random stratified bottom trawl surveys in Div. 1CD and 0A-South which are combined for the stock assessment. Surveys were not conducted in 2018, 2020 or 2021 and the 2019 was conducted with a charter vessel which after review of gear performance measures was not considered comparable to previous surveys. As a result there has been no data from offshore surveys since 2017. The combined 1CD-0A-South biomass index had been relatively stable from 1999 to 2017 and all values were above the Blim for the survey series. Abundance followed a similar pattern. An updated for the index of abundance of age 1 Greenland halibut from the Greenland Shrimp and Fish Survey was available for 2020. Since 2003 there has been an overall declining trend in this index, with the exception of three large year classes producing high abundances of age 1 fish in 2011, 2013 and 2017. In 2020 age-1 abundance was near the average for the last 10 years. No survey was conducted in 2021. Length frequency distribution for the overall 1CD and 0A-South survey show a trend toward larger sizes with the mode increasing from 42-43 cm in 1999 and 2001 to a high of 51 cm in 2015. Secondary modes are present in 2008 and 2012-2017. Modes in the length frequency distribution for fisheries in SA0 and SA1 have been fairly stable, varying from 49 to 51 cm. Prior to 2014 the mode tended to be below 50 cm and since 2014 it has shifted to just above 50 cm. In the SA0 gillnet fishery modal size has declined from approximately 61 cm in 2006 to 56 cm in 2021. A CPUE index for trawlers fishing in SA 0+1 has been declining since a peak in 2018, and the gillnet CPUE for SA0 declined in 2021 after a continued increase from the beginning of the series in 2003 to 2020. However, CPUE is known to have limitations as an index of population status.

1. Description of the Fishery, Catches and TAC

TAC Regulation

Greenland halibut in Subarea 0+1, including 1A inshore, came under quota regulation in 1976 when a TAC of 20,000 t was established (Fig. 1). TAC was increased to 25,000 t in 1979. In 1994 analysis of tagging and other biological information resulted in the creation of separate management areas for inshore Div. 1A and Subarea 0+1A (offshore) and 1B-F. The portion of the TAC allocated to Subarea 0+1A (offshore) and 1B-F was 11,000 t and the TAC remained at this level from 1995-2001, during which time the TAC was fished almost exclusively in Div. 0B and Div. 1CD. A series of surveys took place during 1999-2004 in areas of Div. 0A and 1AB that had not been surveyed before. This new information on biomass in the stock area resulted in an increase in the overall TAC of 4,000 t in both 2001 and 2003 and 5,000 t in 2006 that were allocated to Div. 0A and 1AB. From 2006 to 2009 the advised TAC in Div. 0A+1AB was 13,000 tons and the TAC for 0B and 1C-F remained at 11,000. Based on an observed positive trend in the 1CD survey index the TAC for Div. 0B+Div. 1CF was increased by 3,000 t in 2010 and the overall TAC for Subarea 0+1 (offshore) remained at 27,000 t from 2011-2013. In 2014 the TAC for Div. 0A+Div. 1AB was increased by 3,000 tons to 16,000 t based on positive trends in the survey indices and the overall TAC of 30,000 t remained through 2016. In 2016 an index based harvest control rule (HCR) was accepted as the basis for TAC advice and an increase of 2,300 t was advised for the entire Subarea 0+1A (offshore) and 1B-F stock area for 2017 and 2018. Scientific Council allocated the increase equally to 0A+1A(offshore) and 1B, and 0B+1C-F. In 2018 the HCR was used to advise an increase of 4,070 t for the whole of SA0+1A(offshore) and 1B-F with allocation among divisions left to the managers. In 2020 separate management areas were established for inshore fishing areas in 1B-F and the TAC was maintained at 36,370 t for 2021 and 2022.

Catches in Subarea 0 + 1 (offshore)

Catches were first reported in 1964 and rose to 18,303 t in 1975 before declining to 187 t in 1986 (Fig. 1). Catches then increased to 17,888 t in 1992 due to a new trawl fishery in Div. 0B with participation by Canada, Norway, Russia and Faeroe Islands, and an expansion of the 1CD fishery with participation by Japan, Norway and Faeroe Islands (Tables 1 and 2). Catch declined from 1992 to 1995 primarily due to a reduction of effort by non-Canadian fleets in Div. 0B. Since 1995 catches have been near the TAC, increasing in step with increases in the TAC (Fig. 1). The TAC has been 36,400 t from 2019 to 2022. In 2021 catches were 36,436 t.

Fisheries and Oceans Canada does not include the J-cut, tail off product in its list for Greenland halibut but an interim conversion factor of 1.49 was provided in at-sea observer manuals and used by vessel operators and observers since 2007. In 2021, at the request of the Canadian fishing industry, the CF for J-cut, tail off product was lowered from 1.49 to 1.4. Based on a review of at-sea observer experiments conducted in Subarea 0 the appropriate value to estimate round weight from J-cut, tail off, dressed weight is 1.5 (round weight = J-cut weight x 1.5), which is comparable with J-cut, tail off CF values used by other countries that fish in the SA0+1 stock area (Treble and Hedges 2022). In 2021 the difference amounted to the removal of an additional 1,129 t (round weight) of Greenland halibut (DFO statistics indicated 87% of Arctic Region catch and 90% of Newfoundland Region catch was processed as frozen, gutted, head and tail off, which describes J-cut product). The 2021 SA 0 catches have been adjusted accordingly (Table 1).

Inshore fisheries in the fjords of Div. 1A-F and in Cumberland Sound in Div. 0B are managed separately. However, there is no way to differentiate or separate inshore from offshore catch in the totals reported for these divisions in STATLANT 21A statistics, so it is necessary to rely on the Greenland and Canadian authorities to determine the offshore catch for Subareas 0 and 1.

Bottom otter trawl gear is primarily used in the Subarea 1 fishery while the Subarea 0 fishery is a mix of trawl and gillnet (30-40% of the catch in recent years has been from the gillnet fleet). Longline gear is used occasionally in both Subareas. The trawlers have been using both single and double trawl configurations since about 2000. The gillnet fishery in Subarea 0 began in 2005 and has been using baited gillnets since about 2015. These baited gillnets have recently been reported to increase catch of Greenland halibut by 150% to 250%, depending on how the bait is attached to the gear (Bayse and Grant 2020).

Bycatch and Discards

Discards of Greenland halibut in the trawl fishery in both Subareas is small, normally 1- 2% of retained Greenland halibut. Discards in the Subarea 0 gillnet fishery are slightly higher but usually not more than 3% of the retained catch.

By-catch is estimated by observers on board vessels in SA 0 (Table 3). The targeted at-sea observer coverage is 100% for both the trawl and gillnet fisheries in Div. 0A, 100% for the trawl fishery in Div. 0B and 20% for the gillnet fishery in Div. 0B. The 20% gillnet target is has not always been met, particularly in 2020 and 2021, due to the COVID-19 pandemic. A summary of by-catch was done for 2021 fishing trips licensed by Fisheries and Oceans Arctic Region. Overall bycatch was <2 % of the observed Greenland halibut catch (Table 3). Bycatch in the gillnet fleet was 2-3%, slightly higher than in the trawl fleet (1-2%). Bycatch in SA0 was mainly comprised of 4 species, Greenland shark, roughhead grenadier, Arctic skate and northern wolffish.

By-catch was available from a number of logbooks of Greenland vessels fishing in SA 1 during (Table 4). These data are not complete but do provide a rough estimation of the primary by-catch species for 2017 to 2019. The highest in terms of biomass was Greenland shark (*S. microcephalus*), followed by Redfish (Sebastes species), skate species and roundnose grenadier (*C. rupestris*) (Table 4).

2. Research Survey Data

2.1 Surveys conducted during 1987 to 1996

Surveys began in SA0 and SA1 in the mid 1980's with surveys conducted in 0B by Russia and Germany and in 1BCD jointly by Greenland and Japan (Fig. 2). Since 1997 surveys have been conducted in 0B and 0A-South by Canada and in 1CD by Greenland using the same research vessel (Fig. 2).

2.2 Greenland and Canada Surveys in Divisions 1CD (Davis Strait) and 0A-South (Baffin Bay)

Greenland and Canada have conducted buffered stratified random bottom trawl surveys at depths 400 m to 1500 m in Div. 1CD (since 1997) and in Div. 0A-South (to approximately 72° N) (since 1999) using the Greenland Institute of Natural Resources research vessel RV Paamiut. The 0A-South area was re-stratified in 2008 to include the full extent of Division 0A and to match the depth categories used in the Greenland Subarea 1 stratification. In 2019 there was a change in the research vessel (CV Helga Maria) and in the survey timing; August instead of Sept for Div. 1CD and August instead of September-October for 0A-South (Treble 2020, Nogueira and Estevez-Barcia 2020). As a result the 2019 index is not comparable with the rest of the time series (Nogueira and Treble 2020). No surveys were conducted in 2018, 2020 and 2021.

Given the common research vessel and survey protocols it was possible to develop a combined biomass and abundance index for 1CD and 0A-South for years 1999, 2001, 2004, 2008, 2012, 2014-2017 and 2019 (Figs. 3 and 4) (see Nogueira and Estévez-Barcia 2020 and Treble 2020 for individual survey details). Biomass in 1CD and 0A-South combined was relatively stable from 1999 to 2014, varying between 124,000 t and 172,000 t (Fig. 3). It then increased to 213,000 t in 2016, followed by a decline to 138,000 t in 2017. In 2019 biomass was 164,000 t. Abundance has followed a similar trend (Fig. 4) varying between 15.1*107 and 22.8*10^7. In 2019 abundance was 14.5*10^7.

The overall length distribution (weighted by stratum area) in 1CD was dominated by a mode at 51cm from 2006 to 2017, an increase from a mode of 45 cm observed in 2000. In 2019 the mode was 53 cm (Nogueira and Estévez-Barcia 2020). There has been more variability in the 0A-south length frequency, with a primary mode around 45 cm and secondary modes varying between 20 and 30 cm (Treble 2020). The frequency distribution for 1CD and 0A-South combined typically ranges from 5 cm to just over 100 cm. In 2019 length ranged from 5 to 108 cm. Modal length has varied between lows of 42 cm and 43 cm in 1999 and 2001, respectively, to a high of 51 cm in 2015. In 2019 the modal length was 51cm. Secondary modes are clearly present in 2008, 2012-2017 (Fig. 5).

Survey Age distribution

There has been uncertainty in the accuracy of age determination methods for Greenland halibut which were resolved at a workshop held in Iceland in 2016 (ICES 2017). Effort is currently under way to age the back log of otoliths in order to provide age data for future assessments. Growth curves are available for male and female Greenland halibut for 2017. Female ages ranged from 3-32 years and males from 3-28 years. Age at 45 cm was approximately 10 years for both males and females (Fig. 6).

Survey Length-at-maturity

Maturity information collected during surveys in SA0 were examined in 2006 and updated in 2009 (Harris et al. 2009). Few fish were found to be mature. For females in 0A-South and 0B the length at 50% maturity (L50) ranged from 67-84 cm and 62-67 cm, respectively. Males don't grow to be as large as females and their L50s in 0A-South were 54-65 cm and in 0B it was 39-43 cm.

