



Fisheries and Oceans
Canada

Pêches et Océans
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Ecosystems and
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Sciences des écosystèmes
et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2026/032

Maritimes Region

Assessment Framework Review for Atlantic Cod in NAFO Division 5Z: Part 1 - Review of Data Inputs

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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.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

[http://www.dfo-mpo.gc.ca/csas-sccs/
DFO.CSAS-SCAS.MPO@dfo-mpo.gc.ca](http://www.dfo-mpo.gc.ca/csas-sccs/DFO.CSAS-SCAS.MPO@dfo-mpo.gc.ca)



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ISSN 1919-5044

ISBN 978-0-660-99232-7 Cat. No. Fs70-5/2026-032E-PDF

Correct citation for this publication:

Andrushchenko, I., Clark, C.M., Brunsdon, E., Way-Nee, E., and Benoît, H.P. 2026.
Assessment Framework Review for Atlantic Cod in NAFO Division 5Z: Part 1 - Review of
Data Inputs. DFO Can. Sci. Advis. Sec. Res. Doc. 2026/032. iv + 104 p.

Aussi disponible en français :

*Andrushchenko, I., Clark, C.M., Brunsdon, E., Way-Nee, E., et Benoît, H.P. 2026. Examen du
cadre d'évaluation de la morue franche dans la division 5Z de l'OPANO : Partie 1 - Examen
des données d'entrée. Secr. can. des avis sci. du MPO. Doc. de rech. 2026/032. iv + 112 p.*

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ABSTRACT

In 2023, Fisheries and Oceans Canada (DFO) Science initiated the development of a new framework for transboundary 5Z Atlantic Cod (*Gadus morhua*), prompted by the absence of a functioning population model and associated precautionary approach-compliant reference points for the stock since 2018. This document comprises the first step in the framework development, reviewing all available data sources as they pertain to transboundary Cod, and forms the basis for the subsequent population work. The datasets considered encompass the larger total Georges Bank assessment unit, currently used in domestic assessments in the United States of America, and the smaller eastern Georges Bank assessment unit, currently used by the Transboundary Resource Assessment Committee (TRAC) to provide stock assessment advice to the Transboundary Management Guidance Committee (TMGC) to support the management of transboundary stocks.

INTRODUCTION

Eastern Georges Bank (DFO statistical unit area 5Zjm) is bisected by an international maritime boundary between the United States of America (herein referred to as US) and Canada, with active fisheries on each side. Following the 1977 declaration of exclusive economic zones (EEZs) by coastal states, both countries claimed a zone on eastern Georges Bank. Despite negotiating the East Coast Fisheries Bilateral Agreement in 1979, the fishing interests and governments remained dissatisfied, and the agreement was never ratified. The two parties brought their dispute to the International Court of Justice, whose decision established the Hague Line in October 1984 (ICJ 1984).

Eastern Georges Bank (EGB) Atlantic Cod (*Gadus morhua*) is a transboundary resource that Canada and the US agreed to collaboratively assess through the Transboundary Resource Assessment Committee (TRAC) in 1998 and began co-managing through the Transboundary Management Guidance Committee (TMGC) in 2002. Development of modeling frameworks to accurately represent the population dynamics of the transboundary Cod stock has been attempted through three TRAC benchmark review processes (analogous to a Canadian assessment framework review) for the EGB unit (DFO statistical units 5Zjm; 2002, 2009 and 2013). The models developed in the last joint Cod benchmark (2013) were formally rejected at TRAC in 2018, following several years of poor model performance and increasingly problematic model diagnostics (Ford and Sosebee 2018). In subsequent years, the TRAC has provided catch advice based on a simple management procedure selected through simulation testing using the DLMtool platform (Carruthers and Hordyk, 2018). This approach has always been considered a short-term, interim solution by both the TRAC and the TMGC, until a new transboundary benchmark can be held (TRAC 2021, TMGC 2021). However, US fisheries science human resources have not been dedicated to the joint development of a new EGB Cod benchmark, therefore, TRAC advice for this stock has continued to be provided using the DLMtool. Outside of the TRAC process, the US conducted a Cod research track (Cod RT) process to develop modeling frameworks for the larger Georges Bank Unit (DFO statistical units 5Zjmghno) and four domestic US cod stocks within the rest of Northwest Atlantic Fisheries Organization (NAFO) Division 5Z+6. Canada did not participate as an active partner in the US process.

Although EGB Cod is a transboundary stock, there are requirements under Fisheries and Oceans Canada's (DFO) fishery decision making framework incorporating the precautionary approach (PA framework; DFO 2009) for the domestic management of the Canadian fishery. One component of the PA framework is to define reference points, which has not been possible since the rejection of the EGB cod modeling framework in 2018. Consequently, DFO Science initiated a framework review process to develop a new modeling framework and the associated reference points to provide advice on the status of the transboundary Cod stock. This document outlines the data inputs to be considered in the review of the assessment framework. The review of population modelling approaches and PA-compliant reference points will be conducted in future peer review meetings and reported in separate documents as products of those meetings.

STOCK STRUCTURE

The assessment unit for a biological stock ideally encompasses a self-sustaining population of fish, with minimal movement in and out of the area (Secor 2014). A management unit, on the other hand, tends to balance the biological definition of a stock with practical considerations of monitoring and regulating the fishery in accordance with existing policies and regulations. The

extent to which management and assessment units can misalign before it becomes a conservation concern is case specific, but there is an overall tendency to ensure that these two overlap as much as possible.

A lot of work has gone into the investigation of the biological stock structure of Cod on Georges Bank over time, and management units have evolved accordingly. Following the establishment of EEZs in 1977, both the assessment and the management units for Atlantic Cod on Georges Bank were defined as NAFO Divisions 5Z and 6 (Serchuk et al. 1979). In 1987, a review of analyses looking at ichthyoplankton dispersal, survey and fishery distributions, morphological characteristics, tagging data, and genetic indices redefined both the assessment and the management unit for Canada as DFO unit areas 5Zjm (Bowen 1987), though the larger unit persisted as the basis for the assessment in the US. Starting in the late 1990s, the US and Canada began participating in the other country's assessment processes, initiating a multi-year process which resulted in the creation of the TRAC and subsequently the TMGC. In 2002, the US and Canada formally agreed to co-manage a joint transboundary management unit for Atlantic Cod limited to eastern Georges Bank Cod (5Zej, 5Zem; US unit areas 551, 552, 561, 562; DFO 2002), with a stand-alone assessment for this area. In addition, the US has continued carrying out domestic assessments of Cod on the whole of Georges Bank (NAFO Division 5Z +6; US unit areas 551, 552, 561, 562, 522, 525, 521, 526, 537, 538, 539).

The 2009 TRAC benchmark process reviewed publications that examined stock structure of transboundary Cod based on tagging, spawning, genetics, parasites, and growth, focusing on eastern Georges Bank (5Zjm) and adjacent areas (5Z -jm, NAFO Subarea 6, and NAFO Division 4X; O'Brien and Worcester 2009). The process outlined six possible combinations of coordinated assessment and management units and included the benefits and the limitations of each option (Appendix A). The spatial unit thought to best capture the understanding of Cod components on Georges Bank was a split of Georges Bank into portions east and west of the 68th meridian west. This option could not be pursued as the meridian bisects US unit areas 522 and 525; splitting the units was not feasible given the coarse nature of US commercial fisheries data, and the requirement that assessment and management units be defined at the resolution of whole statistical units (O'Brien and Worcester 2009). In the absence of an alternative that improved the accuracy of the biological stock structure in the assessment, status quo for both assessment and management units (5Zjm transboundary and 5Z+6 USA domestic) was chosen as the least disruptive option to existing scientific and management processes in both countries. However, it was acknowledged that these units ignore known exchanges of Cod with adjacent areas in 4X. In addition, the larger of the two management areas could result in a concentration of fishing effort on a sub-component within it, creating a conservation concern if there is limited exchange between the various sub-components within 5Z+6. The decision came with a recommendation that attempts should be made to harmonize the results of the two assessments, although no framework or platform for this harmonization was proposed.

In 2018, the Atlantic Cod Stock Structure Working Group (ACSSWG) was initiated by the National Oceanic and Atmospheric Administration (NOAA), with full participation by DFO. This group focused on Cod structure in US waters (NAFO Subareas 5 and 6) and also spoke to some interactions between those areas and 4X (McBride and Smedbol 2022). This group reviewed early life history, genetic markers, natural markers (otolith and tissue characteristics, meristics, morphometrics, colour, morphology, and parasites), tagging, and fisherman's ecological knowledge. It concluded that the US Georges Bank Management Unit should be reduced from 11 unit areas to six (551, 552, 561, 562, 522 and 525, Figure 1), with the removed areas attributed to various adjacent stocks (McBride and Smedbol 2022). In 2022, the ACSSWG's work fed directly into the US Cod research track, a domestic US process for developing an assessment framework for various stocks, which proposed a population model

congruent with the revised stock structure for Georges Bank Cod (NEFSC 2023). The reduction of the Georges Bank assessment unit helps abate conservation concerns regarding the potential concentration of fishing effort on a single sub-component within a large area, successfully addressing the shortcoming of the larger domestic US management unit identified during the 2009 TRAC Benchmark (O'Brien and Worcester 2009).

ACSSWG discussed evidence of a boundary between eastern and western Georges Bank around 68°W, identifying limited movement and genetic clustering on either side, as well as the fishermen's acknowledgement of it as a viable division (McBride and Smedbol 2022). Unfortunately, avoiding the uncertainty associated with splitting US statistical areas 522 and 525 outweighed the presented evidence for this division, and the statistical areas were kept intact.

Several processes that have been undertaken to clarify the structure of Atlantic Cod in the transboundary waters on Georges Bank support a vertical stock delineation line somewhere along the arm of the bank, likely close to the 68th meridian west line, with some movement of fish evident both into 4X and into the adjacent component to the west of that line. Unfortunately, the current commercial US fishery data structure and lack of delineation of stock sub-components in 4X do not permit a biologically accurate modeling of this sub-unit. The closest feasible alternative for an assessment unit is a combination of US unit areas that come closest to the 68th meridian west line, resulting in two possible spatial configurations:

1. US unit areas 551, 552, 561, and 562, spanning 5Zejm (Figure 1, Figure 2); henceforth referred to as eastern Georges Bank (EGB). This area is consistent with the eastern Georges Bank assessment and management units currently accepted by TRAC and TMGC (DFO 2002).
2. US unit areas 551, 552, 561, 562, 522, and 525, spanning 5Zejmhn (Figure 1, Figure 2); henceforth referred to as total Georges Bank (TGB). This area is consistent with the domestic Georges Bank assessment unit currently applied in the US (NEFSC 2023). The word total is used instead of 'whole' to avoid confusion with western Georges Bank.

Each of these spatial assessment units is slightly misaligned with the biological stock component. In addition, each has its own set of data limitations and implications for the management of a transboundary resource. This framework attempts to identify the best candidate population model given the inherent spatial misrepresentation and data limitations of both units, while providing DFO's Resource Management with an understanding of the biological risk associated with selecting either one for management purposes.

DFO's Resource Management requires advice for the EGB management unit only (5Zjm). As such, any assessment unit that uses the TGB will require a subsequent step to provide advice specific to EGB. Finally, the approach taken here continues to ignore movement between EGB and 4X, and movement between Georges Bank and adjacent stock areas in US waters. As such, a truly accurate representation of the population dynamics of Atlantic Cod in this area may not be possible in the absence of a coordinated multi-stock model that accounts for mixing between adjacent units.

FISHERY

CANADIAN FISHERIES

In Canadian waters, Cod on EGB is fished primarily by the multispecies groundfish fishery. Other fisheries in the area employing bottom gear include the scallop and lobster fisheries, though management measures exist to ensure limited interaction of these gears with finfish species.

Groundfish Fishery

Cod on EGB are captured as part of a commercial multi-species groundfish fishery. Although the assessment framework being developed is specifically EGB, the fishery description work focuses on various aspects of the multi-species groundfish fishery in NAFO Divisions 4VWX and NAFO Subarea 5 (Figure 3), as deemed relevant to understanding the dynamics of the cod fishery on EGB.

The Canadian management unit for transboundary Cod is limited to 5Zjm, but the commercial groundfish fishery in the Maritimes Region spans Georges Bank, Bay of Fundy, and the Scotian Shelf (NAFO Divisions 4VWX5, Figure 3). Vessels fishing on Georges Bank can also fish in the other areas, even on the same trip, as long as regulations and licence conditions about gear restrictions, temporal closures, and reporting requirements are followed. Specifically for Cod, the quotas are set separately for 5Zjm and 4X5Y, with 4VW under a fishing moratorium for Cod since 1996. As a multi-species fishery, the groundfish commercial fleets are currently permitted to target Haddock (*Melanogrammus aeglefinus*), Pollock (*Pollachius virens*), Cod, redfish (*Sebastes mentella* and *S. marinus*), Silver Hake (*Merluccius bilinearis*), and Halibut (*Hippoglossus hippoglossus*), subject to various gear, time and spatial restrictions. In addition, discarding is not permitted for any groundfish species, whether target or bycatch, except for a few species with a protected designation (DFO 2018), i.e., Northern and Spotted Wolffish (*Anarhichas denticulatus*, *A. minor*) and those for which license conditions permit release, i.e., skates (*Amblyraja radiata*, *Leucoraja ocellata*, *L. erinacea*, *Dipterus laevis*), Longhorn Sculpin (*Myoxocephalus octodecimspinosus*), Spiny Dogfish (*Squalus acanthias*), and Atlantic Wolffish (*Anarhichas lupus*). Finally, both the assessment and management units for the assessed groundfish species vary in scale across this broad area, from relatively small (i.e., 5Zjm for Cod) to those spanning the eastern coast of Canada (i.e., 3NOPs4VWX5Zc for Halibut). As such, the behaviour and logistics of the Canadian groundfish fishery in 5Z are dictated by a temporal-spatial mosaic of species distributions, catch composition, license conditions, available quota for various species, market prices, and management measures currently in place across 4VWX5.

Catch Monitoring Data Streams

Monitoring of Canadian commercial catch in the Maritimes Region is achieved through the coordinated use of three data streams: logbooks/dockside monitoring, port sampling and at-sea observer programs. Accurate and timely submission of logbooks is a condition of the groundfish licence, with set-specific information recorded by the fishermen and supplemented by accurate weights of landed catch verified by the dockside monitoring companies (DMC) during offload. For all groundfish fleets, DMC must be present at offload, meaning that 100% of the groundfish landings are monitored. Required monitoring rates for the fixed gear fleet <50 feet vary depending on the NAFO Division, species caught, and landed catch weights.

In addition to dockside monitoring, there is a port sampling program directed by DFO Science to collect detailed information on the landed groundfish catch, sampling for length frequency, otoliths, length-weight, and maturity of various species. The ports where 5Z Cod are currently landed have become more centralized over time for both mobile (Figure 4) and fixed (Figure 5) gear, with the majority of landings concentrated in three ports in southern Nova Scotia. The port samplers in the Maritimes Region, one full-time and one seasonal port sampler, collect samples from 8–10% of groundfish trips landing Cod from 5Z.

Finally, there is an at-sea observer program that deploys observers on commercial vessels, collecting set-specific information for both retained and discarded catch. The observers conduct set-specific detailed sampling including length frequency, otoliths, and maturity information; individual fish weights are collected but not used in assessments due to the low accuracy of

spring scales used at sea. Unlike the port sampling program, where approximately 250 fish are sampled from the total catch in a fishing trip, the observers sample the catch from each set on a trip. There is generally good correspondence between length frequencies from port samplers and observers on the same trip for 5Z Cod (Figure 6). The observer coverage, or the percentage of trips to which an observer is assigned, varies by fleet, time, fishery, and month, with target coverage ranging from 25% to 100% for EGB groundfish in recent years.

These programs are independent of each other, with the DMC and observer company roles filled by certified third parties, while port sampling is carried out by DFO technicians. Data from all streams are incorporated into various Oracle databases, which allows DFO stock assessment scientists direct access to the raw data being collected. Although collected and processed separately, several unique record identifiers allow linking of data streams. The ability to cross-reference the streams of data at a fine resolution (i.e., set or trip) allows for extensive use of data beyond the traditional characterization of the catch.

Databases

Logbook Database

The commercial logbook database is the longest-running data series of the three, with digitized information starting in 1967. The early part of this time period includes the transition from monthly port reports of landings to trip-specific reports of landings, which coincides with regulatory requirements implemented with the extension of fisheries jurisdiction in 1977 (DFO 2018). A comparison of the domestic data to catch statistics from NAFO yields a high level of agreement for Cod landings across all years, implying that both datasets have equivalent levels of accuracy throughout this time (Figure 7). The scale of removals throughout the early time period is also consistent with publications describing the Georges Bank fishery (Kirby 1982, Serchuk and Wigley 1992), although various reports outline incentives for underreporting of catch during that time (Collins et al. 1984, DFO 1989, Serchuk and Wigley 1992). The chance of underreporting during the early years, coupled with the unexplained decrease and subsequent increase in landings of Cod from 5Z throughout the late 1970s indicate higher level of uncertainty around the total removals of 5Z Cod prior to 1978. An increase in the accuracy of total removals after 1977 is also consistent with the expansion of the EEZ and implementation of controls in subsequent years. Accuracy in total reported landings continued to increase throughout the 1980s as trust in the scientific use of these data grew (DFO 1989), but this increase is thought to be gradual and relatively minor compared to the change in the late 1970s.

Currently, the commercial log database contains set-specific information for every groundfish trip, including information about the location of the set (i.e., NAFO or DFO statistical areas, latitude, and longitude), gear details (e.g., type of gear, hook size, mesh size, etc.), effort specifics (e.g., number of hooks, hours fished, etc.), catch information (i.e., species name, landed form, weight), and fate of the catch (e.g., landed, discarded, bait, etc.). This dataset is used to provide the total commercial fishery removals for the Canadian catch and is a key input in generating the commercial catch-at-age (CAA), length-at-age (LAA), and weight-at-age (WAA) inputs for the population model.

Port Sampling Database

The port sampling database contains information collected by port samplers during offload of the catch from the vessel. The first data records are from 1948, though systematic sampling and collection of data for 5Z Cod started in 1978. Given the relatively small spatial area encompassed by the Canadian portion of the EGB fishery (Figure 3) and the high sample size (Table 1), there are no concerns about spatial representativeness of port samples before 1980, as is the case for adjacent Canadian Cod stocks (Andrushchenko et al. 2022).

The standard collection protocols include length frequencies and otoliths associated with a unique fish identifier, with additional biological parameters collected through special requests. Although started as a stand-alone database, since the 2010s, the collected information is associated with a unique trip identifier, permitting the linkage of port sampling information to both commercial logbooks and observer databases; linkage of older data can be achieved through loose matching of vessel registration numbers (VRNs) and dates landed. The port sampling data are only available on a trip level, as sampling of set-specific catch is not possible during offload at port. The port sample data are used in characterizing the Canadian commercial CAA by providing the length frequencies for each month, gear and year, and samples to determine age as a function of length. These data are also the source of the seasonal length-weight relationships applied to the commercial length frequencies during the process of generating the Canadian commercial CAA, LAA, and WAA.

Observer Database

The observer database contains all of the data collected by the observer program in the Maritimes Region during commercial fishing, as well as during various industry surveys and collaborative initiatives. The observer data set begins in 1978 and contains detailed data describing the observed fishing activity (e.g., location, time, gear configuration for start of set, end of set, start of haul, end of haul of each set), along with various biological metrics collected from the catch (e.g., species, sampled weight, length, weight, otolith, maturity, etc.). This information is collected at the set level, with unique set identifiers making it possible to get a very detailed understanding of the fishing activity at the set level. Observer coverage in the groundfish fishery on EGB varies by fleet but attains some of the highest levels in the region.

There are no known overarching concerns about the quality of the observer dataset for Cod in 5Z. Adjacent Canadian stocks have noted the presence of an 'observer effect' on commercial data, a situation where the presence of an observer aboard a vessel causes a change in fishing behaviour (Benoit and Allard 2009, Clark et al. 2015). However, the high observer coverage of the EGB fishery helps avoid this in 5Z. Given the high observer coverage, the observer length frequencies make up the bulk of the length frequency information used in characterizing the catch and producing the CAA, LAA, and WAA for 5Z Cod. Observer information is also used in estimating the dead discards from the mobile gear fleets on Georges Bank.

Fishery structure

The commercial groundfish fishery is parceled out into fleets based on the gear used and the size of the fishing vessel. In recent years, the major gear types have been limited to bottom trawl (OTB), longline (LL), and gillnet (GN), but mid-water trawl (OTM), handline (HL) and Scottish/Danish seines (SEINE) were used in the past (Figure 8). Currently, fleets are defined based on grouped gear types, with the fixed gear fleet consisting of gillnet, handline, and longline, and the mobile gear fleet consisting of trawl and seine gear. Fleets are further classified based on vessel length with additional details of fleet classification provided in the Integrated Fisheries Management Plan (DFO 2018). In general, groundfish catches in NAFO Division 5Z are dominated by bottom trawl gear, particularly in recent years (Figure 8). The contribution of fixed gear to the catch was substantial in the mid-1990s, but has decreased to approximately 5% in recent years (Figure 8).

In terms of vessel size, the fishery data show a transition from primarily large vessels (tonnage classes 4 and 5, Table 2) up to the mid-1980s, to mostly smaller vessels in recent years (tonnage classes 1, 2 and 3, Table 2, Figure 9). Parceling out the vessels by gear shows that the fixed gear fleet on Georges Bank is currently made up entirely of small vessels (tonnage Class 1; Figure 9). Mobile gear, on the other hand, consists primarily of tonnage Class 3 vessels, with a few smaller (tonnage classes 1 and 2) and one larger (tonnage Class 7) vessel

in recent years (Figure 9). Historical transitions in groundfish vessel sizes on Georges Bank have been gradual, primarily driven by a progressive attrition of vessels starting in the mid-1990s.

In terms of directed species, the Georges Bank groundfish fishery was primarily a Cod fishery until the 1990s, with Cod accounting for 50–75% of the groundfish landings for fixed gear and 25–50% of the mobile gear landings at the time (Figure 10). The remainder of the catch consisted of Cusk (*Brosme brosme*), Haddock, and White Hake (*Urophycis tenuis*) for fixed gear, and Cusk and Pollock for mobile gear (Figure 10). Following the collapse of the Cod fishery and associated quota reductions in the early 1990s, both gear types focused on targeting Haddock. After a quota reduction in 2010/2011, most of the fixed gear fleet shifted to adjacent NAFO Divisions and other fisheries, citing low Haddock total allowable catch (TAC) and a decreased catchability of Haddock even when quotas increased in subsequent years (pers. comms. Scotia Fundy Groundfish Advisory Committee [SFGAC]). An interfleet trade that began in 2019, where fixed gear fleets trade Haddock quota for Halibut quota, has also resulted in a decrease in Haddock catches and an increase in Halibut catches by those fleets. The disappearance of the fixed gear Haddock fishery on Georges Bank increased the importance of Cod to the remaining fixed gear fishermen on Georges Bank, with Cod comprising 50% of the fixed gear catch in recent years (Figure 10). Mobile gear fishing on Georges Bank continues to predominantly target Haddock (Figure 11), with contributions of Cod remaining minimal (<5%) since the 1990s (Figure 10). While directing for Cod remains permitted in 5Z, the fishing industry voluntarily targets other species as much as possible (pers. comms. members of SFGAC meeting, Dartmouth 2022), treating Cod as a bycatch and leaving on average 15% of Canadian TAC in the water since 2010 (TRAC 2023).

Seasonality

The distribution of landings throughout the year varies by fleet and area. On Georges Bank, the fishery is only active from June to the first week of February to protect spring spawning activity, with a May test fishery permitted for mobile gear since 2018 (Figure 12). The mobile gear fleets are active throughout the fishing season, with the winter fishery constituting an increasingly large proportion of the overall catch in recent years (Figure 12). The fixed gear fishery on Georges Bank is currently only active between June and November, with Cod comprising the majority of the catch in recent years. The fixed gear Cod landings are largest between July and October, while landings in June consist primarily of Pollock and Halibut (Figure 13).

Discard Estimation

Estimation of Cod discards from the groundfish fishery follows the method outlined in Gavaris et al. (2007b), which compares the ratio of Cod to Haddock landings between trips that carried and did not carry an at-sea observer. This basic principle is applied within fleet and spatial zones, which were shown to have homogenous fishing outcomes (Gavaris et al. 2007b). If an unobserved trip with a given gear type and in a given zone has a significantly lower ratio of Cod to Haddock than an observed trip with the same gear type in the same zone, the unobserved trip is identified as having discarded Cod. Then, the observed ratio is applied to the unobserved trip to estimate the total amount of Cod the boat was expected to catch. The unobserved trip's reported trip-specific landings are removed from the total to yield an estimate of Cod discarded on the trip. The method for discard estimation has remained consistent over the years, as its base assumptions about the fishery remain valid. In recent years, issues related to confidentiality of the reported estimates have become increasingly problematic, but this relates to the reporting of the estimate and not the validity of the calculation. Groundfish discards are assumed to have the same length frequency as the rest of the groundfish catch and are characterized using the same length frequencies and age-length keys as the overall catch (see

Catch Characterization section, below). There is no indication of high grading for 5Z Cod and discard estimates are included in the total removals for the Canadian fishery.

Catch Characterization

Characterization of the commercial catch is required to transition from total removals to more informative descriptors, such as CAA, LAA, and WAA. In its most basic form, catch characterization involves assigning the length frequencies of a catch sample for a given species to the commercial landings totals of that species. This matching is performed at the finest level sampling permits, which in the case of EGB Cod is year, gear, and month. The assumed length-weight relationship is provided seasonally for EGB Cod (Quarters 1-2, 3, and 4). Year and quarter-specific age-length keys (ALKs) derived from otoliths are applied to each grouping, converting the length composition of the total commercial catch to an age composition of the commercial catch. These basic concepts are common across various applications used to characterize catch, with methods diverging to account for varying degrees of sampling and associated assumptions; cases where sampling is limited, the groupings become progressively more coarse.

CATCH Application

Catch characterization of the 5Z Cod fishery has been historically carried out using the DFO in-house APL application called CATCH. CATCH is linked directly to the observer, port sampling, and commercial logbook databases in the Maritimes Region, removing the need for an in depth understanding of these relational Oracle databases by the user. However, CATCH retains a heavy dependence on user input with respect to organizing and matching samples, as well as creating substitutes in cases where samples for a given month, gear, and area are not available. This was initially done to allow for greater flexibility in characterizing the catch across various species in the Maritimes Region, but also introduced a high level of subjectivity into the process and reduced its replicability. Given the amount of user-specified input required, CATCH can only be done for a single fishing year at a time, so most assessments relying on CATCH simply characterize the catch for the most recent year and add it to a time series of previously completed characterizations. This approach means that the analyses are difficult to replicate retrospectively, and that mistakes during the terminal year characterization often become archived in the series, with no mechanism of detection thereafter. Finally, adding the terminal year only does not allow for the historical catch characterization to reflect updates and corrections made to the various datasets contributing to the catch.

Length frequency samples used to characterize 5Z Cod catch in CATCH consist of pooled observer and port samples aggregated by month, gear, and year. Trips that were both observed and port-sampled were linked and treated as a single sample, while samples with large landings but few fish measured were excluded. In cases where samples were missing from a given month, those from an adjacent month were substituted, though the decision of which adjacent month was subjective. Once all months with associated landings had at least one length frequency sample, the length frequencies and landings were aggregated to quarter.

Condition of the fish in CATCH is parameterized via a length-weight (LW) relationship, with historical parameters used for 5Z Cod summarized in Table 3. Prior to 2000, a single annual relationship was used, derived from Canadian commercial sampling data (Hunt and Buzeta 1992; Waiwood and Neilson 1985). From 2000 until 2015, three seasonal, year invariant LW relationships were used, though their derivation is currently unclear. Since 2015, detailed samples collected by port samplers allowed for three seasonal LW relationships to be generated each year. This progression represents an improvement in sampling over time, though the cost-benefit of annual seasonal relationships should be examined. Use of survey data for

length-weight relationships was not pursued, as the survey takes place in the spring while the fishery is closed to protect spawning activity.

In the case of EGB Cod, annual seasonal age-length keys (ALKs) are used to account for growth throughout the year. No evidence of spatial divergence in growth exists for the Canadian portion of EGB, so no spatial disaggregation was done for the ALKs in CATCH. Given that the fishery is closed from February to May, a single ALK has been generated for quarters 1 and 2 (Q12), which has been historically reflective of the winter fishery (January–February) only, but in recent years encompasses the May test fishery as well. Survey ages have been included in the Q12 ALK consistently since 2005, but only periodically before then (TRAC 2023).

The time series of NAA, WAA, and LAA for EGB Cod commercial catch reported in Table 4 as characterized using the CATCH application is provided in Table 5, Table 6, and Table 7.

CatchR Package and NTS Application

With the progressive loss of APL programming capacity within Maritimes DFO Science, alternative R-based approaches to characterizing catch have been explored. CatchR (Ouellette-Plante et al. 2022), a recently developed and peer reviewed R package from DFO's Quebec Region, is one such alternative. The benefit of CatchR is an internal sample assignment protocol, which consists of a 12 level logical argument and standardizes the process of sample substitution (Ouellette-Plante et al. 2022); a subjective and labor-intensive process in CATCH, with no easily accessible record of the decisions made. A second benefit is that CatchR is able to characterize catch across multiple years, allowing for a relatively efficient update of historical characterizations with revised data or assumptions. In addition to CatchR, the catch composition for 5Z Cod was characterized using R scripts developed for the 4X5Y Haddock framework (NTS; Barrett et al. 2023). This approach has the same benefits as CatchR, but can account for some region-specific nuances in the characterization as well. Both CatchR and NTS were used to characterize the catch composition for 5Z Cod in this document.

One major difference between these applications centers around how the samples are combined within each grouping. Both CatchR and NTS weigh all samples equally, regardless of the number of fish measured or the magnitude of the commercial catch from which the sample is drawn. Meanwhile, CATCH weighs the samples based on the total weight landed for the trip being sampled and the number of fish in the sample. It is also common practice in CATCH to manually exclude trips with high catch and low number of fish measured, avoiding unrepresentative length frequencies from being influential in the overall group characterization. Finally, the approach to filling in missing ages differs between CatchR and NTS, with CatchR looking for missing ages in adjacent quarters first, while NTS is set-up to examine growth in adjacent years first; although CATCH protocol was similar to NTS, the extent to which it was followed is unknown. The disparity in sample weighting, no manual exclusion of samples, and automated filling of ages are expected to cause some differences in the outputs.

Numbers, Length- and Weight-at-Age

The outputs of the three different applications used for characterizing Canadian commercial catch were compared. Landings were pulled back to 1978 and aggregated by month, fleet, and year. Landings by unknown gear (<0.2% of all landings, all pre-2002) have no associated samples, so they were assumed to have the same LFs as the predominant gear of that year, which was always either longline or otter trawl. Length frequencies were drawn from both port and observer samples, with annual number of fish measured ranging from 1,889 in 1984 to an impressive 142,807 in 2007 (Table 1). Cases where the same trip was both observed and port-sampled are linked in CATCH, but could not be linked in NTS or CatchR, so some double sampling does occur in these approaches (i.e., 18 out of 374 trips sampled in 2019 were both

observed and port sampled). The length-weight relationship was originally specified as described in Table 3, generating a comparable run to the historical CATCH. Quarterly ALKs were applied within each year, though surveys were consistently excluded from the Q12 ALK in both CatchR and NTS.

Plots of the catch numbers at age for three applications for catch characterizations are presented in Figure 14, with plots of standardized proportions by age across years (SPAY, Kumar 2020) in Figure 15. In general, all three track the same cohorts (i.e., 1985, 1996, 1998, 2001, 2003, 2013). When quantifying the change in comparison to the original CATCH output, NTS produces the most comparable output in terms of magnitude and balancing positive/negative residuals, although it tends to continually underestimate catch numbers at ages 2–4 throughout the time series (Figure 16, Figure 14). CatchR, on the other hand, consistently overestimates the catch numbers for younger fish and underestimates those of older fish compared to CATCH (Figure 16). The change in directionality of the differences shows that this cannot be tied to the weighting of samples, as CatchR and NTS take the same approach compared to CATCH.

Further comparison of the outputs of CatchR and NTS shows a consistent directional difference in the results, despite identical inputs (Figure 17). This difference has been linked to the substitution algorithm in CatchR which, when combined with the seasonality of this fishery, borrows age-length combinations from later in the year, consistently assigning larger fish to younger ages. For NTS, the missing age-length combinations can come from the same quarter in an adjacent year, which avoids this effect. Figure 18 is illustrative of the occurrence of age-length fills in the Canadian catch. In general, fills only occur at the extremities of the length frequency, with the exception of the 1980s, when full quarters were missing and therefore filled.

Given the difference between the three applications and the limitations of the old APL software, it is recommended that NTS be used to generate the Canadian commercial fishery CAA for this framework. It represents a balance between transparency, replicability, and accuracy in characterizing the catch. This approach was shown to be much less labor-intensive compared to the original, with a replicable method of filling samples, successfully reducing the subjectivity of the analysis. Although CatchR has many of the same benefits, its prioritization of adjacent quarters when filling in age-length gaps introduces a bias into the outputs due to the seasonal nature of this fishery. Otherwise, differences between CATCH and NTS appear relatively small and are likely tied to elimination of subjective decision making in terms of sample matching, treatment of small/unrepresentative samples and automated substitution of missing age-length combinations.

In addition to abundance at age, catch characterization includes WAA and LAA. Currently, NTS only produces LAA, though work is ongoing to develop a comparable WAA output as well. Among the three applications, there is a general consistency in trends of WAA and LAA over time, but CatchR has a tendency to underestimate the LAA for ages 4 through 8 compared to the other two (Figure 19, Figure 20,); likely a function of the bias towards younger fish. The difference between CATCH and NTS is much smaller and thought to be driven mostly by revised data inputs (i.e., manual sample exclusion in CATCH). The available LAA and WAA outputs capture the same trends over time, with the largest values of both WAA and LAA occurring prior to 1994, slowly decreasing throughout the 2000s to a low, which is maintained throughout the 2010s. More recently, both the LAA and WAA have shown a notable increase for young fish (Figure 19, Figure 20).

Following peer review, it was agreed that the final Canadian commercial CAA outputs should be generated by NTS, until modifications can be made to the substitution algorithm of CatchR. The

WAA outputs will continue to rely on CATCH, until the NTS scripts are developed to include WAA calculations or CatchR substitution modifications are feasible, whichever comes first.

Note that the proposed catch products differ slightly from those used in the US Cod RT, which relied exclusively on CATCH outputs. To ensure connectivity between the processes and to evaluate the impact of the relatively small change, a run will need to be made with the pertinent model using both the old and the revised catch products. Given the consistency in proportions at age between them (Figure 15), it is not expected that the change will have a notable impact in the model.

Scallop Fishery on EGB

The Canadian Scallop fishery on EGB is not permitted to keep any incidentally caught Cod; it must be discarded at sea (Keyser et al. 2022). Estimation of Cod discards from the Scallop fishery follows the method initially proposed by Gavaris et al. (2007a) and later revised by Sameoto et al. (2013). The method uses a measure of Scallop fishing effort to raise observed Cod discards to the level of fleet and is applied annually. The total estimate is characterized using Cod length frequencies collected by observers on Scallop trips, with observer coverage of the Scallop fishery ranging from 7 to 23% (Keyser et al. 2022). Discard estimates of 5Z Cod are included in the total removals of the Canadian fishery and contribute to the final commercial CAA.

Starting in 2006, the Canadian Scallop fishery on Georges Bank has been subject to time-area closures, with the intent of protecting spawning aggregations of Cod. A follow-up evaluation of these closures in 2020 found them ineffective in reducing bycatch, recommending improvements to the closure design, or an overhaul to the approach in order to achieve the desired reduction in Cod bycatch (Keith et al. 2020). After being deemed ineffective, the Scallop closures were removed in 2022 and a management approach to protect spawning Cod has yet to be developed.

Jonah Crab and Lobster Fishery on EGB

The offshore Lobster and Jonah Crab fisheries in lobster fishing area (LFA) 41 encompass EGB. There is no method in place to quantify the degree of interaction between these fisheries and Cod, so incidental catch of Cod in these fisheries cannot be accounted for at this time. Management measures currently in place to reduce interaction with Cod include mandatory escape vents and biodegradable panels (DFO 2023), noting that fishing effort directed to both Lobster (*Homarus americanus*) and Jonah Crab (*Cancer borealis*) on EGB has been minimal since 2015.

US FISHERIES

The US fishery CAA datasets used in this framework are a product of the US Cod RT (TGB, NEFMC 2023) and the TRAC (EGB, TRAC 2023). A detailed understanding of the Canadian fishery allows for the evaluation of decisions made in characterizing the fishery catch, and modifications of these decisions were deemed necessary based on increased knowledge of the fishery. In the case of the US fishery, modifications to the CAA products for both TGB and EGB are not possible at this time, so only a brief description of the US fishery is provided here. More detailed information can be found in the Northeast Multispecies (Groundfish) Fishery Management Plan (NEFMC 2024) and the Greater Atlantic Regional Fisheries Office Multispecies (Groundfish) summary page (NOAA 2024).

The implementation of hard quotas for Atlantic Cod on Georges Bank followed the institution of the Magnuson-Stevens Act in 1977, aligning with the declaration of the EEZ by coastal states in

the same year. The available time series of total catch removals by the US fishery for both EGB and TGB begins in 1978 (Table 4).

The US commercial groundfish fishery on Georges Bank comprises primarily vessels participating in the US sector management program (a type of catch share system), an analogous concept to fleets in the Canadian fishery. The sector fishery is subject to a variety of minimum size restrictions, as well as possession, day at sea time/area management, and catch limits to ensure that overall annual TAC is not exceeded. For the Georges Bank fishery, the primary gear is currently bottom trawl, but some gillnet and longline activity takes place as well. The US fishery on Georges Bank is managed domestically as the larger TGB unit, but is also subject to the transboundary management understanding with Canada on the smaller EGB spatial unit that is nested within the TGB. Although a product of a separate, independent assessment, quota from the EGB area can be caught within the western portion of the larger spatial unit of TGB, but not vice versa.

Information about the spatial distribution of US fishery catches of Cod is available as total removals by large management area, as well as proportional catches by statistical areas (Table 4, NEFSC 2023). The EGB fishery (unit areas 551, 552, 561, 562) accounted for approximately 55% of total US removals on TGB prior to the mid-1990s, but has decreased since then to an average of approximately 15% of the total US catches since 2005. The contribution of unit area 522 has increased since then, accounting for 50–75% of US Cod catches on TGB.

Catch Monitoring Data Streams

There are four data streams of information collected from US commercial fisheries: commercial seafood reports (Dealer), vessel trip reports (VTRs), biological port sampling, and observer data. Direct database access to the four streams is not possible at this time, so relevant description and data products have been collated from various publications on the topic, rather than from a direct analysis of the data.

The Dealer stream provides accurate weight of species landed by market category (scrod, market, large), date landed, gear, port, and price for a given trip, and is used to derive the total fishery removals of each species (Wigley et al. 2008). Readily available information detailing the accuracy of the Dealer reporting system back in time is limited. In general, the Dealer totals are assumed to represent the total commercial fishery removals by species and area, though occurrences of misreporting of both eastern and western Georges Bank Cod between 2012 and 2015 have been uncovered (Demarest et al. 2018). A comparison of historical US landings to those reported by NAFO are not informative, as NAFO landings are available for the older Georges Bank management unit (5Ze; includes unit areas 521 and 526, Figure 1) and are substantially larger than those reported by the US Cod RT for the revised Georges Bank Management unit (excludes unit areas 521 and 526, Figure 1, Figure 7). Serchuk and Wigley (1992) detail the logistic issues encountered in the US fisheries management following the extension of the fisheries jurisdictions in 1977, alluding to large-scale misreporting of cod landings between 1977 and 1983.

Information on vessel effort and area fished was collected through port interviews up until 1993, when the submission of vessel trip reports (VTRs) became mandatory (NEFSC 2023). VTRs contain trip-level information on the area fished, estimated amounts of discarded or kept catch, as well as detailed gear and effort information for each trip (Wigley et al. 2008). Due to some compliance and incomplete data issues, VTRs represent a subset of Dealer landings, and some assumptions must be made when combining the two streams. It is currently unclear what proportion of Dealer-Georges Bank landings are also covered by VTRs.

The Dealer and VTR data streams are collected independently of one another without generating unique identifiers for each trip and therefore cannot be cross-referenced. Linking of the two occurs post-hoc, using a multi-tiered allocation, which attempts to match individual trips from each data stream based on common characteristics such as vessel permit, tonnage class, month, day, gear type, and port (Wigley et al. 2008). Records that cannot be matched as a single trip (Level A) get aggregated to progressively larger groups (Levels B, C, D), moving to the next group only in cases where a match is not successful. This allocation proportions the total Dealer landings to various statistical areas and forms the basis of the total commercial catch for both the eastern and TGB management units. The Dealer-VTR matching allocation (AA) was in place from 1994 to 2019 and has since been replaced by a new system (Catch Accounting and Management System, CAMS). Detailed documentation for CAMS is still under development, but it appears to undertake a similar matching exercise to join the two data streams post-hoc, producing total fishery removals by statistical area (O’Keefe et al. 2023).

The port sampling program provides biological information of the US commercial catch and is linked to the Dealer data system. The program is designed to collect length and age information by species, region, market category, gear, stock area, and quarter. Sampling targets trips fishing in a single statistical area only, avoiding having biological samples associated with catch from multiple statistical areas. Overall, the realized sampling of the US fishery on Georges Bank is significantly lower than that of the Canadian fishery (Figure 21).

A final catch monitoring data stream is at-sea observer data, collected since 1989. Currently, observer data are used only for discard estimation. It is collected at the set level and includes information such as length, otolith/age, species, region, market category, gear, stock area, and quarter.

Discard Estimation

Discard estimation from the US fishery for the TGB was carried out by the Cod RT, with methods, revised mortality assumptions and imputation of missing sampling strata explained in NEFSC 2023. Discard estimates are also available for the EGB unit, though age disaggregated data sets are only available up to 2019. Detail on the imputation method and mortality estimates for EGB discards are scarce, but are assumed to be similar to those applied for the TGB. The Cod RT noted that estimation of discards for the smaller spatial unit is subject to higher uncertainty due to the low number of samples used (NEFSC 2023).

Catch Characterization

Characterization of the US commercial catch was completed by the Cod RT for the TGB, and by TRAC for EGB. Following the multi-tiered allocation designed to cross-link Dealer and VTRs, the Dealer landings were apportioned to the appropriate unit areas associated with each spatial unit (EGB: 551, 552, 561, 562; TGB: 551, 552, 561, 562, 522, 525). Landings for the TGB spatial unit also included several transboundary unit areas (464, 542 and 543; Figure 1) based on their proximity to the unit area and similarities in length frequency of the catch (NEFSC 2023).

Port samples were attributed to stratified landings within each year, quarter, gear, area, and market size stratum. If samples within a stratum were absent or low, adjacent quarters were combined to progressively higher aggregations (i.e., half year, annual; Wang et al. 2015, NEFSC 2023). If a given market category was still missing samples when quarters were combined to a full year for the Georges Bank unit (i.e., Large in 2020–2021, Scrod in 2021, Figure 22), they were treated as missing to avoid introducing bias into the final CAA (NEFSC 2023). Decisions made about the treatment of missing market categories for EGB are not documented, but samples from western Georges Bank were used to supplement EGB samples

in cases of poor coverage (i.e., Table 1; Wang et al. 2015). A breakdown of missing samples by market category is not available for EGB.

For the TGB, seasonal length-weight (LW) relationships were applied wherever possible, with annual relationships used in cases where quarterly length-frequency samples were aggregated to annual groupings (NEFSC 2023). Age-length keys for both spatial units were applied by market category and quarter, where possible, and aggregated to semi-annual or annual ones where sample numbers were too low (Wang et al. 2015, NEFSC 2023). For the TGB, missing age-length pairs in the ALKs were filled using a multinomial regression derived from the available data in that temporal-spatial stratum (NEFSC 2023). The LW relationship application for EGB and approach to filling missing age-length key values is not well documented, but has been assumed to mirror that of the TGB.

FISHERY DATA INPUTS–DISCUSSION

The final fishery-derived datasets available for use in the Canadian 5Z Cod framework include total removals, CAA, LAA, and WAA for the Canadian and US fisheries, with the US fishery data products available for both the EGB and TGB units. The total removals are available until 2022 for all three data sets, with the Canadian and US TGB removals expected to be updated through 2023 in advance of the modelling peer review meeting.

