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The Status of the Northern Gulf of St. Lawrence (3Pn, 4RS) Atlantic Cod (*Gadus morhua*) Stock in 2022

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Foreword

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

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ABSTRACT

The Atlantic cod stock in the northern Gulf of St. Lawrence (NAFO Subdivision 3Pn and Divisions 4R and 4S) has been fished for centuries, and has been managed using a total allowable catch since 1977. Following a sharp increase in fishing mortality beginning in the late 1980s, accompanied by an increase in natural mortality, the stock collapsed and was placed under moratorium from 1994-1996. Although some recovery occurred during this period, the stock has fluctuated at a low level of abundance since then, despite relatively low fishing mortality, including a moratorium in 2003 and a closure of the directed commercial fishery for the 2022-2023 season.

A new model developed during the review of the northern Gulf of St. Lawrence cod assessment framework that took place in 2021 and 2022 was used for the first time for this assessment. This document describes the data and methods employed to assess a number of indicators later used in the assessment model as inputs.

Fishing mortality, for which the estimate is based on reported or inferred catches, was low in 2021 and even lower in 2022, specifically at the lowest level since the 2003 moratorium. However, natural mortality has been at high levels for at least a decade and it is likely that part of this natural mortality is in fact made up of unaccounted fishing mortality. In 2022, cod condition was particularly poor, especially in Division 4S, and at levels where increased natural mortality has been observed in the past. The cohort born in 2018, which has been observed annually in the Fisheries and Oceans Canada annual survey since 2019, appears to be the most abundant since the early 1990s. The prospects for this cohort will depend on the mortality it experiences in the coming years. A precautionary approach limit reference point (LRP), based on long-term stock trends in stock spawning biomass (SSB), was adopted at a value of 71,970 t. Other reference points using the same framework as the LRP were proposed, including the upper stock reference point (USR, 143,939 t) and the target reference point (TRP, 179,924 t). The stock has been in the critical zone since 1991, and the SSB estimate for 2022 (42,906 t) corresponded to 60% of the LRP. An examination of stock productivity revealed that the stock had surplus production for the majority of years since 1995 and would likely have grown in the absence of commercial and recreational fisheries. A brief review of other factors that may have affected the productivity of this stock identified some that may have been relevant, to a degree and in some years, but did not conclusively identify the principal drivers of the high natural mortality that is largely preventing recovery.

1 INTRODUCTION

The Atlantic cod[1], *Gadus morhua*, was until the early 1990s the main exploited groundfish species to be landed on the Canadian Atlantic coast. Several cod stocks occur along this coast, including the northern Gulf of St. Lawrence (nGSL) stock which encompasses NAFO[2] Subdivision 3Pn and Divisions 4R and 4S (Figure 1).

The status of the stock has been assessed by Fisheries and Oceans Canada (DFO) since at least the early 1970s (Table 1). Since 2012, the stock's status has been assessed every two to four years. The last time the stock was fully assessed was in February 2019 (Table 1). The latter had determined that the stock was deep into the critical zone, at 10% of the Limit Reference Point (LRP). Since, indicators of stock status have been updated annually, and have not shown any major change in the stock's status (DFO 2020a, 2021b, 2022a). In parallel with these updates, a review of the assessment framework for the stock was completed in order to obtain a new assessment model. It was held in two sessions, the first one focusing on the availability and statistical handling of the data (21-22 April and 12 May 2021, Benoît et al. 2021, 2022; DFO 2022d; Ouellette-Plante et al. 2022a; 2022c) and the second aimed at developing a new assessment model[3] (24-26 May 2022, Benoît et al. 2024a).

In July 2022, DFO announced the closure of the commercial fishery targeted at 3Pn4RS cod for one year and announced that this decision would be reassessed prior to the 2023-24 fishing season (DFO 2022e). The peer-review meeting held from 23 to 24 February 2023 had been requested by Fisheries Management (FM) to provide detailed advice on the status of nGSL cod, with the goal of guiding decisions on the management of this stock for the coming management cycle. Finally, since a new assessment model was accepted at the meeting held in May 2022, revising the Precautionary Approach (PA) reference points was necessary, especially since they are key aspects of the rebuilding plan to come.

The present research document presents the methods, data and results of this last assessment, and acts as a reference to the scientific advice resulting from this review.

1.1 COSEWIC STATUS

In 2010, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed cod from the Laurentian North Designable Unit (DU), which encompasses NAFO Divisions 3P4RS and of which the 3Pn4RS stock is part, as being Endangered (COSEWIC 2010). The last assessment of the recovery potential for cod in this DU dates to 2011 (DFO 2011a).

1.2 SPECIES BIOLOGY

The following section is based in part on the summary of the 3Pn4RS cod stock's biology provided in Dutil et al. (2005). When necessary, updates are provided according to the most recent studies available.

1.2.1 General description

Cod are a species of fish of the order Gadiformes, in the family of Gadidae and the sub-family Gadinae. The members of this sub-family are distinguished by their three dorsal fins and two

[1] The term *cod* is used hereafter to refer to Atlantic cod.

[2] Northwest Atlantic Fisheries Organization. This stock is hereafter referred to as the 3Pn4RS stock.

[3] Other documents related to this meeting are in preparation.

anal fins (Cohen et al. 1990). The coloration of cod is variable, often brownish, greenish or greyish in color on the dorsal portion and paler ventrally (Cohen et al. 1990). Juveniles can be golden red in color (Nozères et al. 2010).

1.2.2 Distribution range

Worldwide, cod is distributed in the North Atlantic Ocean and in the Arctic Ocean (Figure 2, Cohen et al. 1990). In the Americas, it is distributed along the coast from Cape Hatteras in North Carolina (United States) to Ungava Bay in Canada. On the European side, it is observed in Greenland, around Iceland and on the coasts of Europe from the Bay of Biscay in the south to the Barents Sea in the north.

The 3Pn4RS cod stock is distributed in the northern portion of the Gulf of St. Lawrence (GSL), which is a semi-enclosed sea connected to the Atlantic Ocean by two openings: the Cabot Strait to the southeast and the Belle Isle Strait to the northeast. Four other cod stocks are adjacent to the 3Pn4RS stock: the southern GSL cod stock (Divisions 4T + 4Vn [November to April]) to the south, the 3Ps and 4Vn stocks (May to October) to the southeast, and the northern cod stock (Divisions 2J3KL) at the outlet of the Strait of Belle Isle (Figure 1).

Cod in 3Pn4RS have long been known to undertake annual migrations (Figure 3). In winter, high concentrations are found in the deep waters of Subdivision 3Pn. In the spring (April-May), cod begin their northward migration and begin spawning in the Port-au-Port Peninsula area on the west coast of the island of Newfoundland, within the province of Newfoundland and Labrador (NL). The cod then continues to disperse in the coastal and offshore areas of western Newfoundland and the Middle and Lower North Shore of Quebec (QC) during the summer. These migrations are associated with seasonal warming of the waters and food availability (DFO 2003b).

In terms of depth, 3Pn4RS cod is distributed during the summer at depths ranging from about 50 m to more than 500 m. However, most cod are found between 50 and 150 m (Figure 4d). Large cod are found in deeper waters than smaller specimens (Chabot et al. 2008).

1.2.3 Mixing with peripheral stocks

In the early 1990s, DFO winter surveys showed significant movements of the stock to Subdivision 3Ps during the winter, mainly in the Burgeo Bank area (Fréchet and Gagnon 1993; Fréchet et al. 1994). These migrations out of the stock area were then postulated to be the result of regional changes in hydrographic conditions encountered at the usual wintering sites (Ouellet 1997). These observations led to the abandonment of the DFO winter survey conducted since 1978 aboard the MV[4] Gadus Atlantica because the biomass estimates were then skewed downwards.

In general, the results of several tagging studies show that the 3Pn4RS stock is fairly well isolated from the peripheral stocks. Except for Subdivision 3Ps where recaptures of cod tagged in 3Pn4RS are relatively frequent, recaptures elsewhere outside of 3Pn4RS are rare (Bérubé and Fréchet 2001).

1.2.4 Hypoxia

The level of dissolved oxygen concentration in the surrounding environment at which a decrease in the energy budget for a species is observed, i.e. hypoxia, is known to negatively influence the metabolic capacities of fish. At the physiological level, hypoxic conditions will alter

[4] Motor vessel.

cod's digestion, which will influence its growth, fecundity and general condition, among others (Chabot and Dutil 1999). At the stock level, hypoxic conditions could alter the spatial distribution, recruitment, abundance and biomass of the stock, among other things.

Long-term survival of cod is no longer assured when oxygen saturation levels fall below 20% (Chabot and Claireaux 2008). At levels below 50%, swimming and digestion are severely restricted. During the summer and fall, cod are not found in areas where oxygen saturation is < 30% since this level is lethal to some fish (Figure 4c, Chabot and Claireaux 2008). The hypoxic conditions of the deep channels of the nGSL are therefore unfavorable for cod.

1.2.5 Growth

Considered a long-lived species (Trippel 1995), the annual growth of 3Pn4RS cod is not evenly distributed throughout the year. Correlations with measures of condition factors suggest that 3Pn4RS cod would have a period of negative growth around the spawning period, followed by strong growth towards late summer and early fall (Dutil et al. 2005). At the species level, the 3Pn4RS cod stock is one of the least productive stocks in the North Atlantic in terms of individual growth by weight (Dutil and Brander 2003).

1.2.6 Reproduction and early-life stages

Several sampling campaigns were conducted in the late 1980s and early 1990s to acquire knowledge of decapod invertebrate larvae and fish eggs and larvae in the GSL (Ouellet et al. 1994). Analysis of these data showed that simultaneous spawning events were occurring for cod in all areas of the nGSL as early as May. However, according to fishing and ichthyoplankton data, breeding occurs mainly off St. George's Bay (Ouellet et al. 1997). This area is the same as that used by spring-spawning Atlantic herring (*Clupea harengus*) for breeding (Dutil et al. 2005), and is restricted for fishing from June 1 to 23 to promote spawning (Figure 5). Most spawning events occur below the cold intermediate layer (CIL) at depths > 150 m (Dutil et al. 2005).

In general, 3Pn4RS cod begin spawning in late March and spawning activity increases in May and continues until June (Ouellet 1997). Larger cod begin breeding before small cod, and will produce larger eggs (Trippel 1995). It has been suggested that reproduction coincides with the onset of the spring planktonic bloom, which occurs from April to June in a south-north gradient in connection with the retreat of the ice. The duration of spawning varies individually depending on the size of the cod. Larger female cod will produce more eggs at different times than smaller cod (Trippel 1995). As they lay eggs, they reduce in size (Ouellet 1997). Depending on environmental conditions, some cod have been observed to refrain from breeding in other stocks despite having reached sexual maturity (Rideout and Rose 2006).

Following spawning, the cod eggs are bathypelagic5 and disperse with the currents. The development time of eggs and larvae is related to the water temperatures observed in their environment (Templeman 1981). When incubated at 0°C, eggs would take about 40 days to develop, with a shorter timeframe in warmer waters (Templeman 1981; Ouellet 1997). The feeding period of larvae following yolk-sac resorption is quite critical, and environmental conditions during this period may influence the survival of these young cohorts and their future importance to the stock (Rose 2018).

This larval period is followed by a pelagic juvenile phase where cod of about 17 mm in total length will go deeper into the water column. At a total length of about 30 to 60 mm, juvenile cod transition to complex demersal habitats to hide from predators (Rose 2018).

[5] Means that their buoyancy is negative in the upper layer of the water column (Ouellet 1997).

1.2.7 Diet

Cod is a generalist predator. Indeed, 204 different taxa were observed in the 2,004 stomachs collected during DFO's August bottom-trawl surveys of the 2015–-2017 period, which corresponds to 82% of the total number of taxa observed in the stomachs of all predators for which stomachs were collected and analyzed during this period (Ouellette-Plante et al. 2020). The taxa observed for cod corresponded to 74 different prey families.

In August 2015–2017, cod < 30 cm fed mainly on zooplankton (33%[6], mainly hyperiids of the genus *Themisto* sp.), shrimp (24%, mainly northern shrimp [*Pandalus borealis*]), and fish (22%, mainly capelin [*Mallotus villosus*]). From 30 to 55 cm, the contribution of zooplankton dropped, whereas those of fish, including redfish[7] (*Sebastes* spp.) and capelin, and shrimp, increased. The diet of cod ≥ 55 cm consisted mainly of fish, and redfish were the most important prey. All sizes combined, the three taxa contributing the most to the August diet of cod during this period were *1) capelin, 2) northern shrimp, and 3) redfish.*

Apart from data collected during the DFO bottom trawl surveys in August, few data are available to describe the diet of 3Pn4RS cod during the rest of the year. Minet and Perodou (1978) presented the results obtained from 570 and 194 stomachs collected in the winters of 1975–1976 and summer of 1975, respectively. The authors reported that there was very little seasonal variation in cod diet and that it was similar across NAFO Divisions in terms of the main species consumed. Their results showed capelin as the most important prey in both summer and winter. This importance of capelin in winter was not observed later following the implementation of the sentinel survey program in the fall of 1994 (see the *Sentinel surveys* section). Indeed, after obtaining 689 cod stomachs from November 1994 to January 1995, Fréchet and Schwab (1995) showed that invertebrates contributed more to the cod's diet (as a % of the total mass of stomach contents). The Atlantic herring was then the fish that contributed the most to the diet (6.7%), almost twice the contribution of capelin (3.05%). As for the variation in feeding intensity between months of the year, Fréchet et al. (2003) showed that it decreased from July to August and then resumed in the fall. However, the authors mentioned that the different vessel-gear tandems used to acquire the stomachs could have been a parameter affecting stomach fullness between months. From this work, we note large differences, and it is difficult to explain them since the stomachs collected did not necessarily cover the same places and periods (which could reflect the availability of prey), nor were they sampled during comparable surveys.

During the winter season, several studies have shown that cod fed very little (Turuk 1968; Tyler 1971; Fordham and Trippel 1999; Schwalme and Chouinard 1999). For the 3Pn4RS stock, a lower feeding intensity in the winter months is observable according to condition data obtained from the fixed gear sentinel surveys program (Ouellette-Plante et al. 2022b).

1.2.8 Predators

Cod are preyed upon by several predators throughout their development. For example, larvae are preyed upon by Atlantic herring, Atlantic mackerel (*Scomber scombrus*) and even other cod larvae (Bromley et al. 1997; Rose 2018). Juvenile cod otoliths have been found in several northern squid stomachs (*Illex illecebrosus*, Dawe et al. 1997). Based on stomachs from the nGSL collected during the 2015–2017 period, Ouellette-Plante et al. (2020) showed that Atlantic

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[6] Unless otherwise specified, the % values in this section correspond to the contribution of the partial fullness index (PFI) to the total fullness index (TFI), i.e. $\frac{IRP}{IRT} \cdot 100$.

[7] In the text, the term redfish will refer to deepwater redfish (*Sebastes mentella*) and Acadian redfish (*S. fasciatus*).

halibut (*Hippoglossus hippoglossus*) and white hake (*Urophycis tenuis*) also fed on cod. Cannibalism is also observed in adult cod (Fréchet et al. 2003; Ouellette-Plante et al. 2020).

The extent of seal predation on 3Pn4RS cod is somewhat uncertain, but has certainly been less significant than that on the neighboring southern GSL stock (NAFO Divisions 4T and 4Vn [November to April]), where grey seals (*Halichoerus grypus*) are much more abundant locally (Swain et al. 2019b). However, recent aerial surveys have noted an increase in grey seal abundance at Brion Island (Magdalen Islands, Mosnier et al. 2023). Since some of these seals may occasionally feed in the nGSL, according to telemetry work, the level of predation on 3Pn4RS cod may well have increased in recent years.

1.3 ECOSYSTEM

1.3.1 Physical and chemical oceanographic conditions

DFO annually assesses the physical oceanographic conditions prevailing in the GSL as part of the Atlantic Zone Monitoring Program (AZMP). Since 2009, the deep waters of the GSL have been warming with inward advection from Cabot Strait (Galbraith et al. 2023). The deep water layer (>150 m) originates at the entrance to the Laurentian Channel, where the waters of two currents, the Labrador Current (cold, less saline, highly oxygenated) and the Gulf Stream (warm, more saline, less oxygenated) combine into a water mass for which the temperature, salinity and dissolved oxygen depend on their respective contribution. Water temperatures exceeding 7 °C have been recorded since 2012 in the GSL near Cabot Strait and have occupied a significant volume of deep waters in recent years, including those where cod aggregate in winter. Since this warming occurs across the GSL and generally in all layers of the water column at depths of 150 m and above, we therefore observe a warming of the waters where cod are caught during the DFO August survey (Figure 4a). At 150 m depth, the average water temperature in the GSL reached one of the highest values in the series in 2022. During the summer, cod live closer to the CIL, a layer of water formed by the surface layer of the previous winter. In recent years, we have seen a decrease in its volume and an increase in its temperature.

In 2020, the dissolved oxygen concentration in the deep layer of Cabot Strait was the second lowest value in the 2002–2020 series (Blais et al. 2021). Since these waters provide the main inputs to the GSL and that they take three to four years to reach the estuary, further declines in DO can be expected in the deep layers of the GSL in the coming years. Indeed, waters entering the GSL become depleted in dissolved oxygen as they progress due to *in situ* respiration and oxidation of organic matter. A decrease in dissolved oxygen levels is observed at locations where cod are caught during the DFO August survey (Figure 4c).

1.3.2 nGSL community

Until the early 1990s, the nGSL demersal community was dominated by demersal fish (cod, redfish). Following their collapse, the biomass of several species, including northern shrimp, increased. Since the mid-2010s, there has been a significant increase in the deepwater redfish and Acadian redfish populations, so much so that according to the DFO August survey, their biomass represented 82% of the total biomass of all organisms captured during this survey, compared to an average of 15% during the 1995–2012 period (Bourdages et al. 2023).

The DFO August survey also provided abundance and biomass indices for cod prey, such as capelin. However, these indices should be interpreted with caution since the catchability of pelagic species to the survey is not known and is probably very low. That said, capelin appears to be less observed along the west coast of Newfoundland and northeast of Anticosti Island during the survey in recent years. In 2022, very low catches were observed and they were mostly found in the estuary.

1.4 MANAGEMENT MEASURES

This section is largely based on the integrated fisheries management plan developed in January 2017 for groundfish in the GSL(NAFO Subdivisions 3Pn and 4Vn and Divisions 4RST; DFO 2017).

1.4.1 Total allowable catch

A total allowable catch (TAC) has been in place since the expansion of Canada's Exclusive Economic Zone (EEZ) to 200 nautical miles offshore in 1977 (Table 2, Sanguin 1980). The annual TAC is distributed among the different fleets and fleet sectors, according to the sharing agreements in force.

1.4.2 Fishing season

Until 1998, the management year for 3Pn4RS cod was the calendar year. In 1999, a new management cycle was introduced for non-NAFO regulated groundfish stocks. This change was driven by industry requests for a more timely preparation and announcement of the groundfish management plan (DFO 1999). Beginning in 2000, the management year for stocks in the Gulf of St. Lawrence, including 3Pn4RS cod, was changed from May 15 of the current year to May 14 of the following year. To accommodate this change, the management year in 1999 ranged from January 1, 1999 to May 14, 2000.

The start and end dates for the commercial 3Pn4RS cod fishery may vary among fleets and are determined in consultation with industry. However, no directed cod fishing is authorized in NAFO Divisions 3Pn4RS between January 1 and June 23 of each year in order to ensure the protection of fish during the spawning period (see the Conservation Measures section). Since bycatch of cod may be reported in other groundfish fisheries, cod catches are monitored year-round.

1.4.3 Fishing gear used

The use of mobile gear in fisheries targeting 3Pn4RS cod has been prohibited since 1994. The fishing gear configurations to be respected (e.g., mesh size of gillnets or hook openings of longlines) are defined in the conservation-oriented fishing plans. For QC fishermen and depending on the fleet, handlines, longlines and gillnets may be authorized. For the NL inshore fixed gear fleet, the types of gear authorized for a commercial cod fishery include gillnets, handlines, longlines and cod pots, with restrictions in place that are specific to each type of gear.

1.4.4 Fishing restrictions

Several restrictions on commercial fishing apply for this stock and they are often fleet-specific. These notably include:

- A prohibition on leaving fixed fishing gear in the water unattended for a continuous period in excess of a duration that may vary from one fleet to another (maximum 72 hours).
- Harvesters from NL located south of a line from Johnson Cove (48°04'N, 59°09'W, see Figure 5), including those in 3Pn and part of 4Rd, may only use longlines, handlines and cod pots as fishing gear.

1.4.5 At-sea monitoring

At-sea monitoring by approved and independent at-sea observer companies is required for the commercial 3Pn4RS cod directed fishery. This monitoring is at the expense of the industry. The percentage of coverage of fishing trips varies depending on the fleet (5 to 20%).

Since 2007, vessels in the QC large longline fleet have been required to have on board a vessel monitoring system (VMS) that allows for satellite tracking of their movements. In 2021-2022, this measure was not mandatory for the Lower North Shore fleet. Unlike the entire shrimp fleet that uses this system (Bourdages et al. 2022), its use in the 3Pn4RS cod fishery is very limited and the analysis of these data was not considered useful in the present stock assessment.

1.4.6 Dockside monitoring

All landings must be recorded at the dock by a DFO-approved verification company. In some years and in remote areas, dockside weighers have not been available. In these rare cases, DFO uses purchase receipts and logbooks as sources of data to track quotas and landings (S. Beauchamp, DFO, pers. comm. 2023).

1.4.7 Harvest control

Several harvest control measures are in place in the commercial directed fishery. For the 2021-22 season, these included (DFO 2021d):

- For QC harvesters:
    - ITQ (individual transferable quota) system for several fixed gear fleets with access to the Quebec 3Pn4RS cod allocation, and
    - Minimum initial quantity required (including temporary transfers) to be eligible to receive licence conditions for the directed fishery, or
    - Quantity of gear limited based on the fishing location and the quota held (including temporary transfers).
- For NL harvesters:
    - A distribution of the allocation of catches by fixed gear according to different periods during the season.
    - Weekly catch limits per permit holder.

Since 2011, DFO has implemented quota reconciliation in groundfish fisheries. This means that any quota overrun in a given year, whether within an individual quota (IQ), enterprise allocation (EA) system or in a competitive fishery, is deducted from the quota or allocation established for the following season.

1.4.8 Precautionary approach

The first reference to a Limit Reference Point (LRP) for this stock is found in the proceedings of the February 2003 zonal assessment meeting (DFO 2003a). The proposed LRPs then ranged from 74 to 275 kt of spawning stock biomass (SSB). From the 2004 assessment onwards, these values increased to 85–110 kt (DFO 2004). The values of LRP and upper stock reference (USR) used since 2011 have been set at 116 and 180 kt, respectively (Duplisea and Fréchet 2010, 2011). These LRP and USR values were used in the development of decision rules for the 3Pn4RS cod fishery from the 2013–2018 rebuilding plan for this stock (unpublished document).

The 3Pn4RS cod stock is part of the first group of large stocks covered by the fish stocks provisions (sections 6.1 to 6.3 of the Fisheries Act). A new assessment model was adopted in May 2022 and a revision of the PA reference points and decision rules (or harvest control rules) is underway. Given the status of the stock (under its LRP), the development of a rebuilding plan is legally required.

1.4.9 Small fish protocol and bycatch

Areas may be closed to fishing if the number of fish caught of non-legal size exceeds 15% of the total quantity of the targeted species. For cod, non-legal size specimens are those less than 43 cm[8].

In addition, areas may be closed to fishing when bycatch levels are considered to be of concern (these levels vary depending on the species targeted, the gear used and the fleet). For groundfish species fished commercially in 3Pn4RS other than cod, cod bycatch allocations are established. Exceeding these allocations may result in the closure of these fisheries.

1.4.10 Seasonal and spatial closures

In order to limit the harvest of 3Pn4RS cod that could occur during mixing with the 3Ps stock in winter, commercial fishing for 3Ps cod is prohibited from November 15 to mid-May in unit areas 3Psade (Figure 5). However, resident fishers in unit areas 3Psa and 3Psb may target 3Psa cod from mid-May until February 28 (DFO 2022d).

Within the nGSL, seasonal closures exist to protect the stock during the spawning period (Figure 5). From April 1st to June 23rd, directed fishing for groundfish is prohibited for a portion of unit areas 4Rc and 4Rd located offshore of St. George's and Port-au-Port Bays in NL, which is recognized as a spawning area. This same closure period also applies to the entire territory covered by Divisions 3Pn4RS for directed cod fisheries.

Although not directly targeting cod, 11 coral and sponge conservation zones were created in December 2017 in the Estuary and GSL (Figure 5; DFO 2022b). The main objective is to protect areas where high concentrations of these organisms are recorded. The use of fishing gear touching the sea bottom is prohibited. However, certain scientific activities, including DFO bottom-trawl surveys and the mobile gear sentinel surveys, are permitted (DFO 2018; Benoît et al. 2020).

Finally, the Laurentian Channel Marine Protected Area (MPA) established in April 2019 partially overlaps Subdivision 3Pn. All commercial fishing is prohibited there (Figure 5; Government of Canada 2019; DFO 2019b).

Other restrictions on fishing depth also exist and are specific to each species targeted and/or type of gear used.

1.4.11 Recreational fishing

The terms of the recreational fishing seasons for groundfish in the nGSL, which includes cod, are determined by the *Fisheries Management sector* of two DFO regions:

- The QC region manages recreational fishing in the waters adjacent to the sector from Pointe-des-Monts to Blanc-Sablon. This sector is divided into two zones:

[8] In this document and unless otherwise stated, all lengths are fork lengths.

- Zone 4S-West, corresponding to the sector from Pointe-des-Monts to Natashquan (including Anticosti Island).
    - Zone 4S-East, corresponding to the sector from Natashquan to Blanc-Sablon. Historically, the terms of the recreational fishing season in this sector have often been the same as those for the recreational fishing in Divisions 3Pn4R.
- The NL region manages recreational fishing in the waters adjacent to the sector corresponding to Divisions 3Pn4R.

The recreational cod fishery in Divisions 3Pn4RS generally occurs from late June to early October. For the 4S-West zone, the fishing is open for a continuous period with fixed dates since 2020, from June 24 to August 1 (Table 3, Figure 6). For the 4S-East zone and the 3Pn4R sector, fishing is permitted during a series of several long weekends between early July and early September, followed by a nine-day fishing block in late September/early October. During the 2019–2022 period, the fishing season lasted for 39 days. For the sectors where fishing was permitted, the individual daily quota was five cod, and 15 cod per boat (NL only). In NL, special permits for boat tour operators could be requested to increase the quota per trip. There is no reporting of catches in this fishery.

2 METHODS

A summary of the various data sources available for the nGSL cod assessment is provided in Figure 7. The 2019–2022 period is often referred to subsequently, and refers to the period following the last full stock assessment which took place in February 2019 and which used data for years up to 2018 (DFO 2019a; Brassard et al. 2020).

2.1 DATA INPUTS

2.1.1 Commercial fisheries

2.1.1.1 Landings

The 3Pn4RS cod stock has been exploited since at least the 16th century (Chouinard and Fréchet 1994; Mimeault 1997; Lear 1998). However, it was not until the early 1950s that valid landing statistics were published by fishing sector and not by landing sector (Chouinard and Fréchet 1994). A detailed review of the various data sources for landings is provided in Ouellette-Plante et al. (2022a).

Currently, two data sources are compiled to produce the historical series of 3Pn4RS cod landings:

- NAFO 21B data. This dataset is made public by NAFO and the available data start in 1960. These data are generally only used from 1964 in the assessments of this stock, since some landings from 1960–1963 do not provide any information on the month of landing and/or are reported as coming from NAFO Division 3P, which does not allow to distinguish landings from the 3Pn4RS stock from those from the neighboring 3Ps stock (Gascon 1983, Figure 1). The NAFO 21B data provide a breakdown of the landings by year, month, country and gear.
- ZIFF[9] data. Available for Canadian fleets only, these data have the advantage of being reported by fishing trip. These data have been available since 1985.

Two factors come into play in choosing which of these data sources to use for a given year:

[9] Zonal Interchange File Format, STACAC (1984).

- Management year. Beginning in 1999, the management year for this stock was changed and no longer corresponds to the calendar year. See the *Fishing Season* section for details. Since the NAFO 21B data had a monthly resolution, it was then impossible to separate landings from May to the correct management year starting in 1999 and it was therefore necessary to use the ZIFF data.
- Landings by foreign fleets. Foreign fleets fished 3Pn4RS cod until 1992 (Table 4). Since the ZIFF data only provide data for the Canadian fleet, the use of the NAFO 21B data is required.

Based on these constraints, and in order to have the most accurate data possible, the series of commercial landings is constructed as follows:

- 1964–1984: NAFO 21B data.
- 1985–…:
    - Canadian landings: ZIFF data.
    - Foreign fleet landings: NAFO 21B data.

For this stock assessment, NAFO 21B data were extracted on 8 February 2021. Although this extraction is dated, a validation using the STATLANT 21A online tool was performed to ensure that no 3Pn4RS cod landings had been generated by international fleets since then. As for ZIFF data, they were extracted on 16 January 2023. Data from 2021 and 2022 are considered preliminary.

2.1.1.1.1 Catch per unit effort

Since the reopening of the fishery in 1997, following the 1994–1996 moratorium, the completion of logbooks has been required for certain fleets in order to gain better knowledge of their fishing performance (Fréchet et al. 2009). These logbooks provide information such as fishing effort and the immersion times of the gear used.

Fishers in the NL fleets of less than 35 ft (10.66 m, Divisions 3Pn4R) have been required to complete a logbook since 1997. This requirement is an initiative of the NL Science Branch. At the end of each season, fishers in this fleet are required to return their duly completed logbooks to the NL Science Branch, which then forwards them to their counterparts in the DFO QC region in Mont-Joli. These data are then entered, validated and analyzed. Since 2007, GPS positions of fishing activities have also been requested. Although collected by DFO, the additional information from these logbooks is not part of DFO's official statistics and is absent from ZIFF data (Brassard et al. 2020).

For QC fishermen (Division 4S), the completion of logbooks has been required since 1999 for fleets under 45 ft (13.71 m, Fréchet et al. 2009). Unlike NL fishermen, QC fishermen's logbooks are actually forms with three sections that must be completed by as many people:

1. The logbook, completed by the fisherman.
2. The purchase receipt, completed by the buyer's representative.
3. The weighing summary, completed by the dockside inspector.

After each fishing trip, the harvester must return the duly completed form to his sector office. The DFO Statistics and Licensing Division is then responsible for data entry, validation and monitoring. These data are then made available to the Science Branch via ZIFF files.

By combining logbook data from the fixed gear fleets of NL (< 35 ft) and QC (< 45 ft), commercial fishing performance indices can be developed. From 1999 to 2021 and excluding the 2003 moratorium, these two fleets contributed on average 70% of commercial cod landings annually. Annual catch per unit effort (CPUE) values (arithmetic means) and confidence intervals are calculated from the raw data. For this assessment, we used data from logbooks received on January 11, 2023, which corresponded to fishing activities carried out from 1999 to 2021 (2022 was not used, as it was a moratorium year).

A fishing performance index for large QC longliners (≥ 45 ft or 13.71 m) was produced during the 2015, 2017 and 2019 stock assessments (Brassard et al. 2016, 2018, 2020). For the present assessment, it was decided not to continue presenting this index due to the low number of directed cod fishing expeditions carried out by this fleet after 2018 and the fact that their cod catches made after 2018 were principally bycatch in fisheries directed at other species, mainly Atlantic halibut.

2.1.1.2 Dockside sampling program

DFO coordinates a dockside sampling program for commercial landings specifically designed to estimate catch composition (Lambert and Ménager 1998; Daigle and Benoît 2007). Each year for cod, representative samples of fishing trips are collected to obtain data on the length and age composition of commercial catches. Otolith readings for age determination are performed by DFO Science Branch.

2.1.1.3 Catch-at-age

Landings of 3Pn4RS cod were divided into *k* strata defined by year, month, NAFO unit area, and gear category. In the majority of these strata, there were insufficient length frequency (LF) and age readings from the Dockside Sampling Program to infer the LF and age composition of the associated landings, and values were imputed from samples from other strata. Details of the methodology used are provided in Ouellette-Plante et al. (2022c).

In summary, these imputations were made according to a 12-level hierarchy in which the first level is based on stratum-level estimates using data from that stratum, and subsequent levels are based on imputation from data from increasingly different strata. For each stratum *k*, the level of data aggregation used was based on a set of criteria *s* to be met. Failure to meet *s* at a given level of aggregation resulted in moving to the next level, until reaching the one that met *s*. Here is the 12-level hierarchy used:

1 = year + month + NAFO + gear (corresponds to *k*)
2 = year + adjacent months + NAFO + gear
3 = year + month + gear
4 = year + adjacent months + gear
5 = year + gear
6 = year
7 = adjacent years + months + NAFO + gear
8 = adjacent years + adjacent months + NAFO + gear
9 = adjacent years + months + gear
10 = adjacent years + adjacent months + gear
11 = adjacent years + gear
12 = adjacent years

2.1.1.4 At-sea discards

Since December 29, 1992, it has been prohibited to discard groundfish[10] caught in fisheries targeting groundfish (Government of Canada 1993). This discard ban requires that catches be landed and are therefore included in landing statistics. For the most common groundfish fisheries in the nGSL, namely those targeting Greenland halibut (*Reinhardtius hippoglossoides*), Atlantic halibut, redfish, witch flounder (*Glyptocephalus cynoglossus*) and cod, this prohibition therefore limits potential discards of cod. If cod is discarded at sea, these cod are deemed to be spoiled catches as a result of depredation (catch not counted because predated before the gear was lifted) or degradation of the fish (rendered unsaleable by the combined or sole action of scavengers or microbes) (Ouellette-Plante et al. 2022a).

For other fisheries, including those targeting northern shrimp, discards at sea are permitted and it is therefore more difficult to understand the extent of cod bycatch in these fisheries. The use of at-sea observer data is therefore very useful for this purpose. For this stock assessment, at-sea observer data were extracted on February 13, 2023 and included data for the year 2022 from the DFO Maritimes, Gulf and QC regions.

2.1.1.5 Telephone survey

Since 1998, FFAW[11] and the LNSFA[12] have conducted an annual telephone survey of fixed gear harvesters (random draw) holding a directed cod fishing license (DFO 2000). The objective is to document various aspects related to the 3Pn4RS commercial cod fisheries. Through this survey, fishermen are invited to answer several questions relating to their general assessment of the fishing season, their yield, and finally the size and condition of the fish caught. Since no survey was conducted during the 2019–2021 period and 2022 was a year without a directed commercial cod fishery, no new results are available for this data source. A discussion will have to take place with the industry regarding the relevance of repeating the survey in years to come.

2.1.2 Recreational fishery

Unlike commercial fisheries for which landings are well monitored, there is insufficient information on catches from recreational groundfish fisheries, which include cod, to allow a detailed understanding of their impact on the 3Pn4RS cod stock. Although there is regulatory monitoring of compliance with authorized daily quotas, no monitoring of catches and discards (e.g. length frequencies, landed weights) is carried out. Annual values were used for the 2001–2002 (253 t, Fréchet et al. 2003), 2002–2003 (34 t, Fréchet et al. 2003), 2006–2007 (75.3 t, DFO 2008b) and 2008–2009 (67 t, Fréchet et al. 2009) fishing seasons, but the provenance of these data could not be validated in the context of this work. A summary of available data and estimates of potential recreational cod harvest were presented in 2021 at a 3Pn4RS cod framework review meeting (Ouellette-Plante et al. 2022a). In the absence of new information for the present assessment, the values of landings from recreational fishing for the years 2021 and 2022 were assumed to be the same as for the year 2020, i.e. within a range from 253.7 to 600 t (Benoît et al. 2024a).

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[10] For a list of species considered to be groundfish, see Part 2 of Schedule 1 of the Atlantic Fishery Regulations, 1985

[11] Fish Food & Allied Workers

[12] Lower North Shore Fishermen's Association

2.1.3 Scientific surveys

The spatial distribution of the different 2022 surveys detailed in the next sections is provided in Figure 8.

2.1.3.1 DFO August survey

A multidisciplinary bottom trawl research survey has been conducted annually since 1984 in August in the Estuary and the nGSL. The main objective is to obtain biomass estimates for several species, including those of commercial importance (cod, Atlantic halibut, Greenland halibut, redfish and northern shrimp). This survey follows a stratified random sampling design (Figure 9). Four vessel–gear tandems were used during the series:

- 1984–1990: CCGS[13] Lady Hammond equipped with a Western IIA trawl.
- 1990–2004: CCGS Alfred Needler equipped with a URI 81'/114' trawl.
- 2004–2022: CCGS Teleost equipped with a Campelen 1800 trawl with a Rockhopper footgear.
- 2021–2022: CCGS John Cabot equipped with a modified Campelen 1800 trawl with a footgear.

Comparative fishing experiments were conducted in 1990 (two unpublished documents: Gascon et al. 1991[14], Bourdages and Gauthier 2011[15]), 2004–2005 (Bourdages et al. 2007) and in 2021–2022 (Benoît et al. 2024b) to ensure the continuity of the series over the years. The CCGS Teleost will normally no longer be used in this survey after 2022 and will be replaced by the CCGS John Cabot equipped with a modified trawl. A detailed description of the fishing and sampling protocol as well as the calculation methods are presented in Bourdages et al. (2021). Since NAFO Subdivision 3Pn has not been visited since 2003 during this survey (Figure 10), the 3Pn4RS cod abundance and biomass indices were calculated from the tows conducted in Divisions 4RS. Finally, more coastal strata were added to the sampling plan in 1990. To maintain the integrity of the time series, a series excluding these strata is calculated for the data from 1984 to 2022 (strata 801 to 824 and 827 to 833, hereinafter referred to as the reduced strata series) and a second series including them is calculated for the period 1990-2022 (strata 801 to 824 and 827 to 841 [except 840], hereinafter referred to as the uniform strata series).

Unless otherwise noted, all tables and figures associated with DFO August survey data are presented in modified CCGS John Cabot–Campelen vessel–trawl equivalent.

2.1.3.2 DFO winter surveys

A bottom trawl survey using a stratified random sampling design was conducted from 1978 to 1994 in January (excluding 1982) by the charter vessel MV Gadus Atlantica. The study area included NAFO Divisions 4RST and Subdivision 3Pn. Although a stratification scheme identical to that used in the DFO August survey was employed (Figure 9), the spatial coverage achieved in each year was highly variable due to the presence of ice (Fréchet, 1986). In 1995, this survey

[13] Canadian Coast Guard Ship.

[14] Gascon, D., Gagnon, P., Bernier, B., and Savard, L. 1991. Le relevé conjoint crevette/poisson de fond du nord du golfe du Saint-Laurent (divisions de l'OPANO 4RST). CSCPCA Document de travail 91/70 (unpublished working document).

[15] Bourdages, H., and Gauthier, J. 2011. Reanalyses of the August 1990 comparative fishing experiment in the northern Gulf of St. Lawrence between the CCGS Alfred Needler and the Lady Hammond, conversion factor for American plaice (unpublished working document).

was abandoned, mainly because 3Pn4RS cod were found in Subdivision 3Ps during the survey period, resulting in biased biomass estimates (Fréchet and Schwab 1995). Another reason for the latter is the withdrawal of the MV Gadus Atlantica (Fréchet et al. 1994). Further information on this survey can be found in Benoît et al. (2022), and the data will not be presented in this document.

In 2022, a first winter survey since those of the MV Gadus Atlantica in 1994 was carried out and will be repeated during the winters of 2023 and 2024. The objective of this survey was to determine the winter spatial distribution of groundfish species, information limited by the low level of commercial fishing in winter and the abandonment of the winter survey in 1995. The information collected will help inform fisheries management of the potential impacts of a reopening of commercial redfish fishing in the GSL, which was historically carried out partly in winter. The vessel chartered for this survey is the commercial trawler MV Mersey Venture.

2.1.3.3 Sentinel surveys

The nGSL sentinel survey program began in the fall of 1994 following the first moratorium on directed fishing for 3Pn4RS cod. Since the data normally obtained from the commercial fishery were very scarce, i.e. only those from cod bycatch, it was difficult to assess catch rates, size structures, growth and recruitment, among other parameters (Fréchet et al. 1995). Also, the winter series of DFO research surveys (1978–1994 series) had just ended and it was imperative to find an alternative source of data to support the only survey remaining at that time, the DFO August bottom trawl survey, which did not offer the same temporal coverage as a normal fishing season.

It is therefore with the objective of monitoring the status of the 3Pn4RS cod stock, but also to a lesser extent other commercial groundfish species, that this program was created. Carried out with the industry, fishermen who had obtained a contract with DFO through a call for tenders carried out fishing activities following scientific protocols developed by the DFO Science Branch. For the nGSL, the QC DFO region is responsible for the sentinel contracts awarded in NAFO Divisions 4ST, while the NL DFO region manages contracts in 3Pn4R. The nGSL sentinel survey program includes a mobile gear component (bottom trawl) and a fixed gear component (gillnet and longline[16]). As the budgets allocated to this program have decreased over the years, the number of activities has followed the same trend.

Once fishing activities are completed, data validation, analysis and interpretation are carried out by the DFO Science Branch. Although the series begins in 1994, this first year of the program is not included in the analyses since fishing activities were only carried out in the fall.

2.1.3.3.1 Mobile gear sentinel survey

The mobile gear sentinel survey program is conducted by the ACPG[17] in NAFO Division 4S and by FFAW in Subdivision 3Pn and Division 4R. The summer series of this program is used as an abundance index for 3Pn4RS cod. Conducted annually since 1995 in July, this survey has included, in recent years, approximately 230 stations distributed according to a stratified random sampling design (Table 5, Figure 11). The breakdown of successful random tows by year and stratum is provided in Figure 12. The bottom trawl used for this survey is a Star Balloon 300 mounted on a Rockhopper Bicycle with a 40 mm liner in the codend (Fréchet et al. 1995).

[16] Other devices were also used early in the program.

[17] *Association des Capitaines propriétaires de la Gaspésie* (translated to Association of Gaspésie Owner Captains).

The fishing hauls targeted during this survey last 30 min, calculated from the time the winches are stopped after the gear is launched until the time they are restarted to bring the trawl back on board the vessel. The target trawling speed is 2.5 knots. A total of 25 different vessels have participated in the completion of the summer series to date (Figure 13). Annually, the number of vessels participating has varied from nine at the beginning of the series to five in 2022 (Table 5). At the beginning of the survey, a horizontal opening[18] value of 39 feet (ft) provided by the trawl manufacturer was used in the abundance and biomass calculations (Fréchet et al. 1995; Fréchet 1996). However, the geometry of a trawl, and therefore its general performance, can change depending on the vessel used according to their specific characteristics (e.g., power). Although the same trawl was used by the different vessels participating in the program, variations of up to 20% in the horizontal opening of the trawl were observed during tests conducted in the fall of 1995 on eight of the nine vessels participating in the program. The use of a horizontal opening of 19.3 m (62 ft) was then suggested and the installation of a retention cable recommended in order to standardize the horizontal opening between the vessels and the different depths fished (Fréchet 1996). As early as 1996, a study on the effect of a retention cable was conducted, and its use was put forward from then on, using a horizontal opening value of 16.5 m (54 ft, Fréchet 1997). The position of the retention cable was adjusted for each vessel on the warps in order to obtain this standard horizontal opening.

Since 1997, fishing activities in this program have required the use of the retention cable, unless sea conditions compromise safety during fishing. In these situations, a horizontal opening value specific to each vessel is used to calculate the swept area and thus reduce the catches to a standard swept area[19]. These values are provided in Figure 13 and are from calibrations carried out at the beginning of the series (Fréchet 1996, 1997) or are those of calibrated vessels that most closely match the characteristics (length, power) of non-calibrated vessels.

From 1995 to 2002, the survey used only strata whose depth was ≥ 20 fathoms (fm, corresponding to 37 m, Figure 12). Beginning in 2003, three 10–20 fm (18–37 m) depth strata were added on the west coast of Newfoundland. For this reason, two indices are provided from this sampling program: one series for 1995–2022 and one for 2003–2022. In addition to being used for this stock assessment, this survey is useful for work on other commercial species, including Unit 1 redfish, Atlantic halibut, Greenland halibut, and witch flounder in the GSL (Divisions 4RST). From the beginning of the sentinel program until 2006, QC vessels participating in the program were authorized to conduct trawl hauls outside the stations provided by the scientific protocols in order to identify potential fish aggregation sites (Table 5). These discretionary hauls are not used in the calculation of the indices.

The data used for the present assessment were extracted from the database on February 9, 2023. In 2022, 223 successful stratified random tows were performed (Table 5).

2.1.3.3.2 Fixed gear sentinel survey

The fixed gear sentinel survey program was conducted by LNSFA in Division 4S and by FFAW in Subdivision 3Pn and Division 4R. Since 2019, nearly 2,000 fishing activities have been conducted, approximately 75% of which used gillnets as fishing gear (Table 6). Over the same period, more than 29 commercial fishing vessels participated in this program. On average, deployment depths are 90 m for longline (#16 “J” hooks and #12 circle hooks) and 80 m for gillnets (Figure 14).

[18] The distance between the wings of the trawl.

[19] Namely, the calculated area based on a horizontal opening of 54 ft and a towed distance of 1.25 nautical mile.

