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Summary of factors that affect survey and fishing catchability and data available regarding the NAFO Subarea 0+1 (offshore) Greenland Halibut (*Reinhardtius hippoglossoides*) stock and fishery

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Fishery-independent stock assessment surveys rely on consistent sampling methods, equipment and strategies to minimize variability in the data that could mask or confound trends in the assessed stock. Surveys typically use the same vessel and fishing gear each year as changes in either can affect the catchability of species during the survey, and therefore, the representativeness of the survey data. An unrecognized decline or increase in catchability could be interpreted as a decline or increase, respectively, in stock status. These observations could then lead to ill-informed advice to reduce or increase the level of harvest, respectively, producing hidden economic or conservation consequences. Factors that affect catchability, particularly during trawling surveys, are summarized here to help inform data considerations when there are changes in the vessel or gear used to conduct surveys.

Data pertaining to the Greenland Halibut (*Reinhardtius hippoglossoides*) stock in the Northwest Atlantic Fisheries Organization (NAFO) Subareas 0+1 (offshore) (GH-0+1) are collected during several fishery-independent surveys, as well as through commercial logbooks and at-sea observer records. Fisheries and Oceans Canada (DFO) and the Greenland Institute of Natural Resources (GINR) use data from groundfish-focused surveys conducted in Divisions 0A-South and 1CD and a shrimp and fish focused survey in Divisions 1A to F to assess the status of the GH-0+1 stock. However, additional data are available from the Canadian Northern Shrimp Research Foundation survey and a few less frequent surveys conducted by DFO and the Greenland Institute of Natural Resources (GINR) in Divisions 0A-North, 0B and 1AB. This document summarizes the methods used for each survey, the types of data collected and the years and areas where surveys occurred, to provide an overview of data available for assessment and modelling of the GH-0+1 stock.

INTRODUCTION

Fisheries and Oceans Canada (DFO) and the Greenland Institute of Natural Resources (GINR) jointly assess the status of Greenland Halibut (*Reinhardtius hippoglossoides*) in Northwest Atlantic Fisheries Organization (NAFO) Subareas (SA) 0+1 (offshore) (GH-0+1) (Figure 1). DFO and GINR conduct surveys using the same vessel and fishing gear and combine the data to conduct a single assessment for the shared stock. The assessment results are presented to the NAFO Scientific Council, which then provides advice to resource managers in Canada and Greenland regarding sustainable harvest levels.