For the age-disaggregated fishery data products, recent sampling issues in the US result in three different terminal years: 2019 for US EGB, 2020 for US TGB, and 2022 for Canadian EGB (Figure 23). The US TGB CAA is expected to be updated to 2022 during the annual Management Track process in the winter 2022–2023, though issues related to low sample numbers are expected to persist (Figure 22). The Canadian EGB catch time series will be updated annually moving forward, as additional years of data become available. Unlike the other two, the US EGB CAA will not be updated to include data post 2019 due to lack of port samples and substantial resource limitations for US Science, so any extension of the US EGB CAA time series will need to be made post-hoc by Canadian scientists, using existing US data products.

If the final model includes US EGB CAA as an input, a method for characterizing the EGB landings for 2020 onwards needs to be developed. The use of the Woods Hole Assessment Model (WHAM, Stock and Miller 2021) platform allows intermittent years of missing CAA for a given fleet, if the country-specific removals are treated as separate fleets. However, if all fisheries removals are treated as a single, combined fleet, the CAA would need to be trimmed to the terminal year of the US CAA (2019 for EGB, 2020 for WGB).

Alternatively, the missing EGB years could be characterized using the age composition and WAA from TGB for those years. Although not ideal, samples from TGB have been used in the past to characterize EGB catch when sampling was deemed too low (Wang et al. 2015), lending credibility to the assumption that the US fisheries on EGB and TGB are comparable in terms of their selectivity and catchability for Cod. This assumption is further supported by comparing the proportional abundance at age for the EGB and TGB fishery catch in the most recent 10 years, with years where sampling on EGB was too low or supplemented by western Georges Bank excluded. In that case, the majority of the differences in the proportional abundance at age for each year amount to <2% (Figure 24). Given that the US catch on EGB in 2020–2022 accounts for 8–15% of total assumed removals from EGB (Figure 25), this method of extending the US EGB timeseries post hoc is not expected to have a substantial impact on the outcome.

In general, the three CAA time series all pick up on the same major cohorts throughout the time series (those born in 1985, 1990, 1992, 1996, 1998, and 2010, Figure 26). The US CAA for both TGB and EGB also pick up on a notable cohort in 1975, which the DFO CAA largely misses,

likely due to data quality issues in the 1970s (see Canadian Groundfish Database section). Despite relative consistency of all three series up until the 2010 cohort, the ability of the US EGB CAA to detect cohorts degrades after 2014, failing to track the 2013 year class evident in the other two datasets (Figure 23, Figure 26). This coincides with a number of years where US EGB catch characterization relied heavily on some portion of western Georges Bank samples (Table 1), with the exact method of borrowing not known. The inability of the final US EGB CAA to track the year classes in the latter years suggests that the approach to borrowing western Georges Bank samples to characterize EGB catch may have crossed market categories or years, which is detrimental to the final product.

If treated as a single fishing fleet, the combined CAA for both EGB and TGB track the same cohorts throughout the entire time series (Figure 27).

SURVEY

There are three fishery-independent surveys of Georges Bank, two NMFS and one DFO survey, taking place in the winter (DFO), spring (NMFS) and fall (NMFS). All three surveys follow a random stratified design, though the strata boundaries, station protocols and intensity of coverage are specific to each institution. All three surveys are bottom-trawl surveys, initially with a focus on groundfish species in the 1970s and 1980s, gradually expanding over time to a more holistic, ecosystem approach. The similarity of the three surveys in terms of spatial coverage and data products has been acknowledged for some time, with the DFO survey using historical US strata in its inaugural year. The International Council for the Exploration of the Sea (ICES) Working Group on North Atlantic Ecosystem Observations (WGNAEO) was formed in 2018 to align the three surveys' protocols to further increase compatibility of the data products (ICES 2022). Data from all three surveys are used by the existing TRAC assessments and the more recent US Cod RT to produce relative indices of abundance for Cod on Georges Bank. The main difference in their application lies in the use of total abundance indices (DFO) and mean kg per tow indices (NMFS), which appears to be a function of their respective institutions. In addition, during the November 2023 peer review of this work, a mistake was found in the data used by the US Cod RT, where the unconverted Bigelow time series was treated as if conversions had been applied. This mistake has since been corrected by NEFSC, and all relevant figures and tables in this document have been updated with the correct data.

DFO WINTER SURVEY

History

The Maritimes Ecosystem Winter Research Vessel Survey in 5Z has been conducted since 1986 on and around Georges Bank, with the goal of providing age-specific abundance trends for groundfish species. Originally designed as part of a Canada/US co-management agreement for transboundary groundfish stocks, in 1986 it covered the bank as well as the surrounding deeper waters (Gavaris and Waiwood 1986). When it was confirmed that catches of Cod and Haddock in these deeper waters were highly variable during the survey period, and it was documented that covering these deeper waters provided limited useful information at a considerable cost, the area of coverage was restricted to shallower depths up to 183 m in 1987 (Gavaris 1987). In the inaugural year, strata boundaries were based on historical US strata, but in subsequent years, the strata were changed to cover depths less than 100 fathoms from south of Cape Cod to the northeast peak of Georges Bank. These new Canadian strata were named 5Z1–5Z8 (Figure 2). The Canadian strata were designed to follow depth contours of the Bank, but also take into consideration existing management units and the Canada/US international border. As a result of the switch in stratification, data from 1986 are often excluded from some

analyses, but included in age-specific indices of abundance calculated for Cod and Haddock during the TRAC assessments (Stone and Gross 2012).

Vessel and Gear Changes

The CCGS Alfred Needler fishing with a Western IIA trawl was the primary survey vessel and gear for the DFO winter survey from 1986 to 2019. When the Needler was unavailable due to refits or mechanical repairs, the CCGS Teleost (2005–2008, 2016, 2017, 2020, 2021), CCGS Templeman (1993, 2004, 2007, 2008), and the commercial trawler the Mersey Venture (2018, 2023) were employed. All of these vessels continued using the same Western IIA trawl. The CCGS Capt. Jacques Cartier deploying a Northeast Fisheries Science Center Ecosystem Survey Trawl (NEST) will become the primary survey vessel and gear when ongoing comparative fishing is complete. The 2022 winter survey of Georges Bank was carried out using the Cartier/NEST, but when it became clear that conversion factors will not be readily available, the survey reverted to using the old vessel and gear. Consequently, the 2022 survey data will not be available until conversion factors are calculated.

No conversion factors are necessary to compensate for vessel effects of the various vessels used during the Needler time series. In 2005–2006, comparative fishing between the Needler and the Teleost occurred with inconsistent results. Data from the Maritimes Region Ecosystem Summer Research Vessel Survey suggested conversion factors in the opposite direction from conversion factors calculated from data from the DFO Southern Gulf of St. Lawrence Survey, which begins a month after the Maritimes Region's summer survey ends (Benoît 2006, Fowler and Showell 2009). Given the inconsistent results, no conversion factors were recommended. The Needler and the Templeman were 'sister ships' built to similar specifications by the same shipyard at the same time; as a result, the data collected by the Templeman were assumed to have no vessel effect. The Teleost and the commercial trawler Mersey Venture are also sister ships, and the same assumption is made. Comparative fishing between the Cartier and the Needler/Teleost is ongoing and will determine the conversion factor(s) required to compensate for vessel and gear effects.

Survey Timing and Coverage

The timing and coverage of the DFO winter survey has changed from year to year due to vessel refits and mechanical failures (Figure 28). This DFO survey tends to take place over a four-week period throughout February and March, with the exact timing a function of weather, crew change and planning logistics. In recent years, degrading vessel performance has resulted in more sporadic time frames (i.e., 2023), as well as significant gaps between fishing activity (2012, 2018).

The original design for the DFO winter survey includes a variable number of sets per stratum (Table 8), aligning with the goal of providing age-specific abundance trends for Cod and Haddock. One hundred sets were originally assigned to eight strata (5Z1–8, Figure 2), with a density of one per every 200 nm² of stratum area. In 2010, an additional deep water stratum (5Z9) was added with four additional sets. A minimum of two sets are needed in a stratum to calculate variance, though if one set per stratum is completed in a given year, estimates of abundance can still be calculated for that stratum. It should also be noted that a large portion of stratum 5Z3 named 'The Shoals' has been identified as an exclusion zone to survey sets. Although not part of the original stratum delineation, over time it has emerged as an area with high rates of set invalidation due to the bottom conditions and shallow depths. Starting in the early 2010s, The Shoals were formalized as an exclusion zone based on set success history to date (Figure 2).

While the original station allocation still stands, whether or not it is completed in a given year has depended on vessel availability and performance (Figure 29). Increasing certainty in the fact that these failures will occur has affected how the survey is planned, with staff prioritizing coverage of strata 5Z1 through 5Z4, given their importance to the transboundary EGB stock assessments. Coverage of strata furthest from port (5Z5–8) has been most affected, with no sets completed in five of the last ten years (2014–2023). In comparison, only two other years in the entire time series have no sets in these western Georges Bank strata.

The survey strata do not align directly with the DFO statistical units used to characterize EGB (5Zejm) and TGB (5Zejm and portion of 5Zehn). The EGB management unit includes strata 5Z1, 5Z2, and portions of 5Z3, 5Z4 (Figure 2); 5Z8 and 5Z9 are not included in the transboundary assessment due to intermittent coverage. The TGB management unit includes EGB and the remaining parts of 5Z3 and 5Z4, as well as portions of 5Z5, 5Z6, 5Z7, and 5Z8 (Figure 2). The recent lapses in coverage of western Georges Bank strata mean that EGB has more complete coverage at a higher resolution than western Georges Bank does (Figure 29), creating issues when generating indices of abundance or biomass for areas larger than EGB.

The DFO winter survey was originally intended to survey spawning aggregations of Cod and Haddock on Georges Bank, targeting the months of February and March of each year. Historically, spawning activity has been detected as early as January and has continued into the month of May. In addition to historical records, this timing has been more recently reconfirmed with the annual trigger closures of the winter fishery on Georges Bank in February, as well as deferral of the May test fishery until the second week of May, both based on the percent of spawning fish detected in the catch (DFO 2018). It should be noted that some evidence exists of a recent shift to an earlier spawning time for Georges Bank Haddock stocks, but no such analyses have been done for Cod (M. Wuenschel, Working Paper for the Haddock Research Track).

Given the importance of surveying the aggregations of spawning fish on Georges Bank each year, there is general consistency in timing of the DFO winter survey on Georges Bank up until 2022, when the survey went 10 days later than any previous year (Figure 28). Currently, 2022 data are unusable due to the absence of conversion factors, but even when the conversions become available, further investigation may be required to determine whether it should continue to be excluded.

NMFS SPRING AND FALL SURVEYS

History

The NMFS spring and fall bottom trawl surveys have been conducted since 1968 and 1963 respectively. The portion of each survey conducted on and around Georges Bank is part of a larger area of coverage: for the spring, from Cape Hatteras, North Carolina, to Nova Scotia; for the fall, from Hudson Canyon, New York to Nova Scotia. Like the DFO winter survey, the NMFS surveys use a stratified random design, but with their own set of strata that differ from those used for the DFO surveys (Figure 30). The NMFS survey strata are based primarily on depth and known fish distributions, remaining independent of management boundaries such as statistical areas or the Hague Line. The latter basis has proven to be problematic for the US in the past when generating survey data products for spatial management units, often resulting in spatial mismatches (NEFSC 2023). Attempts to align the strata with important management boundaries have begun through the ICES WGENAO (ICES 2022), but timelines for implementation of the new strata are unclear. Currently, TRAC post-stratifies the NMFS survey data to generate the indices for the EGB management unit (5Zjm). The density of sets within

strata is proportional to the stratum area, while considering species distributions and the Hague Line (Grosslein 1969, Politis et al. 2014).

Vessel and Gear Changes

The NMFS surveys were conducted until 2009 using the NOAA ship Albatross IV. In 2009, a new vessel, the NOAA ship Henry B. Bigelow came into service. NOAA ship Delaware was employed when the Albatross was unavailable. These vessels have employed three different nets: the Albatross used a modified Yankee 41 from 1973–1981 and a Yankee 36 in subsequent years, with a change in trawl doors in 1985. Meanwhile the Bigelow has used the NEST to conduct the surveys with revised station protocols since 2009. No net conversion factors are available for Cod for the switch between Yankee 36 and 41 trawls, but calibration factors were calculated for Cod to account for the Albatross-Yankee41/Bigelow-NEST switch (Brooks et al. 2010, Miller et al. 2010). Length-based conversion factors have been applied to all abundance-based NMFS survey data presented here, converting the Bigelow-NEST series back into Albatross-Yankee 41 units. Biomass indices were derived by multiplying the converted abundance by the appropriate weights at age. In general, the Bigelow-NEST combination tends to catch more Cod at all lengths, but also proportionally more small Cod (Brooks et al. 2010), though some concerns have been raised about the validity of the conversion factors during the US Cod RT (NEFSC 2023).

Survey Timing and Coverage

The timing of the NMFS spring survey on Georges Bank targets March–April, though it has begun moving into May more recently (Figure 28). The proximity of the recent US spring survey timing to the end of spawning season on Georges Bank may become problematic, particularly if shifts to an earlier spawning season are detected for Cod as they have been for Haddock. On the other hand, the fall survey initially spanned October–November, moving progressively earlier into September–October throughout the 1990s and 2000s (Figure 28). Since then, the trend has reversed, with sets in 5Z occurring in line with the original timing. The fall survey does not target spawning aggregations on Georges Bank, so a minor shift in timing is not expected to have as much impact on the final data product in the fall as it does in the spring.

The NMFS surveys are designed to have stratum-specific target number of sets (Table 9 a, b). At least three sets are planned per stratum, and two must be completed to provide an estimate of variability (Politis et al. 2014). As with the DFO surveys, whether or not sets in these strata are completed in a given year has been a function of vessel performance and logistics, with only one occurrence of zero sets over the time series (Stratum 1180, 1990; Figure 29). In 2020, both spring and fall NMFS surveys were cancelled due to the COVID-19 pandemic.

As noted above, the NMFS survey strata do not correspond with the NAFO units used to characterize EGB (5Zejm) or TGB (5Zejmhn) management units. EGB includes portions of strata 1160–1220, while TGB includes EGB and portions of strata 1130–1240 (Figure 30). Given their spatial coverage across all of Georges Bank, the NMFS surveys have more consistency in their coverage of both the EGB and TGB management units compared to the DFO winter survey (Figure 29).

The current NMFS survey strata do not delineate The Shoals on Georges Bank as an exclusion zone, but have the same history of high failure in this area (ICES 2022). The ICES WGNEAO has done some work on formalizing a similar exclusion zone to Canada in strata 1190 and 1200, but this has not yet been put into practice.

INDICATORS

Spatial Distribution

The distribution of Cod on Georges Bank for the three surveys are shown for in Figure 31, Figure 32 and Figure 33, with facets aggregated by decade due to the overwhelming number of annual plots. Both DFO winter and NMFS spring surveys show a progressive constriction of positive Cod catches from TGB (pre-2000s) towards the northeastern peak of the bank (2010s and 2020s), remaining mindful of differences in sampling intensity between DFO and NMFS surveys (Figure 31, Figure 32). This is accompanied by a northerly expansion of null catches from the southwestern ridge of Georges Bank towards the centre of the bank (Figure 31, Figure 32). In comparison, the positive sets in the NMFS fall survey have always been concentrated along the northern portion of the bank, even during periods of high Cod abundance in the 1970s and 1980s (Figure 33). With decreasing abundance, the distribution of positive sets in the NMFS fall surveys has contracted to the north-eastern portion of the bank (Figure 33).

Biomass Indices

DFO Winter Survey

Total biomass indices were calculated for both EGB and TGB management units (Figure 34, Table 10). The EGB index included sets in DFO strata 5Z1 and 5Z2, as well as the eastern portion of 5Z3 and 5Z4, as bisected by the 5Zejm line (Figure 2). The total biomass index is generated by raising the average kg/tow in a stratum by the number of trawlable units within that stratum; in cases where a management boundary bisects a stratum, the number of trawlable units is calculated for the area of the stratum falling within the management boundary (i.e., 1,504 nmi of stratum 5Z3 is east of the 5Zejm line).

The outline of the revised TGB (US statistical areas 522, 523, 524, 525, Figure 1) aligns with the area covered by DFO unit areas 5Zejmhn (Figure 3). The western boundary of the revised TGB management unit recently accepted by the US has not been incorporated fully into the post-stratification processing of the DFO survey data; therefore, stratum area estimates for 5Z5, 5Z6 and 5Z7 falling within the revised TGB management unit were estimated using NAFO and DFO strata layers in GIS (Table 11). As such, any survey area-adjusted data products for the revised TGB unit shown here may change slightly once confirmed area estimates of DFO strata within the TGB area become available.

Given that DFO survey set allocation in strata 5Z5, 5Z6, and 5Z7 does not take the split between 5Zehn and 5Zego into account, limiting the sets in 5Z5–5Z7 to those within 5Zehn creates additional holes in the DFO survey's coverage of TGB. Since the original strata design took depth and environment into account, in bisecting strata with relevant management boundaries, each stratum is assumed to be uniform in its environment and species composition. As such, the mean catch of all sets in each bisected strata is considered representative of the portion of each stratum in 5Zehn (Figure 2). Total biomass indices can then be derived for only the portion of the strata in 5Zehn by raising the mean catch per tow to the trawlable units in each stratum's bisected portion (Table 11). This approach limits the number of years with missing coverage in strata 5Z5–5Z7 to those outlined in Table 8.

Addressing the remaining years with missing DFO coverage of strata 5Z5–5Z7 requires further imputation. When disaggregated by stratum, the DFO winter survey total abundance at length shows catches in strata 5Z5 and 5Z7 are relatively small compared to strata 5Z1–5Z4, as fish aggregate on EGB spawning grounds (Figure 35). While the same is true for stratum 5Z6 after 1994, there are notable catches in stratum 5Z6 from 1986 to 1992, followed by a two year break

in coverage (1993, 1994). The NMFS spring survey did not produce large catches in the 5Z6 stratum area during 1993 and 1994 (Figure 36).

To fill the missing years in strata 5Z5–5Z7, a negative binomial generalized linear model was fit to the mean abundance by length bin, with stratum and year as factors. Due to the change in magnitude of Cod catches in stratum 5Z6, the earlier time period (1986–1992) was excluded from the imputation, assuming that all missing years were more similar to the 1995+ time period than years prior to 1992 (Figure 35). Although simple, this approach predicted the range of lengths and proportions at length in the catch (Figure 37). For strata experiencing large interannual fluctuations in magnitude of the catch (i.e., 5Z4, 2005), this approach tended to overestimate the magnitude of the catch in several years (Figure 37). Given the consistently low magnitude of catch at length in strata 5Z5, 5Z6, and 5Z7, this method yields no concern of gross overestimation of catches in missing years. Furthermore, given the relative contribution of observed catches in strata 5Z5–5Z7 compared to those in 5Z1–5Z4, the imputed values for the missing years make very little difference to the DFO total biomass index for TGB (Figure 38).

NMFS Surveys

For the NMFS surveys, the total biomass indices for EGB are generated with strata 16 through 18, and the portions of strata 19 through 22 falling to the east of the 5Zjm line (Figure 30, Figure 34). Mean kg/tow indices for the revised TGB management unit come from the US Cod RT and use strata 13 through 22 entirely without post-stratification, to abide by the western boundary of the TGB unit (NEFSC 2023). The difference in magnitude between the mean kg/tow indices generated by the US Cod RT and total biomass indices generated in this document was corrected by multiplying the mean kg/tow index for a given stratum by the total number of trawlable units in that stratum.

The total NMFS biomass indices for EGB and TGB are presented in Figure 39. Note that the high 1982 NMFS spring survey index value is caused by a single set of over 4,000 kg of Cod. The next largest set that year was 102 kg, with many remaining sets <10 kg. This set has been used as-is in both the TRAC and the US Cod RT processes.

Catch-at-Age

Otoliths from each survey are aged at each agency's respective labs, with annual cross-validation tests taking place between the NMFS and DFO agers to ensure consistency of both survey and commercial ages. The most recent cross-validation exercise for the DFO winter survey (2021) resulted in ager agreement of 96.7%, with a coefficient of variation of 0.42%. The two labs do differ in their assumptions of fish birth date, with a January 1st birthdate assumed at the NMFS lab and a February 1st birthdate assumed at the DFO lab.

The survey CAA for the EGB and TGB management units are shown in Figure 40 and Figure 41. Note that the NMFS survey CAA for the TGB spatial area is only available up to age 9, with the terminal age being a plus group (NEFSC 2023); all other age disaggregated indices are presented to the oldest age without a plus group. In addition, the TGB CAA produced by the US Cod RT is in mean numbers per tow, while the DFO survey and all EGB abundance indices are in units of total abundance. As such, the CAA in mean numbers per tow was adjusted by the total number of trawlable units in the relevant strata, converting it to a total abundance at age index for the area. The number of trawlable units was calculated by dividing the area of each stratum included in the index (13–22) by the area of a standard tow.

The NMFS fall survey shows the most constricted age range for EGB Cod, only consistently catching fish aged 1-6 throughout the time series (Figure 40). The DFO winter and NMFS spring surveys capture a broader age range early in the time series, with NMFS spring survey

generally catching fish to age 9 and the DFO winter survey to age 11 (Figure 40). Since the mid-1990s, however, both the winter and spring surveys have undergone a constriction in the catch's age structure, with the NMFS spring survey only catching fish to age 7 and DFO winter survey to age 8 in recent years. Also reflected in the length frequencies is that the DFO survey consistently catches older fish than the NMFS spring survey, with the DFO winter survey catching both larger fish and more fish at higher lengths than the NMFS spring survey (Figure 42). Although truncated at age 9, the survey indices for the larger TGB area appear to show a similar constriction in age structure as EGB (Figure 41).

The single large tow, noted above, that impacts the 1982 NMFS spring survey biomass index also affects the CAA for that year for EGB and TGB (Figure 39, Figure 40, Figure 41). However, despite a substantial change in magnitude, the proportional age compositions for 1982 are consistent with surrounding years in terms of cohort progression.

The winter and spring surveys consistently identify the same cohorts throughout the common time span for both EGB and TGB (i.e., those born in 1985, 1990, 1996, 1998, 2003, 2010, 2013; Figure 43, Figure 44); cohort identification by the NMFS fall survey is not as evident, due in part to the narrow age range of the catch (Figure 43, Figure 44). The ability of each survey to track cohorts was evaluated through correlation matrices, with the DFO winter survey showing the strongest positive correlations across the broadest range of ages (Figure 45, Figure 46). The cohort tracking by the NMFS spring survey is notably weaker, particularly for ages 4+, while the NMFS fall survey only effectively tracks cohorts up to age 4 (Figure 45, Figure 46).

Recruitment

Recruitment indices are derived from all three surveys by extracting the age 1 abundance-at-age time series (Figure 47). Of the three surveys, the NMFS fall survey catches age 1 more consistently than either the winter or spring surveys. Age 1 fish are only absent in 1977 and 2003 (Figure 47). In comparison, the winter and spring surveys each have six (DFO) and ten (NMFS) years where no age 1 Cod were caught.

Length- and Weight-at-Age

The LAA and WAA for the EGB and TGB spatial areas from the three available surveys are shown in Figure 48 and Figure 49. All six data sets show the same trends in LAA over time, remaining relatively stable or increasing throughout the 1970s and 1980s, then decreasing in the 1990s to a low in the mid-2000s. Since then, LAA for older fish (5+) remained at a low level until the mid-2010s, when after a temporary improvement, it decreased to a new low in 2020. Younger fish (ages 1–4) have remained stable since 2010 and have begun to show improvement in the most recent years (Figure 48).

The difference in LAA between seasons is most obvious for young fish (ages 1–4) and is accounted for by the additional six months of growth experienced between the spring and fall surveys. Within the same season, the DFO winter and the NMFS spring surveys are fairly consistent with one another, and there are no notable differences in LAA between EGB and TGB spatial areas (Figure 50). Trends in WAA echo those seen in LAA, though the weight time series for NMFS survey only starts in 1992. Seasonal differences in WAA are explained by a combination of growth throughout the year and the post-spawning condition of the spring fish (Figure 51).

TRAC has noted the recent increase in LAA of young fish on EGB, but the cause remains unclear (TRAC 2023). The increase persists across all three surveys and in Canadian port sampling and observer data (Figure 52); the US port sampling data are not available for comparison. The change is particularly evident when the age of the fish is adjusted for the time

of year that the fish is caught (partial age) and the different birthdates assumed by the US and Canadian ageing labs (US: Jan. 1, Canada: Feb. 1). The US Cod RT did not detect this change, which may be a function of the terminal year of their dataset (2020–2021) rather than the larger spatial area (48). The use of integer ages in the US instead of partial ages may further mask the difference. An attempt to investigate recent changes in LAA on the western portion of the TGB unit (areas 522 and 525, Figure 1) was unsuccessful due to the low number of Cod caught there in recent years (Figure 53). Interestingly, the same effect is present in the western portion of the 4X5Y Cod management unit (4Xpqr; Figure 54).

Age and Length at Maturity

Age and length at maturity ogives were calculated for the winter and spring surveys only, as macroscopic determination of maturity is only considered reliable during spawning season. Length at 50% maturity (L50) was notably higher prior to the 1990s, particularly for the NMFS spring survey (50 cm, Figure 55). Since the 1990s, it has remained relatively unchanged across both surveys (41 cm) and among TGB and EGB (Figure 55). Age at 50% maturity (A50; 2.1 years) was consistent until the 2020s, when it shifted to below age 2 for both spatial units (Figure 55). A similar trend was detected in the US Cod RT for TGB Cod, despite their time series only including a single year of survey data in the 2020s (NEFSC 2023).

Condition

Condition for Cod on Georges Bank was calculated using both Fulton's K (Fulton 1904) and Le Cren (Le Cren 1951), based on post-spawning fish only (Figure 56). Both winter and spring surveys showed a steady decline in condition until 2010, with the DFO winter survey remaining below the time series average since then, while the NMFS spring survey increased and has remained above the time series mean since 2021 (Figure 56). Due to the metabolic costs associated with reproduction, the condition of Cod is lowest during spawning season, and increases rapidly once spawning is complete (Mello and Rose 2005, Skjæraasen et al. 2010). Given the later timing of the NMFS spring survey compared to the DFO winter survey, the recent increase could be the rapid post-spawning increase in condition, rather than a true improvement. This effect would be further amplified if Cod experience a shift in spawning timing similar to the recent shift for EGB Haddock (M. Wuenschel, Working Paper from US Haddock Research Track). The NMFS fall survey shows no trend in the condition of Cod over time, but occurs at a time of year when spawning metabolic costs are unlikely to impact condition.

When viewed by length group (small ≤ 46 cm, medium = 46–60 cm, large ≥ 60 cm) the decrease in spring condition during the first part of the time series was evident for all three groups (Figure 57; Figure 58). The one notable difference was that condition for the smallest group (≤ 46 cm) stabilized around 2005, while condition of the medium and large individuals continued to decrease to a low around 2010. Condition of fish in the fall varied without trend over time for the three size groups (Figure 59). Post-spawning condition estimates for the smallest size group are also subject to higher variability and lower sample sizes compared to the medium and large groups, as the 46 cm cut-off is close to the length at 50% maturity for this stock (Figure 55).

Relative Fishing Mortality

Relative fishing mortality (RelF) was estimated by dividing the total fishery removals by the total survey biomass each year. The calculation was repeated for each of the three surveys, and each of the two spatial areas (Figure 60). The three surveys show a high RelF throughout the 1980s to 1990s, and a consistently lower level of relative F since 2000.

Total Mortality

Total mortality (Z) was estimated for EGB and TGB spatial areas using catch curve analysis (Sinclair 2001; Figure 61). Z was estimated based on survey catch rates for ages 3–6 in the fall surveys, and ages 4–7 in the winter and spring (Figure 62). These age ranges provide the best fit to a linear decline for the log-transformed catch curve, indicating that they are fully recruited to the surveys, and also exclude older ages that are absent in recent years. Estimates of Z for ages 4–7 from the winter and spring surveys varied without trend throughout the early part of the time series, increasing around 2010 for both EGB and TGB spatial units (Figure 61). Interestingly, from 2015 to 2017, both winter and spring surveys show a drop in Z to pre-2010 levels, before returning to higher levels since 2018 (Figure 61). This temporary decrease in Z was not accompanied by any known change in survey protocol or coverage for either survey, indicating that it was unlikely to be caused by a change in survey catchability (q) or selectivity. This decrease in Z does coincide with a temporary increase in LAA for older fish in the area, implying a possible temporary influx of fish from elsewhere. There is a general absence of any trend in Z estimated from the fall survey and the larger standard errors in the fall estimates suggest that cohort tracking is not as good then as it is in the spring (Figure 61, Figure 62).

Selectivity

At TRAC, the absence of older fish from the NMFS fall survey has been attributed to older fish moving into deeper waters off the bank, resulting in a dome shaped selectivity. Interestingly, inclusion of US strata 22, 29, and 30 (Figure 30) in the NMFS fall index does not expand the age structure of the catch in recent years (2010+), implying that the older fish are not caught by the fall survey in these deeper waters either. Although the movement of older fish in the fall is not clearly understood, their reappearance on the bank in the spring confirms that a dome shaped selectivity remains appropriate for the fall survey.

SURVEY DATA INPUTS–DISCUSSION

The final survey-derived datasets available for use in the Canadian 5Z Cod framework include total biomass indices, CAA, recruitment indices, LAA and WAA, and age and length at maturity. Further discussions on condition, relative fishing mortality, total mortality and selectivity are available to inform decisions made during modeling. All of these are available for the three fishery-independent surveys in each spatial unit: EGB and TGB.

The biomass indices for all areas and surveys are highly variable, but the trend in the relative biomass is consistent between them, showing higher biomass in the 1970s and 1980s, followed by a decrease to a lower level in the early 1990s (Figure 34, Table 10). The three indices remain at this level until approximately 2010, when the winter and spring survey indices drop further while the fall indices remain stable (Figure 34). The DFO decrease around 2010 is present in both spatial units, so is unlikely to be a function of DFO's recent poor coverage of the TGB unit (Figure 29). The same timeline for index divergence was also noted at the US Cod RT and formed the basis of a recommendation to explore the splitting of the NMFS trawl index time series (Albatross/Bigelow; NEFSC 2023).

It should also be noted that a change in maturity for a species can have various causes, but when detected along with an increase in growth for younger fish, a lower age at maturity has been attributed to warming water temperatures (Niu et al. 2023). Increased temperature is associated with increased growth rates for most ectotherm species, with juveniles in warming environments experiencing faster growth and development rates (Angilletta 2004, Foster and Hirst 2012). Many fish species have a size threshold that they need to meet in order to mature, so when growth rates increase with temperature, fish reach that size more quickly, resulting in a

decrease in A50 (Hutchings 2002, Niu et al. 2023). Although the L50 has remained invariant for EGB and TGB Cod, a decrease in A50 is often linked to a decreased in L50 over time, resulting in smaller adult sizes and decreased recruitment (Hutchings 2002). Ecological and evolutionary dynamics both affect these processes (Niu et al. 2023).

Finally, divergence in total mortality and relative fishing mortality in the latter part of the time series indicate that a source of mortality other than reported fishing.

ECOSYSTEM CONSIDERATIONS

The US Cod RT conducted an extensive literature review of climate and ecosystem indicators influencing Atlantic Cod in the region (NEFSC 2023). Their findings were congruent with those of the Canadian-United States Ecosystem Science (CAUSES) working group a few years prior (CAUSES 2019), with the RT progressively whittling down the broad list of influences with theoretical and operational merit to a core five: sea surface temperature (SST), bottom temperature, Gulf Stream Index, marine heatwaves, and zooplankton (NEFSC 2023). A follow-up analysis using generalized additive models identified zooplankton, marine heatwave, and SST as influencing growth and maturity of Georges Bank Cod, which aligns with the theory that shifting A50 is a consequence of increasing temperature (see Survey Data Inputs – Discussion section). None of the five indicators were identified as being a significant driver of the age 1 spring or fall NMFS survey abundance indices for Georges Bank Cod, and links to natural mortality were not explored (NEFSC 2023).

ACKNOWLEDGEMENTS

The authors would like to acknowledge DFO Maritimes Region Resource Management staff and the many Scotia Fundy Groundfish Advisory Committee (SFGAC) and Gulf of Maine Advisory Committee (GOMAC) participants who contributed to this document by sharing their extensive knowledge and experience over time. Also, the port samplers, observers, survey personnel, and agers who have worked tirelessly to coordinate the collection and processing of these data. Finally, a thank you to Phil Politis, Jamie Cournane, Spencer Talmage, Kiersten Curti, Amanda Hart, Alex Hansel, Charles Perretti, and Paul Nitschke for help navigating the US National Marine Fisheries Service research survey and commercial fishery data.

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TABLES

Table 1. Length frequency and age sample sizes used to characterize the catch for the eastern Georges Bank (EGB) Canadian and US fisheries. Numbers indicate the number of fish measured (lengths) or aged (ages) from various data sources and seasons. The shaded numbers include samples from total Georges Bank (TGB). TBD indicates commercial data which were not available for use in this analysis. US data are from TRAC (2023). Dashes indicate no ages used from the winter survey; Q1:April–June; Q2:July–Sept; Q3:October–December; Q4:January–March).

Year	Canada Lengths Observers	Canada Lengths Port samples	Canada Ages Q1	Canada Ages Q2	Canada Ages Q3	Canada Ages Q4	Canada Ages winter survey	USA Lengths EGB	USA Ages EGB	USA Lengths TGB	USA Ages TGB
1978	6,629	7,684	1,299	1,222	1,124	956	—	2,294	384	2,793	548
1979	0	3,103	0	557	1,116	0	205	2,384	402	3,497	740
1980	258	2,784	0	472	668	772	192	2,080	286	2,219	495
1981	835	3,906	228	1,157	752	368	—	1,498	455	2,399	664
1982	3,615	4,705	0	256	1,106	1,080	268	4,466	778	5,561	1,113
1983	2,694	3,822	141	316	1,260	0	150	3,906	903	6,113	1,479
1984	0	1,889	0	102	418	370	858	3,891	1,130	4,998	1,468
1985	549	7,031	0	1,160	888	0	351	2,076	597	3,673	1,030
1986	90	5,890	118	640	1,118	0	103	2,145	643	3,274	998
1987	2,862	9,133	0	614	1,627	528	193	1,865	524	3,934	1,100
1988	2,374	11,350	195	1,205	964	263	510	3,229	797	4,304	1,038
1989	1,518	8,726	452	711	399	61	—	1,572	347	3,151	704
1990	21,602	10,281	62	682	950	39	1,153	2,395	552	3,763	872
1991	11,647	10,873	299	675	796	168	1,782	1,969	442	3,541	769
1992	12,052	10,882	48	730	994	233	359	2,048	489	3,699	821
1993	11,530	12,158	271	502	933	544	—	2,215	569	4,793	1,170
1994	15,471	7,400	0	436	773	193	—	898	180	1,877	410
1995	1,881	4,112	0	75	297	176	—	2,645	14	892	223
1996	7,266	6,374	0	253	386	189	—	4,895	1,163	1,195	271
1997	5,407	8,592	0	455	188	553	—	1,761	82	2,648	623
1998	10,747	11,500	0	437	601	216	—	1,301	338	1,697	443
1999	9,009	8,126	0	269	230	283	410	726	228	2,938	708
2000	16,268	9,946	0	459	625	266	—	500	121	2,992	764
2001	12,745	11,829	0	374	967	490	—	1,434	397	3,795	1,127
2002	9,539	12,419	0	89	608	575	—	1,424	429	3,234	1,228
2003	9,314	11,320	0	157	372	508	—	1,367	416	3,653	1,228
2004	17,623	8,508	0	197	647	452	—	1,547	517	3,883	1,144
2005	20,540	5,499	17	169	220	151	697	297	65	2,535	883
2006	39,791	6,802	38	122	214	159	648	446	151	4,773	1,461
2007	133,815	8,992	26	100	716	236	456	589	183	4,023	1,298
2008	56,120	8,417	112	151	524	314	495	972	295	4,060	1,130
2009	42,500	7,216	115	123	351	623	246	1,286	326	6,305	1,767
2010	24,606	6,748	81	170	443	328	433	1,446	333	7,155	1,960

Year	Canada Lengths Observers	Canada Lengths Port samples	Canada Ages Q1	Canada Ages Q2	Canada Ages Q3	Canada Ages Q4	Canada Ages winter survey	USA Lengths EGB	USA Ages EGB	USA Lengths TGB	USA Ages TGB
2011	31,238	10,660	162	220	368	342	536	1,203	213	4,825	1,136
2012	43,803	7,641	248	105	220	326	216	598	746	3,201	806
2013	62,694	11,684	216	225	278	296	319	2,951	842	3,280	883
2014	50,010	10,288	152	226	307	272	184	547	85	2,922	768
2015	67,173	8,477	44	199	243	282	202	4,677	1,049	4,677	1,059
2016	68,904	9,798	102	132	232	190	282	715	149	3,364	911
2017	41,598	10,516	271	233	247	217	334	4,120	1,150	4,120	1,150
2018	48,280	9,777	107	244	262	283	309	1,695	412	1,695	412
2019	51,646	11,922	218	249	339	344	190	1,180	288	1,180	288
2020	37,476	8,526	229	33	247	389	259	TBD	TBD	305	126
2021	28,457	6,327	222	78	303	386	151	TBD	TBD	326	59
2022	26,568	5,989	112	273	276	201	326	TBD	TBD	TBD	TBD

Table 2. Tonnage class groupings for groundfish vessels in the Maritimes Region.

Tonnage class	Weight (mt)
1	1–24.9
2	25–49.9
3	50–149.9
4	150–499.9
5	500–999.9
6	1,000–1,999
7	2,000+

Table 3. Parameters of the length-weight equation (as used in generating the eastern Georges Bank Cod catch-at-age using the CATCH application (a is the a-intercept; b is slope; Q1–Q4 defined in Table 1).

Year	Q1/Q4 a	Q1/Q2 b	Q3 a	Q3 b	Q4 a	Q4 b
1978–1989	1.58E-05	2.916	1.58E-05	2.916	1.58E-05	2.916
1990–1999	1.63E-05	2.905	1.63E-05	2.905	1.63E-05	2.905
2000–2015	1.05E-05	2.983	1.52E-05	2.907	1.21E-05	2.978
2016	9.90E-06	3.016	8.38E-06	3.071	7.22E-06	3.093
2017	6.97E-06	3.096	1.64E-05	2.891	1.45E-05	2.917
2018	1.15E-05	2.976	1.03E-05	3.009	1.11E-05	2.984
2019	1.04E-05	2.998	6.09E-06	3.131	5.70E-06	3.145
2020	1.03E-05	3.004	8.74E-06	3.046	6.99E-06	3.097
2021	9.42E-06	3.022	6.09E-06	3.131	7.24E-06	3.091
2022	7.60E-06	3.078	6.40E-06	3.119	7.40E-06	3.088

Table 4. Landings (land) and discards (disc) from various sources and spatial areas (eastern Georges Bank [EGB], and total Georges Bank [TGB]) by the US and Canadian (Can) fisheries. (NA-not applicable; TAC-total allowable catch).

Year	EGB US Land	EGB US Disc	EGB US Total	EGB Can Land	EGB Can Disc	EGB Can Disc	Can Total	EGB TAC	TGB US Land	GB US Disc	GB US Total
1978	5,502	NA	5,502	8,777	98	NA	8,875	NA	10,231	96	10,327
1979	6,408	NA	6,408	5,979	103	NA	6,082	NA	12,546	91	12,637
1980	6,418	NA	6,418	8,066	83	NA	8,149	NA	15,479	112	15,591
1981	8,092	NA	8,092	8,508	98	NA	8,606	NA	15,433	108	15,541
1982	8,565	NA	8,565	17,827	71	NA	17,898	NA	15,137	97	15,234
1983	8,572	NA	8,572	12,131	65	NA	12,196	NA	15,890	94	15,984
1984	10,558	NA	10,558	5,761	68	NA	5,829	NA	16,826	80	16,906
1985	6,641	NA	6,641	10,442	103	NA	10,545	NA	11,610	116	11,726
1986	5,696	NA	5,696	8,504	51	NA	8,555	NA	8,298	97	8,395
1987	4,793	NA	4,793	11,844	76	NA	11,920	NA	9,020	103	9,123
1988	7,645	NA	7,645	12,741	83	NA	12,824	NA	13,306	127	13,433
1989	6,182	84	6,266	7,895	76	NA	7,971	NA	10,722	133	10,855
1990	6,414	69	6,483	14,364	70	NA	14,434	NA	11,567	126	11,693
1991	6,353	112	6,465	13,467	65	NA	13,532	NA	11,635	108	11,743
1992	5,080	177	5,257	11,667	71	NA	11,738	NA	8,593	188	8,781
1993	4,019	57	4,076	8,526	63	NA	8,589	NA	7,820	64	7,884
1994	998	5	1,003	5,277	63	NA	5,340	NA	4,226	31	4,257
1995	543	0	543	1,102	38	NA	1,140	NA	2,252	6	2,258
1996	676	1	677	1,924	56	0	1,980	NA	2,595	7	2,602
1997	549	6	555	2,919	58	428	3,405	NA	2,885	20	2,905
1998	679	7	686	1,907	92	273	2,272	NA	2,672	22	2,694
1999	1,195	9	1,204	1,818	85	253	2,156	NA	2,931	21	2,952
2000	772	16	788	1,572	69	0	1,641	NA	2,477	40	2,517
2001	1,488	146	1,634	2,143	143	0	2,286	NA	3,490	296	3,786
2002	1,688	9	1,697	1,278	94	0	1,372	NA	4,112	29	4,141
2003	1,851	85	1,936	1,317	200	NA	1,517	NA	3,582	132	3,714
2004	1,006	57	1,063	1,112	145	NA	1,257	1,300	1,772	73	1,845
2005	171	199	370	630	84	144	858	1,000	1,380	234	1,614
2006	131	94	225	1,096	112	237	1,445	1,700	1,231	134	1,365
2007	234	279	513	1,108	114	NA	1,222	1,900	1,656	512	2,168
2008	224	20	244	1,390	36	103	1,529	2,300	1,453	90	1,543
2009	433	147	580	1,003	69	137	1,209	1,700	1,807	235	2,042
2010	357	97	454	748	44	48	840	1,350	1,446	150	1,596
2011	267	20	287	702	29	13	744	1,050	1,339	54	1,393
2012	96	52	148	395	42	31	468	675	1,032	63	1,095
2013	24	16	40	385	18	21	424	600	509	43	552
2014	114	2	116	430	15	13	458	700	843	9	852
2015	111	5	116	472	13	7	492	650	783	22	805

Year	EGB US Land	EGB US Disc	EGB US Total	EGB Can Land	EGB Can Disc	EGB Can Disc	Can Total	EGB TAC	TGB US Land	GB US Disc	GB US Total
2016	92	5	97	428	9	3	440	624	626	19	645
2017	34	4	38	474	7	7	488	730	196	9	205
2018	47	2	49	510	5	2	517	951	221	7	228
2019	30	1	31	388	5	3	396	650	236	3	239
2020	64	3	67	362	11	4	377	650	216	9	225
2021	39	2	41	420	5	6	431	635	174	10	184
2022	34	3	37	309	10	7	326	571	NA	NA	NA

Table 5. Commercial fishery abundance catch-at-age for the Canadian groundfish fishery on Georges Bank, characterized using the Fisheries and Oceans Canada software application CATCH; a1– a16=ages 1, 2, etc.).