The use of fixed gear sentinel fishing activities as an abundance index is based on the assumption that resource abundance is directly proportional to catch rate. However, there could be a bias if the fishing gear used became saturated, that is, if the fishing gear reached a catch level such that this catch could not increase further, regardless of the abundance of the resource. As a result, the probability of catching a fish would decrease and the catch rate would no longer be directly proportional to abundance. This aspect of fishing gear saturation is assessed annually for the longline sentinel survey program activities (Brulotte and Fréchet 2000) and saturation has not been an issue to date (Figure 15). Additional analyses were conducted by Benoît et al. (2022) and have led to similar conclusions.

Details on the abundance index estimates are provided in Benoît et al. (2022). The data used for this assessment were extracted from the database on January 10, 2023. For the 2022 survey, data from 25 additional fishing activities carried out from late October to December were only available from January 23, 2023. Given time constraints, these could not be validated and integrated in time for this stock assessment. Since very little longline activity is available for the late fall[20] index in recent years, it was decided to stop this index in 2020.

2.1.3.4 Cod reproductive potential survey

Following the termination of the winter survey aboard the MV Gadus Atlantica in 1994, an alternative data source was required to characterize maturity for the 3Pn4RS cod stock. Although maturation data for cod have been available since 1987 in the DFO August survey, this time of year is not optimal for visual examination of gonads at sea since spawning has already occurred. Indeed, a committee of experts was invited to a zonal meeting on the subject. The document by Trippel et al. (1997), which resulted from this meeting, shows that visual examinations of maturity at sea must take place near spawning for the results to reflect what would have been obtained from histological analyses, which are more precise (e.g. those of Morrison 1990).

A new survey aimed at characterizing the maturity of 3Pn4RS cod at the time of spawning, called the Cod Reproductive Potential (CRP) survey, began in 2002. As part of the Fisheries Science Collaboration Program (FSCP, in collaboration with FFAW), this survey was then renewed annually from 2004 to 2016, and biannually since then (Table 7). This survey is conducted in late April or early May and has included a grid of approximately forty stations in recent years (Figure 16). The territory historically covered includes NAFO Division 4R and Subdivision 3Pn (Table 7). Since 2011, only Division 4R has been visited during this survey, in the St. George’s Bay area near the west coast of the island of Newfoundland.

Using a trawl identical to the one used for the summer series of the mobile gear sentinel survey, this survey aims to harvest cod in order to mainly assess their level of maturity. The targeted duration and speed of trawling are the same as during the mobile sentinel survey. However, no retention cable is used in this survey. At each station of the sampling grid, once the fishing activity is completed, the catch is sorted, weighed and counted by species. Specific protocols by species are then carried out. For cod, the length, sex and maturity are recorded for each specimen. For fishing hauls where > 350 cod were caught, a maximum of 350 randomly selected individuals are measured. During each survey, otoliths are collected for age readings following a length-based stratification. Also following a stratification by length, specimens are collected whole, frozen and brought back to the laboratory for additional measurements (length, total weight, gonad weight, stomach content weight, liver weight) to determine body condition.

[20] Activities carried out at Zone 1 sites and site 8 in Zone 2 during a period ranging from the 271st to the 365th day of the year. See Benoît et al. (2022).

The data used for this assessment were extracted from the database on February 9, 2023.

2.2 BIOLOGICAL INDICATORS

2.2.1 Age readings

Cod otoliths are collected during DFO research surveys, sentinel surveys, the reproductive potential survey, and commercial fisheries. Sampling stratification is based on NAFO Divisions, time of year, fishing gear, and fish size. In the laboratory, using an ISOMET™ slow saw, the otolith is cut in half along its narrow side. Annual growth rings are counted by applying a drop of alcohol to the otolith and using directed lighting on the side of the otolith.

A reference otolith collection is reread annually in preparation for new readings to ensure consistency of age readings.

2.2.2 Condition

Various measurements used in calculations to characterize the condition of cod in the 3Pn4RS stock have been collected each year since 1995 as part of fixed gear sentinel surveys. These measurements are length, total weight, gonad weight, liver weight and stomach content weight. The condition of the harvested cod is then assessed using two indices. The first is the Fulton somatic index (K_{som}) which represents the specific health status of the cod, calculated as:

$$K_{som} = \left(\frac{W}{L^3}\right) \cdot 100 \quad (1)$$

where *W* is the somatic weight (in g, corresponding to the total weight minus that of the gonads and stomach contents) and *L* is the length in cm. The use of somatic weight in the index, and not total weight for example, arises from the fact that feeding intensity (reflected in the weight of stomach contents) and gonad maturation (reflected in the weight of the gonads) can vary widely and independently of the seasonal condition of cod (Lambert and Dutil 1997b).

The second index monitored is the hepato-somatic index (HSI). The latter requires knowledge of the liver weight (*LW*, in g), and characterizes the lipid energy reserve of the cod. It is calculated as follows:

$$HSI = \left(\frac{LW}{W}\right) \cdot 100 \quad (2)$$

In order to minimize the effect of cod length, seasonal changes in cod condition are presented for four 10 cm length classes, respectively centered on the values of 35, 45, 55 and 65 cm. The indices obtained were then interpreted following Dutil et al. (1995).

The data from the DFO August survey have also made it possible to determine the condition of cod in August of each year since 1990. However, the protocols changed in the late 2000s and the calculation of somatic weight is no longer possible due to a lack of gonad weight and stomach content values. Although the Fulton index based on total weight (K_{tot}) has disadvantages, which were mentioned above, the long series of this survey in addition to the large number of measurements still make it an important source of data retained in the analysis of 3Pn4RS cod condition. In addition to K_{tot}, annual mass-length relationships were also explored following the approach described in Bourdages and Ouellet (2011).

2.2.3 Maturity

Visual examination of the maturity of cod in the 3Pn4RS stock has been conducted since 1987 for the DFO August survey. For the winter series of the MV Gadus Atlantica, these examinations began in 1983. The maturity codes used are those provided in Smith and Somerton (1981) in their Appendix A.2. All maturity codes were classified as describing mature specimens, except for codes 100 and 500, describing immature male and female specimens, respectively, and codes 310 and 710, describing male and female specimens, respectively, for which maturity was not assessed (and therefore eliminated from subsequent analyses).

Fish maturity data are a valuable source of information since they allow for an assessment of the age or length at which fish become sexually mature. Maturity data can be used in a number of ways, such as assessing whether the age or length at which 50% of specimens are mature (denoted A_{50} and L_{50}, respectively) has changed over time, which could be a sign of overfishing (Trippel 1995). Maturity data are also required in calculations to estimate SSB.

A knife-edge approach was used until the mid-1990s to estimate SSB (Fréchet and Schwab 1998). Thus, it was assumed that specimens aged seven years and older were all sexually mature. Following a zonal meeting from which the paper by Trippel et al. (1997) originated, a more stock-specific approach was developed to calculate mature proportions. The calculations were later described in detail in Morgan and Hoenig (1997) and the first application of this approach for the 3Pn4RS stock assessment was by Fréchet and Schwab (1998).

Although an effort to assess cod maturity is also made during DFO summer surveys, Trippel et al. (1997) questioned the validity of using maturity data from periods of the year other than those preceding spawning, in the spring. For the 3Pn4RS stock, the first data used for maturity were those from the MV Gadus Atlantica winter survey carried out in January from 1983 to 1993. Since the assessment model starts in 1974, which is the year from which commercial sampling was considered adequate (Fréchet and Gascon 1986), the proportions mature according to age from the year 1983 were used for the period 1974–1982 (Fréchet and Schwab 1998). For 1994, it seems that although data from the winter survey were available, it was chosen to use data from another survey of the MV Gadus Atlantica carried out the same year, but in May and therefore closer to spawning (Brassard et al. 2020).

Since the winter survey ended in 1994, a new source of data for maturities was required and the CRP survey provided them from 2002 (Table 7). For the period 1995–2001, the data used appear to have been obtained from surveys carried out on the CCGS Teleost in May 1995, 1997 and 1998 (Brassard et al. 2020).

Given the type of data available, proportions of mature females at length were determined first and then, proportions of mature females at age were estimated. Females were classified as immature or mature. Catch-weighted proportions of mature females at length (P) were estimated using the following equation:

$$P = \frac{1}{1 + e^{-(a+b \cdot l)}} \tag{3}$$

where:

- l = 1-cm length class.
- a and b = equation parameters.

Proportions of mature females at age were estimated from mean lengths at age obtained from age-length keys and corresponding proportions of mature females at length from logistic equations. A moving average encompassing 4 consecutive surveys is used as an input in the sequential population analysis up to 2022. Pending a review of the maturity calculations for this stock planned for 2024, the ogives for the year 2000 to 2022 were assumed to be the same. Likewise, the ogives for years prior to 1985 were assumed to be the same of the ogive for that year.

2.2.4 Total mortality

A modified catch curve analysis was used to estimate annual total mortality *Z* values (Sinclair, 2001). Values are available from the different series used in the assessment model: DFO August survey (2 series), mobile gear sentinel survey, gillnet sentinel survey, and longline sentinel survey (2 series). Details are provided in Benoît et al. (2022).

2.2.5 Tagging

Tagging activities have been conducted annually since 1995 as part of the nGSL sentinel fisheries tagging program (Ouellette-Plante et al. 2022a). In parallel, tagging projects have been conducted in Division 4S since 2017. Since the new assessment model does not incorporate these data, it was decided not to present the tagging data for this assessment.

2.3 BEGINNING OF YEAR STOCK WEIGHTS

Beginning of year weights are used to calculate (spawning) stock biomass from the product of assessment estimates of age-specific abundance and weight-at-age, and then summed across ages. Beginning of year weights are sometimes termed stock weights (SW), as they are intended to represent a biological characteristic of the stock.

The procedure used to estimate SW for nGSL cod is fully described in Benoît et al. (2024a). It involved first estimating summer weights using the annual length frequency data, age-length keys, and length-weight relationships from the DFO August survey over 1985-2022 (individual weight values were not available for the 1984 survey). These summer weights were then converted to January 1st equivalents using the approach of Rivard (1982), which employs a geometric mean of weights in adjoining years for individual cohorts. Values of SW for ages 11+ were estimated assuming that cod of these ages were equally catchable by the survey. Sampling variability, particularly in years when cod were less numerous in DFO August survey catches, resulted in variability in SW that was not always consistent with cohort growth, i.e., values at subsequent ages that were equivalent or smaller. A mixed-effects model that accounts for effects of year, age and cohort (described below) was therefore employed to smooth over errors in estimates of age-specific SW, which might otherwise contribute to uncertainty in estimates of biomass, and even more to uncertainty in estimates of SSB because of the fewer age classes that contribute to SSB compared to total biomass. Values of SW for years prior to 1985 were derived from commercial fishery weights, as described in Benoît et al. (2024a).

The mixed-effects model for SW (Benoît et al. 2024a) is:

$$\log(SW_{ay}) = \beta_a + \delta_y + \delta_c + \delta_{ay} + \varepsilon_{ay} \quad (4)$$

where β_a is the age-effect, the terms δ_y, δ_c, δ_{ay} are for random effects of year, cohort, and age-year interactions, respectively, and ε_{ay} are sampling measurement errors. The δ_y are assumed to be multivariate normal (MVN) distributed with mean zero and first-order autoregressive, AR(1), covariance with correlation φ_Y and stationary variance σ_Y^2; note the Y subscript indicates a parameter for the year effect and does not indicate a specific year.

Similarly, δ_c is assumed to be MVN with mean zero, AR(1) lag one correlation φ_C and stationary variance σ_C^2. The δ_{ay} are MVN with a separable covariance matrix Σ with elements:

$$Cov\left(\Sigma_{ay}, \Sigma_{a-i,y-j}\right) = \sigma_{AY}^2 \rho_A^{|i|} \rho_Y^{|j|}. \quad (5)$$

where *i* indexes a number of ages and *j* a number of years, ρ_A and ρ_Y are the correlations for age and year, respectively, and σ_{AY}^2 is the stationary variance. The ε_{ay} are assumed to have independent normal distributions with mean zero and user-specified variances, $\sigma_{\varepsilon,ay}^2$, with an assumed coefficient of variation of 0.3 (see Benoît et al. 2024a).

The age effects are assumed to be monotonically increasing such that $\beta_{a+x} > \beta_a$ if $x > 0$, consistent with growth dynamics. An effect for age two is freely estimated and a monotone regression model is used for the other ages:

$$\beta_{a_i} = \begin{cases} \exp(\gamma_i), & i = 1, \\ \beta_{a_{i-1}} + \exp(\gamma_i) & i = 2, \dots, 11. \end{cases} \quad (6)$$

The advantages of using the monotonic model over an assumed parametric growth model (e.g., von Bertalanffy) to estimate SW include that it can better accommodate SW in the plus group, which are unlikely to conform to a growth model if older cod are abundant, as well as impacts of size-specific mortality which could cause weights at age to deviate from patterns expected from growth alone.

2.4 STOCK ASSESSMENT MODEL

A new model for the assessment of the nGSL cod stock was developed as part of the 2021-2022 assessment framework review. Details for the model, including justification of model structure, model sensitivity analyses and basic simulation testing are provided in Benoît et al. (2025)[21]. Below we describe the basic model structure and fitting procedure and refer readers to the research document from the framework review for additional details and background. Throughout we used the convention *X*+ to denote the cod at ages *X* and above.

The model employs the state-space modelling paradigm, accounting for measurement errors in the inputs (data and data-derived quantities) separately from process error or variability in population dynamics (e.g., Nielsen and Berg 2014; Cadigan 2016b; Stock and Miller 2021). Unlike the popular SAM model, which assumes that process errors act on the entire population equation (all rates affecting changes in abundance at age; Nielsen and Berg 2014; Berg and Nielsen 2016), the nGSL cod model assumes that process errors are associated with natural mortality rates (*M*), like the model for NAFO 2J3KL cod (Cadigan 2016b, 2016a). This choice was guided by the concerns about important, likely directional, changes in *M* for the nGSL stock (Brassard et al. 2020; Benoît et al. 2022). Although process error associated with *M* is implemented in the widely available Woods Hole Assessment Model (WHAM; Stock and Miller 2021), a bespoke assessment model was developed to address a number of particularities for the nGSL cod assessment. These are mentioned in the model description below.

2.4.1 Population processes

The model is founded on the commonly used cohort model with a plus age group *A*:

[21] Benoît, H. P., Cadigan, N., Ouellette-Plante, J., and Brassard, C. In preparation. Review of the Assessment Framework for Atlantic Cod in NAFO 3Pn4RS: Population Modelling and Elements Relevant to a Renewed Precautionary Approach and Rebuilding Plan. DFO Can. Sci. Advis. Sec. Res. Doc.

$$\log(N_{a,y}) = \begin{cases} \log(N_{a-1,y-1}) - Z_{a-1,y-1}, & a < A, \\ \log\{N_{a-1,y-1}\exp(-Z_{a-1,y-1}) + N_{a,y-1}\exp(-Z_{a,y-1})\}, & a = A, \end{cases} \quad y = 1, \dots, Y, \tag{7}$$

where $N_{a,y}$ is stock abundance at age *a* in year *y*, $Z_{a,y} = F_{a,y} + M_{a,y}$ is the total mortality rate, where $F_{a,y}$ is the fishing mortality rate and $M_{a,y}$ is the natural mortality rate. The ages for the model are 2-11+ and years are 1973-2022.

Recruitment in the model occurs at age 2. The recruitment vector, $R = (N_{2,1}, \dots N_{2,Y})$, is assumed to be a lognormal random vector variable,

$$\log(R) \sim MVN(\mu_R, \Sigma_R), \tag{8}$$

where the parameter vector μ_R of length Y consists of two time-blocks with constant values, one for $y \leq 1990$, and the other for $y > 1990$. These time-blocks were chosen to account for major changes in recruitment levels, and results were found to be generally insensitive to small changes in the choice of the pivotal year (Benoît et al. 2025[21]). $\Sigma_R$is the stationary covariance matrix of an AR(1) process defined by σ_R and φ_R. The correlation between $\log(R_i)$ and $\log(R_j)$ is $\varphi_R^{|i-j|}$, where *i* and *j* index specific years.

The numbers at ages 2-11+ in the first year are treated as unknown and free parameters to be estimated. Initial values for the estimation were calculated assuming an equilibrium age structure.

Natural mortality rates, $M_{a,y}$, were assumed to vary as a function of age and, beginning in 1984 when long-term DFO August survey data became available, also by year for most ages (information on cohort dynamics contained in survey data is required to estimate temporal variation in natural mortality). Values of *M* for ages 2 and 3 were assumed to be temporally invariant. The assumption for age 2 was necessary because recruitment and natural mortality processes for that age are confounded in the model in the absence of independent information on recruitment. The assumption was also necessary for age 3 given the intention to estimate an unaccounted-for change in survey catchability which occurred in 1990 (Benoît et al. 2022, 2025[21]), noting that catchability and natural mortality parameters are typically highly correlated in assessment models.

Natural mortality rates were modelled using assumed age-specific fixed values m_a and, for the relevant ages and years, age-specific mortality process errors, $\delta_{a,y}$:

$$log(M_{a,y}) = log(m_a) + \delta_{a,y}. \tag{9}$$

The following values were assumed for m_a: $m_{a=2}$ = 1.0, $m_{a=3}$ = 0.65, $m_{a=4}$ = 0.45 and $m_{a=5+}$ = 0.15. The value for cod ages 5+ was assumed based on an estimate of total mortality of 0.25 for the early 1950s presented in Wiles and May (1968), which is consistent with values for other cod stocks in the Northwest (NW) Atlantic at that time (see Benoît et al. 2022, for details). The values for younger ages are based on the average lengths at those ages and the equation of Gislason et al. (2010), assuming von Bertalanffy growth parameters of L_∞=130 and *k*=0.10, which are reasonable for cod in the NW Atlantic according to FishBase (Froese and Pauly 2022).

The natural mortality process errors were modelled as an AR(1) stochastic process in age and year, and the elements of Σ_M are based on

$$Cov\{\delta_{a,y},\delta_{a-j,y-k}\} = \frac{\sigma^2_{M,4+}\varphi^j_{M,age}\varphi^k_{M,yr}}{(1-\varphi^2_{M,age})(1-\varphi^2_{M,yr})}; Corr\{\delta_{a,y},\delta_{a-j,y-k}\} = \varphi^j_{M,age}\varphi^k_{M,yr}. \quad (10)$$

To improve model convergence and to help ensure identifiability for the simultaneous estimation of natural mortality process errors and temporally varying age-specific fishing mortality (below), adjoining ages were coupled in the estimation of the $\delta_{a,y}$'s. Specifically, common $\delta_{a,y}$ values were estimated for ages 4-5, 6-7, 8-9 and 10-11+. Model results were generally insensitive to reasonable alternative groupings (Benoît et al. 2025[21]).

Catches at ages 2-11+ were modelled using the Baranov catch equation,

$$C_{a,y} = N_{a,y}\frac{\{1-\exp(-Z_{a,y})\}F_{a,y}}{Z_{a,y}}. \quad (11)$$

The *F*'s are modelled as a stochastic process about a small number of mean values μ_F , which are estimated as fixed effects. There are 15 values of μ_F according to blocks of ages and years (Figure 85). These parameters account for large shifts in mean *F* that occurred over time, including as a result of the 1994-1996 and 2003 moratoria.

If ***F*** is an (A-1)Yx1 vector of all $F_{a,y}$'s for ages 2-11+, then

$$\log(\boldsymbol{F}) \sim MVN(\mu_F, \Sigma_F), \quad (12)$$

Similar to the *M* process errors, $\Delta_F = \log(\boldsymbol{F}) - \mu_F$ is modelled as an AR(1) stochastic process in age and year, and the elements of Σ_F are based on

$$Cov\{\Delta_{F,a,y},\Delta_{F,a-j,y-k}\} = \frac{\sigma^2_{Fa}\varphi^j_{F,age}\varphi^k_{F,yr}}{(1-\varphi^2_{F,age})(1-\varphi^2_{F,yr})}; Corr\{\Delta_{F,a,y},\Delta_{F,a-j,y-k}\} = \varphi^j_{F,age}\varphi^k_{F,yr}. \quad (13)$$

σ^2_{Fa} parameters were estimated for ages 2-3 combined, 4, 5, and 6+.

Estimates of *F* for approximately ages 6+ in 1986 and 1987 derived by Myers et al. (1996) from tagging experiments, were included as priors when fitting the model.

2.4.2 Observation equations

Model parameters are estimated using marginal maximum likelihood, first modelling the probabilities of the data conditional on the states of recruitments, *M*'s and *F*'s (i.e. observation equations), and then integrating over all the likely states of recruitment, *M*'s and *F*'s to get the marginal distribution of the data on which the marginal likelihood is based. The Template Model Builder (TMB) package (Kristensen et al. 2016) was used to calculate the marginal negative loglikelihood (mnll) for the model and model parameters were estimated using the *nlminb()* function in R.

2.4.2.1 Fishery catches

Fishery catch (commercial and recreational fishery landings and commercial discards) and estimates of the catch age-compositions (Benoît et al. 2024a) were modelled separately because these two data sources originate from different and independent sampling programs.

There is some dependency between the two, for instance because the catch-at-age estimation involves weighting by landings (Ouellette-Plante et al. 2022a), but this is ignored for simplicity.

Expected catch (tonnes) was calculated in the model, using Equation 11 to obtain $C_{a,y}$, which was then multiplied by the individual annual age-specific catch weights and summed over ages. For years ≤2005, the likelihood of the input catches was evaluated using a log-normal likelihood with a mean equal to the expected catch and an assumed standard deviation of 0.1, roughly equivalent to a CV of 10%. This choice was dictated by an expected absence of bias and reasonable level of precision in the catch data for those years.

For years >2005, a censored likelihood approach (e.g., Cadigan 2016b, 2016a; Van Beveren et al. 2017) was used. In this approach, the reliability of the catch is quantified by lower and upper bounds that are inputted to the assessment model (Benoît et al. 2025[21]), and 'observed' catch is not directly used to estimate expected catch. If L_y denotes the true but unknown landings (catch) in year *y*, and $L_{lo,y}$ and $L_{hi,y}$ are the lower and upper bounds (i.e. the data), then the conditional censored nll landings observation equation for the stock assessment model parameters (collected in a vector *θ*) is

$$nll(\theta | L_{lo,y}, L_{hi,y}) = -\sum_{y=1}^{Y} \log\left[\phi_N\left\{\frac{\log(L_{hi,y}) - \log(L_y)}{\sigma_l}\right\} - \phi_N\left\{\frac{\log(L_{lo,y}) - \log(L_y)}{\sigma_l}\right\}\right], \quad (14)$$

where ϕ_N is the cumulative distribution function of a standard normal random variable. The σ_l parameter controls the sharpness of the bounds and is set at $\sigma_l = 0.02$, a value that provides some ability for model estimates to fall outside the specified bounds.

The time-series of catch proportions (by number) at ages *2,…, 11+*, $P_{a,y}$, hereafter the catch age compositions, were modelled using the multiplicative logistic multivariate normal distribution based on the continuation ratio logit (crl) transformation of the proportions (Cadigan 2016b). The crl proportions, $X_{a,y}$, were computed as follows. Indexing assessment model ages as *a = 1,…,A* where *A = 10*, which corresponds to stock ages *2,…,11+*, the following computations were made:

$$P_{a,y} = \frac{C_{a,y}}{\sum_{a=1}^{A} C_{a,y}}.$$

$$\pi_{a,y} = Prob(age = a | age \geq a) = \frac{P_{a,y}}{P_{a,y} + \ldots + P_{A,y}}, \quad a = 1, \ldots, A-1.$$

$$X_{a,y} = \log\left(\frac{\pi_{a,y}}{1-\pi_{a,y}}\right), \quad a = 1, \ldots, A-1.$$

crl values $X_{a,y}$ are obtained for both the observed and the model predicted catches. There are only *A-1* crl's derived from *A* catch proportions because catch proportions only contribute *A-1* independent observations since $\sum_{a=1}^{A} P_{a,y} = 1$. The crl is defined only for catch-at-age proportions > 0, which was always the case for the nGSL cod data.

The observation equation nll for the vector across ages 1 to *A*-1, X_{oy}, of observed crl's in year *y* is based on

$$X_{oy} = X_y + \varepsilon_{X,y}, \ \varepsilon_{X,y} \sim MVN(0, \Sigma_X), \quad (15)$$

where X_y is the vector of model predicted crl's and Σ_X is AR(1) in form, with variance parameter σ_X^2 and correlation φ_X; thus, the crl errors are assumed AR(1) correlated within years but independent between years.

2.4.2.2 Abundance indices

There are six abundance indices for the nGSL cod model: the Minet (1978) bottom-trawl surveys (1973-1976; ages 3-11+), the DFO August survey (1985-2022; ages 2-11+), the mobile gear sentinel survey (bottom-trawl; 1995-2022; ages 2-11+; hereafter sentinel mobile) and three fixed-gear sentinel survey indices: gillnet (GNS, 1995-2022; ages 4-11+), summer longline (LLS1, 1995-2022; ages 3-11+) and fall longline off southwestern Newfoundland (LLS2, 1995-2020; ages 3-11+). The youngest ages were excluded for some of the indices because their abundance in the surveys was low and considered too variable.

Let $I_{s,a,y}$ denote the observed age-based abundance index for survey s and t be the midpoint of the survey dates which is expressed in a fraction of the year. The model predicted index is

$$E(I_{s,a,y}) = q_{s,a} N_{y,a} \exp^{-t_{s,y} Z_{y,a}}. \quad (16)$$

The $\exp^{-t_{s,y} Z_{y,a}}$ term projects beginning-of-year abundance to the time of the survey, accounting for in-season mortality. The $q_{s,a}$'s are catchability parameters to estimate and are specified in different manners depending on *s*, *a* and also *y* (given a change in 1991), as described below. Given

$$\mu_{s,y,a} = log\{E(I_{s,a,y})\} = log(q_{s,a}) + log(N_{y,a}) - t_{s,y} Z_{y,a}. \quad (17)$$

The observation equation for the indices, for all survey ages and years, including the plus group indices is

$$log(I_{s,a,y}) = \mu_{s,y,a} + \varepsilon_{s,y,a}. \quad (18)$$

We assume the ε observation errors are independent $\varepsilon_{s,y,a} \sim N(0, \sigma_{s,a}^2)$. A single survey specific error variance across all ages and years for each survey is assumed, except for the two sentinel longline indices where a separate age 3 variance was estimated to accommodate higher dispersion at that age. Equation 18 requires $I_{s,a,y}$> 0. The ensemble of survey index data for nGSL contains only two instances where $I_{s,a,y}$= 0 and these are simply omitted from the fitting process.

2.4.2.3 Catchability – bottom-trawl indices

Catchabilities for the three bottom-trawl surveys were assumed to follow survey-specific logistic selectivity functions with respect to age,

$$S_{s,a} = \left(1 + \exp\left[\frac{-\log(19)\left(a - {s_s}^{50\%}\right)}{{s_s}^{95\%} - {s_s}^{50\%}}\right]\right)^{-1} \quad (19)$$

where ${s_s}^{50\%}$ and ${s_s}^{95\%}$ are the ages at which 50% and 95% of available cod are selected (note the equation element log[19] derives from the algebra associated with defining the logistic function with respect to the 95% selectivity). These two sets of parameters respectively determine the location and rate of the selectivity function, which has a maximum value of 1. Catchabilities for these three surveys were then calculated as

$$q_{s,a} = S_{s,a} q_{Full,s} \tag{20}$$

where $q_{Full,s}$ is the fully selected (asymptotic) catchability, and is an estimated parameter. A lognormal error was assumed for $q_{Full,s}$. Furthermore, a lognormal prior was set on this parameter for the DFO August and sentinel mobile surveys, assuming a mean value for $\log(q_{Full,s})$ =0 and a fairly wide (permissive) standard deviation of 0.7. Sensitivity runs as part of the current assessment revealed that results were insensitive to whether the prior was used or not for the sentinel mobile survey (results not shown). Results are however sensitive to this choice for the DFO August survey (Benoît et al. 2025[21]). Also as part of the current assessment, we attempted a model employing a non-parametric catchability function for the sentinel mobile survey, like those for other sentinel surveys (see below), but model convergence could not be achieved. This was attempted because there was evidence from the former Sequential Population Analysis model for the stock that the catchability function for that survey may not be asymptotic (see Figure 5 in Benoît et al. 2025[21]).

In contrast to the DFO August and sentinel mobile surveys, for which the indices are in units of swept area abundance, Minet (1978) provided only the annual relative survey age compositions. To account for interannual changes in total survey abundance, reflected in the selectivity function asymptote, estimated fully selected catchability parameters were freely estimated for each of the four years of those surveys.

The nGSL cod model also estimates some adjustments for catchability at ages 2 and 3 associated with the change in survey vessel and gear that occurred in 1991 and which was not fully accounted for by conversion factors estimated from a comparative fishing experiment. Equation 17 (and related equations) were modified such that for *s*=DFO August survey, *a*=2,3 and *y*<1990,

$$\mu_{s,y,a} = log\{E(I_{s,a,y})\} = log(q_{s,a}) + log(\delta q_{s,a}) + log(N_{y,a}) - t_{s,y} Z_{y,a}. \tag{21}$$

where $\delta q_{s,a}$ are catchability deviations, estimated as fixed effects, one for age 2 and the other age 3.

2.4.2.4 Catchability – sentinel fixed gear indices

Gillnets and longlines often have non-asymptotic selectivity functions, such that the selectivity may decline at older ages (larger sizes). In the absence of information on the shape of the selectivity functions, the $q_{s,a}$ values were freely estimated for the three sentinel fixed gear indices.

2.4.2.5 Adjustments for changes in survey coverage – DFO August and sentinel mobile indices

Adjustments are required in the model to account for a change in survey coverage that occurred in 1990 in the DFO August survey and 2003 in the sentinel mobile survey. Adjustments were deemed necessary for ages 2-11+ in the DFO August survey and only ages 2 and 3 in the sentinel trawl survey (Benoît et al. 2022). The adjustments, $\delta c_{s,a}$, were estimated using abundance index data from the surveys representing the original and current survey sampling areas, for those years in which the current survey area was sampled,

$$E\left(log(I_{CURRENT,s,a,y})\right) = log(I_{ORIGINAL,s,a,y}) + \delta c_{s,a} \tag{22}$$

The $\delta c_{s,a}$ parameters were estimated freely using a normal likelihood and survey-specific standard deviations, $\sigma_{\delta c_s}$.

3 RESULTS

3.1 DATA INPUTS

3.1.1 Commercial fisheries

3.1.1.1 Landings

Prior to 1977, there was no annual TAC for the 3Pn4RS cod stock and annual landings ranged from 58,237 t (1972) to 105,465 t (1970; Table 2, Figure 17). Following the expansion of Canada's EEZ to 200 nautical miles offshore in 1977, an initial TAC of 55,000 t was implemented (Sanguin 1980). Both landings and annual TACs then increased until the early 1980s when a maximum of 106,080 t was landed in 1983. The stock subsequently collapsed and there were three moratoria on directed commercial fishing: 1994–1996, 2003[22] and 2022. Prior to the 2022 directed cod moratorium, the annual TAC for the previous three years was 1,000 t, corresponding to an allocation available to the fishery of 641 t[23]. Preliminary landings for 2021–2022 and 2022–2023, including bycatch and sentinel survey catches, are 677 and 132 t, respectively. Since the management year has changed from 1999, Table 8 is also provided to view 1999–2022 landings by calendar year.

Since 1985, approximately 60% of cod landings have come from Division 4R (Table 9, Figure 18a). The majority of landings are from the NL and QC fleets (Figure 18b). At a finer scale, over 65% of landings over the past ten years (2013–14 to 2022–23) have come from Subdivision 3Pn and NAFO Unit Areas 4Ra and 4Sw (Table 9, Figure 19a). Landings are primarily from July to September (Figures 19b, 20). In 2022, it is observed that landings are more distributed over the calendar year, which is due to a greater percentage of cod bycatch in landings in the absence of a directed commercial cod fishery (Tables 10-13).

Since the reopening of the fishery in 1997, after the first moratorium (1994–1996), the directed fishery has been conducted almost exclusively using fixed gear, namely gillnets and longlines (Tables 14-17, Figure 19c). Gillnets are primarily used in Divisions 4RS, while longlines are primarily used in Subdivision 3Pn.

The various fishing ports where 3Pn4RS cod was commercially landed during the 2021/2022 management year are shown in Figure 21. These are mainly located on the west coast of NL and the Lower North Shore in QC.

3.1.1.2 Fishing vessels

The number of commercial fishing vessels targeting cod during the 1993–2022 period has been decreasing since the beginning of the series, from 1,433 vessels in 1993 to fewer than 300 vessels in recent years (Figure 22).

By taking the last year in which a commercial 3Pn4RS cod fishery took place, in 2021, it is possible to follow the activities of the 237 vessels when the fishery targeted cod (Figure 23). It appears that the majority of vessels begin fishing for cod in mid-July and end around the end of

[22] The 2003 moratorium is the only one of the three where recreational cod fishing was also prohibited.

[23] 1,000 t minus the allocation from France (26 t, 2.6%), scientific (200 t), for food, social and ritual purposes (FSR, 53 t) and recreational fishing (80 t).

September. It can be seen that the cod fishing season is very short for a significant number of vessels.

For these same 237 commercial fishing vessels targeting 3Pn4RS cod in 2021, Figure 24 shows the evolution of landings for each vessel according to the species targeted. It is noted that the majority of vessels involved in cod fishing also engage in other fisheries, including American lobster (*Homarus americanus*), snow crab (*Chionoecetes opilio*) and Atlantic halibut.

3.1.1.3 Catch per unit effort

Indices of performance (longline and gillnet) calculated from commercial fishing logbook data for QC (< 45 ft) and NL (< 35 ft) vessels show an increase in post-moratorium CPUE (2003) for the period 2004–2006, followed by a decline until 2009 (Figures 27-28). From 2009 to 2018, the longline index was increasing and was above its series average as early as 2013. It then decreased in 2019 to remain stable but still above the series average in 2020. In 2021, a significant decrease in the index is observed. However, since only four longline fishing activities were used to produce the 2021 estimate, and additional logbooks were not available at the time of these analyses, this result should be taken with caution. The gillnet index increased from 2010 to 2016, after which it decreased until 2020 and then stabilized slightly below its series average.

These two indices have become increasingly less representative of the fishing activities of these two fleets due to the significant decrease in the percentage of cod landings for which commercial fishing logbook data are available (Figure 29).

3.1.1.4 Dockside sampling program

During the 2019–2022 period, a total of 43 samples of 3Pn4RS cod were collected as part of the DFO commercial sampling program (Table 18). These samples provided length frequencies corresponding to over 6,000 specimens. The ages of 1,500 cod were determined from otoliths collected during this period. In 2022, 10 samples were collected, all from the longline fisheries in Division 4S. This is the lowest annual sampling during the 2019–2022 period since 2020 when only four samples had been collected.

3.1.1.5 Catch at age

Based on the Dockside Sampling Program data (LF and age readings), the LF and age composition of landings could be inferred. The aggregation levels of the data used during the period 2018–2022 are presented in Table 19. In 2022, length frequency and age reading data were matched for 104 strata representing unique combinations of year, month, NAFO unit area and gear type.

Commercial catch data expressed as catch at age, mean weight at age and mean length at age could be produced (Tables 20-22). Catches in the commercial fishery are mainly composed of cod aged 5–10 years (Figure 25). The 2018 cohort, followed for several years now (Brassard et al. 2020; DFO 2020a, 2021b, 2022c), is beginning its entry into commercial fishing (Figure 26).

3.1.1.6 Bycatch

Excluding moratorium years and excluding cod landings for which the target species was not specified, on average 90% of 3Pn4RS cod landings were from the cod-directed fishery (Table 23, Figure 30). Over the last ten years (2013–2022), the majority of cod landings taken as bycatch came from fisheries targeting Atlantic halibut, Greenland halibut and redfish, for an annual average of approximately 111 t excluding landings for which the target species was not specified.

By investigating the four target species (excluding cod) for which cod catches had been the highest over the last 10 years (2013–2022) in at-sea observer data, the ratios of catch weights for cod to that of the target species were calculated annually to produce a time series for each of the target species retained (northern shrimp, redfish, Atlantic and Greenland halibut, Figure 31). For northern shrimp, redfish and Greenland halibut, cod bycatch has mean annual ratios < 3%. For Atlantic halibut, on the other hand, this ratio is on average much higher over the period 1999–2022 (~17%) and also shows strong annual variations. The spatial variations of these ratios over the period 2018–2022 can be seen in Figures 32-35. For Greenland halibut, the majority of cod bycatch comes from the Sept-Îles sector in QC.

Of the four target species selected in Figure 31, fisheries targeting northern shrimp are the only ones not subject to the ban on discarding groundfish at sea introduced in December 1992 (Government of Canada 1993). This means that cod bycatch from these fisheries is not included in the official landing statistics used by DFO (ZIFF data). The work of Bourdages et al. (2022) showed that cod was caught in just over 20% of monitored shrimp fishing activities. These catches are on average < 1 kg per tow and the cod caught are small (< 30 cm, i.e. 1-2 year old cod) given the introduction of the Nordmore grid starting in 1993 (Figures 36-37). This device limits the capture of groundfish to individuals of smaller lengths (Savard et al. 2013).

Data from at-sea observers can also be used to monitor new cohorts of cod. Thus, the 2018 cohort was observed in the first year (Figure 38). In 2022, the latter no longer appears to be captured by shrimpers, which means that the lengths reached by these cod now seem sufficient to be discarded from the catch following contact with the Nordmore separation grid.

3.1.2 Scientific surveys

3.1.2.1 DFO August survey

The mean numbers of cod per haul for both strata series declined significantly between 1991 and 1993 (Figure 39). Following the 1994–1996 moratorium, these indices recovered slightly until the end of the 1990s. Subsequently, the indices were mainly below their historical averages until 2013 (2014 for the series with reduced strata), with an unusual peak in 2003 (moratorium year). From 2015 to 2019, both indices varied around their series average. Since 2020, both indices have been above their series average and increasing. Generally speaking, the values of the index using the reduced series of strata are almost always lower than those of the series that includes the expanded series of strata. This difference is explained by the inclusion in this latter index of shallow strata in which cod concentrations are generally higher than average (Benoît et al. 2022).

The spatial distribution of cod along the west coast of Newfoundland (Division 4R) remained similar during the 1990–2022 series (Figures 40-41), while the western part of the Gulf (Division 4S) shows a gradual decrease between the periods 1990–1995 and 2002–2007. Following 2007, there was an increase in abundance in Division 4S, particularly north and west of Anticosti Island. A decrease in abundance in the Anticosti and Esquiman channels was observed in the recent 2018–2022 period, and could be linked to the increase in water temperature observed at the bottom of these channels (Galbraith et al. 2023). In 2022, the largest catches were made north of Anticosti Island, east of Sept-Îles and west of Havre-Saint-Pierre (Figure 40).

The annual length frequencies of the two series of strata used show similar patterns (Figure 42). The higher mean numbers per tow with the uniformly sampled strata sequence reflect higher catches in shallower strata, as noted for Figure 39. Beginning in 2018, the abundant 2018 cohort is observed to reach a modal size of approximately 38 cm in 2022 (Figures 42-44). Unlike the series starting in 1990, the series starting in 1984 shows higher abundances of large cod and reflects strong cohorts during the 1989–1991 period. In 2022, there were two modes in the length frequency distribution of the DFO August survey, one for cod measuring 10–20 cm (juveniles) and another for cod measuring 30–42 cm (2018 cohort). Abundances were above the series average for both length ranges (Figures 42-44). The abundance of larger cod has declined over the last two years to be slightly below the historical average (Figures 43-44). While a peak in abundance was detected in very small cod (< 10 cm) in 2018, which is unusual for this survey, no such observations have been reported since (Figure 42).

The raw catch values by age, as well as those standardized in SPAY[24], are almost identical depending on the data used. The series going back to 1984 provides additional information on important cohorts that would not have been observed by the other series (1975 and 1977 cohorts for example, Figures 45-46).

Another way to monitor the progression of cohorts is by means of catch curves (Figure 47). Indeed, as cohorts age, their abundance decreases. For the DFO August survey data, there are only rare instances where the abundance of a cohort increases for a year (e.g., 1980 cohort), which is a sign that the survey is not tracking cohorts well over time. The absence of breaks in 1990, 2004, and 2005, where comparative fishing experiments took place during vessel changes, also demonstrates the effectiveness of the conversion factors developed to perpetuate the time series. Another measure for judging the quality of cohort tracking, internal uniformity, can be seen in Figures A1–A2.

3.1.2.2 DFO winter surveys

During 2022, the first year of the winter survey by the MV Mersey Venture, the majority of stations sampled north of the Laurentian Channel included cod in their catches (Figure 48). The renewal of the winter survey by DFO during the winters of 2023 to 2024 will provide new information that should allow a better understanding of the behavior of this stock in winter.

3.1.2.3 Mobile gear sentinel survey

The indices in number and mean weight per tow of the mobile sentinel survey do not show a clear trend during the period 1995–2015 (Figure 49). From 2016 to 2019, both indices were decreasing, and the observed values were among the lowest observed during their respective series. In 2020, the index in number rose to values close to the series average, at the same time as a strong cohort was observed in the survey (Figure 50). Since 2020, the values of mean number per tow have been around the series averages, with a decrease below the latter in 2022. In terms of mean weight per tow, although having a small peak in 2020, the values since then have been decreasing and remain below the series average. Except for a few years (2007, 2008, 2015), the two indices provide very similar values. The differences between the indices for these years appear to be caused by generally larger catches (all sizes combined) in shallower waters in 2008 and 2015, while a peak in catches in the 15-20 cm length range appears to have been absent from deeper waters in 2007 (Figure 50).

In 2022, similar to the DFO August survey, catches were mainly reported from the west coast of Newfoundland and in the northern sector of Anticosti Island (Figures 40, 51).

The raw catch-at-age and standardized catch (SPAY) values from the mobile sentinel data show that this survey also allows for cohorts to be well monitored (e.g., 2018 cohort, Figure 52). The 2004 and 2005 cohorts appear to have been better monitored with the mobile sentinel survey than with the DFO August survey. Similar to the DFO August survey, the mobile sentinel

[24] Standardized proportions at age and year

survey follows the cohorts well, according to the catch curves (Figure 53). The internal uniformity of the cohorts can be seen in Figure A3.

The mean weight values per tow by stratum are presented in Table 24. The numbers by age are shown in Table 25.

3.1.2.4 Fixed gear sentinel survey

Since 1995, the annual coverage by the sentinel longline survey in NAFO Subdivision 3Pn (corresponding to area 1 in Figure 14) has made it possible to monitor cod migration. Indeed, cod historically arrive in the Gulf via the Cabot Strait in early May and leave from mid-September, culminating in a peak CPUE value in November (Figure 54). During 2021 and 2022, cod appear to have been leaving the Gulf earlier.

The summer aggregate abundance index for individuals aged 3+ on longlines has fluctuated over the years (Figure 55). The trend was upward from 1995 to 2006, followed by a decline until 2010, before rising two consecutive years and generally declining since then. In 2022, the index was below the series average at values close to those of the early 2000s. Cohort tracking is generally good for this index, although some cohorts (e.g., 1991) are less well tracked than with the DFO August survey index (Figure 56). This index generally tracks cohorts well based on catch curves (Figure 57), a finding also made based on Figure A4.

The gillnet abundance index also fluctuated considerably over the series (Figure 58). After a period of increase from 1995 to 2006, it generally varied around the series average. In 2022, the index declined and was below the series average but above the last dip in 2019. Like the other indices used, the gillnet index tracked some cohorts from the early 1990s well, and some (2004–2005) were better tracked by the sentinel gillnet survey than by the DFO August survey (Figures 45-46, 59). To date, the 2018 cohort has not been abundant according to this index. The sentinel gillnet index tracks the cohorts well according to the catch curves (Figure 60). The internal uniformity of the cohorts can be seen in Figure A5.

The non-standardized indices by gear type and area, traditionally provided in previous research documents, can be seen in Figures A6 and A7. It is important to note that these two figures should not be interpreted as abundance indices since no standardization has been made for them and that the fishing seasons and sampling sites, in particular, have varied over the years of the fixed gear sentinel survey.

3.2 BIOLOGICAL INDICATORS

3.2.1 Condition

Monitoring of cod condition carried out under the fixed gear sentinel survey program shows an annual cycle (Figures 61-62). Historically, both K_{som} and HSI indices are lower in the spring before spawning and then increase from summer to fall to be maximal in preparation for winter. In 2021 and 2022, K_{som} values were generally lower than the series average for all length classes and the observed values would be considered good according to the criteria of Dutil et al. (1995). For the period 2021–2022, only the 35 cm class showed values above its respective average, in a range of values considered excellent according to Dutil et al. (1995).

In 2021 and 2022, the observed HSI values, representing the recent feeding success of the fish, showed values generally below the historical averages for the months of July to September. Overall, HSI conditions are considered good according to Dutil et al. (1995).

The cod condition index from the DFO August survey (K_{tot}) is estimated from total weight, which is influenced by stomach fullness and gonad development. From 2010 to 2017, the index was generally decreasing (Figure 63). From 2018 to 2020, K_{tot} increased to values close to the historical average and then fell in 2021 and 2022 to the lowest values observed during the different series for 35, 55 and 45 cm cod. For 65 cm cod, the 2022 value is the second worst condition value after that of 1992. 4S cod generally have lower K_{tot} values than 4R cod. In 2022, this difference between NAFO Divisions was much more pronounced.

Another way to observe this decline in condition in 2022 is to investigate the annual mass-length relationships from the DFO August survey (Figure 64), where it appears that the 2022 curve is lower than those of other years. This therefore translates into a lower total individual weight for the same length (Figure 65).

This downward trend in cod condition does not appear to affect the growth in length of cod aged eight years and under (Figures 66-67). For older cod, it is difficult to observe a trend since the lower annual numbers of cod of these ages generate large variations in length at age during the 1990–2022 series.