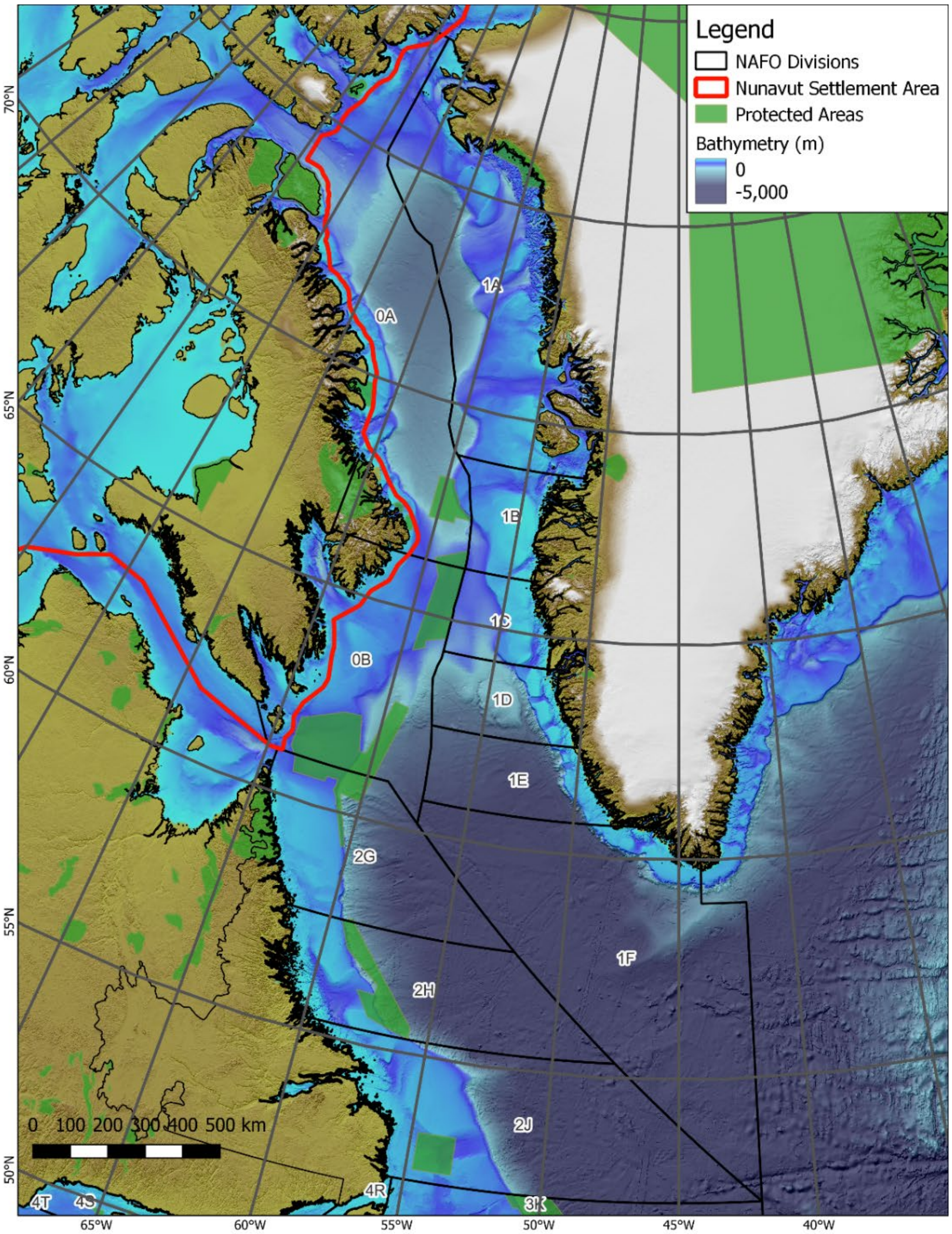

Figure 1. Map of NAFO Subareas 0+1 showing Divisions 0A-B and 1A-F. Red line indicates the boundary of the Nunavut Settlement Area. Established Protected Areas are shown as green polygons.

From 1999 to 2017 the R.V. *Paamiut*, owned by GINR, was used to conduct the surveys in Canada and Greenland. The R.V. *Paamiut* was reaching the end of its operational life and in 2017 GINR developed a plan to retire the vessel after the 2018 survey and construct a new research vessel for use in 2021 and beyond. However, in winter 2018 an audit of the vessel identified significant repairs that were required to keep the vessel operating in 2018. GINR determined the costs were prohibitive for a single additional year of surveying and retired the R.V. *Paamiut* earlier than planned, preventing an opportunity to conduct standardization experiments between the old and new survey vessels. Standardization between vessels typically involves paired trawling experiments throughout the range of fishing depths and habitats that are encountered during surveys. The resulting data are then used to calculate conversion factors that are applied to historic data to scale and align them with the time series from the newer vessel.

Facing a potential 3-year gap in the survey time series, GINR contracted the F.V. *Sjurdarberg* to conduct the 1A-F survey in 2018, and the F.V. *Helga Maria* to conduct all the surveys in 2019 and 2020. The Alfredo III bottom trawl and Cosmos 2000 shrimp trawl, the trawl doors, bridles and rigging, and Marport sensors used on doors and headlines, were transferred from the *R.V. Paamiut* to the *F.V. Helga Maria* to minimize differences in fishing conditions between the two vessels. Despite these efforts, gear performance was still found to differ between the R.V. *Paamiut* and F.V. *Helga Maria* for the Alfredo III bottom trawl (at fishing depths below 700 m) and the data from the 2019 survey could not be used to assess Greenland Halibut stock status (Nogueira and Treble 2020). Consequently, the survey planned for 2020 was not undertaken. Gear performance was acceptable for the Cosmos 2000 shrimp trawl used by the *Sjurdarberg* (2018) and *Helga Maria* (2019 and 2020) in the GINR 1A-F survey (where the maximum survey depth is 600 m), allowing data for shrimp and fish abundances (e.g., small Greenland Halibut) from these vessel-gear combinations to be used comparably to previous surveys (Nogueira and Treble 2020). In 2021, construction was completed on GINR’s new vessel, R.V. *Tarajoq*, but the vessel did not complete sea trials until November, therefore missing the planned 2021 surveys. Following the R.V. *Tarajoq* christening in May 2022 in Nuuk, GINR and DFO conducted surveys in October and November 2022, respectively, starting a new time series with the R.V. *Tarajoq* and Bacalao 476 bottom trawl.