Year	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16
1978	1	71	2,341	720	216	76	57	12	11	3	1	1	0	0	0	0
1979	4	553	532	794	267	57	15	12	2	1	1	0	0	0	0	0
1980	1	705	1,078	201	499	135	31	14	26	13	3	1	0	0	0	0
1981	3	272	888	637	184	278	93	43	28	10	1	0	0	0	0	0
1982	7	2,200	1,455	901	689	154	234	105	30	8	17	3	0	3	1	0
1983	15	411	1,430	863	290	219	90	127	70	11	11	2	0	0	0	0
1984	0	25	133	380	258	156	95	18	35	15	7	3	0	2	0	0
1985	3	2,162	960	403	554	155	46	50	13	9	1	1	1	0	0	0
1986	10	244	1,359	396	157	240	38	22	12	2	1	0	0	0	0	0
1987	20	3,057	605	764	99	82	116	25	15	4	2	1	0	0	0	0
1988	18	229	2,726	345	411	63	72	129	43	15	10	3	0	0	0	0
1989	1	390	340	928	136	200	35	26	41	12	6	4	0	0	0	0
1990	8	429	2,108	702	834	88	93	7	9	20	2	2	1	0	0	0
1991	35	688	654	1,301	582	481	67	49	15	9	7	3	2	0	1	0
1992	44	1,747	918	293	550	204	216	38	28	3	4	2	1	0	0	0
1993	5	269	1,159	624	193	247	97	73	19	15	2	0	0	0	0	0
1994	3	149	358	640	229	38	50	25	17	1	1	0	0	0	0	0
1995	1	41	163	62	57	12	5	3	2	0	0	0	0	0	0	0
1996	1	28	170	283	55	38	11	3	2	0	0	0	0	0	0	0
1997	3	105	148	273	245	61	26	10	3	1	0	0	0	0	0	0
1998	0	58	210	102	95	80	16	9	3	1	0	1	0	0	0	0
1999	4	41	263	177	48	28	26	7	1	0	0	0	0	0	0	0
2000	0	30	59	238	95	23	14	8	2	0	0	0	0	0	0	0
2001	0	9	185	114	213	61	18	9	3	0	0	0	0	0	0	0
2002	0	3	35	145	42	76	14	5	2	1	0	0	0	0	0	0
2003	0	5	56	73	142	28	39	9	2	1	0	0	0	0	0	0
2004	0	3	60	64	54	73	18	19	4	1	0	0	0	0	0	0
2005	0	6	12	83	24	19	21	8	4	1	0	0	0	0	0	0
2006	0	3	111	44	125	32	14	14	2	1	0	0	0	0	0	0

Year	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16
2007	0	17	29	236	19	57	10	6	6	0	0	0	0	0	0	0
2008	0	18	96	48	201	13	29	4	2	1	0	0	0	0	0	0
2009	0	13	88	68	23	92	7	8	1	1	0	0	0	0	0	0
2010	0	8	47	129	45	10	20	2	1	0	0	0	0	0	0	0
2011	0	20	50	57	81	17	10	6	0	0	0	0	0	0	0	0
2012	0	18	50	27	20	21	5	1	1	0	0	0	0	0	0	0
2013	0	13	86	43	10	6	2	0	0	0	0	0	0	0	0	0
2014	0	11	59	70	18	2	0	0	0	0	0	0	0	0	0	0
2015	0	42	25	51	39	5	1	0	0	0	0	0	0	0	0	0
2016	0	7	84	12	27	20	3	0	0	0	0	0	0	0	0	0
2017	0	9	38	79	8	14	5	1	0	0	0	0	0	0	0	0
2018	1	12	26	43	61	5	5	3	0	0	0	0	0	0	0	0
2019	3	33	40	34	19	21	1	1	1	0	0	0	0	0	0	0
2020	5	27	69	27	17	5	3	0	0	0	0	0	0	0	0	0
2021	7	23	50	54	13	4	0	0	0	0	0	0	0	0	0	0
2022	1	19	30	31	15	3	1	0	0	0	0	0	0	0	0	0

Table 6. Commercial fishery weight-at-age for the Canadian groundfish fishery on Georges Bank, characterized using Fisheries and Oceans Canada software application CATCH. Units are kg; a1–a16=ages 1, 2, etc.

Year	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16
1978	0.7	1.2	2.1	2.7	3.4	5.6	5.9	9.3	8.4	12.7	14.6	15.3	13.6	12.2	18.1	19.7
1979	1.3	1.5	1.5	3.3	4.2	5.5	8.9	10.5	9.8	14.5	12.0	14.7	20.6	18.7	0	0
1980	0.6	1.2	2.3	3.1	4.8	6.2	6.7	12.3	11.2	12.5	16.9	17.8	0	0	0	0
1981	0.8	1.3	2.1	3.2	4.7	6.6	8.0	9.1	10.1	16.1	21.1	19.7	0	0	0	0
1982	0.6	1.4	2.1	3.7	5.1	6.7	8.5	10.0	11.7	13.6	16.0	17.3	20.9	17.3	19.9	0
1983	0.9	1.4	2.1	3.1	4.8	6.1	8.0	10.1	11.4	13.0	13.5	13.7	0	0	0	0
1984	0	1.5	2.5	3.8	5.0	6.1	8.1	9.7	10.8	11.8	15.3	15.6	21.2	20.8	0	18.7
1985	0.7	1.3	1.8	3.3	4.5	6.0	7.7	9.2	10.4	12.1	16.2	20.0	19.8	20.9	23.8	0
1986	0.7	1.5	2.7	3.6	5.2	6.8	7.9	8.9	9.3	8.8	11.5	19.7	0	0	0	0
1987	0.6	1.5	2.5	4.0	5.6	7.2	9.0	9.7	11.7	13.6	17.6	17.8	16.5	0	0	0
1988	0.7	1.1	2.2	3.4	5.0	6.3	8.8	10.3	11.4	12.8	15.5	16.5	18.7	27.5	0	0
1989	0.8	1.2	2.0	3.7	5.2	6.4	7.1	10.0	11.0	13.3	15.7	14.6	19.2	18.2	0	0
1990	0.8	1.7	2.6	3.4	4.8	6.1	7.8	10.4	11.5	13.1	15.5	15.3	17.6	0	18.7	0
1991	0.8	1.6	2.5	3.2	4.2	5.5	7.4	9.8	9.6	13.9	14.0	13.4	17.5	22.5	11.0	0
1992	0.9	1.5	2.3	3.5	4.4	5.9	7.0	8.8	11.6	15.2	13.8	17.5	16.8	0	0	0
1993	0.8	1.4	2.2	2.9	4.3	5.5	6.7	8.5	8.8	11.2	15.3	29.2	22.7	0	0	0
1994	0.8	1.4	2.2	3.6	4.5	6.5	7.3	8.1	7.7	10.9	12.2	0	0	0	0	0
1995	0.4	1.3	2.3	3.4	5.2	6.5	10.2	10.1	10.3	13.0	0	0	0	0	0	0
1996	0.9	1.5	2.2	3.1	5.0	6.0	6.6	8.9	10.4	11.7	11.8	0	0	0	0	0
1997	0.9	1.5	2.1	3.0	3.9	5.5	7.6	8.6	11.6	9.8	13.6	18.9	0	0	0	0

Year	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16
1998	0.7	1.4	2.2	3.0	4.0	5.5	6.7	8.1	10.4	13.6	15.7	14.0	17.6	0	0	0
1999	0.6	1.4	2.2	3.3	3.9	5.9	6.8	8.1	11.2	14.9	16.5	0.0	0	0	0	0
2000	0.7	1.5	2.1	3.0	4.2	4.9	5.9	7.3	8.9	14.1	11.1	18.5	0	17.3	0	0
2001	0.0	1.5	2.3	3.0	4.0	5.1	5.1	7.9	9.3	14.7	14.3	0	0	0	0	0
2002	0.7	1.4	2.3	3.1	4.4	5.1	6.9	8.1	8.7	9.7	13.8	12.9	0	22.1	0	0
2003	0.0	1.3	2.2	2.8	3.8	4.4	5.7	7.1	7.7	8.0	12.4	0.0	0	0	0	0
2004	0.7	1.4	2.0	2.8	3.4	4.6	5.5	7.4	9.0	8.9	11.5	14.9	0	19.4	19.9	24.3
2005	0.6	1.3	1.7	2.5	3.8	4.9	5.2	7.0	8.2	9.8	14.4	14.9	9.6	19.9	19.9	0
2006	0.1	1.1	1.9	2.4	3.5	4.6	6.3	5.9	7.3	7.2	8.8	8.7	0	0	0	0
2007	0.2	1.2	1.8	2.5	3.3	4.2	6.3	7.0	7.0	9.9	10.8	0	0	0	0	0
2008	0	1.3	2.1	2.8	3.7	5.0	5.9	8.0	8.0	8.7	10.4	0	22.7	0	0	0
2009	0	1.2	1.9	3.0	3.5	4.6	5.8	6.9	10.2	10.3	18.4	0	0	0	0	0
2010	0.6	1.2	1.9	2.5	3.3	3.5	5.3	6.1	9.5	10.9	13.5	21.3	0	0	0	0
2011	0.4	1.3	1.8	2.6	3.5	4.4	4.2	6.2	10.0	9.4	19.5	0	0	0	0	0
2012	0.4	1.2	2.0	3.0	3.8	4.1	4.7	5.7	5.4	5.2	0	0	0	0	0	0
2013	0.4	1.2	2.0	2.9	3.8	4.9	5.4	5.8	7.8	7.2	0	0	0	0	0	0
2014	0.4	1.2	2.2	2.9	4.0	5.6	6.0	7.7	0	0	0	0	0	0	0	0
2015	0.5	1.3	2.1	3.4	4.1	5.2	7.6	13.3	10.7	6.3	0	0	0	0	0	0
2016	0.5	1.1	1.9	3.2	4.5	4.5	5.8	7.6	15.2	0	0	0	0	0	0	0
2017	0.2	1.2	1.8	2.8	5.0	6.4	7.0	7.0	11.2	0	0	0	0	0	0	0
2018	0.6	1.2	1.9	3.0	3.8	5.4	7.1	6.7	9.2	0	8.9	0	0	0	0	0
2019	0.5	1.1	1.9	2.8	3.7	4.4	5.4	5.1	7.3	9.7	0	0	0	0	0	0
2020	0.6	1.3	2.2	3.0	3.3	4.1	4.9	5.3	8.1	0	0	0	0	0	0	0
2021	0.8	1.4	2.5	3.4	3.8	4.0	5.5	4.4	0.0	0	0	0	0	0	0	0
2022	0.6	1.5	2.5	3.8	4.4	5.1	5.0	7.4	12.8	0	0	0	0	0	0	0

Table 7. Commercial fishery length-at-age for the Canadian groundfish fishery on Georges Bank, characterized using CATCH application. Units are cm. Dashes indicate no data; a1–a16=ages 1, 2, etc.

Year	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16
1978	39.5	48.1	58.4	62.6	67.9	79.7	80.5	97.1	93.2	107.3	114.0	115.1	112.0	108.1	123.1	127.0
1979	49.0	51.6	52.7	68.0	74.3	80.8	95.8	101.7	99.4	114.3	107.3	115.0	124.0	124.0	—	—
1980	36.7	48.9	59.8	66.3	77.1	83.9	86.3	106.9	103.4	107.9	120.2	118.0	—	—	—	—
1981	42.6	49.2	58.1	67.4	77.2	86.6	92.2	96.4	98.8	111.2	129.9	127.0	—	—	—	—
1982	36.8	49.9	58.1	70.3	78.6	86.8	94.3	98.6	105.4	111.5	116.1	121.0	125.0	121.0	127.0	—
1983	43.7	50.7	58.7	66.8	77.4	84.5	92.7	100.3	104.7	108.9	111.3	112.4	—	—	—	—
1984	NA	52.1	62.5	72.0	78.3	84.2	92.8	98.5	102.5	105.6	115.5	115.3	130.0	128.2	—	119.9
1985	39.1	49.6	55.5	67.7	75.7	83.5	91.1	96.3	100.2	106.4	118.3	125.3	127.1	129.5	135.2	—
1986	40.8	52.6	63.6	70.5	79.2	86.8	92.3	95.9	96.4	95.7	104.8	127.0	—	—	—	—
1987	38.4	52.0	61.5	72.8	81.5	89.0	95.9	98.6	105.6	110.5	121.3	120.6	119.3	—	—	—
1988	39.8	47.7	59.6	68.6	78.2	85.0	95.8	101.1	104.6	108.8	116.1	118.9	124.5	142.0	—	—
1989	41.6	48.6	57.7	71.2	79.7	85.5	88.0	100.3	103.5	110.4	117.0	114.7	125.8	123.3	—	—
1990	41.0	54.3	62.9	68.7	77.0	83.5	91.1	101.8	105.1	110.0	116.7	115.9	121.9	—	124.7	—
1991	41.2	53.0	62.0	67.3	73.4	80.5	89.7	99.2	97.7	112.0	112.2	110.5	121.4	132.5	102.7	—
1992	43.7	51.6	60.5	69.2	74.8	82.8	87.3	94.3	104.6	115.0	112.3	121.1	120.2	—	—	—
1993	41.3	51.1	59.1	65.0	73.6	81.1	86.5	94.6	94.2	104.2	116.2	139.4	131.0	—	—	—
1994	42.9	50.1	59.5	69.7	75.2	85.0	89.2	91.8	89.4	102.4	106.8	—	—	—	—	—
1995	33.0	50.5	59.7	68.5	79.5	85.4	100.6	99.5	99.8	109.1	0.0	—	—	—	—	—
1996	43.9	51.2	59.2	66.5	77.5	83.2	84.8	93.4	100.7	105.6	106.0	—	—	—	—	—
1997	43.7	51.4	58.6	65.7	72.1	80.7	91.0	94.6	105.4	99.0	111.0	124.9	—	—	—	—
1998	40.0	50.7	59.3	65.4	72.5	80.9	86.3	92.4	101.1	110.9	114.1	111.8	121.6	—	—	—
1999	37.7	50.4	58.5	67.6	71.6	82.7	87.0	92.1	103.7	114.5	115.0	—	—	—	—	—
2000	40.0	51.3	58.4	65.6	73.1	76.9	82.3	88.2	94.6	112.2	102.3	124.0	—	121.0	—	—
2001	NA	51.7	59.8	65.2	72.1	78.0	77.9	90.6	96.8	111.7	109.7	—	—	—	—	—
2002	40.0	49.8	59.3	66.0	74.2	78.1	86.6	90.9	93.7	97.1	108.3	107.4	—	127.0	—	—
2003	NA	48.8	58.9	63.7	71.0	74.4	81.2	87.5	90.3	90.0	106.1	—	—	—	—	—
2004	40.1	49.8	56.9	64.1	67.9	75.1	80.3	88.6	95.0	94.3	104.1	114.6	—	123.2	127.0	136.0
2005	37.8	48.5	53.9	61.4	70.5	77.6	78.8	86.3	92.2	97.6	113.4	115.0	98.6	127.0	127.0	—
2006	16.0	45.9	55.7	60.7	68.6	75.3	84.7	82.9	89.2	89.0	95.5	94.9	—	—	—	—
2007	25.0	48.1	55.1	60.9	67.0	73.2	84.2	87.7	87.6	98.6	102.3	—	—	—	—	—
2008	NA	49.0	58.2	63.7	70.0	77.3	82.1	91.1	91.6	94.6	101.4	—	133.0	—	—	—
2009	NA	47.0	56.2	65.3	68.3	75.3	81.3	86.5	99.9	100.7	123.7	—	—	—	—	—
2010	37.0	47.9	56.2	61.3	67.6	68.5	79.5	83.1	97.6	102.7	110.6	130.0	—	—	—	—
2011	31.9	48.4	54.7	61.7	69.1	74.4	72.9	83.3	99.1	95.7	121.5	—	—	—	—	—
2012	33.5	48.3	56.3	64.8	70.2	72.8	76.2	82.4	80.3	81.3	—	—	—	—	—	—
2013	32.1	47.8	56.7	64.3	70.8	77.2	81.0	83.0	91.9	88.6	—	—	—	—	—	—
2014	34.0	47.8	57.8	62.6	69.3	77.6	81.2	87.5	—	—	—	—	—	—	—	—
2015	35.4	49.6	56.4	66.7	70.7	76.1	87.3	106.2	98.3	82.0	—	—	—	—	—	—
2016	35.2	47.3	55.8	66.8	74.6	74.9	82.5	91.2	115.7	—	—	—	—	—	—	—
2017	28.0	47.1	55.0	63.3	76.1	83.7	86.0	86.9	103.0	—	—	—	—	—	—	—

Year	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	a12	a13	a14	a15	a16
2018	37.3	47.4	55.4	63.8	68.8	76.9	84.3	82.7	93.4	—	94.0	—	—	—	—	—
2019	35.5	47.6	55.9	63.3	69.2	73.1	79.1	76.7	85.7	96.4	—	—	—	—	—	—
2020	39.2	49.1	58.6	64.4	66.9	71.8	75.9	78.7	90.4	—	—	—	—	—	—	—
2021	41.5	51.1	61.2	67.6	70.0	70.8	78.4	73.6	0.0	—	—	—	—	—	—	—
2022	39.4	51.7	61.6	70.3	73.8	76.7	76.9	87.0	104.6	—	—	—	—	—	—	—

Table 8. Number of successful stratified random sets per strata on the Fisheries and Oceans Canada winter ecosystem research vessel survey in Northwest Atlantic Fisheries Organization Division 5Z (1987–2023). The number of planned sets in the survey design is indicated in the final row. NA indicates not applicable.

Year	5Z1	5Z2	5Z3	5Z4	5Z5	5Z6	5Z7	5Z8	5Z9	Total
1987	9	7	7	11	9	5	12	8	NA	68
1988	24	28	16	16	12	11	15	10	NA	132
1989	18	25	12	15	12	9	16	9	NA	116
1990	23	22	14	16	13	8	17	10	NA	123
1991	23	25	13	17	12	14	18	10	NA	132
1992	11	32	11	15	4	10	5	3	NA	91
1993	10	36	11	6	NA	NA	NA	2	NA	65
1994	6	24	9	5	NA	NA	NA	1	NA	45
1995	9	32	11	12	5	10	4	2	NA	85
1996	9	33	14	13	4	9	3	1	NA	86
1997	9	32	11	15	5	11	4	3	NA	90
1998	10	37	16	13	5	9	4	2	NA	96
1999	8	31	10	15	3	8	4	3	NA	82
2000	10	35	15	15	5	12	5	3	NA	100
2001	9	33	9	13	3	3	3	3	NA	76
2002	10	34	5	15	5	12	5	3	NA	89
2003	11	37	15	13	4	11	4	3	NA	98
2004	10	35	11	12	4	8	3	2	NA	85
2005	14	48	25	20	4	12	5	3	NA	131
2006	12	39	14	20	NA	4	1	2	NA	92
2007	10	35	11	15	1	11	5	NA	NA	88
2008	8	26	11	12	2	6	2	2	NA	69
2009	6	19	12	13	5	9	4	NA	NA	68
2010	9	23	15	10	3	NA	NA	3	3	66
2011	10	35	14	15	5	10	5	3	2	99
2012	10	36	14	15	NA	NA	NA	3	4	82
2013	9	30	14	10	5	8	5	3	4	88
2014	6	24	11	11	3	7	3	2	4	71
2015	7	22	11	7	NA	NA	NA	NA	4	51
2016	8	25	15	13	5	9	4	3	5	87
2017	7	23	10	10	2	3	3	NA	4	62
2018	10	27	9	12	NA	NA	NA	NA	2	60

Year	5Z1	5Z2	5Z3	5Z4	5Z5	5Z6	5Z7	5Z8	5Z9	Total
2019	11	33	12	15	5	11	5	3	4	99
2020	8	27	11	13	NA	NA	NA	2	4	65
2021	8	26	11	9	NA	NA	NA	NA	2	56
2022	12	34	7	7	NA	NA	NA	NA	6	66
2023	13	38	13	14	NA	NA	NA	NA	3	81
Planned	10	35	15	15	5	12	5	3	4	104

Table 9a Number of successful stratified random sets per strata on the National Marine Fisheries Service fall surveys in Northwest Atlantic Fisheries Organization Division 5Z (1970–2022). The number of planned sets in the survey design is indicated in the final row.

Year	13	14	15	16	17	18	19	20	21	22	Total
1970	7	4	4	8	4	3	9	6	4	4	53
1971	9	4	3	11	4	3	9	6	4	4	57
1972	9	4	3	12	4	3	9	6	4	4	58
1973	9	4	3	11	4	3	9	6	4	4	57
1974	9	4	4	12	4	3	9	6	4	4	59
1975	9	4	3	11	4	3	9	6	4	4	57
1976	9	4	3	10	4	3	9	5	3	3	53
1977	10	4	3	17	7	1	11	7	8	4	72
1978	18	4	3	30	8	5	18	14	8	10	118
1979	18	4	2	20	4	3	18	12	8	8	97
1980	9	5	2	20	8	3	9	6	7	8	77
1981	9	4	2	10	4	3	9	9	4	5	59
1982	8	3	3	10	3	1	9	6	4	4	51
1983	9	5	2	9	3	3	9	6	4	4	54
1984	9	4	3	10	4	3	9	6	4	4	56
1985	9	4	2	10	4	3	8	5	4	4	53
1986	9	3	3	10	4	3	9	5	4	4	54
1987	10	3	1	10	3	2	9	6	4	4	52
1988	9	3	1	10	3	1	9	6	4	4	50
1989	9	3	1	10	3	1	9	6	4	4	50
1990	9	3	1	16	3	1	9	6	4	4	56
1991	9	3	1	10	3	1	9	5	4	4	49
1992	9	3	1	10	3	1	9	5	4	4	49
1993	9	3	1	10	3	1	9	6	3	5	50
1994	9	3	1	13	3	1	9	6	4	4	53
1995	9	3	1	11	3	1	9	6	4	4	51
1996	9	3	1	10	3	1	9	6	4	4	50
1997	9	3	1	10	3	1	9	6	4	4	50
1998	9	3	1	10	3	1	9	6	4	4	50
1999	9	3	1	10	3	1	9	6	4	4	50
2000	9	3	1	10	3	1	9	6	4	3	49
2001	9	3	1	10	3	1	9	6	4	4	50
2002	9	3	1	10	3	1	9	6	4	4	50
2003	9	3	1	11	2	1	9	6	4	4	50
2004	9	3	1	10	4	2	9	6	4	4	52
2005	9	3	1	10	3	2	9	6	4	4	51
2006	9	3	1	20	3	2	9	6	4	4	61
2007	9	3	1	20	3	2	9	6	4	4	61
2008	9	3	1	20	3	2	9	6	4	4	61
2009	10	4	2	14	4	2	9	6	4	4	59
2010	10	4	2	13	4	4	8	5	4	4	58
2011	9	4	3	12	4	4	7	5	4	4	56
2012	10	4	3	13	4	3	8	6	4	4	59
2013	10	3	3	14	4	4	9	6	4	4	61
2014	10	4	3	14	4	4	9	5	4	4	61
2015	10	4	3	14	4	4	9	6	4	4	62

Year	13	14	15	16	17	18	19	20	21	22	Total
2016	10	4	3	14	4	4	9	6	4	4	62
2017	10	4	3	10	4	4	5	4	3	4	51
2018	10	4	3	12	3	2	8	5	3	3	53
2019	10	4	2	14	4	4	8	5	4	4	59
2021	10	4	3	14	4	4	9	6	4	4	62
2022	7	3	3	10	4	4	7	4	3	4	49
Planned	10	4	3	14	4	4	8	6	7	4	64

Table 9b. Number of successful stratified random sets per strata on the National Marine Fisheries Service spring surveys in Northwest Atlantic Fisheries Organization Division 5Z (1970–2022). The number of planned sets in the survey design is indicated in the final row. Dashes indicate not applicable.

Year	13	14	15	16	17	18	19	20	21	22	Total
1970	9	4	3	10	4	3	8	5	4	4	54
1971	9	4	3	12	4	2	9	6	5	3	57
1972	8	4	3	13	4	3	9	6	4	5	59
1973	9	4	3	10	4	3	9	6	4	4	56
1974	8	3	3	10	3	3	9	6	5	2	52
1975	9	4	3	10	4	3	9	6	4	4	56
1976	9	4	3	10	3	2	9	6	4	4	54
1977	9	5	3	9	4	2	9	6	4	4	55
1978	9	5	3	12	4	3	9	6	4	5	60
1979	18	4	3	20	4	3	18	12	8	8	98
1980	8	4	3	10	5	2	9	6	4	4	55
1981	9	4	2	10	4	—	9	6	4	4	52
1982	9	4	3	10	4	3	9	6	4	4	56
1983	9	4	3	10	4	2	9	6	4	4	55
1984	9	4	3	11	4	3	9	6	4	4	57
1985	9	5	2	10	4	2	9	6	3	5	55
1986	8	4	3	10	4	3	9	6	4	4	55
1987	9	4	3	10	4	3	9	6	4	4	56
1988	9	3	1	10	3	1	9	6	4	4	50
1989	9	3	1	10	3	1	9	6	4	4	50
1990	9	3	1	10	3	—	9	6	4	4	49
1991	9	3	1	10	3	1	9	6	4	4	50
1992	9	3	1	10	3	1	9	6	4	4	50
1993	9	3	1	10	3	1	9	6	4	4	50
1994	9	3	1	10	3	1	9	6	4	4	50
1995	9	3	1	9	3	1	9	6	4	4	49
1996	9	3	1	10	3	1	9	6	4	4	50
1997	9	3	1	10	3	2	9	6	4	4	51
1998	9	3	1	10	3	1	9	6	4	4	50
1999	9	3	1	10	3	1	9	6	4	4	50
2000	9	3	1	10	3	1	9	6	4	4	50
2001	9	3	1	10	3	1	9	6	4	4	50
2002	9	3	1	10	3	1	9	6	3	4	49
2003	9	3	1	10	3	1	9	4	4	4	48
2004	9	3	1	10	3	1	9	6	4	4	50
2005	9	3	1	10	3	1	9	6	4	4	50
2006	9	3	1	10	3	2	9	6	4	4	51
2007	9	3	1	20	3	2	9	6	4	4	61
2008	9	3	1	20	3	1	9	6	4	4	60
2009	9	4	3	14	3	3	9	6	4	4	59
2010	10	4	3	14	3	3	9	5	4	3	58
2011	10	4	3	13	4	4	9	5	4	4	60
2012	9	4	3	12	4	4	9	5	4	3	57
2013	15	4	3	13	5	4	9	6	4	4	67
2014	8	3	2	12	4	3	8	4	4	4	52
2015	10	4	3	14	4	3	8	6	4	4	60
2016	10	3	2	14	4	4	9	6	4	4	60
2017	10	4	3	14	4	4	9	5	4	4	61

Year	13	14	15	16	17	18	19	20	21	22	Total
2018	5	3	2	11	4	3	5	2	4	4	43
2019	10	4	3	14	4	4	8	6	4	4	61
2021	8	3	3	14	4	4	8	6	4	4	58
2022	10	4	3	14	4	4	9	6	4	4	62
Planned	10	4	3	14	4	4	8	6	7	4	64

Table 10. Available aggregated survey indices for eastern Georges Bank (EGB) and total Georges Bank (TGB) spatial units from Fisheries and Oceans Canada (DFO) winter and National Marine Fisheries Service (NMFS) spring and fall surveys. Length-based conversion factors (Miller et al. 2010) have been applied to account for vessel and trawl door changes in the NMFS surveys for EGB. Dashes indicate no data or index available. The mean kg/tow indices are a data product of the US Cod Research Track.

Year	EGB DFO Winter swept area biomass (mt)	EGB NMFS Spring swept area biomass (mt)	EGB NMFS Fall swept area biomass (mt)	TGB DFO Winter Mean (kg/tow)	TGB NMFS Spring Mean (kg/tow)	TGB NMFS Fall Mean (kg/tow)
1970	—	7,801	5,054	—	8.95	5.65
1971	—	10,435	5,287	—	9.65	3.13
1972	—	13,779	3,947	—	12.43	3.51
1973	—	82,311	11,697	—	74.61	9.71
1974	—	27,269	2,741	—	25.52	3.47
1975	—	23,503	5,246	—	18.47	3.66
1976	—	10,354	5,082	—	12.12	4.05
1977	—	9,335	9,509	—	10.31	7.71
1978	—	22,731	12,213	—	34.69	12.43
1979	—	12,831	13,050	—	18.23	13.14
1980	—	20,520	4,494	—	28.76	3.88
1981	—	18,568	7,256	—	29.07	7.69
1982	—	172,300	2,216	—	133.60	2.25
1983	—	20,376	2,449	—	24.55	1.97
1984	—	4,808	7,018	—	14.86	7.30
1985	—	23,190	2,390	—	26.65	2.85
1986	18,633	12,532	2,174	18,633	16.52	2.69
1987	8,824	7,615	2,634	11,924	10.42	3.60
1988	19,452	9,294	6,764	28,689	14.90	5.70
1989	14,547	12,104	5,145	37,192	12.01	4.18
1990	56,665	10,828	5,121	75,007	12.64	5.17
1991	25,068	9,391	435	42,819	10.49	0.56
1992	14,581	6,113	1,734	34,064	7.33	1.70
1993	16,545	6,598	606	16,545	6.96	0.96
1994	13,140	1,294	1,734	13,140	1.23	2.35
1995	8,118	10,113	1,220	9,660	9.24	1.86
1996	32,173	6,613	1,790	34,371	8.30	2.13
1997	11,004	4,051	1,875	14,025	3.99	1.44
1998	5,006	12,267	2,970	5,583	11.32	2.05

Year	EGB DFO Winter swept area biomass (mt)	EGB NMFS Spring swept area biomass (mt)	EGB NMFS Fall swept area biomass (mt)	TGB DFO Winter Mean (kg/tow)	TGB NMFS Spring Mean (kg/tow)	TGB NMFS Fall Mean (kg/tow)
1999	9,178	5,308	1,044	12,429	5.53	1.05
2000	32,298	7,374	895	36,841	8.04	0.96
2001	18,037	3,721	1,159	19,939	4.19	1.13
2002	20,333	4,432	11,525	21,115	5.26	10.67
2003	6,218	6,405	608	8,009	5.28	0.85
2004	5,661	21,080	8,347	11,066	19.20	7.36
2005	26,200	4,407	1,446	26,952	5.55	1.42
2006	12,546	7,331	2,165	12,692	6.43	1.99
2007	11,228	6,066	424	13,249	5.81	0.48
2008	13,657	5,327	792	19,004	4.95	0.73
2009	23,180	4,104	1,135	23,180	3.66	0.96
2010	26,352	3,402	668	26,553	3.75	0.54
2011	8,437	1,579	1,900	9,144	2.26	2.17
2012	2,449	4,299	490	2,566	4.89	0.65
2013	11,113	2,702	2,141	11,364	7.78	2.09
2014	2,409	2,849	1,233	2,646	4.27	1.16
2015	3,594	1,549	2,852	3,594	1.65	3.49
2016	3,656	2,897	4,986	4,640	3.84	4.44
2017	14,566	12,909	525	15,557	14.93	0.85
2018	7,198	2,773	2,182	7,692	3.45	2.09
2019	4,059	7,748	1,309	5,275	8.01	1.99
2020	4,214	NA	NA	4,214	—	—
2021	1,821	2,512	790	1,852	2.79	0.88
2022	—	3,307	788	NA	3.48	—
2023	1,891	—	—	1,935	—	—

Table 11. Area estimates in square nautical miles (nm²) of Fisheries and Oceans Canada (DFO) survey strata bisected by various DFO statistical unit boundaries. The number of trawlable units (TrwlUnit) within each area is estimated based on a standard tow by the CCGS research vessels Needler/Teleost fishing the Western IIA trawl.

Strata	Unit Area	Area (nm ²)	TrwlUnit
5Z1	5ZEJM	795	67,369
5Z2	5ZEJM	1,252	106,096
5Z3_jm	5ZEJM	1,504	127,451
5Z3_hn	5ZEHN	791	67,030
5Z4_jm	5ZEJM	1,350	114,401
5Z4_hn	5ZEHN	1,729	146,518
5Z5_go	5ZEGO	1,470	124,599
5Z5_hn	5ZEHN	866	73,357

Strata	Unit Area	Area (nm²)	TrwlUnit
5Z6_go	5ZEGO	628	53,247
5Z6_hn	5ZEHN	1,010	85,559
5Z7_hn	5ZEHN	1,050	89,013
5Z7_go	5ZEGO	2,149	182,075
5Z8_jm	5ZEJM	236	19,999
5Z8_hn	5ZEHN	1,080	91,542
5Z8_go	5ZEGO	698	59,128

FIGURES

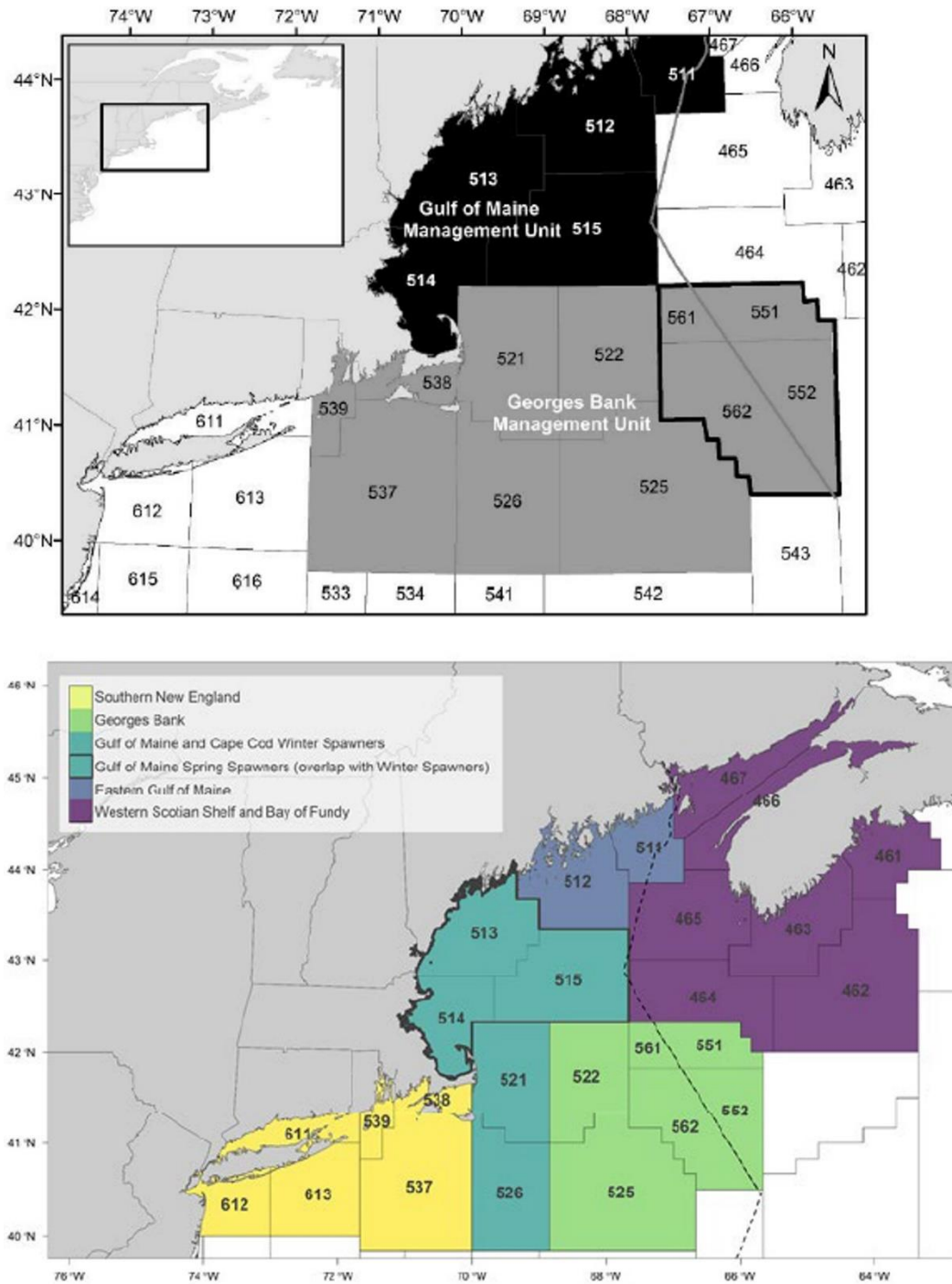


Figure 1. The original (upper panel) and revised (lower panel) biological stock structure of Atlantic Cod in US waters (Northwest Atlantic Fisheries Organization (NAFO) Subareas 5 and 6). Figures originally from McBride and Smedbol (2022). Dashed/grey line represents the Hague Line.

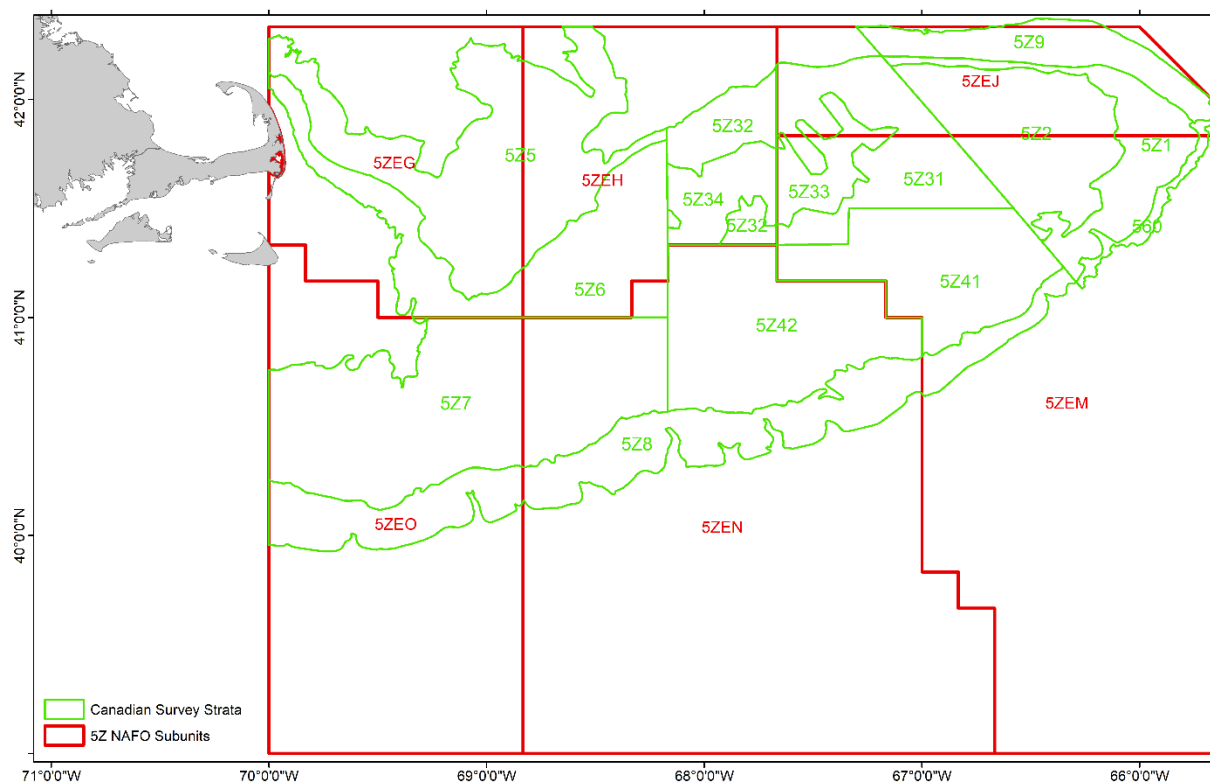


Figure 2. Winter Fisheries and Oceans Canada (DFO) RV Survey strata in 5Z (green). No sets are made in the shoals of Georges Bank (5Z33, 5Z34). Red lines represent DFO statistical areas and generally align with US statistical areas as follows: 5ZEJ = 551+561, 5ZEM = 552 + 562, 5ZEH = 522, 5ZEN = 525, 5ZEG = 521, 5ZEO = 526.

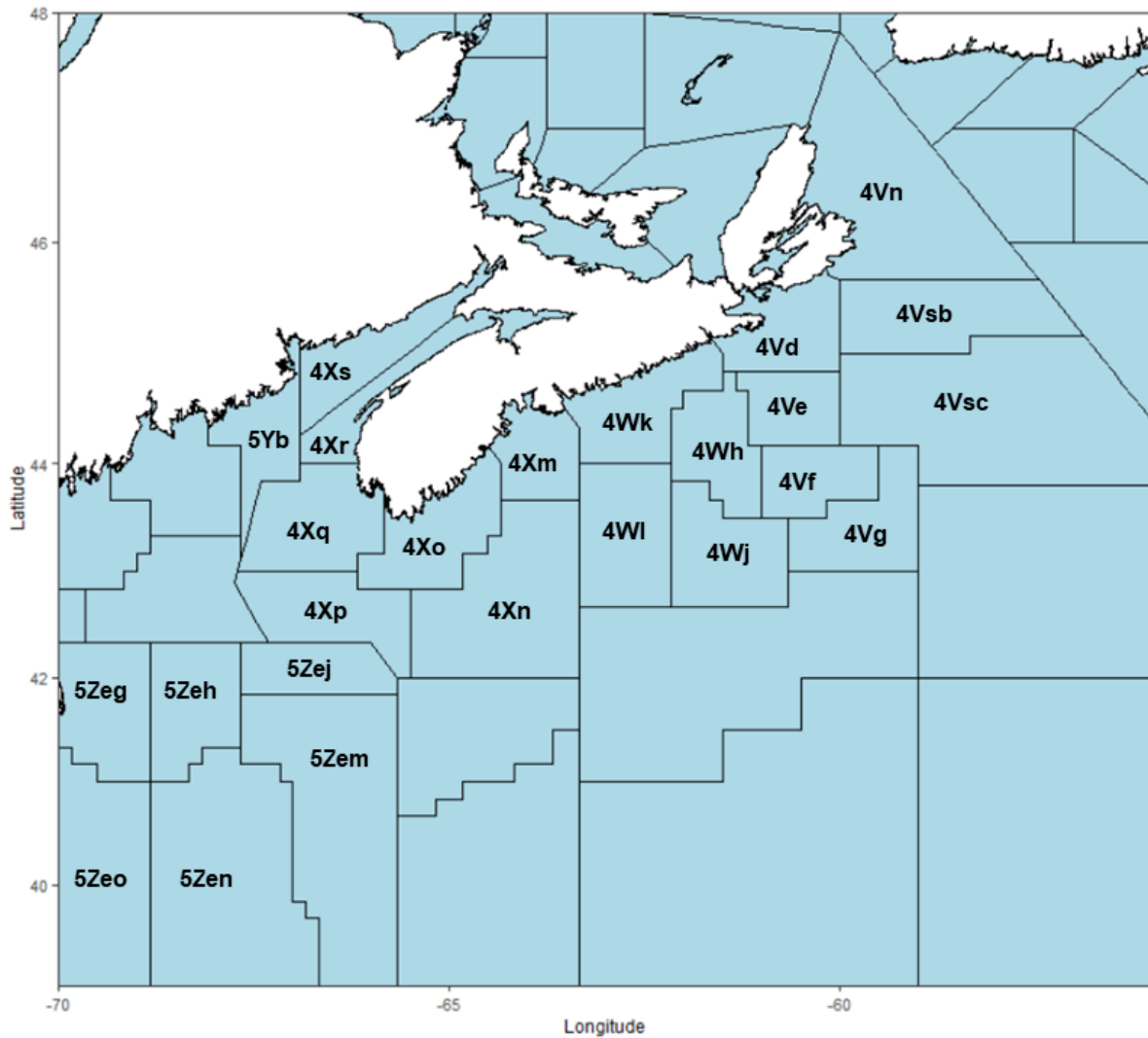


Figure 3. Northwest Atlantic Fisheries Organization (NAFO) Divisions (e.g., 4X) and their respective subunits (e.g., 4Xm), from Georges Bank to Cape Breton.

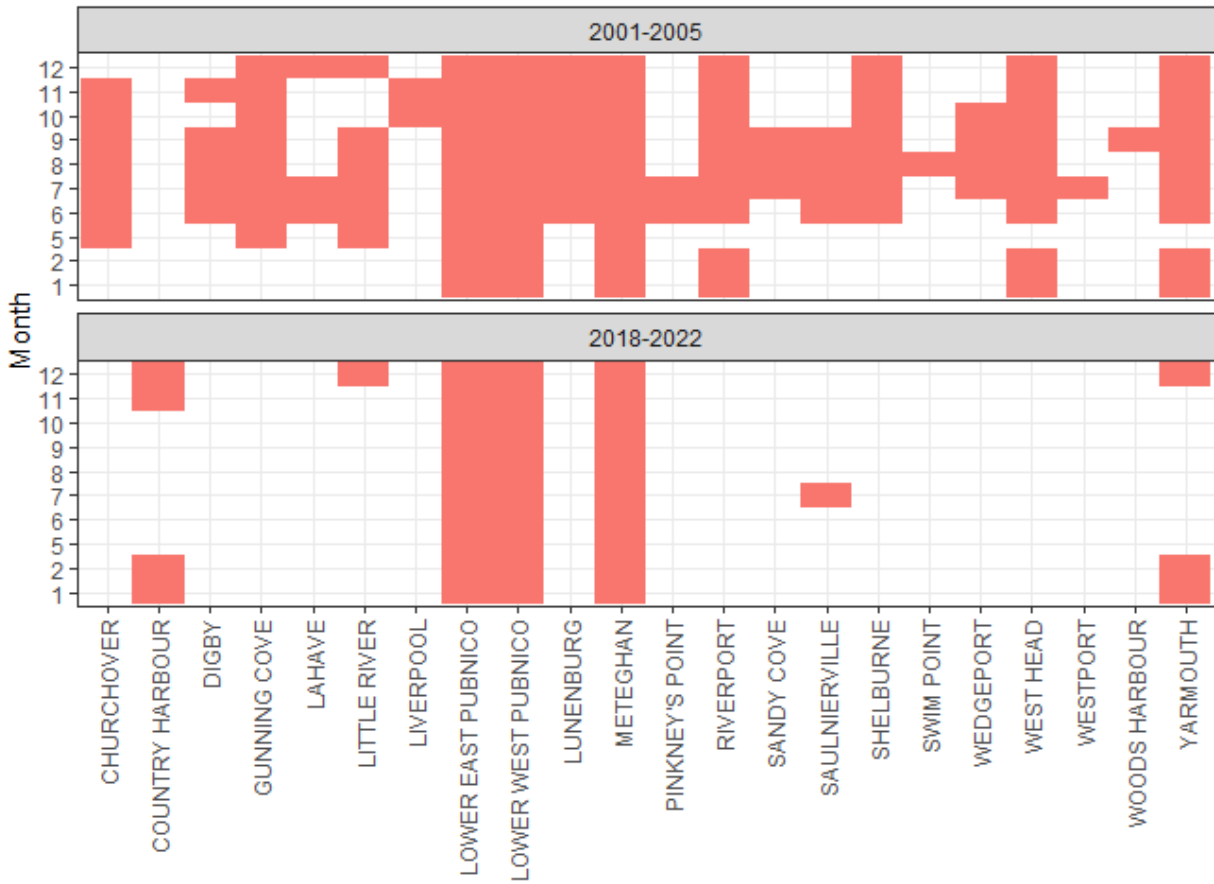


Figure 4. Centralization of Canadian ports where 5Z Cod is landed by mobile gear over time. Upper panel shows ports and months where 5Z Cod was landed from 2001 to 2005, while bottom panel shows ports and months where 5Z Cod was landed from 2018 to 2022. Red indicates Cod landed, while white indicates no Cod landed.