3.2.2 Total mortality

Analyses of the modified catch curves based on the various surveys and indices are shown in Figures 68 to 72. The Z estimated from different surveys show the same trends (Figure 73).

By combining the various Z values, it can be seen in Figure 73 that the trends were very comparable between the various indices. For the series from the DFO August survey starting in 1984, we note that Z had increased to a peak in values for this series in the early 1990s, which then led the stock to its collapse (Figure 68). Given the virtual absence of fishing during the period 1994–1996 (1st moratorium), we can assume that the value of Z (~0.7) then corresponded to natural mortality. Following this first dip, Z values increased following the reopening of fishing, before falling again during the 2003 moratorium. A second increase in Z was then observed with the reopening of fishing.

A difference in amplitude between fisheries-independent surveys using bottom trawls and those using fixed gear (longlines and gillnets) is observed: the peaks of indices from fixed gear are higher. This difference was explained in Benoît et al. (2022) by the age ranges used, which differed between surveys. As larger, and therefore older, cod are normally caught by fixed gear, it was necessary to restrict the age range used to higher values to ensure that the ages used in the calculations represent those fully recruited to the fishery. However, doing this introduces a gear effect since these cod are known to face greater fishing mortality, and in addition senescence increases with age. This would therefore explain why the Z values reach higher values for fixed gear surveys. Finally, changes in the distribution of cod between the coastal and offshore sectors could also affect the estimates produced by decreasing or increasing the annual values according to changes in the spatial distribution of cod.

3.3 TREATMENT OF CATCH IN THE ASSESSMENT MODEL

The assessment model developed during the last review of the 3Pn4RS cod assessment framework incorporates landing values that are not reported by the usual data sources used in traditional stock assessments (i.e. ZIFF data, NAFO data, etc.). These additional catches were estimated from work involving a structured questionnaire with current or former fishermen as respondents (Benoît et al. 2021), estimates of discards at sea from commercial fisheries using at-sea observer data, and estimates of landings generated by recreational fisheries (Ouellette-Plante et al. 2022a).

The remainder of this section is essentially an update of the document by Benoît et al. (2024a) presented in the May 2022 model review. For recreational catches, the same lower and upper bound values as in 2020 were used for 2021 and 2022, namely 253.7 and 600.0 t, respectively, given the absence of new information on this subject. For estimates of discards at sea from commercial groundfish and shrimp fisheries, the same approach as the one described in Ouellette-Plante et al. (2022a) was used to update the estimates (Table 26, Figures 74-77).

Until the early 2010s, recreational landings estimates represented only a small share of total landings. However, with the TAC reductions of the early 2010s, our estimates of recreational fishery catches represent a larger proportion of overall landings, so that with the closure of the commercial cod fishery in 2022–2023, the presumed catches of this fishery would now be higher than those of the commercial fishery (Table 2, Figure 74).

The significant contribution of recreational fishing to total mortality in 2022 is not new. Multiple sources of information (Canadian recreational fishing surveys, science surveys, tag returns, etc.) indicate that recreational fishing has expanded since the early 2000s (Ouellette-Plante et al. 2022a). Since no catch monitoring is conducted for this fishery, we assumed for the period 1974–2021 that the age composition of this fishery followed that of the commercial fishery. For 2022, however, we noted that the age composition of the commercial fishery differed from that from the sentinel longline survey program (summer index, Figure 78). Until now, we had assumed that the age composition of the recreational fishery was the same as the commercial fishery. For 2022 only, therefore, we assumed that the age composition of the recreational fishery corresponded to that of the summer longline index.

3.4 BEGINNING OF YEAR STOCK WEIGHTS

The age-effects account for much of the variation in SW (Figure 79). Year and cohort effects were greater than the year-age interactions (Figure 80), with year effects ranging from -0.066 to 0.056, cohort effects ranging from -0.063 to 0.041 and the interactions ranging from -0.016 to 0.013. This is also indicated by the somewhat smaller estimate of σ_{AY} compared to σ_Y and σ_C (Table 27). Standard errors (SE) for $\log(\sigma_{AY})$ and $\log(\sigma_Y)$ were relatively large, and the SE for the latter was much larger than in a previous analysis of the data to 2020 (Benoît et al. 2024a). This effect, which is evident in the width of the estimated 95% confidence intervals on the year effects (Figure 79), resulted from the unusually low survey weight values for 2022 at many older ages (Figure 81).

Estimated correlation parameters were relatively large for each of these effects (Table 27), ranging from around 0.80 for the cohort effect (following inverse logit transformation of the parameter), to around 0.85 for the age and year effects in the interaction. This is why the predicted effects in Figures 79 and 80 vary smoothly.

The model fit the survey mean weights reasonably well (Figures 81-82). Fits were better at ages more commonly sampled in the survey, generally ages 3 to 8. There were no obvious patterns in residuals, although the residual variation was somewhat greater at the youngest and oldest ages (Figures 83-84).

3.5 ASSESSMENT MODEL

3.5.1 Abundance and biomass

The biomass of cod ages 2+ (all fish ages 2 and above, including the oldest age plus-group) and SSB fluctuated without trend after 1998 (Figure 86, Table 28). Beginning in 2015, the 2+ biomass declined before increasing again from 2019 to 2020 with the arrival of the 2018 cohort, before slightly declining thereafter. Beginning in 2017, SSB also declined and has been slowly increasing since 2019.

The 2018 cohort, estimated at age 2 in 2020 in the model, constitutes the largest estimated recruitment since 1990 (Figure 87, Table 29). The abundance of the two cohorts that have followed is estimated to be comparable to the 1991-2022 average. Estimated log recruitment deviations from the 1973-1990 and 1991-2022 multi-decadal means appear to follow a cyclic pattern with an approximately 8-10 year period (Figure 87, bottom panel). However, the strength and persistence of this cyclic pattern has not been quantified, and additional research is required to better understand the drivers of these patterns.

Plots of biomass and log numbers at age show the progression of four larger cohorts that emerged since the mid-1995 (Figure 88). These generally did not result in notable increases in biomass or numbers at older ages, and only moderate increases in mature fish biomass (Tables 28-29).

3.5.2 Fishing and natural mortality

Key model variance and covariance parameters, including those used to estimate *F* and *M* deviations are presented in Table 30.

Average fishing mortality for ages 5 to 7 and 7 to 10 peaked in the early 1990s, and then again at progressively lower values around 2000, in the late 2000s and in 2018 (Figure 89, Table 31). These values, which reflect observed (input) catch and, since 2006, additional estimated (censored) catch, have been declining steadily since 2018. Since the early 1990s there has been a tendency for age-specific fishing mortality to be increasingly targeted toward older ages (Figure 90). This is particularly evident when these values are expressed as a function of the age 6 to 9 average (Figure 91). In most years since 2010, fishing has been targeted to fish ages 9+. Estimated standardized log-*F* deviation values, from which the age-specific *F* values are derived, are shown in Figure 92.

In contrast to *F*, *M* is estimated to have fluctuated at elevated values at all ages and in most years since the mid 1990s (Figure 93, Table 32). Following a dip in values in 2003 associated with a moratorium on commercial and recreational fishing, in which *M* at most ages reached values comparable to those assumed historically, *M* increased with spikes in the late 2000s and around 2018, particularly at older ages. At most ages, estimated *M* increased since 2020. Natural mortality currently constitutes almost all of *Z*, in contrast to the 1970s and early 1980s when *M* represented much less than half of *Z* for ages 6+.

The estimated standardized natural mortality process error values for each of the four age blocks is shown in Figure 97. Benoît et al. (2025)[21] concluded that the limited magnitude of the deviations in the first few years, which for some ages resulted in a decrease in *M* in the mid-1980s (Figure 93), indicated that assumed background *M* values were set adequately and that the subsequent increases in the process errors was consistent with actual increases in mortality. Notably, the increase in process errors (and *M*) in the late 1980s, and subsequently declines in the mid to late 1990s, is consistent with *M* associated with particularly cold bottom-water temperatures and low cod condition (Lambert and Dutil 1997a; Dutil and Lambert 2000; Lambert 2011), and corresponds to similar patterns in the neighboring sGSL stock (Neuenhoff et al. 2019; Swain et al. 2019b). In contrast, fluctuations in *M* across all age groups since then have generally corresponded with fluctuations in the TAC in most years (Figure 95) and *F* (Figure 93). The most parsimonious explanation is that fluctuations in *M* reflect fluctuations in unaccounted fishing mortality, which would likely be due to unreported catch (kept and/or discarded) and, possibly also, to depredation from the fixed fishing gear (if greater TAC resulted in greater fishing effort and therefore more opportunities for scavengers). Despite a low TAC of 1000 t in 2021 and a moratorium on directed fishing in 2022, *M* was estimated to be larger than in 2020, although there is some uncertainty surrounding the terminal 2022 value (see results of the retrospective analysis below). In those years, and previous ones, removals from the recreational fishery, which are otherwise not well quantified, likely contributed to *M*, although the magnitude of this contribution cannot be determined with the existing information.

Catch estimated by the model was close to the upper catch bound in 2011-2016 and 2019-2020 when catches were relatively low, and near the lower bound in 2017-2018 when catches were greater (Figure 96, Table 33). In 2021, estimated catch was approximately intermediate to the catch bounds. The pattern of estimated catch relative to the catch bounds for 2011-2021 may reflect a tendency for the model to seek to minimize fluctuations in *F* deviations over time and therefore to smooth the time series of estimated total catch, as was evident in sensitivity tests undertaken by Benoît et al. (2025)[21], in which the width of bounds was increased, in some cases by a considerable amount.

While the censored catch likelihood allows for the estimation of unreported and unaccounted catch, the approach as implemented in this model assumes that the input catch-at-age proportions from the reported catch are an unbiased sample of the age-specific proportions of the true total catch. In other words, it assumes that reported catch and unaccounted catch have the same annual age composition, and that this composition is reflected in the reported catch-at-age proportions. Reasons to expect the age-composition of unreported catch to differ from that of reported catch, include high grading (discarding of undersized fish associated with a non-negligible discard mortality rate), targeting of larger/older fish and generally a different selectivity for the recreational fishery. The age composition of mortality lost to *M* in the model was generally poorly or moderately correlated with the estimated age composition of the catch (Figure 97), which likely explains why natural mortality losses are not attributed to censored catch by the model, even though *M* does fluctuate to some extent with *F* and TAC.

As noted above and by Benoît et al. (2025)[21], the values of *M* in 2003 when both directed fishing and the recreational fishery were closed, were generally similar, albeit greater, than historical values. Furthermore, the decrease in TAC in 2018 to a relatively low value was associated with decreases in *M* close to 2003 values. These patterns suggest that *M* in excess of the 2003 values may reflect unaccounted catch. Based on this hypothesis, we calculated the amount of unaccounted catch implied by the difference in *M* in each year and for each age, associated with the age and year specific abundances and individual weights (Table 33). The resulting attribution of mortality losses is presented disaggregated by age in Figure 98. With the exception of age 4, for which there is little reported catch and high *M*, hypothesized unaccounted catch generally represented between about 15-50% of total catch prior to 2010, and generally between 80-95% more recently. Considering the sum of catches for ages 5+, which constitute the bulk of fishery sizes, hypothesized unaccounted catch was less than twice TAC from 2004-2008 and 2 to 8 times TAC since then (Figure 99). Although these latter values are high and may appear unlikely, we note for instance that estimates of recreational fishery retained catches from two independent sources in 2014-2015, the Canadian recreational fishing survey and estimates based on recreational fishery catch rates on the 2J3KL stock, were values in excess of 800 t annually (Ouellette-Plante et al. 2022a). These values do not include any mortality associated with released cod. Anecdotal information provided to us by recreational cod harvesters in NAFO 4R, other parts of Newfoundland and in the St. Lawrence Estuary suggests that the number of cod caught and released in the recreational fishery may be two or more orders of magnitude greater than the number retained. When combined with unreported catches in the commercial fishery, recalling the correspondence between *M* and TAC (Figure 95), and possible discards of age 4 (possible age 5) cod which comprise sizes below or at the regulatory size limit (Figure 100), we conclude the hypothesis of considerable unaccounted catch cannot be rejected with the current information available. Other possible sources of mortality are discussed in a later section.

3.5.3 Catchability and availability

The estimated catchability-at-age functions for the five surveys are essentially identical to those estimated by Benoît et al. (2025)[21] for the data up to 2020 (Figure 101). Asymptotic catchabilities for the DFO August and sentinel mobile surveys had values above 1, which may be elevated based on swept area assumptions. The cause of these high values requires further research (Benoît et al. 2025[21]). All ages are reasonably well captured by the August survey, as are ages 3 and above in the sentinel mobile survey. Meanwhile younger ages are not very catchable to the three sentinel fixed gear surveys, particularly the Gillnet survey. The catchability functions for the Minet surveys are presented in Figure 102, recalling that differences in the value of the asymptote between years reflects differences in abundance of older fish in the stock.

The model also estimated corrections for the availability of cod to the two bottom-trawl surveys as a result of smaller survey coverage prior to 1990 in the DFO August survey and 2003 in the sentinel mobile surveys. Survey abundance series corrected for these changes in coverage are presented in Figure 103, noting that for the sentinel survey a change is only estimated for ages 2 and 3 (for an explanation see Benoît et al. 2025[21]). The magnitude of the corrections for the DFO August survey varied between 1.24 and 1.35 for ages 2-5, and an increasing function of age from a value of 1.37 at age 6 to 2.33 at ages 11+. The corrections for the sentinel survey were smaller, with values of 1.24 and 1.12 at ages 2 and 3, respectively.

3.5.4 Model fit

The model fit the abundance indices at age reasonably well, although at age 3 the model underestimated the two sentinel longline indices prior to 2010 and overestimated them thereafter (Figure 104). There were no strong patterns in model residuals that would suggest model misspecification, such as patterns along cohorts or large blocks of similar sized residuals (Figure 105). There did appear to be a small conflict between the DFO August and sentinel mobile survey over the most recent 10 years, with the two surveys displaying opposite residual patterns. There is evidence of a small survey year effect in the DFO August survey in 2003-2004 and a somewhat larger survey effect for the sentinel mobile survey in 2011-2012, but these do not appear to have repercussions on other aspects of model fit. There were no strong patterns in abundance index residuals as a function of year and none as a function of age (Figure 106). There were somewhat stronger patterns in residuals as a function of cohorts, notably with the DFO August survey producing positive residuals of increasing magnitude since 2010.

The large 2018 cohort is not evident in the abundance indices for the fixed gear sentinel surveys (Figure 104), which may partly be due to the low catchability of cod to those surveys at young ages. Although that cohort has been particularly abundant in the catches of the DFO August surveys since 2020 when it was observed at age 2, its abundance in the sentinel mobile survey has been relatively much lower and comparable to that of the 2011-2013 cohorts (Figure 107). However, when the sentinel index is recalculated using the same strata as those of the DFO August survey (i.e., excluding strata in NAFO 3Pn and coastal strata along western Newfoundland), the 2018 cohort appears relatively more abundant (blue line in Figure 107); the values for the recalculated series peak at age 2 in 2020, age 3 in 2021 and age 4 in 2022, which is not the case for the original series. This suggests that cod in that cohort, on average, have a less coastal distribution and are less present in NAFO 3Pn that other recent cohorts and may therefore have been more available to the DFO August survey. This may also contribute to explaining why the fixed gear sentinel indices do not indicate high relative abundance for that cohort. Because the DFO August survey does not cover the entire stock distribution, changes in the availability of recruiting cohorts to that survey will contribute to possible biases in the estimates of abundance which should be investigated further. In the case of the 2018 cohort, the inclusion of the sentinel mobile survey index in the model will serve to attenuate a possible positive bias associated with increasing availability.

Standardized residuals for the Minet (1978) survey abundance indices were generally small and displayed no patterns with respect to age or year, suggesting an adequate fit (Figure 108).

Model estimated fishery catch proportions at age corresponded well with the input values (Figure 109). With the exception of the fits since 2017 for ages 11+, which correspond to generally low proportions, the model fit the magnitude and fluctuations well. There were no temporal patterns in catch-proportions at age residuals (Figure 110). There were no patterns in the crl residuals (Figure 111). Although values tended to be somewhat larger at older ages and in the years surrounding 2020 for ages 4 and 5 (Figure 111), there were no overall patterns as a function of year, age or cohort (Figure 112).

3.5.5 Retrospective analysis

A seven year retrospective analysis was undertaken and a value of Mohn's rho, which is a measure of systematic retrospective bias, was calculated for several model outputs (Mohn 1999). Sequential peels of the assessment model had a negligible effect on estimated mean fishing mortalities (Figure 113), SSB and recruitment (Figure 114). Values of Mohn's rho were very small, indicating little or no bias. The retrospective analyses for *M* show some sensitivity in the last year or two of an assessment, but no strong bias, i.e., the occurrence and magnitude of over and under estimates is comparable (Figure 115). Consequently, estimates of *M* from the terminal assessment year should be interpreted with some caution, but long-term trends appear reliable within the context of the model.

3.6 PROJECTIONS

Three-year projections from the fitted model were made for four catch scenarios (0, 500, 1,000 and 1,500 t) based on the following conditions and assumptions:

- The age-specific values of maturity, stock weights and fishery catch weights for 2022 were assumed the three subsequent years;
- The estimated average fishery selectivity for 2020-2022 was assumed;
- Recruitment was generated from the 2022 estimate assuming the age and year correlations estimated in the model, although the simulated values will not contribute to SSB within the three-year simulation;
- Natural mortality was also generated from the 2022 estimate assuming the age and year correlations estimated in the model;
- The parameters above, as well as the estimated 2022 abundance, were simulated using the model parameter estimates and covariance matrix.

Ten thousand independent simulations were made. From these we estimated probabilities associated with particular stock outcomes.

With a catch option of zero tonnes, there is an estimated 0.51 probability that SSB will, by the end of the projection period, increase by any amount, and around 0.40 chance of a 10% or greater increase (Table 34, Figure 116). With a catch option of 1,500 t, these probabilities decrease to 0.45 and 0.33, respectively. With a catch option of zero, there was a 0.038 probability of reaching or exceeding an SSB of 71,970 t, the value for the LRP accepted at the advisory meeting (details below). For a 1,500 t catch, the probability was 0.028. The probabilities of any increase in the abundance of cod ages 5+ and of a ≥10% increase were around 0.27 and 0.20, respectively, for a 1,500 t catch, and 0.32 and 0.23, respectively, with no catch.

The modest probabilities of an increase in adult cod biomass and abundance, despite the large 2018 year-class that is presently recruiting to the adult population, reflects the high natural mortality estimated for age 4 cod in particular, and for other ages in 2022 (Figure 93). Uncertainty in those estimates and in the values projected for 2023 and 2024 are such that the projections may over or under estimate the coming stock changes.

4 DISCUSSION AND MANAGEMENT CONSIDERATIONS

4.1 PROPOSED ELEMENTS FOR A PRECAUTIONARY APPROACH

The important revisions that were made to the assessment model for the NAFO 3Pn4RS cod stock require a re-assessment of reference points for the stock. Notably a new LRP needs to be defined given a legislated requirement that a rebuilding plan aimed at rebuilding the stock above its LRP be completed by April 2024 (Government of Canada 2022).

Under DFO's Fishery decision-making framework incorporating the precautionary approach (DFO 2009b), the LRP represents the upper bound of undesirable stock states that should be avoided to prevent serious harm to the stock, and is the boundary between the Critical and Cautious zones. Serious harm may be typified by persistent states of impaired productivity resulting from changes to one of more biological processes, including recruitment, mortality, growth and maturation (Kronlund et al. 2018; DFO 2023a). In some instances, serious harm can be associated with depensation or Allee effects (e.g., Swain et al. 2019b).

The NAFO 3Pn4RS cod stock has been considered to be in the Critical zone of the PA since the early 1990s. We begin by reviewing the evidence that the stock has experienced serious harm manifested as persistent periods of low biomass and low overall productivity (sensu Kronlund et al. 2018), of recruitment impairment, and of potentially adverse life history changes. We also evaluate whether the stock has experienced or is experiencing depensation, which would require defining the LRP at a higher level of SSB than might otherwise be necessary (e.g., Swain et al. 2019b). We then very briefly review which of the different approaches for setting an LRP are possible and most likely to be reliable for the stock, and propose a value based on the best available approach. Operationalization of the PA also requires other reference points, notably an USR, which defines the boundary between the Cautious and Healthy zones, a target reference point (TRP) and a removal reference, typically a fishing mortality limit (F_{lim}). Unlike the LRP, establishing these other reference points is not within the purview of DFO Science. However, because these will, to varying extents, be based on scientific considerations, that they may help guide the development of a rebuilding plan (e.g., establishment of a rebuilding target) and may be defined from the same framework used to establish the LRP, candidate values are proposed.

4.1.1 Evidence for impaired productivity

Kronlund et al. (2018) used the relationship between surplus production and SSB to identify persistent periods of low production and low biomass to define LRPs for Pacific herring stocks (*Clupea pallasii*). Unlike those authors which considered production of spawners, we considered the production over all ages 2+. This is the same approach taken by Mohn and Chouinard (2004) and later Swain et al. (2019b) for NAFO 4TVn cod, and extends an existing analysis by Dutil et al. (1999) who considered productivity for ages 3+. Consistent with Dutil et al. (1999), productivity components (mass) were defined as follows, using the notation from section 2.4:

Recruitment biomass: $BR_y = N_{2.y}SW_{2.y}$

Somatic growth biomass: $BG_y = \sum_{a=2}^{10} N_{a.y}\,(SW_{a.y} - SW_{a-1.y-1})$

Fishing removals (landings): L_y

Natural mortality removals: $BM_y = \sum_{a=2}^{11+} N_{a.y}SW_{a.y}(1 - \exp(-Z_{a.y}))\, {}^{M_{a.y}}\!/_{Z_{a.y}}$

Net production: $NP_y = BR_y + BG_y - BM_y - L_y$

Surplus production: $SP_y = BR_y + BG_y - BM_y$

Two scenarios were considered for natural mortality removals, one based on values of *M* estimated by the model the second assuming that any natural mortality in excess of $M_{a.2003}$ values constituted additional, unaccounted fishery removals.

Phase plots of surplus production and surplus production rate ($SP_y / \sum_{a=2}^{11+} N_{a.y}SW_{a.y}$) as a function of 2+ biomass for the estimated *M* and hypothesized unaccounted catch scenarios are presented in Figures 117 and 118, respectively. In both, the years 1990 to 1993 are associated with negative surplus production, while in the estimated *M* scenario, approximately one third of the years since 1993 are additionally associated with negative surplus production (i.e., stock decline even in the absence of fishing). On average surplus production since the mid 1990s has been between about 10 to 25%, the values estimated for the 1970s and 1980s. Normally, surplus production rate is expected to decline with increasing biomass as a result of density-dependence (Nicholson 1933); however since the early 1990s, the surplus production rate has on average been below that of the earlier period, regardless of the scenario. This is consistent with impaired productivity which has persisted over the low biomass states of the past 30 years, and provides strong evidence that the stock has been in the Critical zone as is defined by the DFO PA framework and recent Science advice (DFO 2023a).

In the neighboring NAFO 4TVn stock, the low biomass, low productivity state is further associated with a decrease in surplus production rate with decreasing biomass (Swain et al. 2019b). This positive density-dependence constitutes an Allee effect, which in the case of that stock appears to be driven by predation by grey seals (Gascoigne and Lipcius 2004; Neuenhoff et al. 2019). In contrast to that stock, the surplus production rate for nGSL cod does not suggest that an Allee effect is present.

The negative surplus production experienced by nGSL cod in the early 1990s was driven principally by the increase in natural mortality and, to a lesser extent, a reduction in the contribution of somatic growth to biomass and reduced recruitment (Figure 119; Dutil et al. 1999). These conditions were associated with a cold bottom-water period and would have led to stock decline even in the absence of fishing (Lambert and Dutil 1997a). Nonetheless, net production was negative beginning in 1983 as a result of fishing in excess of surplus production. Since 1995, net production has alternated between period of positive and negative values, with only modest production available to allow stock growth.

There is also evidence of serious harm in the stock-recruitment patterns and recruit per spawner versus stock biomass for the stock (Figure 120). Theoretical stock-recruit models such as the Ricker and Beverton-Holt typically predict that the recruits produced per SSB will follow a continuous curvilinear monotonic declining function of SSB. Instead, recruits per SSB at nGSL cod SSB levels between 40,000 to 50,000 t were estimated to be comparable or inferior to values at SSB levels three to five time greater. There appear to be two recruit-per-SSB vs SSB relationships for nGSL cod, one that prevailed prior to 1989, and one that has prevailed since.

The factors underlying this change require further investigation. Some likely contributors are briefly reviewed.

The changes in recruitment productivity are likely in part driven by other life history changes, which themselves may in part reflect serious harm experienced by the stock. During the cold-water period of the late 1980s and early 1990s, the proportions of cod that were mature at all ages 5 and above declined to differing extents (Figure 121). The simultaneous reduction across ages, rather than along cohorts, is consistent with an environmental effect on maturation and likely increased skipped spawning (Rideout et al. 2005; Rideout and Tomkiewicz 2011). While this is accounted for in the calculation of SSB, it may indicate a stress also imposed on reproductive individuals. Meanwhile, cohorts born in the late 1980s and early 1990s were associated with an increasingly earlier maturation age. While more detailed analysis is required to better establish the causes, this pattern is consistent with changes in life history resulting from particularly elevated levels of fishing and total mortality in the years those cohorts were born (e.g., Olsen et al. 2004, 2005). Beginning in the late 1990s, maturation age followed an increasing trend (lower proportions mature at ages 4 to 6), which reversed towards earlier maturation in the 2010s. These patterns are also consistent with mortality-driven changes as they are respectively associated with cohorts born in years with lower fishing and total mortalities in the mid to late 1990s and decreasing values in the early 2000s, and the spike in mortality particularly at older ages from 2008 to 2010 (Figure 93). Younger, smaller cod have been shown in the laboratory to be likely inferior spawners compared to larger older individuals on a mass-specific basis as they tend to produce smaller eggs, which are released in fewer batches (Trippel 1998), and due to an allometry between mass and reproductive output (Barneche et al. 2018). Evidence from northeast Arctic cod and Barents Sea cod stocks indicates that recruitment success and resilience to environmental change are associated with SSB comprising older individuals (Ohlberger et al. 2022; Ottersen and Holt 2023).

Jointly these results provide strong evidence that the low SSB period since the mid-1990s has constituted a period during which the stock displayed signs of serious harm. Although more detailed research is required, this harm appears to be associated to a non-negligible extent to fishing, particularly if patterns in *M* since 2003 have comprised an important unaccounted catch component.

4.1.2 Proposed limit reference point

Approaches to estimating and selecting an LRP were recently reviewed as part of a national DFO Science advisory process (DFO 2023a). Many of these were also evaluated during the assessment framework review for nGSL cod (Benoît et al. 2025[21]).

Traditional model-based estimates of LRPs are typically derived from estimates of B_{MSY} or unfished biomass, B_0. These in turn require a defined stock-recruitment relationship and generally stationary demographic parameters affecting productivity. Neither of these conditions are met for nGSL cod. The resilience of a stock is related to the steepness of the stock-recruit function (the slope at the origin). The absence of recruitment values (and SSB) at levels intermediate to the low recruit/low SSB and high recruit/high SSB states observed for nGSL cod (Figure 120) preclude the reliable estimation of steepness. Furthermore, it precludes the use of proxies such as the SSB that produces 50% maximum recruitment (Myers et al. 1994; Shelton and Rice 2002; Rivard and Rice 2003), which was the basis for the previous LRP value for the stock (Duplisea and Fréchet 2011).

While dynamic reference points can address some temporal changes in productivity parameters (Berger 2019), they are not suitable when these parameters have varied as a result of fishing or density dependence.

Theoretical maximum sustainable yield (MSY) proxies based on population dynamics theory, such as those based on spawner-per-recruit and recruit-per-spawner considerations assume equilibrium conditions, which are not met for nGSL cod. These were nonetheless considered by Benoît et al. (2025)[21] for different productivity periods for the stock. The results were very sensitive to the choice of the life-history characteristics and recruitment rates.

Other LRP proxies commonly employed in the absence of model based estimates and stock-recruit and equilibrium MSY proxies are B_{loss}, the lowest observed biomass, and $B_{recover}$, lowest observed biomass that produced recruitment leading to stock recovery (DFO 2023a). Neither of these proxies are appropriate for the nGSL cod stock, as the lowest observed SSB is clearly associated with a state of serious harm, and no substantive recovery has been demonstrated for the stock over the period of assessment since 1973.

In light of these limitations, Benoît et al. (2025)[21] recommended using historical stock states and dynamics estimated from an assessment model to define reference points consistent with MSY. The authors extended the accepted assessment model back to 1966 by incorporating information on population age composition from research surveys that took place in 1962-1966 and fishery catch at age representative of 1966 (Wiles and May 1968), and from estimates of fishing mortality from tagging experiments undertaken in 1964-1967 (Myers et al. 1996), as well as landings data. Using similar data for earlier years, they also independently estimated SSB values for 1953 and 1958, and an additional value for 1966 based on slightly different inputs than those in the extended model. Additional details are provided in Benoît et al. (2025)[21].

The extended assessment model was not updated for this assessment, but produced very similar estimates of SSB (Figure 122), mean fishing mortality (Figure 123) and recruitment (Figure 124) as the current assessment model. The differences between the two result from a difference in the estimated catchability function asymptote for the DFO August survey (Figure 125). Consequently, biomass reference points derived from the extended model can easily be adjusted to the scale of the assessment model.

The historical estimates and extended model show that, following some depletion of the stock in the early 1960, resulting from increased fishing mortality (Myers et al. 1994), there was a 20 year period during which the stock fluctuated around a relatively elevated SSB level (Figure 122), that produced good recruitment on average (Figure 124), while supporting an elevated average level of fishery catch (Figure 126). Over the 1966-1985 period, average fishing mortality fluctuated with only minor trends, decreasing slightly for ages 4 to 6 and increasing slightly for ages 6 to 9. Although limited to a 20-year period, these conditions appear consistent with fishing at F_{MSY}. Though somewhat subjective, the mean SSB over the 1966-1985 period, 168,340 t, appears to be a reasonable proxy for B_{MSY} (Figure 127). This value is further supported by alternative reasoning. Using a surplus-production-type model fit to 500 years of catch data, Schijns et al. (2021) estimated that around 1960, the SSB for the neighboring NAFO 2J3KL (Northern) cod stock was at a value around 1.5 x B_{MSY} and, by the mid to late 1960s, around B_{MSY}. Assuming that the historical fishery and depletion dynamics of nGSL and northern cod were similar and that the mean SSB value for nGSL cod for 1953 and 1958 constitutes 1.5 times B_{MSY} results in a rough estimate of B_{MSY} = 185,000 t, a value comparable to the 1966-1985 average (Figure 127). Applying the provisional DFO PA framework defaults results in a proposed TRP = B_{MSY}, USR = 0.8 B_{MSY} = 134,672 t and a proposed LRP = 0.4 B_{MSY} = 67,336 t. Adjusting for the difference in asymptotic catchability (1.926 in the extended model; 1.802 in the current) results in the following proposed values at the scale of the assessment model:

Target reference point – 179,924 t

Upper stock reference – 143,939 t

Limit reference point – 71,970 t

The previous LRP had been set at 116,000 t (Duplisea and Fréchet 2011), and the previous assessment of the stock had placed SSB at around 10% of this value (Brassard et al. 2020). Duplisea and Fréchet (2011) used characteristics of the stock-recruit relationship, which in perspective, is difficult to support, as explained above. The revised assessment model estimates that the level of stock depletion between the 1980s and 2000s was considerably less than previously estimated (Figure 128). This, combined with a different approach for setting the LRP results in a proposed value that is considerably less than the previous one. Furthermore, the SSB for the stock is closer to the (proposed) LRP, with the estimated SSB for 2022 at 60% of the proposed LRP.

Consistent with the foregoing reasoning, the fishing mortality that prevailed from 1966-1985 may constitute a reasonable proxy for F_{MSY} = 0.49 (*F* for ages 6-9). However, this mortality rate cannot be considered independently of the prevailing rates of natural mortality, whether they be truly associated with natural or non-fishing mortality, or whether they subsume unaccounted fishing mortality (Figure 129). Values of total mortality *Z* for ages 6 to 9 near or below the mean value for the 1966-1985 period have generally led to stock stability or some stock growth, while values in excess of this level (1987-1993, 2001, 2007-2009 and 2017-2018) have generally resulted in stock decline, even when accounted fishing mortality has been low (Figure 127). This pattern clearly suggests an upper limit to *Z* above which stock decline is likely. In the context of high and variable *M*, which may subsume important quantities of unaccounted catch that may be difficult or impossible to quantify, adopting a total mortality-based limit appears to be sensible. To our knowledge, there is little precedence for such an approach as part of a precautionary approach and it clearly requires further research. Notably it will require an ability to reliably project the anticipated *Z* associated with different (accounted for) catch options, and will need to be robust to the uncertainty associated with *M* estimates in the terminal year of an assessment.

4.2 ASSESSMENT FREQUENCY AND INTERIM YEAR ADVICE

Currently the assessment for NAFO 3Pn4RS cod is meant to occur on a biennial cycle. This species is a relatively long lived groundfish and the stock tends to fluctuate with low frequency variation (e.g., Figure 86). Consequently, full assessments involving an update of the assessment model are likely not required every second year. Groundfish in the neighboring southern GSL, including NAFO 4TVn cod, are assessed on a five year cycle, comprising a full assessment every five years, with interim updates in intervening years (DFO 2020b, 2021c). The process includes an exceptional circumstances protocol in which unexpected results identified during an interim year update would trigger a full assessment, although in practice there have been no triggering instances. A five-year assessment cycle is likely to be adequate for NAFO 3Pn4RS cod given that the frequency of stock variation is comparable to the neighboring ground fish stocks.

During interim years, simple stock indicators can be monitored to evaluate whether stock conditions remain consistent with projections made during the preceding full assessment. Estimation of SSB requires annual age composition information and fitting of the assessment model, which is resource-consuming, not necessarily possible each year and detracts from other activities such as research on the factors affecting stock productivity. Instead, the index of biomass of cod ≥ 43 cm derived from the DFO August survey, based on the regulatory size limit and roughly corresponding to SSB, can provide a proxy for SSB. Excluding large SSB values prior to 1992 which might otherwise dominate the relationship, the biomass index and SSB were found to be correlated with r=0.40 (Figure 130). Regressing SSB on the index, and assuming a nil intercept, we derived an adjustment for the survey index that approximates SSB. Smoothing the adjusted index using loess with a span=0.2 produced an SSB proxy that generally tracked SSB fluctuations since 1992 (Figure 131). The reliability of this proxy should be reviewed periodically, particularly if there are notable increases in SSB.

Interim year updates using the smoothed survey indicator will allow tracking of stock status with respect to stock trends projected at the full assessment. Deviations in stock trajectory relative to projected trends more than a specific amount could trigger a full assessment under an exceptional circumstance protocol. The magnitude of deviation that would trigger an assessment needs to be defined. A key consideration is the uncertainty in the smoothed survey index given that one would only want to consider deviations that are larger than those expected based on sampling variability alone. A measure of uncertainty for the smoothed index should be developed if the assessment is moved from a biennial to a less frequent assessment cycle.

4.3 ENVIRONMENTAL FACTORS AFFECTING THE PRODUCTIVITY OF NGSL COD

Section 1.2 of this document summarized the key habitat associations and aspects of biology that characterize the cod stock in NAFO 3Pn4RS. In the section, we very briefly summarize the current understanding of how various environmental factors have affected the major aspects of productivity of the stock. This is not intended as an exhaustive review, but rather as a summary of key factors. This information supported the drafting of the rebuilding plan for the stock, which must include a section on the probable causes of the stock's decline. The purpose of that section of the rebuilding plan is to summarize the probable factors that have led to the decline of the stock as well as those that may affect rebuilding. The factors to cover include fishing mortality from all sources (which has been described in preceding sections of this document), natural mortality, predator/prey interactions, environmental impacts (including climate, oceanographic and ecosystem factors), and habitat limitations.

From spring to fall, 3Pn4RS cod principally inhabit depths of approximately 50 to 150 m, which occur within or just below the CIL. Beginning in 1973, the first year included in the assessment for the stock, the CIL minimum temperature index and the mean temperature at 150 m have fluctuated around average in the 1970s, above average in the early 1980s, below average from the mid-1980s to mid-1990s, and around average after the late 1990s (Figure 132). There has been a warming trend for temperature at 150 m since the late 2000s. A notable feature of these series is the cold below-average period centered around 1990. That period has previously been associated with an increase in natural mortality resulting from lower condition, both for nGSL cod (Lambert and Dutil 1997a; Dutil and Lambert 2000; Figure 133 of this document) and neighboring sGSL cod (Swain et al. 2011a, 2011b). In addition, during the cold-water years, the maturity ogives for nGSL cod showed a concurrent drop across numerous ages in the proportion of fish classified as mature based on macroscopic examination of gonads (Figure 133). The concurrent change across ages are consistent with within-year environmental effects on maturity status, in contrast to a change in life history resulting from a selective effect of fishing (Heino et al. 2015), which would track along cohorts. It is also consistent with skipped spawning, which is well known to be associated with poor condition and which, in more advanced cases, could cause gonads to macroscopically appear immature (Rideout et al. 2000, 2005; Rideout and Tomkiewicz 2011). Along with a reduction in weight-at-age for cod alive during those year and cohorts born in those years (Figure 133, right panel), it seems clear that the cold-water period affected all major components of productivity, resulting in the estimated reduction in production reported for the 1985-1995 period in Figure 119.

Late juvenile and adult nGSL cod overwinter in the deeper waters of the channels in the eastern portion of the GSL and off of southwestern Newfoundland (Fréchet 1990). Water temperature at these depths has trended upwards since the mid-2000s, increasing by about 2 degrees Celsius over the period (Figure 132; Galbraith et al. 2022). Concurrently, dissolved oxygen concentrations have been declining, most prominently in the St. Lawrence Estuary (Blais et al. 2023). Jointly, the trends in these two factors is expected to increase the metabolic stress in cod, with consequences for life history traits such as growth and reproduction (Lavaud et al. 2019). However, anticipated negative effects may be attenuated given that a key effect of hypoxia is a reduction in ingestion rates (Chabot and Dutil 1999), which may have fewer consequences for nGSL cod which feed very little during the winter (Ouellette-Plante et al. 2022b). Furthermore, nGSL cod are not believed to be particularly active in winter, which should therefore attenuate possible metabolic stress.

No consistent effect of environmental and ecological variables on the stock-recruitment relationship for nGSL cod is apparent (Figure 134). Previous studies have identified poor physiological condition, high abundance of pelagic fish predators of cod eggs and larvae, and cold temperatures for settling cod as contributing negatively to recruitment as a function of SSB (Swain and Sinclair 2000; Duplisea and Robert 2008; Lambert 2011; Bryhn et al. 2022). Model estimates of stock and recruitment from the short period when the stock collapsed in the late 1980s and 1990s were indeed characterized by poor physiological condition of adults that is not entirely accounted for in SSB, high abundance of Atlantic mackerel, and below average bottom-temperatures that may have contributed to higher mortality in settling and settled juveniles (Dutil and Lambert 2000; Lambert 2011; DFO 2021a; Galbraith et al. 2022; see also Figure 134). However, the effect of these factors is not consistent over the broader series and, notably, values for all of these variables have been at favorable levels during much of the post collapse period (years with SSB < 50,000 t in Figure 134).

The analysis of the components of production presented in Figure 119 identified natural mortality as a key factor limiting the productivity of nGSL cod, with elevated values in most years since about 1990 (Figure 93). Although poor condition associated with cold water temperatures may explain increases in *M* in years around 1990, it cannot explain subsequent trends in *M*.

Predation by seals has often been proposed as an important contributor to elevated natural mortality in NW Atlantic cod stocks (DFO 2008a, 2009a). Harp seals (*Pagophilus groenlandicus*) and grey seals have been implicated as potentially important predators (Hammill and Stenson 2000; DFO 2011b). Meanwhile, harbour seals (*Phoca vitulina*) are considered much less abundant, found mainly in coastal areas where cod generally do not occur and generally feed on smaller fish. Hooded seals (*Cystophora cristata*) are also less abundant and their presence in the GSL is restricted to a short period during the winter (Hammill and Stenson 2000; M. Hammill, DFO, pers. comm. 2021).

Predation by harp seals specifically has previously been considered for nGSL cod and northern cod (NAFO 2J3KL). For nGSL cod, factors affecting recruitment and ongoing fishing were found to be the principal causes for lack of rebuilding following collapse, although predation by harp seals on younger cod also contributed somewhat (Chassot et al. 2009; Bousquet et al. 2014). Meanwhile, for northern cod, bottom-up effects were considered to be a principal driver, with only a minor effect of harp seal predation (Buren et al. 2014). Although the abundance of harp seals increased considerably over the period 1970-1995 and since 2010 (DFO 2020b), these trends do not correspond with those for nGSL cod natural mortality, further indicating that predation by harp seals is not an important driver. Furthermore, with climate warming and the disappearance of the stable sea ice harp seals require for pupping, harp seals are expected to become less and less present in the GSL over time (Stenson and Hammill 2014), such that any current predation impact is likely to diminish in the future.

Predation by grey seals has been identified as the principal cause of the elevated natural mortality that has prevented the recovery of sGSL cod and that has resulted in ongoing declines in that stock (Neuenhoff et al. 2019). More generally, predation by grey seals appears to be a major factor in the elevated natural mortality (Benoît et al. 2011; Swain and Benoît 2015; Swain et al. 2019a) and important distribution shifts (Swain et al. 2015) for several groundfish populations in the sGSL. There has been considerably less examination of the potential impacts of grey seal predation in the nGSL.

The NW Atlantic grey seal population increased considerably from about 6,000 animals in the 1960s to over 365,000 in 2021 (Hammill et al. 2023). Grey seals are present year-round in the GSL, although the number that spend time there seasonally is currently not well defined. Within the GSL, grey seals have principally occupied the sGSL. The geographic distribution of pups, which serves as a proxy for adult distribution in early winter, is largely limited to the sGSL, the Scotian Shelf and the Gulf of Maine (Figure 135). Aerial surveys of hauled out grey seals in the GSL undertaken in the early summer (principally June) of 1983, 1996/2000 and 2019, identified haul-out sites in the nGSL along the QC Lower North Shore, the west coast of Newfoundland and Anticosti Island (Figure 136). Counts at these sites largely remained the same across these three sets of surveys which were separated in time by decades. In contrast, counts in the sGSL, in the Northumberland Strait, and in particular at the Magdalen Islands, increased considerably. Satellite telemetry of small numbers of grey seals tagged in most years since 1993 indicates that grey seals principally spend time on the eastern Scotian Shelf, centered around Sable Island, and in the sGSL in most seasons (Figure 137). From December to April, tagged seals spent relatively little time in the waters off southwest Newfoundland where nGSL cod aggregate to overwinter. During the remainder of the year, tagged seals occupying the nGSL were mainly concentrated exclusively on the northwestern tip of Anticosti Island, although they spent some time in nearshore areas along the QC Lower North Shore and the west coast of Newfoundland. Although presentation of the tagging data in Figure 137 does not account for tagging effort (tagging location, e.g., Figure 138, and the fraction of animals tagged per location) and therefore does not represent a population scale estimation of space use by grey seals, it does suggest that grey seals are much less present in the areas where nGSL cod occur compared to areas to the south. Predation by grey seals is therefore less likely to have been important for mortality in nGSL cod compared to sGSL cod. The lack of correspondence between the trends in nGSL natural mortality and the increasing trend in NW Atlantic grey seal abundance, further corroborates this conclusion.

Although grey seal predation is not likely to have been an important contributor to natural mortality in nGSL cod in the past, it could become so in the future. The number of grey seals hauling out at Brion Island (Magdalen Island archipelago) has increased by several orders of magnitude in recent decades (Figure 136). Seals tagged at that location are amongst those that spend some time in the nGSL (Figure 138), and there is some evidence from recent telemetry that their use of the nGSL may be increasing (X. Bordeleau, DFO, pers. comm. 2023). Additionally, grey seals, which routinely breed and pup on land, are predicted to extend their breeding areas northward in the GSL with the retreat of sea ice under climate warming (Hammill and Galbraith 2012). Importantly, the impact of predation by grey seals is also driven by the abundance of cod. The estimated functional response of grey seals feeding on sGSL is such that predation rates for a given seal abundance are much higher when cod are at low abundance compared to higher abundance (Neuenhoff et al. 2019; Rossi et al. 2024). This phenomenon is generally called an emergent, predation-driven Allee effect. Taken together, the increased presence of grey seals in the nGSL combined with the current low abundance of nGSL cod, could result in an important increase in predation and therefore natural mortality for nGSL cod. Barring any possible management actions aimed at reducing the abundance of grey seals in the GSL, actions aimed at promoting the rapid rebuilding of the nGSL stock are the best and perhaps only option to minimize the risks associated with increasing number of grey seals in the nGSL (Rossi and Benoît, manuscript in prep.).

Finally, in northern cod, changes in natural mortality have been associated with poor condition linked to low abundance of key prey species, capelin and shrimp (Regular et al. 2022). Although poor condition has been linked to increases in natural mortality in nGSL cod in the late 1980s and early 1990s, as described earlier in this section, condition in all years subsequent have been around average, except in 2022 when values were particularly low, especially for cod in 4S captured in the DFO August survey (Figure 63). Populations of northern shrimp in the nGSL, which are an important prey for nGSL cod, have declined considerably in abundance over the past two decades (DFO 2023c). However, possible impacts on cod feeding and on condition have yet to be examined. The importance of capelin in the diet of adult nGSL cod varies among years (roughly between 5-45%, with an average around 15%; DFO 2023b). Although the status of capelin is uncertain, an abundance index for the nGSL suggest that abundance may have been low in most years since about 2013. As with shrimp, it is not clear whether this may have affected overall feeding success in nGSL cod, and in turn, their condition.