2.3 Greenland Shrimp and Fish Survey

Since 1988 surveys with a shrimp trawl have been conducted off West Greenland during July-September. The survey covers the area between 59° N and 72° 30' N (Div. 1A-1F) from 50 m to 600 m. The survey area was re-stratified in 2004 based on better information about depths. All biomass and abundance indices have been re-calculated. The re-calculation did not change the trends in the development of the different stocks. The Skjervoy trawl was changed to a Cosmos trawl in 2005. Calibration experiments were conducted (Rosing and Wieland, 2005), and data from 1988 to 2004 were converted so the time series are comparable. The RV Paamiut was used for the survey from 1991 to 2017. In 2018 the CV Sjuderberg was used to conduct the survey and in 2019 and 2020 the CV Helga Maria. An examination of gear parameters found that the effects of these vessel changes had a minimal effect on trawl performance (Nogueira and Treble 2020). No survey was conducted in 2021.

Greenland halibut is widely distributed throughout the 1A-F survey area, but highest concentrations are found in nursery areas in Division 1A, 1B-North and Disko Bay. Biomass has varied with a general increasing trend from 2010 to 2020 (Fig. 7). Abundance has been more variable, with notable peaks of high abundance in 2011, 2013 and 2017. Abundance is mainly driven by year to year variability in the number of one- and two-year old recruits, which typically constitute 80-90% of the Greenland halibut caught during the survey (Nygaard and Nogueira, 2021).

Clear modes can be found in the length distribution at 12-15 cm and 23 cm, corresponding to fish at age 1 and 2, using the Peterson method to assign age based on length frequencies (Nygaard and Nogueira, 2021). This allows for the development of an age-1 index. Since 2003 there has been an overall declining trend, with the exception of three large year classes producing high abundances of age 1 fish in 2011, 2013 and 2017 (Fig. 8). The index declined from 2017 to 2019 but in 2020 it had increased to a level near average for the last 10 years. There was no survey in 2021. It is unclear if the age 1 abundance index is representative of future recruitment.

3. Commercial Fishery Data

Information on fisheries and sampling in SA 1 for 2021 were available from Greenland (Greenland Institute of Natural Resources 2022) and Russia (Fomin and Pochtar 2022) research reports. Catch distribution for SA 1 and SA 0 have been plotted for 2021 (Figs. 9 and 10).

3.1 Length Distribution

Trawler

Length frequency samples available from SA0 and SA1 fisheries have been combined to create an overall length frequency. Given differences observed in length frequencies between Baffin Bay (Div. 0A+1AB) and Davis Strait (Div. 0B+1CD) plots of these areas are also provided. In SA0 and SA1 the modal length has varied from 49 to 51 cm (Fig. 11). From 2004 to 2014 the mode was at or below 50 cm, since 2014 the mode has remained above 50 cm. In the Baffin Bay area (0A+1AB) the length frequency range is typically 20 to 90 cm with a mode fluctuating between 45-51 cm (Fig. 12). In the Davis Strait area (0B+1CD) the length frequency range is typically 30 to 100 cm, with a mode varying between 45 and 53 cm (Fig. 13).

Gillnet

Length samples were available from gillnet fisheries in SA0 and are plotted for 2006 to present. Lengths typically range from 40 to 90 cm. Prior to 2014 modal size was approximately 61 cm, from 2015 to 2020 it varied around 59 cm. The 2020 sample was much lower than in other years that may have affected the results for that year. In 2021 there was a decline to approx. 56 cm (Fig. 14).

Longline

There is occasionally a longline fishery in SA1. Length frequencies were available from Greenland for Divs. 1AB (2001 and 2016) and 1CD (2001, 2005-2009 and 2013). The longline length frequencies have been combined for the whole SA1. Longlines typically catch larger fish (40 to 100+ cm) and in Div. 1CD the modal length has been in the range of 55 cm (Figure 15).

3.2 Age Distribution

Preliminary results from otoliths sampled during the 2019 SA 0 fishery ranged in age from 4 to 26 years, with a modal age of 12 years (Fig. 16).

3.3 Catch rate-Standardization

Subarea 0 + 1 (offshore) Trawl CPUE

The trawl catch rate is standardized using a General Linear Model. Data were aggregated by Year, Month, Gear, catches (t) and hours fished. Values less than 10 are removed. CPUE observations were log-transformed prior to the GLM analysis. Data were fit in R v. 4.40.40. (R Core Team, 2020) and least squares means were estimated with package “emmeans” (Lenth et al. 2018).

Catch rates for SA1 were available from logbooks submitted by all countries to the Greenland authorities. Until 2008 the fleets in the catch rate analysis have been grouped by nation, but information about gross tonnage is now available in the Greenland logbook database and the fleets are grouped based on size and gear. This has not changed the trends in the CPUE series, but the SE and CV of the estimates have been reduced significantly.

The standardized CPUE for SA 0 and 1 increased from 1999 to 2018 and has declined since then (Fig. 17) (Appendix 2).

The gillnet catch rate is also standardized using a General Linear Model. Data were aggregated by Year, Month, Gear, Country/region (Newfoundland and Arctic), catches (t) and nets fished (per 100 nets). Gillnet CPUE increased from the beginning of the series in 2003 to 2020, then declined in 2021 (Fig. 18) (Appendix 3).

CPUE indices should be interpreted with caution:

1) It is not known how the technical development of fishing gear has influenced the catch rates. For example the catch from single and double trawl gear was often aggregated as “otter trawl” catch when this gear was first introduced to the fishery in the early 2000s and bait has been attached to the gill nets in SA0 beginning in 2015;
2) Coding of gear type in the log books is not always reliable, which can influence the estimation of catch rates;
3) Changes in fleets and fishing grounds have occurred in both SA0 and SA1.

4. Assessment

Age based analysis are not available for this stock due to the challenges concerning age determination for Greenland halibut. Several workshops have been held over the years to investigate the problems and examine methods. In 2015 agreement was reached on the comparability of methods and labs are now starting to address the back-log of ageing (ICES 2017).

Several attempts have been made over the years to model the stock but none have been accepted:

1) Yield per Recruit Analysis – 1994-1996 (SCR 96/67);
2) XSA – 1996, 1999, 2002 (SCR 02/68), 2003 (SCR 03/54);
3) ASPIC – 1999, 2009, 2012 (SCR 12/031);
4) Schaefer model – 2014 (SCR 14/027).

Previous assessments were based on an index of biomass from surveys conducted in 1CD and 0A-South (following comment from an ICES benchmark meeting on Greenland halibut stocks (ICES 2013) (Fig. 3). The application of the ICES guidance on data limited stocks (DLS) method 3.2 (ICES 2012a and 2012b, ICES 2014) was adopted by SC in 2016 as the basis for advice. This harvest control rule (HCR) was developed and tested as an empirical approach that uses the trend in the stock response to fishing pressure (ICES 2012a, Jardim et al. 2015). The empirical basis was given the generic expression Cy+1=Catchrecent*r. The term Catchrecent is the average catch over some period and in this case the advised TAC in the previous year was used (Jørgensen and Treble 2016, Magnusson et al. 2018). The trend in development of the stock (r), is normally SSB over some period (e.g. 7 year time frame, r=mean of recent 3 year/mean of next 4 years). This HCR was used to provide advice in 2016 and 2018.

The 2019 surveys were not considered comparable to previous years and there was no survey in 2020 or 2021, therefore, there is no longer sufficient data to use the HCR to provide TAC advice.

Effort is underway to explore spatial and length based models using all available survey indices as well as fishery catch and length frequencies, to identify the potential for their use in future assessments of this stock. Information on this work is provided in Appendix 4.

5. Reference Points

Bmsy is not known for this stock. However, in 2015 a proxy for Blim was developed based on 30% of the 0A-South and 1CD index over a period of stability (1999-2012) (NAFO 2012, Jørgensen and Treble 2016) (Fig. 3).

No surveys were conducted in 2018, 2020 or 2021 and the 2019 survey was not considered comparable to the previous surveys, therefore, the previous Blim is no longer valid.

6. Conclusion

The surveys that provide the main index for this stock were not conducted in 2018, 2020 or 2021. The survey in 2019 was conducted with a charter vessel and after review of gear performance measures it was not considered comparable to previous surveys (Treble and Nogueira 2020). As a result there has been no data from offshore surveys since 2017. From 1999-2017 the 0A-South+1CD combined survey biomass index had been relatively stable with more variability observed near the end of the time series and all values were above Blim.

There is an update from 2020 for the Greenland fish and shrimp survey in Divs. 1A-F. Although the survey experienced vessel changes during 2018-2020, the results are considered comparable with previous years. Since 2003 the abundance index has had an overall declining trend, with the exception of three large year classes in 2011, 2013 and 2017. Abundance of age-1 fish was near average in 2020. It is unclear if the age-1 abundance index is representative of future recruitment.

Since 1995, catches have been near the TAC, increasing in step with increases in the TAC, reaching a high of 36,446 t in 2019. The TAC from 2019 to 2022 has been 36,400 t and catches in 2021 were 35,955 t.

The surveys and trawl fisheries have almost all seen slight increases in modal lengths over the last 10 to 15 years, from values below 50 cm (48-49cm) to values above 50cm (51-52cm). However, the modal size in the SA0 gillnet fishery has declined, from approx. 61 cm to 59 cm, and in 2021 it was approx. 56 cm.

A standardized CPUE index for trawlers fishing in SA 0+1 has been declining since a peak in 2018 and the gillnet CPUE for SA0 declined in 2021 after a continued increase from the beginning of the series in 2003 to 2020. However, CPUE is known to have limitations as an index of population status.

7. Research Projects

Fisheries and Oceans has undertaken research on geospatial and other population models that could be used to improve the stock assessment. Preliminary findings will be reviewed during a DFO meeting to be held in late fall 2022. Models that show potential will be further developed and run including the 2022 survey data for review by STACFIS in June 2023. An overview of this effort to identify alternative assessment methods for the Subarea 0+1 (offshore) Greenland halibut stock is presented as an information in Appendix 4.

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Table 1. Greenland halibut catches (metric tons) by year and country for Subarea 0, 1987 to 2019. Based on STATLANT, with information from Canada used to exclude 0B inshore catch.

Year	0A CAN	0A Other[a]	TOT 0A	0B CAN	0B Other[a]	TOT 0B	SA0 Total
1987					388	388	388
1988				2	1022	1024	1024
1989				180	907	1087	1087
1990				844	8909	9753	9753[b]
1991				395	8350	8745	8745
1992				2624	10164	12788	12788
1993	681		681	592	6605	7197	7879[c]
1994				402	4274	4676	4676
1995	82		82	1859	1292	3151	3233
1996		576	576[d]	2354	1678	4032	4608
1997	3		3	3868	452	4320	4323
1998				3924		3924	3924
1999	517		517	4267		4267	4784
2000				5438		5438	5438[e]
2001	2628	445	3073	5034		5034	8107
2002	3561		3561	3910		3910	7471[f]
2003	4142		4142	5059		5059	9201
2004	3751		3751	5771		5771	9522
2005	4209		4209	5789		5789	9998
2006	6634		6634	5585		5585	12219
2007	6173		6173	5318		5318	11491
2008	5257		5257	5175		5175	10432
2009	6627		6627	5622		5622	12249
2010	6390		6390	6941		6941	13331
2011	6365		6365	6814		6814	13179
2012	6365		6365	7257		7257	13622
2013	6314		6314	7352		7352	13666
2014	7934		7934	7003		7003	14937
2015	7922		7922	7491		7491	15413
2016	7559		7559	6402		6402	13961
2017	8458		8458	7932		7932	16390
2018	8408		8408	7563		7563	15971
2019	9708		9708	8619		8619	18327[g]
2020	9429		9429	8489		8489	17918[g]
2021	10061		10061	9033		9033	19094[gh]

a Other countries may include Faroe Islands, Poland, Russia, Estonia, Latvia, Japan, or Norway.
b Norwegian catch double reported.
c The Russian catch is reported as area unknown, but has previously been reported from Div. 0B
d Caught under a Canadian charter.
e STACFIS estimate
f Excluding 782 tons reported by error
g STATLANT 21A data are not available
h STACFIS estimate using 1.5 conversion factor for J-cut, tailed product; 1,129 t increase over reported catch.