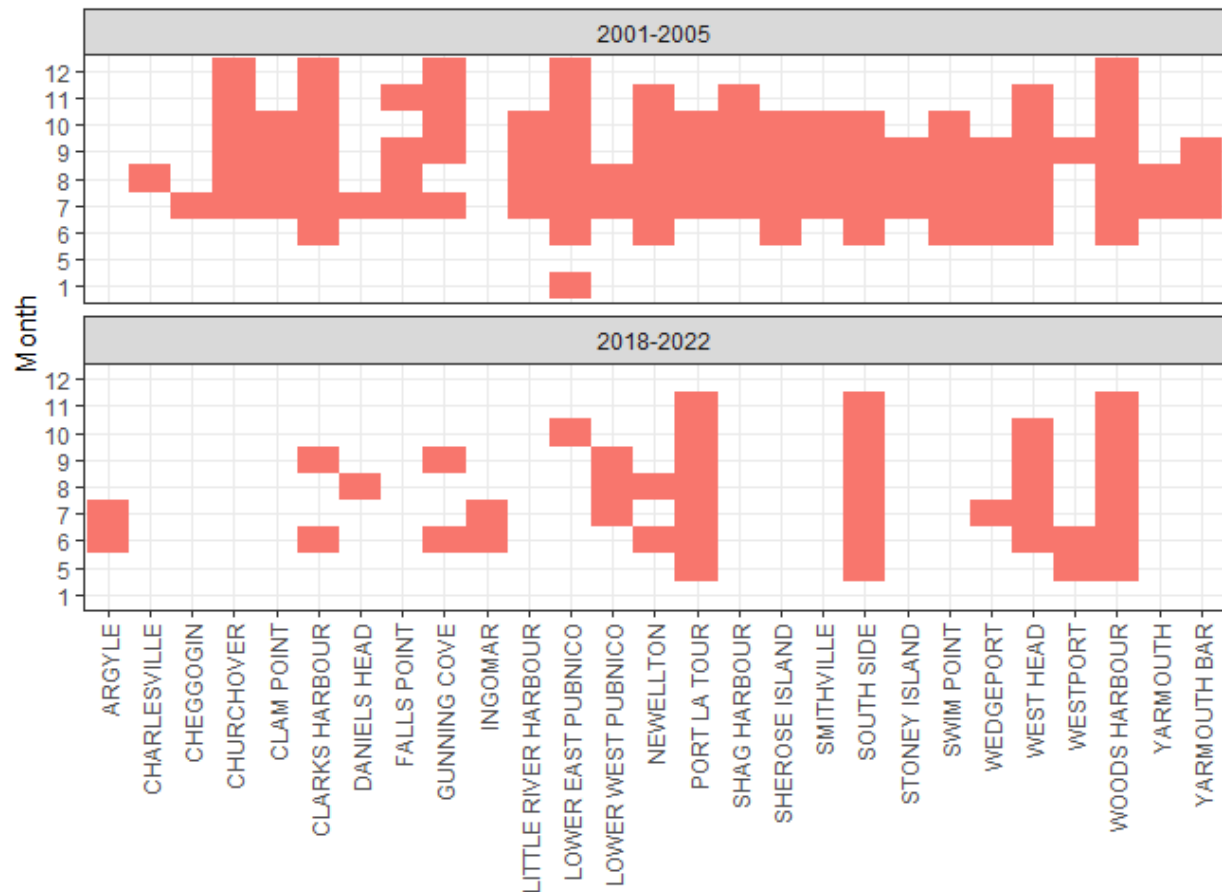


Figure 5. Centralization of Canadian ports where 5Z Cod is landed by fixed gear over time. Upper panel shows ports and months where 5Z Cod was landed from 2001 to 2005, while bottom panel shows ports and months where 5Z Cod was landed from 2018 to 2022. Red indicates Cod landed, while white indicates no Cod landed.

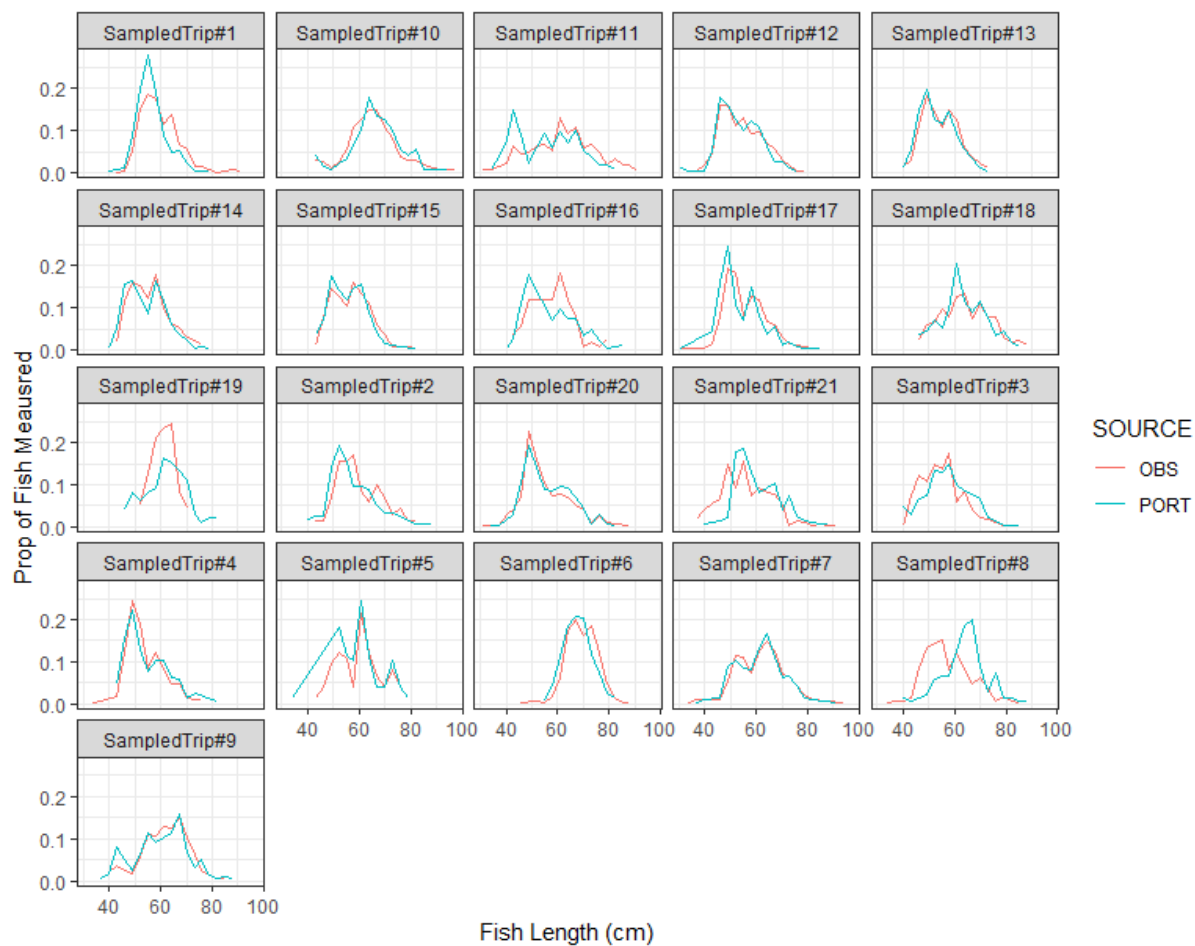


Figure 6. Proportion of fish measured at length for 5Z Cod collected by port samples (PORT) and at-sea observers (OBS) from the same commercial fishing trip. Each facet is a trip sampled by both 2021 and 2022.

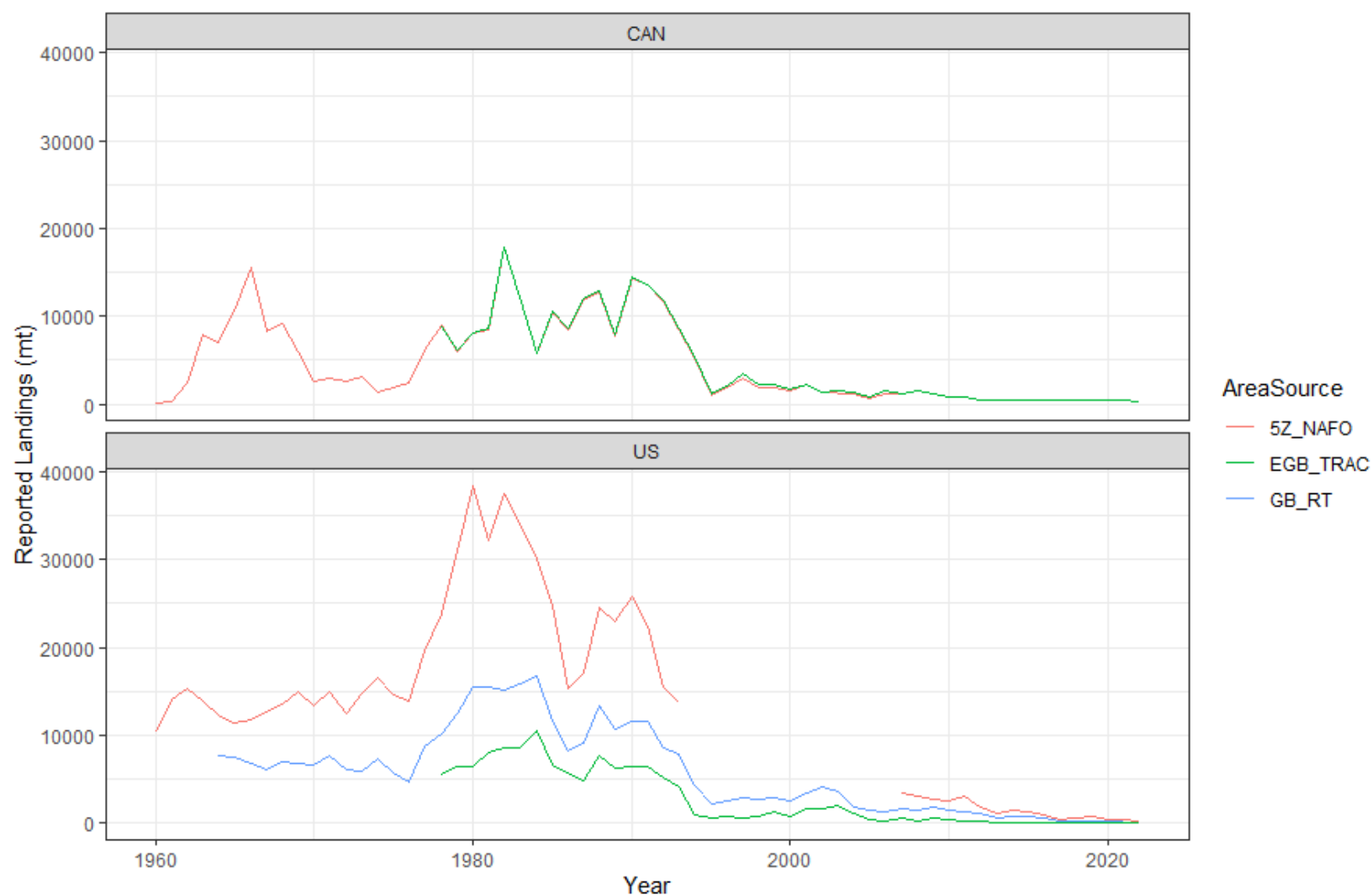


Figure 7. Commercial landings (mt) of cod for Canada(CAN) and US by area and data source (colours). Sources of various landings datasets are: Transboundary Resources Assessment Committee (TRAC)–TRAC 2023 RT–Cod Research Track Report (Final Report Ref), and Northwest Atlantic Fisheries Organization (NAFO) is an extract of NAFO STATLANT 21A/B data (NAFO 2023) completed on October 3, 2023. Canadian landings represent an extraction from the commercial landings and Maritimes Fisheries Information System (MARFIS) databases.

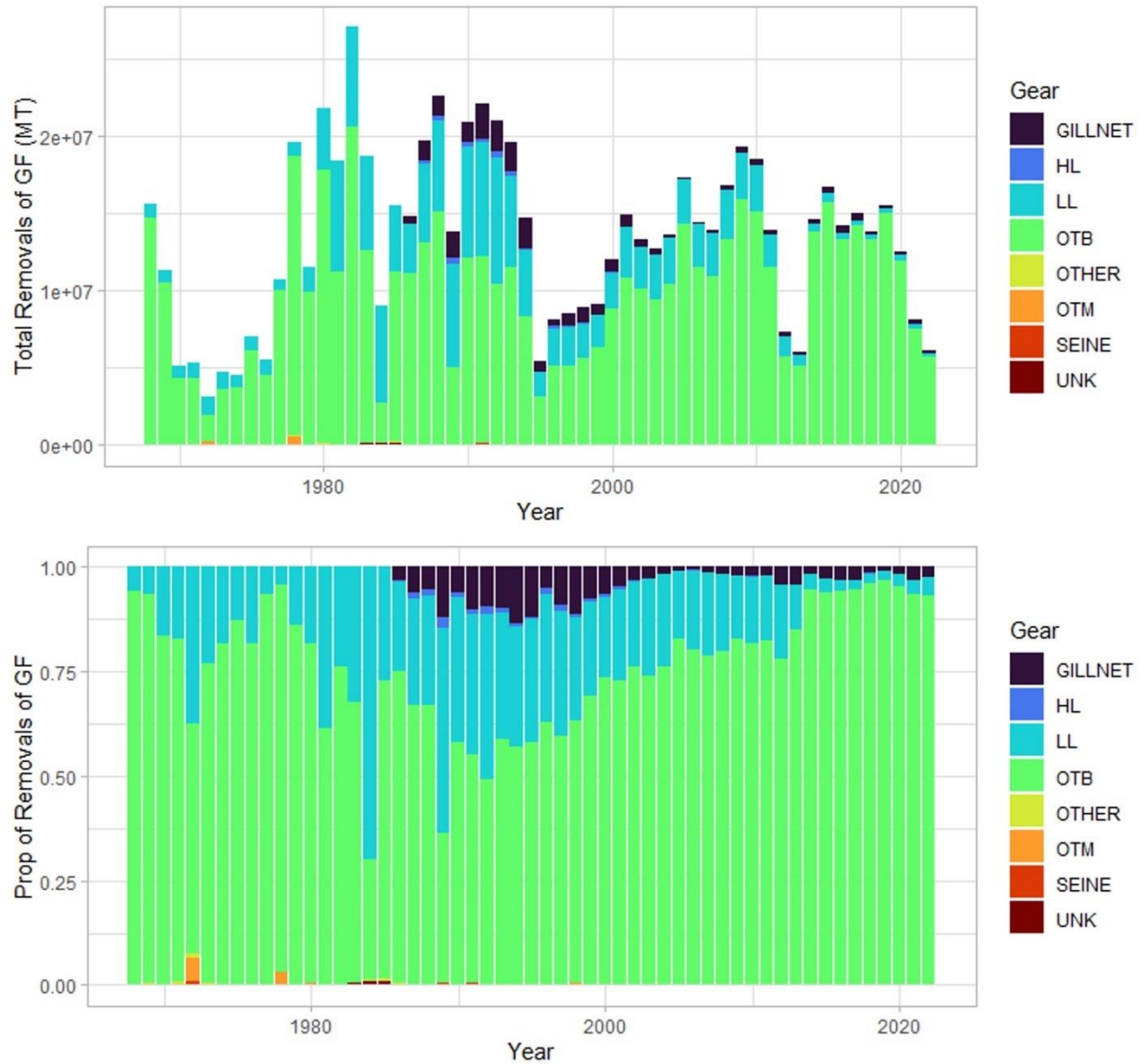


Figure 8. Landings of 5Z groundfish (GF) by various types of gear. Top panel denotes totals, while bottom panel denotes proportion of totals. Gears are HL=Handline, LL=longline, OTB=bottom trawl, OTM=midwater trawl, Seine=Danish/Scottish seine, Gillnet=gillnet, Unknown (UNK) indicates no record.

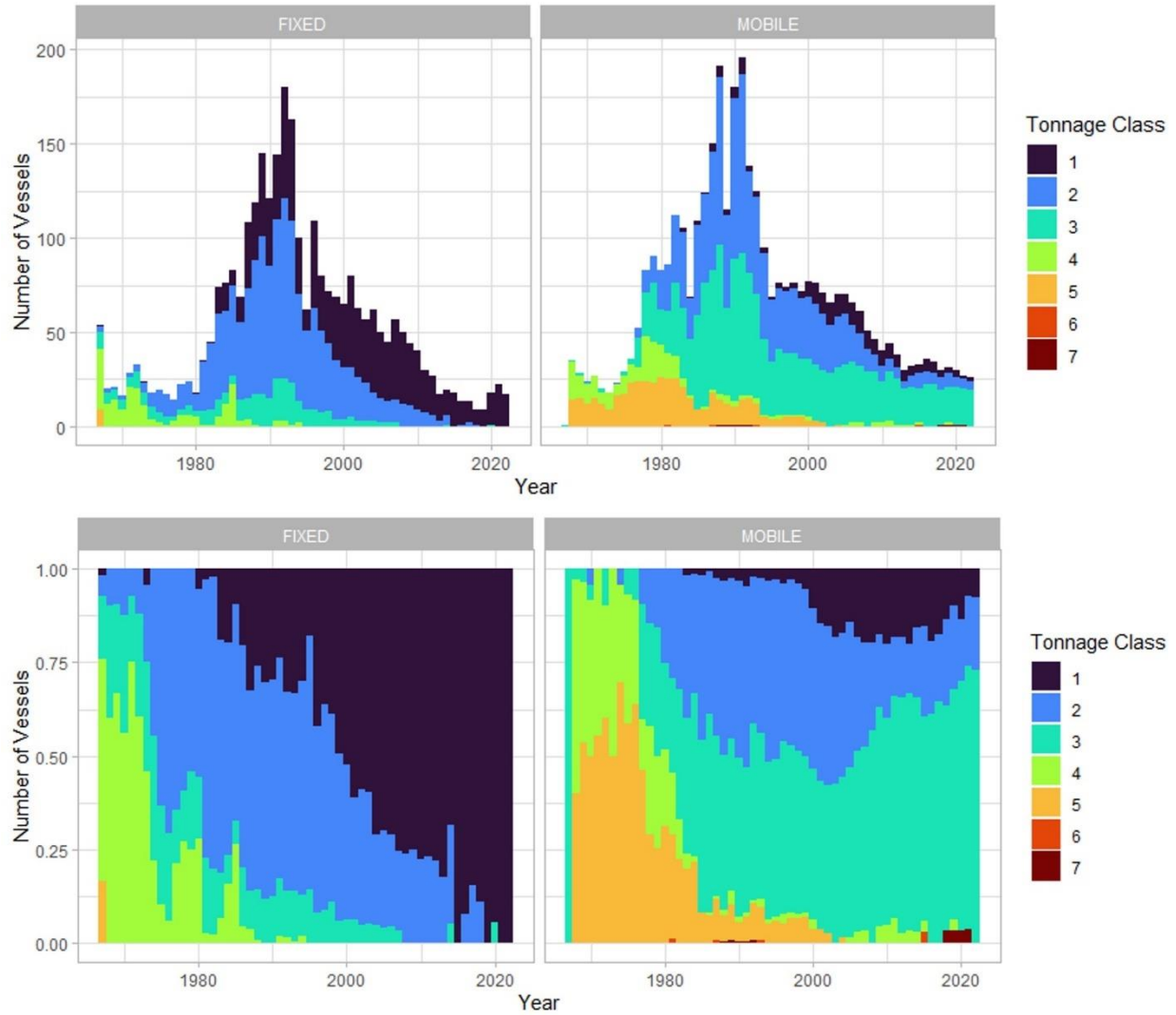


Figure 9. The number (upper panel) and proportion (lower panel) of groundfish vessels fishing yearly in Northwest Atlantic Fisheries Organization (NAFO) Division 5Z, with Tonnage Class 0 (unknown) excluded, separated by gear type. The colours refer to the tonnage class (size) of vessels, as defined in Table 2.

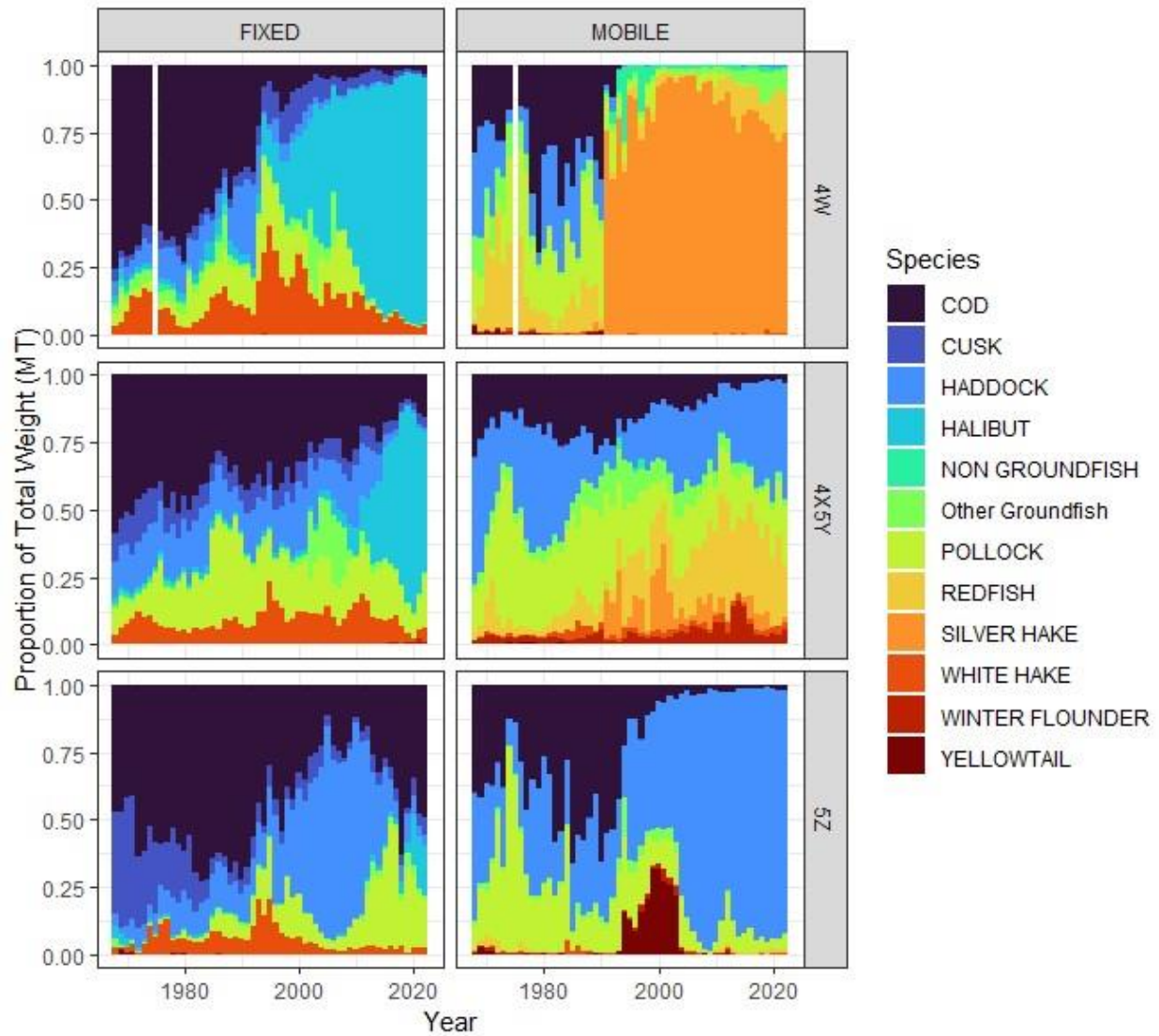


Figure 10. Proportion of total landings attributed to various commercial species by the major gear classes in the groundfish fishery and Northwest Atlantic Fisheries Organization (NAFO) divisions across years.

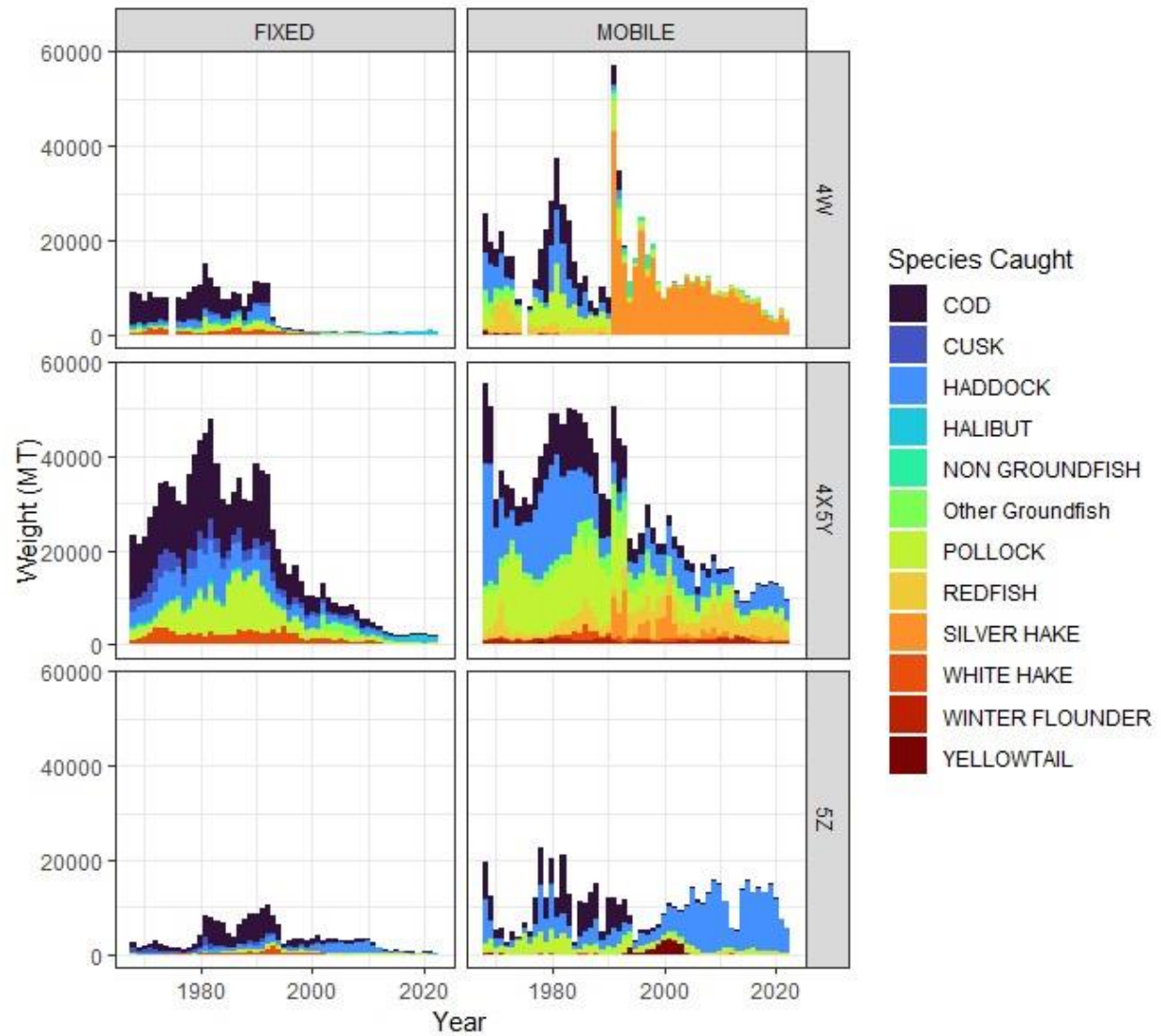


Figure 11. Total landings of various commercial species by the major gear classes in the groundfish fishery and Northwest Atlantic Fisheries Organization (NAFO) divisions across years.

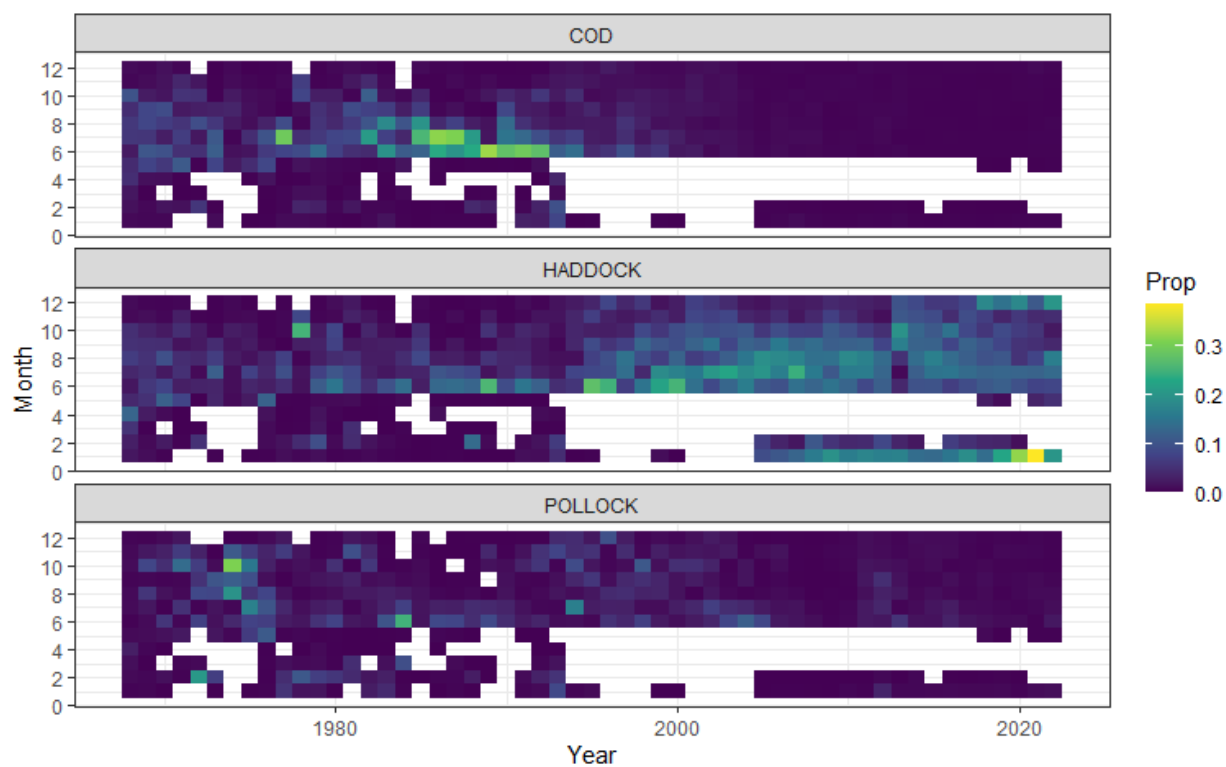


Figure 12. Proportion of total annual landings (calendar year) by month of three major groundfish species on Georges Bank by mobile gear. White cells indicate absence of fishing activity.

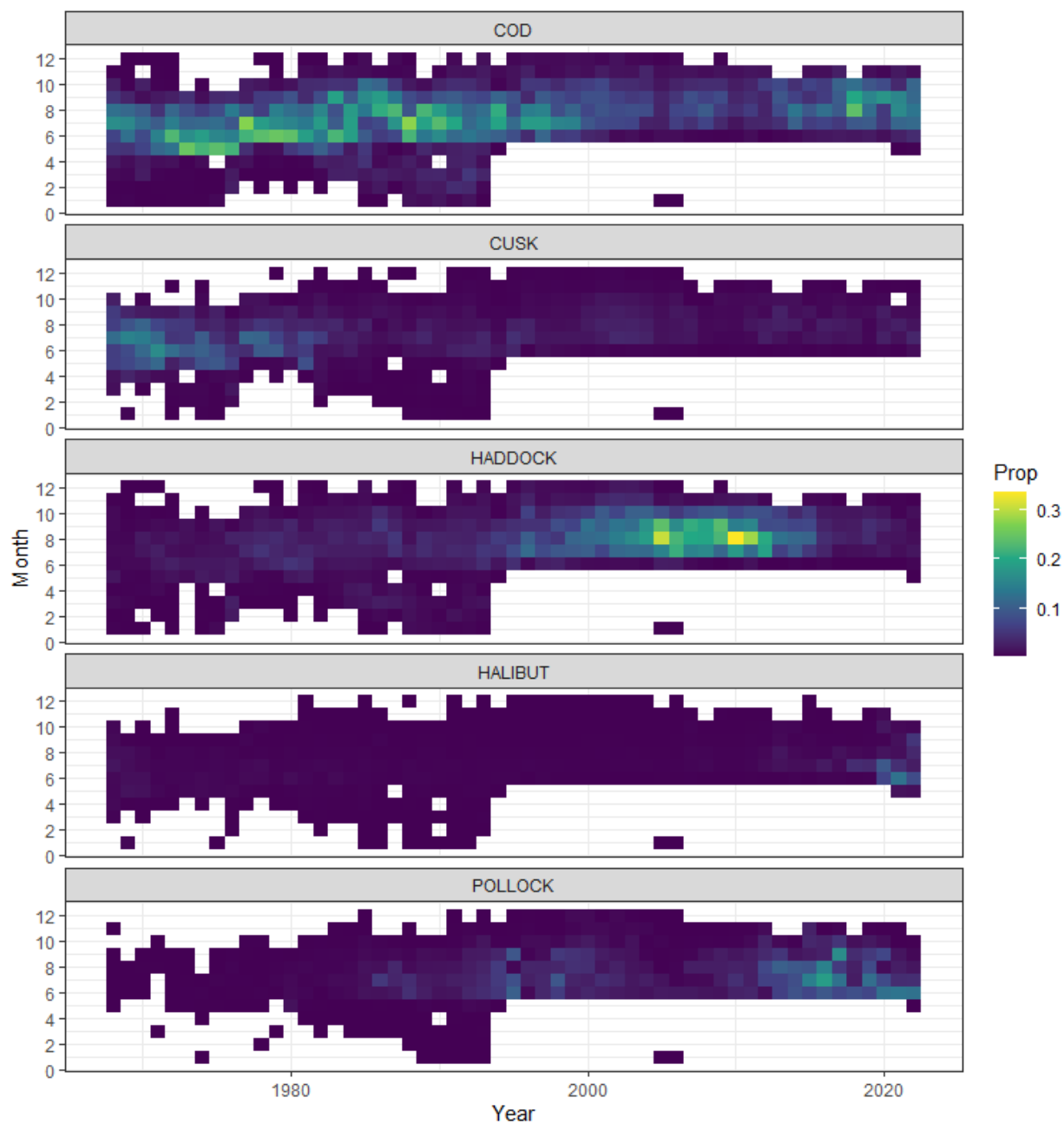


Figure 13. Proportion of total annual landings (calendar year) by month of three major groundfish species on Georges Bank by fixed gear. White cells indicate absence of fishing activity.

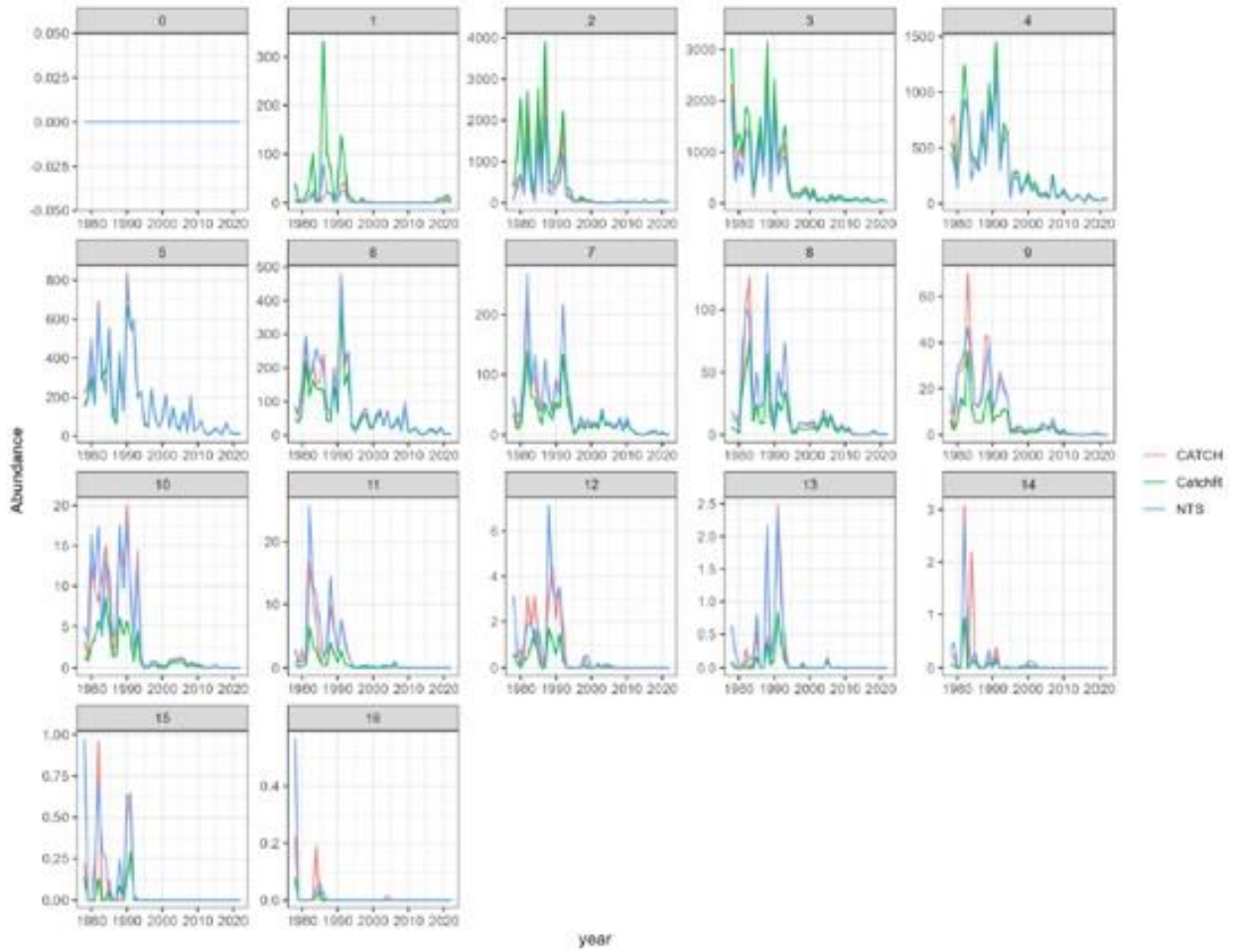


Figure 14. Catch-at-age for eastern Georges Bank Cod from the Canadian groundfish fishery, characterized by three software applications (CATCH, CatchR, NTS) and faceted by age.

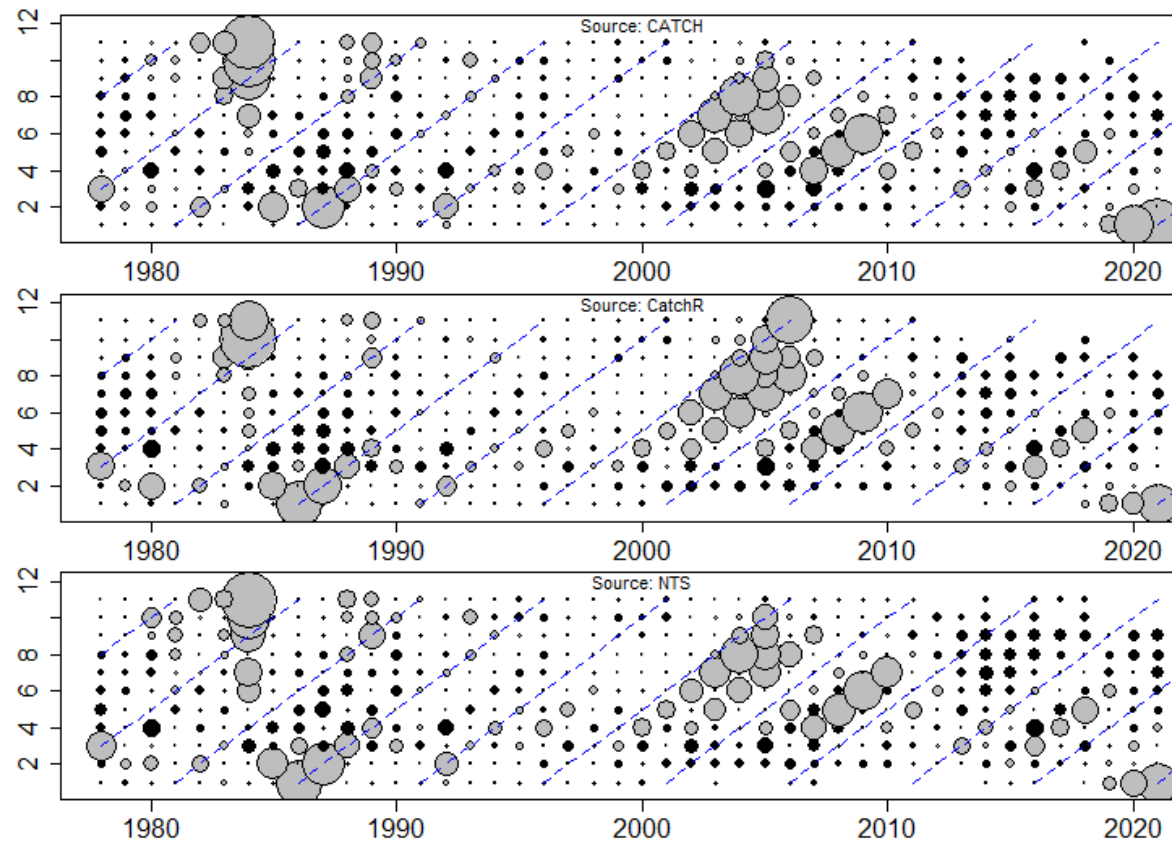


Figure 15. Standardized proportions by age (y-axis) across years (SPAY) plots of Canadian commercial groundfish fishery catch-at-age for Cod characterized using the three applications (CATCH , CatchR, NTS). Grey circles identify values greater than average and black circles identify values smaller than average; average values appear as small dots.

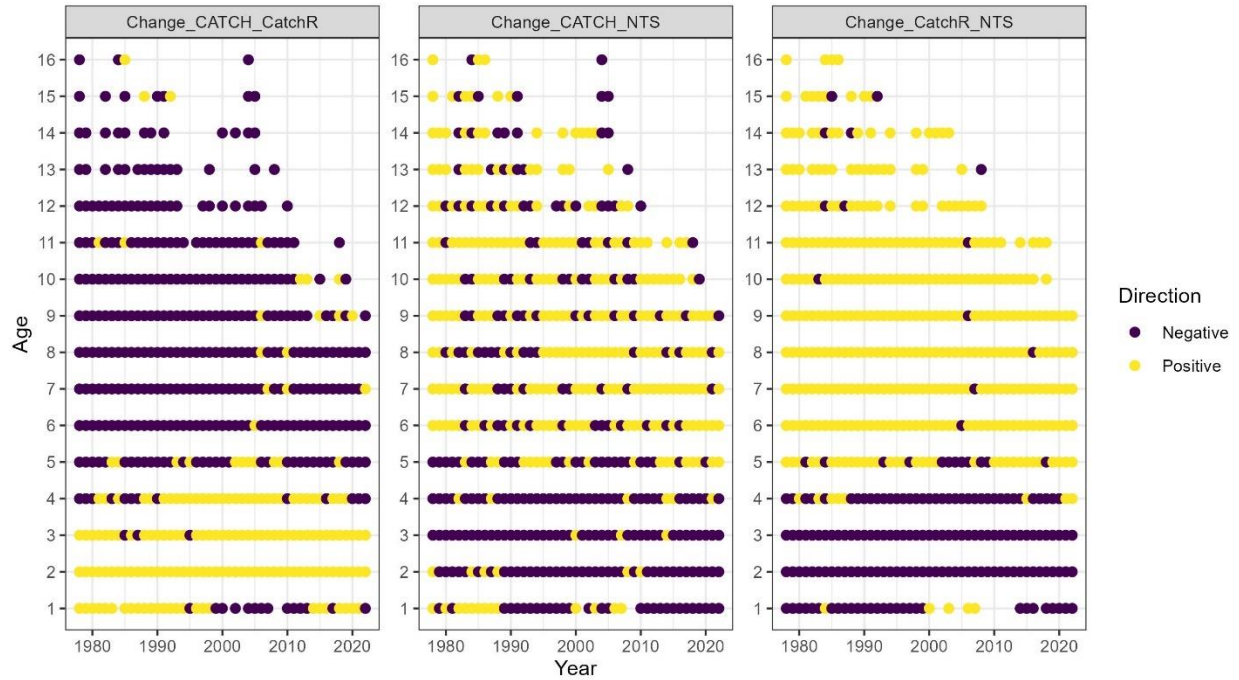


Figure 16. Directionality of change when comparing the three applications. The title of each panel identifies which two applications the plot applies to, while the colour shows the direction of the change: purple=negative change; yellow=positive change.