4.4 SOURCES OF UNCERTAINTY

Several uncertainties exist for this stock. First, there is the recreational fishery for which no monitoring of catches (quantities, sizes and weights) and discards is carried out. Since the directed commercial fishery was closed in 2022, it is likely that the recreational fishery corresponds to a significant portion of current actual catches. This difficulty in estimating it contributes to high M values in the new assessment model, the estimation of which would include a component of unrecorded fishing mortality whose magnitude is currently unknown. In addition to recreational fishing, this unaccounted component would also be combined with discards at sea, unreported commercial fishing and depredation.

The poor condition of cod observed in 2022 raises several questions about the probable causes and especially the consequences for the population. This deterioration in condition should be studied in more detail in the coming years. In particular, the effect of changing oceanographic and ecological conditions in the nGSL, particularly water temperature and DO content, as well as prey availability and potential competition with redfish, will need to be studied.

Finally, the acquisition of additional data over the next few years should improve estimates of the 2018 cohort’s abundance, survival, and contribution to the SSB.

5 CONCLUSION

The present assessment indicates that the 3Pn4RS cod stock remains in the critical zone under the precautionary approach. The SSB estimate for 2022 (42,906 t) represents 60% of the LRP (71,970 t) adopted in this assessment. Under the precautionary approach, removals from all sources should be as low as possible to promote recovery in SSB.

Three-year SSB projections based on scenarios of accounted catch ranging from 0 to 1,500 t were performed using the new model. Under these scenarios, the probability of SSB increasing ranged from 0.51 (0 t) to 0.45 (1,500 t). The high natural mortality rate explained this modest outlook despite significant recruitment to adult biomass of the strong 2018 cohort.

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8 TABLES

Table 1. List of the various 3Pn4RS cod related CSAS publications published since 1996. The Year and Date columns refer to the year and date of the meeting. For documents whose associated meeting could not be traced, the year value corresponds to the year of publication. SAR = scientific advice report, SR = science response, RD = research document, SSR = stock status report, PROC = proceedings.

Year	Date	SAR	SR	RD	SSR	PROC
1996	-	-	-	-	1996/053	-
1997[a]	03-05/03	-	-	1998/055	-	1997/006
1998	-	-	-	1998/018	1998/127, 1998/A4-01	-
1999[a]	01-12/03	-	-	-	1999/A4-01	1999/005
2000[a]	22-25/02	-	-	2000/106	-	2000/017
2000[a]	16-17/10	-	-	-	-	2000/027
2000	-	-	-	2000/118, 2000/150	2000/A4-01	-
2001	-	-	-	-	2001/A4-01	-
2002[a]	05-08/11	-	-	-	-	2002/033
2002	-	-	-	2002/082	2002/083, 2002/A4-01	-
2003[a]	17-26/02	-	-	2003/065, 2003/066	2003/017	2003/021
2004	22-24/03	-	-	2004/042, 2004/044, 2004/093	2004/019, 2004/041	-
2004[a]	25-29/10	-	-	-	-	2004/040
2005	16-17/02	2005/003	-	2005/019, 2005/055, 2005/060	-	2005/030
2006	17/01	-	2006/001	-	-	-
2006[a]	6-10/02	2006/010	-	-	-	2007/054
2006[a]	22-24/03	-	-	2006/086	-	2006/013
2007	15-16/02	2007/003	-	2007/068	-	2007/046
2007[a]	31/01-01/02	2007/002	-	2007/066	-	2007/050
2008[a]	25-29/02	2008/003	-	2009/012	-	2008/019
2008[a]	3-5/03	-	-	2009/027	-	-
2009[a]	24/02-06/03	2009/010	-	2009/090, 2009/097	-	2009/050
2010	23-24/02	2010/011	-	-	-	2010/013, 2010/013
2010	15/10	-	-	2011/003	-	2011/006

Year	Date	SAR	SR	RD	SSR	PROC
2011[a]	21-25/02	2011/026	-	-	-	2011/048
2012	08-09/03	2012/005	-	2012/056	-	2012/013
2012	17/12	-	2012/043	2012/171	-	-
2013	06/12	-	2014/009	-	-	-
2015	19/02	2015/041	-	2016/010	-	2015/024
2017	23/02	2017/042	-	2018/039	-	2017/036
2019	21-22/02	2019/032	-	2019/075	-	2019/012
2020	14/01	-	2020/007	-	-	-
2021	14/01	-	2021/006	-	-	-
2021	21-22/04, 12/05	-	-	2021/067, 2022/015, 2022/033, 2022/049	-	2022/008
2022	26/01	-	2022/009	-	-	-
2022	24-26/05	-	-	-	-	2023/026
2023	23-24/02	2023/035	-	-	-	2023/039
2023	12/10	-	-	2023/085	-	-

[a]Zonal meeting.

Table 2. *Historical monthly commercial landings statistics (t) for the period 1964-2022. The annual TAC is also provided. Until 1998, the management year corresponded to the calendar year. Since 1999, the management year has begun on May 15 of the current year and ended on May 14 of the following year. Unk. = unknown. '0' values indicate landings ≤ 0.5 t. Source: NAFO 21B and ZIFF data.*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Unk.	Total	TAC
1964	1,104	24,423	15,760	6,059	3,106	10,349	12,526	5,853	2,154	1,385	864	651	-	84,234	-
1965	791	12,577	21,171	3,698	2,146	5,267	10,421	5,945	3,636	1,359	927	990	-	68,928	-
1966	1,965	22,817	8,929	2,516	1,638	8,371	7,483	4,740	2,493	1,146	1,779	1,208	-	65,085	-
1967	7,873	7,028	14,792	8,448	2,017	7,524	12,665	5,232	7,154	3,314	1,352	1,912	1	79,312	-
1968	725	7,980	22,799	9,060	3,087	10,719	17,214	9,400	4,913	1,784	1,171	819	-	89,671	-
1969	875	4,654	9,675	4,220	5,192	10,958	12,103	8,639	7,866	3,557	2,035	1,366	-	71,140	-
1970	1,635	25,494	18,223	27,886	4,816	6,017	8,963	3,896	2,184	3,114	1,937	1,300	-	105,465	-
1971	845	44,587	7,580	5,265	2,346	5,857	8,427	3,042	2,343	1,600	1,003	915	-	83,810	-
1972	1,494	14,961	5,337	7,400	7,334	4,594	6,818	3,296	2,365	1,406	994	212	2,026	58,237	-
1973	16,472	10,556	7,586	4,826	3,235	5,860	5,125	4,145	2,365	1,459	1,016	567	2,593	65,805	-
1974	12,995	10,753	5,959	5,665	6,231	5,021	6,235	5,396	2,214	1,331	1,009	479	3,148	66,436	-
1975	8,232	19,486	2,702	2,616	5,316	5,122	5,042	4,488	2,767	1,267	819	704	1,672	60,233	-
1976	15,637	15,204	3,610	3,437	7,071	6,930	6,978	4,310	3,348	2,286	1,537	578	6,055	76,981	-
1977	11,143	8,603	3,790	11,312	10,057	7,368	8,133	5,780	3,361	1,751	1,814	454	-	73,566	55,000
1978	20,754	6,307	5,161	3,156	6,717	9,796	13,255	7,000	2,836	1,979	1,309	236	-	78,506	55,000
1979	15,543	4,273	6,475	6,647	8,517	12,890	12,085	8,660	2,971	2,449	1,816	451	-	82,777	75,000
1980	5,280	8,965	9,925	8,087	7,147	14,096	23,158	10,719	5,687	2,773	1,311	431	-	97,579	75,000
1981	9,156	15,368	3,170	3,763	12,835	17,257	16,344	10,343	5,676	2,550	1,172	277	-	97,911	75,000
1982	2,289	11,671	10,122	5,544	12,723	16,826	22,492	9,136	8,412	4,465	1,227	32	-	104,939	93,300
1983	4,152	10,213	11,335	6,251	21,049	18,341	16,228	8,173	5,698	3,956	530	154	-	106,080	100,000
1984	5,002	11,079	9,494	4,260	15,205	13,349	22,300	10,962	5,238	4,644	1,113	997	-	103,643	100,000
1985	2,416	16,369	7,661	3,407	6,904	12,612	13,874	11,414	7,730	3,130	1,005	1,959	-	88,481	100,000
1986	2,468	18,021	10,611	4,847	12,057	7,613	12,739	5,960	4,348	2,956	834	944	-	83,399	92,100
1987	8,264	7,382	5,072	3,945	6,411	8,222	9,060	7,492	5,745	2,842	1,022	1,089	-	66,545	80,300
1988	1,505	2,710	4,270	2,697	9,897	4,971	7,679	6,282	3,264	1,747	1,143	1,536	-	47,702	73,900
1989	6,198	7,511	1,982	2,048	6,520	6,229	6,306	4,797	2,080	2,189	721	181	-	46,762	76,540
1990	5,646	2,537	1,102	394	7,953	7,741	4,664	3,122	1,968	1,554	1,856	464	-	39,000	58,000
1991	1,532	2,001	3,113	3,736	4,229	4,477	5,314	2,891	3,242	2,016	1,810	121	-	34,481	35,000
1992	4,453	2,551	226	1,825	4,696	1,729	3,211	3,538	2,316	1,869	1,868	1,261	-	29,546	35,000
1993[1]	9	51	1,255	1,244	1,489	4,350	3,811	2,234	1,119	1,088	1,173	629	-	18,452	18,000
1994	14	48	41	7	26	12	14	100	206	28	24	18	-	537	0

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Unk.	Total	TAC
1995	-	-	-	0	12	5	26	95	25	21	-	-	-	185	0
1996	0	0	0	0	5	10	150	56	38	33	23	2	-	317	0
1997	0	1	-	2	357	255	1,189	962	815	1,038	145	27	-	4,792	6,000
1998	3	0	0	2	27	246	908	1,051	418	552	22	-	-	3,229	3,000
1999/00	1	51	132	107	106	870	1,985	1,458	1,031	1,014	395	39	-	7,191	7,500
2000/01	86	72	49	33	561	907	1,251	1,533	1,087	775	398	82	-	6,833	7,000
2001/02	110	58	6	10	447	518	1,847	1,269	1,339	865	293	125	-	6,886	7,000
2002/03	0	-	0	0	146	58	2,519	1,484	843	869	393	7	-	6,320	7,000
2003/04	0	-	0	13	8	13	118	131	48	31	39	5	-	405	0
2004/05	0	-	0	14	30	25	1,887	205	537	356	207	13	-	3,274	3,500
2005/06	-	-	0	24	44	69	2,434	628	774	473	22	3	-	4,471	5,000
2006/07	1	0	0	15	19	101	3,285	591	645	298	669	17	-	5,640	6,000
2007/08	-	-	1	7	22	132	3,711	447	1,126	578	447	5	-	6,474	7,000
2008/09	-	-	1	3	45	117	2,973	924	1,240	551	301	2	-	6,157	7,000
2009/10	1	0	2	2	7	176	1,691	693	690	696	687	51	-	4,696	7,000
2010/11	0	0	0	15	10	54	1,362	882	556	499	185	1	-	3,566	4,000
2011/12	0	0	0	12	15	50	1,006	163	315	11	193	9	-	1,773	2,000
2012/13	0	0	0	22	16	40	671	110	296	20	131	3	-	1,310	1,500
2013/14	-	-	-	7	11	34	699	77	220	10	147	3	-	1,208	1,500
2014/15	-	-	-	4	18	16	644	92	344	26	100	23	-	1,266	1,500
2015/16	-	-	-	10	12	19	731	138	187	18	137	13	-	1,264	1,500
2016/17	-	0	0	23	9	27	840	140	156	30	154	7	-	1,387	1,500
2017/18	-	1	7	12	16	30	903	706	637	24	206	129	-	2,672	3,185
2018/19	-	0	0	10	18	19	861	774	323	221	268	74	-	2,570	3,185
2019/20	1	0	-	1	15	23	304	97	167	28	87	38	-	760	1,000
2020/21	1	-	-	20	11	17	383	63	66	117	15	8	-	702	1,000
2021/22[2]	1	1	7	18	13	25	372	65	44	129	3	-	-	677	1,000
2022/23[2]	-	-	-	-	9	15	36	36	26	7	2	1	-	132	0

[1]The TAC of 18 kt was established in August 1993. It was originally planned to be 35 kt (Fréchet et al. 1994).

[2]Preliminary data.

Table 3. Description of the 2019-2022 nGSL recreational cod fishing seasons. Zone 4S-West refers to the area between Pointe-des-Monts and Natashquan. Zone 4S-East refers to the area between Natashquan and Blanc-Sablon. IDQ = individual daily quota, MDQB = maximum daily quota per boat, D = season duration (d).

Year	Zone	IDQ	MDQB	D	Opening dates
2019	4S-West	5	-	39	29/6-1/7, 6-8/7, 13-15/7, 20-22/7, 27-29/7, 3-5/8, 10-12/8, 17-19/8, 24-26/8, 31/8-2/9, 21-29/9
2019	4S-East	5	-	39	29/6-1/7, 6-8/7, 13-15/7, 20-22/7, 27-29/7, 3-5/8, 10-12/8, 17-19/8, 24-26/8, 31/8-2/9, 21-29/9
2019	3Pn4R	5	15	39	29/6-1/7, 6-8/7, 13-15/7, 20-22/7, 27-29/7, 3-5/8, 10-12/8, 17-19/8, 24-26/8, 31/8-2/9, 21-29/9
2020	4S-West	5	-	39	24/6-1/8
2020	4S-East	5	-	39	29/6-27/7, 18-27/9
2020	3Pn4R	5	15	39	4-6/7, 11-13/7, 18-20/7, 25-27/7, 1-3/8, 8-10/8, 15-17/8, 22-24/8, 29-31/8, 5-7/9, 26/9-4/10
2021	4S-West	5	-	39	24/6-1/8
2021	4S-East	5	-	39	3-5/7, 10-12/7, 17-19/7, 24-26/7, 31/7-2/8, 7-9/8, 14-16/8, 21-23/8, 28-30/8, 4-6/9, 25/9-3/10
2021	3Pn4R	5	15	39	3-5/7, 10-12/7, 17-19/7, 24-26/7, 31/7-2/8, 7-9/8, 14-16/8, 21-23/8, 28-30/8, 4-6/9, 25/9-3/10
2022	4S-West	5	-	39	24/6-1/8
2022	4S-East	5	-	39	2-4/7, 9-11/7, 16-18/7, 23-25/7, 30/7-1/8, 6-8/8, 13-15/8, 20-22/8, 27-29/8, 3-5/9, 24/9-2/10
2022	3Pn4R	5	15	39	2-4/7, 9-11/7, 16-18/7, 23-25/7, 30/7-1/8, 6-8/8, 13-15/8, 20-22/8, 27-29/8, 3-5/9, 24/9-2/10

Table 4. Annual landings reported by country/entity other than Canada since 1960. Source: NAFO 21B data.

Year	Landings (t)	Country/entity[a]
1960	49,871	1, 2, 3, 4, 5, 6
1961	61,784	1, 3, 5
1962	39,259	1, 3, 5
1963	25,006	1, 3, 5, 7
1964	42,251	1, 3, 4, 5, 6, 7, 8, 9
1965	31,481	1, 3, 4, 5, 6
1966	28,327	1, 3, 4, 5, 6, 8, 10
1967	41,948	1, 3, 4, 5, 6, 7
1968	39,102	1, 3, 4, 5, 6
1969	20,703	1, 3, 4, 5
1970	57,243	1, 3, 4, 5, 9
1971	48,474	1, 3, 4, 5, 9
1972	27,385	1, 3, 4, 5, 6, 11
1973	37,236	1, 3, 4, 5, 11
1974	32,265	1, 3, 4, 5, 6, 11, 12
1975	31,644	1, 3, 4, 11
1976	34,275	1, 3, 4, 11
1977	18,138	1, 4
1978	15,771	1, 4
1979	13,769	1, 4
1980	9,396	1, 4
1981	12,508	1, 4
1982	12,013	1, 4
1983	10,684	1, 4
1984	11,623	1, 4
1985	9,185	1, 4
1986	13,122	1, 4
1987	1,535	4
1989	2,587	4
1990	2,485	4
1991	2,447	4
1992	2,333	4

[a]1 = France Mainland, 2 = Italy, 3 = Portugal, 4 = Saint Pierre and Miquelon, 5 = Spain, 6 = United Kingdom, 7 = Soviet Union, 8 = Iceland, 9 = United States of America, 10 = Poland, 11 = Faroe Islands, 12 = Norway

Table 5. *Summary of the different surveys of the mobile sentinel survey program used in the calculations of the summer series. RS = random stratified set, D = discretionary set, F = failed set, whether random stratified or discretionary.*

Year	Survey	Source	Date (MM-DD)		Duration (d)	Nb. vessels	Number of sets	
			Start	End			Total	Details
1995	3	ACPG	08-06	08-15	9	4	145	136RS, 0D, 9F
		FFAW	07-25	08-02	8	5	181	175RS, 0D, 6F
1996	5	ACPG	06-21	07-22	20	3	168	121RS, 26D, 21F
		FFAW	07-03	07-18	11	5	164	151RS, 7D, 6F
1997	7	ACPG	07-06	07-21	13	4	162	138RS, 19D, 5F
		FFAW	07-08	07-22	7	5	151	147RS, 0D, 4F
1998	9	ACPG	06-25	07-16	15	4	176	147RS, 27D, 2F
		FFAW	07-06	07-14	8	5	144	142RS, 0D, 2F
1999	11	ACPG	06-25	07-14	15	4	168	144RS, 23D, 1F
		FFAW	07-05	07-09	5	5	167	150RS, 16D, 1F
2000	13	ACPG	07-03	07-18	13	4	163	141RS, 16D, 6F
		FFAW	07-03	07-12	8	5	161	150RS, 9D, 2F
2001	15	ACPG	07-01	07-16	14	4	157	125RS, 26D, 6F
		FFAW	07-05	07-09	5	5	160	150RS, 7D, 3F
2002	20	ACPG	06-29	07-09	11	4	135	111RS, 20D, 4F
		FFAW	07-03	07-19	10	5	158	150RS, 8D, 0F
2003	22	ACPG	07-07	07-28	18	4	165	136RS, 21D, 8F
		FFAW	07-01	07-04	4	5	161	159RS, 0D, 2F
2004	25	ACPG	07-01	07-13	13	4	167	132RS, 22D, 13F
		FFAW	07-01	07-03	3	5	150	148RS, 0D, 2F
2005	28	ACPG	07-06	07-17	12	4	153	135RS, 15D, 3F
		FFAW	07-01	07-08	7	5	150	148RS, 0D, 2F
2006	32	ACPG	07-03	07-17	13	4	175	145RS, 27D, 3F
		FFAW	07-02	07-06	5	5	150	150RS, 0D, 0F
2007	34	ACPG	07-01	07-13	13	4	147	141RS, 0D, 6F
		FFAW	06-30	07-04	5	5	150	150RS, 0D, 0F
2008	36	ACPG	07-02	07-14	10	4	143	139RS, 0D, 4F
		FFAW	07-01	07-04	4	5	150	150RS, 0D, 0F
2009	38	ACPG	07-01	07-19	15	4	135	132RS, 0D, 3F
		FFAW	06-30	07-04	5	5	150	150RS, 0D, 0F

Year	Survey	Source	Date (MM-DD)		Duration (d)	Nb. vessels	Number of sets	
			Start	End			Total	Details
2010	40	ACPG	07-01	07-19	13	4	134	130RS, 0D, 4F
		FFAW	06-30	07-05	6	5	150	150RS, 0D, 0F
2011	42	ACPG	07-09	07-18	10	4	138	135RS, 0D, 3F
		FFAW	06-30	07-05	6	5	150	150RS, 0D, 0F
2012	44	ACPG	07-03	07-14	11	3	138	127RS, 0D, 11F
		FFAW	06-30	07-07	8	5	150	150RS, 0D, 0F
2013	46	ACPG	07-02	07-18	16	3	147	142RS, 0D, 5F
		FFAW	07-01	07-06	6	4	148	148RS, 0D, 0F
2014	48	ACPG	07-02	07-16	15	3	143	139RS, 0D, 4F
		FFAW	07-01	07-11	8	3	150	149RS, 0D, 1F
2015	50	ACPG	07-01	07-14	13	3	147	142RS, 0D, 5F
		FFAW	06-30	07-04	5	3	148	146RS, 0D, 2F
2016	52	ACPG	06-30	07-20	16	3	144	144RS, 0D, 0F
		FFAW	06-30	07-03	4	3	145	145RS, 0D, 0F
2017	53	ACPG	07-05	07-30	19	3	149	145RS, 0D, 4F
		FFAW	07-08	07-14	6	3	120	120RS, 0D, 0F
2018	55	ACPG	07-14	07-27	13	3	132	130RS, 0D, 2F
		FFAW	06-30	07-05	6	3	120	120RS, 0D, 0F
2019	56	ACPG	06-29	07-15	15	3	130	126RS, 0D, 4F
		FFAW	06-30	07-05	6	3	118	117RS, 0D, 1F
2020	58	ACPG	07-04	07-24	14	3	122	106RS, 0D, 16F
		FFAW	07-02	07-07	6	3	119	114RS, 0D, 5F
2021	59	ACPG	07-08	07-24	15	3	123	116RS, 0D, 7F
		FFAW	07-05	07-15	10	3	118	113RS, 0D, 5F
2022	61	ACPG	07-12	07-27	13	3	122	118RS, 0D, 4F
		FFAW	07-01	07-09	8	2	105	105RS, 0D, 0F

Table 6. Number of fixed gear sentinel survey program activities by year, zone, gear and month over the period 2019-2022.

Year	Zone	Gillnet							Longline													Total
		1	6	7	8	9	10	Total	1	2	3	4	5	6	7	8	9	10	11	12	Total	
2019	1	-	-	-	-	-	-	-	-	-	-	-	4	4	2	11	3	19	6	5	54	54
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	10	9	1	4	3	3	30	30
	3	-	-	9	17	12	-	38	-	-	-	-	-	-	1	9	4	4	-	-	18	56
	4	-	-	17	13	3	2	35	-	-	-	-	-	-	-	-	4	8	-	-	12	47
	5	1	7	51	36	36	-	131	-	-	-	-	-	2	-	13	28	-	-	-	43	174
	6	-	9	69	60	14	-	152	-	-	-	-	-	-	-	1	-	-	-	-	1	153
	Total	**1**	**16**	**146**	**126**	**65**	**2**	**356**	**0**	**0**	**0**	**0**	**4**	**6**	**13**	**43**	**40**	**35**	**9**	**8**	**158**	**514**
2020	1	-	-	-	-	-	-	-	1	1	4	-	2	6	1	8	16	10	16	8	73	73
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	8	9	4	3	4	-	28	28
	3	-	1	13	14	10	-	38	-	-	-	-	-	-	-	-	-	-	-	-	-	38
	4	-	3	20	20	5	4	52	-	-	-	-	-	-	-	-	2	-	-	-	2	54
	5	-	12	45	38	24	5	124	-	-	-	-	-	-	-	12	14	3	-	-	29	153
	6	-	13	68	70	8	-	159	-	-	-	-	-	-	-	-	-	-	-	-	-	159
	Total	**0**	**29**	**146**	**142**	**47**	**9**	**373**	**1**	**1**	**4**	**0**	**2**	**6**	**9**	**29**	**36**	**16**	**20**	**8**	**132**	**505**
2021	1	-	-	-	-	-	-	-	2	1	1	-	3	5	3	7	4	4	7	3	40	40
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	8	10	-	3	1	-	22	22
	3	-	-	10	14	8	6	38	-	-	-	-	-	-	-	8	4	6	-	-	18	56
	4	-	2	20	20	10	2	54	-	-	-	-	-	-	-	-	-	-	-	-	-	54
	5	-	17	41	40	15	-	113	-	-	-	-	-	-	-	17	6	-	-	-	23	136
	6	-	17	70	76	8	-	171	-	-	-	-	-	-	-	-	-	-	-	-	-	171
	Total	**0**	**36**	**141**	**150**	**41**	**8**	**376**	**2**	**1**	**1**	**0**	**3**	**5**	**11**	**42**	**14**	**13**	**8**	**3**	**103**	**479**
2022	1	-	-	-	-	-	-	-	-	-	-	1	9	2	4	5	9	6	3	-	39	39
	2	-	-	-	-	1	-	1	-	-	-	-	-	-	10	4	4	4	3	-	25	26
	3	-	-	14	16	8	-	38	-	-	-	-	-	-	-	-	5	7	-	-	12	50
	4	-	6	16	24	6	5	57	-	-	-	-	-	-	-	-	-	-	-	-	-	57
	5	-	6	49	45	33	-	133	-	-	-	-	-	-	-	24	18	-	-	-	42	175
	6	-	23	59	60	9	-	151	-	-	-	-	-	-	-	-	-	-	-	-	-	151
	Total	**0**	**35**	**138**	**145**	**57**	**5**	**380**	**0**	**0**	**0**	**1**	**9**	**2**	**14**	**33**	**36**	**17**	**6**	**0**	**118**	**498**
Total		**1**	**116**	**571**	**563**	**210**	**24**	**1,485**	**3**	**2**	**5**	**1**	**18**	**19**	**47**	**147**	**126**	**81**	**43**	**19**	**511**	**1,996**

Table 7. Summary of the different surveys aimed at estimating the nGSL cod reproductive potential (CRP). S = systematic set, D = discretionary set, F = failed set, whether systematic or discretionary.

		Date (MM-DD)					Number of sets	
Year	**Survey**	**Start**	**End**	**Duration (d)**	**Nb. vessels**	**NAFO**	**Total**	**Details**
2002	19	04-29	05-19	13	1	3Pn, 4R	63	39S, 23D, 1F
2004	24	05-05	05-12	7	1	3Pn, 4R	46	29S, 16D, 1F
2005	27	05-16	05-24	6	1	3Pn, 4R	41	27S, 14D, 0F
2006	31	05-05	05-12	5	2	3Pn, 4R	49	49S, 0D, 0F
2007	33	05-23	05-29	5	2	3Pn, 4R	50	50S, 0D, 0F
2008	35	05-03	05-08	6	2	3Pn, 4R	50	50S, 0D, 0F
2009	37	05-12	05-19	5	2	3Pn, 4R	50	50S, 0D, 0F
2010	39	05-04	05-13	6	2	3Pn, 4R	50	50S, 0D, 0F
2011	41	05-02	05-03	2	1	4R	25	25S, 0D, 0F
2012	43	05-07	05-09	3	1	4R	40	40S, 0D, 0F
2013	45	05-03	05-06	4	1	4R	41	41S, 0D, 0F
2014	47	05-28	05-31	4	1	4R	40	40S, 0D, 0F
2015	49	05-12	05-14	3	1	4R	40	40S, 0D, 0F
2016	51	05-02	05-04	3	1	4R	40	40S, 0D, 0F
2018	54	05-22	05-25	4	1	4R	40	40S, 0D, 0F
2020	57	05-27	05-30	4	1	4R	38	38S, 0D, 0F
2022	60	05-24	05-26	3	1	4R	28	28S, 0D, 0F

Table 8. Historical monthly commercial landings statistics (t) for the period 1999-2022, by calendar year. Unk. = unknown. '0' values indicate landings ≤ 0.5 t. Source: NAFO 21B and ZIFF data.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Unk.	Total
1999	0	0	0	5	92	870	1,985	1,458	1,031	1,014	395	39	-	6,890
2000	1	51	132	102	538	907	1,251	1,533	1,087	775	398	82	-	6,857
2001	86	72	49	33	455	518	1,847	1,269	1,339	865	293	125	-	6,950
2002	110	58	6	10	173	58	2,519	1,484	843	869	393	7	-	6,529
2003	0	-	0	0	5	13	118	131	48	31	39	5	-	389
2004	0	-	0	13	30	25	1,887	205	537	356	207	13	-	3,274
2005	0	-	0	14	43	69	2,434	628	774	473	22	3	-	4,461
2006	-	-	0	24	23	101	3,285	591	645	298	669	17	-	5,652
2007	1	0	0	15	22	132	3,711	447	1,126	578	447	5	-	6,483
2008	-	-	1	7	40	117	2,973	924	1,240	551	301	2	-	6,158
2009	-	-	1	3	13	176	1,691	693	690	696	687	51	-	4,700
2010	1	0	2	2	6	54	1,362	882	556	499	185	1	-	3,552
2011	0	0	0	15	14	50	1,006	163	315	11	193	9	-	1,775
2012	0	0	0	12	19	40	671	110	296	20	131	3	-	1,303
2013	0	0	0	22	10	34	699	77	220	10	147	3	-	1,222
2014	-	-	-	7	10	16	644	92	344	26	100	23	-	1,262
2015	-	-	-	4	21	19	731	138	187	18	137	13	-	1,267
2016	-	-	-	10	9	27	840	140	156	30	154	7	-	1,373
2017	-	0	0	23	12	30	903	706	637	24	206	129	-	2,671
2018	-	1	7	12	18	19	861	774	323	221	268	74	-	2,578
2019	-	0	0	10	20	23	304	97	167	28	87	38	-	774
2020	1	0	-	1	9	17	383	63	66	117	15	8	-	681
2021[2]	1	-	-	20	14	25	372	65	44	129	3	-	-	672
2022[2]	1	1	7	18	15	15	36	36	26	7	2	1	-	164

[2]Preliminary data.

Table 9. Reported landings (t) of Atlantic cod in the commercial fishery of the NAFO Divisions 3Pn4RS for the period 1985-2022, by year and NAFO unit area. The last four rows show the contributions (in %) of the different unit areas to the landings reported over different time intervals. Source: NAFO 21B and ZIFF data.

Year	3Pn	4R						4S								
		4Ra	4Rb	4Rc	4Rd	4Ru	Tot.	4Si	4Ss	4Sv	4Sw	4Sx	4Sy	4Sz	4Su	Tot.
1985	14,320	15,783	11,082	3,551	6,880	17,508	54,804	3,169	776	1,853	4,247	3,003	4,188	2,119	0	19,356
1986	22,612	12,576	12,983	2,519	6,873	8,763	43,713	3,048	958	1,553	1,903	2,766	4,305	2,411	129	17,073
1987	18,349	16,297	5,801	2,936	7,936	804	33,774	2,113	1,004	1,284	1,346	1,810	3,181	2,997	687	14,422
1988	8,939	7,580	5,315	1,862	4,728	10,097	29,583	1,966	569	1,345	1,801	1,013	1,443	979	64	9,180
1989	7,280	9,439	4,124	1,239	6,409	8,213	29,424	1,733	240	1,939	1,814	1,079	2,042	1,161	52	10,058
1990	6,145	6,284	7,481	1,833	5,330	4,431	25,358	2,541	865	1,048	1,283	276	597	708	178	7,496
1991	7,290	6,131	6,099	2,761	4,485	2,143	21,619	1,089	191	831	1,517	360	884	659	41	5,572
1992	9,210	4,941	3,616	4,214	2,594	990	16,356	909	300	581	1,228	262	144	553	4	3,980
1993	3,194	4,071	5,679	2,021	1,723	-	13,494	53	340	342	654	39	88	249	-	1,763
1994	196	67	44	60	114	-	284	2	5	1	17	22	6	3	1	57
1995	35	3	17	5	11	-	35	0	2	62	42	2	1	4	-	115
1996	72	13	22	13	31	-	80	1	5	33	123	0	0	2	0	165
1997	2,006	806	600	593	299	-	2,298	0	7	141	327	7	1	4	-	488
1998	877	387	367	316	637	-	1,706	0	13	77	526	27	0	3	-	647
1999/00	1,382	1,552	1,481	915	1,007	-	4,954	1	29	126	632	44	20	2	1	854
2000/01	1,482	1,215	1,466	794	809	0	4,284	1	47	197	714	94	13	1	0	1,067
2001/02	1,712	1,311	1,267	960	720	17	4,275	1	26	246	570	26	12	1	18	900
2002/03	1,521	1,173	1,376	795	590	3	3,938	1	22	123	686	20	7	0	2	861
2003/04	104	36	81	21	70	0	209	1	6	20	60	4	1	1	-	93
2004/05	777	595	642	297	350	1	1,884	0	14	98	442	45	11	1	3	613
2005/06	872	976	701	437	770	68	2,952	0	7	278	293	5	11	3	50	647
2006/07	1,197	1,197	680	434	1,167	193	3,671	0	12	297	427	11	20	2	2	772
2007/08	1,072	1,574	939	748	914	369	4,544	1	15	146	668	11	5	5	9	859
2008/09	1,123	1,705	973	665	832	2	4,177	2	18	194	610	16	14	2	3	858
2009/10	1,360	921	799	424	592	-	2,735	2	12	183	380	14	8	2	-	601
2010/11	710	1,135	546	270	223	1	2,175	4	15	276	346	22	14	4	0	681
2011/12	319	511	188	143	84	0	925	12	17	132	239	115	11	3	-	530
2012/13	195	372	188	105	66	-	730	7	10	73	181	104	5	4	-	385
2013/14	173	365	145	151	99	0	761	8	5	57	163	32	6	4	-	275
2014/15	159	491	138	105	49	-	784	13	10	79	167	41	2	11	0	324

Year	3Pn	4R						4S								
		4Ra	4Rb	4Rc	4Rd	4Ru	Tot.	4Si	4Ss	4Sv	4Sw	4Sx	4Sy	4Sz	4Su	Tot.
2015/16	150	422	141	85	57	-	705	9	19	123	197	31	3	27	0	408
2016/17	187	510	130	79	81	-	799	8	7	114	150	86	4	32	-	400
2017/18	348	1,202	298	230	135	-	1,866	83	14	69	194	40	1	57	0	459
2018/19	428	1,239	207	109	89	-	1,644	40	6	91	247	32	1	81	-	498
2019/20	143	250	68	20	41	-	379	40	2	22	104	31	1	37	1	239
2020/21	155	194	95	36	53	-	378	8	13	32	91	13	1	10	-	169
2021/22	144	206	72	22	39	-	339	10	7	33	91	32	13	9	-	194
2022/23	8	4	4	1	13	-	22	10	3	9	46	24	2	6	1	101
Last 2 years	18.8	26.0	9.4	2.8	6.4	-	44.7	2.5	1.2	5.2	17.0	6.9	1.8	1.9	0.1	36.5
Last 5 years	18.1	39.1	9.2	3.9	4.8	-	57.1	2.2	0.6	3.9	12.0	2.7	0.4	2.9	0.0	24.8
Last 10 years	15.0	38.6	10.3	6.6	5.2	0.0	60.7	1.8	0.7	5.0	11.5	2.9	0.3	2.2	0.0	24.3
Since 1985	21.5	19.1	14.0	5.9	10.5	9.9	59.4	3.1	1.0	2.6	4.5	2.1	3.2	2.2	0.2	19.1

Table 10. Preliminary landings statistics (t) for Atlantic cod in NAFO Subdivision 3Pn in 2022. NL = Newfoundland and Labrador, NS = Nova Scotia. Source: ZIFF data.

Province	Gear	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
NL	Bottom trawls	0.2	-	1.7	0.1	-	-	0.0	0.0	-	-	-	-	**2.0**
	Longlines	-	-	-	12.9	7.7	2.4	-	-	-	-	1.3	-	**24.3**
	Handlines	-	-	-	0.5	-	-	-	-	-	-	-	-	**0.5**
	Total	**0.2**	**0.0**	**1.7**	**13.5**	**7.7**	**2.4**	**0.0**	**0.0**	**0.0**	**0.0**	**1.3**	**0.0**	**26.8**
NS	Bottom trawls	-	-	-	0.0	0.1	-	-	-	-	-	-	-	**0.1**
	Longlines	-	-	-	0.0	-	-	-	-	-	-	-	-	**0.0**
	Seines	-	-	-	0.4	-	-	-	-	-	-	-	-	**0.4**
	Total	**0.0**	**0.0**	**0.0**	**0.4**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.5**
	Great total	**0.2**	**0.0**	**1.7**	**13.9**	**7.8**	**2.4**	**0.0**	**0.0**	**0.0**	**0.0**	**1.3**	**0.0**	**27.3**

Table 11. Preliminary landings statistics (t) for Atlantic cod in NAFO Division 4R in 2022. NL = Newfoundland and Labrador, NS = Nova Scotia, QC = Quebec. Source: ZIFF data.

Province	Gear	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
NL	Bottom trawls	0.6	0.6	5.3	0.2	-	-	0.0	-	-	-	0.0	-	**6.8**
	Gillnets	-	-	-	-	-	-	0.3	1.3	-	0.2	-	-	**1.8**
	Longlines	-	-	-	3.5	3.4	1.8	4.2	3.9	-	4.2	0.5	0.8	**22.3**
	Seines	-	-	-	-	-	-	0.7	1.0	0.4	0.1	-	-	**2.2**
	Total	**0.6**	**0.6**	**5.3**	**3.7**	**3.4**	**1.8**	**5.2**	**6.3**	**0.4**	**4.5**	**0.5**	**0.8**	**33.1**
NS	Bottom trawls	-	-	-	-	-	-	0.0	-	-	-	-	-	**0.0**
	Total	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
QC	Longlines	-	-	-	-	-	-	0.0	0.1	0.0	-	-	-	**0.1**
	Total	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**
	Great total	**0.6**	**0.6**	**5.3**	**3.7**	**3.4**	**1.8**	**5.3**	**6.3**	**0.4**	**4.5**	**0.5**	**0.8**	**33.2**

Table 12. Preliminary landings statistics (t) for Atlantic cod in NAFO Division 4S in 2022. NS = Nova Scotia, QC = Quebec. Source: ZIFF data.

Province	Gear	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
NS	Longlines	-	-	-	-	-	-	-	-	2.7	-	-	-	**2.7**
	Total	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**2.7**	**0.0**	**0.0**	**0.0**	**2.7**
QC	Bottom trawls	-	-	-	-	0.1	-	1.5	-	-	0.3	-	-	**1.8**
	Gillnets	-	-	-	-	0.0	4.8	25.1	21.2	9.8	-	-	-	**60.9**
	Longlines	-	-	-	0.8	2.8	5.2	5.6	7.8	13.2	2.6	0.0	-	**37.8**
	Shrimp trawls	-	-	-	-	-	-	0.1	-	-	-	-	-	**0.1**
	Total	**0.0**	**0.0**	**0.0**	**0.8**	**2.8**	**10.0**	**32.3**	**29.0**	**22.9**	**2.8**	**0.0**	**0.0**	**100.7**
	Great total	**0.0**	**0.0**	**0.0**	**0.8**	**2.8**	**10.0**	**32.3**	**29.0**	**25.6**	**2.8**	**0.0**	**0.0**	**103.5**

Table 13. Preliminary landings statistics (t) for Atlantic cod in NAFO Divisions 3Pn4RS in 2022. NL = Newfoundland and Labrador, NS = Nova Scotia, QC = Quebec. Source: ZIFF data.

Province	Gear	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
NL	Bottom trawls	0.8	0.6	7.0	0.3	-	-	0.0	0.0	-	-	0.0	-	**8.8**
	Gillnets	-	-	-	-	-	-	0.3	1.3	-	0.2	-	-	**1.8**
	Longlines	-	-	-	16.4	11.1	4.2	4.2	3.9	-	4.2	1.8	0.8	**46.6**
	Seines	-	-	-	-	-	-	0.7	1.0	0.4	0.1	-	-	**2.2**
	Handlines	-	-	-	0.5	-	-	-	-	-	-	-	-	**0.5**
	Total	**0.8**	**0.6**	**7.0**	**17.2**	**11.1**	**4.2**	**5.2**	**6.3**	**0.4**	**4.5**	**1.8**	**0.8**	**59.9**
NS	Bottom trawls	-	-	-	0.0	0.1	-	0.0	-	-	-	-	-	**0.1**
	Longlines	-	-	-	0.0	-	-	-	-	2.7	-	-	-	**2.7**
	Seines	-	-	-	0.4	-	-	-	-	-	-	-	-	**0.4**
	Total	**0.0**	**0.0**	**0.0**	**0.4**	**0.1**	**0.0**	**0.0**	**0.0**	**2.7**	**0.0**	**0.0**	**0.0**	**3.3**
QC	Bottom trawls	-	-	-	-	0.1	-	1.5	-	-	0.3	-	-	**1.8**
	Gillnets	-	-	-	-	0.0	4.8	25.1	21.2	9.8	-	-	-	**60.9**
	Longlines	-	-	-	0.8	2.8	5.2	5.6	7.8	13.2	2.6	0.0	-	**38.0**
	Shrimp trawls	-	-	-	-	-	-	0.1	-	-	-	-	-	**0.1**
	Total	**0.0**	**0.0**	**0.0**	**0.8**	**2.8**	**10.0**	**32.4**	**29.0**	**22.9**	**2.8**	**0.0**	**0.0**	**100.9**
	Great total	**0.8**	**0.6**	**7.0**	**18.5**	**14.0**	**14.2**	**37.6**	**35.3**	**26.1**	**7.3**	**1.8**	**0.8**	**164.0**

Table 14. Annual landings statistics (t, calendar year) for the period 1964-2022 in Subdivision 3Pn, by gear categories. '0' values indicate landings ≤ 0.5 t. OTB = Bottom trawls, GNS = Gillnets, LLS = Longlines, OTM = Mid-water trawls, SDN = Seines, LHP = Handlines, FPN = Traps and others, ST = Shrimp trawls, OTHER = Others and unknown. Source: NAFO 21B and ZIFF data.

Year	OTB	GNS	LLS	OTM	SDN	LHP	FPN	ST	OTHER	Total
1964	6,283	-	3,416	-	-	558	-	-	4,875	15,132
1965	9,104	-	2,702	-	-	113	-	-	4,815	16,734
1966	8,258	-	2,499	-	-	16	-	-	2,851	13,624
1967	16,300	-	657	-	33	-	-	-	3,438	20,428
1968	6,748	-	85	-	12	33	-	-	5,031	11,909
1969	524	429	3,630	-	10	270	-	-	54	4,917
1970	458	612	3,378	-	5	675	44	-	33	5,205
1971	1,555	364	5,574	-	-	217	-	-	134	7,844
1972	3,893	181	5,593	-	545	115	10	-	20	10,357
1973	3,908	175	5,431	2	174	1,515	-	-	95	11,300
1974	10,087	297	2,460	16	58	180	-	-	915	14,013
1975	3,575	61	2,418	9	6	152	-	-	12	6,233
1976	2,747	163	4,467	55	163	225	9	-	636	8,465
1977	1,492	73	5,679	2	119	163	37	-	-	7,565
1978	1,293	34	5,323	25	17	103	7	-	-	6,802
1979	3,215	40	7,338	1	181	116	25	-	-	10,916
1980	2,238	13	6,443	4	18	83	-	-	-	8,799
1981	7,460	3	7,560	3	28	72	4	-	-	15,130
1982	7,707	8	7,670	-	12	87	1	-	-	15,485
1983	9,154	46	6,789	-	20	97	1	-	-	16,107
1984	8,177	129	7,089	-	499	45	2	-	-	15,941
1985	7,740	37	5,633	-	167	25	5	-	714	14,320
1986	17,016	7	5,526	-	17	46	0	-	-	22,612
1987	11,680	24	6,576	29	27	12	-	-	-	18,349
1988	5,510	11	3,326	63	24	4	-	-	-	8,939
1989	5,358	146	1,722	44	1	8	0	-	-	7,280
1990	4,887	231	879	106	19	23	-	1	-	6,145
1991	5,345	280	1,217	349	76	22	0	-	-	7,290
1992	7,587	184	1,156	214	33	35	-	-	-	9,210
1993	1,192	153	1,387	405	0	57	-	-	-	3,194
1994	14	3	6	91	-	81	-	-	-	196
1995	0	13	22	0	0	0	0	-	-	35
1996	1	14	58	-	-	-	-	-	-	72
1997	12	5	1,969	-	-	20	-	-	-	2,006
1998	0	2	859	0	-	15	-	-	-	877
1999	2	2	1,110	-	2	49	-	-	-	1,165
2000	0	3	1,442	-	0	33	-	-	-	1,478
2001	1	2	1,715	-	-	21	-	-	-	1,740
2002	15	0	1,657	-	-	40	-	-	-	1,713
2003	1	1	85	-	-	-	-	-	-	86
2004	0	1	772	-	-	10	-	-	-	783
2005	0	1	851	-	-	4	-	-	-	856
2006	3	1	1,198	-	-	5	1	-	-	1,208
2007	0	3	1,074	-	-	4	-	-	-	1,081
2008	0	3	1,125	-	-	3	-	-	-	1,131
2009	0	6	1,345	-	-	6	-	-	-	1,357
2010	0	2	697	-	-	6	-	-	-	705
2011	0	7	302	-	-	6	1	-	-	316
2012	0	10	176	-	0	2	-	-	-	187
2013	-	1	182	-	0	2	-	-	-	185

Year	OTB	GNS	LLS	OTM	SDN	LHP	FPN	ST	OTHER	Total
2014	0	3	149	-	-	1	-	-	-	153
2015	0	1	153	-	-	0	-	-	-	155
2016	0	0	172	-	-	2	-	-	-	174
2017	0	1	341	-	-	3	-	-	-	345
2018	8	3	422	-	-	5	-	-	-	439
2019	2	2	147	-	-	2	-	-	-	153
2020	1	-	134	-	-	2	-	-	-	136
2021	3	-	142	-	-	2	-	-	0	147
2022	2	-	24	-	0	0	-	-	-	27

Table 15. Annual landings statistics (t, calendar year) for the period 1964-2022 in Division 4R, by gear categories. '0' values indicate landings ≤ 0.5 t. OTB = Bottom trawls, GNS = Gillnets, LLS = Longlines, OTM = Mid-water trawls, SDN = Seines, LHP = Handlines, FPN = Traps and others, ST = Shrimp trawls, OTHER = Others and unknown. Source: NAFO 21B and ZIFF data.