Table 2. Greenland halibut catches (metric tons) by year and country for Subarea 1 from 1987 to 2019, not including inshore areas. Based on STATLANT, with information from Greenland used to exclude 1A-F inshore catch.

	1AB				1CF							SA1
Year	GRL	RUS	FRO	TOT 1AB	GRL	RUS	FRO	EU	NOR	JPN	TOT 1CD	Total
1987					1646					855	2501	2501
1988					605					1576	2181	2181
1989					540					1300	1840	1840
1990					841		54			985	1880	1880
1991					933		123		611	673	2340	2340
1992					191		151		2432	2895	5669	5669
1993					186	5	128	46	2344	1161	3870	3870
1994					872		780	266	3119	820	5857	5857
1995					1399	296		527	2472	323	5017	5017
1996					1876	254		455	1785		4370	4370
1997					2312		127	446	1893		4778	4778
1998			117	117	2295	543	125	350	1338		4651	4768
1999					2529	552	116	330	1360		4887	4887[a]
2000			96	96	2059	792	147	444[b]	1590		5032	5128
2001	340	85	150	575	2012	829	150	537[b]	1550		5078	5653
2002	1619	279	150	2048	2284	654	150	536	1734		5358	7406
2003	3558	259	117	4007	2059	1328	135	543	1423		5488	9495[cd]
2004	3500	241	153	4035	2102	1214	150	665f	1364		5495	9530[ce]
2005	3363	549	125	4037	2380	1147	149	549	1456[b]		5681	9718[e]
2006	5530	565	128	6223	2430	1222	147	544	1379		5722	11945[e]
2007	5596	575	125	6296	1805	689	150	1516	1441		5601	11897[e]
2008	5524	570	149	6243	1592	763	184	1517	1452[b]		5508	11751
2009	6094	517	124	6735	1457	1057	149	1511	1514		5688	12423
2010	5682	654	126	6462	2491	1214	152	1818	1581		7256	13718
2011	5722	648	102	6472	2493	865		1824	1720		6902	13374[e]
2012	5810	546	103	6459	2660	1227		1784	1761		7432	13891
2013	5865	546	102	6513	3514	1223		2017	1496		8250	14763[e]
2014	7333	550	102[b]	7985	4072	1224		1751	1464		8511	16496[f]
2015	7366	548	102	8016	3834	1215		1880	1503		8432	16448[f]
2016	7682	550	103	8335[g]	4367	1215		1885	1382		8849	17184[f]
2017	8003	549	103	8655	4968	1224		1929	1495		9616	18271[f]
2018	7953	550	104	8607	3079	1121		1878	1488		7566	16173
2019	8821	550	103	9474	3995	1119		1881	1526		8521	17995
2020	7107	550	105	7762	5932	1118		1883	1429		10362	18124[f]
2021	7791	550	104	8445	4902	893		1673	1429		8897	17342

a Excluding 7603 t reported to STATLANT in error

b Catch reported to the Greenland Fisheries License Control Authority.

c Includes Spanish research fishery catch, 75 t in 2003 and 272 t in 2004.

d Excludes 1366 t reported for Div. 1A in error

e STATLANT 21A data for Div. ICD from Greenland includes double reporting.

f STATLANT unknown catches for Greenland were distributed based on information from Greenland authorities or assumed to come from Div. 1A inshore.

g Norway STATLANT 21A reported catch in Div. 1A that was actually caught in 1D.

Table 3. By-catch (tons) as reported by at-sea observers assigned to the 2021 Canadian Greenland halibut fishery (Fisheries and Oceans Canada Arctic Region). Species selected based on reported catches > 1t. Corresponding catch of Greenland Halibut and bycatch relative to Greenland Halibut catch (%) is also given.

Species	0A Bycatch (t)		0B Bycatch (t)		Total SA0
	Gillnet	Trawl	Gillnet	Trawl	
Redfish (Sebastes)	3.22	0.31	0.81	1.31	5.65
Spotted wolffish (*A. Minor*)	0.07	0.72		0.34	1.13
Northern wolffish (*A. denticulatus*)	1.16	2.47	0.14	58.98	62.76
Blue Hake (*A. rostrata*)				1.65	1.65
Three beard rockling (*G. ensis*)	0.00	0.98		0.13	1.10
Thorny skate (*A. radiata*)	2.37	0.86	0.05	0.09	3.37
Spinytail skate (*R. spinicauda*)		1.69		12.21	13.90
Jensen's skate (*A. jenseni*)		0.88		0.51	1.39
Arctic skate (*A. hyperborea*)	22.04	14.84		0.65	37.54
Skate sp.	0.03	3.17		2.57	5.77
Black Dogfish (*C. fabricii*)	0.03		0.26	1.70	1.99
Greenland shark (*S. microcephalus*)	0.12	43.18		39.64	82.93
Roughhead grenadier (*M. berglax*)	21.30	3.88	2.25	27.84	55.25
Rock grenadier (*C. Rupestris*)		0.00	0.05	1.10	1.15
Grenadier sp.		0.49		3.26	3.75
Spiny Eel (*N. chemnitzi*)				1.55	1.55
Jelly fish (Scyphozoa)	0.10	0.30		2.53	2.93
Sponge (Porifera)	0.79	0.02		0.27	1.08
TOTAL Bycatch	51.23	73.78	3.54	156.32	284.87
Greenland halibut catch (*R. hippoglossoides*)	3791.67	5701.93	158.02	5545.17	15196.79
% of Greenland Halibut catch	1.35	1.29	2.24	2.82	1.87
Greenland halibut discards (*R. hippoglossoides*)	111.15	49.71	4.11	89.93	254.90
% of Greenland Halibut catch	2.93	0.87	2.60	1.62	1.68

Table 4. By-catch (tons) as reported on logbooks by Greenland vessels fishing in Subarea 1. Species selected based on reported catches > 1t.

Species (kgs)	FAO code	2017	2018	2019
Somniosus microcephalus	GSK	53.93	21.47	27.43
Sebastes mentella	REB	22.73	5.78	14.67
Sebastes marinus	REG	5.38	1.21	10.74
Coryphaenoides rupestris	RNG	18.76	15.59	22.26
Anarhichas denticulatus	CAB	1.84	8.80	10.75
Hippoglossus hippoglossus	HAL	1.04	0.19	1.30
Dogfish spp	DGX	1.18	1.06	2.31
Skate spp	SKA	11.94	21.81	23.89
Bony fish spp	MZZ	24.88	22.28	38.73

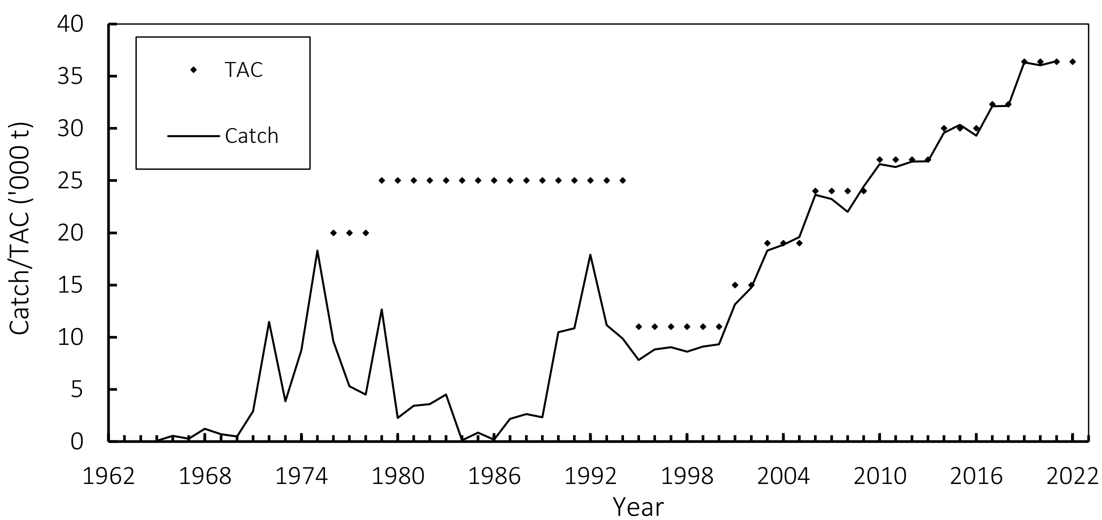

Figure 1. Catches and recommended TAC for SA0+1 (offshore) Greenland halibut.

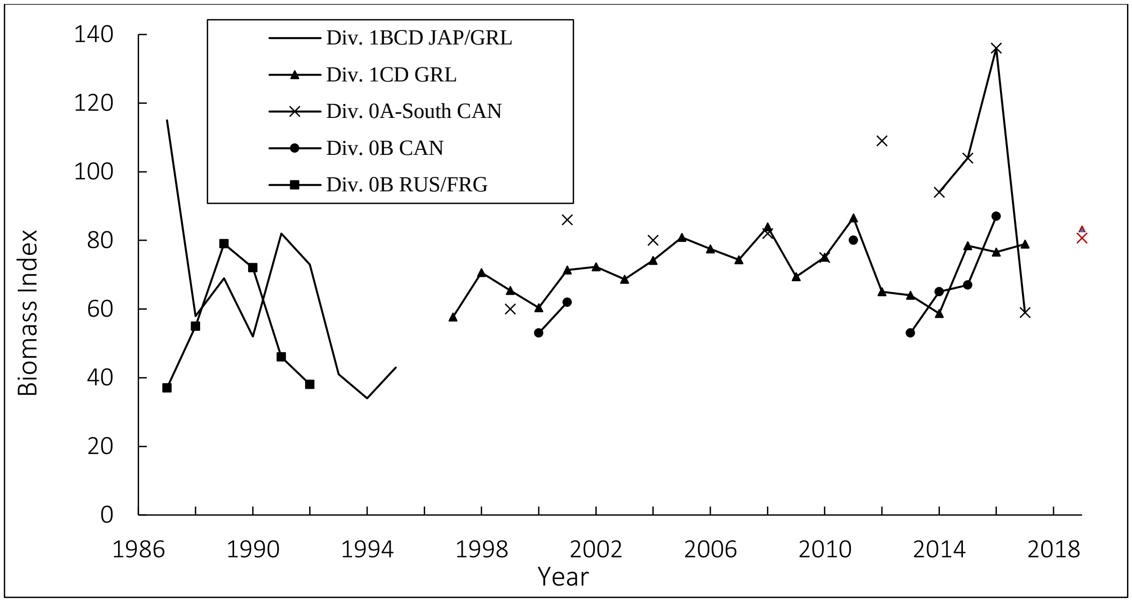

Figure 2. Biomass estimates from surveys conducted in SA 0 and 1 since 1986. There was a change in vessel for the 2019 surveys in 1CD and 0A-South and these estimates are not considered comparable to previous years.