During 2021–22, DFO explored analytical approaches for stock assessment and provision of advice for the GH-0+1 stock. This document summarizes factors that affect catchability during surveys (or fishing) to highlight issues that should be considered when using data collected by different vessels and fishing gears to develop a stock assessment framework; and provides an overview of data that are available to inform assessment of the GH-0+1 stock.

RESULTS

FACTORS AFFECTING CATCHABILITY

Catchability is a concept in fishery biology that reflects the efficiency of a particular fishery or vessel and gear to capture individual species (Arreguín-Sànchez 1996). To provide reliable assessments of stock abundance, catchability needs to be kept constant or at least reliably estimated. Factors that affect how well the fishing gear stays on the bottom (or at the target depth for pelagic gear), the morphology of the gear (fully open or erect vs. slack), and the ability of fish to avoid the gear (move out of the way of active gear or detect and move around passive gear) all have consequences for catchability. In the current context, these factors need to be considered when examining data from the R.V. *Paamiut* and the R.V. *Tarajoq*. Note that differences in catchability among vessels are sometimes assumed to be negligible for shallower surveys, such as for the DFO-Northern Shrimp Research Foundation (NSRF) survey that occurs in waters shallower than 700 m. In that case, this assumption has been further supported by the comparison of catchability among the R.V. *Paamiut*, the F.V. *Sjurdarberg*, and the F.V. *Helga Maria* (Nogueira and Treble 2020), which found that catchability only differed when fishing below 700 m.

Factors that can contribute to differences in catchability of Greenland Halibut and other fish and invertebrate species are summarized in Table 1.

Table 1. Factors that affect catchability during surveys and fishing.

Factor Category	Example Factors	Potential Impact
Vessel	Horsepower, size, age, noise, trawling speed, tow duration	Affects trawl avoidance behaviour, frequency of hang-ups, trawl damage
Vessel stern morphology	Width of stern	Affects ability to fish in ice and rough conditions
Trawl	Design, dimensions, material, mesh size (liners), colour, footgear	Affects trawl avoidance behaviour, minimum size retained, length frequency, frequency of hang-ups and damage
Trawl sensors	Presence or absence	Use of sensors can improve consistency in trawl morphology and bottom contact
Captain/crew	Crew size, vessel/gear experience, local knowledge	Consistency in bottom contact, trawl morphology, inconsistency in handling/gear repair
Environmental conditions	Sea and/or ice state, bottom type, currents, light, depth	Consistency in bottom contact, trawl morphology; facilitates trawl avoidance
Species	Size, morphology, distribution, behaviour (seasonality)	Trawl avoidance; species availability

GREENLAND HALIBUT DATA SOURCES

The following sections provide brief overviews of each source of catch data that is available for the SA 0+1 (offshore) stock (see Treble 2020, 2022, Nogueira and Estévez-Barcia 2020, and Nygaard and Nogueira 2021 for surveys that contribute to the GH-0+1 assessment; and, Treble and Nogueira 2022 for information on the Greenland Halibut fisheries). The spatial distribution of fishery-independent depth-stratified random surveys conducted from 1991 to 2020 is shown in Figure 2. The distribution of surveys across years by vessel and gear is described in Table 2 and Table 3. Length frequency distributions for each survey timeseries are presented in Figure 3. It should be noted that while Greenland Halibut data are available from several survey timeseries, the status of the GH-0+1 stock has been assessed by calculating indices from the 0A-South and 1CD surveys, with supporting information on small Greenland Halibut from the 1A-F Shrimp and Small Fish survey.