Year	OTB	GNS	LLS	OTM	SDN	LHP	FPN	ST	OTHER	Total
1964	39,862	-	123	-	192	-	-	-	18,783	58,960
1965	26,773	-	156	-	144	-	-	-	16,766	43,839
1966	28,422	-	201	-	53	-	-	-	15,532	44,208
1967	28,672	-	207	-	87	-	-	-	20,975	49,941
1968	42,436	289	1,138	-	62	-	-	-	26,116	70,041
1969	32,913	10,905	4,405	-	198	1,622	3,943	-	2,646	56,632
1970	74,946	4,319	5,489	-	239	1,856	2,349	-	1,948	91,146
1971	53,804	3,714	3,076	-	247	1,295	3,790	-	436	66,362
1972	27,729	2,835	1,115	324	16	1,107	1,582	-	2,875	37,583
1973	31,192	3,154	2,564	284	120	1,007	2,007	-	2,766	43,094
1974	27,393	5,182	1,358	1,121	223	1,714	1,789	-	666	39,446
1975	28,615	6,462	978	1,358	221	1,413	2,032	-	490	41,569
1976	37,672	7,671	527	2,750	155	1,445	1,572	-	4,238	56,030
1977	39,624	7,866	1,429	169	147	1,591	2,414	-	147	53,387
1978	33,277	13,235	2,462	1,881	233	1,749	4,103	-	-	56,940
1979	30,978	11,479	5,031	1,760	311	3,138	3,071	-	-	55,768
1980	33,527	11,607	7,768	580	467	2,380	8,354	-	-	64,683
1981	37,883	5,796	8,936	348	384	2,096	5,408	-	327	61,178
1982	38,088	9,465	7,208	790	337	2,126	7,473	-	-	65,487
1983	38,345	11,849	6,614	2	473	5,047	3,415	-	-	65,745
1984	43,622	6,625	7,305	21	-	2,821	2,899	-	-	63,293
1985	33,637	4,390	7,270	-	267	2,294	3,773	496	2,678	54,804
1986	29,118	4,849	4,648	1	700	1,027	2,847	523	-	43,713
1987	20,917	4,951	4,650	21	949	748	1,290	247	-	33,774
1988	18,110	5,438	2,658	335	837	733	980	493	-	29,583
1989	21,154	4,078	1,610	159	772	632	736	283	-	29,424
1990	19,065	1,797	1,929	74	773	863	387	469	-	25,358
1991	11,816	2,532	2,275	362	606	1,187	2,308	532	-	21,619
1992	9,482	1,555	1,686	200	521	1,142	1,471	300	-	16,356
1993	7,473	1,739	566	169	190	846	2,458	52	-	13,494
1994	30	13	69	13	9	148	-	2	-	284
1995	0	14	15	-	4	1	-	0	-	35
1996	1	30	33	-	11	0	4	-	0	80
1997	43	233	1,712	0	8	245	57	0	-	2,298
1998	0	131	1,295	1	30	247	2	0	-	1,706
1999	7	2,801	1,151	-	32	890	0	0	-	4,882
2000	24	2,230	1,491	-	36	515	26	-	0	4,322
2001	23	1,683	1,814	-	64	716	8	-	-	4,308
2002	17	1,939	1,371	-	29	582	-	-	-	3,938
2003	9	80	95	-	25	1	1	-	-	210
2004	28	956	566	-	44	290	0	-	-	1,884
2005	32	1,673	978	-	50	217	1	-	-	2,951
2006	76	1,971	1,412	-	38	174	0	-	-	3,672
2007	0	2,638	1,746	-	31	130	-	-	-	4,544
2008	1	2,285	1,657	-	25	204	0	-	-	4,173
2009	1	1,417	1,129	-	23	166	1	-	-	2,738
2010	2	1,268	648	-	13	244	0	-	-	2,176
2011	1	681	152	-	12	74	0	4	-	923
2012	1	558	101	-	4	67	-	-	-	732

Year	OTB	GNS	LLS	OTM	SDN	LHP	FPN	ST	OTHER	Total
2013	0	464	171	-	2	123	1	0	-	761
2014	2	571	84	-	3	123	0	0	-	783
2015	-	571	89	-	4	42	-	-	-	706
2016	2	613	120	-	5	58	1	-	-	799
2017	3	1,490	204	-	6	163	-	-	-	1,866
2018	3	1,433	153	-	7	49	0	0	-	1,644
2019	5	287	51	-	3	33	-	-	-	379
2020	3	303	46	-	1	24	-	-	0	377
2021	2	283	30	-	4	12	-	-	0	330
2022	7	2	22	-	2	-	-	-	-	33

Table 16. Annual landings statistics (t, calendar year) for the period 1964-2022 in Division 4S, by gear categories. '0' values indicate landings ≤ 0.5 t. OTB = Bottom trawls, GNS = Gillnets, LLS = Longlines, OTM = Mid-water trawls, SDN = Seines, LHP = Handlines, FPN = Traps and others, ST = Shrimp trawls, OTHER = Others and unknown. Source: NAFO 21B and ZIFF data.

Year	OTB	GNS	LLS	OTM	SDN	LHP	FPN	ST	OTHER	Total
1964	3,490	-	486	-	-	-	-	-	6,166	10,142
1965	4,060	24	320	-	1	-	3,358	-	592	8,355
1966	3,385	973	441	-	-	-	1,656	-	798	7,253
1967	3,840	1,618	305	-	-	710	2,470	-	-	8,943
1968	2,568	1,127	333	-	-	623	3,070	-	-	7,721
1969	4,450	1,960	262	-	-	607	2,312	-	-	9,591
1970	5,435	846	252	-	-	792	1,789	-	-	9,114
1971	5,163	963	564	1	-	503	2,410	-	-	9,604
1972	5,802	1,418	511	15	-	511	2,040	-	-	10,297
1973	5,632	1,774	402	124	-	470	885	-	2,124	11,411
1974	6,661	2,326	976	348	-	402	200	-	2,064	12,977
1975	5,799	2,072	136	83	-	2,337	579	-	1,425	12,431
1976	6,441	2,900	46	369	-	353	992	-	1,385	12,486
1977	7,229	4,089	36	94	2	303	861	-	-	12,614
1978	8,420	3,626	28	316	2	194	2,178	-	-	14,764
1979	7,667	6,578	148	190	-	467	1,043	-	-	16,093
1980	8,740	1,376	1,796	527	-	-	-	-	11,658	24,097
1981	5,936	364	2,678	17	51	-	3	-	12,554	21,603
1982	8,267	27	3,688	340	3	-	13	-	11,629	23,967
1983	8,295	622	3,890	-	174	2	-	-	11,245	24,228
1984	7,845	8,923	4,301	2	1,694	961	675	-	8	24,409
1985	4,466	6,183	4,325	0	-	893	1,210	1,651	627	19,356
1986	6,356	4,277	2,869	0	120	379	52	3,020	-	17,073
1987	6,908	3,065	2,185	8	46	219	9	1,982	0	14,422
1988	3,281	3,775	1,228	33	28	42	1	793	-	9,180
1989	4,263	3,207	1,394	3	9	377	3	803	-	10,058
1990	3,949	1,824	675	34	12	159	1	842	-	7,496
1991	1,888	1,467	682	15	0	480	48	991	-	5,572
1992	1,967	1,142	345	5	-	78	25	419	-	3,980
1993	796	609	172	18	-	138	-	31	-	1,763
1994	4	7	23	2	-	-	-	3	19	57
1995	1	20	6	-	0	-	-	0	88	115
1996	1	150	7	-	-	-	0	0	6	165
1997	3	300	176	-	-	-	-	1	7	488
1998	3	496	148	0	0	-	-	0	-	647
1999	2	598	214	-	1	29	-	0	-	844
2000	0	813	234	0	-	9	-	0	-	1,057
2001	1	335	433	-	-	128	5	0	-	903
2002	2	733	127	-	1	12	5	0	0	879
2003	1	81	11	-	-	-	0	0	-	93
2004	0	525	71	-	-	11	-	0	-	607
2005	3	612	26	-	0	8	5	0	-	653
2006	5	712	46	-	-	9	-	0	-	772
2007	-	789	48	-	-	21	-	0	-	858
2008	0	739	106	-	-	8	-	0	-	854
2009	0	429	140	-	-	35	1	0	-	605
2010	1	439	218	-	-	13	0	0	-	671
2011	0	316	217	-	-	4	-	0	-	537
2012	1	252	126	-	-	5	-	0	-	384

Year	OTB	GNS	LLS	OTM	SDN	LHP	FPN	ST	OTHER	Total
2013	1	206	61	-	-	6	0	1	-	275
2014	0	210	110	-	-	5	-	0	-	325
2015	1	300	100	-	-	5	-	0	-	406
2016	1	253	141	-	-	4	0	0	-	400
2017	0	256	199	-	-	5	-	0	-	460
2018	2	357	136	-	-	1	-	0	-	496
2019	2	151	85	0	-	4	-	0	-	242
2020	1	126	38	-	-	2	-	0	0	168
2021	-	140	54	1	-	-	-	0	-	195
2022	2	61	41	-	-	-	-	0	-	103

Table 17. Annual landings statistics (t, calendar year) for the period 1964-2022 in Divisions 3Pn4RS, by gear categories. '0' values indicate landings ≤ 0.5 t. OTB = Bottom trawls, GNS = Gillnets, LLS = Longlines, OTM = Mid-water trawls, SDN = Seines, LHP = Handlines, FPN = Traps and others, ST = Shrimp trawls, OTHER = Others and unknown. Source: NAFO 21B and ZIFF data.

Year	OTB	GNS	LLS	OTM	SDN	LHP	FPN	ST	OTHER	Total
1964	49,635	-	4,025	-	192	558	-	-	29,824	84,234
1965	39,937	24	3,178	-	145	113	3,358	-	22,173	68,928
1966	40,065	973	3,141	-	53	16	1,656	-	19,181	65,085
1967	48,812	1,618	1,169	-	120	710	2,470	-	24,413	79,312
1968	51,752	1,416	1,556	-	74	656	3,070	-	31,147	89,671
1969	37,887	13,294	8,297	-	208	2,499	6,255	-	2,700	71,140
1970	80,839	5,777	9,119	-	244	3,323	4,182	-	1,981	105,465
1971	60,522	5,041	9,214	1	247	2,015	6,200	-	570	83,810
1972	37,424	4,434	7,219	339	561	1,733	3,632	-	2,895	58,237
1973	40,732	5,103	8,397	410	294	2,992	2,892	-	4,985	65,805
1974	44,141	7,805	4,794	1,485	281	2,296	1,989	-	3,645	66,436
1975	37,989	8,595	3,532	1,450	227	3,902	2,611	-	1,927	60,233
1976	46,860	10,734	5,040	3,174	318	2,023	2,573	-	6,259	76,981
1977	48,345	12,028	7,144	265	268	2,057	3,312	-	147	73,566
1978	42,990	16,895	7,813	2,222	252	2,046	6,288	-	-	78,506
1979	41,860	18,097	12,517	1,951	492	3,721	4,139	-	-	82,777
1980	44,505	12,996	16,007	1,111	485	2,463	8,354	-	11,658	97,579
1981	51,279	6,163	19,174	368	463	2,168	5,415	-	12,881	97,911
1982	54,062	9,500	18,566	1,130	352	2,213	7,487	-	11,629	104,939
1983	55,794	12,517	17,293	2	667	5,146	3,416	-	11,245	106,080
1984	59,644	15,677	18,695	23	2,193	3,827	3,576	-	8	103,643
1985	45,843	10,610	17,228	0	434	3,211	4,987	2,148	4,019	88,481
1986	52,490	9,134	13,043	1	837	1,452	2,899	3,543	-	83,399
1987	39,506	8,039	13,411	58	1,023	979	1,299	2,229	0	66,545
1988	26,901	9,223	7,211	431	889	779	981	1,286	-	47,702
1989	30,775	7,431	4,726	206	782	1,017	739	1,086	-	46,762
1990	27,900	3,852	3,483	214	805	1,045	388	1,312	-	39,000
1991	19,050	4,279	4,174	727	683	1,689	2,357	1,523	-	34,481
1992	19,036	2,881	3,187	419	554	1,254	1,496	718	-	29,546
1993	9,461	2,501	2,124	592	190	1,041	2,458	83	-	18,452
1994	48	23	98	106	9	229	-	5	19	537
1995	1	48	42	0	4	1	0	0	88	185
1996	4	193	97	-	11	0	4	0	6	317
1997	58	538	3,857	0	8	265	57	1	7	4,792
1998	4	629	2,302	1	30	261	2	0	-	3,229
1999	11	3,401	2,475	-	35	968	0	0	-	6,890
2000	24	3,046	3,167	0	36	557	26	0	0	6,857
2001	26	2,020	3,963	-	64	864	13	0	-	6,950
2002	34	2,672	3,155	-	30	634	5	0	0	6,529
2003	10	161	191	-	25	1	1	0	-	389
2004	29	1,482	1,408	-	44	310	0	0	-	3,274
2005	35	2,285	1,855	-	50	229	6	0	-	4,461
2006	84	2,685	2,655	-	38	189	1	0	-	5,652
2007	0	3,430	2,868	-	31	154	-	0	-	6,483
2008	2	3,027	2,889	-	25	215	0	0	-	6,158
2009	2	1,852	2,615	-	23	207	2	0	-	4,700
2010	3	1,710	1,563	-	13	263	0	0	-	3,552
2011	1	1,004	671	-	12	84	1	4	-	1,775
2012	2	820	403	-	4	74	-	0	-	1,303

Year	OTB	GNS	LLS	OTM	SDN	LHP	FPN	ST	OTHER	Total
2013	1	670	415	-	2	131	1	1	-	1,222
2014	2	785	342	-	3	129	0	0	-	1,262
2015	1	872	342	-	4	48	-	0	-	1,267
2016	3	866	433	-	5	64	1	0	-	1,373
2017	3	1,747	744	-	6	171	-	0	-	2,671
2018	14	1,793	711	-	7	54	0	0	-	2,578
2019	9	441	283	0	3	38	-	0	-	774
2020	5	429	218	-	1	28	-	0	0	681
2021	5	423	225	1	4	14	-	0	0	672
2022	11	63	87	-	3	0	-	0	-	164

Table 18. Description of 3Pn4RS cod samples taken as part of the DFO dockside monitoring program during the period 2019-2022. The last two columns provide the number of cod measured for length (LF) and having been aged (Age). GN = Gillnet (unspecified), GNS = Gillnet (anchored), LL = Longline (unspecified), LLS = Longline (anchored).

Year	Sample	Date	State at landing	NAFO	Gear	LF	Age
	1	2019-05-16	Gutted head on	4Si	LLS	156	43
	2	2019-06-24	Gutted head on	4Sy	LLS	148	38
	3	2019-07-09	Gutted head on	4Si	LLS	150	40
	4	2019-07-18	Gutted head on	4Ra	GN	45	40
	5	2019-07-18	Gutted head on	4Sz	LLS	150	35
2019	6	2019-07-24	Gutted head on	4Rb	GN	115	41
	7	2019-08-16	Gutted head on	4Si	GNS	152	39
	8	2019-09-05	Gutted head on	4Sy	LLS	151	37
	9	2019-09-16	Gutted head on	4Sx	LLS	151	39
	10	2019-11-18	Gutted head on	4Rd	LL	168	24
		10 samples	**-**	**-**	**-**	**1,386**	**376**
	11	2020-06-25	Gutted head on	4Si	LLS	151	42
	12	2020-08-17	Gutted head on	4Sy	LLS	150	47
2020	13	2020-09-14	Gutted head on	4Sv	LLS	157	37
	14	2020-09-24	Gutted head on	4Ss	LLS	152	54
		4 samples	**-**	**-**	**-**	**610**	**180**
	15	2021-06-15	Gutted head on	4Sx	LLS	110	36
	16	2021-07-02	Gutted head on	4Sx	LLS	150	36
	17	2021-07-07	Gutted head on	4Si	LLS	28	28
	18	2021-07-08	Round	4Sw	GNS	155	18
	19	2021-07-11	Round	4Sw	GNS	165	22
	20	2021-07-12	Gutted head on	4Sx	LLS	153	35
	21	2021-07-13	Gutted head on	4Rb	GN	167	48
	22	2021-07-14	Gutted head on	4Rb	GN	157	49
	23	2021-07-20	Gutted head on	4Sx	LLS	251	38
2021	24	2021-07-20	Gutted head on	4Rb	LL	73	29
	25	2021-07-21	Gutted head on	4Rb	GN	161	44
	26	2021-07-25	Round	4Sw	GNS	184	34
	27	2021-08-03	Gutted head on	4Sx	LLS	155	25
	28	2021-08-10	Gutted head on	4Sy	LLS	160	38
	29	2021-08-23	Gutted head on	4Sx	LLS	151	37
	30	2021-09-06	Gutted head on	4Sx	LLS	150	31
	31	2021-09-20	Gutted head on	4Sx	LLS	152	24
	32	2021-10-21	Gutted head on	3Pn	LL	181	28
	33	2021-10-22	Gutted head on	4Rd	GN	174	36
		19 samples	**-**	**-**	**-**	**2,877**	**636**
	34	2022-06-07	Gutted head on	4Si	LLS	122	31
	35	2022-07-04	Gutted head on	4Si	LLS	152	33
2022	36	2022-07-04	Gutted head on	4Sx	LLS	133	36
	37	2022-07-29	Round	4Si	LLS	118	35
	38	2022-08-05	Gutted head on	4Sx	LLS	151	36

Year	Sample	Date	State at landing	NAFO	Gear	LF	Age
	39	2022-08-09	Gutted head on	4Sx	LLS	120	37
	40	2022-09-10	Gutted head on	4Si	LLS	151	31
	41	2022-09-22	Gutted head on	4Sx	LLS	101	33
	42	2022-09-23	Gutted head on	4Sx	LLS	150	33
	43	2022-10-03	Gutted head on	4Si	LLS	150	32
		10 samples	**-**	**-**	**-**	**1,348**	**337**
Total		**43 samples**	**-**	**-**	**-**	**6,221**	**1,529**

Table 19. Summary of length frequency (LF) and age readings data matches from the k strata used in annual catch-at-age calculations of commercial landings for the 2018-2022 period. See the Catch at age section for details.

	Aggregation level				
Year	**LF**	**Age**	**# k**	**% k**	**% landings**
2018	1	1	3	1.9	4.7
	1	2	1	0.6	5.6
	1	3	1	0.6	0.0
	2	2	7	4.4	8.0
	2	4	3	1.9	1.2
	3	3	35	21.9	51.6
	3	4	10	6.2	2.3
	4	4	35	21.9	19.7
	5	5	18	11.2	3.9
	6	6	47	29.4	2.9
		Total	**160**	**100.0**	**100.0**
2019	1	11	1	0.6	0.0
	2	4	1	0.6	0.3
	3	4	23	14.9	37.3
	3	5	9	5.8	6.8
	4	4	28	18.2	13.7
	4	5	19	12.3	5.2
	5	5	31	20.1	30.3
	6	6	42	27.3	6.5
		Total	**154**	**100.0**	**100.0**
2020	3	4	12	8.8	3.7
	3	10	1	0.7	0.0
	4	4	11	8.0	2.3
	4	5	23	16.8	20.6
	5	5	17	12.4	5.5
	6	6	73	53.3	67.9
		Total	**137**	**100.0**	**100.0**
2021	1	1	2	1.5	8.9
	1	2	2	1.5	2.6
	1	3	1	0.8	8.4
	2	2	1	0.8	0.3
	2	4	2	1.5	4.9
	2	5	1	0.8	0.1
	3	3	18	13.7	36.4
	3	4	18	13.7	3.4
	4	4	19	14.5	4.2
	4	5	6	4.6	18.2
	5	5	26	19.8	8.9
	6	6	33	25.2	3.6

Year	Aggregation level		# k	% k	% landings
	LF	Age			
	9	10	1	0.8	0.0
	10	11	1	0.8	0.0
		Total	**131**	**100.0**	**100.0**
2022	1	2	2	1.9	9.6
	1	3	1	1.0	0.4
	2	2	1	1.0	1.7
	2	4	5	4.8	6.0
	3	3	8	7.7	3.0
	3	4	12	11.5	4.2
	3	10	1	1.0	0.1
	4	4	12	11.5	7.5
	5	5	16	15.4	20.9
	6	6	46	44.2	46.7
		Total	**104**	**100.0**	**100.0**

Table 20. Catch at age ('000) in the commercial fishery.

Year	2	3	4	5	6	7	8	9	10	11+
1974	0	741	4,069	9,607	13,498	5,303	6,658	2,794	1,509	858
1975	12	35	4,313	7,707	5,091	7,185	2,930	2,757	1,719	1,487
1976	3	217	5,210	12,535	6,323	4,244	5,750	1,991	2,561	1,781
1977	0	14	2,672	10,124	12,756	7,943	2,628	3,274	1,098	1,895
1978	0	61	2,678	10,794	17,616	9,292	2,163	1,064	1,261	1,574
1979	0	70	3,404	13,995	12,871	12,592	4,822	1,429	721	1,282
1980	1	605	3,390	17,515	20,196	11,624	7,064	1,531	483	974
1981	2	316	6,689	8,999	20,054	13,971	4,730	2,154	939	1,075
1982	12	229	3,231	18,782	12,747	13,768	8,673	3,372	2,109	1,041
1983	116	840	4,901	15,255	18,451	10,206	6,002	3,061	1,161	1,438
1984	0	47	2,947	7,733	13,493	20,246	7,394	5,688	2,095	1,598
1985	7	175	2,518	15,909	13,820	10,688	9,818	3,179	2,317	1,193
1986	11	215	2,415	8,534	15,635	11,847	6,024	6,189	2,284	2,536
1987	0	15	1,194	8,426	12,310	11,864	7,210	3,650	1,843	2,696
1988	2	117	1,274	6,037	11,452	6,078	5,145	1,515	656	1,417
1989	0	99	1,750	5,072	7,637	8,365	3,800	2,431	971	1,107
1990	0	225	2,748	6,608	4,636	5,860	4,173	1,806	896	677
1991	0	267	4,218	7,809	6,242	3,283	2,690	2,232	594	711
1992	0	739	4,081	8,822	5,877	2,860	1,409	903	686	389
1993	96	459	3,291	5,336	6,867	2,713	599	262	143	103
1994	14	70	140	165	76	63	21	10	3	2
1995	13	10	13	15	26	29	28	6	2	1
1996	1	17	21	30	37	37	41	17	9	1
1997	65	274	656	495	730	429	398	210	189	41
1998	0	0	107	392	639	457	197	157	152	70
1999	1	0	249	566	1,602	525	726	264	145	120
2000	0	9	213	856	1,093	1,288	329	269	131	30
2001	0	3	475	600	1,014	920	941	285	104	44
2002	0	1	185	457	934	759	813	521	127	65
2003	0	0	6	36	59	49	37	26	8	6
2004	0	2	20	236	401	408	301	203	100	59
2005	0	0	25	81	338	764	442	306	117	196
2006	0	0	37	276	639	663	966	367	147	166
2007	1	13	122	395	637	597	657	533	172	142
2008	0	5	394	505	750	700	448	410	161	92
2009	0	197	725	1,210	746	460	206	156	49	47
2010	0	0	236	389	639	437	229	209	56	38
2011	25	7	62	231	336	313	135	64	31	16
2012	0	1	8	43	161	272	200	57	29	16
2013	5	0	40	52	204	215	147	83	16	5
2014	0	7	43	68	109	118	160	114	53	11
2015	0	1	31	78	143	107	183	99	26	11
2016	0	4	28	104	161	160	67	92	35	35
2017	0	1	29	76	248	345	230	142	52	100
2018	0	1	54	141	250	361	245	90	31	35
2019	0	0	5	9	40	83	89	67	14	29
2020	3	2	67	97	37	82	79	63	21	4
2021	1	2	5	50	77	51	65	49	34	23
2022	1	0	16	16	39	31	9	8	4	1

Table 21. Mean weights at age in the commercial fishery (kg).

Year	2	3	4	5	6	7	8	9	10	11+
1974	0.00	0.46	0.64	0.99	1.31	1.67	1.98	2.51	2.89	5.04
1975	0.06	0.40	0.72	1.00	1.52	1.89	2.34	2.61	3.08	4.27
1976	0.20	0.44	0.76	1.13	1.68	2.15	2.60	2.90	3.12	4.77
1977	0.00	0.46	0.65	1.02	1.48	2.02	2.52	2.77	3.17	3.78
1978	0.00	0.57	0.75	0.96	1.44	1.98	2.63	3.22	3.32	4.12
1979	0.00	0.35	0.65	0.94	1.42	1.87	2.59	3.40	3.84	4.74
1980	0.27	0.51	0.62	0.93	1.43	1.91	2.41	3.41	4.15	4.60
1981	0.32	0.57	0.79	0.98	1.33	1.85	2.49	3.34	4.55	6.20
1982	0.12	0.45	0.85	1.11	1.44	1.77	2.12	2.66	3.13	4.70
1983	0.13	0.38	0.93	1.30	1.60	1.90	2.18	2.45	3.47	5.11
1984	0.00	0.42	0.79	1.03	1.45	1.77	2.03	2.30	2.71	3.83
1985	0.38	0.63	0.79	0.98	1.22	1.62	1.93	2.15	2.32	3.06
1986	0.36	0.64	0.73	0.98	1.19	1.47	1.92	2.22	2.46	2.78
1987	0.00	0.45	0.60	0.77	1.01	1.31	1.58	2.09	2.65	2.93
1988	0.46	0.51	0.73	0.88	1.20	1.49	1.81	2.27	2.74	3.16
1989	0.00	0.40	0.69	0.94	1.12	1.42	1.67	2.02	2.33	3.27
1990	0.16	0.59	0.75	0.93	1.18	1.39	1.64	1.86	2.16	3.31
1991	0.00	0.42	0.59	0.81	1.08	1.36	1.60	1.94	2.05	3.10
1992	0.00	0.42	0.65	0.85	1.05	1.40	1.63	1.91	2.17	2.72
1993	0.10	0.38	0.57	0.76	0.99	1.26	1.69	1.89	2.24	2.77
1994	0.15	0.33	0.61	1.01	1.29	1.46	1.70	2.06	2.23	2.81
1995	0.10	0.26	0.60	0.93	1.36	1.68	1.88	2.41	2.83	4.42
1996	0.15	0.36	0.71	1.00	1.41	1.68	2.06	2.63	2.25	4.38
1997	0.15	0.44	0.75	1.03	1.40	1.74	2.09	2.17	2.51	3.19
1998	0.10	0.28	0.65	1.07	1.34	1.58	1.90	1.92	1.98	2.59
1999	0.11	0.14	0.81	1.13	1.49	1.81	2.01	2.18	2.34	2.87
2000	0.10	0.53	0.77	1.14	1.47	1.87	2.09	2.31	2.29	3.14
2001	0.10	0.56	0.77	1.06	1.40	1.66	2.07	2.19	2.76	3.27
2002	0.10	0.36	0.65	1.12	1.38	1.71	1.94	2.34	2.49	3.02
2003	0.09	0.17	0.75	1.04	1.37	1.75	2.06	2.51	2.40	3.05
2004	0.16	0.48	0.79	1.22	1.54	1.98	2.15	2.39	2.28	3.14
2005	-	0.41	0.86	1.21	1.49	1.71	2.14	2.35	2.85	2.70
2006	-	-	0.62	1.16	1.41	1.63	1.85	2.08	2.41	2.59
2007	0.11	0.52	0.83	1.28	1.70	1.86	2.28	2.29	2.82	3.29
2008	-	0.44	0.82	1.16	1.66	1.94	2.10	2.44	2.45	3.32
2009	0.10	0.38	0.61	0.96	1.39	1.73	2.36	2.34	3.09	3.90
2010	0.09	0.37	0.86	1.08	1.42	1.82	2.23	2.16	2.60	3.17
2011	0.11	0.53	0.78	0.99	1.25	1.74	1.97	2.14	2.35	3.10
2012	0.09	0.49	0.63	1.05	1.31	1.55	1.92	2.18	2.39	2.65
2013	0.09	0.16	0.69	1.02	1.41	1.64	1.72	2.24	2.66	3.69
2014	0.10	0.44	0.69	1.03	1.44	1.84	2.08	2.34	2.71	3.80
2015	0.09	0.63	0.90	1.30	1.81	1.80	1.97	2.14	2.66	3.75
2016	0.10	0.51	0.84	1.29	1.79	2.17	2.25	2.38	2.85	3.06
2017	-	0.39	0.68	1.02	1.54	1.95	2.44	2.89	3.46	3.65
2018	-	0.45	0.86	1.15	1.62	2.09	2.61	3.27	4.01	4.42
2019	0.10	0.60	0.69	0.90	1.21	1.62	2.22	2.75	4.53	4.60
2020	0.10	0.48	0.77	1.07	1.11	1.50	1.79	2.19	2.98	4.99
2021	0.09	0.52	0.75	1.30	1.49	1.75	1.89	2.35	2.57	3.30
2022	0.10	0.52	0.68	0.92	1.24	1.48	1.83	1.90	2.29	2.76

Table 22. Mean lengths at age in the commercial fishery (cm).

Year	2	3	4	5	6	7	8	9	10	11+
1974	-	36.78	41.06	47.59	52.40	56.69	59.95	64.72	67.16	80.99
1975	-	35.17	42.76	47.91	54.96	59.15	63.23	65.57	68.98	76.75
1976	-	36.11	43.64	49.82	56.85	61.83	65.85	68.24	69.83	79.61
1977	-	37.00	41.35	48.08	54.45	60.53	65.14	67.22	70.09	74.14
1978	-	39.24	43.30	47.21	53.91	60.03	66.13	70.50	70.97	75.53
1979	-	33.25	41.14	46.62	53.67	58.85	65.27	71.65	74.13	79.68
1980	-	38.17	40.67	46.49	53.79	59.20	63.91	71.62	76.39	79.09
1981	-	39.26	44.01	47.47	52.49	58.30	63.96	69.95	77.75	87.81
1982	-	36.49	44.94	49.50	53.95	57.79	61.32	65.82	69.06	79.39
1983	-	33.44	46.37	52.06	55.96	59.08	61.48	63.81	70.99	80.74
1984	-	35.88	44.05	48.23	54.20	57.91	60.42	62.75	65.90	73.37
1985	-	40.65	44.06	47.40	51.03	56.04	59.36	61.28	62.88	67.92
1986	-	41.36	42.93	47.33	50.58	54.10	59.02	61.94	64.00	66.30
1987	-	36.65	40.18	43.83	47.80	52.21	55.24	60.53	65.25	67.25
1988	-	37.97	42.83	45.69	50.65	54.35	58.01	62.09	66.01	68.98
1989	-	41.40	42.98	47.14	50.05	53.85	56.81	60.30	63.44	69.63
1990	-	40.77	43.94	46.79	50.14	53.24	56.04	58.39	62.54	69.12
1991	-	36.50	40.68	45.10	49.52	53.23	56.31	59.77	60.25	67.97
1992	-	36.27	41.85	45.75	48.87	53.52	56.01	58.83	61.23	65.17
1993	22.21	35.04	40.20	44.08	48.11	51.88	56.68	58.48	61.83	65.10
1994	25.92	34.05	41.83	48.96	52.74	55.16	57.80	61.55	62.29	67.84
1995	22.34	29.75	39.94	45.93	52.11	56.05	58.05	62.51	65.77	75.97
1996	25.73	33.05	42.72	47.75	53.51	56.53	60.49	65.16	61.66	77.62
1997	24.84	36.10	43.20	48.05	52.96	56.70	59.90	60.57	63.71	68.08
1998	22.01	31.15	41.85	49.16	53.02	56.00	59.41	59.11	59.29	65.44
1999	23.46	25.05	44.99	50.05	54.82	58.50	60.57	62.37	63.35	67.61
2000	22.63	39.24	44.23	50.18	54.27	58.72	60.96	62.86	62.75	68.54
2001	22.82	39.96	44.03	49.08	53.70	56.79	61.04	62.19	67.08	70.52
2002	22.14	33.85	40.92	48.74	52.36	56.06	58.47	62.06	63.43	67.27
2003	22.00	26.84	43.47	48.16	52.44	56.64	59.72	63.58	62.70	67.41
2004	26.82	37.34	44.09	50.28	54.17	58.54	60.13	62.09	61.03	67.34
2005	-	35.89	44.45	50.05	53.77	56.23	60.39	62.05	65.99	64.71
2006	-	-	41.00	50.45	53.50	56.08	58.52	60.61	63.60	64.81
2007	23.27	39.03	45.41	51.92	56.78	58.46	62.52	62.39	66.78	69.87
2008	-	37.00	45.08	50.22	56.36	59.06	60.58	63.64	63.57	69.54
2009	22.61	35.18	40.46	46.98	53.21	56.86	62.91	62.45	68.29	72.88
2010	22.34	34.97	45.76	49.11	53.48	58.05	61.77	60.98	64.45	69.15
2011	23.71	38.41	44.53	48.03	51.82	57.55	59.60	61.10	62.89	69.20
2012	22.30	38.99	42.11	49.50	53.11	56.05	59.98	62.60	64.10	66.20
2013	22.53	26.91	42.89	48.47	53.87	56.45	56.94	62.28	65.62	72.92
2014	22.85	36.97	42.88	48.71	54.05	58.59	61.05	63.42	66.50	73.53
2015	22.25	41.99	46.77	52.56	58.54	58.33	60.04	61.65	65.64	73.74
2016	22.89	39.35	45.96	52.49	58.54	62.35	62.71	64.13	67.79	68.98
2017	-	36.04	42.99	49.10	56.25	60.56	65.62	68.84	72.46	74.16
2018	-	37.00	45.20	49.63	55.24	59.63	63.57	67.63	72.52	74.89
2019	22.37	41.00	42.69	46.34	50.80	55.62	61.35	65.83	77.07	77.48
2020	23.00	37.74	44.00	48.73	49.29	54.26	57.04	60.79	66.71	79.47
2021	22.41	39.24	43.93	52.45	54.86	57.72	59.17	63.38	64.72	70.04
2022	23.40	40.26	44.15	48.53	53.42	56.70	60.61	61.29	65.40	69.78

Table 23. 3Pn4RS Atlantic cod stock landings (t) by target species for the period 1985-2022. The last column indicates the percentage of landings where the target species was Atlantic cod out of all those for which a target species was specified. COD = Atlantic cod, RED = redfish, ATLH = Atlantic halibut, AMEP = American plaice, WITCH = witch flounder, TURB = Greenland halibut, SHR = northern shrimp, OTHER = other species, UNK = unknown. Source: NAFO 21B and ZIFF data.

Year	COD	RED	ATL	AMEP	WITCH	TURB	SHR	OTHER	UNK	% targeted
1985	13,119	95	7	-	57	4	1,900	11	73,288	86.3
1986	21,828	233	1	43	15	14	2,592	0	58,673	88.3
1987	17,873	219	1	96	16	35	1,542	1	46,762	90.3
1988	15,444	546	-	88	34	16	795	0	30,779	91.3
1989	20,534	248	0	84	121	13	774	3	24,984	94.3
1990	21,717	263	11	59	36	39	761	30	16,084	94.8
1991	17,715	1,012	55	31	63	19	839	6	14,741	89.7
1992	17,022	647	27	94	129	15	513	6	11,090	92.2
1993	15,048	874	19	52	60	20	59	301	2,020	91.6
1994	20	131	92	1	8	3	3	0	278	7.9
1995	-	0	14	1	4	-	0	0	165	0.0
1996	2	1	14	3	5	1	-	2	289	8.6
1997	435	2	20	3	6	2	2	0	4,322	92.6
1998	2,476	1	48	44	30	30	-	7	594	94.0
1999	6,184	3	169	35	35	39	0	7	418	95.6
2000	6,213	13	213	36	36	35	0	27	283	94.5
2001	6,498	3	147	24	63	25	0	13	178	95.9
2002	6,114	4	61	26	29	9	0	10	275	97.8
2003	116	5	91	44	25	6	0	19	82	37.8
2004	2,870	8	92	33	44	15	0	12	201	93.4
2005	4,005	19	64	35	49	9	-	9	270	95.6
2006	5,166	8	72	2	38	4	0	5	357	97.6
2007	5,842	0	90	10	31	16	0	6	487	97.4
2008	5,813	0	77	-	25	23	0	4	216	97.8
2009	4,559	2	41	4	23	10	0	1	61	98.3
2010	3,430	2	25	2	12	13	0	2	65	98.4
2011	1,603	1	64	8	12	16	0	1	72	94.1
2012	1,178	2	62	7	4	23	0	0	26	92.2
2013	1,131	1	45	4	2	17	1	1	19	94.1
2014	1,185	1	50	2	3	12	0	0	7	94.5
2015	1,154	1	101	3	4	5	0	0	0	91.1
2016	1,224	2	126	1	5	10	0	2	2	89.3
2017	2,526	3	121	-	6	15	0	-	-	94.6
2018	2,344	13	102	-	7	36	0	0	77	93.7
2019	613	9	99	-	3	23	0	0	26	82.1
2020	596	4	62	-	1	1	0	-	17	89.7
2021	551	6	87	-	4	3	0	0	22	84.7
2022	62	11	88	-	2	0	-	0	-	37.8

Table 24. Mobile gear sentinel surveys. Average cod catch (kg) per tow by stratum and NAFO Division.

Year	3Pn				4R												
	302	303	304	305	101	102	103	801	802	809	810	811	812	813	820	821	822
1995	32.3	8.7	0.0	0.1	-	-	-	0.7	0.0	0.0	0.0	9.5	1.6	68.8	37.2	73.0	28.1
1996	31.2	8.7	0.3	0.0	-	-	-	1.5	0.0	0.0	0.0	4.9	8.0	18.3	29.8	162.3	68.5
1997	69.6	3.9	0.4	0.0	-	-	-	0.4	0.0	0.0	0.0	5.4	1.2	33.3	78.1	77.2	172.0
1998	45.8	3.7	0.3	0.0	-	-	-	0.3	0.0	0.2	0.7	8.2	6.0	25.8	44.9	66.1	53.6
1999	10.2	2.1	0.5	0.0	-	-	-	0.0	0.0	0.8	0.0	4.7	3.1	12.7	137.7	129.7	37.1
2000	17.3	0.8	0.4	0.0	-	-	-	0.4	0.0	0.0	0.3	0.1	1.5	16.6	23.8	56.4	77.2
2001	121.2	5.1	0.0	0.1	-	-	-	0.0	0.0	0.2	0.0	9.2	3.7	82.5	21.8	76.2	53.4
2002	191.3	10.2	0.0	0.0	-	-	-	2.2	0.0	0.1	0.0	9.9	18.1	14.2	33.0	27.3	29.5
2003	28.0	5.1	0.0	0.0	38.3	580.7	11.0	0.7	0.0	2.1	0.5	7.8	1.8	28.8	32.7	36.5	96.8
2004	26.4	9.4	0.8	0.1	37.3	240.4	174.6	0.0	0.1	0.0	1.1	6.8	3.7	35.4	54.1	28.6	114.8
2005	26.5	14.9	0.0	0.0	37.2	117.0	144.9	0.0	0.4	0.0	0.6	34.6	8.1	5.9	87.1	194.2	86.4
2006	20.9	3.7	0.0	0.0	61.2	126.9	1.5	0.9	0.0	0.5	0.0	46.0	13.0	7.8	34.2	83.2	64.5
2007	11.6	16.1	0.1	0.0	54.6	336.1	15.6	1.2	0.0	0.1	0.0	7.7	9.4	31.7	55.2	34.5	51.2
2008	1.6	0.0	0.0	0.0	23.4	612.6	839.4	2.0	0.0	0.4	0.0	2.0	3.6	17.2	4.2	27.5	24.0
2009	1.5	1.6	0.2	0.0	23.9	62.7	1.5	2.9	0.0	0.0	0.0	2.3	3.4	87.4	7.0	10.5	55.9
2010	1.2	0.1	0.0	0.0	53.5	12.6	359.1	0.2	0.0	0.0	0.0	4.6	3.6	37.5	25.1	9.8	30.5
2011	0.1	0.0	0.0	0.0	0.0	11.7	462.8	0.0	0.0	0.0	0.0	6.9	2.6	1.5	22.1	38.1	28.0
2012	2.4	0.1	0.0	0.0	35.3	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.8	9.2	9.6	12.3
2013	2.5	1.8	0.0	0.0	0.6	21.7	24.9	0.2	0.0	0.9	0.0	1.1	0.3	7.2	2.1	0.6	1.3
2014	1.3	0.1	0.0	0.0	18.2	26.0	9.6	4.2	0.1	0.5	0.0	1.9	26.4	22.0	4.5	15.9	19.5
2015	2.4	0.0	0.0	0.0	676.7	1.6	46.2	3.8	0.0	0.1	0.0	1.9	8.5	4.9	23.8	4.6	14.4
2016	1.7	0.2	0.0	0.0	12.2	39.0	-	0.7	0.0	0.0	0.2	5.4	8.3	7.7	11.0	11.5	13.2
2017	2.3	1.8	0.0	0.0	2.6	34.7	0.7	0.0	0.0	0.0	0.0	0.4	0.8	1.8	17.2	7.1	33.7
2018	3.7	1.0	0.0	0.0	7.5	3.5	34.6	0.0	0.5	0.1	0.0	0.3	0.9	2.0	0.9	0.9	30.5
2019	0.0	0.0	0.0	0.0	26.8	-	0.0	0.2	0.0	0.0	0.0	0.0	0.3	1.9	9.9	4.5	18.6
2020	7.2	0.7	0.0	0.0	10.2	79.6	40.2	-	0.0	0.0	0.0	0.0	0.1	4.5	8.9	15.2	42.1
2021	1.1	0.0	0.0	0.0	37.5	2.6	27.0	0.0	0.0	0.0	0.0	0.0	0.6	0.5	14.1	15.5	20.4
2022	0.4	0.0	0.0	0.0	5.8	3.7	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.3	3.7	6.8	25.7

Table 24 (continued)

Year	4R							4S									
	823	824	835	836	837	838	840	803	804	805	806	807	808	814	815	816	817
1995	158.0	40.1	46.4	31.6	17.4	29.4	0.4	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.5	5.5	14.1
1996	123.9	123.0	67.2	37.8	17.9	8.7	2.6	0.1	0.0	0.0	-	0.2	0.3	8.2	37.6	10.3	5.8
1997	249.4	163.0	78.9	120.3	90.5	58.8	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.7	0.8	0.3
1998	265.6	541.1	62.3	105.8	211.6	41.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.3	1.1	0.0
1999	39.8	77.2	77.8	147.0	27.2	11.0	15.2	0.0	0.0	0.0	0.0	1.2	0.0	4.3	2.1	4.2	0.0
2000	74.8	44.0	114.5	195.8	295.7	179.5	7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	6.7	0.0
2001	149.6	241.4	105.4	66.1	516.8	58.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.2	0.4
2002	55.5	66.3	79.2	147.3	192.2	98.6	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.0	0.0	0.0	0.3
2003	1240.9	108.8	209.2	57.1	107.9	18.1	4.8	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.5	5.8	0.6
2004	316.0	348.8	89.1	121.3	484.5	9.7	7.3	0.0	0.2	-	0.2	0.0	0.0	0.5	0.7	1.1	0.7
2005	63.2	107.9	59.3	72.1	187.6	213.7	4.9	0.1	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
2006	83.6	8.5	139.1	176.2	278.7	328.1	12.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.1	0.1
2007	31.0	53.1	56.7	38.9	129.3	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.5	0.5	33.8	0.2
2008	69.2	36.2	11.1	71.9	196.7	12.8	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.3	4.2	0.4	0.0
2009	46.5	45.8	26.8	65.4	460.7	77.6	0.0	0.0	0.0	0.0	0.2	0.4	0.0	1.6	0.2	1.2	0.3
2010	18.0	4.1	12.6	22.3	141.0	74.2	7.4	0.0	0.0	0.1	0.2	0.0	0.5	9.5	0.5	7.7	0.3
2011	153.3	99.6	13.2	73.0	1079.2	22.8	7.3	0.0	0.0	0.1	0.0	0.0	0.0	53.2	0.2	0.1	3.2
2012	4.6	18.2	6.8	18.1	88.4	26.5	0.5	0.0	0.0	0.0	0.5	0.0	0.0	1.0	0.9	0.1	0.9
2013	16.9	3.4	0.7	137.3	135.8	198.0	200.6	0.0	0.2	0.1	0.0	0.8	0.0	4.8	6.3	2.2	0.5
2014	34.9	49.0	19.4	51.7	633.7	61.8	3.1	0.2	0.4	0.1	1.2	1.2	0.5	5.8	6.7	7.1	0.3
2015	86.1	71.0	35.8	74.7	511.0	146.1	4.5	0.0	0.0	0.1	1.5	0.0	0.0	4.0	3.1	5.9	3.3
2016	30.9	32.4	19.3	77.3	58.6	26.1	0.0	0.0	0.9	0.4	0.4	0.0	0.0	3.6	8.1	15.1	6.1
2017	5.8	86.1	16.0	34.4	53.4	101.8	12.0	0.0	0.1	0.6	0.0	0.1	0.0	0.7	1.9	1.8	26.9
2018	10.7	17.0	4.5	23.7	119.5	2.3	24.7	0.0	0.0	0.0	0.0	0.0	0.0	0.8	2.4	0.2	1.1
2019	8.0	32.7	22.6	45.7	33.8	1.7	0.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.3	4.9	1.7
2020	146.2	108.2	65.9	51.9	85.8	3.7	1.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.7	17.6	0.0
2021	9.0	13.3	13.3	57.1	181.7	49.3	0.7	0.0	0.0	0.0	0.4	0.0	0.0	1.4	0.0	0.2	6.1
2022	67.3	3.5	27.6	32.5	14.4	13.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.1	0.7	2.3

Table 24 (continued)

Year	4S											Mean weight per set
	818	819	827	828	829	830	831	832	833	839	841	
1995	0.3	1.0	1.3	3.0	2.4	7.3	6.0	12.5	0.0	-	-	12.8
1996	3.0	0.9	0.0	0.0	27.7	-	12.5	15.3	0.0	0.0	5.2	16.2
1997	0.0	0.9	11.3	-	7.3	22.8	-	4.2	3.0	0.8	2.0	24.6
1998	0.2	11.5	0.3	3.2	22.3	29.6	3.7	8.8	0.6	1.0	0.6	25.1
1999	0.5	0.0	5.4	2.4	44.0	32.2	8.0	5.6	5.0	2.3	0.0	16.9
2000	0.5	0.0	0.6	34.5	12.1	4.3	0.0	5.8	0.0	0.0	1.7	29.7
2001	1.5	-	0.0	-	6.3	-	8.4	3.9	0.3	0.0	2.4	33.1
2002	3.0	3.0	-	0.5	25.0	4.1	0.0	1.8	0.0	0.5	1.2	22.7
2003	3.3	30.5	2.4	0.0	0.0	6.1	0.0	1.8	0.0	0.3	2.8	25.1
2004	3.1	0.3	0.0	0.5	9.8	1.8	5.9	4.8	0.0	0.0	0.0	36.5
2005	2.4	-	2.0	3.7	24.5	11.4	12.0	3.8	0.0	2.2	4.3	26.8
2006	0.7	0.7	0.5	3.9	13.9	3.1	13.6	3.3	5.4	1.6	6.4	35.3
2007	0.2	0.7	7.4	-	0.7	3.8	119.8	14.0	2.7	2.7	11.7	16.4
2008	0.7	0.3	1.0	-	3.6	12.2	18.3	19.0	1.1	0.8	1.0	25.1
2009	8.6	0.0	5.0	3.3	-	22.5	6.0	23.3	0.0	1.7	1.5	26.3
2010	1.8	0.0	4.1	-	22.2	8.9	-	30.9	4.3	10.4	2.2	17.0
2011	5.1	-	0.0	3.9	0.0	51.1	27.7	6.2	0.0	13.7	1.0	38.7
2012	5.0	0.6	6.7	0.0	0.2	8.4	-	10.7	4.2	3.7	-	6.5
2013	4.3	3.7	17.6	3.0	4.3	11.4	26.4	23.6	5.3	1.5	4.2	19.4
2014	3.3	5.7	27.1	-	2.4	38.6	9.8	37.5	2.9	8.1	-	29.5
2015	17.0	4.2	30.7	5.1	35.1	9.7	9.7	46.2	4.1	17.2	1.3	30.0
2016	5.0	12.1	27.1	-	54.7	10.8	33.9	105.1	7.9	185.5	0.9	24.5
2017	10.8	0.0	4.2	23.5	40.3	13.2	14.0	26.5	42.1	2.1	0.5	13.6
2018	3.8	1.2	1.5	56.9	1.9	13.5	0.0	113.9	4.0	10.9	0.0	12.5
2019	0.5	0.0	24.8	21.8	33.1	10.0	6.1	96.3	2.5	0.2	1.5	10.7
2020	0.0	2.0	16.8	64.2	61.1	21.3	1.2	89.1	1.8	2.8	0.0	18.9
2021	3.8	3.1	26.8	29.5	2.5	201.6	0.6	3.4	6.2	8.2	0.0	16.1
2022	1.3	1.1	5.8	247.0	78.8	1.9	2.5	24.8	10.1	8.5	0.0	13.4

Table 25. Mobile gear sentinel surveys. Average numbers at age.