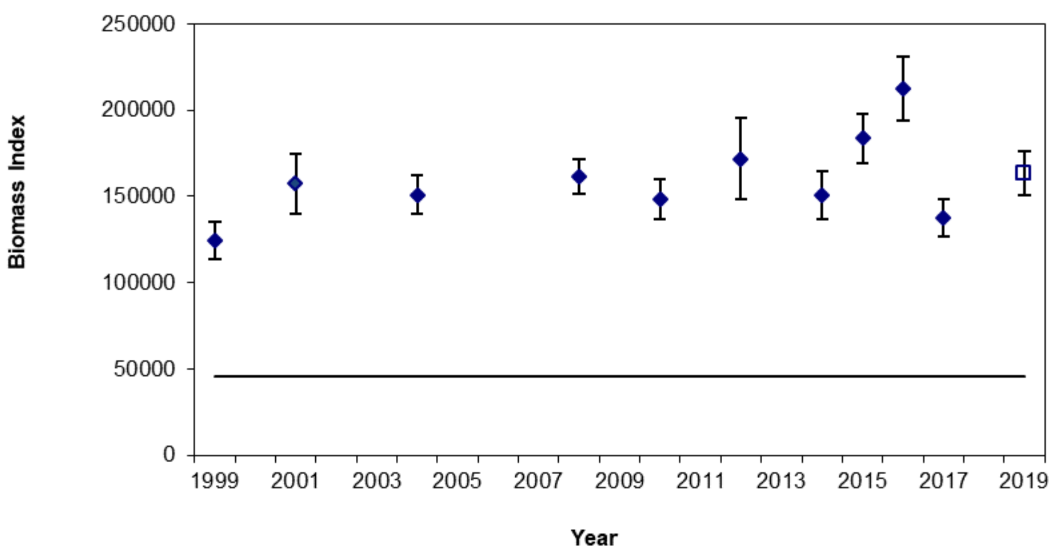

Figure 3. Combined survey biomass index for Div. 0A-South+Div. 1CD and the series Blim (30% of the mean biomass from 1999 to 2012).

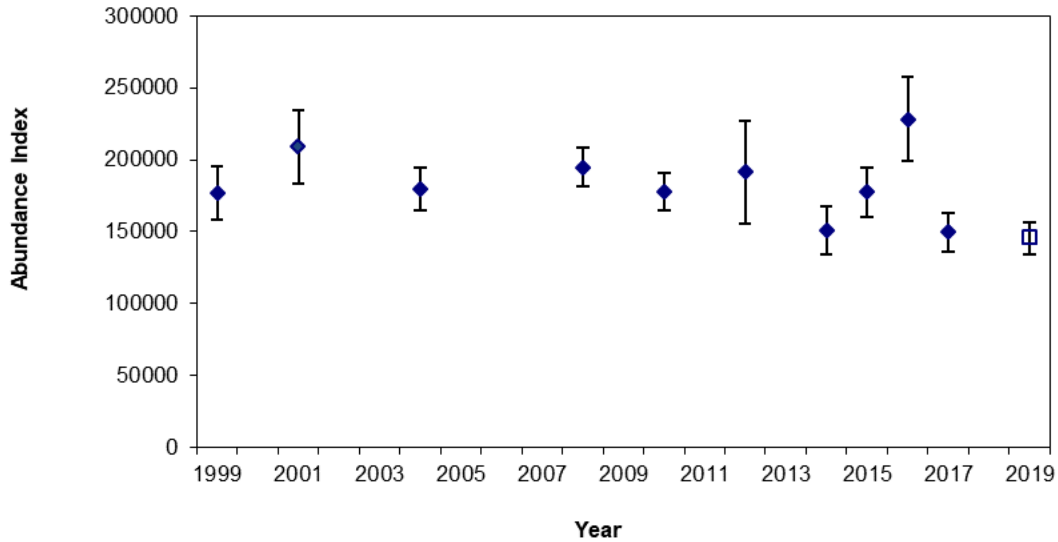

Figure 4. Combined survey abundance index for Div. 0A-South+Div. 1CD.

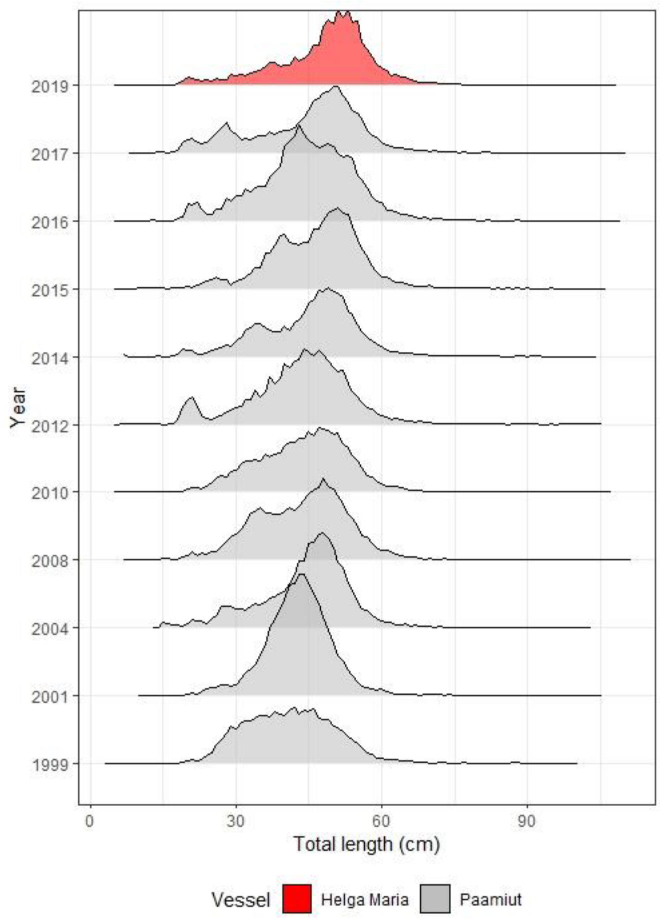

Figure 5. Length distribution of Greenland halibut (numbers weighted by stratum area) for the Div. 0A-South+Div. 1CD surveys.

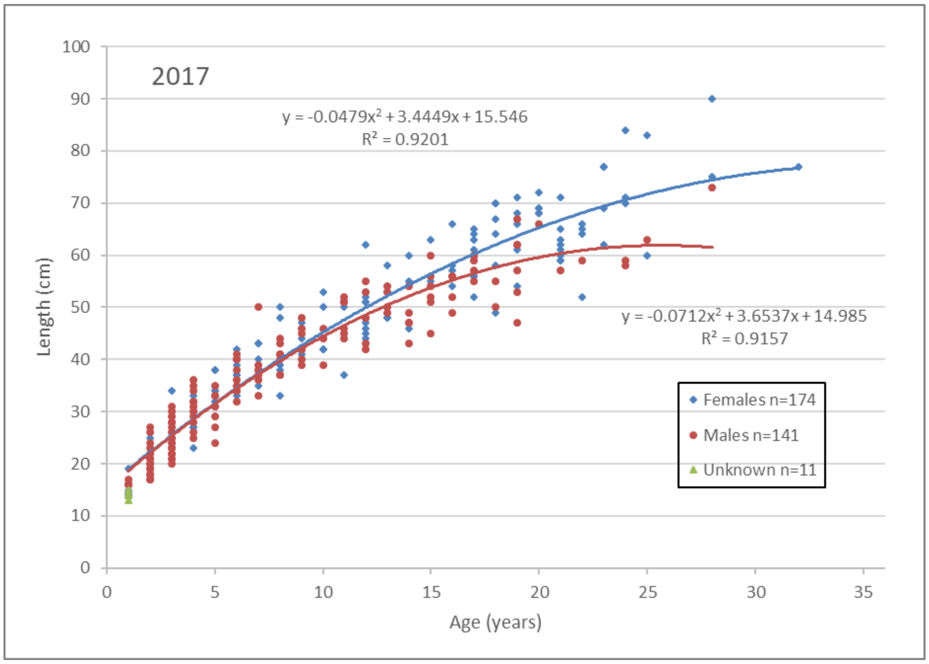

Figure 6. Growth curves for Greenland halibut, by sex, for the 2017 survey in Div. 0A-South.

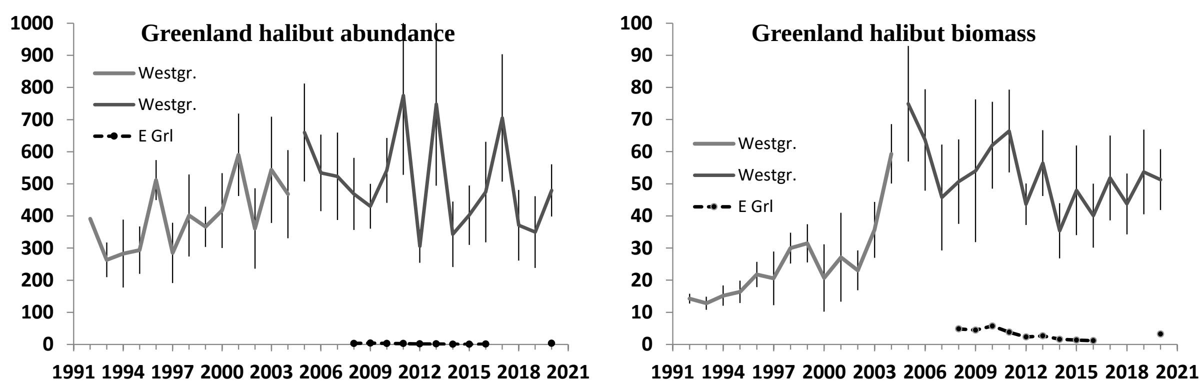

Figure 7. Greenland halibut abundance and biomass indices from the Greenland Fish and Shrimp Survey in 1A-F (50-600 m) (Nygaard and Nogueira 2021).

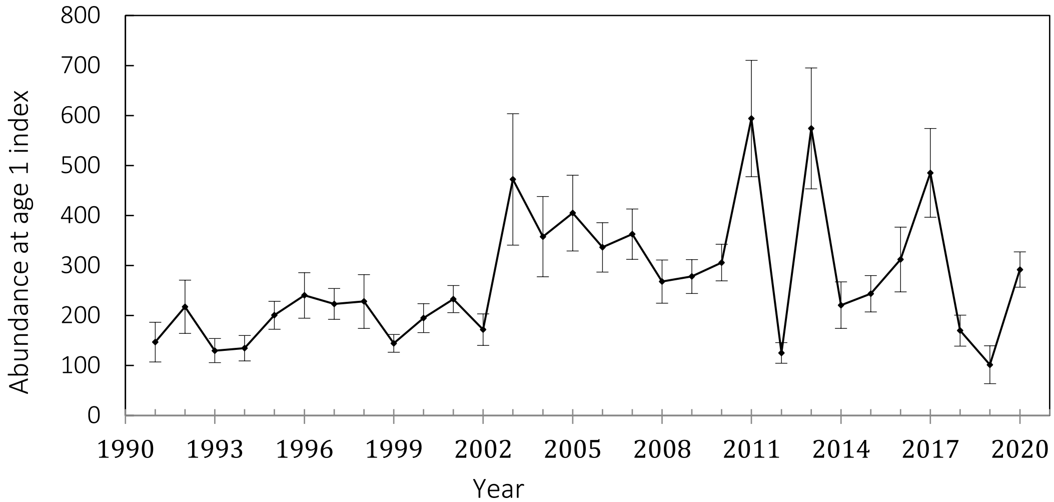

Figure 8. Abundance of age 1 Greenland halibut from the Greenland Fish and Shrimp Survey, for the entire survey area, including inshore Disko Bay, Div. 1A (North of 70○37.5'N) and several sets on the adjacent shelf in 0A.