NAFO Subarea 0

Multispecies Surveys

Fishery-independent surveys conducted by DFO in SA 0 were summarized by Treble (2022). In brief, the R.V. Paamiut with Alfredo III trawl gear was used to conduct research surveys in SA 0 (1999–2017) followed by a charter vessel, the F.V. Helga Maria with the same Alfredo III trawl (2019) (Table 2 and Table 3). The surveys used a depth stratified random sampling design that was adjusted in 2008 to align with the 1CD depth strata (Treble 2020). Set allocation was set proportional to the strata at a target rate of 1 set/750 km^2. During 1999–2003, sets were selected by randomly drawing a number of grid cells within each depth strata. In 2004, a buffered random sampling method that automatically avoided selecting stations in adjacent cells was adopted (Kingsley et al. 2004). NAFO Div. 0A has been divided into 0A-North and 0A-South at approximately 72^o N. The surveys span 400–1500 m and covered different areas over time (i.e., 12 years in 0A-South (Treble 2020), 3 years in 0A-North (Treble 2013), and 7 years in 0B (Treble 2017). Surveys were not conducted in 2002, 2003, 2005, 2018, 2020 or 2021. In 2006, survey coverage of deep water strata was poor and this survey was not considered representative, therefore, it was dropped from the combined 0A-South and 1CD index used in the assessment. In 2022, surveys were conducted using the new research vessel, R.V. *Tarajoq*, and trawl gear, Bacalao 476, however, post-survey quality assurance/control procedures were not completed in time for those data to be include here.

Canadian Shrimp Surveys

The Northern Shrimp (*Pandalus borealis*) and Striped Shrimp (*P. montagui*) fishery in SA 0 and Hudson Strait is divided into several management units: 1) Shrimp Fishing Areas (SFA) 0 and 1 that correspond to Div. 0A; 2) the Eastern Assessment Zone (EAZ) that is comprised of previous management units referred to as SFA 2 (or 2EX) and Resolution Island Shrimp Area (RISA) that corresponds to Div. 0B; and 3) the Western Assessment Zone (WAZ) comprised of a portion of the previous SFA 3 that corresponds to Eastern Hudson Strait and Ungava Bay (DFO 2021). From 2006–2013, surveys by DFO using the R.V. *Paamiut* and Cosmos trawl alternated between Div. 0A (SFA 0 and 1) and 0B (EAZ), respectively, and in 2009 the survey extended into Western Hudson Strait.

The NSRF and DFO jointly conduct surveys in the EAZ and WAZ using commercial fishing vessels and a Campelen 1800 shrimp trawl. The NSRF coordinates the vessel and crew, and DFO plans the survey stations and sampling plan. From 2005 to 2013, the EAZ was surveyed annually using two fishing vessels (*Cape Ballard* from 2005 to 2011 and *Akviq* from 2012 to 2013). Starting in 2014, the WAZ was added to the NSRF survey and three commercial fishing vessels have been used to conduct the surveys (*Kinguk* in 2014, *Katsheshuk II* in 2015 and 2020, and *Akviq* from 2016 to 2019) (Table 2). All surveys use a depth stratified random design with an allocation of sets proportional to the strata. The NSRF survey used a standard Campelen trawl in 2006 and 2007. In 2008, a modified Campelen trawl was developed to reduce tear ups and improve survey coverage (Siferd and Legge 2014). Based on performance in flume tank trials, the impacts of the changes on catchability were considered minimal. No standardization experiments have been conducted between vessels, or between the trawl net configurations, but the data are treated as a single time series for the shrimp stock assessments. Generally, fish caught in the NSRF surveys are identified to species, but only total counts and weights are recorded for each set. However, Greenland Halibut were measured for length during surveys in 2006–2013 (Figure 3).