Year	1	2	3	4	5	6	7	8	9	10	11+
1995	1.042	1.959	2.217	4.570	3.050	1.833	1.282	1.122	0.224	0.054	0.031
1996	0.117	1.636	6.962	5.912	4.747	2.296	1.166	0.786	0.618	0.140	0.037
1997	0.000	2.834	5.947	13.425	4.799	4.283	1.661	0.666	0.496	0.159	0.045
1998	0.037	2.013	8.211	6.459	6.921	2.923	2.842	0.930	0.634	0.243	0.187
1999	0.093	2.043	5.091	5.832	3.415	2.943	1.089	0.935	0.190	0.085	0.060
2000	0.359	1.220	7.433	10.218	5.743	3.892	3.485	0.800	0.792	0.281	0.072
2001	1.207	5.632	11.254	9.884	5.021	3.111	1.809	1.373	0.480	0.320	0.153
2002	0.023	0.600	3.035	8.159	4.663	3.783	2.055	1.655	0.880	0.264	0.098
2003	0.051	1.107	4.248	7.426	6.421	3.260	2.438	1.198	0.964	0.751	0.363
2004	0.016	0.728	3.669	6.680	5.738	5.370	3.292	2.134	1.299	0.635	0.615
2005	0.025	1.865	4.837	6.209	4.895	3.321	2.650	1.066	0.707	0.388	0.356
2006	0.962	3.672	4.644	7.686	5.155	3.851	2.423	2.382	1.075	0.531	0.389
2007	9.826	2.724	7.722	6.301	2.871	1.667	1.080	0.664	0.560	0.345	0.410
2008	0.023	4.637	5.882	10.553	4.089	3.034	1.707	1.168	0.813	0.359	0.203
2009	0.056	4.194	6.507	10.426	10.413	2.232	1.692	0.939	0.291	0.162	0.035
2010	0.037	0.395	6.087	6.337	5.382	2.512	0.858	0.562	0.166	0.065	0.021
2011	0.073	1.317	3.315	12.867	8.555	9.565	3.745	2.031	1.032	0.303	0.217
2012	0.908	0.619	1.134	1.145	1.560	1.321	0.926	0.328	0.183	0.036	0.019
2013	2.368	6.081	5.508	6.050	3.065	2.190	1.848	0.995	0.497	0.165	0.212
2014	0.325	7.063	11.675	10.518	6.560	4.384	1.721	1.237	0.642	0.134	0.207
2015	0.431	9.501	22.538	17.732	7.026	3.403	1.584	0.999	0.404	0.290	0.054
2016	0.202	4.501	7.586	9.636	7.818	4.356	1.311	0.610	0.427	0.080	0.097
2017	0.162	3.755	5.100	5.252	4.053	2.809	1.512	0.496	0.239	0.095	0.091
2018	0.322	2.342	3.631	2.452	2.348	1.984	1.777	0.497	0.179	0.128	0.072
2019	0.013	0.632	5.224	3.933	1.560	1.890	1.541	0.775	0.268	0.123	0.070
2020	0.132	9.979	6.773	8.957	4.945	1.939	1.442	1.118	0.618	0.201	0.097
2021	0.108	1.567	18.418	6.802	2.527	1.371	0.472	0.419	0.504	0.203	0.129
2022	0.097	0.318	2.209	14.556	2.231	1.534	0.557	0.230	0.063	0.107	0.110

Table 26. Catch at age (thousands) for ages 2 to 11+, 1974-2022, used as input in the nGSL cod assessment model.

Year	2	3	4	5	6	7	8	9	10	11+
1974	30.7	871.7	4,573.8	10,328.9	14,512.2	5,701.5	7,158.3	3,003.9	1,622.4	922.5
1975	43.5	112.7	4,847.5	8,306.3	5,486.9	7,743.7	3,157.8	2,971.4	1,852.7	1,602.6
1976	33.8	308.0	5,792.9	13,458.4	6,788.8	4,556.6	6,173.6	2,137.7	2,749.7	1,912.2
1977	30.7	90.0	3,068.9	10,873.3	13,700.1	8,530.9	2,822.5	3,516.3	1,179.3	2,035.3
1978	30.7	140.5	3,074.0	11,587.7	18,911.3	9,975.2	2,322.0	1,142.2	1,353.7	1,689.7
1979	30.7	150.1	3,849.3	15,007.1	13,801.8	13,502.6	5,170.7	1,532.3	773.1	1,374.7
1980	31.7	722.6	3,827.9	18,748.6	21,618.4	12,442.7	7,561.5	1,638.8	517.0	1,042.6
1981	32.7	413.3	7,360.5	9,634.6	21,470.3	14,957.7	5,064.1	2,306.1	1,005.3	1,150.9
1982	43.4	320.0	3,655.5	20,092.2	13,636.2	14,728.5	9,278.0	3,607.2	2,256.1	1,113.6
1983	154.7	973.6	5,441.9	16,318.7	19,737.6	10,917.7	6,420.5	3,274.4	1,242.0	1,538.3
1984	30.7	125.3	3,351.6	8,272.2	14,433.9	21,657.7	7,909.6	6,084.6	2,241.1	1,709.4
1985	38.1	262.6	2,898.0	17,052.1	14,813.0	11,456.0	10,523.5	3,407.4	2,483.5	1,278.7
1986	42.4	305.5	2,788.5	9,150.1	16,763.8	12,702.3	6,458.9	6,635.8	2,448.9	2,719.1
1987	35.1	279.3	1,670.1	8,919.7	12,857.6	12,369.1	7,513.5	3,805.1	1,919.6	2,807.9
1988	51.1	521.9	1,634.1	6,499.5	12,126.6	6,429.8	5,431.4	1,600.4	692.5	1,496.8
1989	36.0	684.3	2,189.1	5,425.1	8,051.1	8,771.9	3,976.6	2,545.2	1,018.0	1,159.3
1990	55.3	809.9	3,231.6	7,153.1	4,976.2	6,280.5	4,481.2	1,929.8	958.7	725.6
1991	303.7	1,641.7	5,958.9	8,720.9	6,849.7	3,566.5	2,911.7	2,425.2	641.8	766.6
1992	185.8	1,101.3	4,832.3	9,741.5	6,399.5	3,108.1	1,530.6	980.6	743.0	421.9
1993	116.0	519.6	3,546.3	5,734.2	7,373.4	2,912.2	643.6	280.7	153.6	110.9
1994	20.9	101.0	150.2	173.1	79.2	66.1	22.4	10.4	2.7	2.1
1995	69.4	17.2	18.8	17.2	27.3	30.8	29.5	6.6	2.2	0.8
1996	14.9	21.9	22.8	31.4	38.5	38.7	42.6	17.5	9.1	1.2
1997	80.1	278.8	665.6	501.3	740.1	434.8	403.7	213.1	191.2	41.2
1998	19.0	4.8	118.6	430.3	701.4	501.6	215.6	172.4	166.9	76.6
1999	76.0	3.4	264.4	600.1	1,699.4	556.8	770.3	279.9	154.3	126.8
2000	10.2	13.1	226.3	910.2	1,162.4	1,369.5	349.4	286.4	139.4	31.5
2001	20.3	8.9	507.5	640.7	1,082.8	982.4	1,005.4	304.6	110.6	47.4
2002	4.4	5.4	192.5	471.2	963.1	782.3	838.2	536.7	131.0	66.9
2003	53.0	7.9	7.8	37.5	60.3	50.7	38.1	26.6	8.4	6.3
2004	28.5	5.4	20.7	241.0	409.1	415.7	307.2	207.5	102.0	60.6
2005	26.5	2.6	26.1	82.9	345.8	782.3	452.9	313.3	119.4	200.9
2006	19.3	4.3	42.7	312.7	723.7	750.7	1,094.1	415.3	166.4	187.7

Year	2	3	4	5	6	7	8	9	10	11+
2007	15.4	20.6	137.9	441.9	713.2	667.7	735.0	596.7	192.5	158.4
2008	107.9	21.0	448.8	569.3	843.4	787.4	504.3	460.8	181.7	103.7
2009	26.8	229.3	836.1	1,394.2	859.2	530.0	237.6	180.1	56.3	53.9
2010	16.6	3.5	283.4	466.2	765.2	523.6	274.9	250.9	67.1	45.2
2011	54.6	11.7	87.6	325.0	472.7	441.2	190.6	90.4	43.3	22.0
2012	131.0	6.9	14.5	67.5	252.0	424.0	311.8	88.7	45.6	24.3
2013	126.0	7.5	64.3	83.1	326.1	344.4	235.5	132.7	25.7	8.0
2014	41.4	13.3	71.3	113.3	180.6	195.0	264.2	188.9	86.9	18.8
2015	11.8	3.1	51.4	127.4	234.2	175.9	300.2	163.1	43.2	18.2
2016	6.6	7.4	46.9	172.6	267.9	265.8	112.1	152.9	58.7	58.4
2017	17.8	3.4	40.6	102.8	336.1	467.3	311.4	192.4	70.9	134.8
2018	37.1	3.5	73.7	190.9	339.1	489.1	331.9	121.9	42.2	46.9
2019	15.6	1.9	11.5	19.7	85.2	179.1	191.2	145.1	29.9	62.6
2020	8.0	5.5	152.5	221.1	83.8	187.0	179.4	143.3	46.8	8.5
2021	1.6	3.8	12.0	113.1	176.5	115.5	147.9	110.8	76.9	51.7
2022	2.1	0.8	69.0	104.0	139.6	133.8	84.7	81.4	59.9	27.5

Table 27. Parameter estimates (Est), standard errors (SE), and negative loglikelihood gradients (GRD) for the stock weights mixed-effects model.

Parameter	Est	SE	GRD
γ_2	-2.675	0.046	-0.000003
γ_3	0.023	0.037	-0.000025
γ_4	-0.324	0.053	-0.000103
γ_5	-0.614	0.070	-0.000051
γ_6	-0.997	0.103	-0.000017
γ_7	-1.375	0.151	-0.000040
γ_8	-1.527	0.175	-0.000051
γ_9	-1.654	0.199	-0.000045
γ_{10}	-1.735	0.216	-0.000036
γ_{11+}	-1.233	0.131	-0.000026
$\log(\sigma_Y)$	-3.008	1.251	0.000008
$\log(\sigma_C)$	-3.107	0.434	-0.000002
$\log(\sigma_{AY})$	-3.261	2.169	0.000004
$logit(\varphi_Y)$	1.725	1.027	-0.000002
$logit(\varphi_C)$	1.371	1.046	0.000000
$logit(\rho_A)$	2.419	4.837	0.000001
$logit(\rho_Y)$	1.854	1.158	0.000004

Table 28. Estimates of beginning of year biomass at age, 2+ biomass and spawning stock biomass (SSB; tonnes).

	Age											
Year	2	3	4	5	6	7	8	9	10	11+	2+	SSB
1973	39942	23343	19026	43916	28313	42825	26208	20511	12157	15607	271849	150023
1974	49712	40827	23611	20548	42669	22415	30658	18968	12938	21615	283961	145057
1975	46351	50813	43788	25163	20373	34771	16555	21338	11623	20882	291656	127748
1976	55987	47376	56260	48056	27531	17376	26204	12007	13257	23311	327367	128506
1977	62759	57228	48374	56740	46020	20734	11029	16547	6669	19066	345165	127327
1978	45522	64150	62933	52415	59465	35295	12608	7719	9557	16304	365967	143743
1979	67330	46530	65555	63130	56762	46053	22077	9149	4494	18729	399808	163027
1980	43335	68822	46452	70356	69691	45341	29907	15876	5372	13784	408937	184286
1981	40461	44295	77668	51702	74993	54328	29289	22040	10128	15894	420799	204876
1982	43119	41357	52050	80676	56545	61439	35278	19055	12027	14389	415935	207936
1983	32870	44072	51179	56753	85637	46964	42274	23353	12341	20341	415784	227518
1984	42534	33587	49612	46276	52184	65958	30894	28422	14669	17357	381493	209095
1985	35203	42559	36008	56574	51167	42339	43969	20183	17689	17550	363241	196491
1986	32218	35908	45810	41725	59922	39960	27032	26307	12113	21109	342105	184595
1987	40611	32759	38507	52311	44471	45649	24606	14805	13572	17577	324868	164746
1988	51053	40803	34716	36515	52911	31092	25529	11588	6618	14211	305036	132798
1989	45196	50407	42453	23523	33061	34547	17130	12302	5411	8274	272306	104153
1990	26529	45785	53771	25248	20033	20376	17913	7954	5329	5116	228055	72287
1991	11891	27257	49465	26550	19459	10821	9064	7696	3085	3703	168991	51564
1992	7753	12083	28860	24574	19062	9405	4311	3489	2773	2220	114529	40576
1993	9637	7955	12836	10037	15026	7010	2671	1170	867	1063	68271	25833
1994	7717	10031	8612	5417	6084	5381	1963	725	277	377	46583	15324
1995	13596	8181	11180	4700	5387	4613	3908	1415	515	333	53829	19391
1996	13448	14554	9220	6930	4946	4112	3376	2669	954	371	60581	23306
1997	16239	14197	16159	6657	7591	3985	3172	2354	1843	615	72812	31511
1998	15725	17042	15632	13907	7401	6131	2952	1985	1456	1086	83316	40873
1999	22524	16399	18705	12280	15170	5930	4550	1914	1222	1147	99841	48495
2000	16491	23264	17840	11336	12043	10512	3733	2456	970	847	99492	46809
2001	12865	16677	24778	11623	11149	8742	6846	2260	1362	809	97112	46121
2002	10002	13057	17836	10198	9845	6784	4773	3787	1178	1019	78480	38435
2003	12126	10208	14037	12609	10494	7536	4615	3191	2386	1367	78570	40278
2004	10769	12322	10928	10842	13837	9385	6464	4181	2850	3242	84819	48912
2005	13550	11002	13261	8580	11863	11727	7401	5113	3164	4251	89913	51428
2006	19218	13811	11809	10524	9418	9690	8801	5354	3548	4549	96722	50943
2007	17362	19781	14962	10247	11905	7639	7155	5927	3464	4427	102869	49965
2008	21894	17684	21196	10227	10516	7567	4365	3510	2701	2304	101963	40179
2009	11960	22112	18788	15573	10591	6754	4359	2118	1538	1218	95010	40642
2010	9609	12149	23593	12696	15636	6296	3647	2009	873	477	86985	40035
2011	12702	9672	12861	12406	11864	8760	3228	1736	882	271	74383	37368
2012	15677	12757	10213	9428	13165	8795	6046	2119	1093	525	79817	40958
2013	24285	16006	13699	6926	9914	9178	5739	3802	1290	790	91629	37913
2014	21975	25169	17440	9699	7463	7207	6299	3793	2428	1123	102595	40494
2015	21345	22762	27392	14156	10936	6127	5605	4389	2542	2078	117333	47698
2016	12790	21765	24373	15793	14103	7912	4193	3366	2534	2332	109161	50130

						Age						
Year	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**	**2+**	**SSB**
2017	11906	12712	22700	10498	14013	9887	5228	2510	1919	2397	93769	49424
2018	15655	11917	13352	6087	7973	8047	5272	2247	1022	1219	72793	35420
2019	14238	15866	12679	3667	4686	5175	4844	2858	1164	867	66043	27784
2020	32151	14338	16773	6591	3494	3972	4113	3574	2030	1152	88189	34605
2021	12177	31915	14934	8550	6138	2935	3136	3081	2597	1903	87366	38462
2022	10187	12088	33250	5613	7228	4499	2033	2006	1922	2003	80830	42906

Table 29. Estimates of beginning of year abundances-at-age (thousands)

Year	Age										
	2	3	4	5	6	7	8	9	10	11+	2+	5+
1973	577331	121424	50916	65372	29006	33463	16431	9630	4916	3224	911712	162042
1974	718544	212372	63184	30587	43713	17515	19221	8905	5231	4465	1123738	129638
1975	669955	264319	110415	37276	19589	25581	9583	9741	4556	5088	1156102	111413
1976	809247	246441	137885	67008	25288	11957	14371	5074	5163	5083	1327519	133946
1977	907123	297684	128467	83255	44774	14744	6148	7233	2577	5247	1497253	163979
1978	657977	333694	155328	79169	58548	25359	6873	3015	3607	4122	1327691	180693
1979	973191	242039	174095	96295	56224	34062	12133	3427	1570	4110	1597145	207819
1980	626372	357998	126242	107851	68822	33180	17057	5933	1797	3116	1348369	237756
1981	584831	230411	186430	77334	76353	40398	16429	8369	3212	2669	1226435	224763
1982	623245	215127	119993	113518	55673	46689	21425	8580	4677	3184	1212113	253747
1983	475113	229253	112070	73489	80460	34459	25334	11155	4552	4145	1050029	233594
1984	614789	174709	119085	67580	51226	50124	19148	14193	6114	4716	1121683	213100
1985	525693	226149	91107	81143	50173	31414	26098	10002	7417	5545	1054741	211792
1986	486063	193371	117882	61127	59167	30360	16146	12900	5035	6637	988688	191372
1987	611943	178789	100734	78181	44996	35054	15111	7335	5604	5500	1083246	191780
1988	799503	225099	93125	56112	55222	24731	16011	5961	2787	4457	1283008	165281
1989	741945	294090	117148	37730	36132	28880	11342	6589	2412	2698	1278967	125784
1990	442692	272923	153052	40680	22342	17457	12211	4410	2426	1733	969925	101258
1991	195732	162822	141878	43546	21524	9342	6253	4337	1434	1264	588132	87700
1992	127482	71853	83765	41035	21689	8138	3028	2010	1324	781	361104	78005
1993	155735	46790	36746	16815	17261	6186	1864	680	419	381	282879	43608
1994	120683	57228	24071	8839	6926	4734	1379	414	133	135	224541	22559
1995	203531	44382	29800	7368	5880	3960	2696	800	240	117	298773	21060
1996	191979	74839	23155	10272	5145	3358	2255	1470	436	125	313034	23061
1997	222829	70615	39051	9441	7585	3152	2049	1276	835	207	357040	24545
1998	209712	81929	36736	19075	7106	4675	1851	1042	650	361	363136	34759
1999	292746	77137	42766	16482	14168	4367	2762	979	530	377	452315	39665
2000	214463	107661	40266	14925	11089	7578	2201	1222	412	271	400088	37698
2001	169672	78889	56196	15423	10278	6340	4032	1115	574	259	342778	38021
2002	133582	62408	41177	13538	9106	4903	2814	1857	490	323	270199	33031
2003	163086	49139	32576	16962	9674	5448	2707	1565	987	428	282572	37770
2004	147697	59969	25647	14724	12980	6791	3807	2048	1183	1013	275860	42547
2005	187566	54317	31303	11724	11175	8586	4336	2498	1303	1325	314133	40947
2006	270067	68987	28354	14508	8951	7140	5226	2605	1460	1408	408704	41297
2007	240406	99341	36011	14237	11303	5620	4228	2889	1403	1353	416791	41033
2008	302633	88430	51848	14395	10164	5614	2598	1717	1104	699	479203	36292
2009	165632	111283	46147	22464	10454	5140	2636	1051	635	376	365819	42756
2010	132518	60915	58000	18283	15716	4860	2245	1005	363	148	294052	42620
2011	173458	48741	31797	18048	12009	6942	2032	891	373	85	294375	40380
2012	224054	63779	25438	13826	13489	7031	3912	1113	475	168	353283	40013
2013	355837	82337	33289	10062	10069	7303	3684	2019	564	256	505419	33956
2014	320661	130819	42977	13548	7396	5598	3964	1969	1058	361	528352	33894
2015	305021	117932	68285	20075	10429	4646	3443	2233	1083	665	533810	42573
2016	180275	112202	61563	23034	13877	5866	2554	1698	1075	741	402883	48844
2017	169577	66314	58570	15935	14568	7770	3197	1289	828	778	338825	44365

Year	Age										
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11+**	**2+**	**5+**
2018	224547	62374	34616	9372	8567	6636	3396	1151	447	400	351507	29970
2019	205177	82588	32560	5599	5039	4352	3232	1522	500	284	340853	20529
2020	465038	75468	43112	10032	3750	3364	2816	1983	913	374	606849	23231
2021	179771	171073	39395	13223	6669	2521	2198	1784	1237	657	418528	28289
2022	154356	66133	89306	8905	7975	3909	1444	1189	955	732	334902	25108

Table 30. Estimates of key model variance and covariance parameters for the assessment model (estimates for other model parameters are presented graphically). SE = standard error.

Parameter	Estimate	SE
σ_R	0.316	0.049
φ_R	0.347	0.178
$\sigma_{Fa=2-3}$	2.257	0.358
$\sigma_{Fa=4}$	1.415	0.192
$\sigma_{Fa=5}$	0.668	0.108
$\sigma_{Fa=6+}$	0.467	0.049
$\varphi_{F,age}$	0.758	0.040
$\varphi_{F,yr}$	0.853	0.037
$\sigma_{M,4+}$	0.943	0.088
$\varphi_{M,age}$	0.882	0.049
$\varphi_{M,yr}$	0.937	0.030
σ_X	0.298	0.024
φ_X	0.371	0.101
$\sigma_{s=RV}$	0.514	0.021
$\sigma_{s=GNS}$	0.537	0.027
$\sigma_{s=LLS1,4+}$	0.449	0.024
$\sigma_{s=LLS2,4+}$	0.426	0.023
$\sigma_{s=SenTrawl}$	0.538	0.025
$\sigma_{s=LLS1,3}$	1.631	0.225
$\sigma_{s=LLS2,3}$	1.133	0.165

Table 31. Estimated fishing mortality-at-age and mean fishing mortality, expressed as instantaneous rates.

	Age										
Year	2	3	4	5	6	7	8	9	10	11	5-7 avg	7-10 avg
1973	0	0.003	0.06	0.252	0.354	0.404	0.463	0.46	0.492	0.39	0.315	0.315
1974	0	0.004	0.078	0.296	0.386	0.453	0.53	0.52	0.561	0.422	0.369	0.369
1975	0	0.001	0.049	0.238	0.344	0.427	0.486	0.485	0.562	0.43	0.322	0.322
1976	0	0.001	0.055	0.253	0.389	0.515	0.537	0.528	0.59	0.452	0.316	0.316
1977	0	0	0.034	0.202	0.419	0.613	0.563	0.546	0.567	0.456	0.312	0.312
1978	0	0.001	0.028	0.192	0.392	0.587	0.546	0.503	0.52	0.449	0.325	0.325
1979	0	0.001	0.029	0.186	0.377	0.542	0.565	0.496	0.501	0.431	0.309	0.309
1980	0	0.002	0.04	0.195	0.383	0.553	0.562	0.464	0.475	0.452	0.313	0.313
1981	0	0.002	0.046	0.179	0.342	0.484	0.5	0.432	0.461	0.467	0.306	0.306
1982	0	0.002	0.04	0.194	0.33	0.461	0.503	0.484	0.498	0.478	0.287	0.287
1983	0	0.005	0.056	0.211	0.323	0.438	0.429	0.451	0.456	0.469	0.3	0.3
1984	0	0.001	0.035	0.181	0.352	0.516	0.514	0.514	0.5	0.491	0.333	0.333
1985	0	0.002	0.034	0.194	0.359	0.522	0.562	0.544	0.502	0.469	0.308	0.308
1986	0	0.002	0.03	0.179	0.369	0.543	0.632	0.677	0.57	0.541	0.327	0.327
1987	0	0.002	0.025	0.161	0.369	0.554	0.7	0.738	0.609	0.637	0.307	0.307
1988	0	0.003	0.026	0.148	0.299	0.431	0.548	0.565	0.525	0.589	0.261	0.261
1989	0	0.003	0.03	0.181	0.326	0.46	0.564	0.619	0.588	0.635	0.311	0.311
1990	0	0.004	0.039	0.231	0.383	0.538	0.601	0.689	0.644	0.668	0.34	0.34
1991	0.002	0.015	0.078	0.309	0.483	0.637	0.704	0.756	0.7	0.688	0.401	0.401
1992	0.002	0.021	0.123	0.372	0.598	0.817	0.906	0.98	0.989	0.861	0.492	0.492
1993	0.001	0.015	0.158	0.465	0.715	0.923	0.962	1.085	1.122	0.887	0.643	0.643
1994	0	0.003	0.01	0.016	0.015	0.019	0.021	0.022	0.024	0.018	0.016	0.016
1995	0	0.001	0.001	0.005	0.008	0.011	0.015	0.014	0.019	0.014	0.007	0.007
1996	0	0	0.002	0.005	0.009	0.014	0.02	0.017	0.026	0.017	0.008	0.008
1997	0.001	0.003	0.023	0.053	0.128	0.177	0.257	0.256	0.374	0.266	0.101	0.101
1998	0	0	0.006	0.032	0.109	0.148	0.218	0.257	0.367	0.271	0.067	0.067
1999	0	0	0.009	0.049	0.149	0.209	0.319	0.369	0.474	0.339	0.109	0.109
2000	0	0	0.01	0.056	0.147	0.219	0.296	0.372	0.45	0.293	0.123	0.123
2001	0	0	0.014	0.057	0.153	0.225	0.317	0.364	0.347	0.27	0.121	0.121
2002	0	0	0.007	0.043	0.13	0.211	0.301	0.347	0.287	0.25	0.102	0.102
2003	0	0	0	0.003	0.007	0.012	0.016	0.017	0.013	0.013	0.006	0.006
2004	0	0	0.001	0.015	0.048	0.083	0.116	0.147	0.121	0.13	0.041	0.041
2005	0	0	0.001	0.014	0.052	0.1	0.144	0.172	0.137	0.159	0.051	0.051
2006	0	0	0.002	0.021	0.07	0.129	0.201	0.227	0.176	0.194	0.06	0.06
2007	0	0	0.005	0.033	0.088	0.16	0.234	0.294	0.23	0.241	0.076	0.076
2008	0	0	0.012	0.045	0.102	0.176	0.238	0.326	0.258	0.287	0.088	0.088
2009	0	0.002	0.022	0.056	0.1	0.162	0.193	0.291	0.238	0.314	0.082	0.082
2010	0	0	0.008	0.034	0.069	0.124	0.152	0.219	0.201	0.283	0.059	0.059
2011	0.001	0	0.003	0.015	0.049	0.087	0.115	0.142	0.146	0.215	0.04	0.04
2012	0.001	0	0.001	0.008	0.034	0.067	0.094	0.112	0.116	0.148	0.03	0.03
2013	0.001	0	0.002	0.009	0.033	0.057	0.084	0.103	0.098	0.102	0.031	0.031
2014	0	0	0.002	0.009	0.03	0.051	0.083	0.107	0.096	0.091	0.024	0.024
2015	0	0	0.001	0.007	0.027	0.05	0.084	0.109	0.086	0.087	0.019	0.019
2016	0	0	0.001	0.008	0.026	0.053	0.078	0.113	0.085	0.103	0.02	0.02

						Age					
Year	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**5-7 avg**	**7-10 avg**
2017	0	0	0.002	0.01	0.034	0.076	0.114	0.153	0.116	0.153	0.033	0.033
2018	0	0	0.003	0.014	0.038	0.081	0.114	0.144	0.117	0.155	0.04	0.04
2019	0	0	0.001	0.009	0.027	0.059	0.082	0.105	0.09	0.126	0.03	0.03
2020	0	0	0.003	0.015	0.032	0.06	0.077	0.093	0.087	0.089	0.028	0.028
2021	0	0	0.001	0.01	0.027	0.05	0.068	0.079	0.081	0.081	0.02	0.02
2022	0	0	0.001	0.012	0.028	0.048	0.063	0.074	0.077	0.069	0.025	0.025

Table 32. Natural mortality rate at age, assumed (in italics) or estimated by the model, expressed as instantaneous rates.

	Age									
Year	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1973	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1974	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1975	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1976	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1977	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1978	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1979	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1980	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1981	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1982	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1983	*1*	*0.65*	*0.45*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*	*0.15*
1984	*1*	*0.65*	0.35	0.12	0.14	0.14	0.14	0.14	0.17	0.17
1985	*1*	*0.65*	0.36	0.12	0.14	0.14	0.14	0.14	0.18	0.18
1986	*1*	*0.65*	0.38	0.13	0.15	0.15	0.16	0.16	0.2	0.2
1987	*1*	*0.65*	0.56	0.19	0.23	0.23	0.23	0.23	0.29	0.29
1988	*1*	*0.65*	0.88	0.29	0.35	0.35	0.34	0.34	0.42	0.42
1989	*1*	*0.65*	1.03	0.34	0.4	0.4	0.38	0.38	0.47	0.47
1990	*1*	*0.65*	1.22	0.41	0.49	0.49	0.43	0.43	0.54	0.54
1991	*1*	*0.65*	1.16	0.39	0.49	0.49	0.43	0.43	0.54	0.54
1992	*1*	*0.65*	1.48	0.49	0.66	0.66	0.59	0.59	0.77	0.77
1993	*1*	*0.65*	1.27	0.42	0.58	0.58	0.54	0.54	0.78	0.78
1994	*1*	*0.65*	1.17	0.39	0.54	0.54	0.52	0.52	0.81	0.81
1995	*1*	*0.65*	1.06	0.35	0.55	0.55	0.59	0.59	1.03	1.03
1996	*1*	*0.65*	0.9	0.3	0.48	0.48	0.55	0.55	0.97	0.97
1997	*1*	*0.65*	0.69	0.23	0.36	0.36	0.42	0.42	0.71	0.71
1998	*1*	*0.65*	0.8	0.27	0.38	0.38	0.42	0.42	0.66	0.66
1999	*1*	*0.65*	1.04	0.35	0.48	0.48	0.5	0.5	0.79	0.79
2000	*1*	*0.65*	0.95	0.32	0.41	0.41	0.38	0.38	0.59	0.59
2001	*1*	*0.65*	1.41	0.47	0.59	0.59	0.46	0.46	0.63	0.63
2002	*1*	*0.65*	0.88	0.29	0.38	0.38	0.29	0.29	0.37	0.37
2003	*1*	*0.65*	0.79	0.26	0.35	0.35	0.26	0.26	0.32	0.32
2004	*1*	*0.65*	0.78	0.26	0.37	0.37	0.31	0.31	0.38	0.38
2005	*1*	*0.65*	0.77	0.26	0.4	0.4	0.37	0.37	0.48	0.48
2006	*1*	*0.65*	0.69	0.23	0.4	0.4	0.39	0.39	0.57	0.57
2007	*1*	*0.65*	0.91	0.3	0.61	0.61	0.67	0.67	1.14	1.14
2008	*1*	*0.65*	0.82	0.27	0.58	0.58	0.67	0.67	1.3	1.3
2009	*1*	*0.65*	0.9	0.3	0.67	0.67	0.77	0.77	1.66	1.66
2010	*1*	*0.65*	1.16	0.39	0.75	0.75	0.77	0.77	1.57	1.57
2011	*1*	*0.65*	0.83	0.28	0.49	0.49	0.49	0.49	0.85	0.85
2012	*1*	*0.65*	0.93	0.31	0.58	0.58	0.57	0.57	0.8	0.8
2013	*1*	*0.65*	0.9	0.3	0.55	0.55	0.54	0.54	0.72	0.72
2014	*1*	*0.65*	0.76	0.25	0.44	0.44	0.49	0.49	0.66	0.66
2015	*1*	*0.65*	1.09	0.36	0.55	0.55	0.62	0.62	0.77	0.77
2016	*1*	*0.65*	1.35	0.45	0.55	0.55	0.61	0.61	0.76	0.76

					Age					
Year	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2017	*1*	*0.65*	1.83	0.61	0.75	0.75	0.91	0.91	1.26	1.26
2018	*1*	*0.65*	1.82	0.61	0.64	0.64	0.69	0.69	0.96	0.96
2019	*1*	*0.65*	1.18	0.39	0.38	0.38	0.41	0.41	0.64	0.64
2020	*1*	*0.65*	1.18	0.39	0.37	0.37	0.38	0.38	0.58	0.58
2021	*1*	*0.65*	1.49	0.5	0.51	0.51	0.55	0.55	0.87	0.87
2022	*1*	*0.65*	1.37	0.46	0.5	0.5	0.55	0.55	0.85	0.85

Table 33. Input and estimated catches and hypothesized unaccounted (Unacc.) catch calculated assuming that age-specific natural mortality in excess of 2003 (moratorium) values constituted unaccounted fishing. All value are in tonnes.

Year	Input	Estimate	Unacc. Age 4	Unacc. Age 5+
1973	70146	72669	-	-
1974	73140	73428	-	-
1975	62521	64181	-	-
1976	80910	77948	-	-
1977	78929	74902	-	-
1978	81733	82388	-	-
1979	89605	90806	-	-
1980	105619	104801	-	-
1981	103745	106335	-	-
1982	112830	109261	-	-
1983	113172	116706	-	-
1984	113162	107559	-	-
1985	93115	92977	-	-
1986	90527	87909	-	-
1987	70330	70514	-	-
1988	51412	56322	-	-
1989	46309	46373	-	-
1990	39573	39509	-	-
1991	36606	35030	-	-
1992	30100	31567	-	-
1993	19833	19680	-	-
1994	574	508	-	-
1995	209	242	-	-
1996	337	328	-	-
1997	4858	4752	-	-
1998	3546	3740	-	-
1999	7319	6770	-	-
2000	7295	7294	-	-
2001	7429	7179	-	-
2002	6734	6087	-	-
2003	407	407	-	-
2004	3345	3869	0	611
2005	4570	4687	0	1632
2006	5907	5520	0	1871
2007	6761	6839	2776	6764
2008	6452	5992	1095	4790
2009	4918	5089	3322	5930
2010	3759	3495	12531	8802
2011	2002	2337	773	2860
2012	1548	1965	2195	5392
2013	1469	1896	2262	4417
2014	1492	2003	0	2280
2015	1479	1995	12154	5927
2016	1685	2221	18790	8096

Year	Input	Estimate	Unacc. Age 4	Unacc. Age 5+
2017	3019	2796	27846	12946
2018	2899	2689	16334	7243
2019	1067	1599	7320	1531
2020	950	1481	9741	1861
2021	932	1266	14201	5048
2022	437	1003	28003	3954

Table 34. Results of 3-year projections from the assessment model under different catch options, based on 10,000 simulations.

Catch option (t)	Prob. of any increase in SSB	Prob. of >10% increase in SSB	Prob. of reaching or exceeding B_{lim}	Prob. of any increase in age 5+ abundance	Prob. of >10% increase in age 5+ abundance
0	0.5143	0.3973	0.0377	0.3178	0.2321
500	0.5092	0.3912	0.0335	0.3120	0.2248
1000	0.4814	0.3654	0.0311	0.3000	0.2142
1500	0.4488	0.3333	0.0275	0.2772	0.2004

9 FIGURES

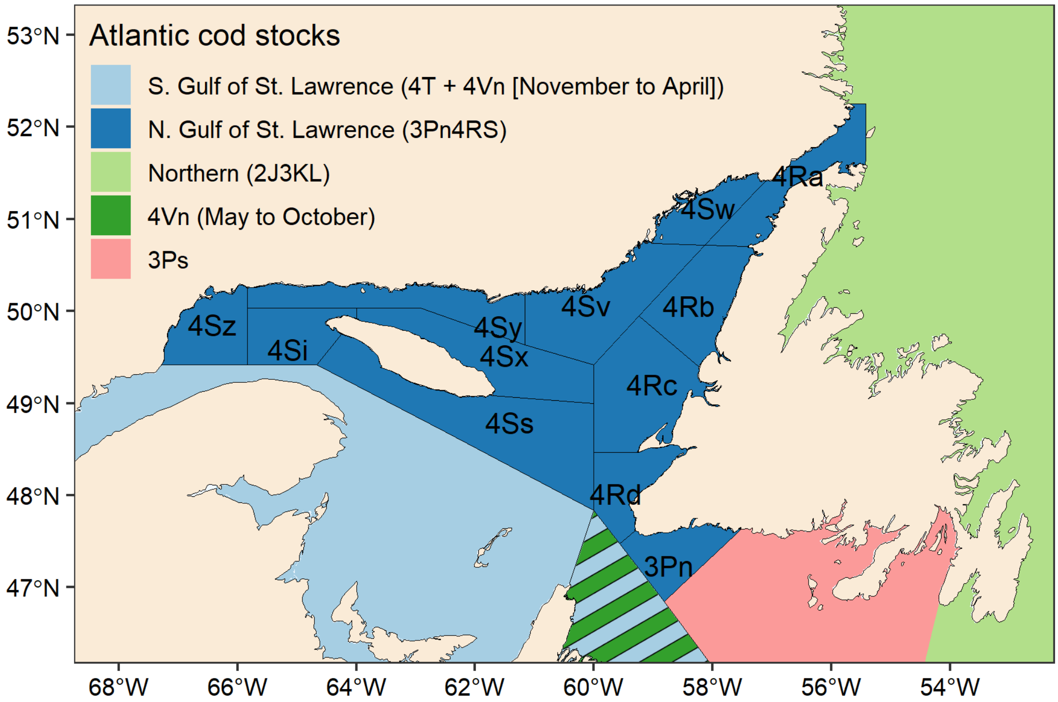

Figure 1. Different stocks of Atlantic cod from the northwest Atlantic surrounding the 3Pn4RS stock. NAFO unit areas for the 3Pn4RS stock are provided.

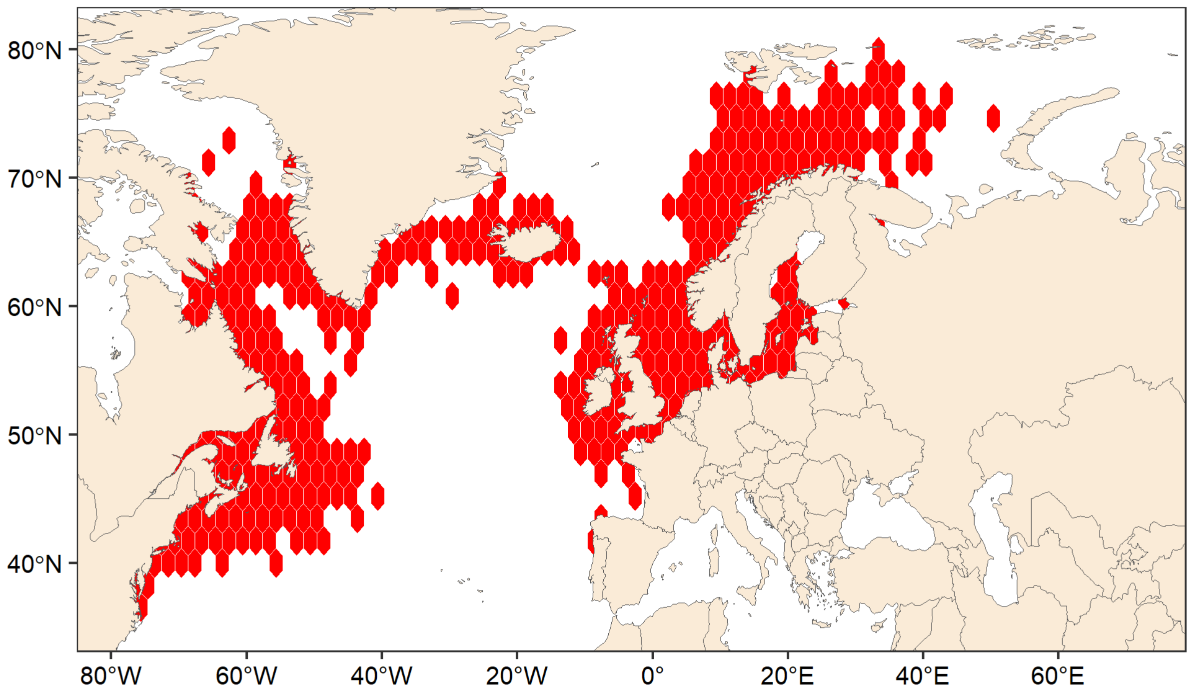

Figure 2. Global distribution area of Atlantic cod, Gadus morhua. Data source: OBIS.