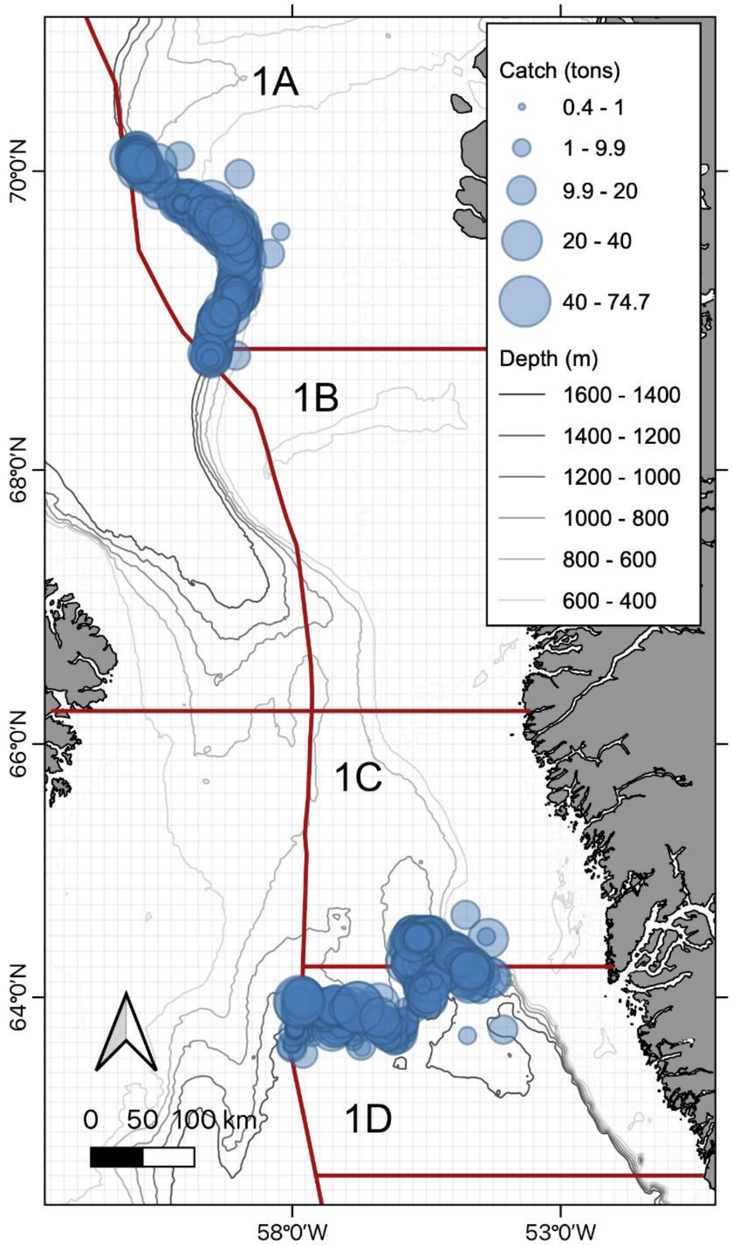

Figure 9. Greenland halibut commercial catch distribution for offshore Subarea 1 in 2021.

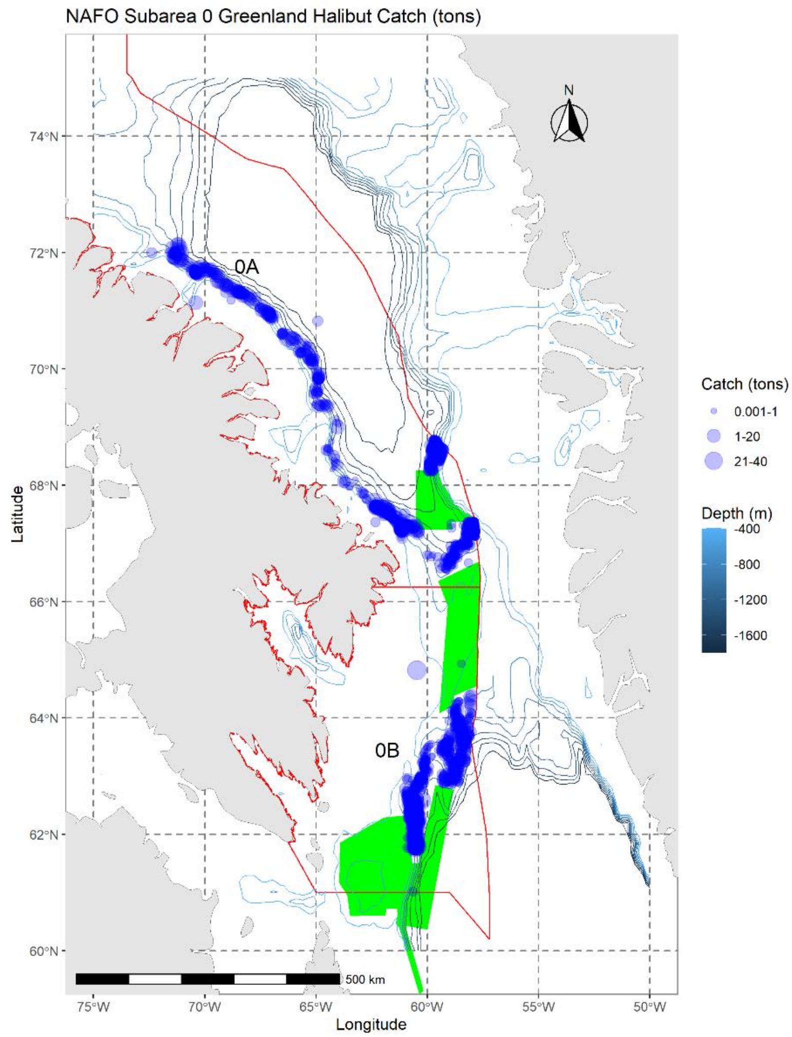

Figure 10. Greenland halibut commercial catch distribution for Subarea 0 in 2021. Three marine refuges that are closed to bottom contact fishing are in shown in green. From north to south: Disko Fan, Davis Strait and Hatton Basin.

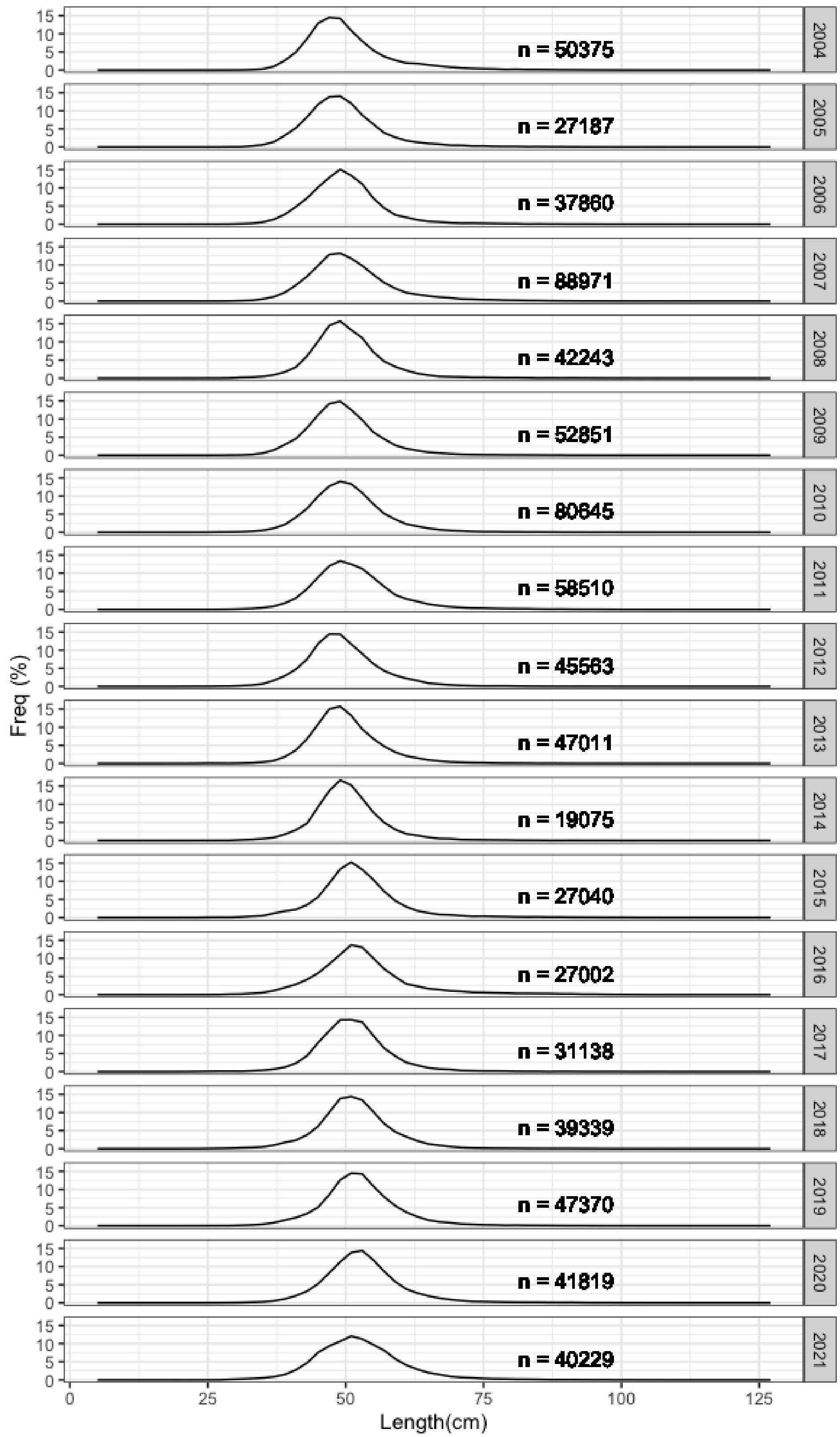

Figure 11. Length distribution from the trawl fisheries in Subarea 0+1 (offshore).