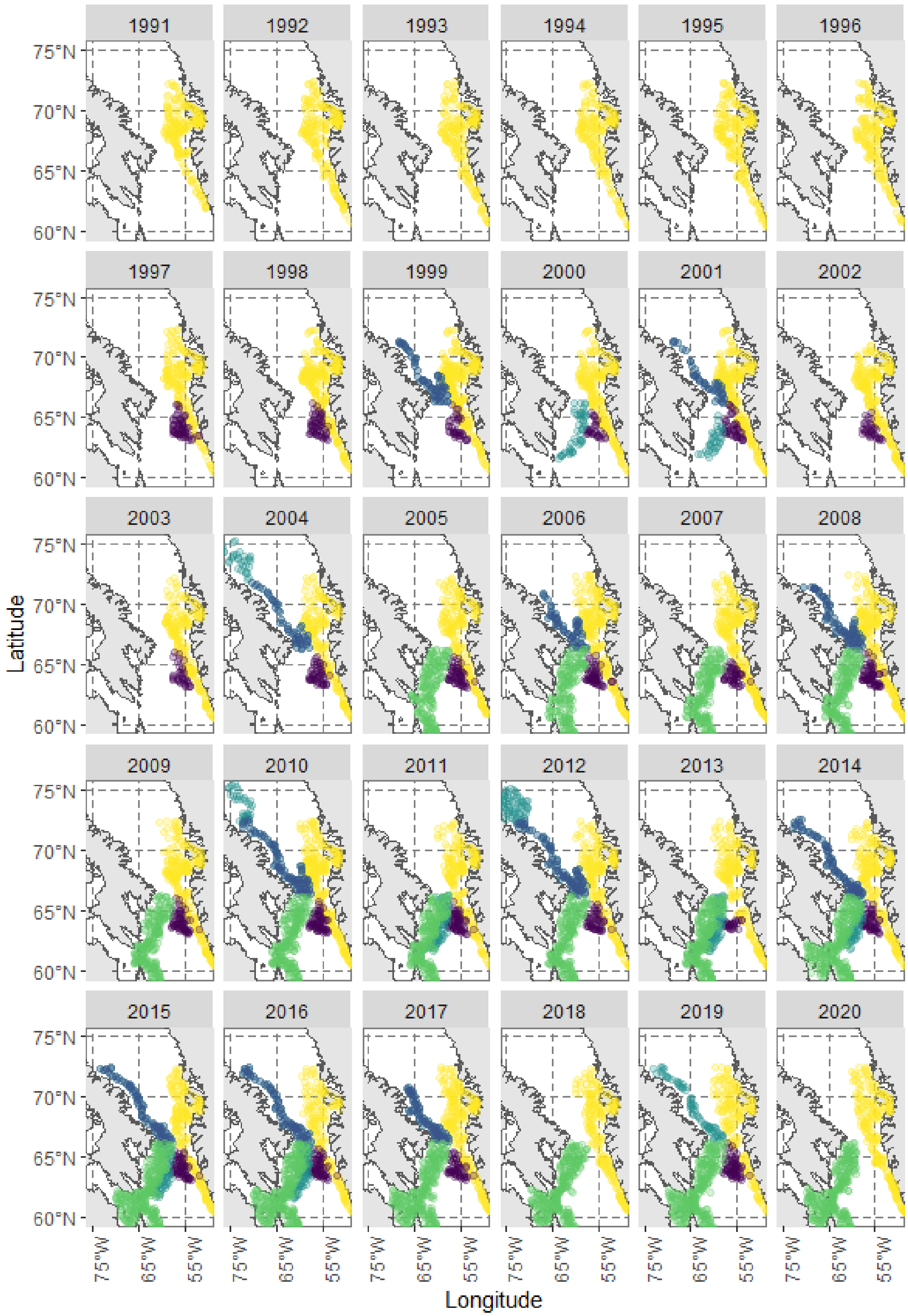

Figure 2. Survey coverage by year from 1991 to 2020, including DFO 0A-South (dark blue), 0A-North and 0B (light blue), NSRF-DFO shrimp (green; overlaps with the 0B survey), GINR 1C-D (purple) and 1A-F (yellow).