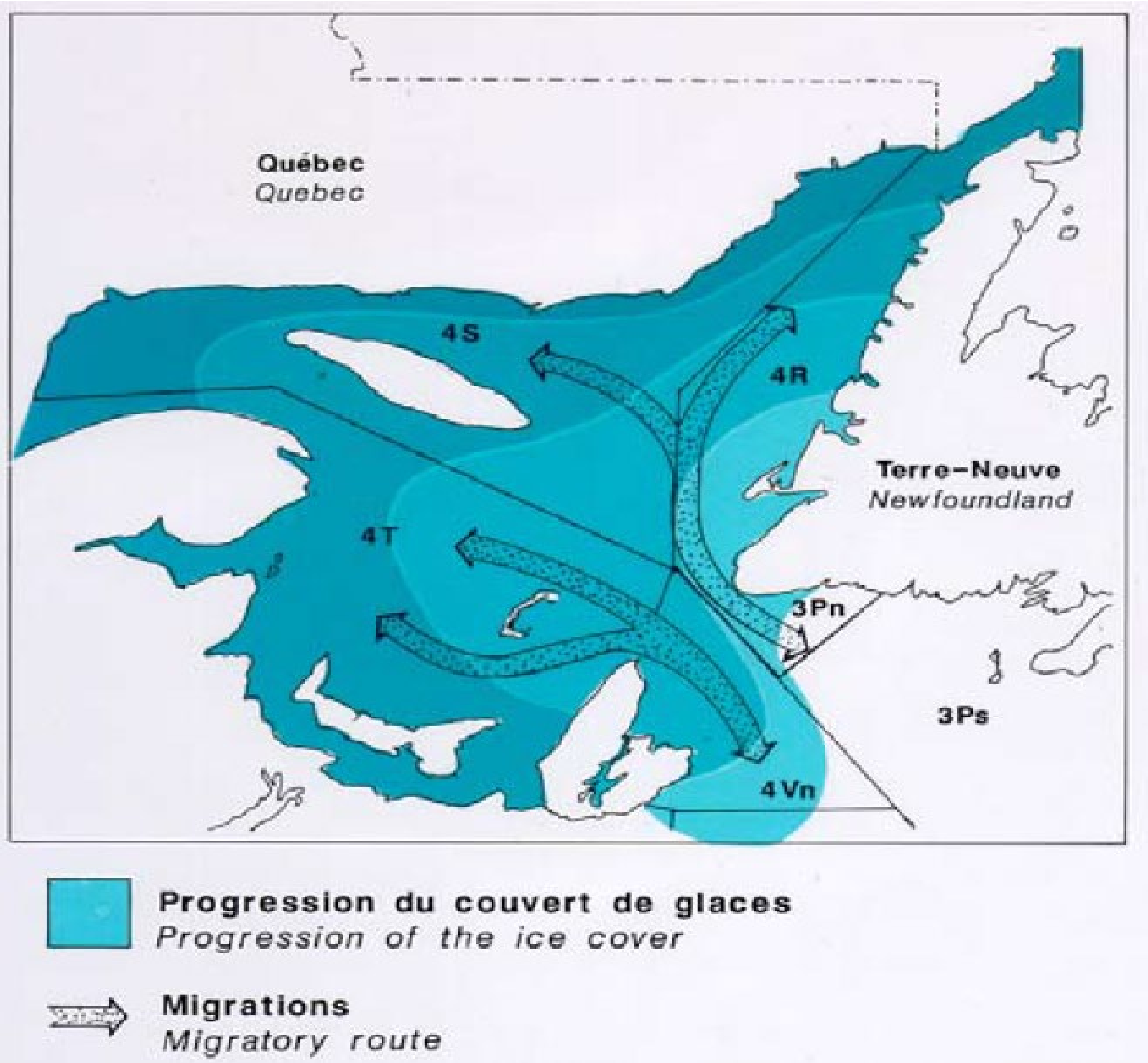

Figure 3. General migration routes of cod stocks in the Gulf of St. Lawrence. Figure taken from Yvelin et al. (2005) and from the work of Fréchet (1990).

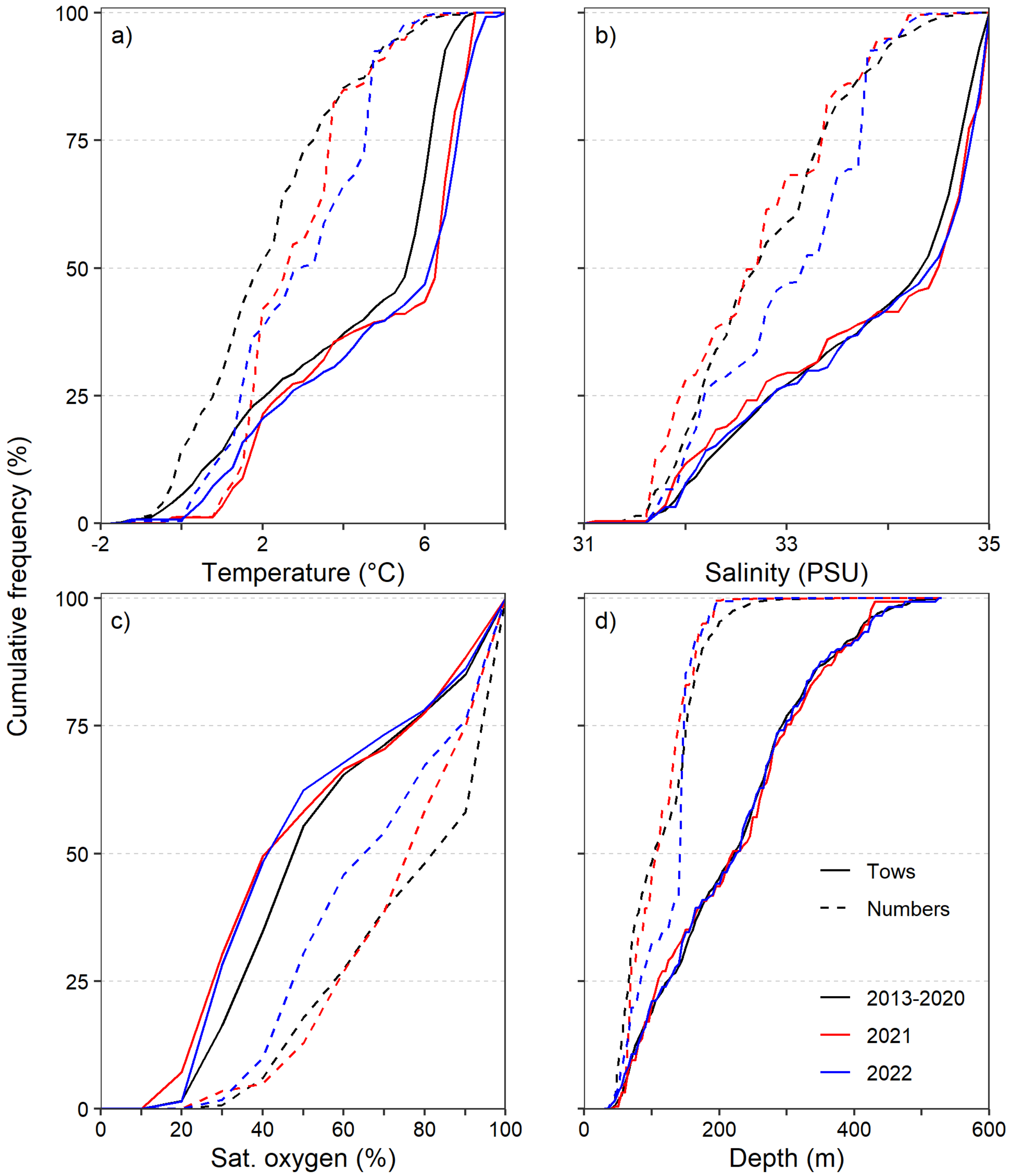

Figure 4. Distribution of catches in numbers by a) bottom temperature, b) bottom salinity, c) bottom oxygen saturation (%) and (d) depth in the DFO August survey during the last 10 years. Only tows performed in NAFO Divisions 4RS were considered.

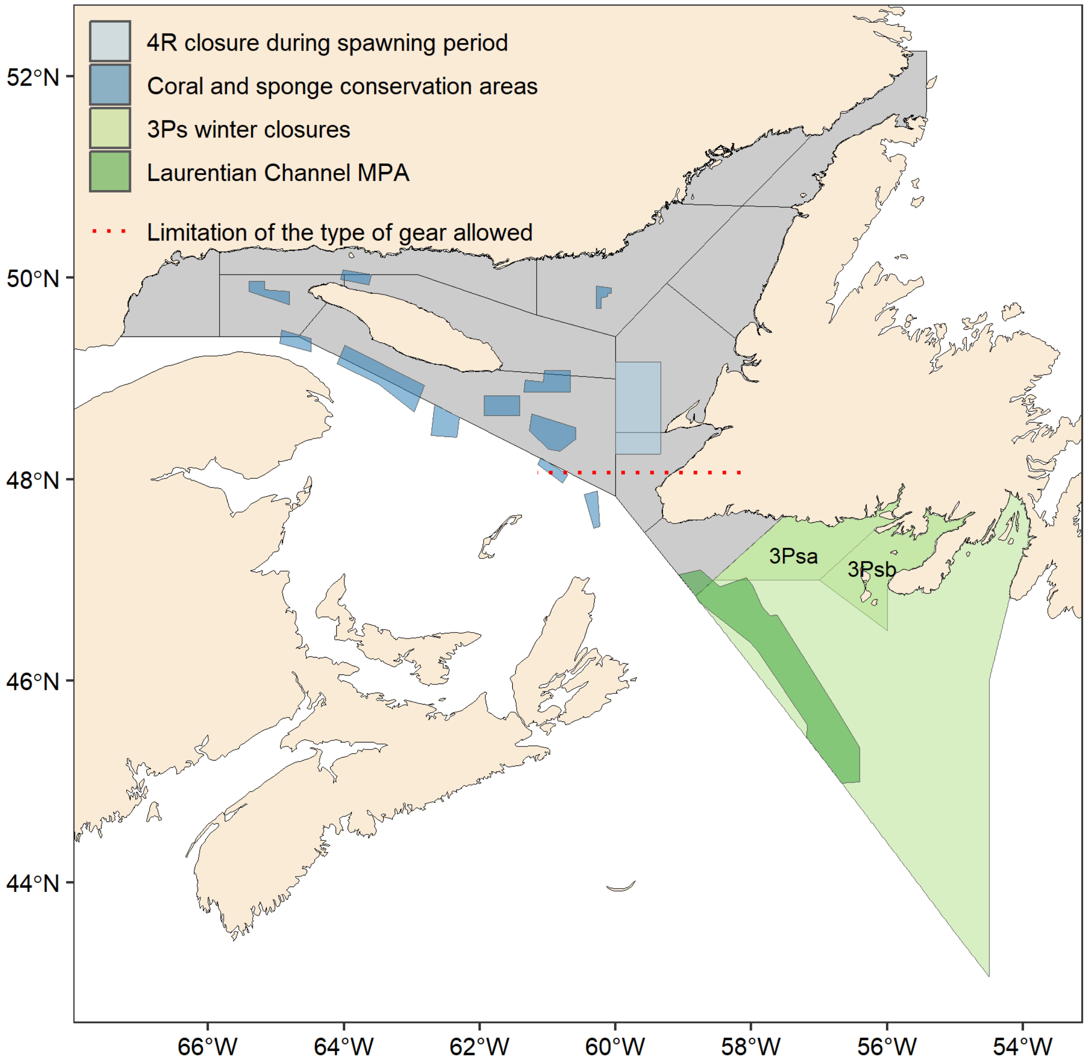

Figure 5. Summary of selected management and conservation measures impacting the nGSL cod stock, the distribution of which is shown in grey. Details are provided in the text. MPA = marine protected area.

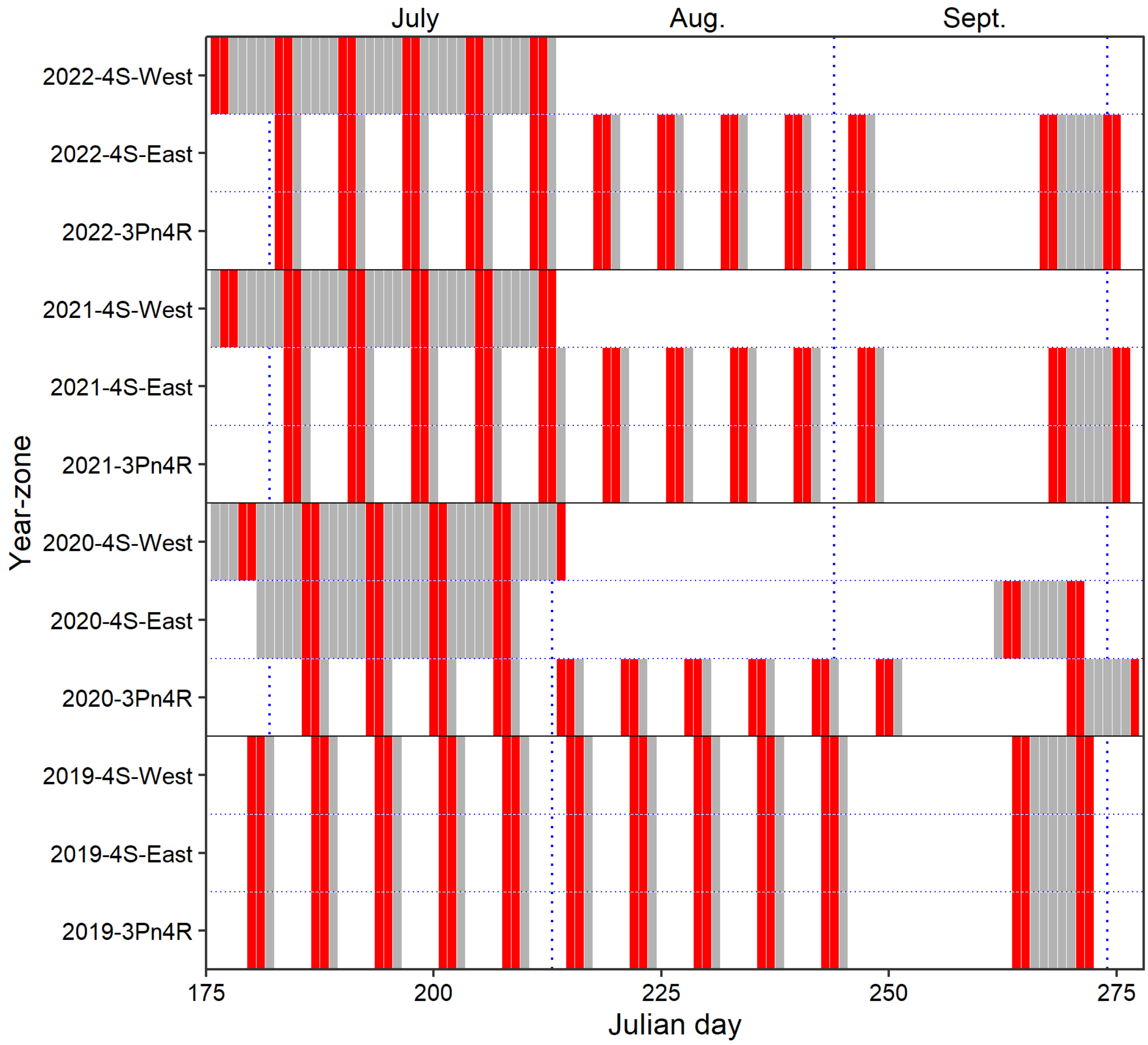

Figure 6. Visualization of the 2019-2022 nGSL recreational cod fishing seasons. Cells in red are weekend days while those in grey are weekdays. Zone 4S-West refers to the area between Pointe-des-Monts and Natashquan. Zone 4S-East refers to the area between Natashquan and Blanc-Sablon.

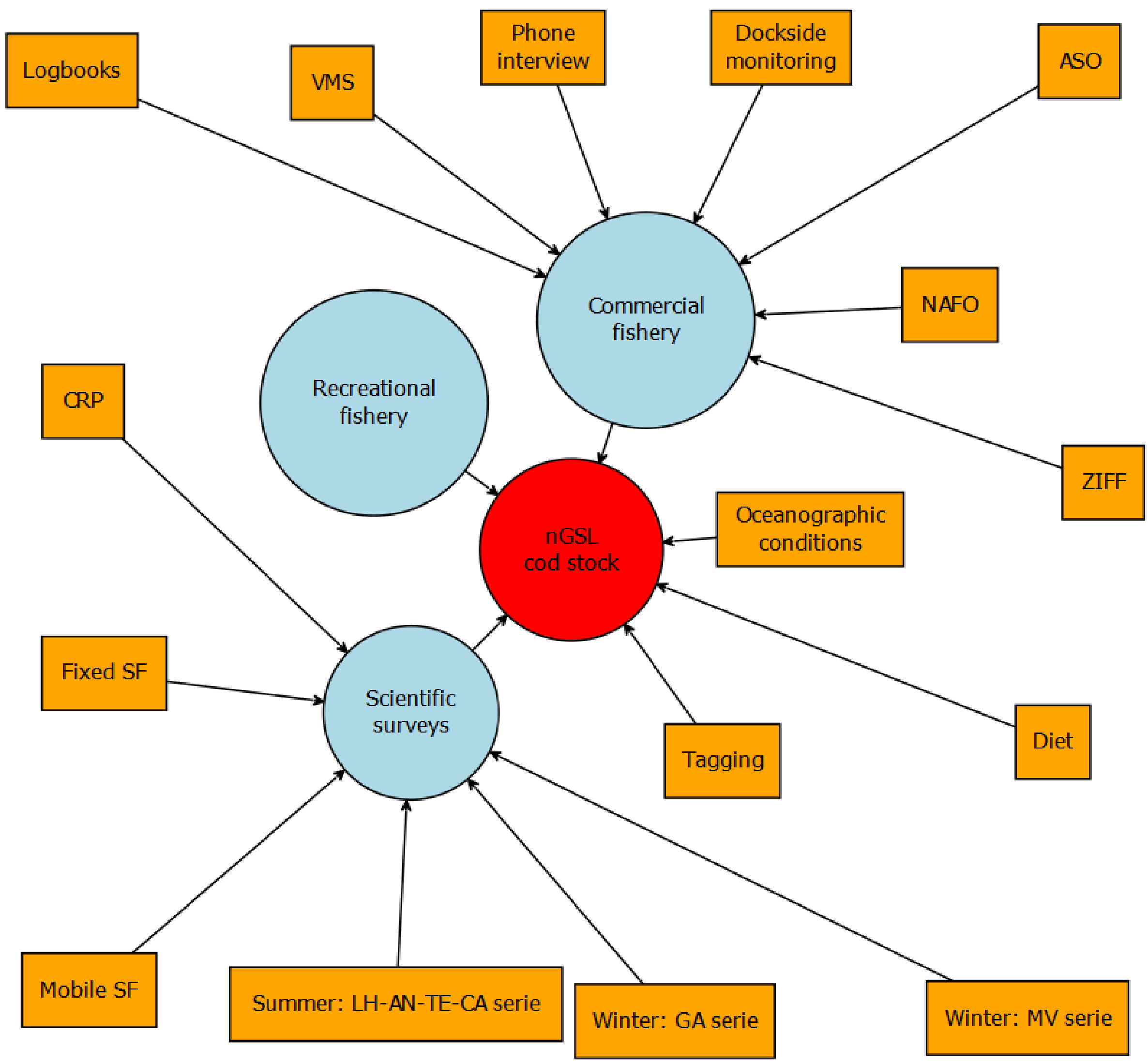

Figure 7. Different sources of data (orange) available for the assessment of Atlantic cod in the northern Gulf of St. Lawrence. AN = Alfred Needler, ASO = at-sea observers, CA = John Cabot, CRP = cod reproductive potential, GA = Gadus Atlantica, LH = Lady Hammond, MV = Mersey Venture, NAFO = Northwest Atlantic Fisheries Organization, SF = sentinel fishery, TE = Teleost, VMS = vessel monitoring system, ZIFF = Zonal Interchange File Format.

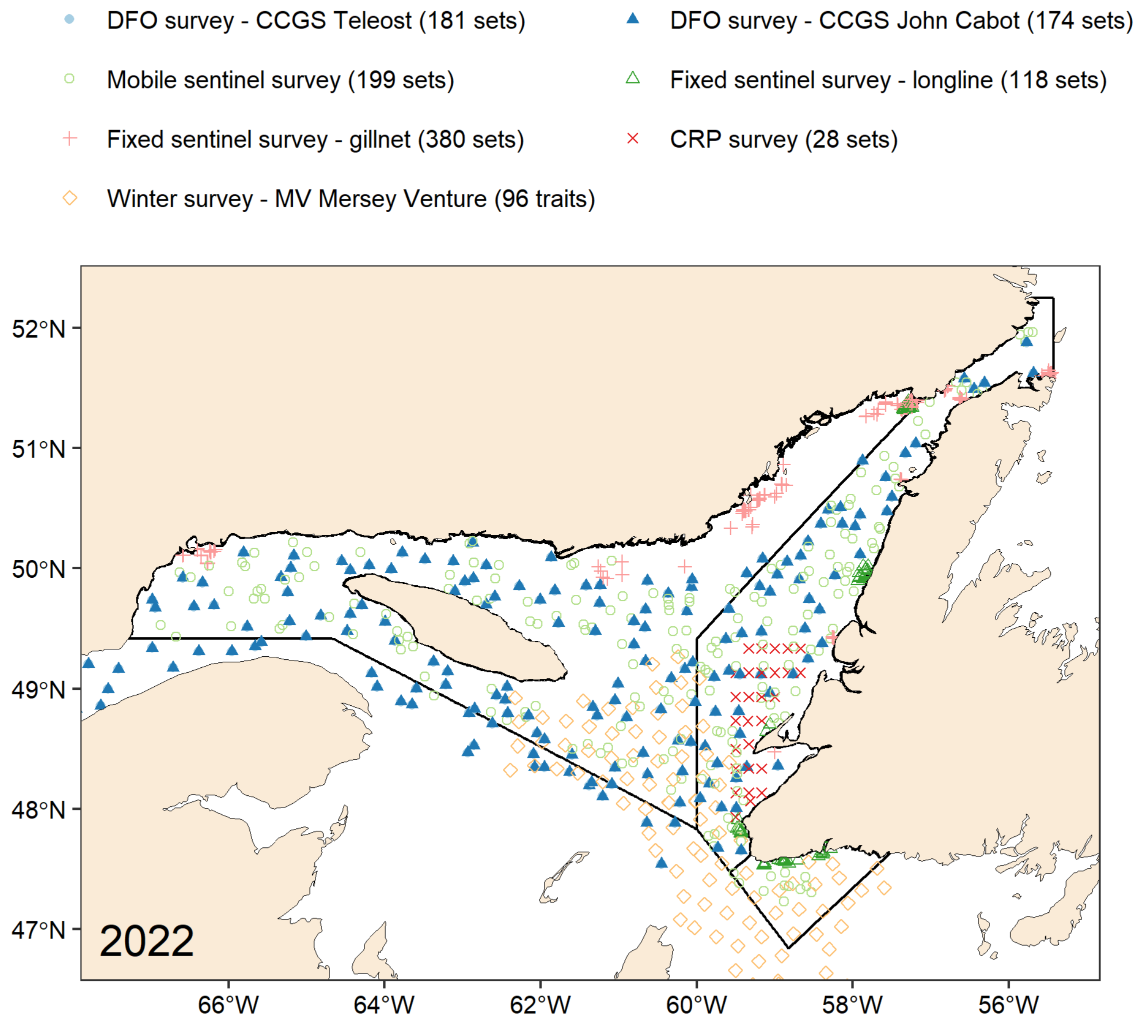

Figure 8. Spatial distribution of the various surveys carried out in 2022 and detailed in this stock assessment.

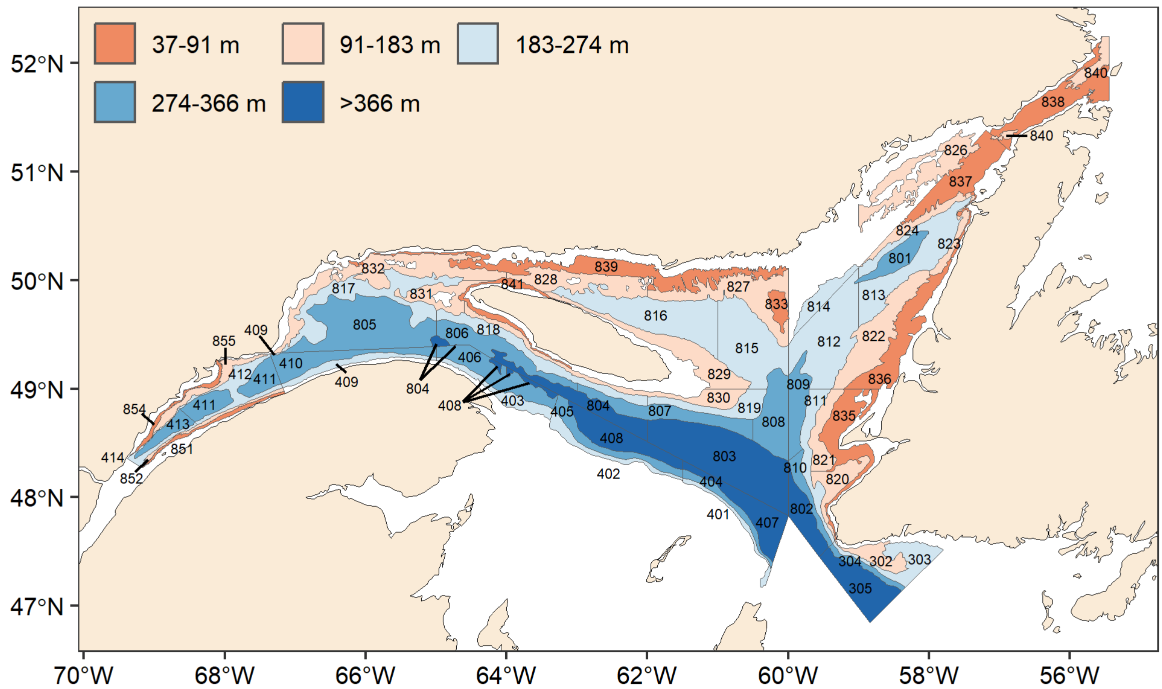

Figure 9. Stratification scheme used for the DFO August survey carried out in the Estuary and northern Gulf of St. Lawrence.

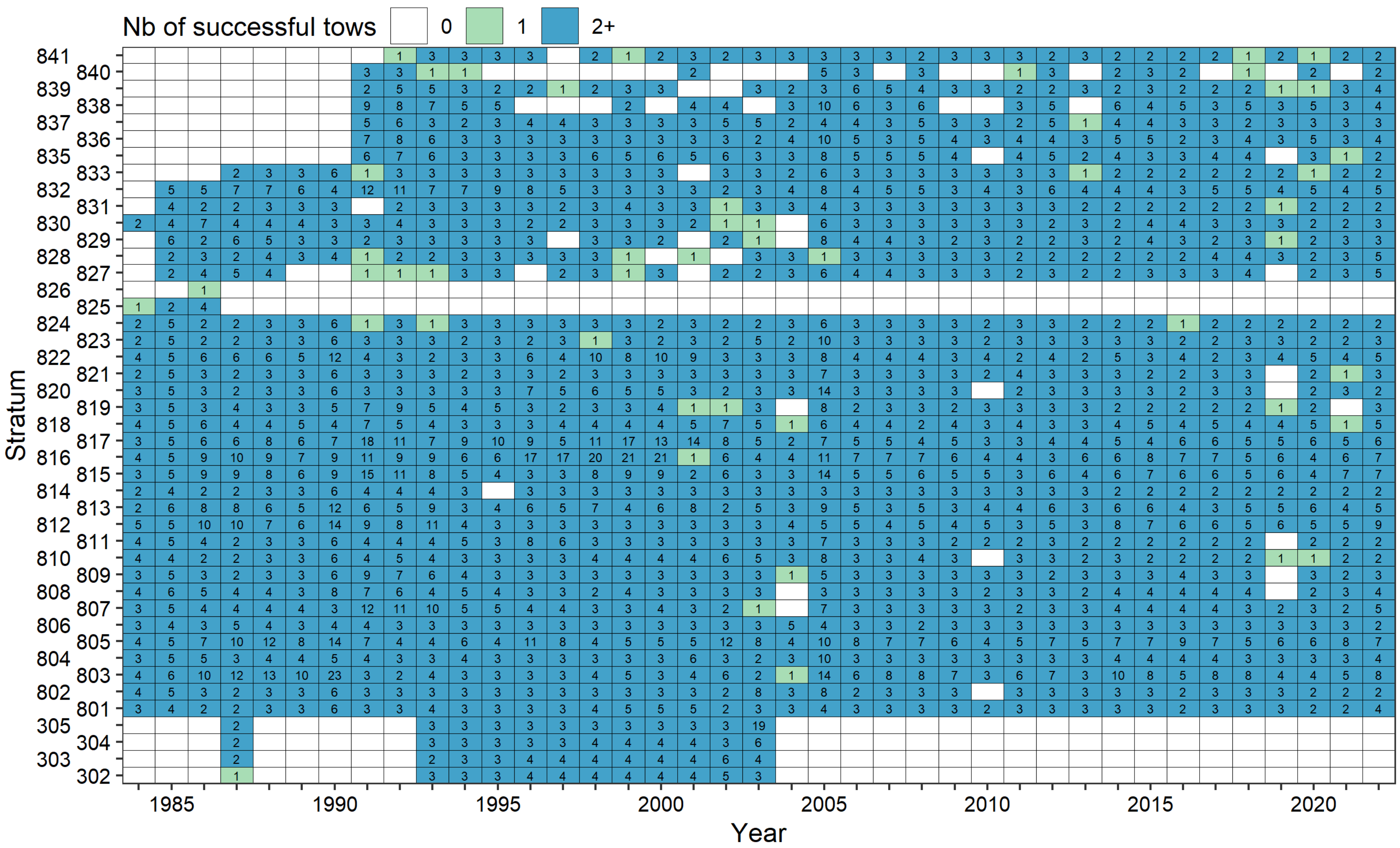

Figure 10. Number of successful tows made in each stratum during the DFO August survey, by year. Only 3Pn4RS strata are shown.

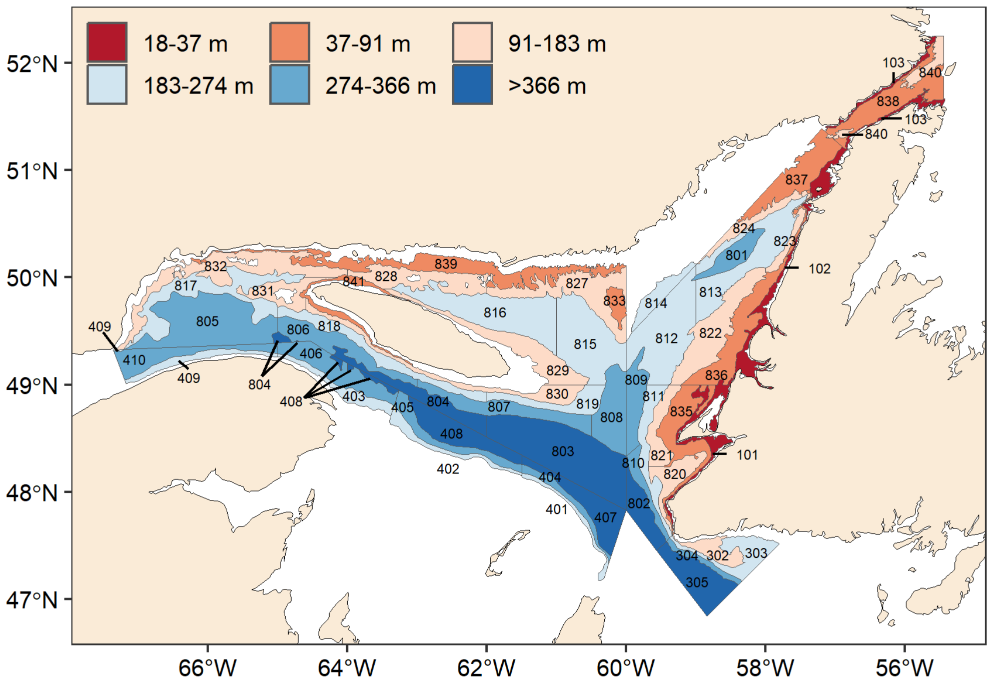

Figure 11. Stratification scheme used for the mobile sentinel survey. Strata 101 to 103 (18-37 m) were added in 2003.

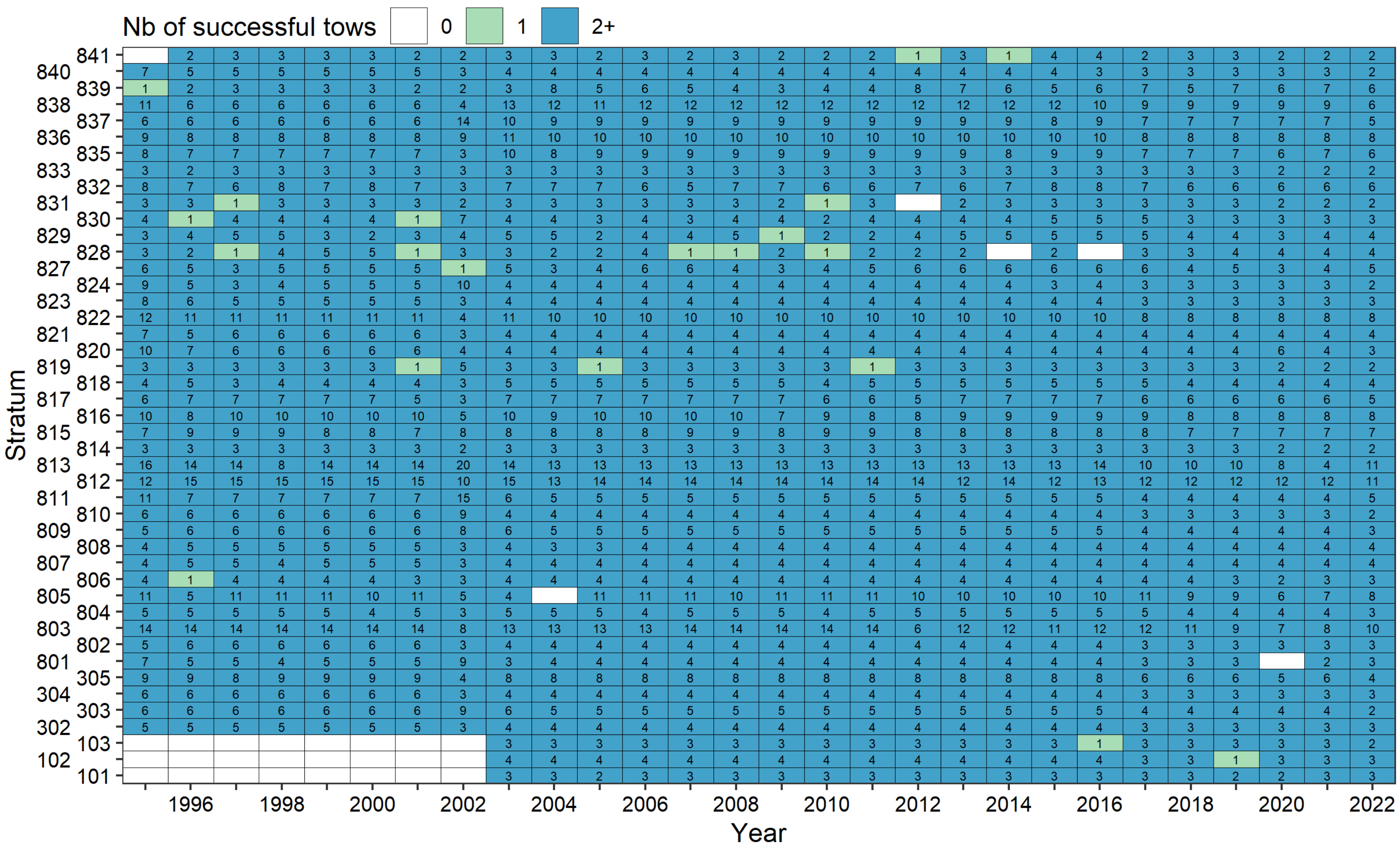

Figure 12. Number of successful tows made in each stratum during the mobile sentinel survey, by year. Only 3Pn4RS strata are shown.

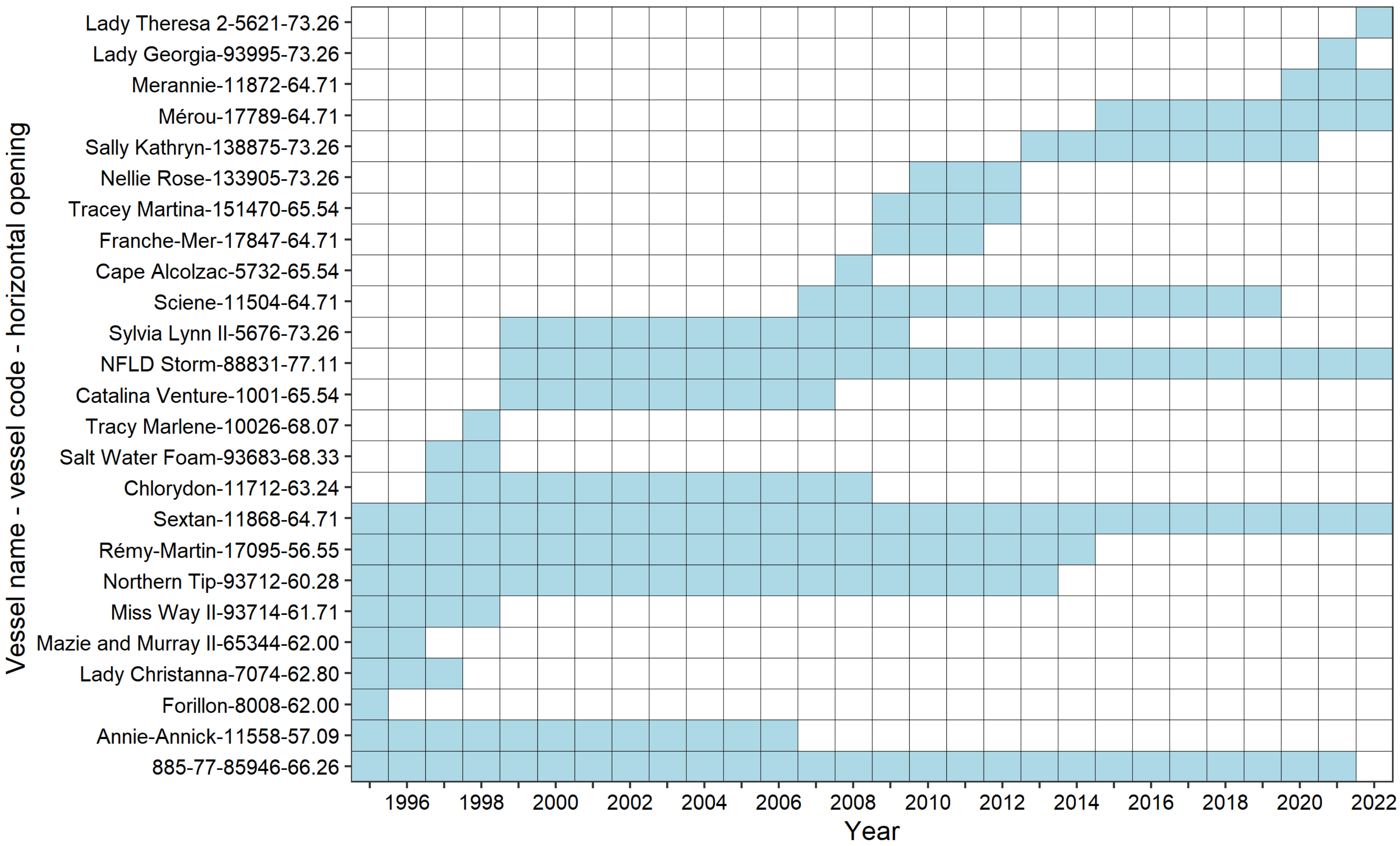

Figure 13. Evolution of vessels used in the July mobile sentinel survey. The horizontal opening values are in feet and correspond to the values used in the calculations for activities where the retention cable was not used.

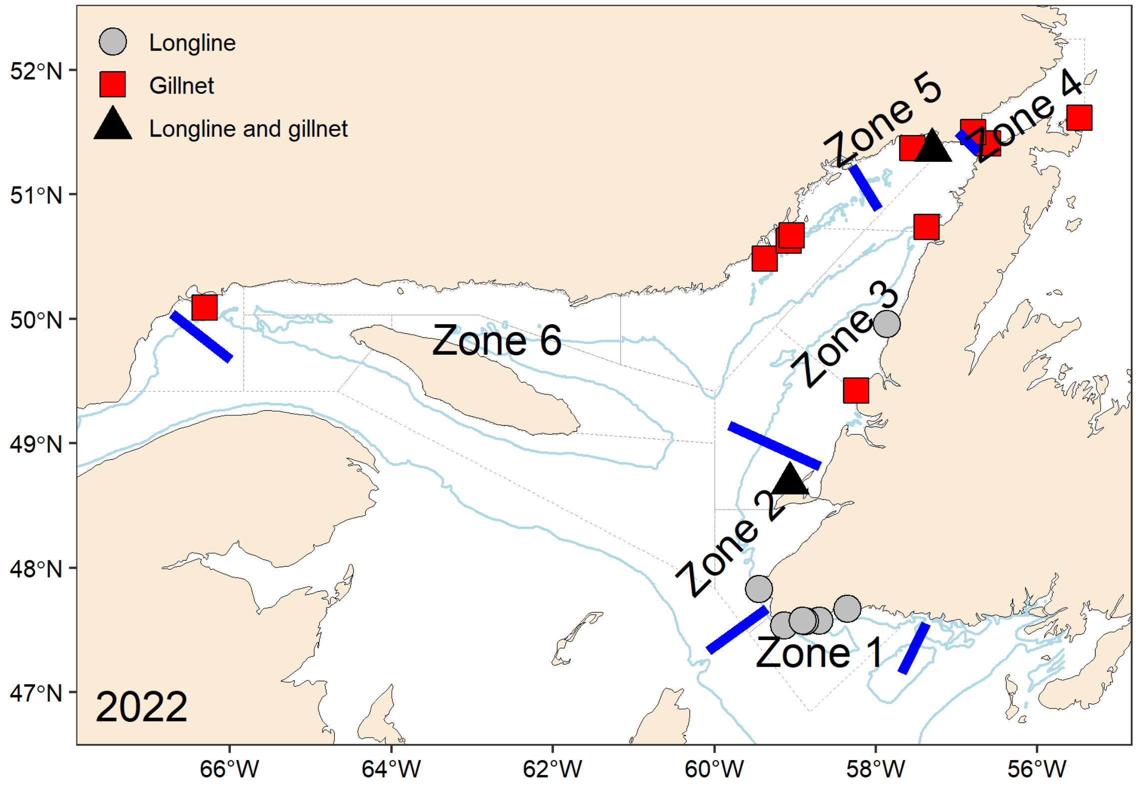

Figure 14. Spatial distribution of sampling effort for fixed gear sentinel survey indices in 2022. The blue lines delimit the six zones.

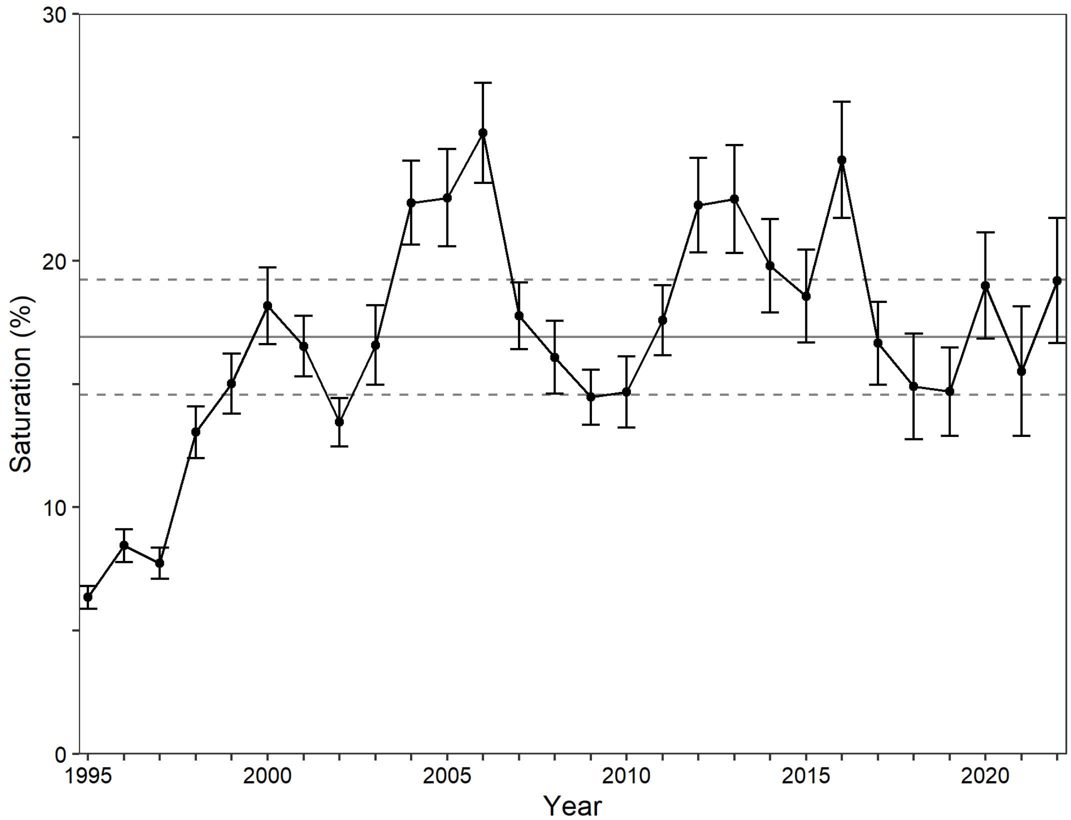

Figure 15. Mean annual saturation (± 95% confidence intervals) of longline fishing activities in the sentinel survey program. The solid horizontal line represents the mean 1995-2022. Hatched horizontal lines represent the series mean ± 0.5 standard deviation.