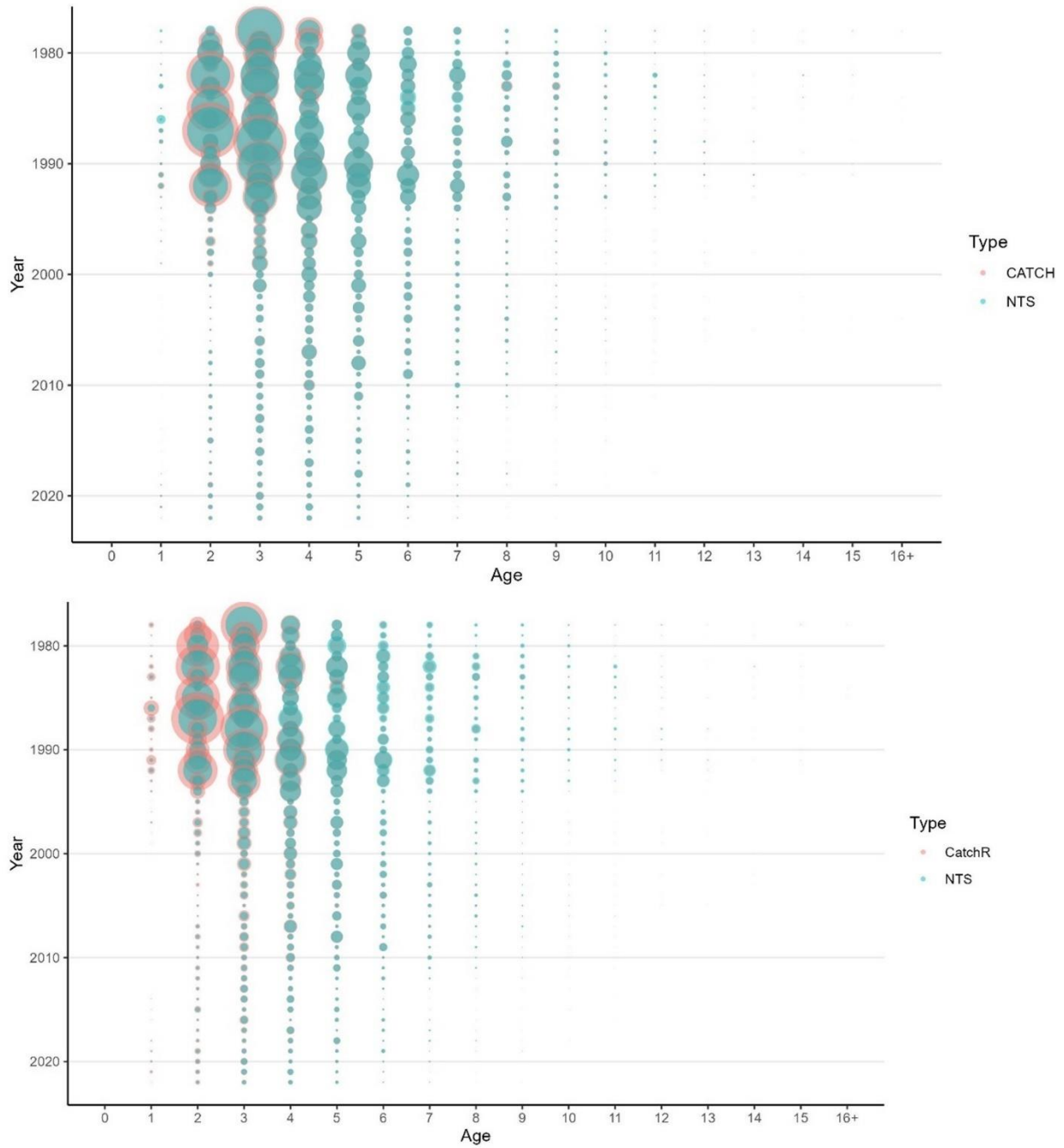


Figure 17. Comparison of numbers-at-age outputs between CATCH-NTS applications (upper panel), and CatchR-NTS applications (lower panel). Size of bubble is proportional to abundance.

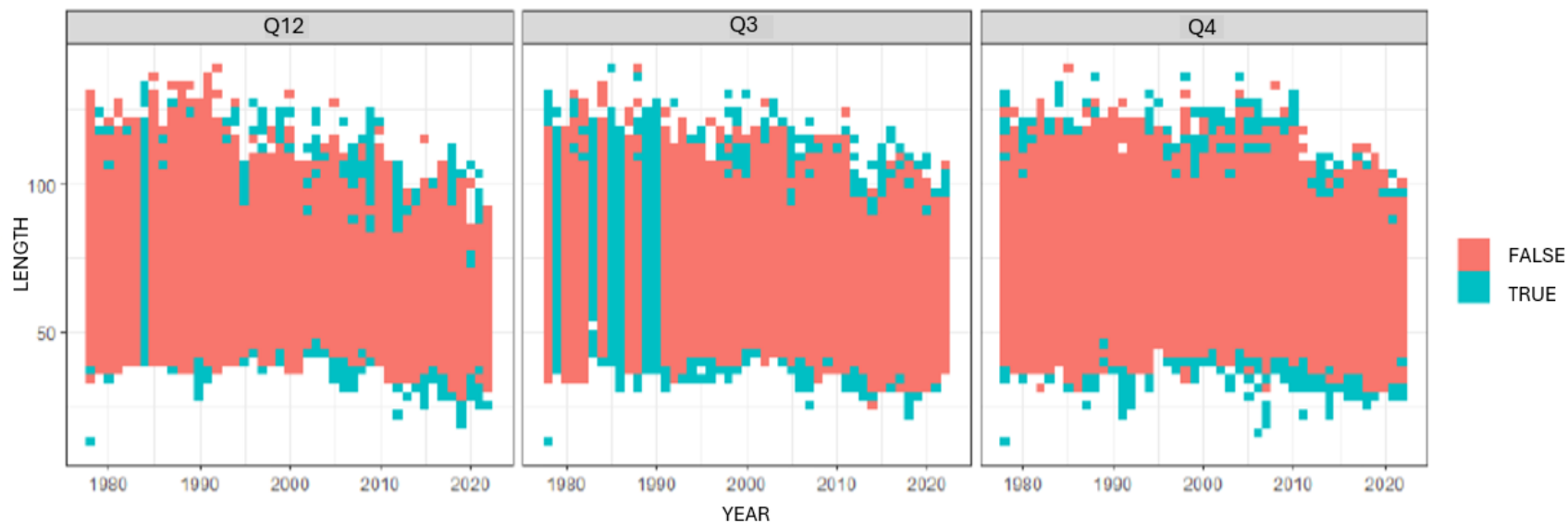


Figure 18. The occurrence of length-age fills in the Canadian catch-at-age calculation. “TRUE” represents lengths at which ages were borrowed from adjacent years or quarters, while “FALSE” represents lengths at which data was present and did not need to be borrowed. Q=fishing year quarter.

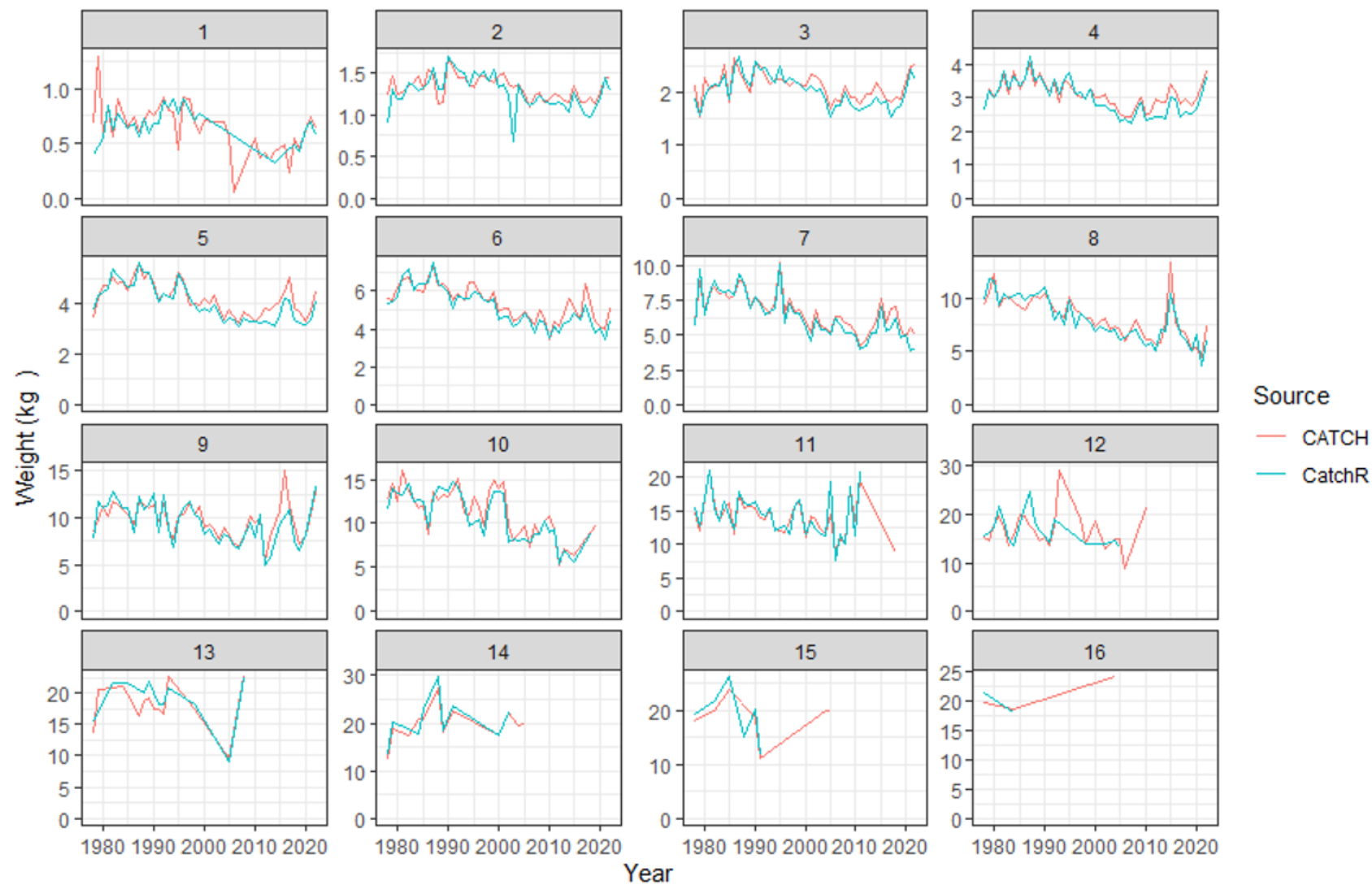


Figure 19. Commercial fishery weight-at-age by the CATCH and CatchR applications for the Canadian catch of eastern Georges Bank Cod.

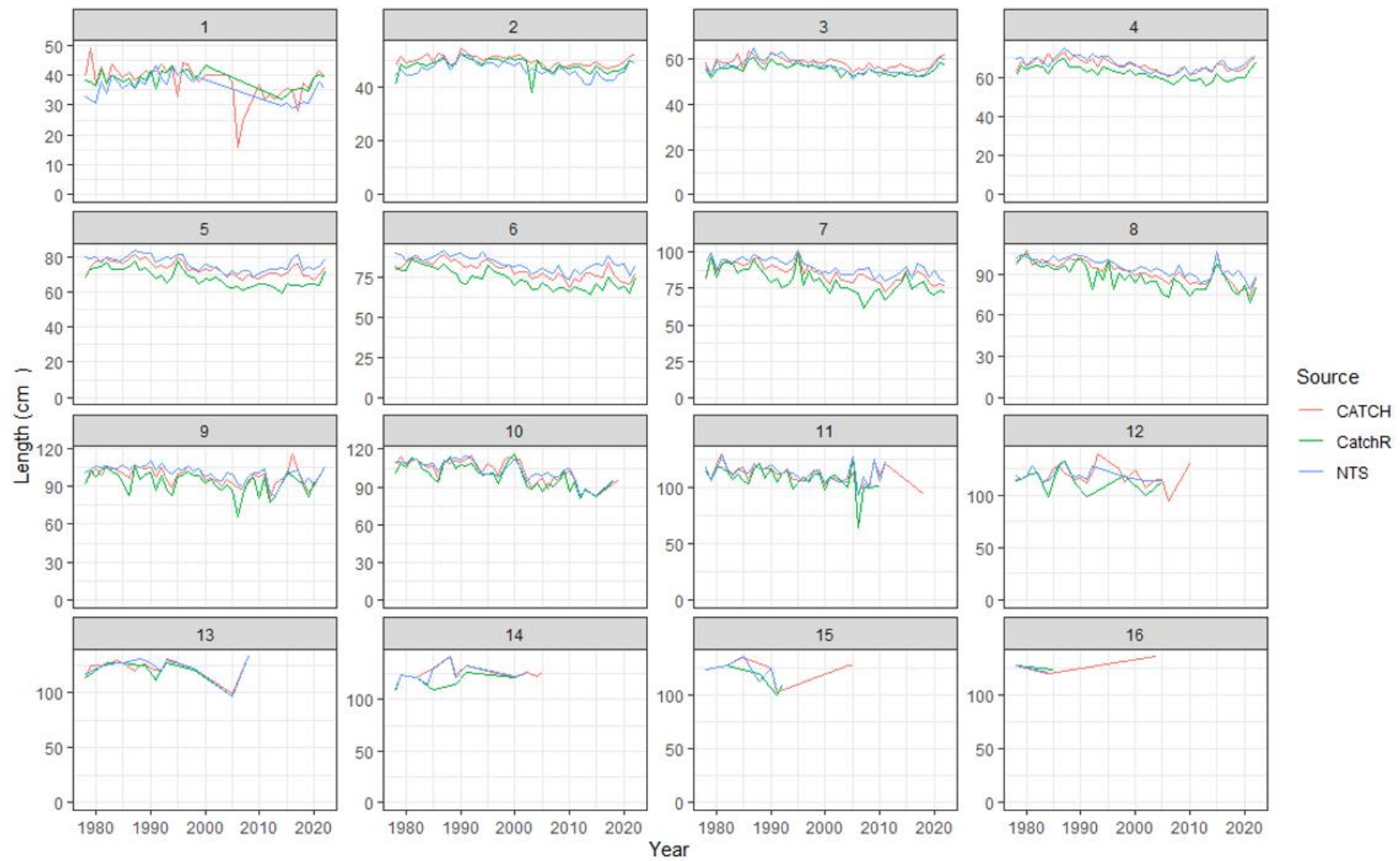


Figure 20. Commercial fishery length-at-age by the Catch, CatchR, and NTS applications for the Canadian catch of eastern Georges Bank Cod.

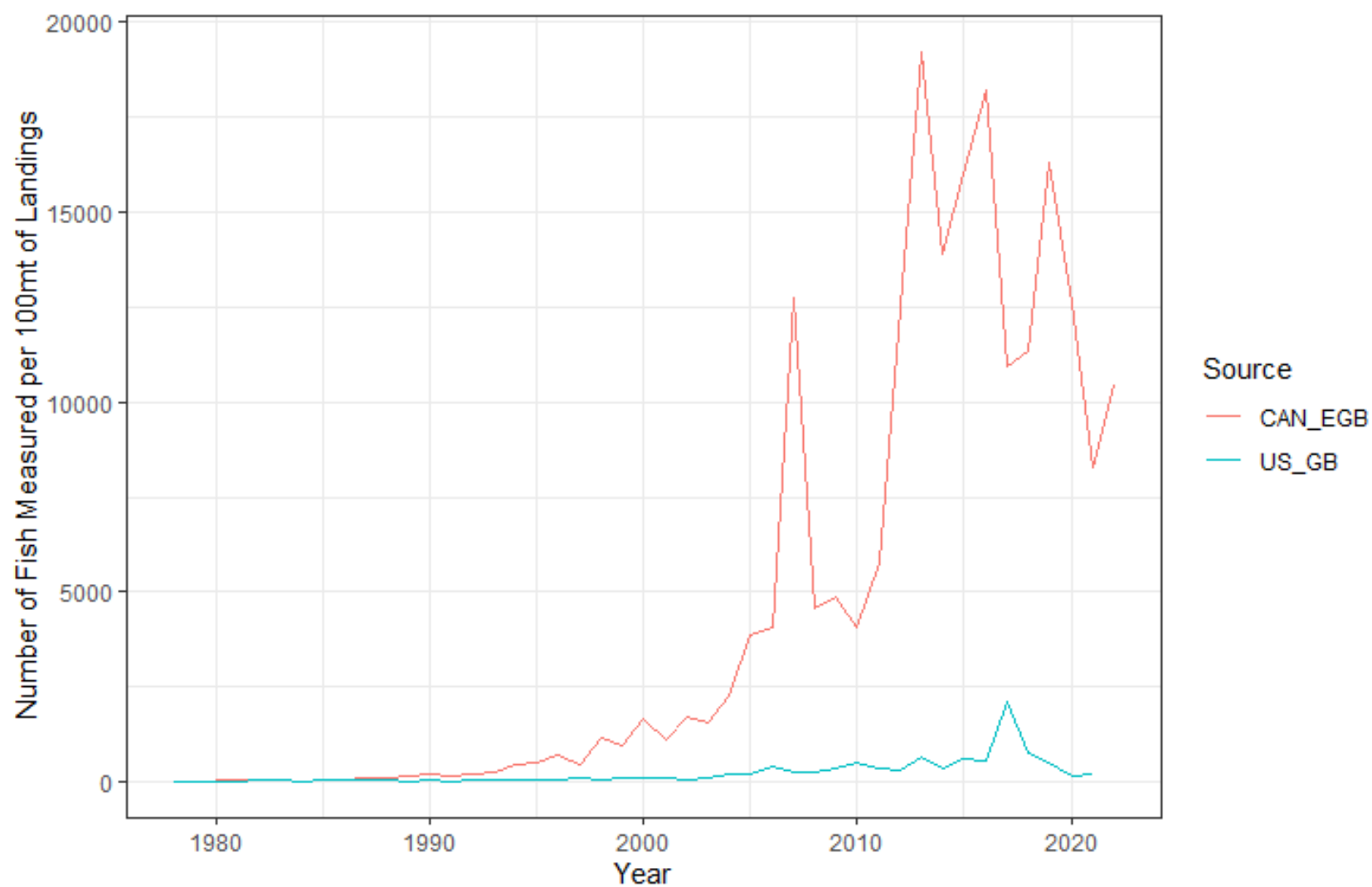


Figure 21. Sampling intensity of the US (US_GB, blue line) and Canadian (CAN_EGB, red line) commercial catch, expressed as the number of Cod measured per 100 mt of cod landings. The US fishery spans total Georges Bank (GB), as the number of fish sampled on eastern Georges Bank (EGB) only is not available.

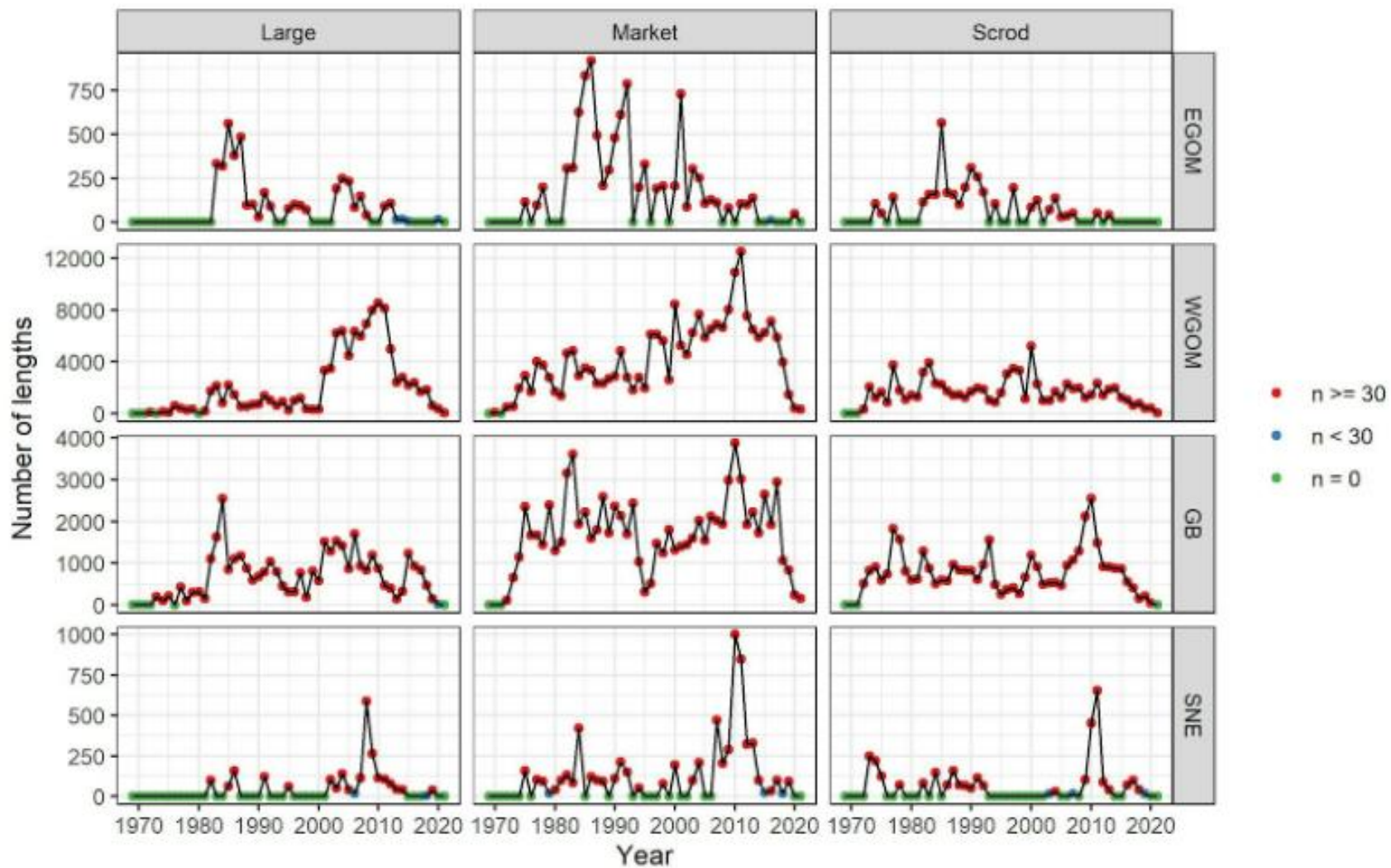


Figure 22. Number of length samples from US commercial landings, by market category (large, market, scrod) and stock area (EGOM—eastern Gulf of Maine, WGOM—western Gulf of Maine, GB—Georges Bank, SNE—southern New England). Figure originally from NEFSC (2023).

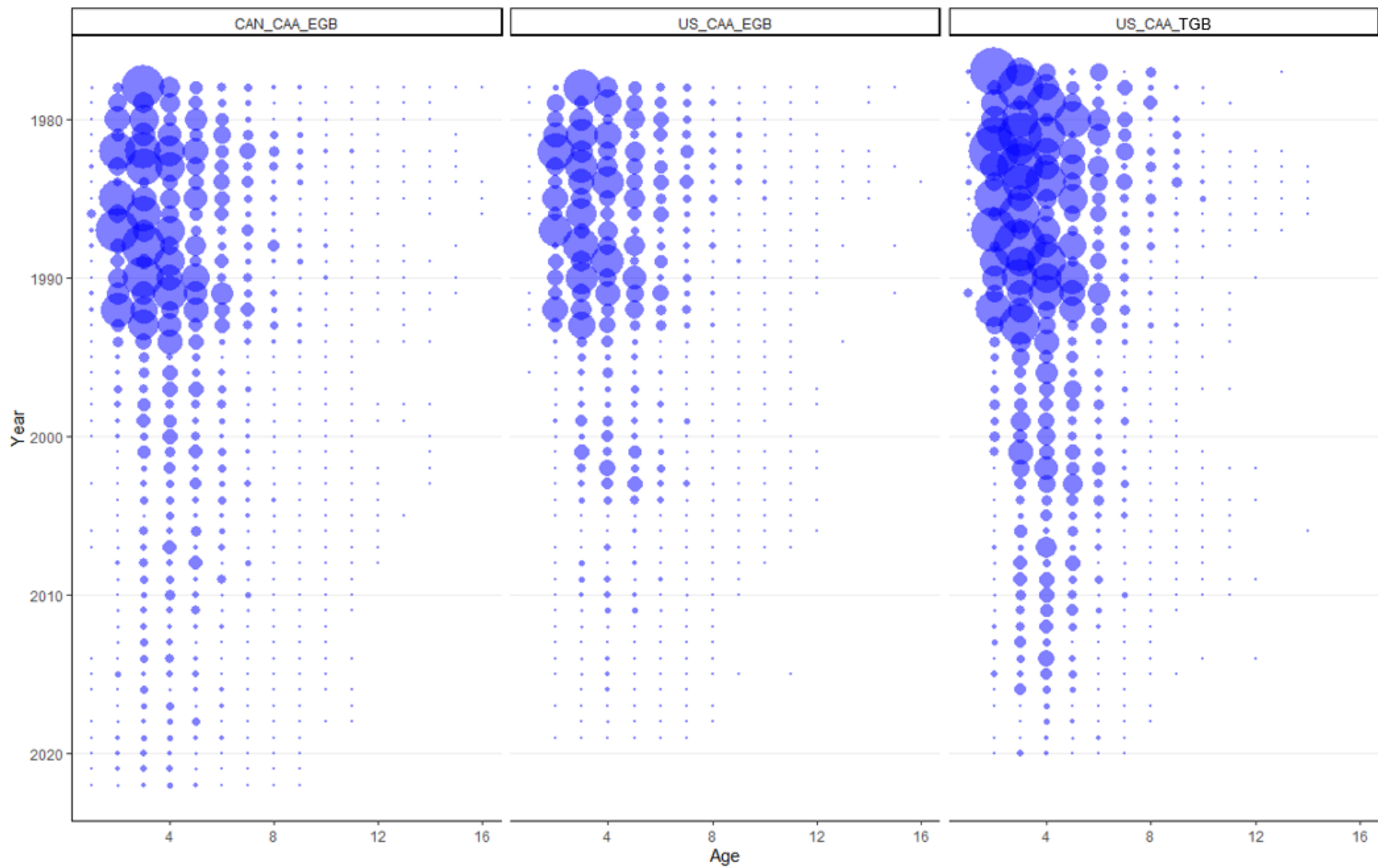


Figure 23. Final fishery catch-at-age (CAA) for Canadian and US commercial catch. The US CAA is available for both the eastern Georges Bank (EGB) and total Georges Bank (TGB) spatial units.

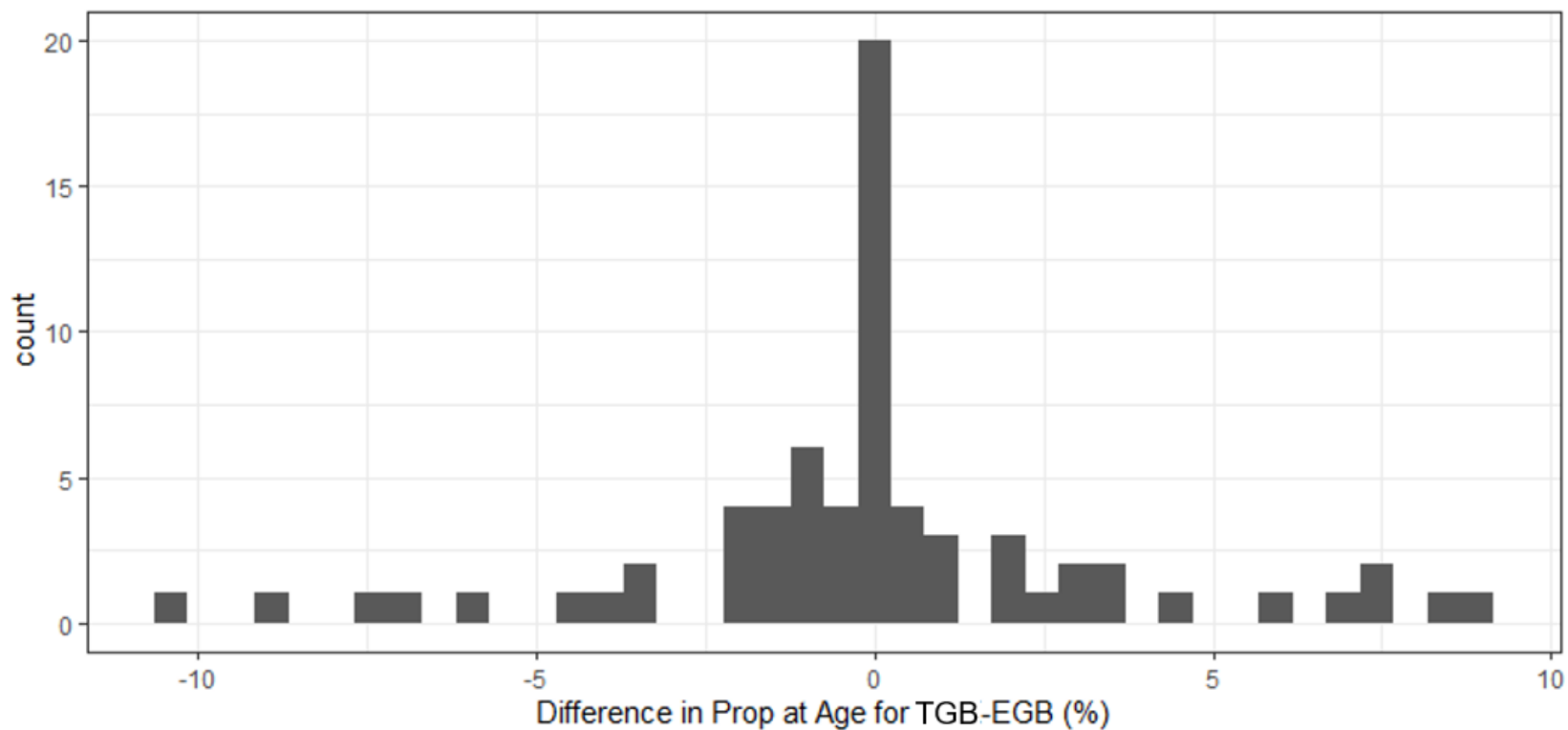


Figure 24. Distribution of the percent differences between the proportional abundance at age of the US eastern Georges Bank (EGB) and US total Georges Bank (TGB) catch-at-age for the last 10 years where sampling has been sufficient and no substitutions have been made (2002–2004, 2007–2012, 2018).

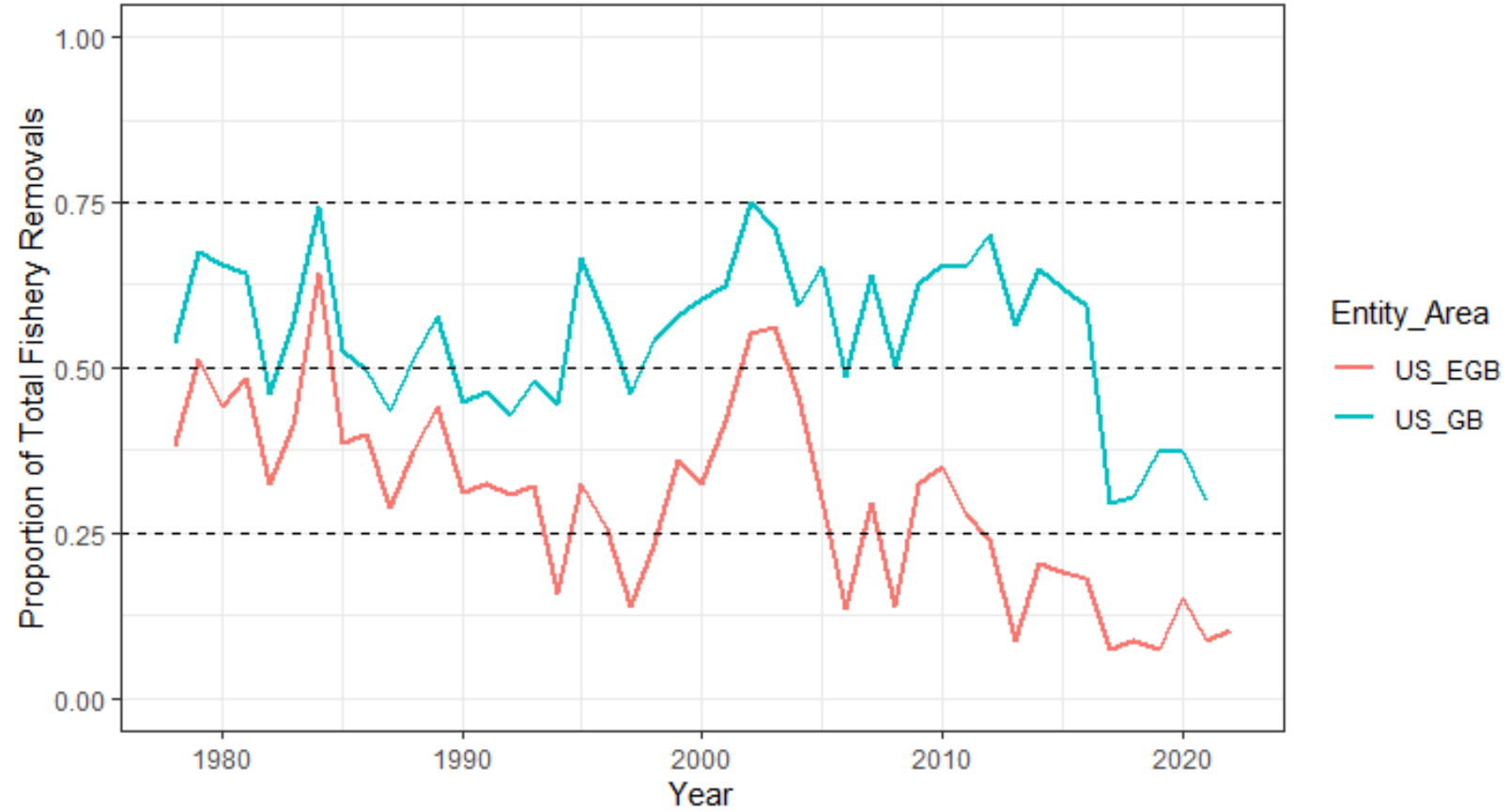


Figure 25. Proportions of removals from eastern Georges Bank (US_EGB, red line) and total Georges Bank (US_GB, blue line) attributed to the US commercial fishery.

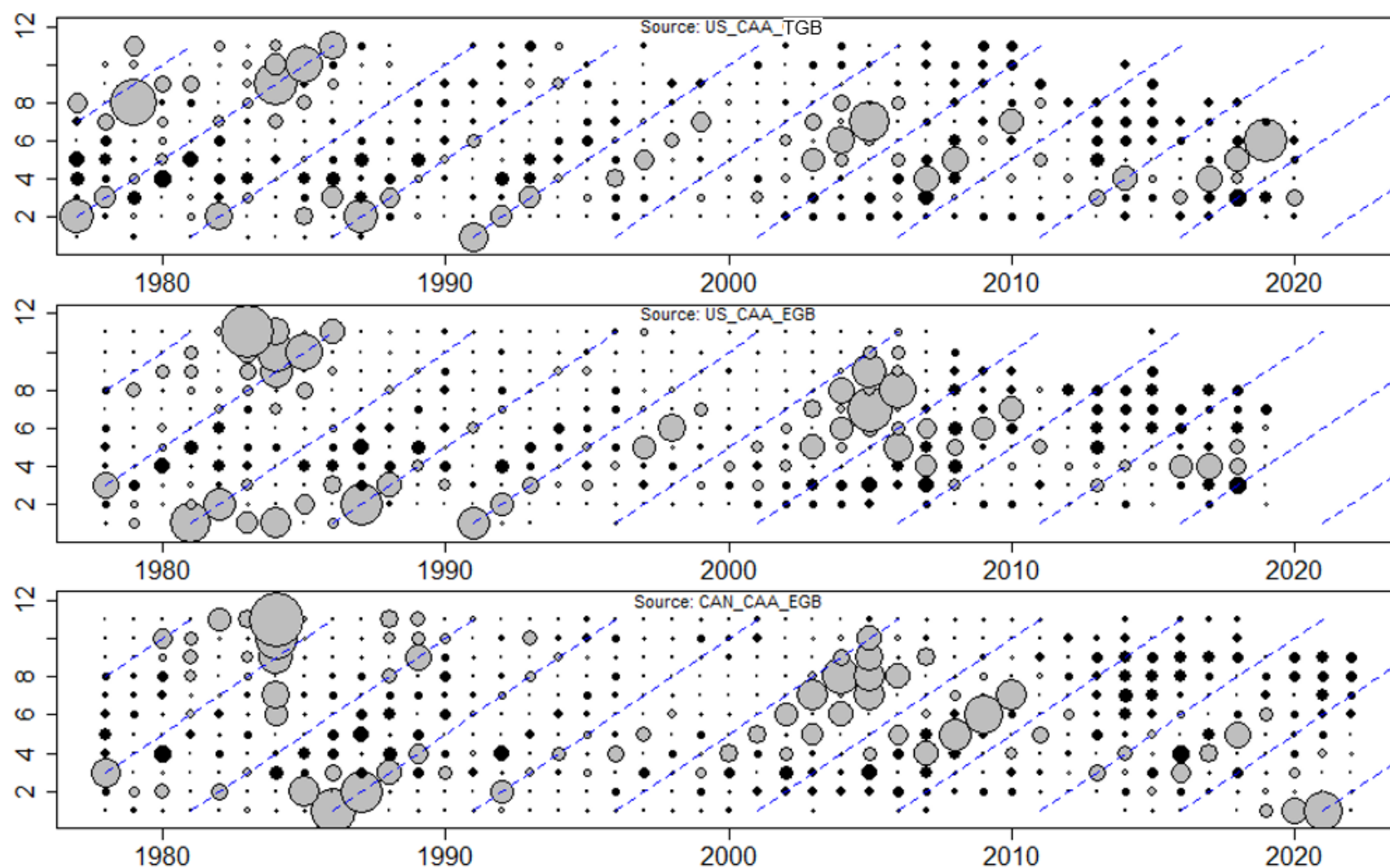


Figure 26. Standardized proportions by age across years (SPAY) plots of commercial catch-at-age (CAA) for Canadian and US commercial fisheries. The US CAA is available for both eastern Georges Bank (EGB) and total Georges Bank (TGB) spatial units. Grey circles identify values greater than average and black circles identify values smaller than average; average values appear as small dots. Dashed blue lines follow individual cohorts and are drawn for reference.

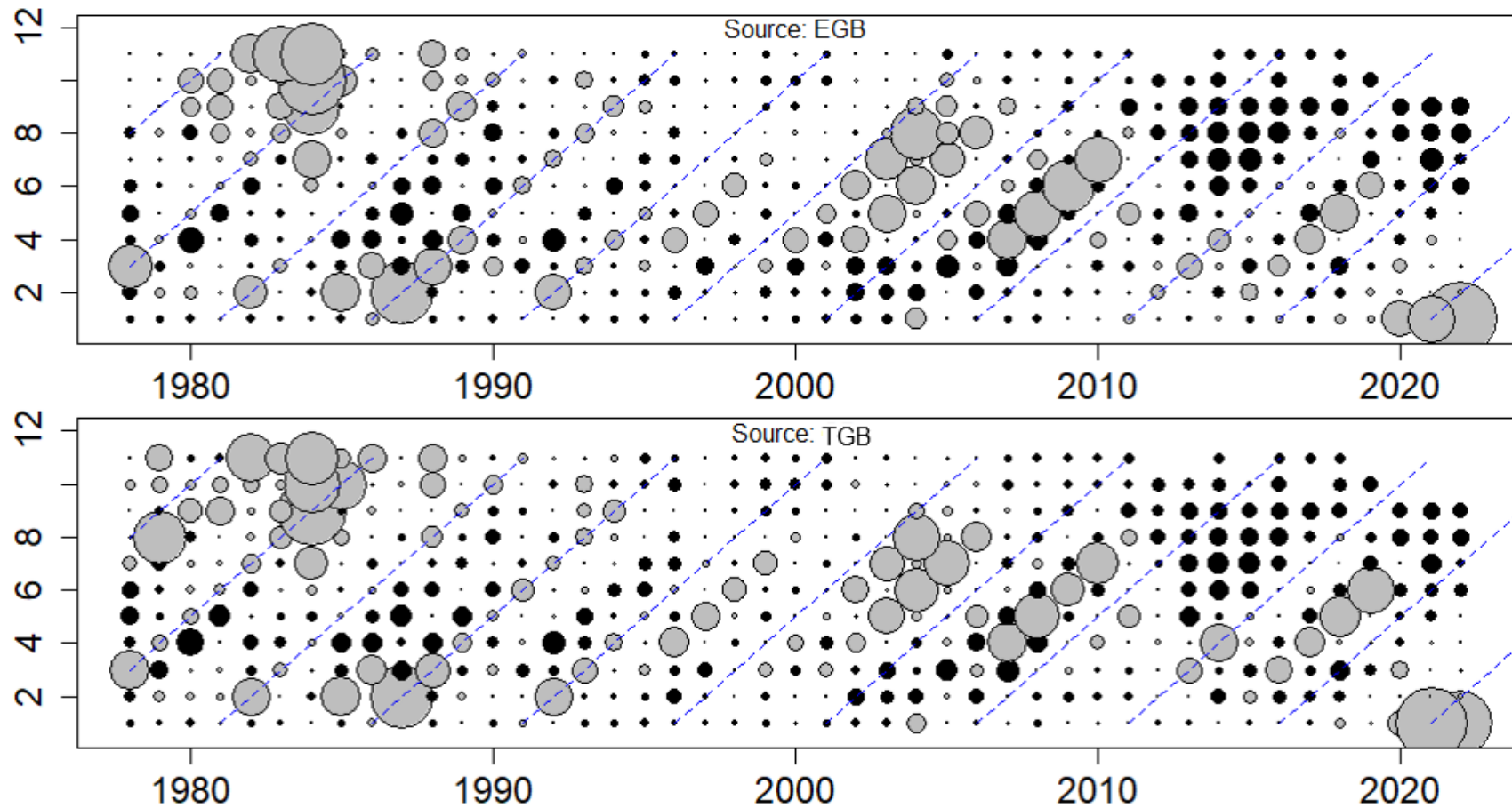


Figure 27. Standardized proportions by age across years (SPAY) plots of combined fishery catch-at-age (landings and discards) for the eastern Georges Bank (EGB) and total Georges Bank (TGB) spatial units. Grey circles identify values greater than average and black circles identify values smaller than average; average values appear as small dots. Dashed blue lines follow individual cohorts and are drawn for reference.