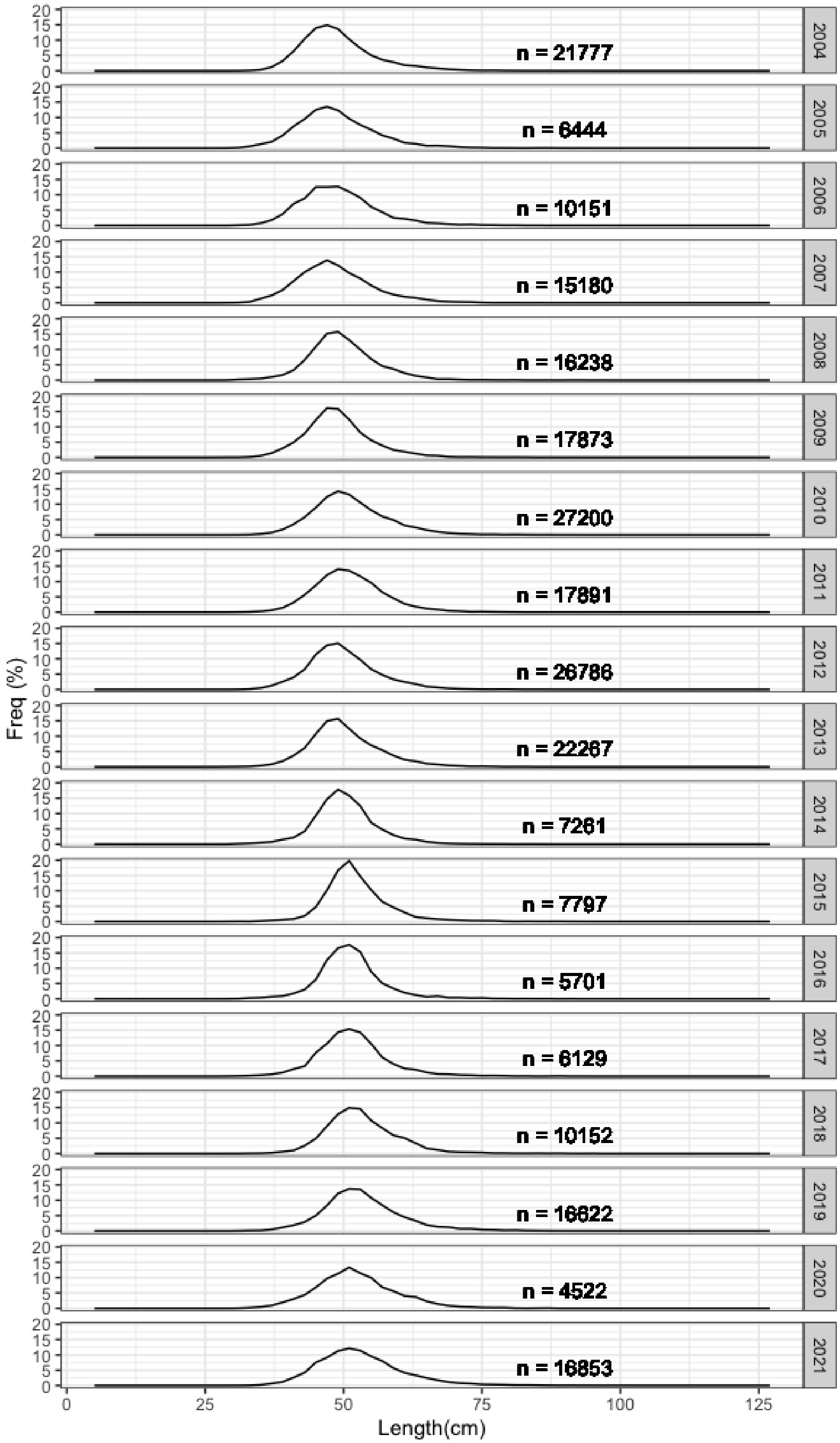

Figure 12. Length frequencies in commercial catches from trawlers in Div. 0A and 1AB .

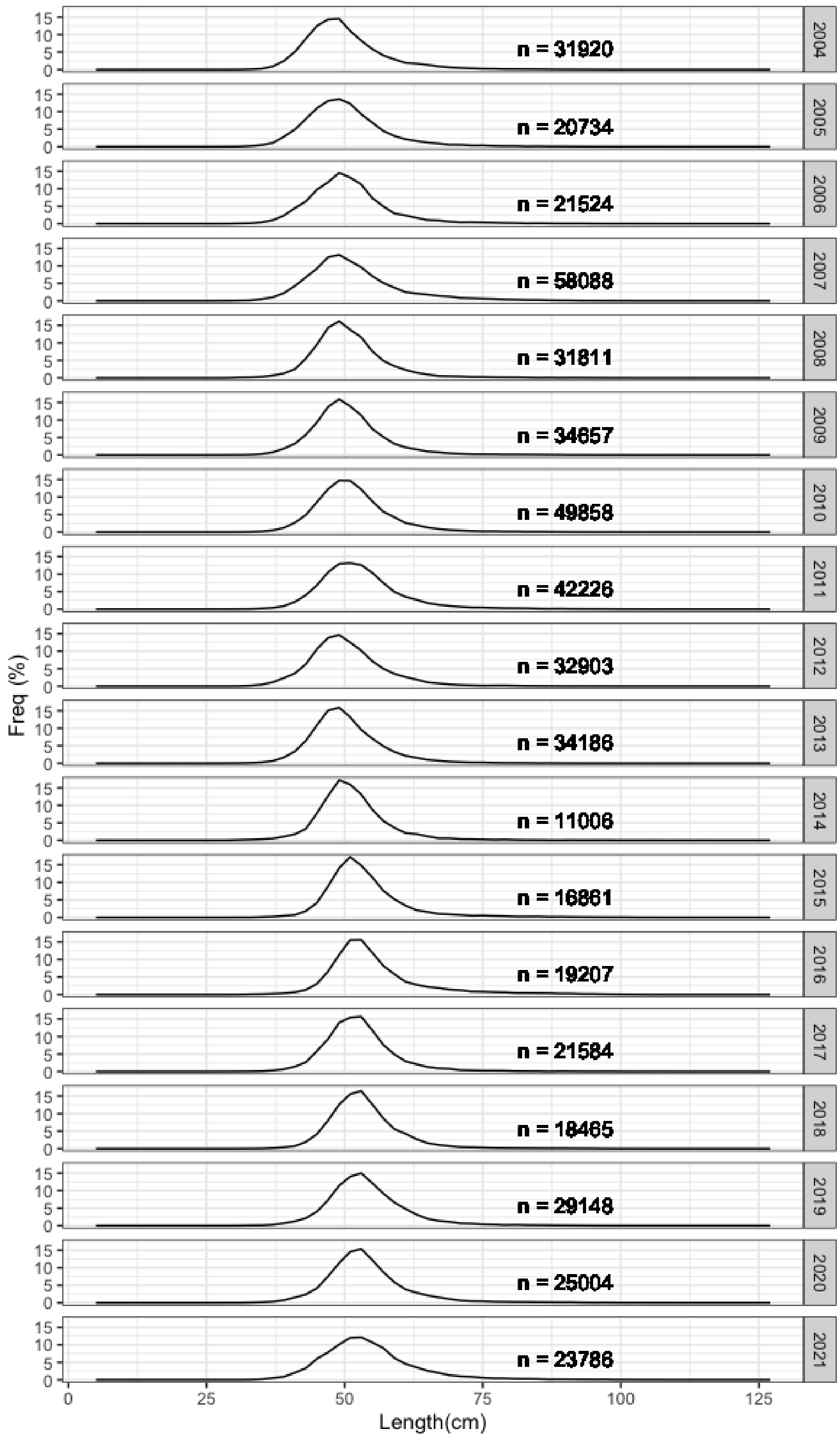

Figure 13. Length frequencies in commercial catches from trawl gear for Div. 0B and 1CD.

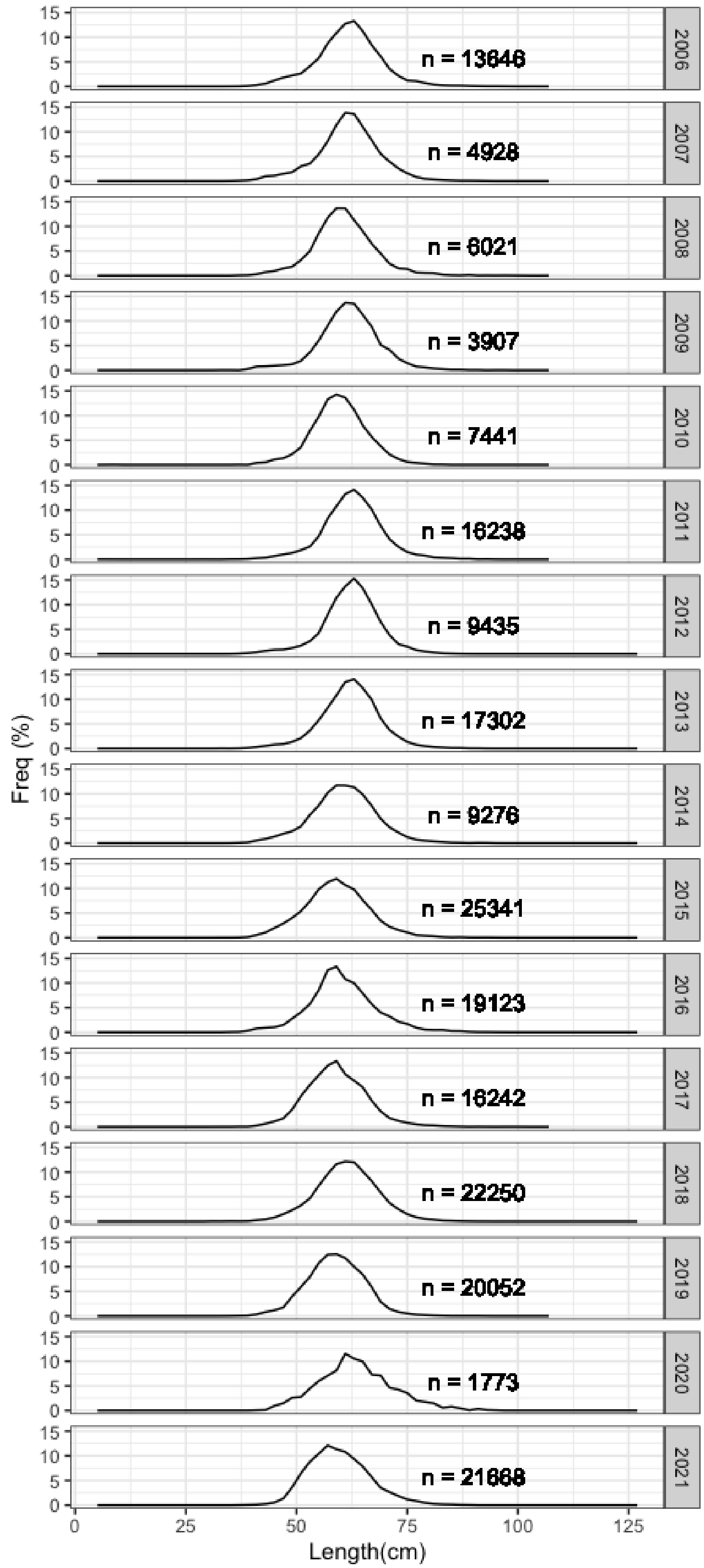

Figure 14. Length frequencies in commercial catches from gillnet gear for Subarea 0.

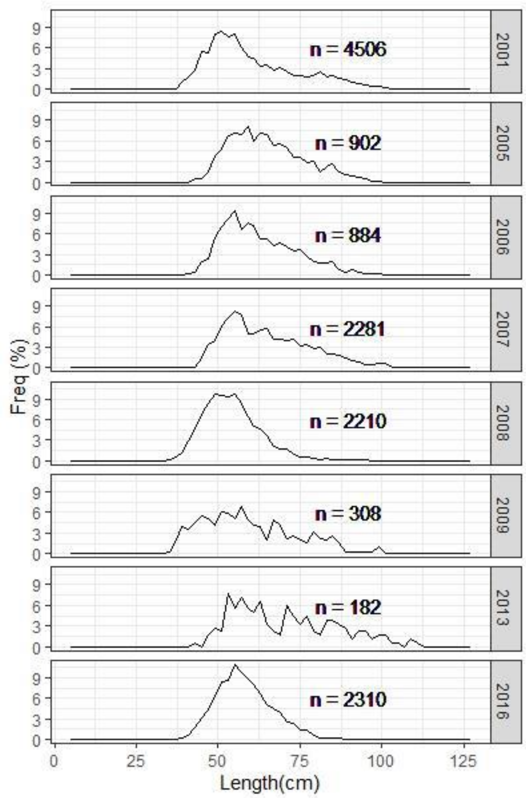

Figure 15. Length frequencies in commercial catches from longline gear for Division 1A-D.