Table 2. Surveys completed each year: deep water (green) and coastal/shelf water (orange). Differences in shading indicate the different vessels were used for each survey. Letter codes indicate vessel and gear used: PAA – Paamiut with Alfredo III trawl; HMA – Helga Maria with Alfredo III trawl; PAC – Paamiut with Cosmos trawl; SUC – Sjurdarberg with Cosmos trawl; HMC – Helga Maria with Cosmos trawl; CB - Cape Ballard with Campelen trawl; CBm - Cape Ballard with modified Campelen trawl; AQm – Aqviq with modified Campelen trawl; KIm – Kinguk with modified Campelen trawl; KAm - Katsheshuk II with modified Campelen trawl.

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
DFO-0A-North	-	-	-	-	-	PAA	-	-	-	-	-	PAA	-	PAA	-	-	-	-	-	-	-	-
DFO-0A-South	PAA	-	PAA	-	-	PAA	-	PAA	-	PAA	-	PAA	-	PAA	-	PAA	PAA	PAA	PAA	-	HMA	-
DFO-0B	-	PAA	PAA	-	-	-	-	-	-	-	-	-	PAA	-	PAA	PAA	PAA	PAA	-	-	-	-
GINR-1CD	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	PAA	-	HMA	-
GINR-1AF	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	PAC	SUC	HMC	HMC
DFO-0A-Shrimp	-	-	-	-	-	-	-	PAC	-	PAC	-	PAC	-	PAC	-	-	-	-	-	-	-	-
DFO-0B-Shrimp	-	-	-	-	-	-	-	-	PAC	-	PAC	-	PAC	-	PAC	-	-	-	-	-	-	-
NSRF	-	-	-	-	-	-	CB	CB	CB	CBm	CBm	CBm	CBm	AQm	AQm	KIm	KAm	AQm	AQm	AQm	AQm	KAm