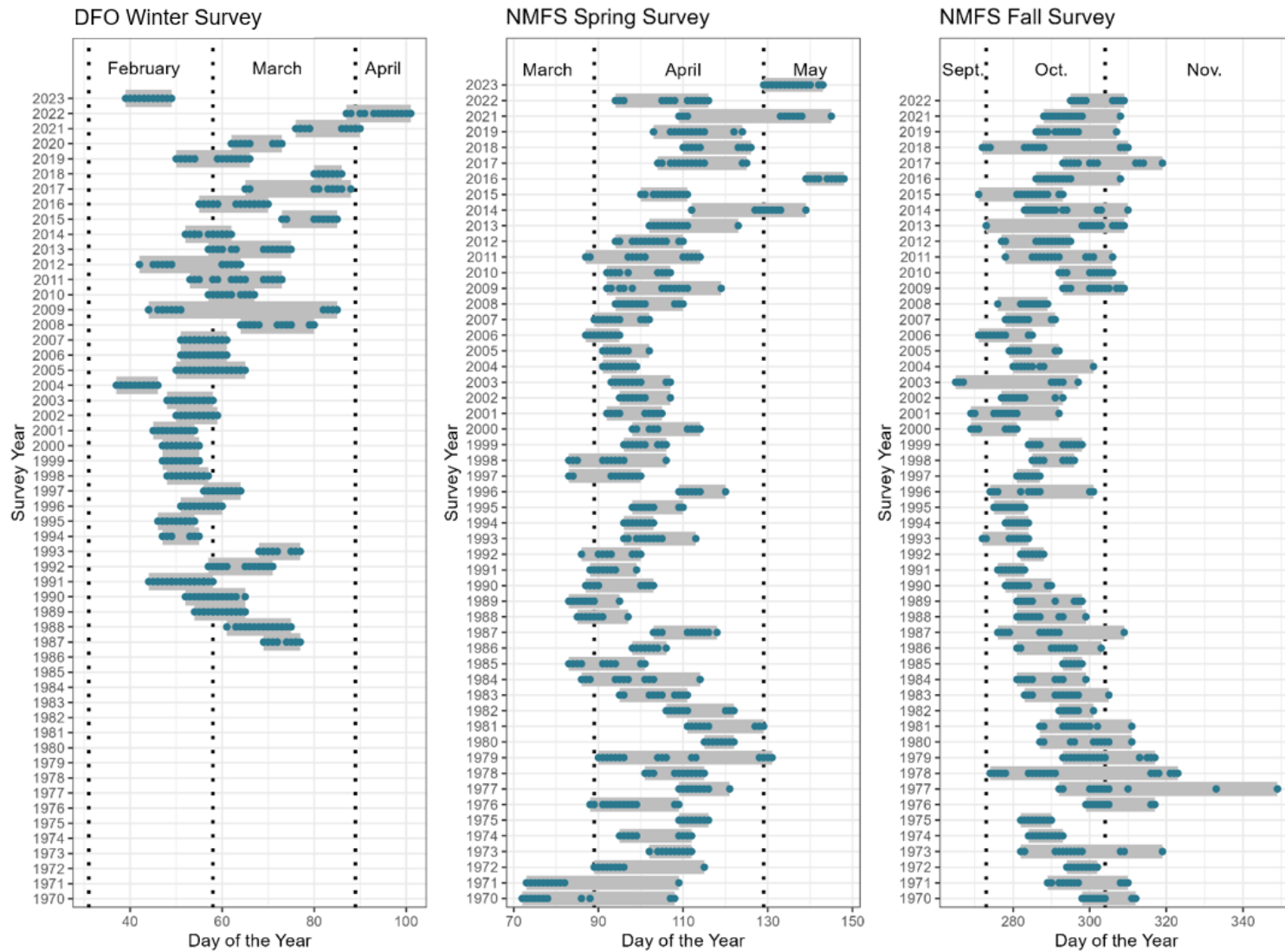


Figure 28. Survey timing by year. Grey bars represent the time period between the first and last successful standardized sets of the survey in Northwest Atlantic Fisheries Organization (NAFO) Division 5Z. Points represent days with successful sets in 5Z during the survey. DFO=Fisheries and Oceans Canada winter survey, NMFS=National Marine Fisheries Service.

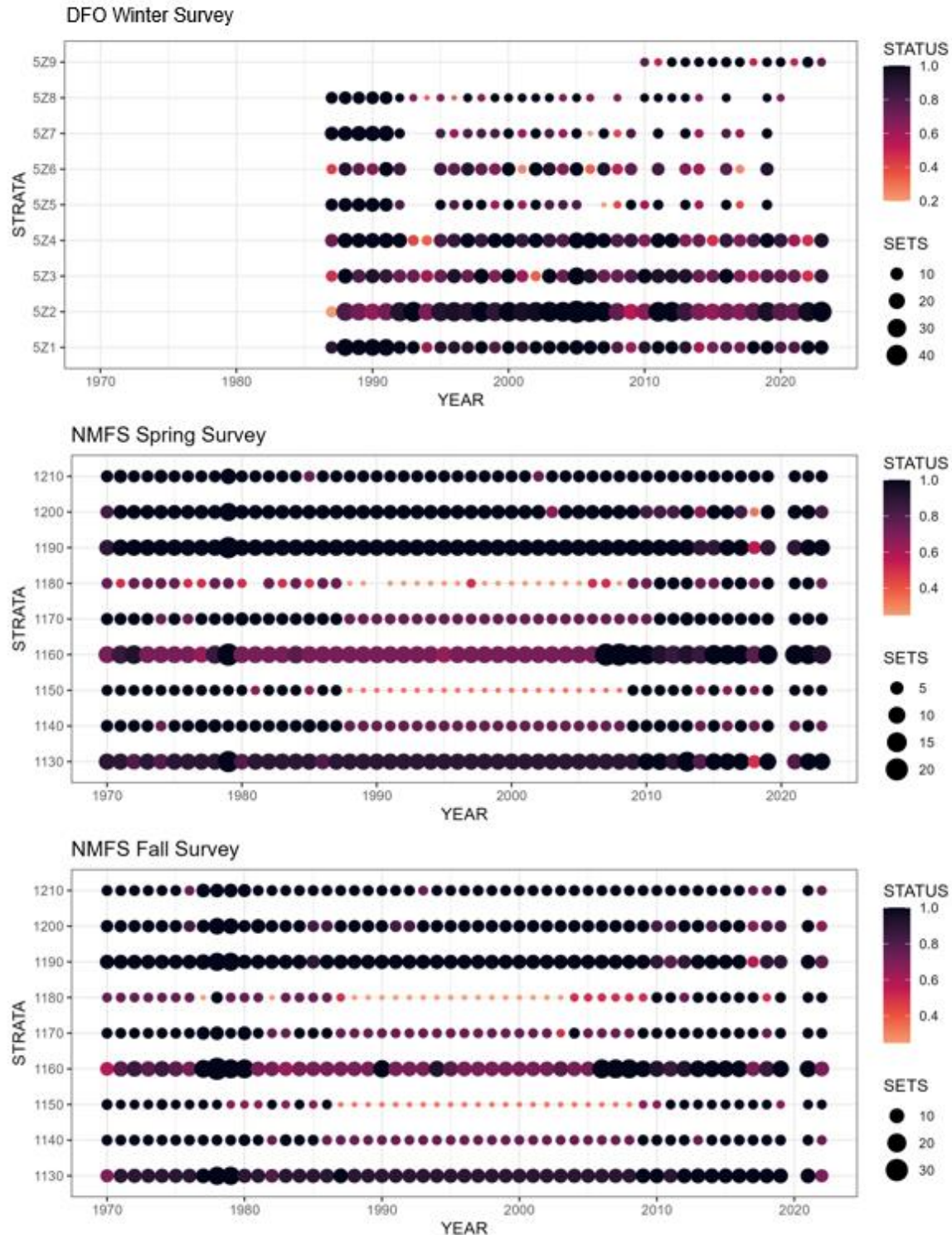


Figure 29. Number of sets per strata on the Fisheries and Oceans Canada (DFO) winter and National Marine Fisheries Service (NMFS) spring and fall surveys with coverage on George's Bank. Size of the bubble represents the number of sets carried out. The colour of the bubble represents the proportion of planned sets per stratum completed in a given year. For DFO, 80% of planned sets in a given stratum is considered complete.

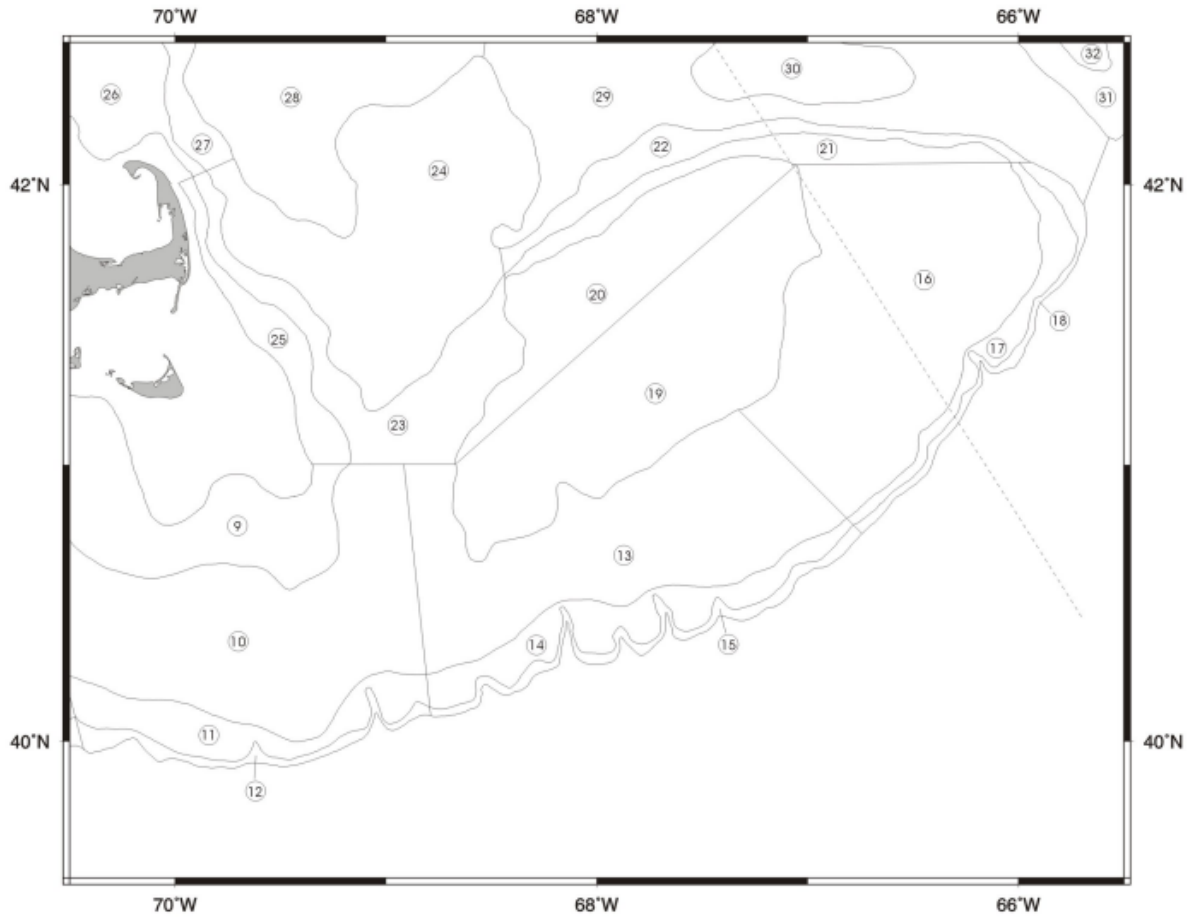


Figure 30. Northeast Fisheries Science Centre standard bottom trawl survey offshore strata. Strata numbers are generated by inserting the number identified in the Figure into '01xx0', as in Stratum 16 becomes Stratum 01160. Figure originally printed in Politis et al. (2014)

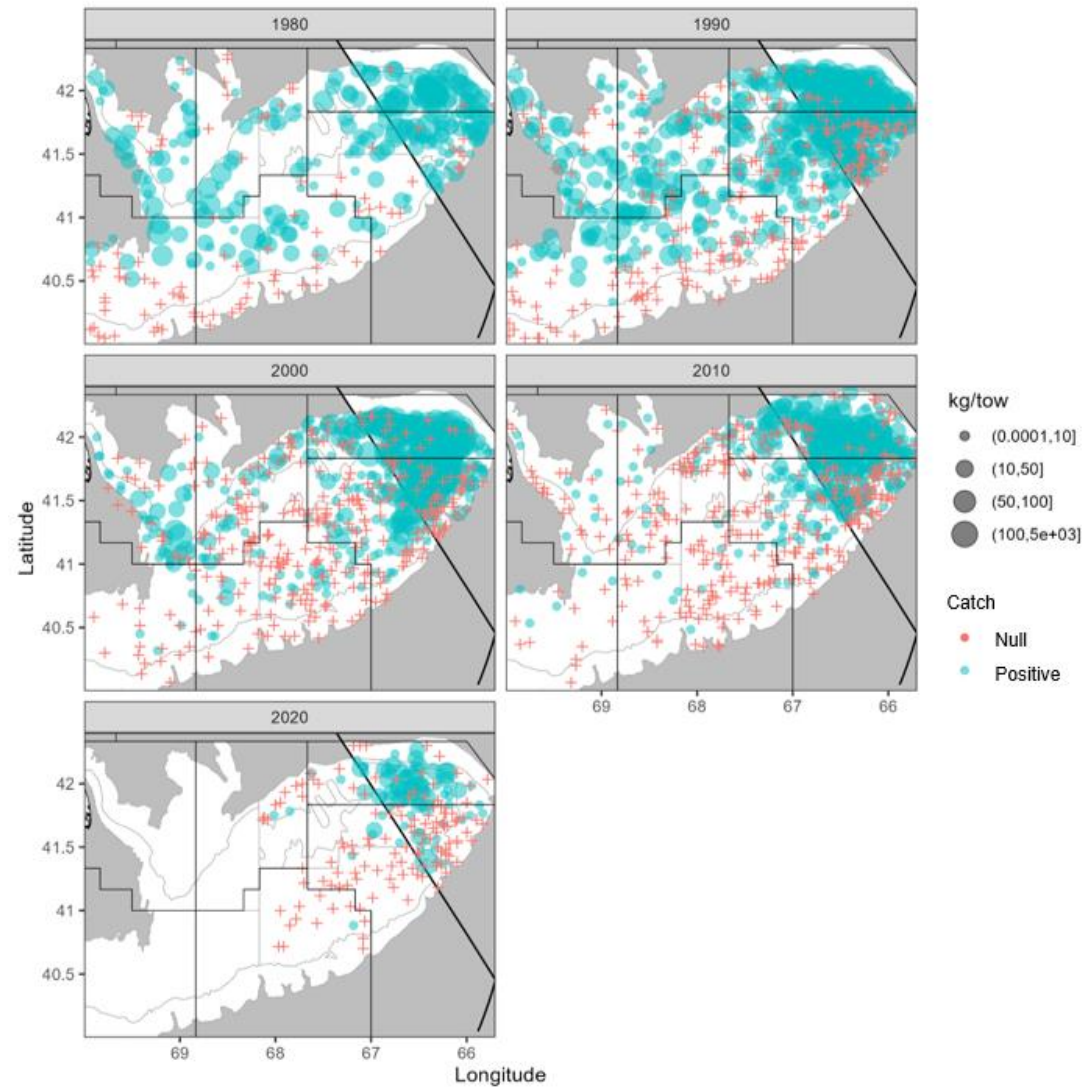


Figure 31. Survey mean Atlantic Cod catch (mean kg/tow) standardized for tow length, for all valid Fisheries and Oceans Canada (DFO) winter survey sets from 1987 to 2023, with the exception of 2022. Black lines represent Northwest Atlantic Fisheries Organization (NAFO) divisions. Blue lines show DFO survey strata for reference. Note that the 1980s and 2020s facets do not represent a full decade worth of data.

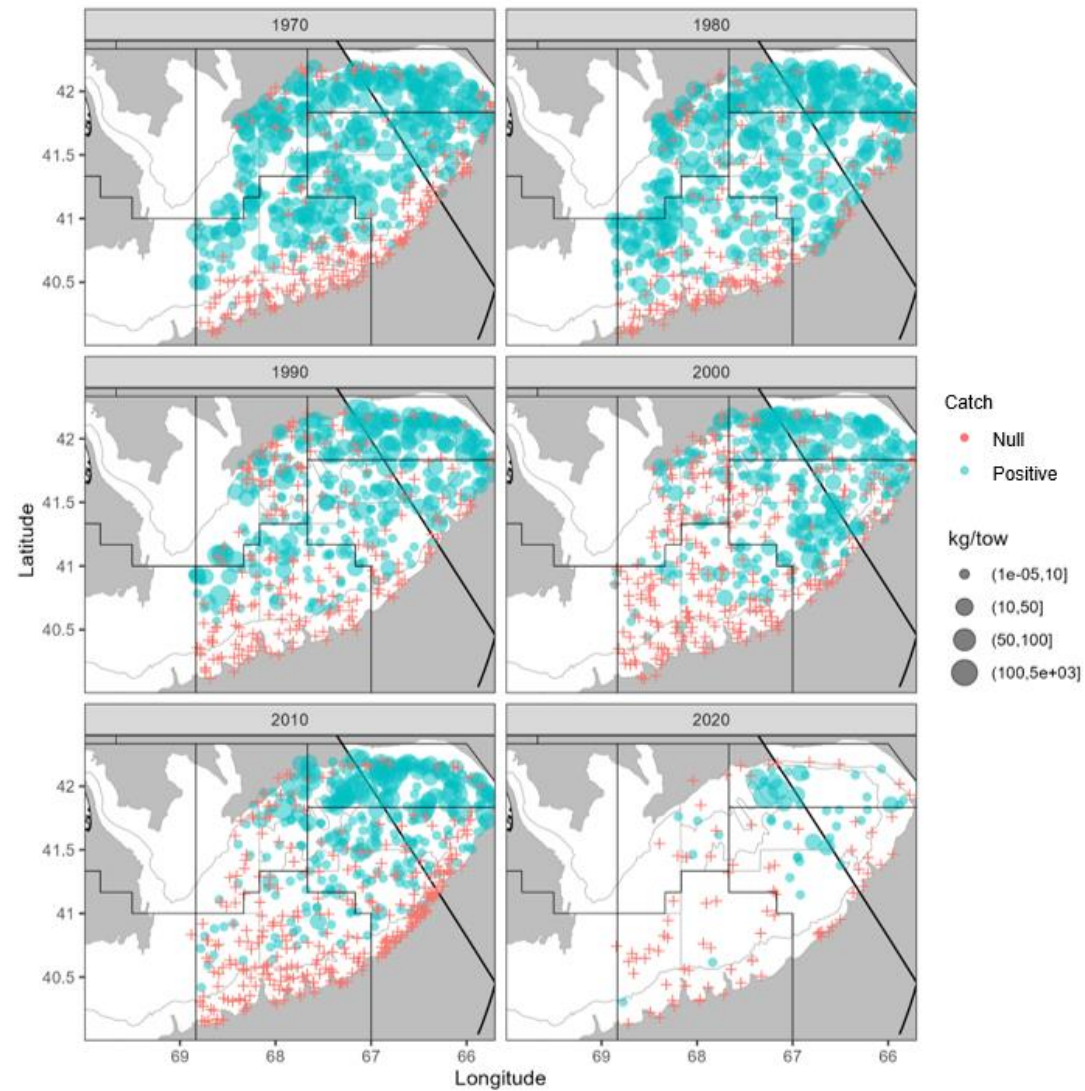


Figure 32. Survey mean Atlantic Cod catch (mean kg/tow) standardized for tow width, for all valid National Marine Fisheries Service (NMFS) spring survey sets from 1970 to 2022. Black lines represent Northwest Atlantic Fisheries Organization (NAFO) divisions. Blue lines show Fisheries and Oceans Canada (DFO) survey strata for reference. Note that the 2020s facet does not represent a full decade worth of data.

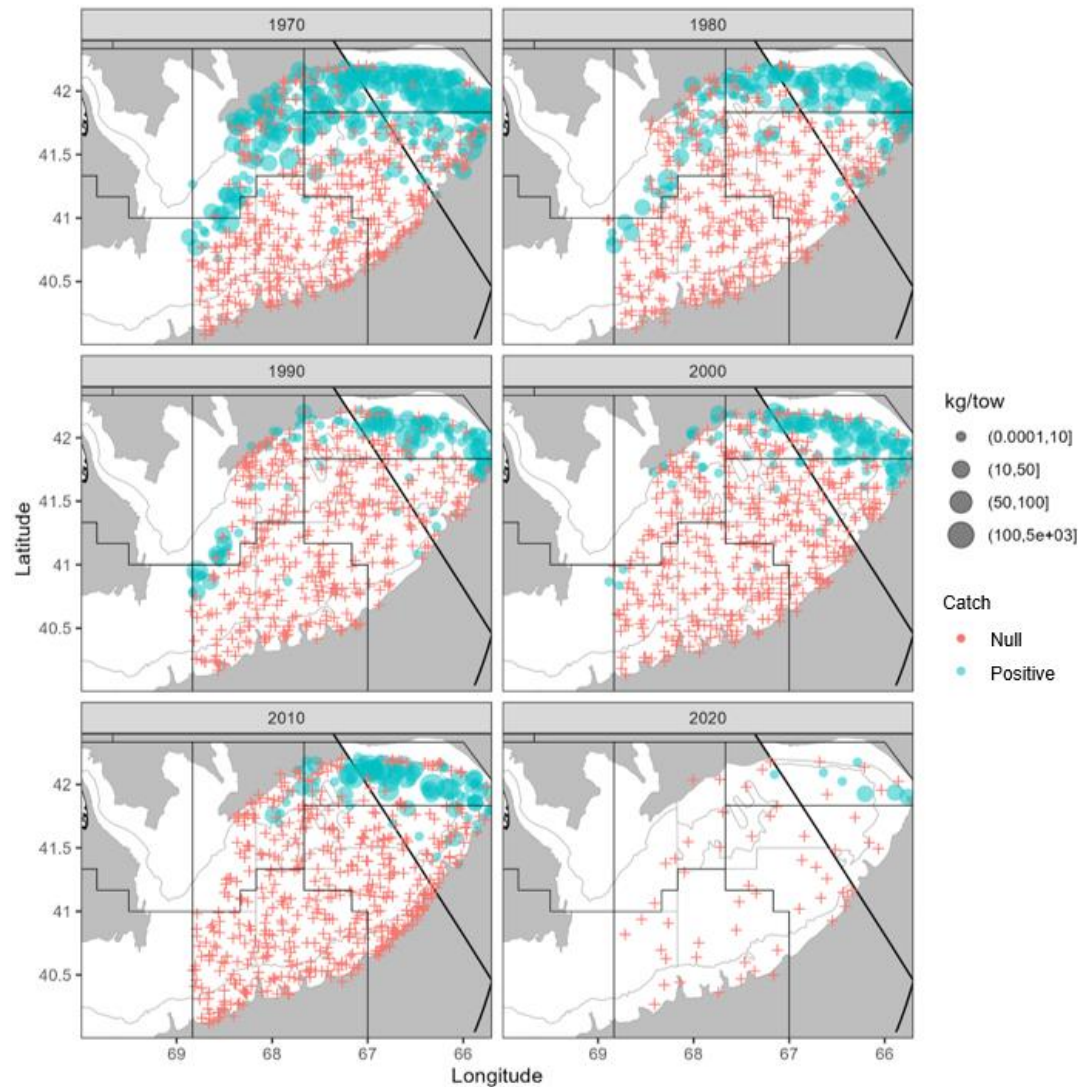


Figure 33. Survey mean Atlantic Cod catch (mean kg/tow) standardized for tow width, for all valid National Marine Fisheries Service (NMFS) fall survey sets from 1970 to 2022. Black lines represent Northwest Atlantic Fisheries Organization (NAFO) divisions. Blue lines show Fisheries and Oceans Canada (DFO) survey strata for reference. Note that the 2020s facet does not represent a full decade worth of data.

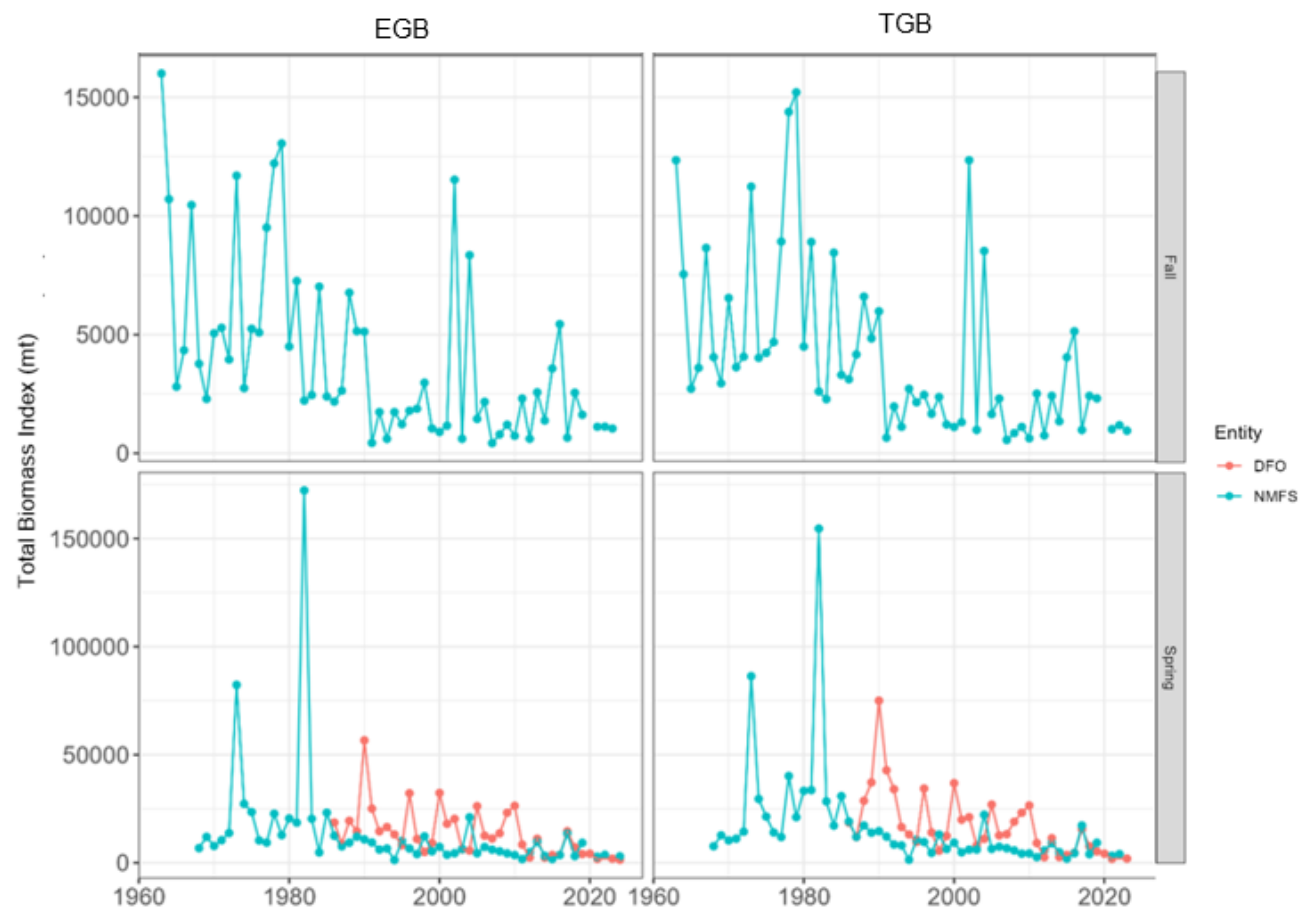


Figure 34. Total survey biomass (ages 1+, mt) indices for cod in Northwest Atlantic Fisheries Organization Division (NAFO) 5Z. Facets show spatial units for columns (eastern Georges Bank, EGB; total Georges Bank, TGB) and seasons for rows (fall, spring). The US indices (blue lines) have length-based conversion factors applied to account for vessel and net changes (Brooks et al. 2010). For Fisheries and Oceans Canada (DFO) surveys (red lines), EGB includes 5Zjm and total GB includes 5Zhjmn. For National Marine Fisheries Service (NMFS), EGB includes US statistical areas 551, 552, 561, 562; total GB includes survey strata 13–21. Data from the DFO winter (2022) survey are missing, pending calculation of a vessel conversion factor.

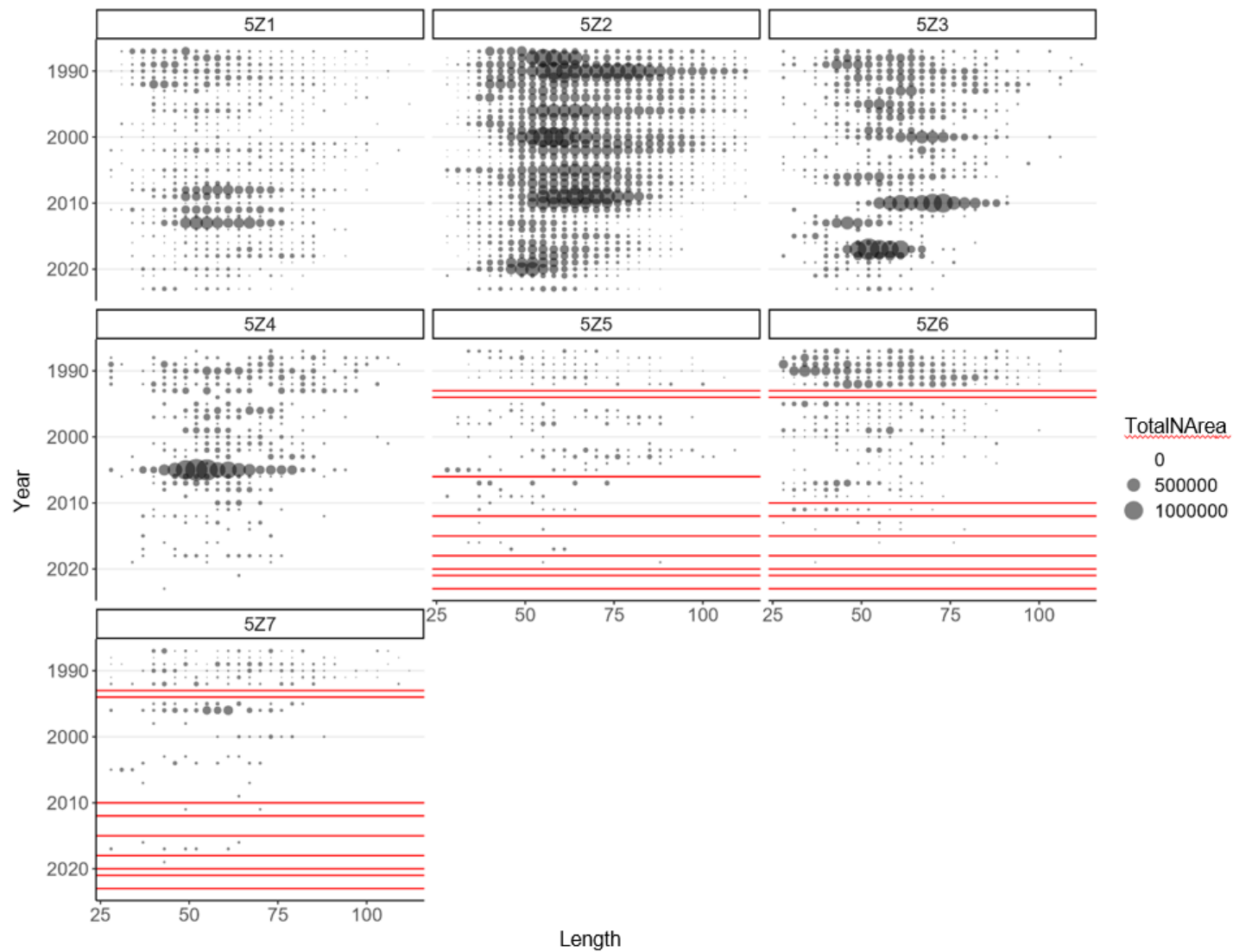


Figure 35. Total abundance at length for each stratum in the Fisheries and Oceans Canada (DFO) winter survey. The size of the bubbles is proportional to abundance. Horizontal red lines indicate years of no coverage in that stratum, consequently no observed value exists.

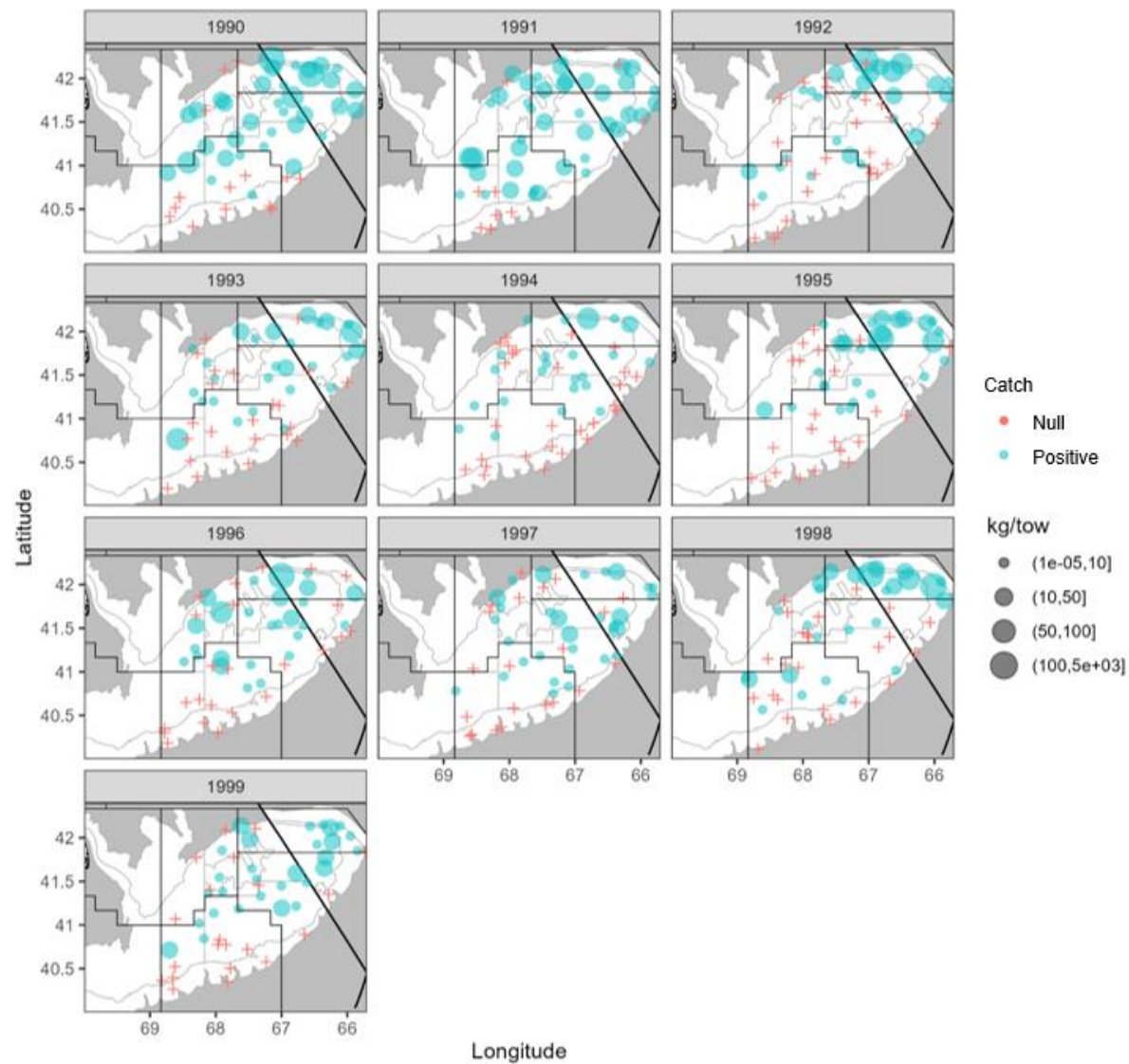


Figure 36. Mean kg/tow from the US spring survey between 1990 and 1999. Blue lines indicate Fisheries and Oceans Canada (DFO) winter survey strata boundaries and black lines indicate Northwest Atlantic Fisheries Organization (NAFO) Divisions. Red crosses indicate null catches.

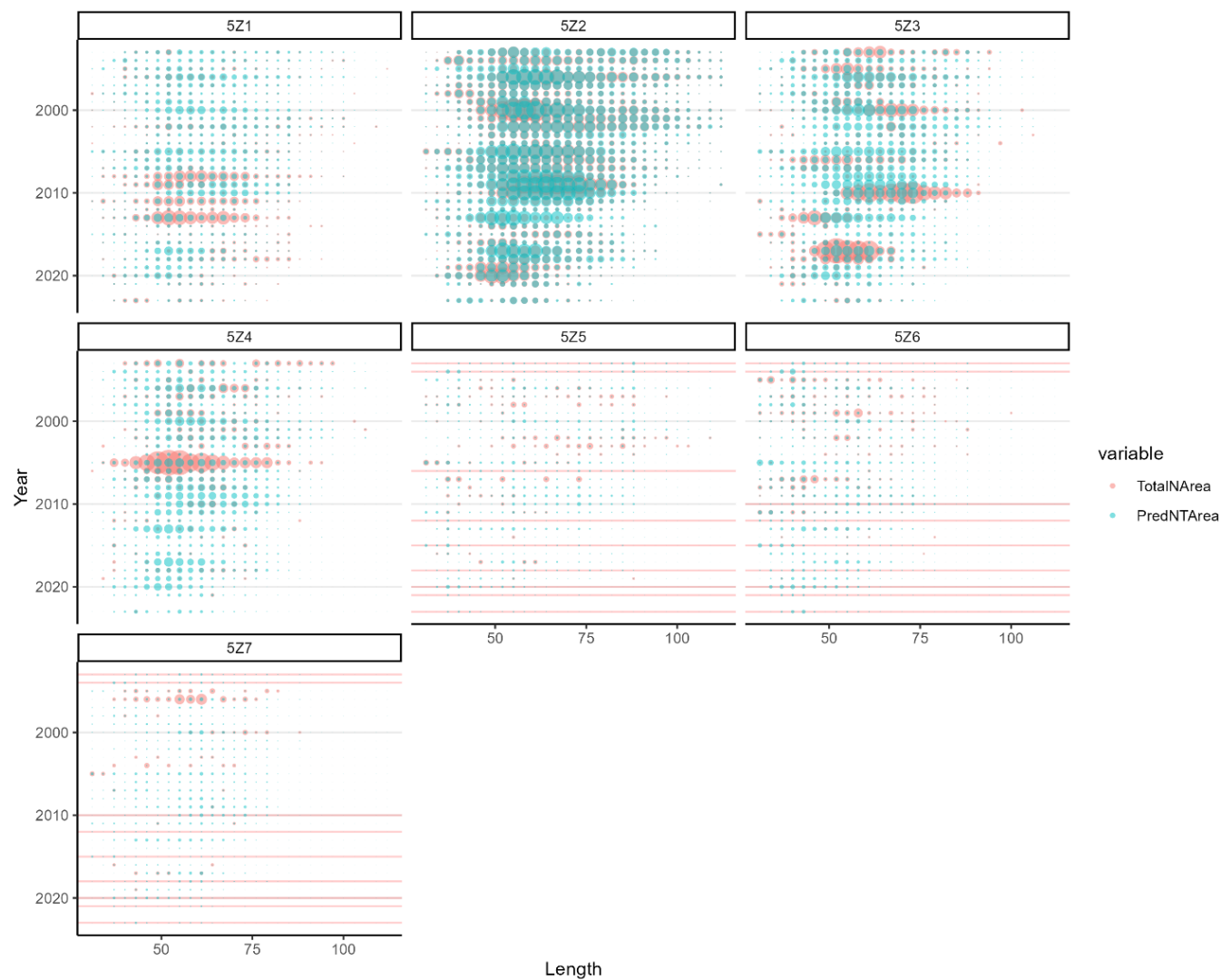


Figure 37. Observed (red) and predicted (blue) total abundance at length by year and stratum for the Fisheries and Oceans Canada (DFO) winter survey. Horizontal red lines indicate years of no coverage in that stratum, consequently no observed value exists.

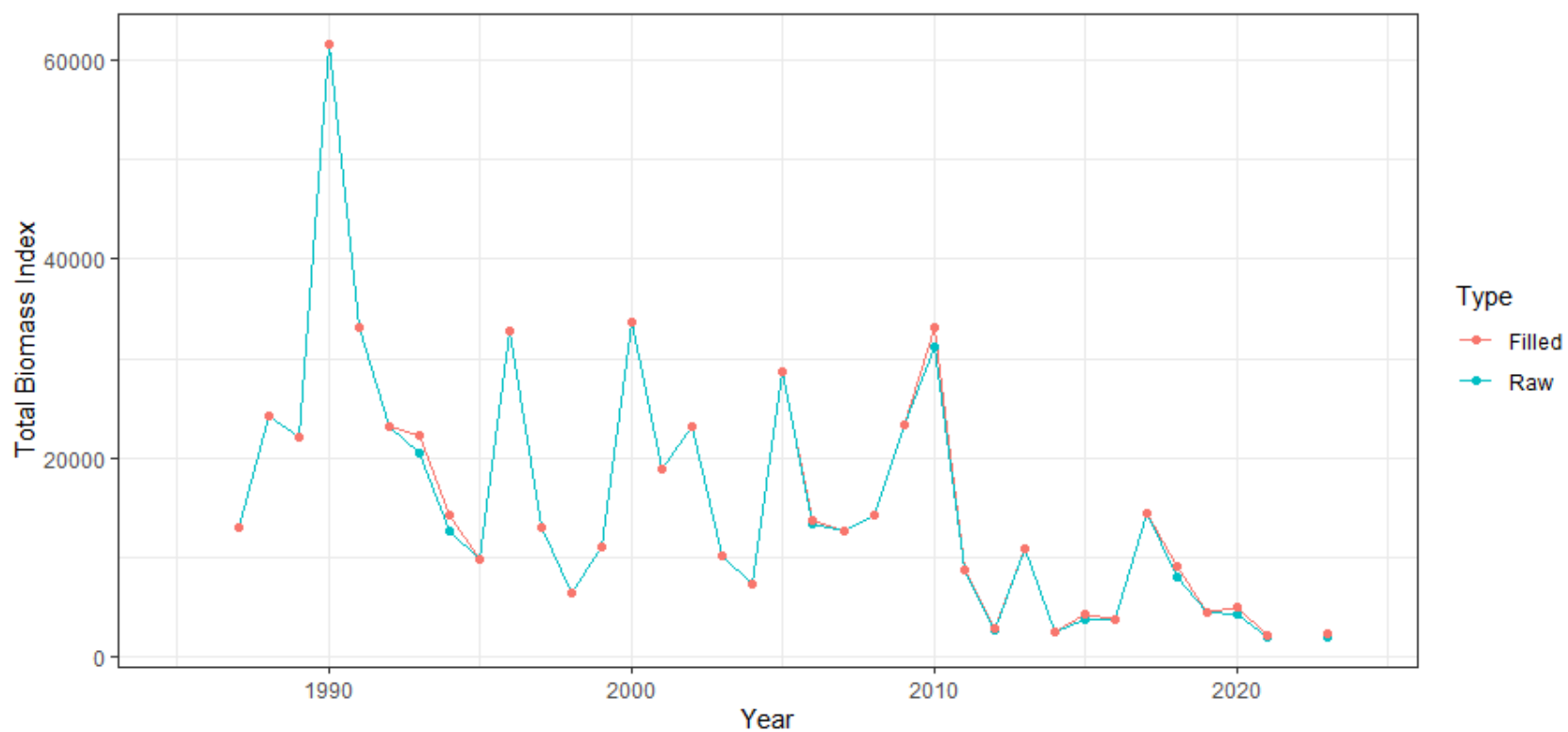


Figure 38. Total biomass (ages 1+, mt) index from the Fisheries and Oceans Canada (DFO) winter survey for total Georges Bank in DFO unit areas 5ZEjmh. Red index includes imputed values for missing coverage years in strata 5Z5–5Z7. Blue index has no imputation.