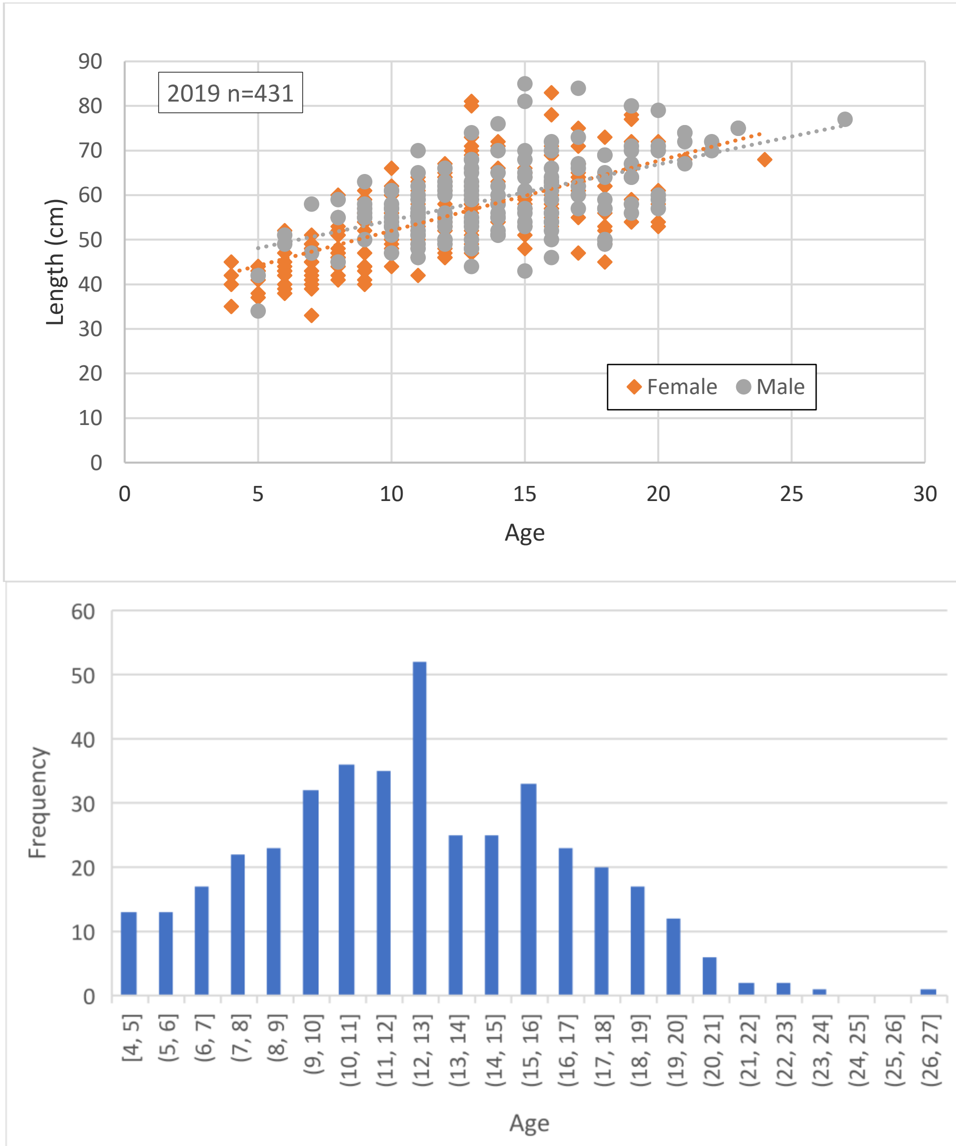

Figure 16. Age-length distribution (top) and frequency (bottom) for samples from commercial trawl and gillnet vessels fishing in SA0 in 2019.

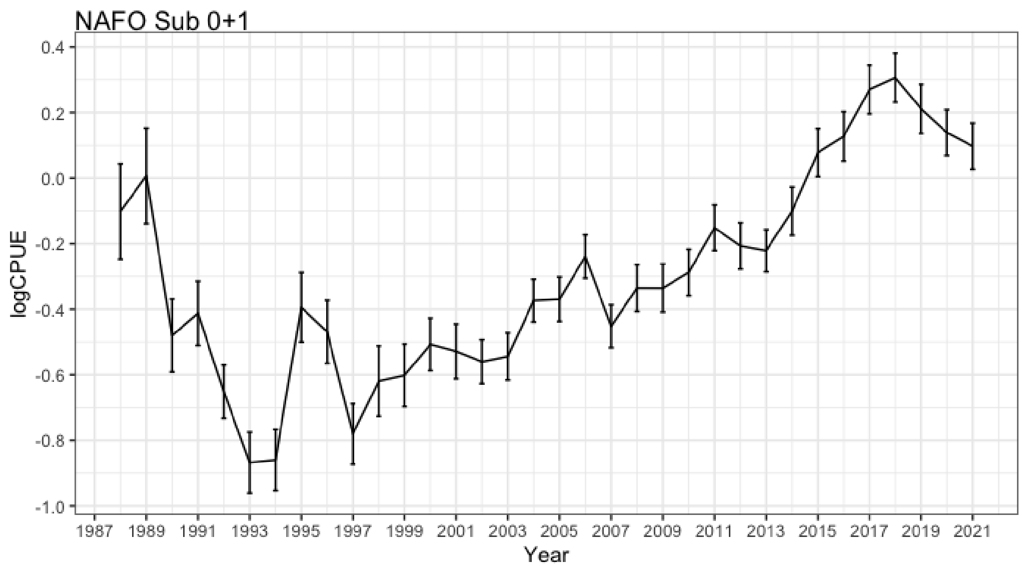

Figure 17. Combined standardized trawl CPUE index from trawlers in SA 0+1, with S.E.

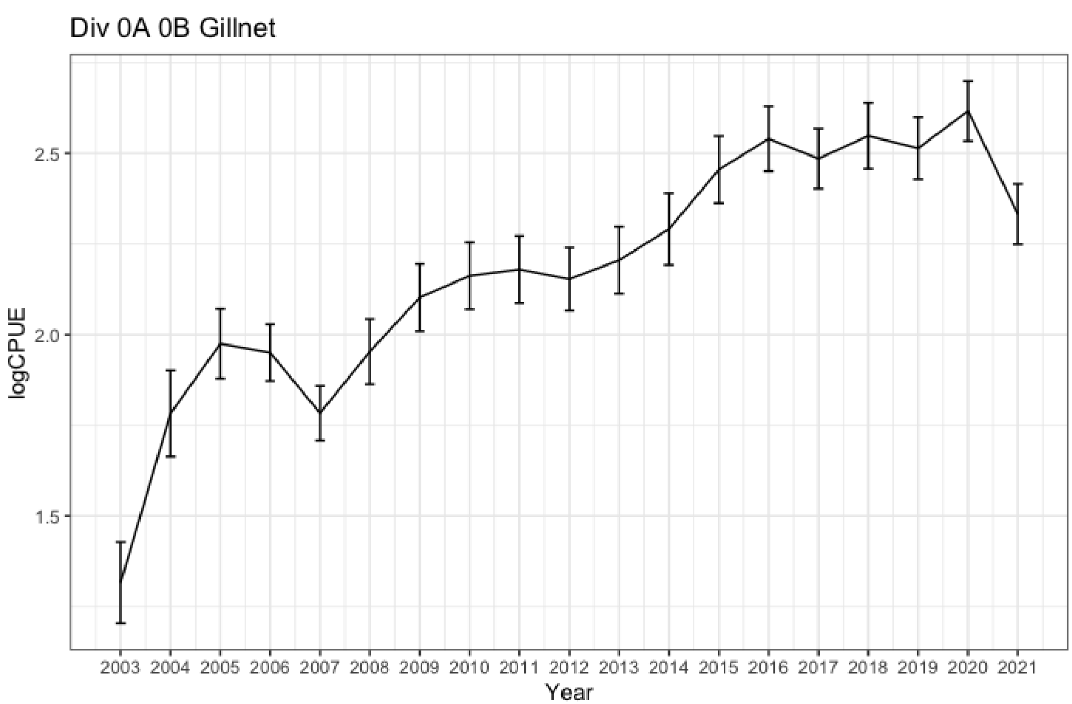

Figure 18. Standardized CPUE index from gillnets in SA 0, with S.E. Note that bait bags have been added to the gillnets since 2015.

Appendix 1. NAFO codes used in the CPUE standardization.

Code for Trawl Gear
Bottom otter trawl (charters), 8, OTB
Bottom otter trawl (side or stern not specified), 10, OTB
Bottom otter trawl, 12, OTB-2
Otter twin trawl, 192, OTT

Code for Boat (Tonnage)
0 Not known
2 0-49.9
3 50-149.9
4 150-499.9
5 500-999.9
6 1000-1999.9
7 2000 and over

e.g. BoatC1924 = vessel (BoatC), twin trawl (192), class (4)
Boat3414= Newfoundland region vessel (Boat3), gillnet (41), class (4)
Boat40413= Arctic region vessel (Boat 40), gillnet (41), class (3)

Appendix 2. Standardized CPUE index for trawlers in SA 0+1

```
Call:
lm(formula = lcpue ~ Year + Month + Boat)

Residuals:
    Min       1Q   Median       3Q      Max
-1.17737 -0.17179  0.01317  0.17575  1.10570

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.0516785  0.2752622  -0.188 0.851134
Year1989     0.1085120  0.1969520   0.551 0.581845
Year1990    -0.3783458  0.1753525  -2.158 0.031307 *
Year1991    -0.3110713  0.1679187  -1.853 0.064386 .
Year1992    -0.5495025  0.1591401  -3.453 0.000589 ***
Year1993    -0.7661841  0.1658257  -4.620 4.58e-06 ***
Year1994    -0.7582056  0.1656482  -4.577 5.60e-06 ***
Year1995    -0.2928421  0.1728851  -1.694 0.090752 .
Year1996    -0.3674399  0.1665237  -2.207 0.027681 *
Year1997    -0.6790325  0.1639051  -4.143 3.86e-05 ***
Year1998    -0.5176249  0.1720229  -3.009 0.002718 **
Year1999    -0.5000494  0.1650621  -3.029 0.002543 **
Year2000    -0.4056647  0.1571936  -2.581 0.010070 *
Year2001    -0.4269914  0.1592736  -2.681 0.007521 **
Year2002    -0.4584552  0.1548925  -2.960 0.003185 **
Year2003    -0.4424345  0.1532410  -2.887 0.004011 **
Year2004    -0.2720251  0.1503503  -1.809 0.070850 .
Year2005    -0.2678318  0.1515367  -1.767 0.077604 .
Year2006    -0.1375706  0.1511747  -0.910 0.363140
Year2007    -0.3503184  0.1517661  -2.308 0.021283 *
Year2008    -0.2336397  0.1533564  -1.524 0.128097
Year2009    -0.2338959  0.1546762  -1.512 0.130957
Year2010    -0.1860186  0.1528630  -1.217 0.224066
Year2011    -0.0500445  0.1523817  -0.328 0.742699
Year2012    -0.1051682  0.1528915  -0.688 0.491775
Year2013    -0.1197391  0.1507054  -0.795 0.427168
Year2014     0.0008283  0.1544741   0.005 0.995723
Year2015     0.1795191  0.1541435   1.165 0.244581
Year2016     0.2289707  0.1547742   1.479 0.139501
Year2017     0.3721710  0.1546207   2.407 0.016350 *
Year2018     0.4079709  0.1546980   2.637 0.008550 **
Year2019     0.3127700  0.1546208   2.023 0.043483 *
Year2020     0.2404886  0.1522049   1.580 0.114565
Year2021     0.1986953  0.1530151   1.299 0.194545
Month2      -0.1963476  0.0893030  -2.199 0.028238 *
Month3      -0.1233772  0.1325374  -0.931 0.352243
Month4       0.0554180  0.0979467   0.566 0.571719
Month5       0.2264436  0.0735630   3.078 0.002166 **
Month6      -0.2458186  0.0692730  -3.549 0.000414 ***
Month7      -0.2706088  0.0672739  -4.022 6.41e-05 ***
Month8      -0.1502209  0.0647537  -2.320 0.020643 *
Month9      -0.0609912  0.0636567  -0.958 0.338340
Month10     -0.0679072  0.0635097  -1.069 0.285341
Month11     -0.0760386  0.0636572  -1.195 0.232699
```

```
Month12      0.0663047  0.0665533   0.996 0.319476
BoatC124    -0.1230954  0.2457551  -0.501 0.616613
BoatC125    -0.5241664  0.2336288  -2.244 0.025181 *
BoatC126    -0.1638947  0.2307737  -0.710 0.477826
BoatC127     0.2120101  0.2304197   0.920 0.357845
BoatC1926    0.3276600  0.2351761   1.393 0.163999
BoatC1927    0.4142355  0.2308212   1.795 0.073160 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3101 on 679 degrees of freedom
Multiple R-squared:  0.7152,	Adjusted R-squared:  0.6943
F-statistic: 34.11 on 50 and 679 DF,  p-value: < 2.2e-16
```