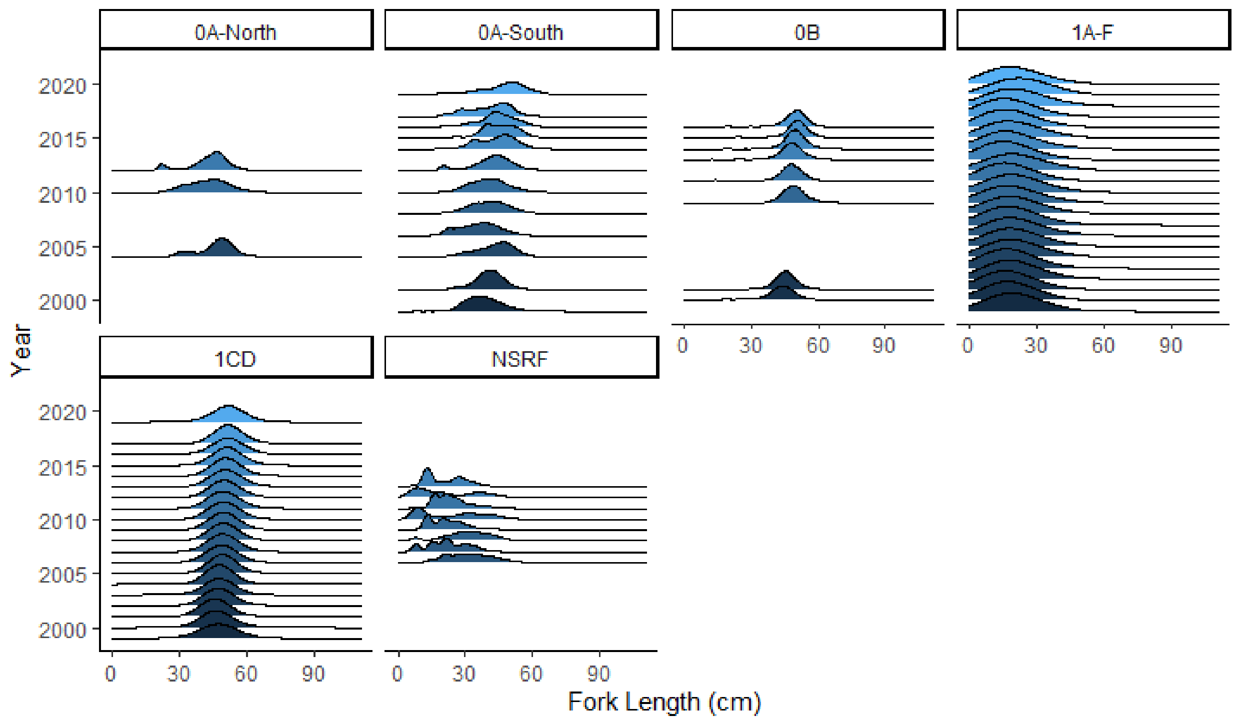

Figure 3. Greenland Halibut length-frequency distributions by survey. The 0A-North, 0A-South, 0B and 1CD surveys were conducted using an Alfredo III trawl that targeted groundfish. These surveys had length-frequency distributions centered roughly between 30 and 60 cm fork length. The 1A-F and NSRF surveys used Cosmos and Campelen trawls that target shrimp and small fishes. These surveys had length-frequencies generally centered below 30 cm fork length.

NAFO Subarea 1

Multispecies Surveys

The GINR used the R.V. *Paamiut* to conduct depth stratified random surveys of Divs. 1C-D from 1997 to 2017 (Nogueira and Estévez-Barcia 2020), 1A-B in 2001 (Jørgensen 2002), and 1A in

2004 (Jørgensen 2005). A total of 70 hauls are assigned in the Div. 1C-D survey with a minimum of two per stratum and the remaining hauls allocated based on the stratum area and on predictions, from past surveys, of the variability in Greenland Halibut catch in order to optimize set coverage and estimation of Greenland Halibut abundance and biomass (Nogueira and Estévez-Barcia 2020). The surveys use a buffered random sampling method that automatically avoids selection of stations in adjacent cells (Kingsley et al. 2004). Japan and GINR collaborated on a survey of Divs. 1B-D from 1987–1995 (also 1A in some years) using the research vessel, *Shinkai Maru*, but calibration experiments with the R.V. *Paamiut* were not performed. There was also a short survey time series conducted by Russia and the Federal Republic of Germany from 1987 to 1992 (Treble and Nogueira 2020). Divs. 1C-D were not surveyed in 2018 because of the retirement of the R.V. *Paamiut*. In 2019, the F.V. *Helga Maria* was chartered to conduct the survey. The R.V. *Tarajoq* was used to conduct the survey in 2022, but data were not available when the current summary was compiled.

GINR Shrimp and Small Fish Survey

GINR has conducted an annual survey in SA 1, including Disko Bay, since 1988, from the 3-nm line along the coast of Greenland to the 600 m contour (minimum depth was initially 150 m but expanded to include waters as shallow as 50 m since 2004; Nygaard and Nogueira 2021). Several vessels were used from 1988 to 1990, therefore, these years are not included in the current time series that begins with the R.V. *Paamiut* in 1991. Initially, the Skjervoy 3000/20 trawl was used and when it was replaced by the Cosmos 2000 trawl comparative tow experiments were conducted (Rosing and Wieland 2005). While some problems in the design/analyses of the trawl calibration experiment were noted, the results have been implemented and the 1A-F surveys from 1988–2004 have been converted to Cosmos 2000 equivalent values (Treble and Nogueira 2020, Nygaard and Nogueira 2021). During 1991–1999, a proportional allocation strategy was used to divide the survey stations among strata. To improve the precision of overall biomass estimates, a dynamic allocation scheme was adopted starting in 2000, with station allocations being higher in strata that showed higher shrimp biomass variance in preceding years (with more recent years having greater influence). This process was subsequently expanded to incorporate catch data for Atlantic Cod (*Gadus morhua*) and Greenland Halibut in addition to shrimp, to strive to minimize the weighted combination of the survey precision for all three species. Survey stations are designated using a buffered random sampling scheme. Starting in 1999, 50% of the survey stations were fixed based on the previous year and the remaining stations were determined using the buffered random scheme.

Table 3. Surveys conducted in the offshore waters of NAFO Subareas 0+1 (SFA = Shrimp Fishing Area; WAZ = Western Assessment Zone, EAZ = Eastern Assessment Zone).