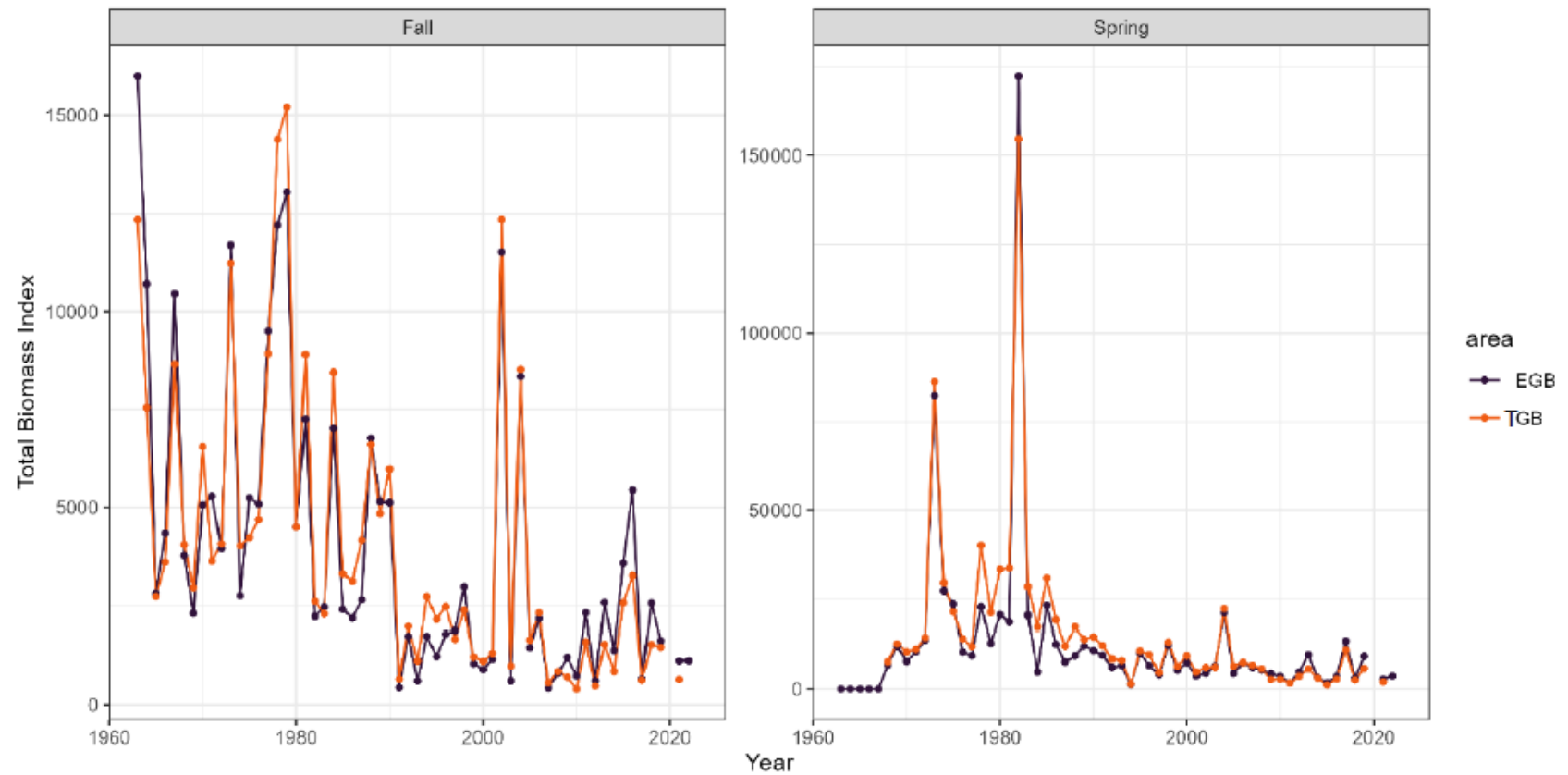


Figure 39. Total biomass survey indices (ages 1+, mt) for eastern (EGB, black lines) and total Georges Bank (TGB, red lines) Cod from the US fall (left panel) and spring (right panel) surveys. Total biomass indices for TGB were generated by multiplying the mean kg/tow index from NEFMS (2023) by the total number of trawlable units in the relevant strata.

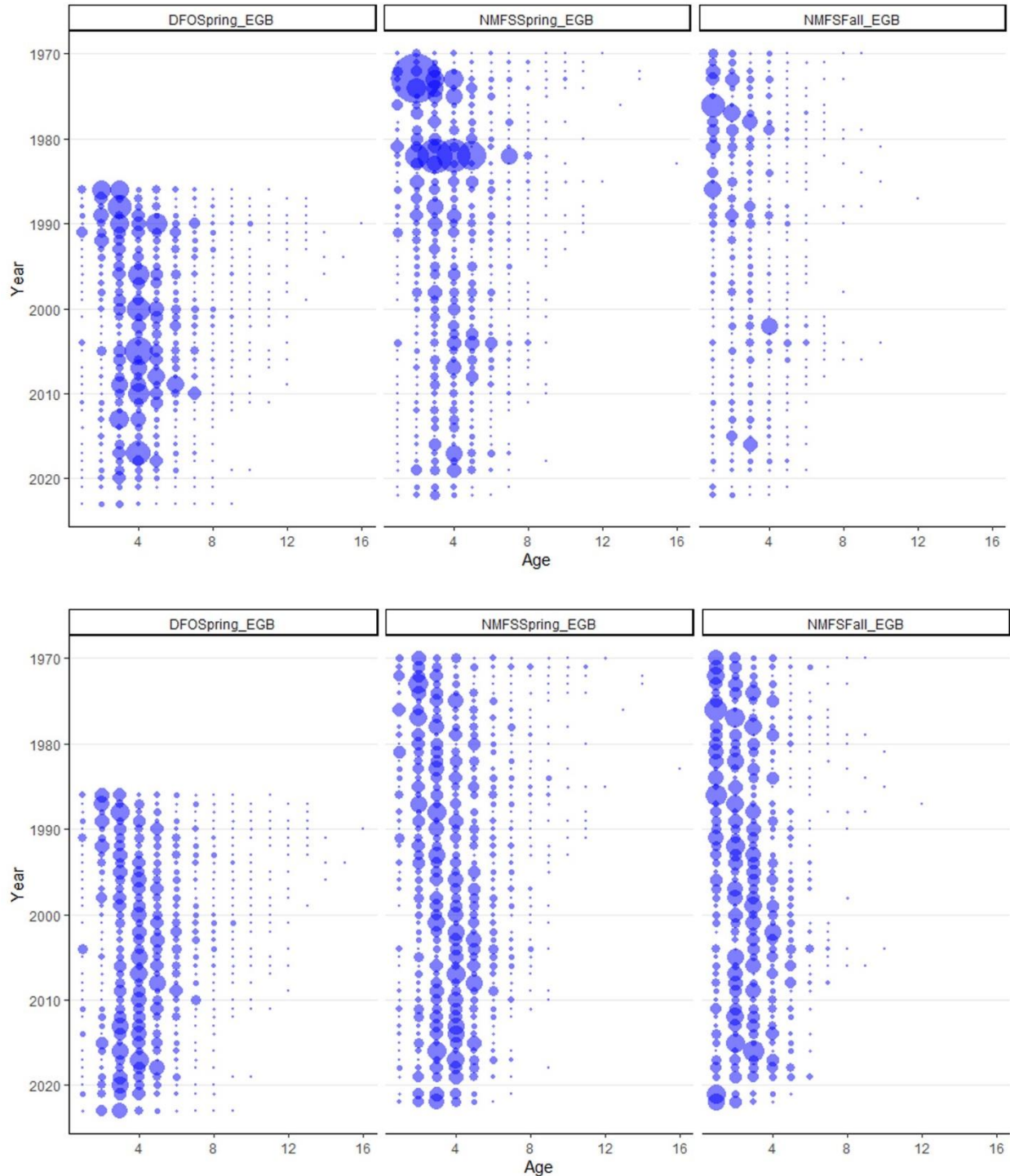


Figure 40. Survey catch-at-age abundance (top row) and proportion (bottom row) for the Fisheries and Oceans Canada (DFO) winter, National Marine Fisheries Service (NMFS) spring and NMFS fall Surveys for the eastern Georges Bank (EGB) spatial unit (5Zjm for DFO; Statistical Areas 551, 552, 561, 562 for US). The relative size of the bubbles is representative of abundance (top panels) or annual proportion (bottom panels). NMFS surveys were cancelled in 2020. Data from the 2022 DFO survey are missing pending calculation of a vessel conversion factor.

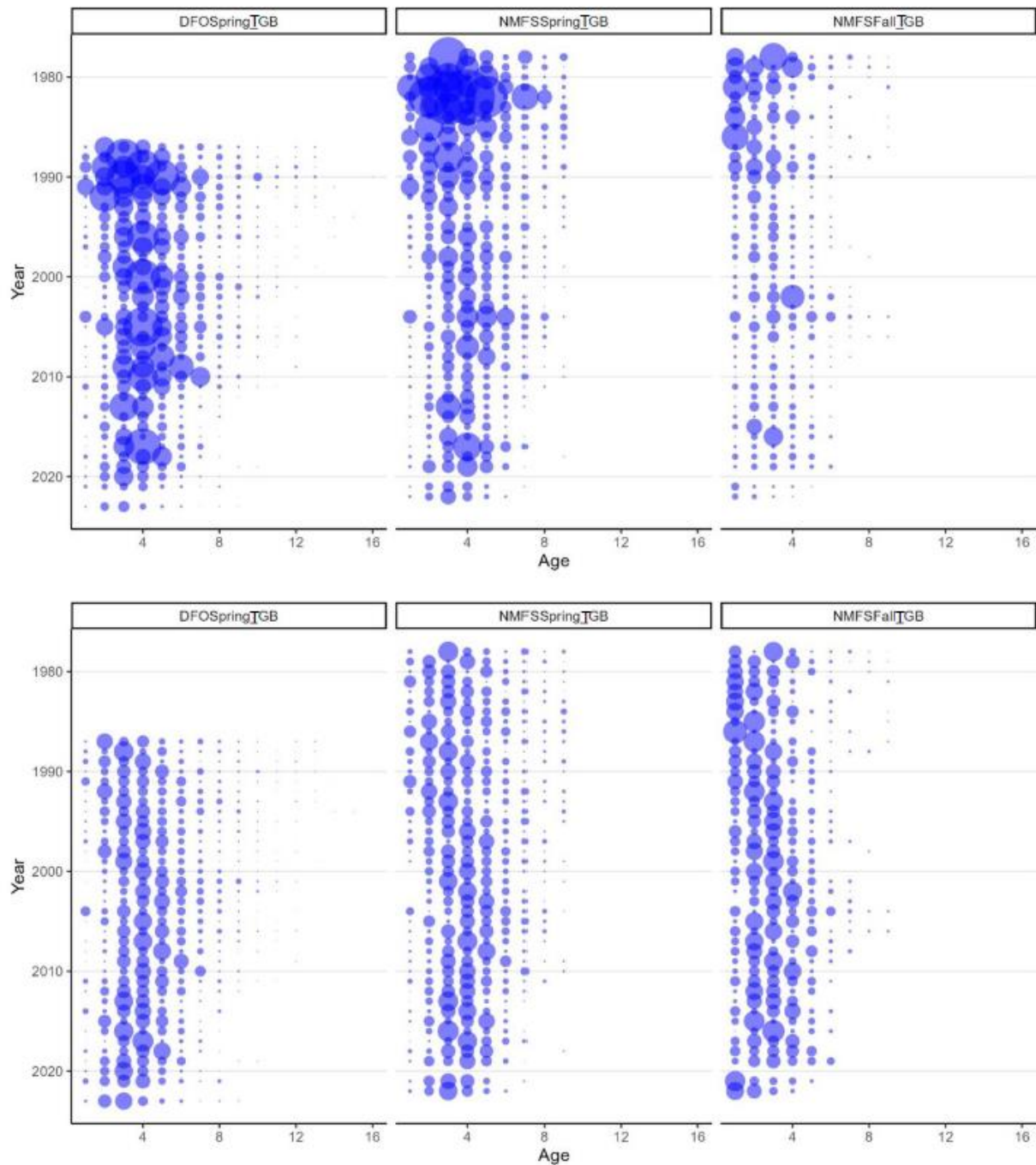


Figure 41. Survey catch-at-age abundance (upper row) and proportion (lower row) for the Fisheries and Oceans Canada (DFO) winter, National Marine Fisheries Service (NMFS) spring and NMFS fall Surveys for the total Georges Bank (TGB) spatial unit (5Zjmghno for DFO; Statistical Areas 551, 552, 561, 562, 522, 525 for US). The relative size of the bubbles is representative of abundance (top panels) or annual proportion (bottom panels). NMFS surveys were cancelled in 2020. Data from the 2022 DFO survey are missing pending calculation of a vessel conversion factor.

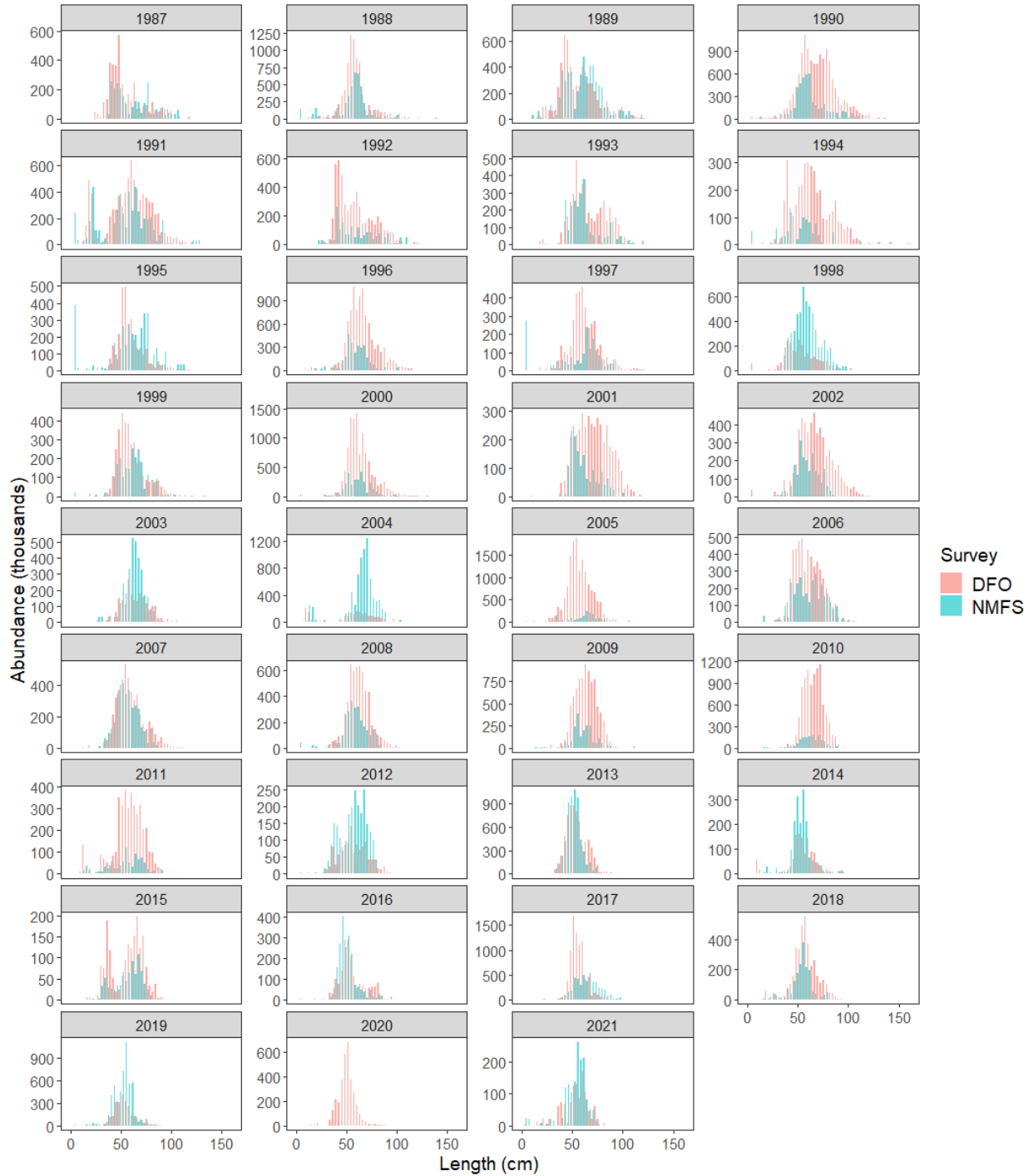


Figure 42. Eastern Georges Bank Cod length frequency raised to the total stratum area from the Fisheries and Oceans Canada (DFO) winter survey (red bars) and National Marine Fisheries Service (NMFS) spring survey (blue bars) by year.

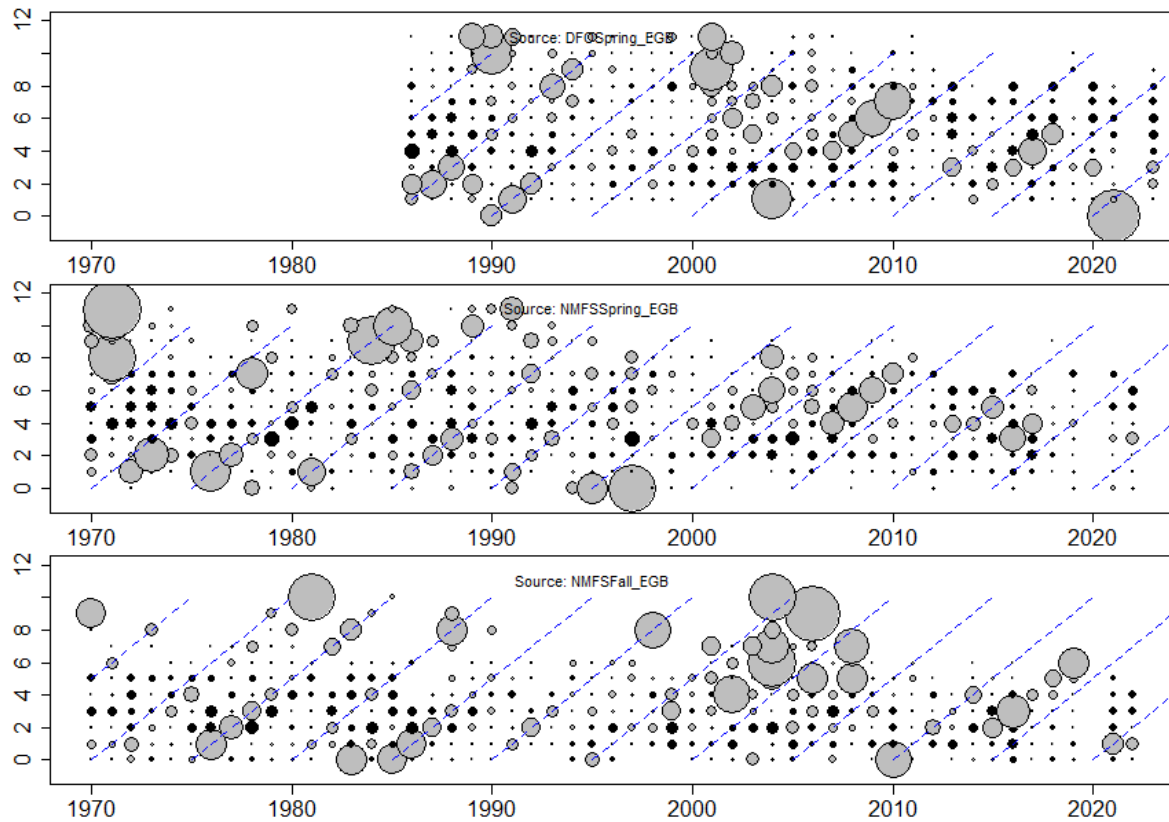


Figure 43. Standardized proportions by age across years (SPAY) plots of the three surveys covering eastern Georges Bank (EGB). Grey circles identify values greater than average and black circles identify values smaller than average; average values appear as small dots. Dashed blue lines follow individual cohorts and are drawn for reference. (DFO - Fisheries and Oceans Canada, NMFS - National Marine Fisheries Service)

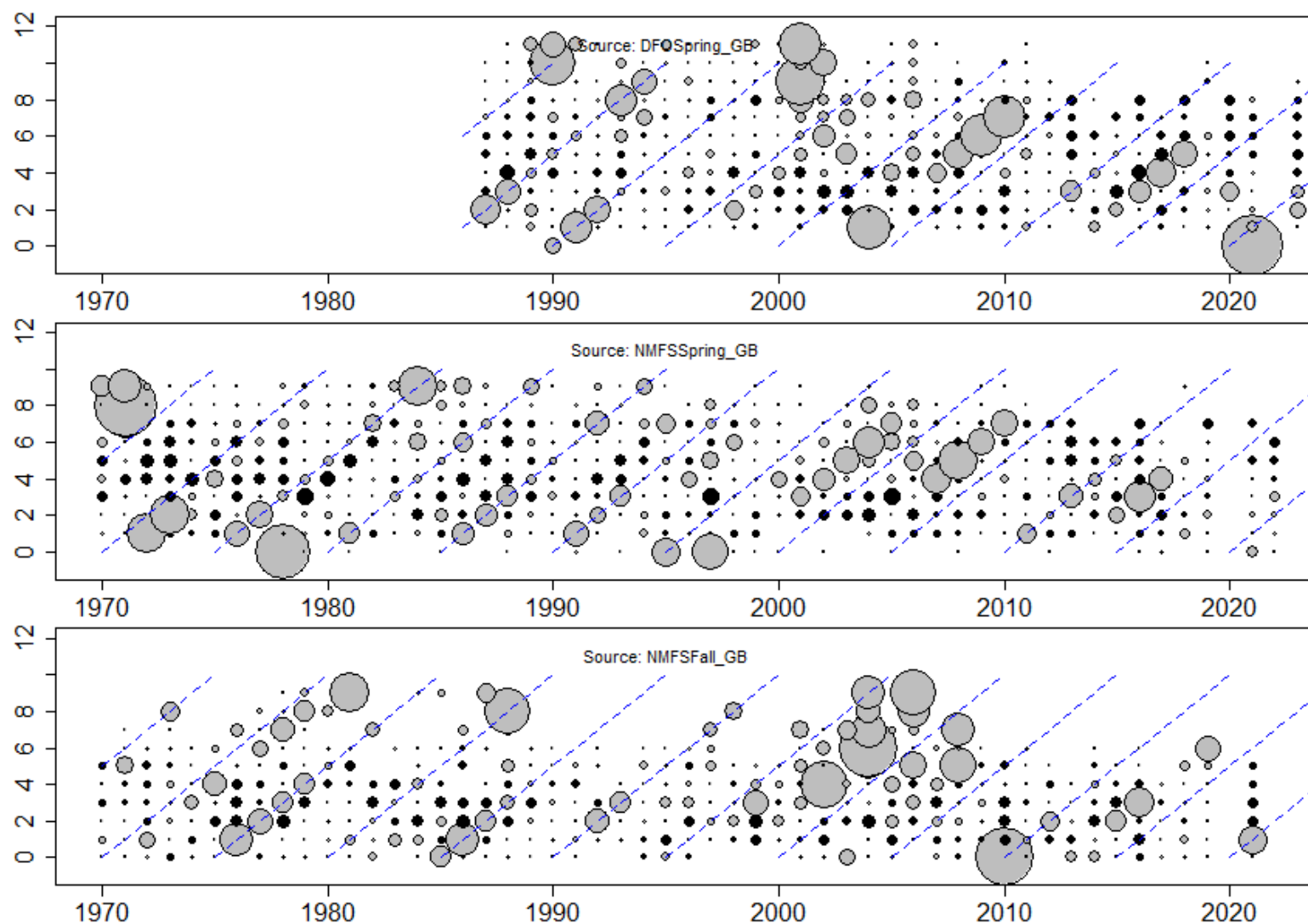


Figure 44. Standardized proportions by age across years (SPAY) plots of the three surveys covering total Georges Bank (TGB). Grey circles identify values greater than average and black circles identify values smaller than average; average values appear as small dots. Dashed blue lines follow individual cohorts and are drawn for reference. DFO - Fisheries and Oceans Canada, NMFS: National Marine Fisheries Service

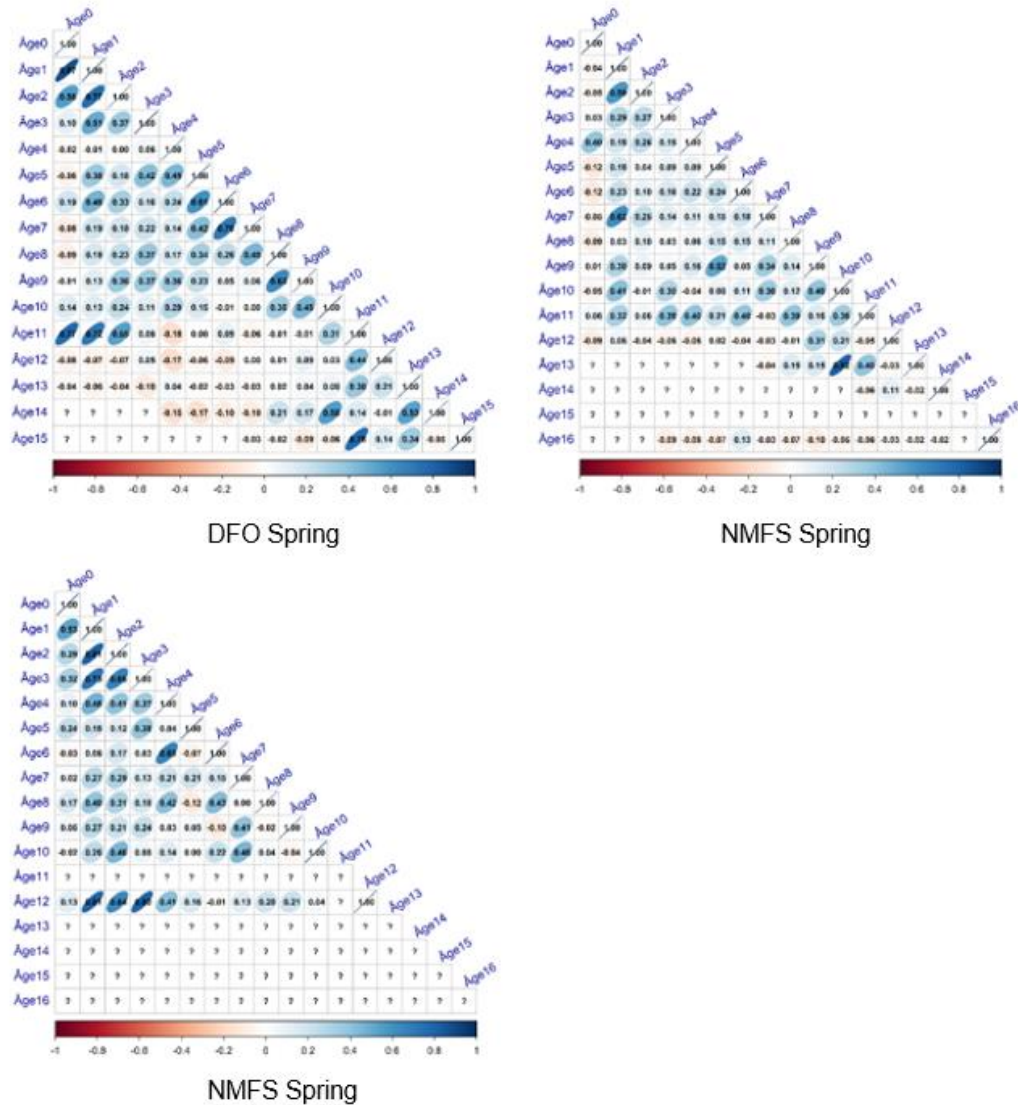


Figure 45. Correlation matrices (number of fish at each age against the number of fish at every other age in a survey) for each of the surveys, illustrating their ability to track cohorts of cod over time. (DFO-Fisheries and Oceans Canada; NMFS-National Marine Fisheries Service).

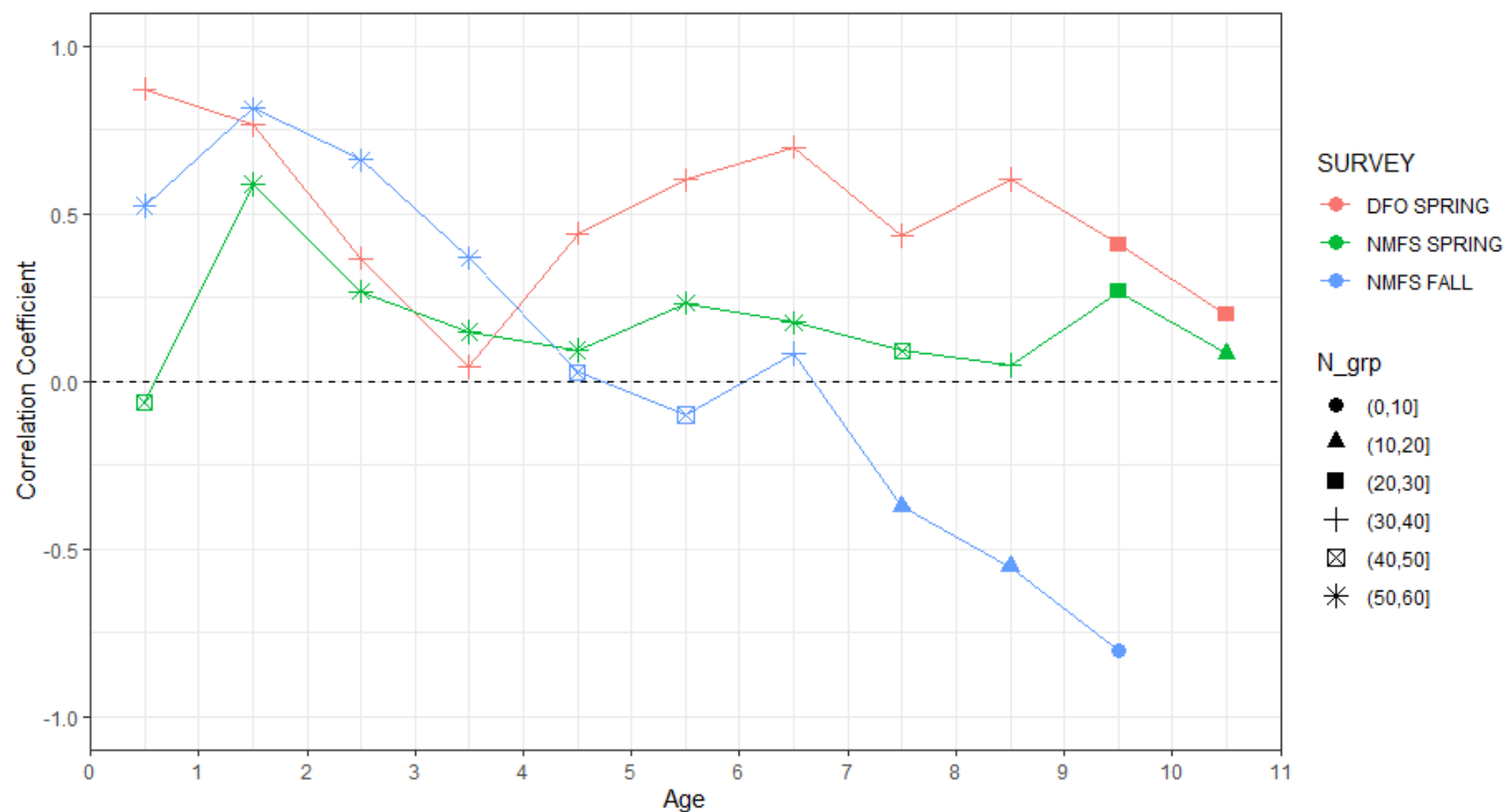


Figure 46. Correlation coefficient for adjacent ages of Cod in the Fisheries and Oceans Canada (DFO Spring) winter, National Marine Fisheries Service (NMFS) spring and NMFS fall surveys. Symbols identify the sample size contributing to the calculation of the coefficient.

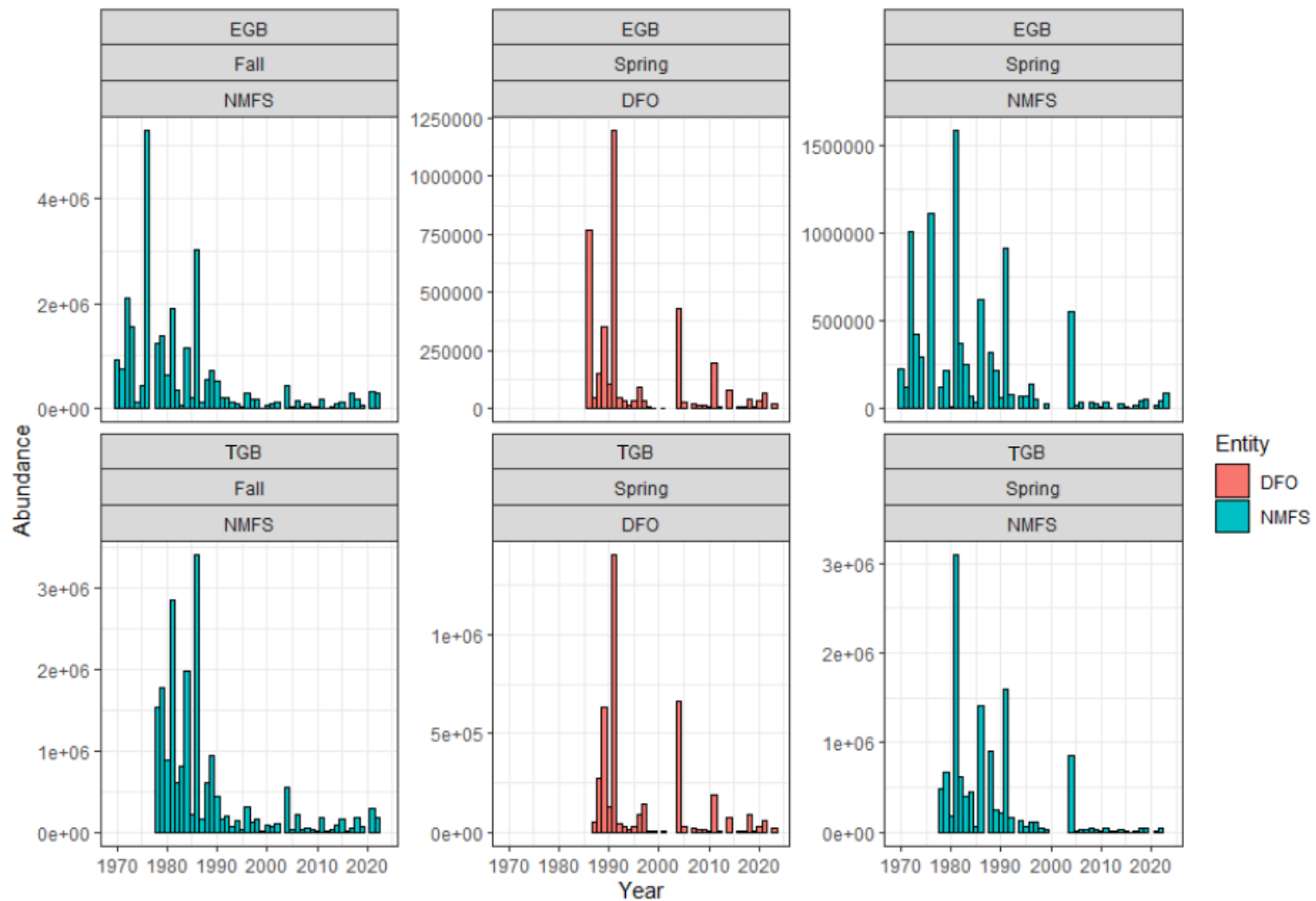


Figure 47. Age 1 indices of abundance from the Fisheries and Oceans Canada (DFO) and National Marine Fisheries Service (NMFS) surveys by season (DFO Spring survey takes place in Winter/Spring), area and entity (facets). EGB—eastern Georges Bank; TGB—total Georges Bank.

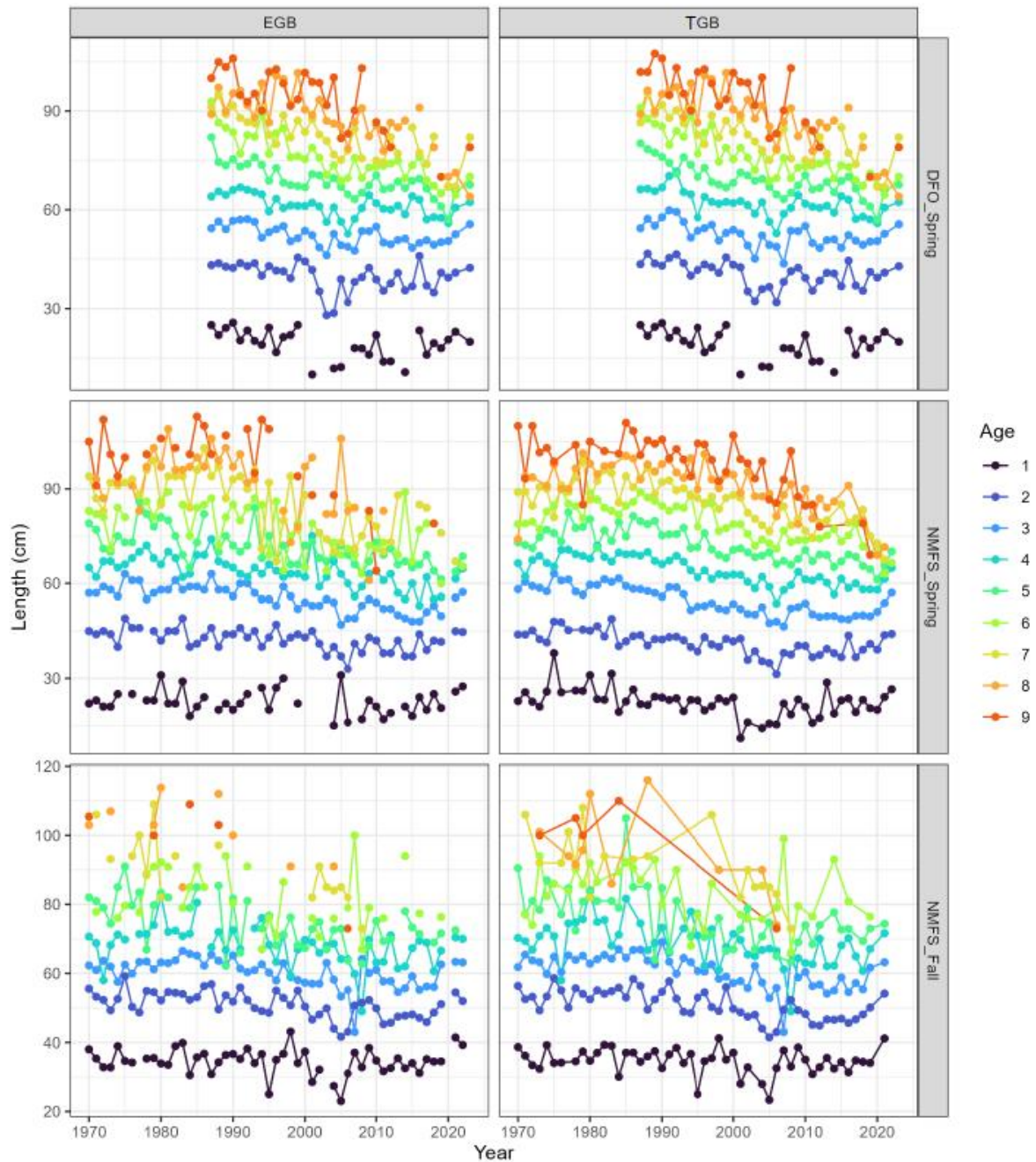


Figure 48. Length-at-age for the National Marine Fisheries Service (NMFS) spring, NMFS fall and Fisheries and Oceans Canada (DFO Spring) winter surveys on eastern Georges Bank (EGB) and total Georges Bank (TGB).

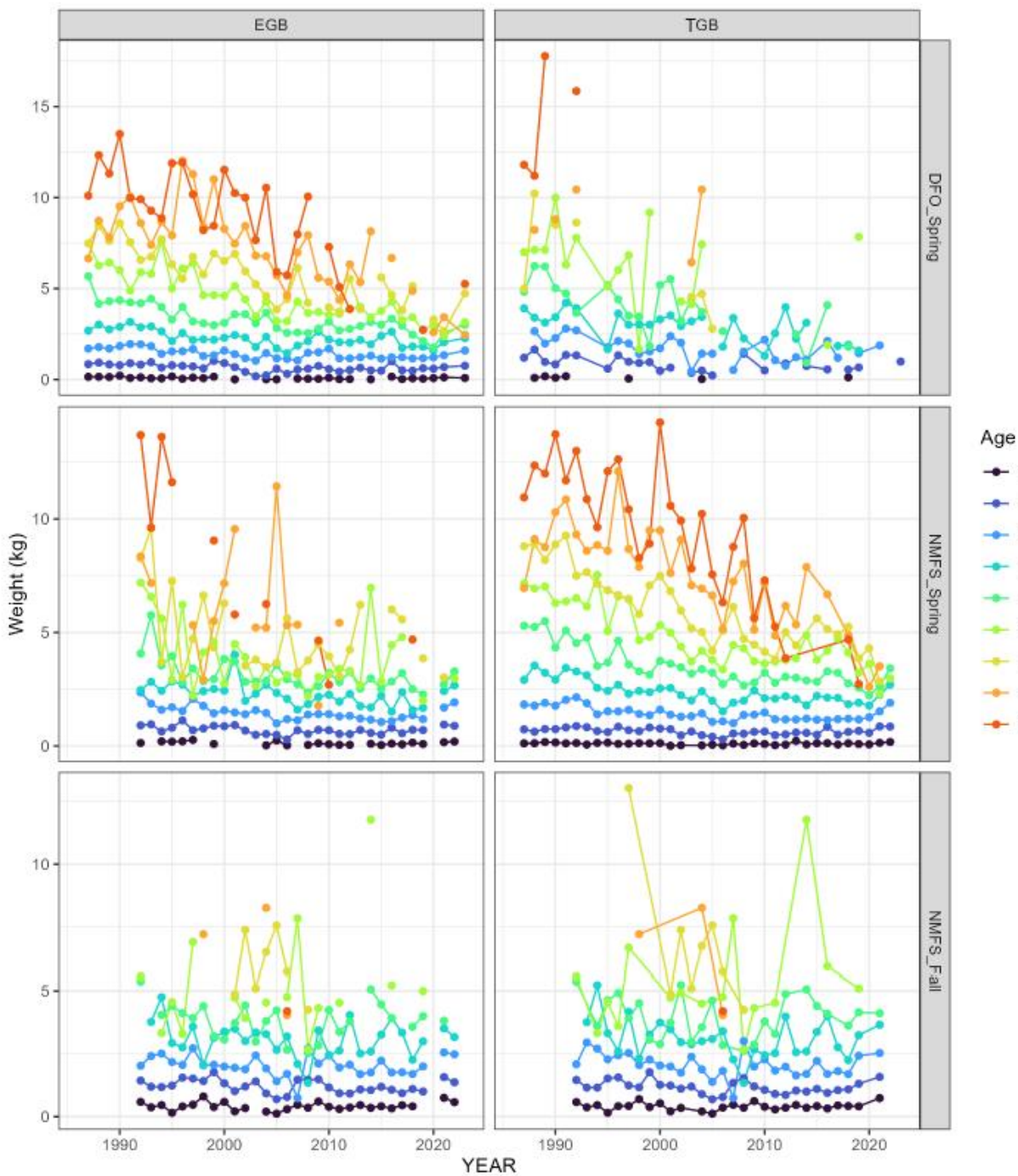


Figure 49. Weight-at-age for the National Marine Fisheries Service (NMFS) spring, NMFS fall and Fisheries and Oceans Canada (DFO Spring) winter surveys on eastern Georges Bank (EGB) and total Georges Bank (TGB).

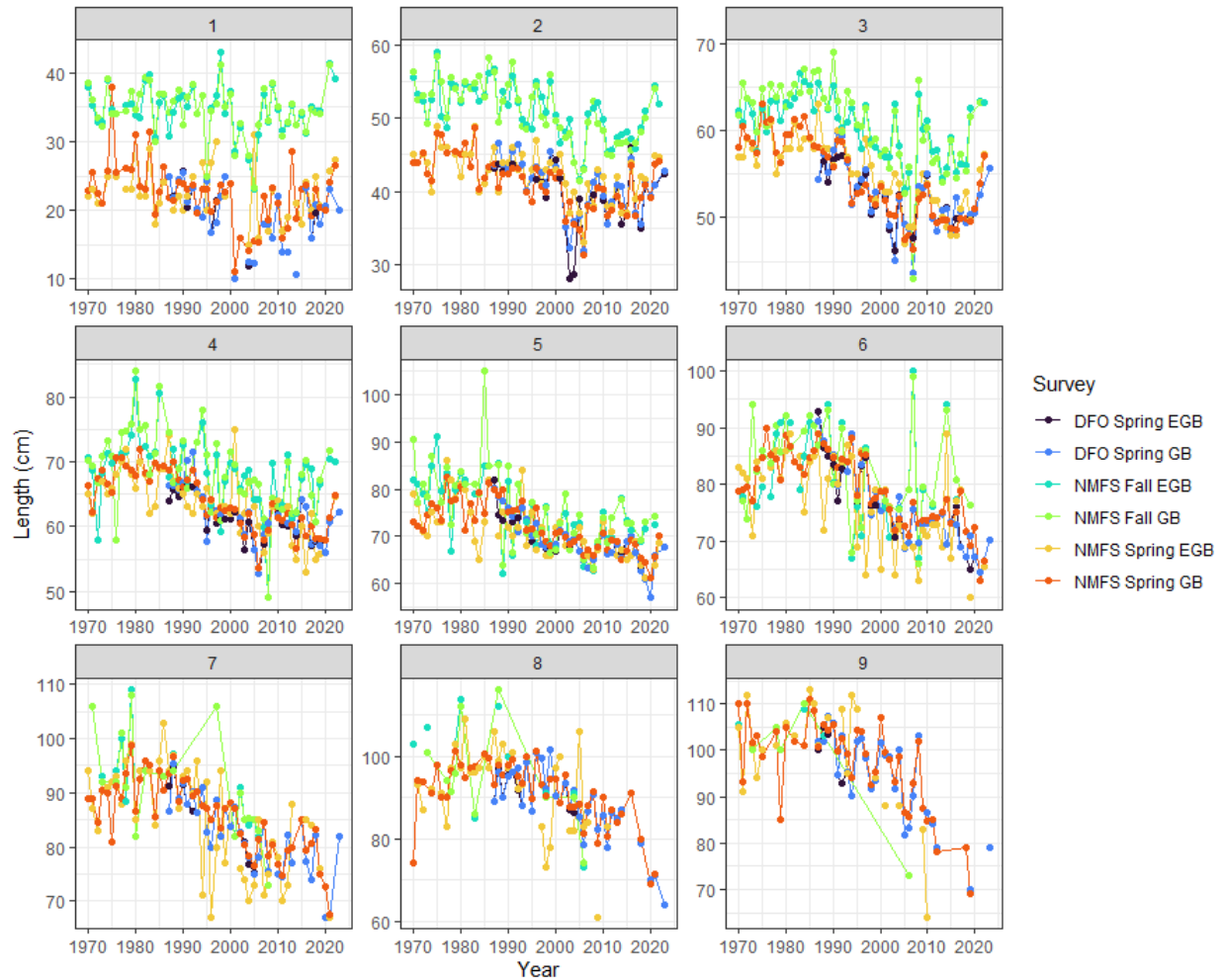


Figure 50. Length-at-age for the National Marine Fisheries Service (NMFS) spring, NMFS fall and Fisheries and Oceans Canada (DFO) winter surveys on eastern Georges Bank (EGB) and total Georges Bank (GB).