Appendix 3. Standardized CPUE index for gillnets in SA 0

```
Call:
lm(formula = lcpue ~ Year + Month + Boat)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.37613 -0.11353  0.01418  0.14747  0.67187 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept)  1.394605   0.299194   4.661 5.67e-06 ***
Year2004     0.466373   0.141689   3.292  0.00117 ** 
Year2005     0.658853   0.130877   5.034 1.05e-06 ***
Year2006     0.634313   0.123640   5.130 6.71e-07 ***
Year2007     0.467471   0.117678   3.972 9.86e-05 ***
Year2008     0.637178   0.121360   5.250 3.80e-07 ***
Year2009     0.786290   0.123557   6.364 1.27e-09 ***
Year2010     0.846041   0.123557   6.847 8.66e-11 ***
Year2011     0.863596   0.123557   6.989 3.85e-11 ***
Year2012     0.836940   0.120032   6.973 4.24e-11 ***
Year2013     0.889078   0.123557   7.196 1.16e-11 ***
Year2014     0.974914   0.128148   7.608 1.01e-12 ***
Year2015     1.138726   0.123557   9.216  < 2e-16 ***
Year2016     1.223779   0.121992  10.032  < 2e-16 ***
Year2017     1.169241   0.120027   9.741  < 2e-16 ***
Year2018     1.231838   0.124913   9.862  < 2e-16 ***
Year2019     1.197784   0.121639   9.847  < 2e-16 ***
Year2020     1.300423   0.121711  10.685  < 2e-16 ***
Year2021     1.016012   0.120649   8.421 6.59e-15 ***
Month5       0.007851   0.269564   0.029  0.97679    
Month6      -0.389026   0.269119  -1.446  0.14984    
Month7      -0.482176   0.268826  -1.794  0.07435 .  
Month8      -0.100810   0.268096  -0.376  0.70729    
Month9      -0.055624   0.268392  -0.207  0.83602    
Month10     -0.034092   0.270067  -0.126  0.89967    
Month11     -0.157747   0.271413  -0.581  0.56174    
Month12     -0.335495   0.373536  -0.898  0.37016    
Boat3414    -0.177408   0.083673  -2.120  0.03519 *  
Boat3415     0.323900   0.121873   2.658  0.00849 ** 
Boat40413    0.144604   0.110950   1.303  0.19393    
Boat40414    0.176589   0.084655   2.086  0.03822 *  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.2542 on 204 degrees of freedom
Multiple R-squared:  0.7441,	Adjusted R-squared:  0.7065 
F-statistic: 19.78 on 30 and 204 DF,  p-value: < 2.2e-16
```

Appendix 4: Develop Stock Assessment Options for SA01 Greenland Halibut

Introduction

Fisheries and Oceans Canada (DFO) has collaborated with the Greenland Institute of Natural Resources on bottom trawl surveys in Baffin Bay and Davis Strait since 1999. These surveys use a buffered random, depth-stratified design to sample Greenland halibut (*Reinhardtius hippoglossoides*) and other benthic fishes and invertebrates. Indices of Greenland halibut biomass and abundance are calculated from data generated by the surveys and these indices have been used to assess stock status and provide management advice. The stock assessment is considered data-poor and an appropriate quantitative model has not yet been identified.

In 2018 the research vessel used to conduct the surveys (*R/V Paamiut*) was retired. In 2019 a contract vessel (*F/V Helga Maria*) was used to conduct the survey using the same trawl (Alfredo) that was used from 1999 to 2017. In 2022 a new research vessel (*R/V Tarajoq*) and a new trawl (Bacalao) will begin a new survey time series. It was not possible to conduct comparative tows with the previous vessel and gear prior to its' decommissioning and data from gear monitoring devices found substantial differences in gear performance at depths beyond 700 m between the original survey vessel and the contract vessel used in 2019. As a result the 2019 biomass index value was not accepted during the 2020 assessment.

The next assessment for Subarea 0+1 (offshore) Greenland halibut is in June 2024 and DFO has sought suggestions about alternative methods that could be used to improve the Subarea 0+1 (offshore) Greenland halibut stock assessment and management advice, given the transition between vessels and trawl types. A Canadian Science Advisory Secretariat (CSAS) meeting is planned for late fall 2022, at which several alternative analytical methods will be presented and discussed. The meeting will involve reviews by DFO Scientists, GINR scientist and academics; the steering committee includes DFO Scientists, DFO Resource Managers and representatives from the Canadian fishing industry. Following completion of the CSAS meeting and new surveys in 2022, DFO will conduct assessments using all methods that are recommended by the CSAS meeting and will present these to the NAFO Scientific Council in June 2023 for consideration as analytical options during the 2024 stock assessment.

This paper provides an overview of analytical methods that will be presented during the 2023 CSAS meeting and a timeframe for advisory processes to determine methods that could be presented to NAFO SC during the 2024 Subarea 0+1 (offshore) Greenland halibut assessment.

Methods

DFO contracted two companies to develop alternative analytical approaches or processes to improve the stock assessment and provision of management advice for Subarea 0+1 (offshore) Greenland halibut. In addition, DFO Science has conducted a literature review of methods used to bridge changes in survey vessels and gear, and is exploring the outcomes of a spatial delta-GAM (general additive model) as an alternative assessment method.

Contract 1 (Blue Matter Science):
Blue Matter Science (BMS) developed a framework for establishing a spatial operating model and implementing a simulation for Subarea 0+1 (offshore) Greenland halibut by using various software packages, including SimSurvey (Regular et al. 2020), sdmTMB (Anderson et al. 2021), and openMSE (Hordyk et al. 2021). SimSurvey is the umbrella package used in the simulation framework; the other packages were used to inform inputs to SimSurvey. The results were used to compare two indices of abundance (0A-South+1CD, 0AB+1CD) that differed in spatial coverage.

BMS developed an age-structured model by first estimating annual Greenland Halibut abundance using a Rapid Conditioning Model (RCM) in the SAMtool package (Huynh et al. 2021) from the openMSE software (see Description at https://openmse.com/tutorial-rcm-eq/). The model used catches from Division 0A-0B and 1A-D (1987 – 2019) and the abundance index from fishery-independent trawl surveys (0A-South and 1CD offshore; Treble and Nogueira 2020), and corresponding length frequencies from the fishery and survey.

Biological parameters, such as growth and maturity, were estimated from survey samples and sex-specific length-at-age keys. Natural mortality was estimated using the Then et al. (2015) estimator; the value was within the range used for southern Greenland halibut stocks (Subarea 2, Divisions 3KLMNO; Morgan et al. 2019). RCM estimated initial abundance and annual recruitment as deviations from mean recruitment, selectivity parameters for the fishery and survey, and fishing mortality by year and fleet. Selectivity for the trawl gear was assumed to be dome-shaped as gillnets caught notably larger individuals.

The spatial distribution of the stock was characterized using a raster grid that incorporated the full spatial scale, restricted to 400-1500 m depth. Bathymetry data from the ETOPO1 Ice Surface Global Relief Model was used. The spatial distribution was determined by fitting a spatial GLMM (generalized linear mixed model) to the survey data in 0A and 1CD, implemented in sdmTMB. Fixed effects in the model included the intercept, year, depth, and the square of depth. Random spatial and spatiotemporal effects were estimated as separate random fields. To account for ontogenetic differences in behavior catch rates were calculated for three size classes: Small (0-45 cm), Medium (45-70 cm), and Large (70+ cm). Separate GLMMs were used for each size class. Population density was estimated using the fitted spatial GLMMs. The population distribution was used to generate spatial abundance in the operating model. These inputs were provided to the SimSurvey package in the `sim_abundance` and `sim_distribution` functions.

The DFO multi-species survey was simulated in SimSurvey by identifying the depth, division and strata of each spatial cell. Sampling intensity was constant each year and set to one sample per 750 sq. km, with a minimum of two samples per stratum. The swept area per tow was set to 0.08 sq. km, based on the observed median value. One hundred simulations were run. Two indices were generated: an index using samples from 0A-South+1CD and a second that included samples from 0AB+1CD.

Four comparisons were made between the operating model and the simulated indices: 1) relative trends in the index vs. relative trends in total abundance; 2) relative trends in the index vs. relative trends in total vulnerable abundance (to account for gear selectivity); 3) r ratio in the index vs. in total abundance; 4) r ratio in the index vs. in total vulnerable abundance.

Contract 2 (Landmark Fisheries Research):
Landmark Fisheries Research (LFR) developed a Spatially Implicit Statistical Catch-At-Length (SISCAL) operating model for the Subarea 0+1 (offshore) Greenland halibut stock. The model was then used to assess stock status and productivity and to conduct closed loop simulations to evaluate harvest strategies. The SISCAL model fits reasonably well to available data, as determined by standard goodness of fit metrics; some sensitivities and data issues were noted. The retrospective behaviour of the model was also reasonable; from simulation-evaluation self-tests, the model was unlikely to be biased over a large number of simulated data sets. After testing, SISCAL was used to condition a closed-loop simulation framework to test management procedures against performance metrics based on NAFO's precautionary approach to fishery management policy. For example, LFR defined an adaptive model/index-based management procedure that set total allowable catches on a biennial basis, using decision rule parameters that were updated via simulated SISCAL stock assessments every 6 years. Simulated SISCAL stock assessments were fit to historical and simulated catch and biological data from six commercial fleets (country and fishing gear) and stock indices and length compositions from three fishery independent surveys. The three surveys included two existing deep (Divisions 0A-South+1CD) and a shallower (Divisions 1A to F) RV surveys, as well as an additional proposed survey that will start in 2022 that is assumed will encounter small fish in inshore waters of Division 0B. For comparison, a non-adaptive index-based method was also tested, where decision rule parameters were based on the initial SISCAL model for the entire simulation. The adaptive procedure performed well, keeping biomass above the limit reference point of B_{lim} = 0.3BMSY in all simulations, and avoiding the limit fishing mortality rate (F_{lim}) with high probability. In contrast, the non-adaptive procedure ended up slightly overfishing the NAFO-GH stock, with biomass continuing to decline past the end of the simulation. Moreover, the non-adaptive procedure had an approximately neutral probability of exceeding F_{lim}.

Conclusion

DFO received modelling results and reports in March 2022. The models and reports will be peer reviewed during a CSAS meeting in late fall 2022. The first surveys with a new research vessel, *R/V Tarajoq*, will be completed in fall 2022. Following completion of the CSAS meeting and resulting advice regarding the suitability and potential of the various analytical methods discussed, recommended assessment methods will be run including the 2022 survey data. The outcomes of the 2022 CSAS meeting and results of the subsequent analyses will be presented to the NAFO Scientific Council in June 2023 for further review and discussion to determine their potential for Subarea 0+1 (offshore) Greenland halibut assessment and provision of TAC advice. This overview of DFO's efforts to identify alternative assessment methods for the Subarea 0+1 (offshore) Greenland halibut stock is presented as an information document in preparation for detailed presentations and discussions in June 2023.

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