Name	Area	Vessel(s)	Trawl Gear	Depth range	Period
DFO Multispecies	Division 0A (split into north and south portions at 72° N)	*Paamiut*	Alfredo III	400–1500 m	2 weeks between late September and mid-November
		Helga Maria			2 weeks in August 2019
	Division 0B	*Paamiut*	Alfredo III	400–1500 m	2 weeks between late September and mid-November
DFO Shrimp	Division 0A-B (i.e. SFA 0, 1, and 2 (or EAZ))	*Paamiut*	Cosmos 2000	100–750 m	2 weeks between late September and mid-November
NSRF/DFO Shrimp	Division 0B (i.e. SFA 2 and 3, or EAZ and WAZ)	*Cape Ballard, Aqviq, Kinguk, Katsheshuk II*	Campelen 1800	100–750 m	4 weeks in August
GINR Multispecies	Divisions 1C-D	*Paamiut, Helga Maria*	Alfredo III	400–1500 m	2 weeks between August and September
GINR Shrimp and small fish	Divisions 1A-F	*Paamiut, Sunderberg, Helga Maria*	Cosmos 2000	50–600 m	4 weeks between July and August

Age Data

Greenland Halibut caught in surveys are sampled for length, sex, maturity and otoliths are collected for age estimation. At-sea observers also collect length, sex and otoliths from fish caught in the commercial fisheries. Greenland Halibut are difficult to age and researchers have been working for many years to develop and validate age estimation methods for this species (Gregg et al. 2006, Treble et al. 2008, Albert et al. 2009, Albert 2016, Dwyer et al. 2016, Brogan et al. 2021). At the last international meeting in 2016, two methods were considered acceptable for use in assessments (i.e., right frozen whole and left whole to age 10 and/or left section), but given the low precision (coefficient of variation greater than 5%), it was recommended that an ageing error matrix or growth curve be used to account for the uncertainty in age estimation (ICES 2017). The growth curve developed for this analysis was based on sub-samples of 365 and 326 otoliths collected during the 2014 and 2017 surveys, respectively. These sub-samples were comprised of a selection of otoliths across sex and size class (3/sex/1 cm group/survey). Additional age estimates from the 2019 commercial fishery are also available (n = 903), 249 from the gillnet fleet and 654 from the trawl fleet.

Fishery-Dependent Data

Fishery-dependent data are available from logbooks and the Canadian at-sea observer (ASO) program. All commercial fishing is required to be recorded in official logbooks maintained by a ship's captain, while ASO data are only available from a subset of fishing sets depending on the ASO coverage required for the fishery (i.e., percentage of trips that are required to have an ASO on board) and if fishing sets are hauled in while the ASO is off-shift. Target coverage levels are 100% for both the trawl and gillnet fisheries in Div. 0A and the trawl fishery in Div. 0B, and 20% for the gillnet fishery in Div. 0B. ASO data are collected by third-party companies that are contracted by fishing companies and vessels. The ASOs provide their data directly to DFO. ASO and logbook data are available prior to the start of fishery-independent surveys in 1999. The fishery began in the late 1960s in the southern portion of the stock, but catches disaggregated by division aren't available until 1987. Some ASO data is available from as early as 1980 but it is not until the mid-late 1990s when data becomes increasingly available for this fishery. There was an expansion northwards into Divisions 0A and 1A-B in the early 2000s. The fishery is dominated by trawl in SA 1 and a mix of trawl and gillnet in SA 0. Bottom set longlines are used occasionally and represents a small fraction of the fishing effort and catch. Two standardized (general linear model based) catch-per-unit effort (CPUE) indices are calculated from the commercial data and presented as accessory information during assessments of the GH-0+1 stock (Treble and Nogueira 2020); one for the trawl fleets in SA 0+1, and one for the SA 0 gillnet fleet. These fishery-dependent indices are not used as primary indicators of stock status because of concerns regarding hyperstability of the indices (i.e., because fishers are good at maximizing their catch rate, resulting CPUE indices are not responsive to all changes in stock abundance or biomass and can remain high despite declines in the overall stock status, until status has changed significantly).

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