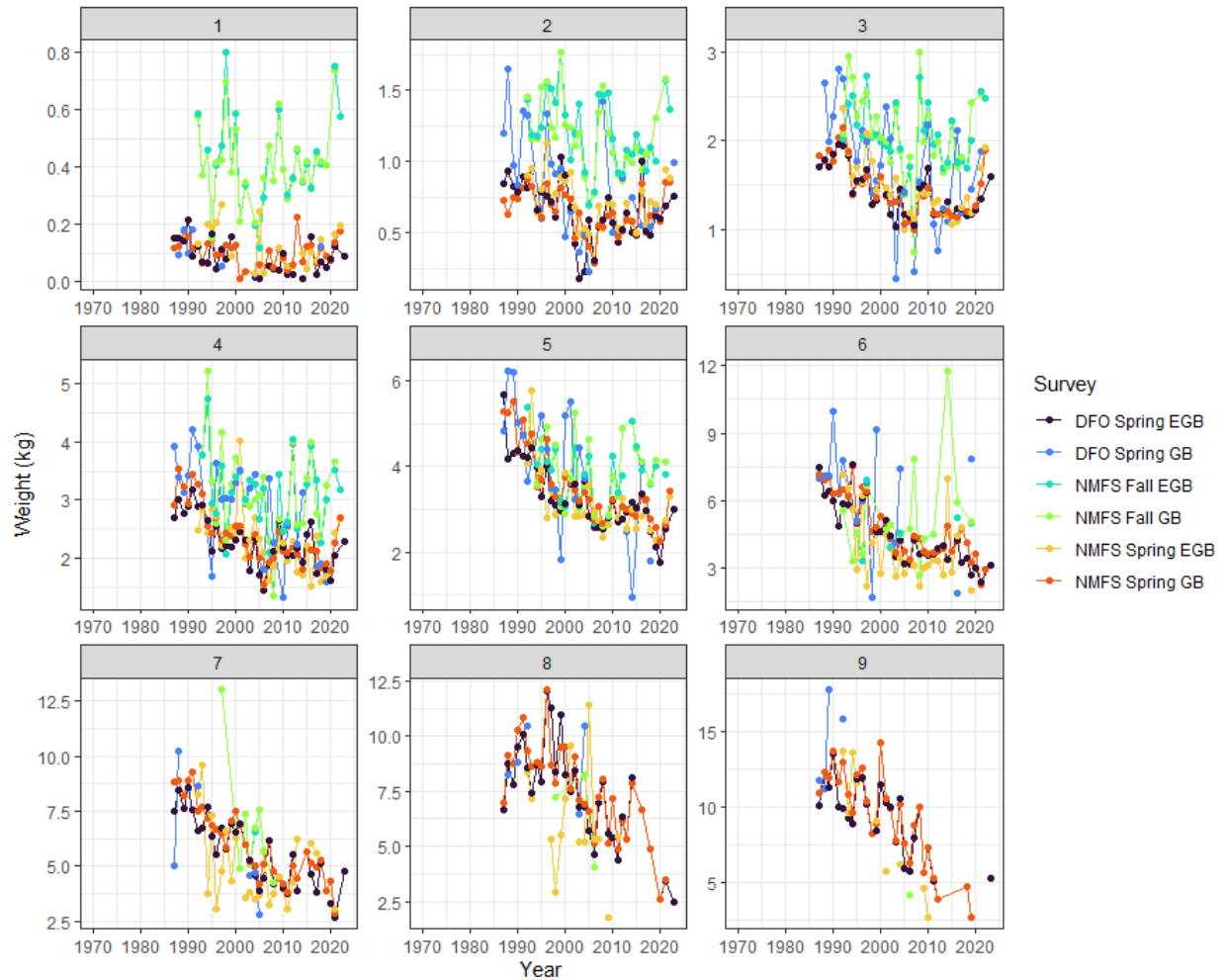


Figure 51. Weight-at-age for the National Marine Fisheries Service (NMFS) spring and fall Surveys on Eastern Georges Bank (EGB), and the Fisheries and Oceans Canada (DFO) winter survey on eastern Georges Bank and western Georges Bank.

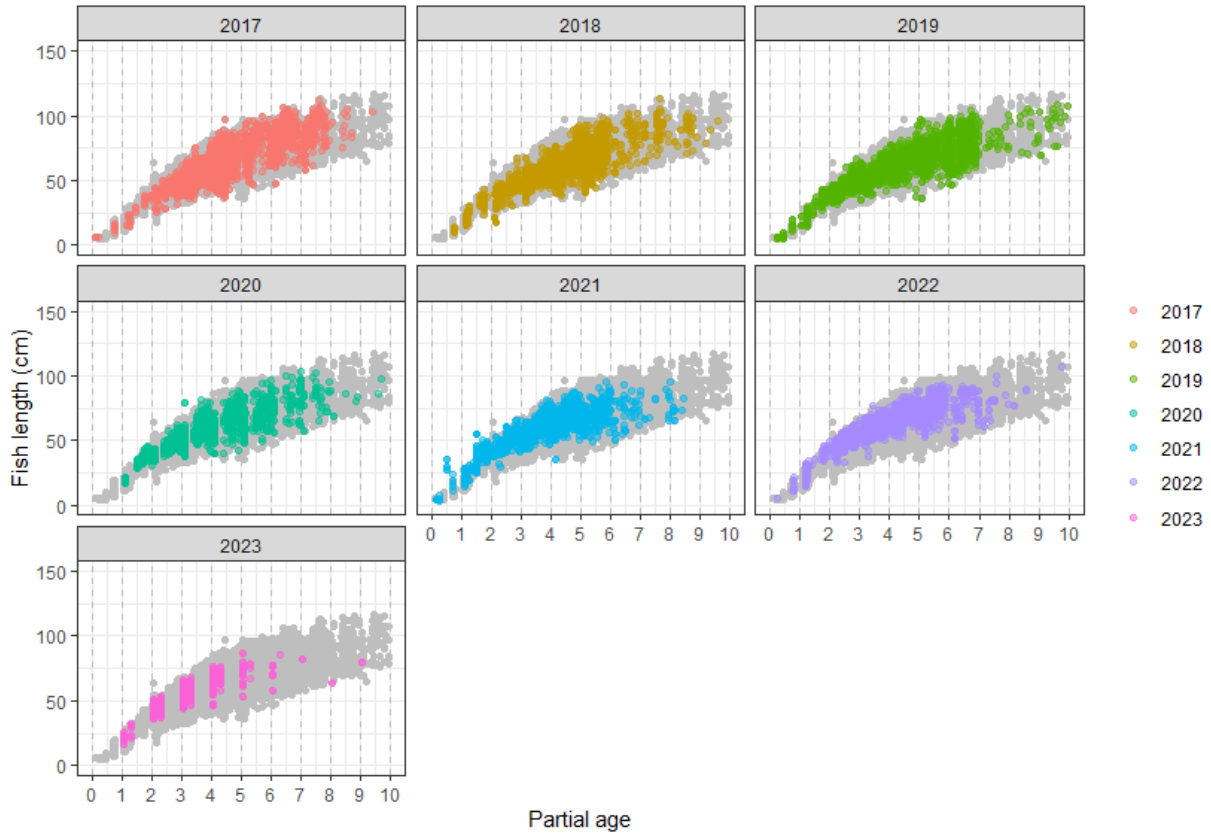


Figure 52. Length-at-age of 5Zjm cod sampled from the Canadian fishery, the National Marine Fisheries Service (NMFS) spring survey, the Fisheries and Oceans Canada (DFO) winter survey, and the NMFS fall survey data sets. Age has been adjusted to partial age based on the date of capture (surveys) or date sampled (fishery) for each fish. Partial age takes into accounts the birthdate assigned by the ageing lab where the fish was aged. Grey points show all data from 2010 to 2019.

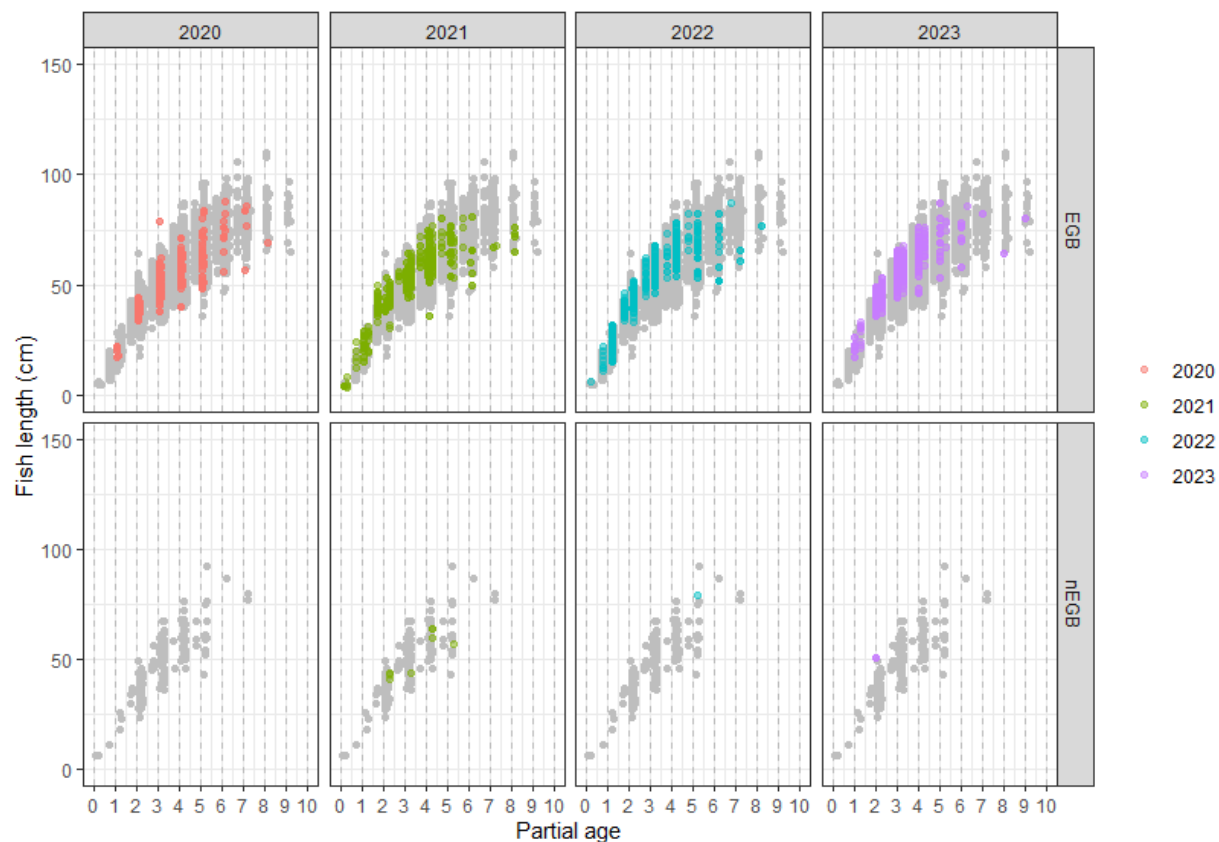


Figure 53. Length-at-age of 5Z cod on eastern Georges Bank (EGB) and the western portion of total Georges Bank (nEGB) management unit, sampled from the available US and Canadian survey data sets. Age has been adjusted to partial age based on the date of capture or each fish. Partial age takes into accounts the birthdate assigned by the ageing lab where the fish was aged. Grey points show all data from 2010 to 2019.

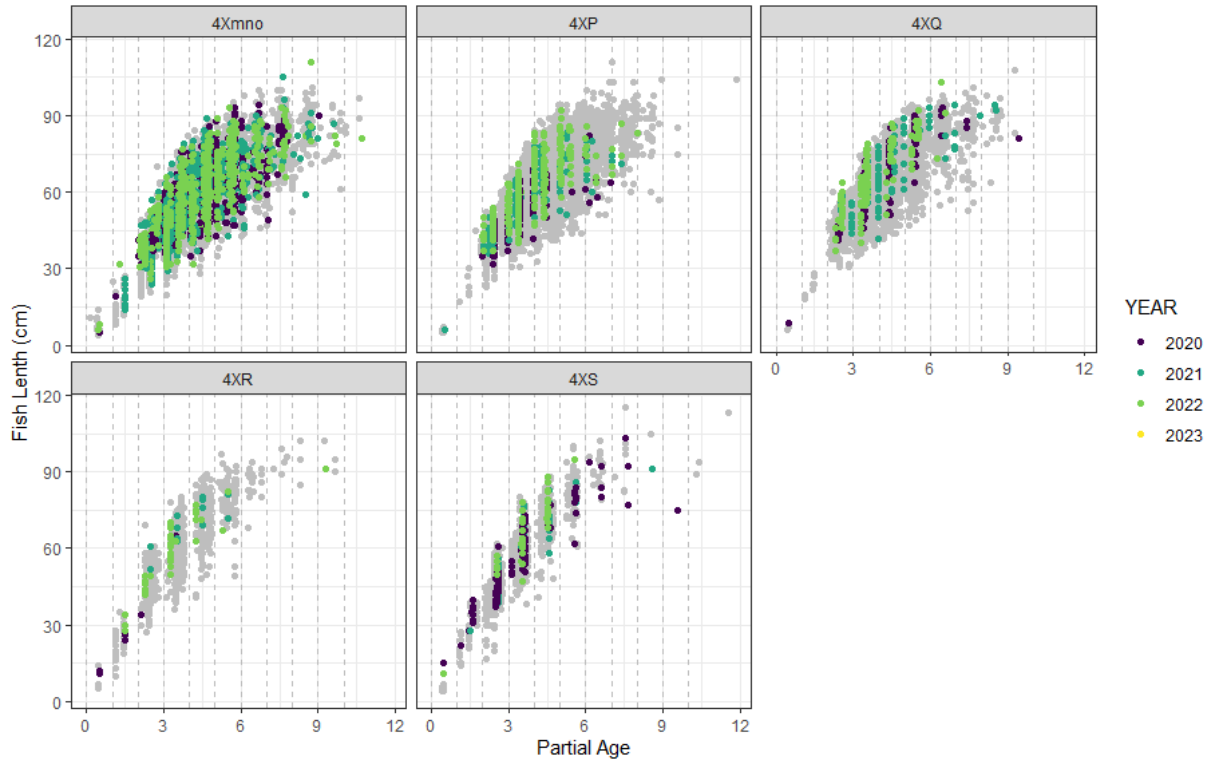


Figure 54. Length-at-age of 4X5Y cod sampled from the Canadian fishery, the Fisheries and Oceans Canada (DFO) winter and summer surveys data sets and the National Marine Fisheries Service (NMFS) spring and fall surveys. Age has been adjusted to partial age based on the date of capture (surveys) or date sampled (fishery) for each fish. Partial age takes into accounts the birthdate assigned by the ageing lab where the fish was aged. Grey points indicate data from each stratum from 2010 to 2019.

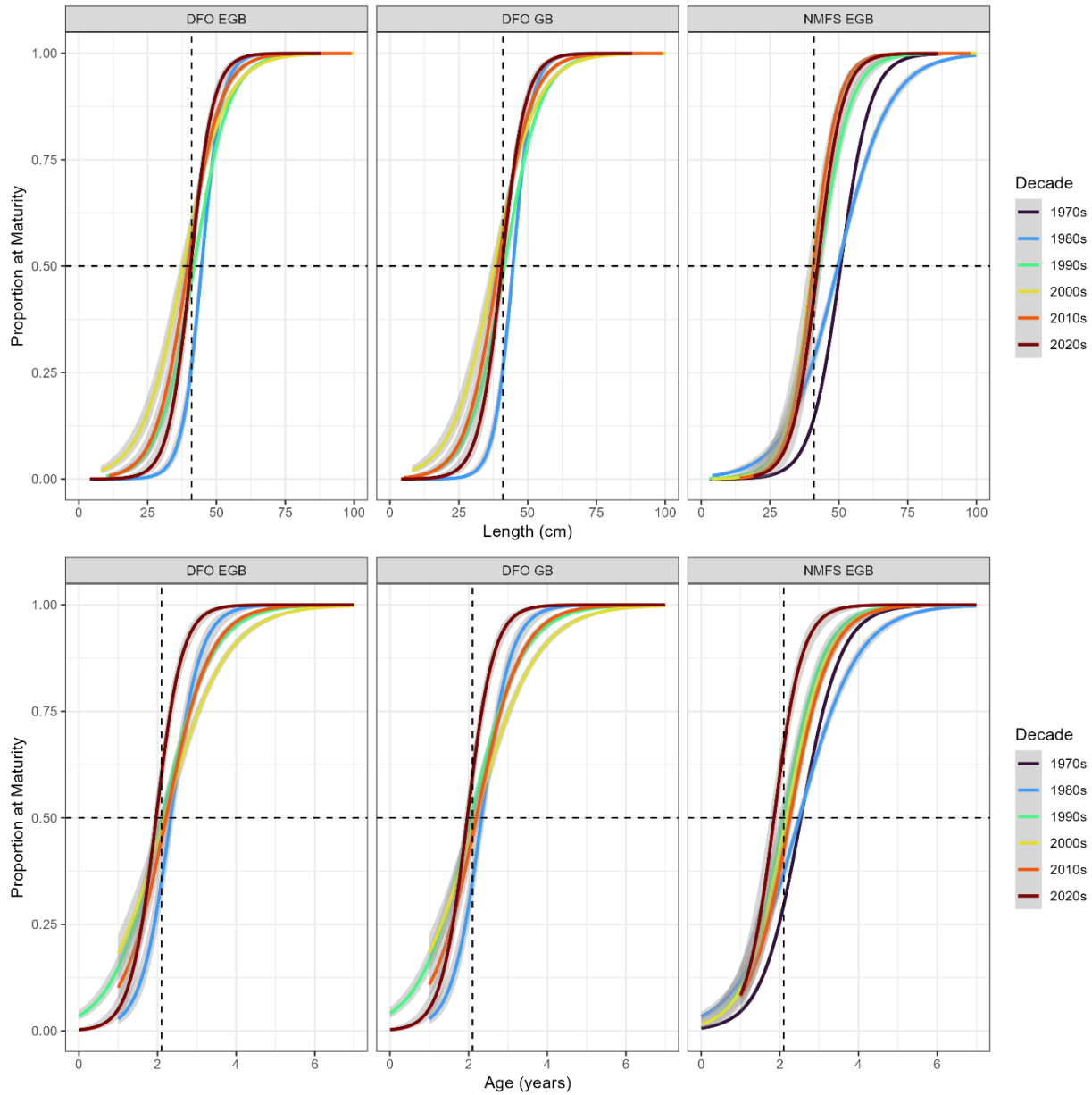


Figure 55. Length and age at maturity ogives for the Fisheries and Oceans Canada (DFO) winter survey on eastern Georges Bank (EGB) and total Georges Bank (GB), and the National Marine Fisheries Service (NMFS) spring survey (eastern Georges Bank). Dashed horizontal lines indicate 50%, while vertical dashed lines represent the L50 (41 cm) and A50 (2.1 years) values for 1990-until 2022 (NMFS spring survey) and 2023 (DFO winter survey and NMFS spring surveys).

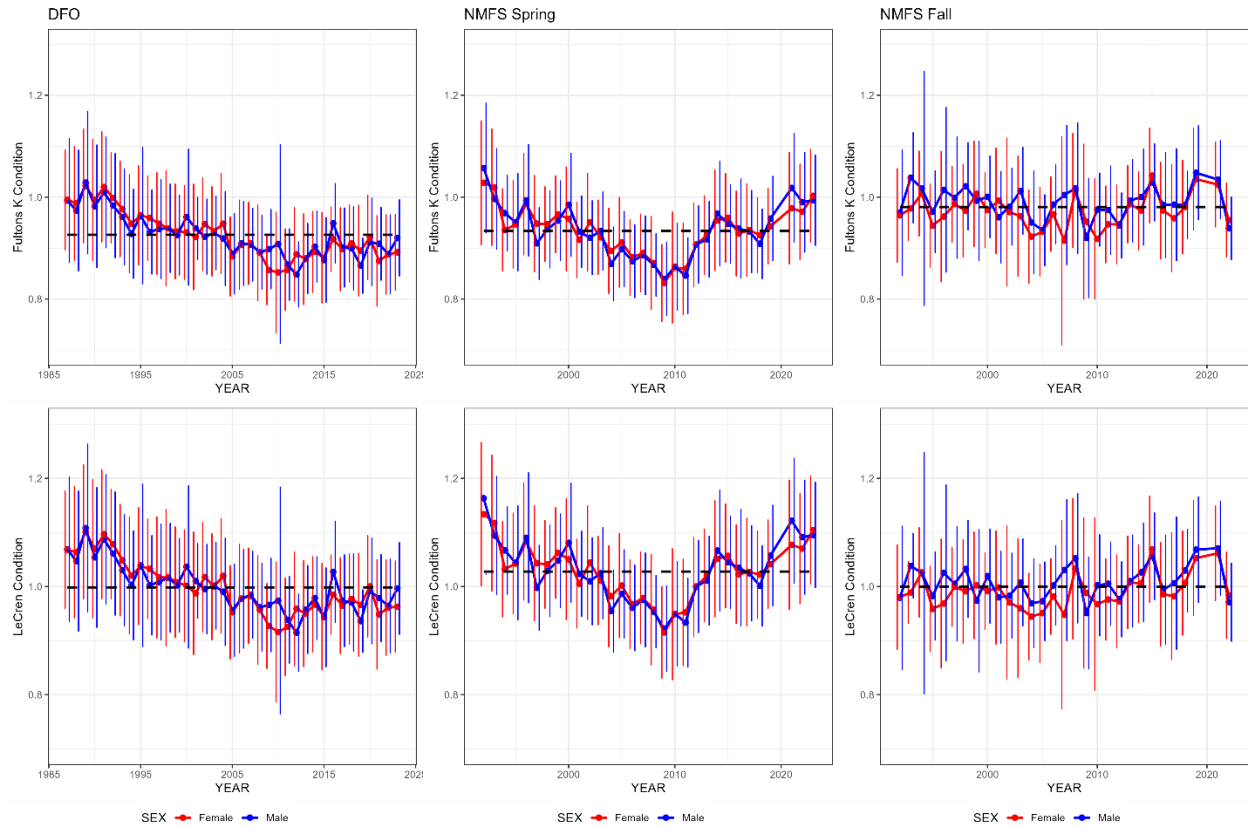


Figure 56. Fulton's K and Le Cren's condition index for Georges Bank Cod from the Fisheries and Oceans Canada (DFO) winter survey (5Z1–9), and the National Marine Fisheries Service (NMFS) fall and spring Surveys (survey strata 13–22). A higher 'value' when comparing Fulton's K and LeCren does not indicate a higher condition, as these are relative indices and can only be compared to themselves.

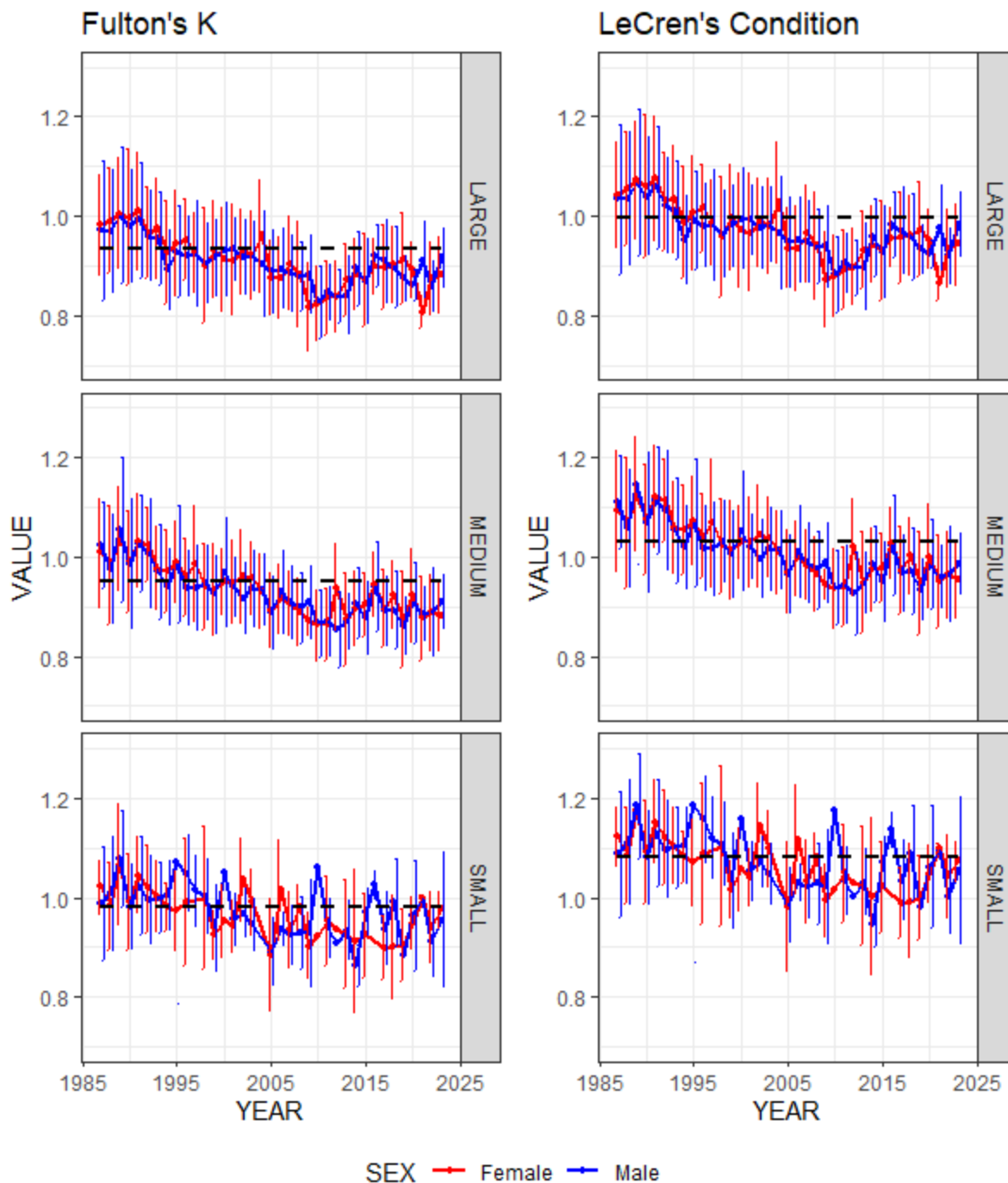


Figure 57. Fulton's K and Le Cren's condition index for Georges Bank Cod from the Fisheries and Oceans Canada (DFO) winter survey, faceted by length group (small =<46 cm, medium = 46–60 cm, large =>60 cm). A higher 'value' when comparing Fulton's K and LeCren does not indicate a higher condition, as these are relative indices and can only be compared to themselves.

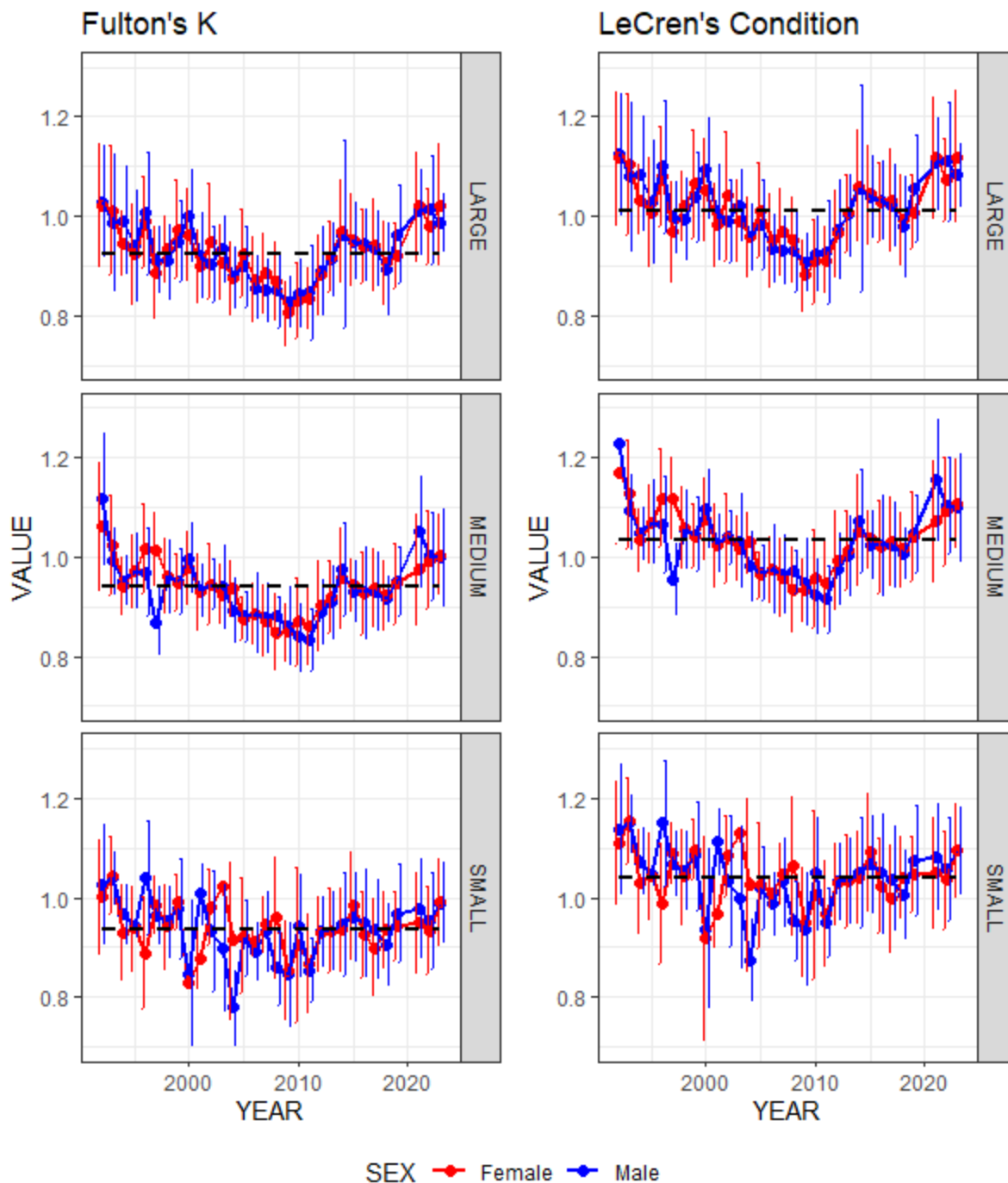


Figure 58. Fulton's K and Le Cren's condition index for Georges Bank Cod from the National Marine Fisheries Service (NMFS) Spring Survey (survey strata 13–22), faceted by length group (small =<46 cm, medium = 46–60 cm, large =>60 cm). A higher 'value' when comparing Fulton's K and LeCren does not indicate a higher condition, as these are relative indices and can only be compared to themselves.

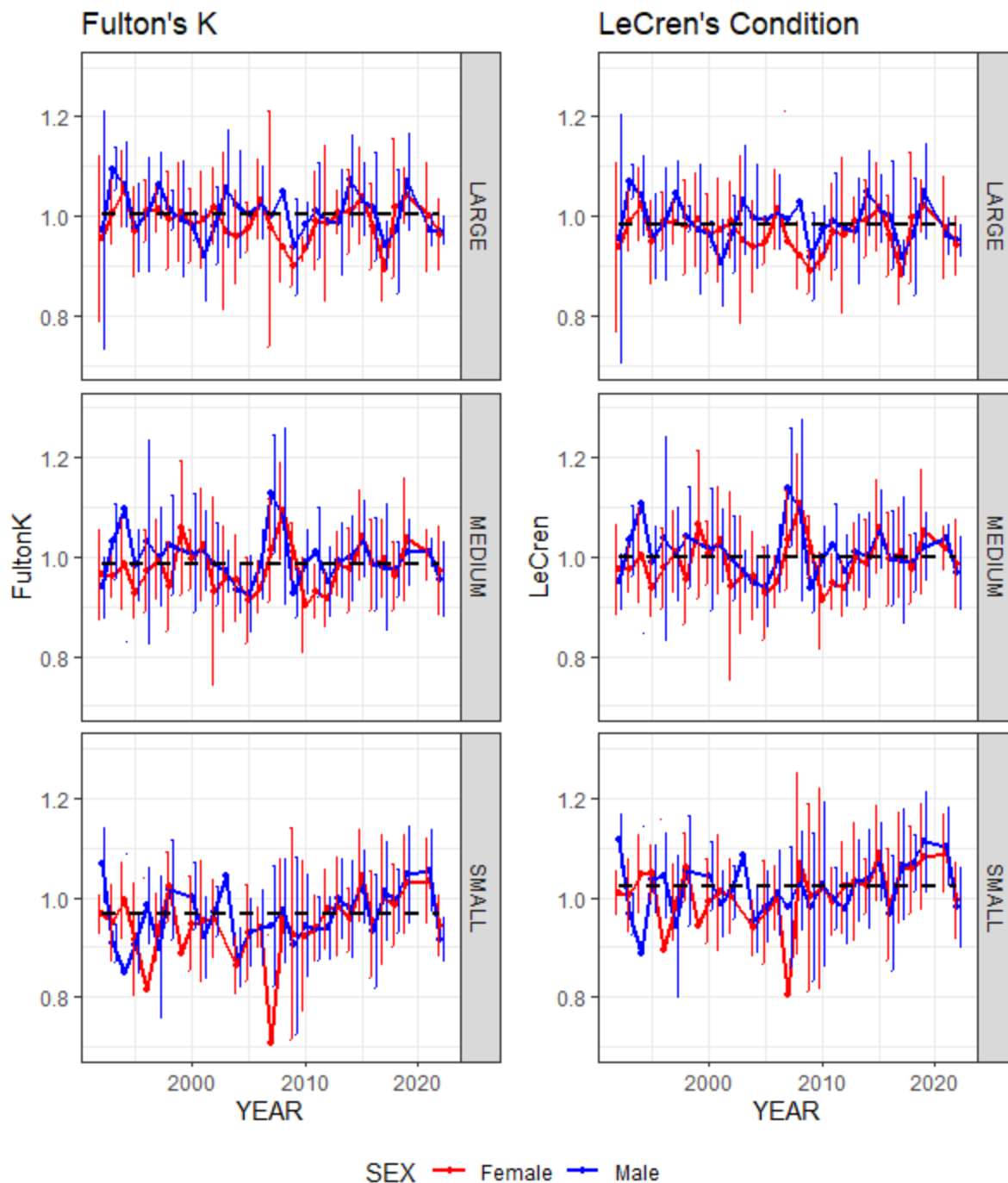


Figure 59. Fulton's K and Le Cren's condition index for Georges Bank Cod from the National Marine Fisheries Service (NMFS) fall Survey (survey strata 13-22), faceted by length group (small =<46 cm, medium = 46–60 cm, large =>60 cm). A higher 'value' when comparing Fulton's K and LeCren does not indicate a higher condition, as these are relative indices and can only be compared to themselves.

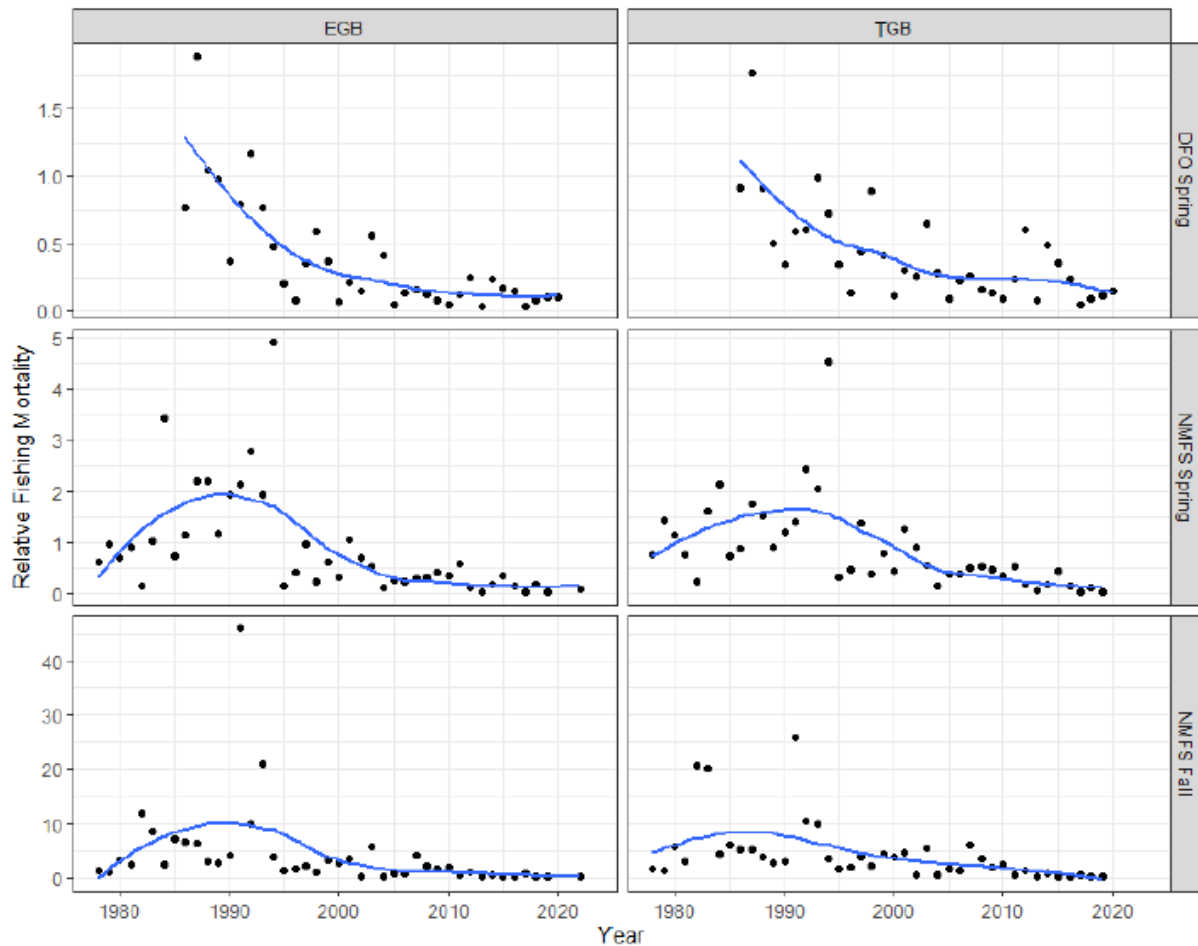


Figure 60. Relative fishing mortality (total removals / survey biomass) for both eastern Georges Bank (EGB; left column) and total Georges Bank (TGB; right column) for each of the three available surveys (rows). Points represent annual estimates and blue line is a loess smoother. (Fisheries and Oceans Canada – DFO, National Marine Fisheries Service – NMFS)



Figure 61. Total mortality estimates for Cod on eastern Georges Bank (EGB) and total Georges Bank (GB) for ages 4–7 (spring) and 3–6 (fall) surveys. Vertical bars indicate standard error. (DFO - Fisheries and Oceans Canada, NMFS - National Marine Fisheries Service)

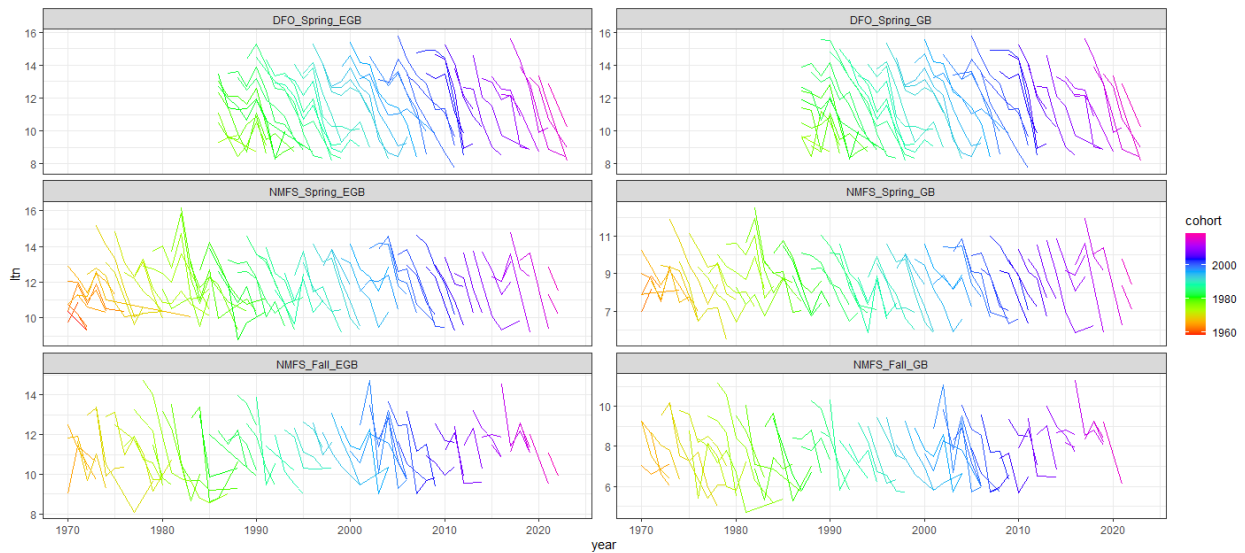


Figure 62. Cohort log transformed catch curves for the Fisheries and Oceans Canada (DFO) and National Marine Fisheries Service (NMFS) surveys for the eastern (left column) and total (right column) Georges Bank units. Colours indicate cohort year. Lines have been limited to ages 4–7 in the spring, and ages 3–6 in the fall.

APPENDIX A

Excerpt from the 2009 trac benchmark proceedings, outlining various ways forward with respect to assessment unit and considerations.

Management Unit Options (preferred option highlighted)

In order to effect regulatory measures at the resolution of management units, status determination must be provided at the scale of management units. Status determination may initially be determined at a scale larger than the management units, but the assessment must include decomposition to the management units. At present, we are limited to defining management units at the resolution of statistical unit areas.

A. 5Z+6

- assumes exchange with Div. 4X can be ignored
- may result in concentration of exploitation on a component within 5Z+6, a potential conservation concern if exchange is low

B. 5Zjm and 5Z(-jm)+6

- assumes exchange between 5Zjm and 4X and between 5Zjm and 5Z(-jm)+6 can be ignored
- Fish between 5Zjm and 68 may be missed
- ability to achieve management objectives may be compromised if exchange is appreciable

C. 5Z+6 (USA domestic) and 5Zjm (transboundary)

- status quo – least disruptive to existing process
- respective implications listed above apply
- require concurrent assessment reviews to harmonize results

D. Statistical Units 561, 562, 551, 552, 522, 525

- may captures too much of South Channel component (half of Wilkinson Basin)
- potentially reflects more of tagging results
- additional work with tagging results would be required

E. East of 68

- splits statistical units 522 and 525 in half – cannot be done currently
- best captures understanding of cod components

F. Inclusion of part of 4X (4Xp, 4Xq, 4Xr, 4Xs)?

- difficulty in setting appropriate eastern boundary (which statistical/unit areas)?
- e.g., 4Xp includes both western and eastern Browns Bank
- survey issues – don't have a survey that covers the whole area at one time
- would take into account observed exchange