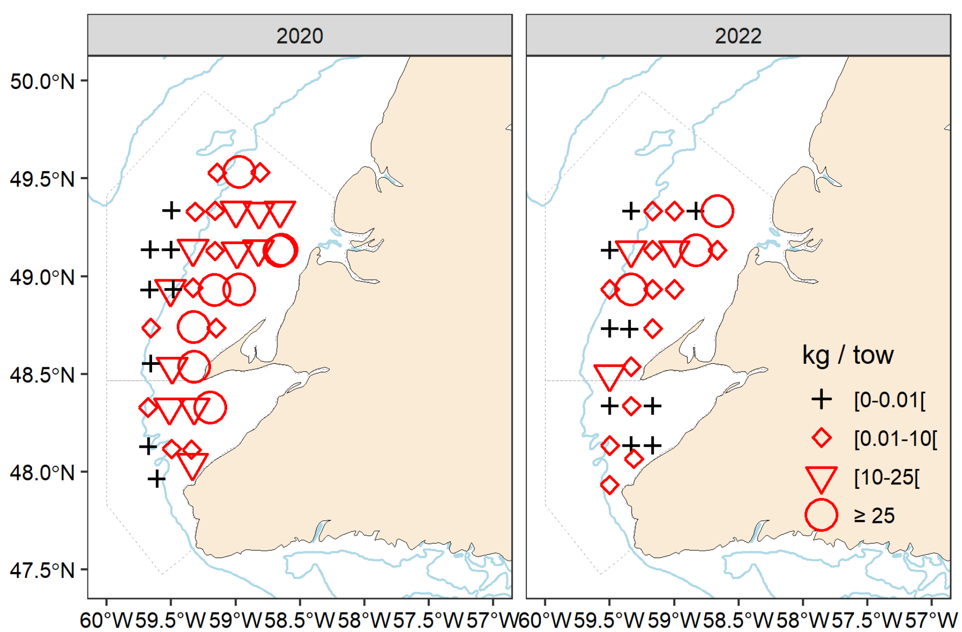

Figure 16. Distribution of cod catch rates (kg per tow) during the May 2020 and 2022 reproductive potential survey. The 200 m isobath is shown in light blue, as well as the delineation of NAFO unit areas 4Rc and 4Rd in hatched gray.

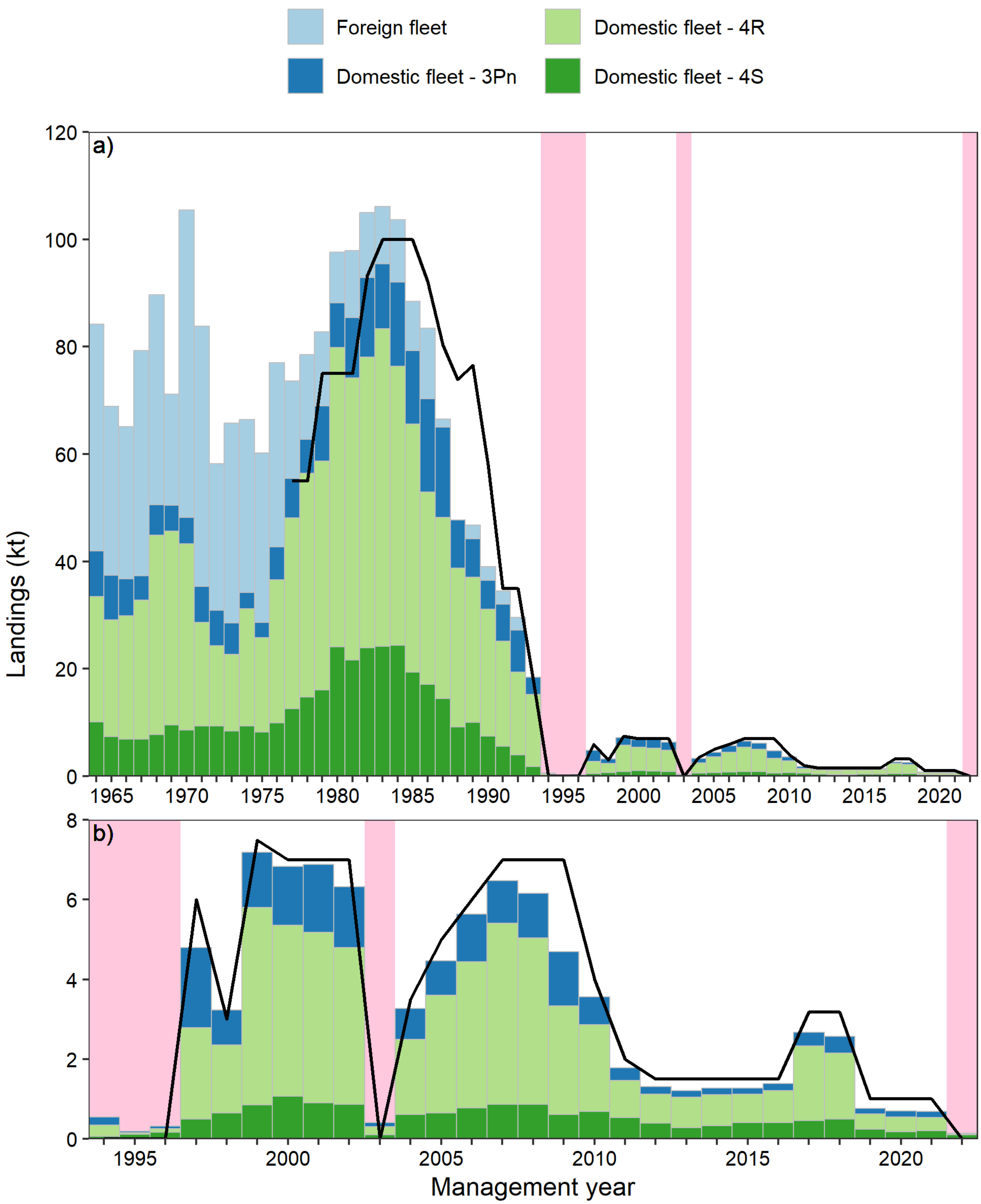

Figure 17. Annual landings of 3Pn4RS Atlantic cod and total allowable catch (TAC, black line) by management year. The complete series is shown in a) and the period 1994–2022 in b). Moratorium years are shaded in pink. Until 1998, the management year corresponded to the calendar year. The 1999/2000 management year began on January 1st, 1999 and ended on May 14th, 2000. Thereafter, the management year begins on May 15th of the current year and ends on May 14th of the following year. Source: NAFO 21B and ZIFF data.

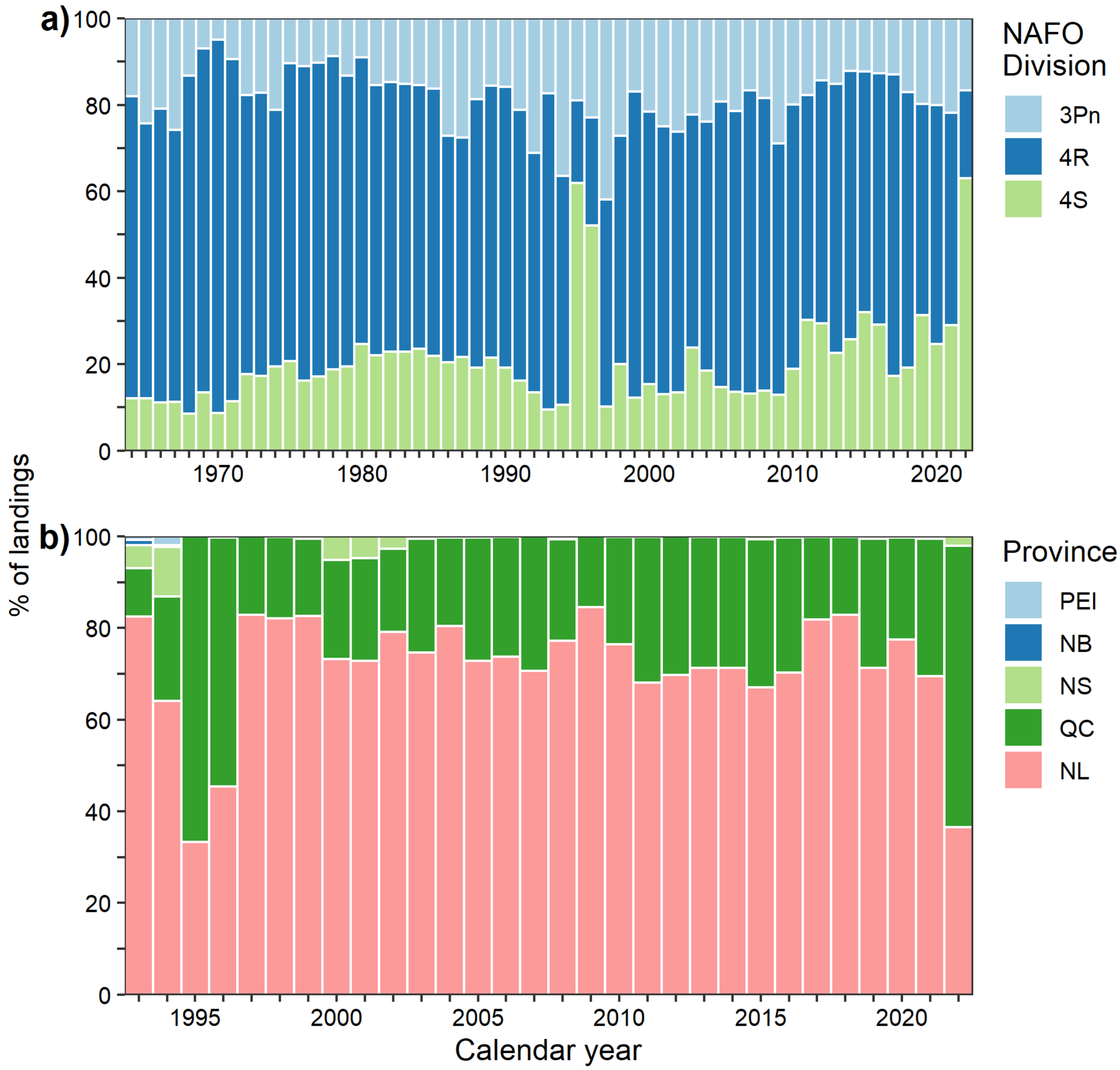

Figure 18. Percentage of reported annual 3Pn4RS Atlantic cod landings by a) NAFO Division and b) province. The series begins in 1993 in b) in order to eliminate foreign fleets landings. PEI = Prince Edward Island, NB = New Brunswick, NS = Nova Scotia, QC = Quebec, NL = Newfoundland and Labrador. Source: NAFO 21B and ZIFF data.

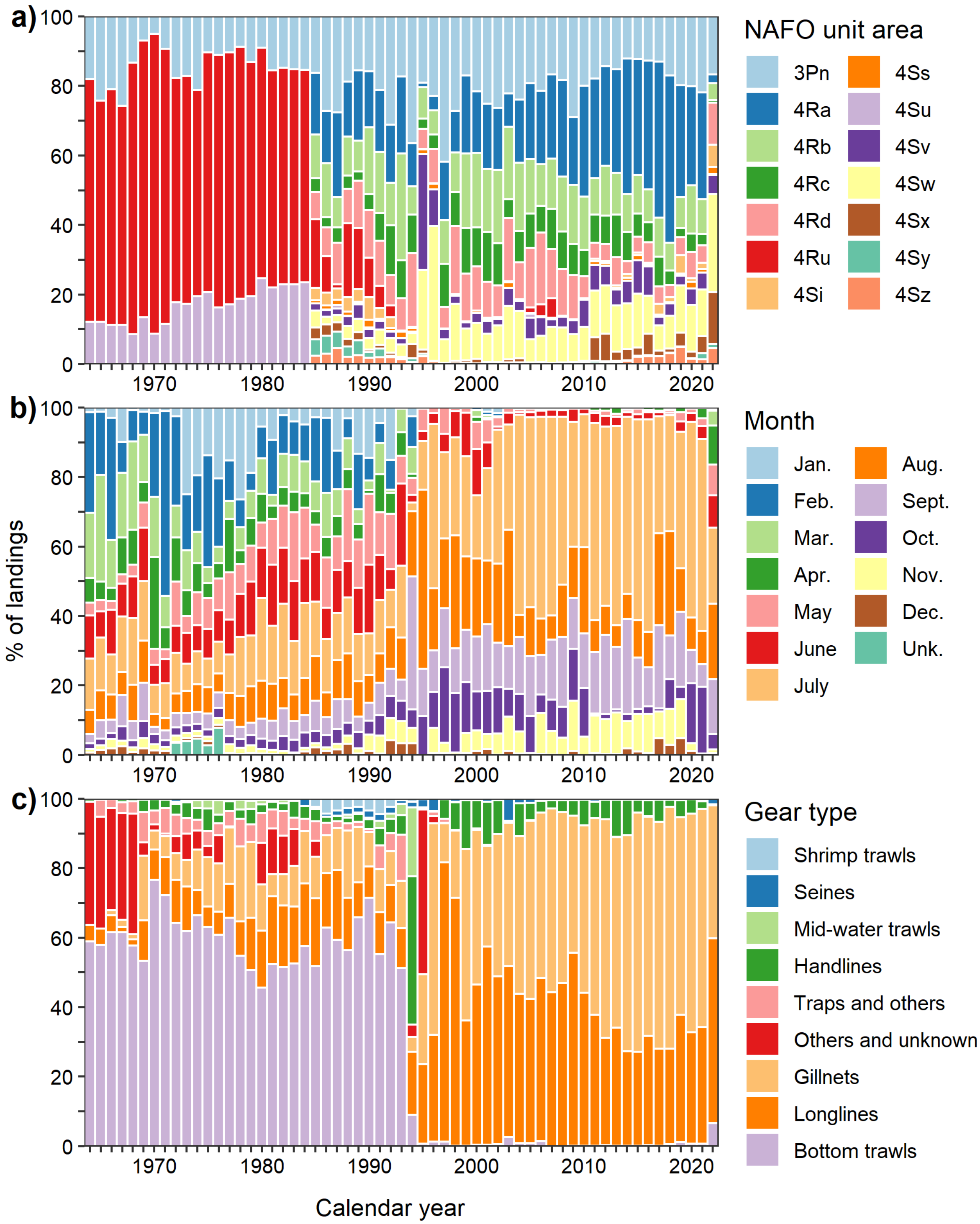

Figure 19. Percentage of annual reported 3Pn4RS Atlantic cod landings by a) NAFO unit area, b) month, and c) type of fishing gear for the period 1964–-2022. In a), unit areas 4Ru and 4Su correspond to landings recorded in Divisions 4R and 4S respectively, but for which the exact unit area is unknown. Data from the last two years are provisional. Source: NAFO 21B and ZIFF data.

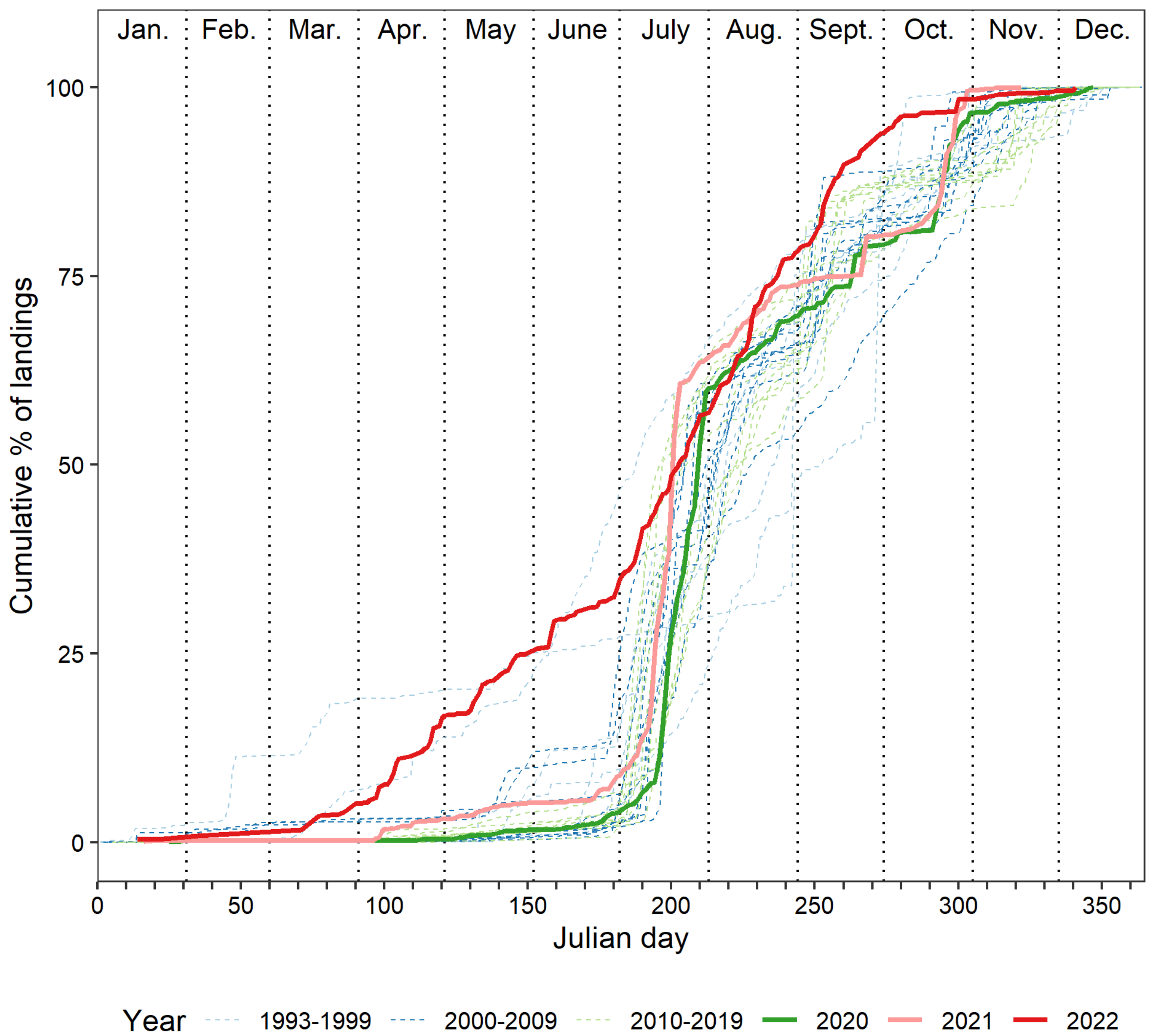

Figure 20. Annual cumulative landings (%) of Atlantic cod from the 3Pn4RS stock as a function of day of year for the period 1993–2022. Source: ZIFF data.

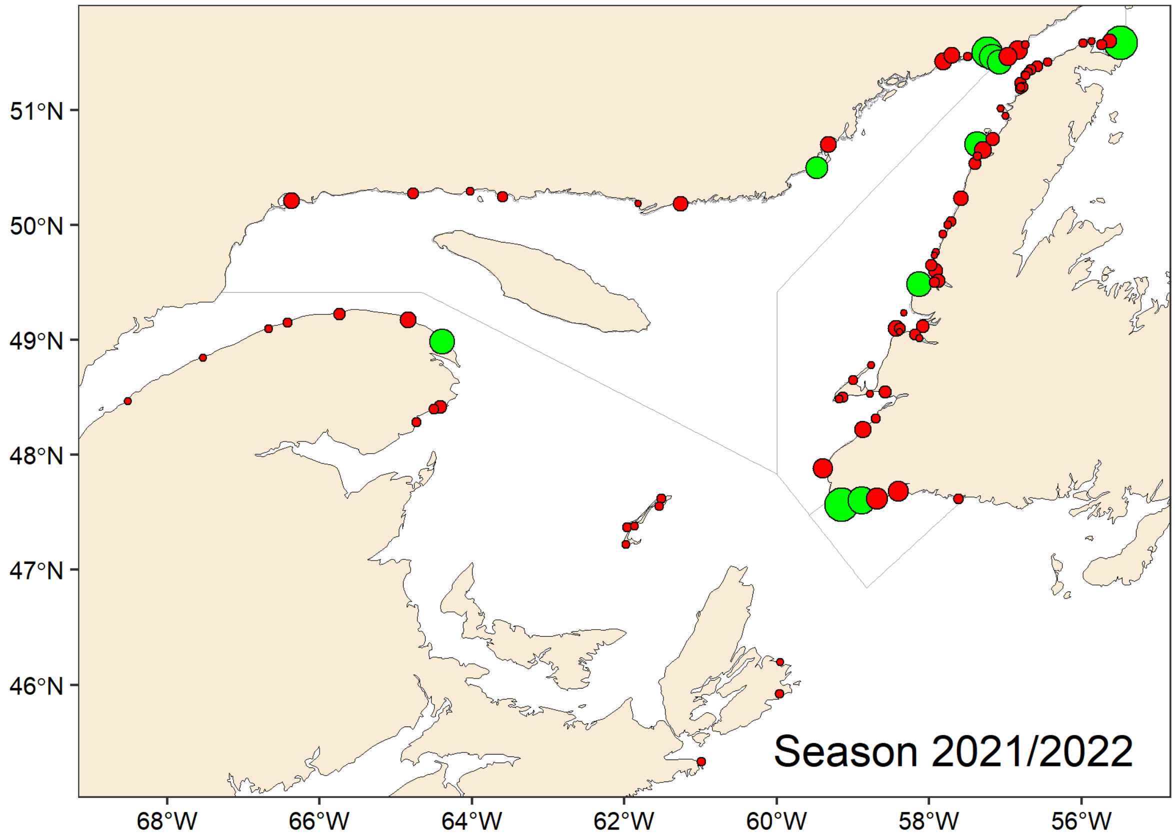

Figure 21. Fishing ports where cod from the 3Pn4RS stock were commercially landed during the 2021/2022 management year. The top 10 ports in terms of landings are shown in green. The size of the points increases according to the reported landings. Source: ZIFF data.

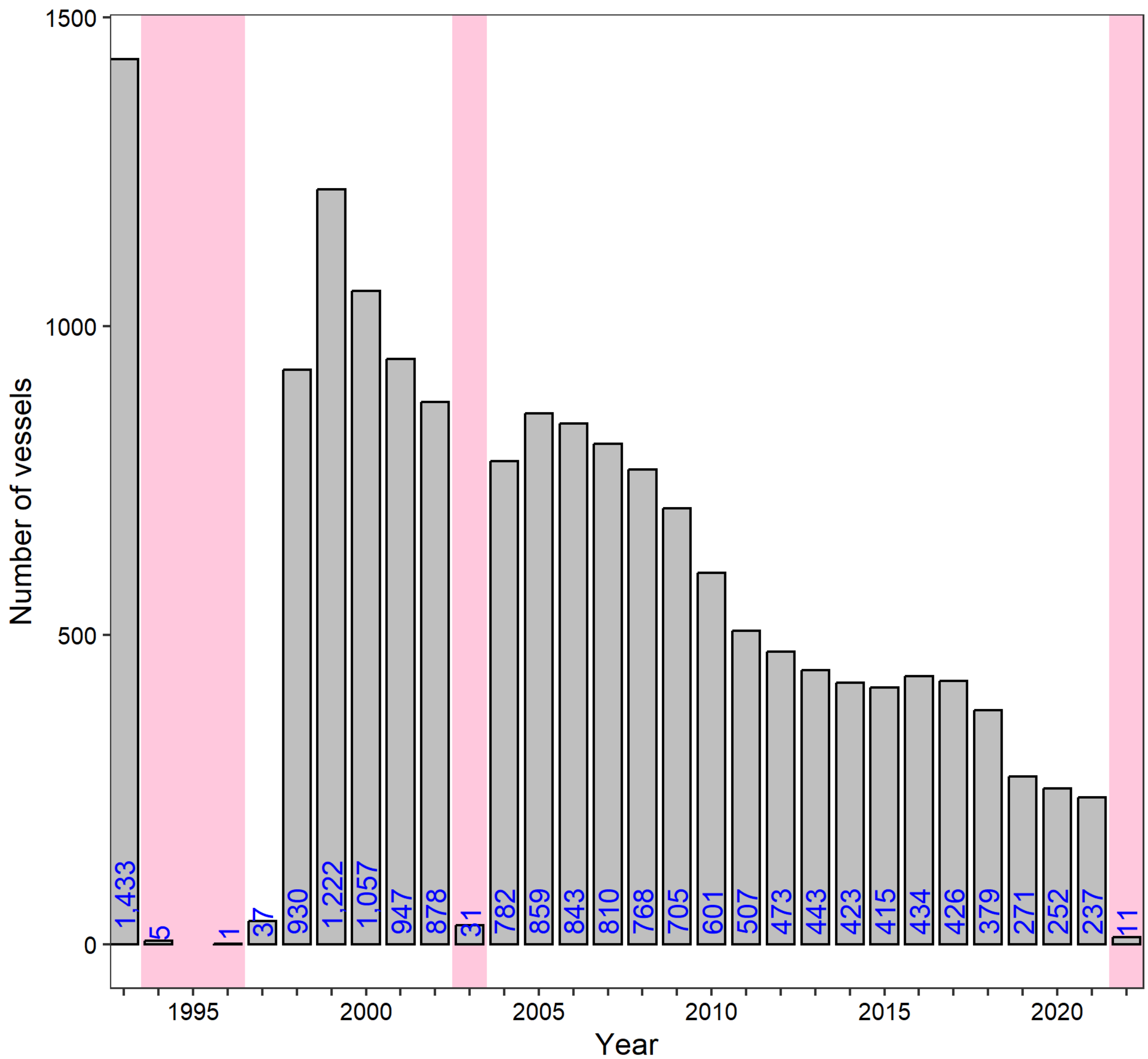

Figure 22. Changes in the number of commercial fishing vessels that targeted Atlantic cod over the period 1993–2022. Moratorium years are shaded in pink. Source: ZIFF data.

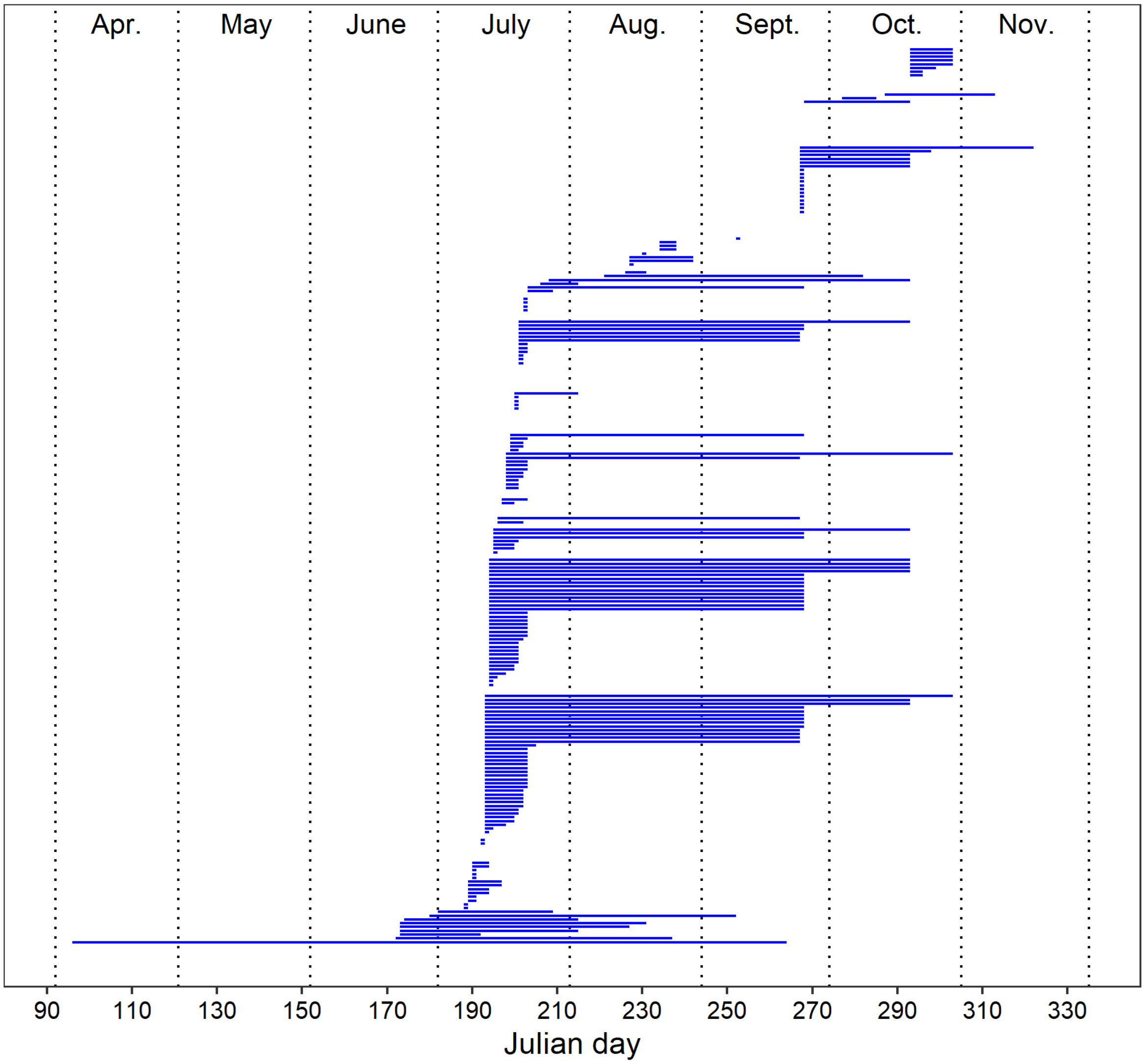

Figure 23. Summary of fisheries targeting 3Pn4RS cod for each of the 237 commercial fishing vessels that targeted this species in 2021. Each row represents a vessel, and extends from the earliest to the latest date that the species targeted and landed is cod. Source: ZIFF data.

Figure 24. Changes in target species for each of the 237 commercial fishing vessels who targeted Atlantic cod in 2021. Each line represents the fishing season of a vessel. Each point represents a dockside landing, colored according to the target species. For vessel–landing date combinations where more than one target species was listed, the one with the largest round weight at landing was used. Source: ZIFF data.

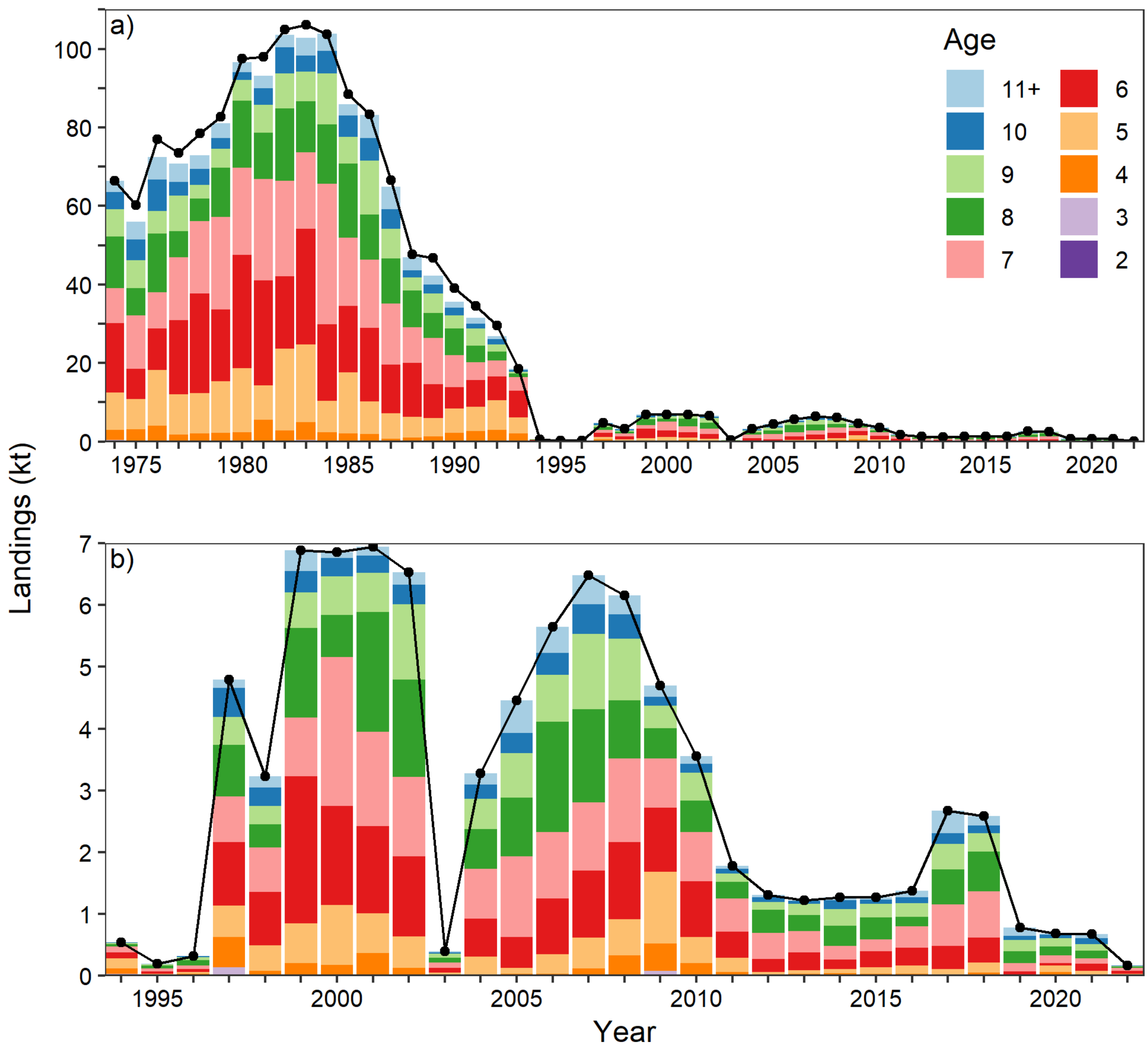

Figure 25. Correspondence between annual landings reported in the ZIFF and NAFO 21B databases (black line) and annual landings at age for the periods a) 1974–2022 et b) 1994–2022.

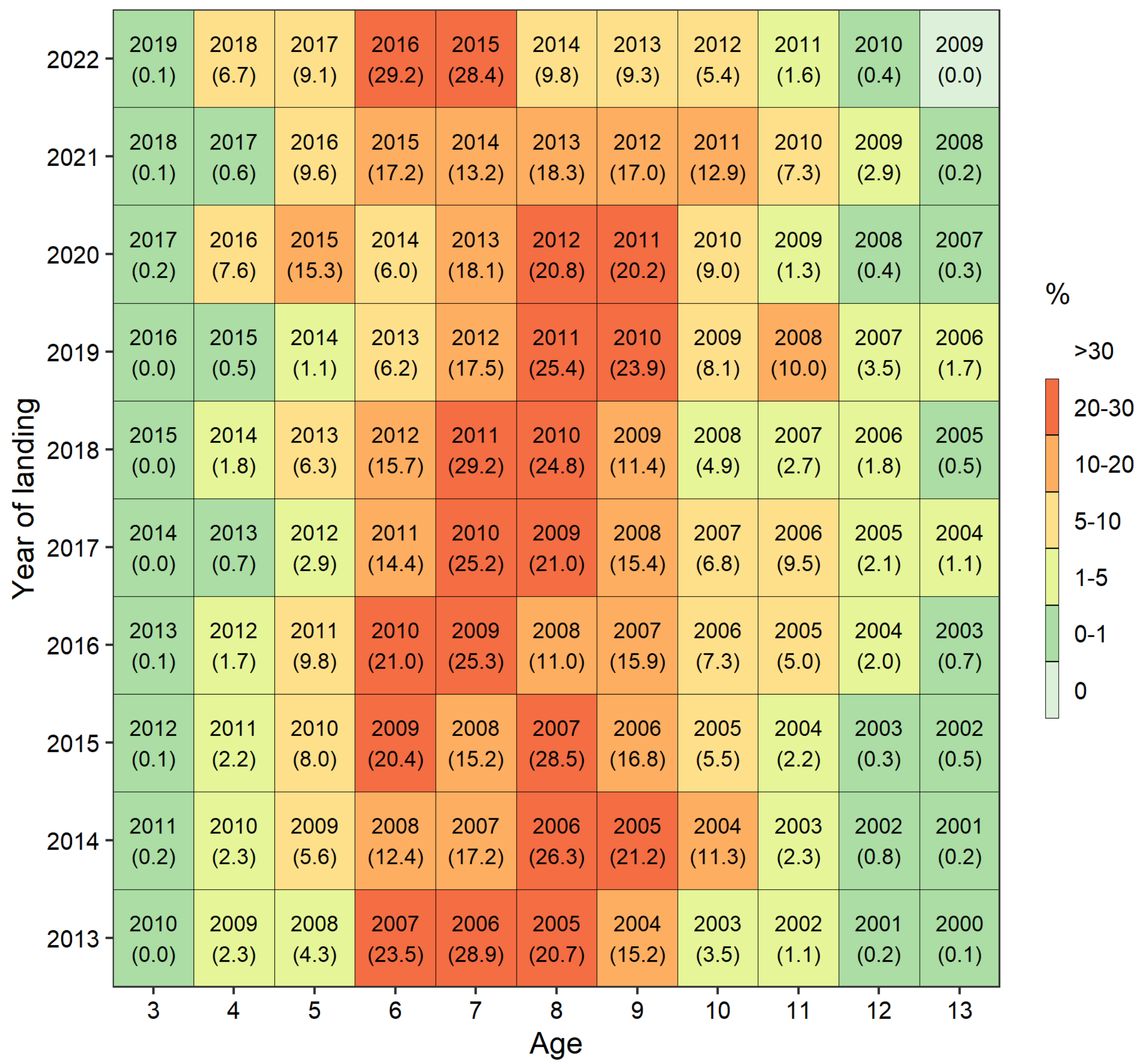

Figure 26. Annual contribution (in %) by age/cohort to the total annual commercial landing of 3Pn4RS cod over the last ten years. Ages < 3 and > 13 are not shown.

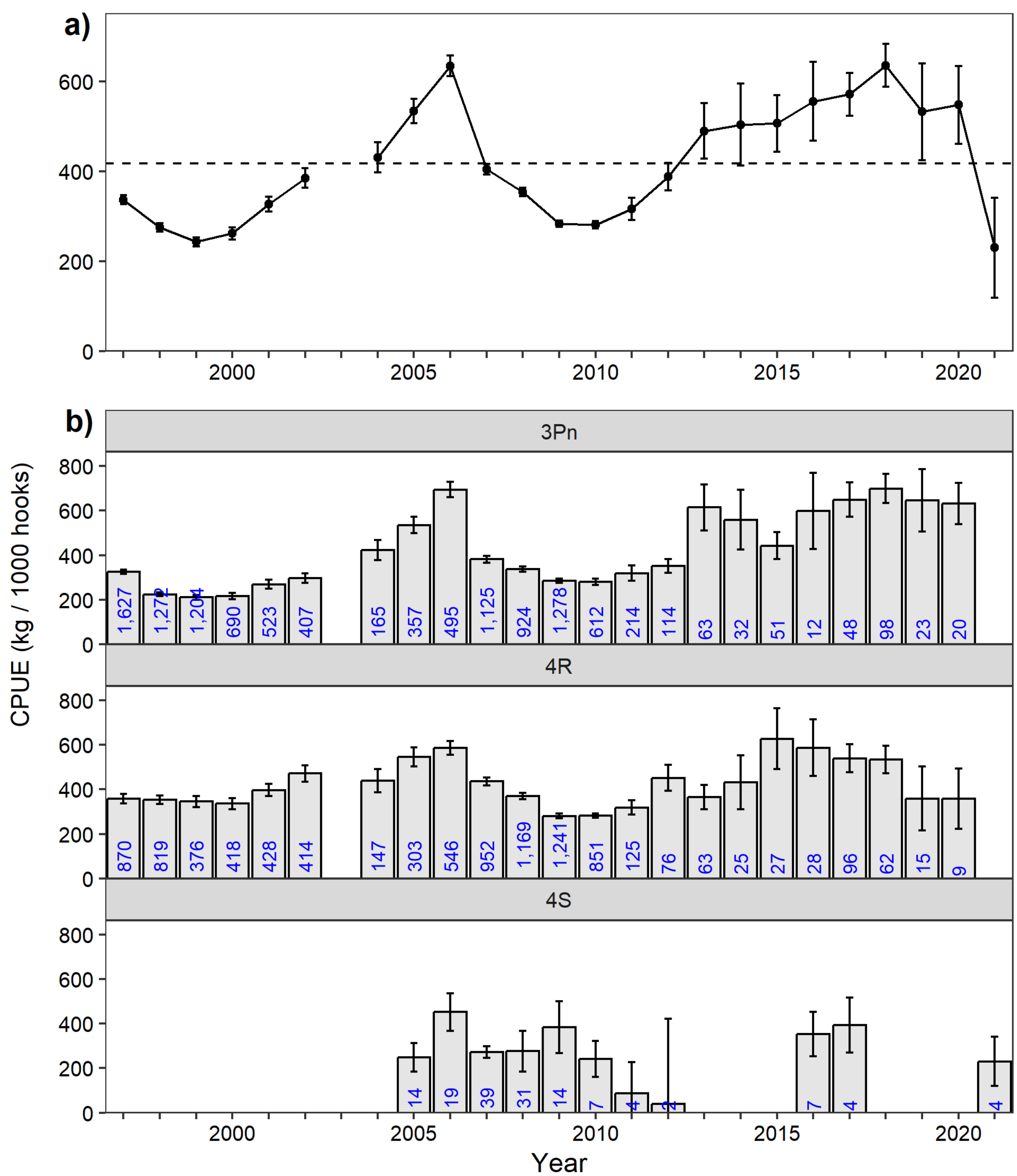

Figure 27. Cod catch per unit effort (CPUE ± 95% CI) from commercial longline logbook data for Quebec (< 45 ft) and Newfoundland and Labrador (< 35 ft) vessels targeting cod in 3Pn4RS from 1997 to 2021 (a). The hatched horizontal line represents the average of the 1997–2021 series. In b), CPUEs (± 95% CI) are broken down by NAFO Division. Values in blue indicate the number of activities used for the calculations.

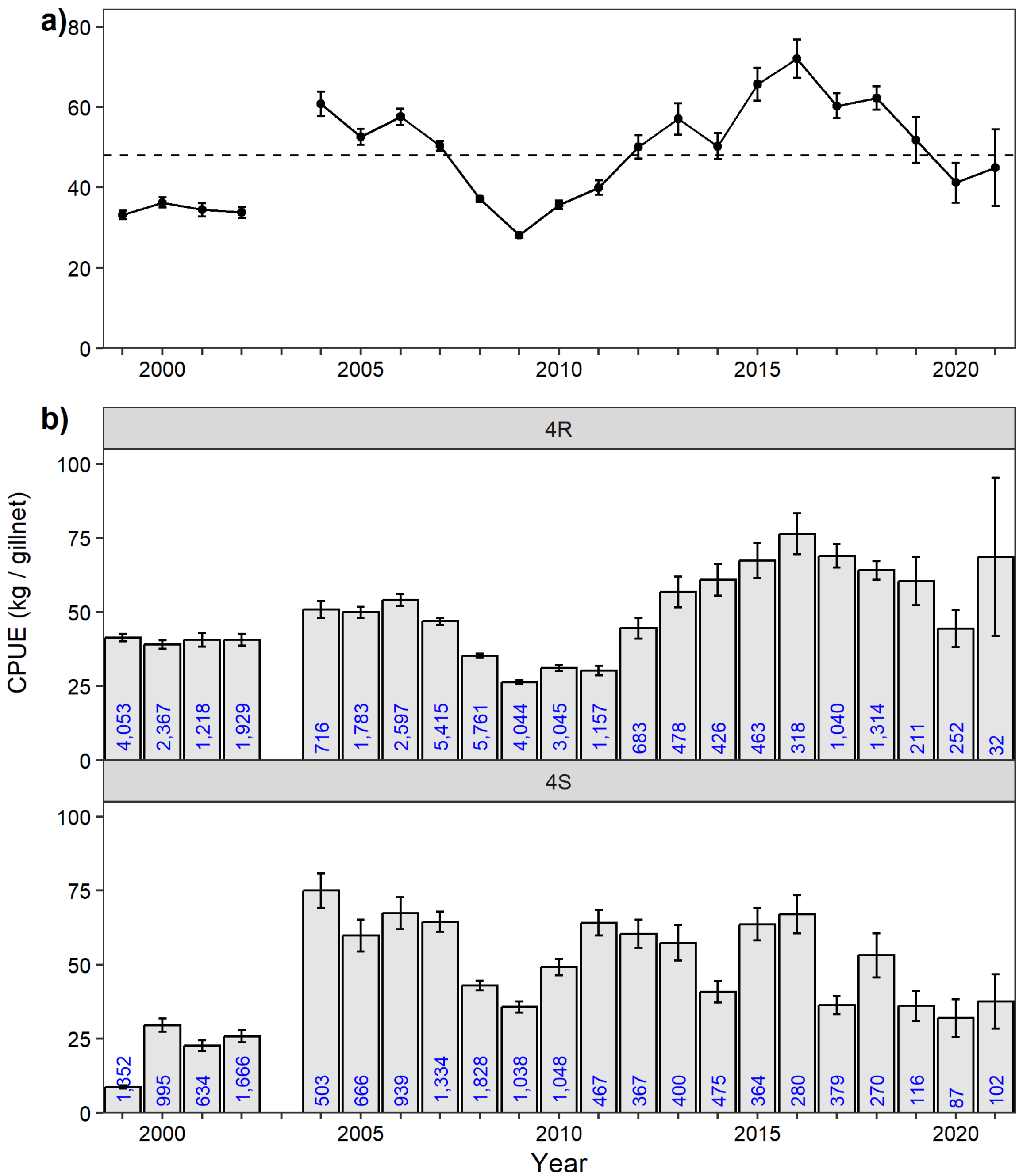

Figure 28. Cod catch per unit effort (CPUE ± 95% CI) from commercial gillnet logbook data for Quebec (< 45 ft) and Newfoundland and Labrador (< 35 ft) vessels targeting cod in 4RS from 1999 to 2021 (a). The hatched horizontal line represents the average of the 1999–2021 series. In b), CPUEs (± 95% CI) are broken down by NAFO Division. Values in blue indicate the number of activities used for the calculations.

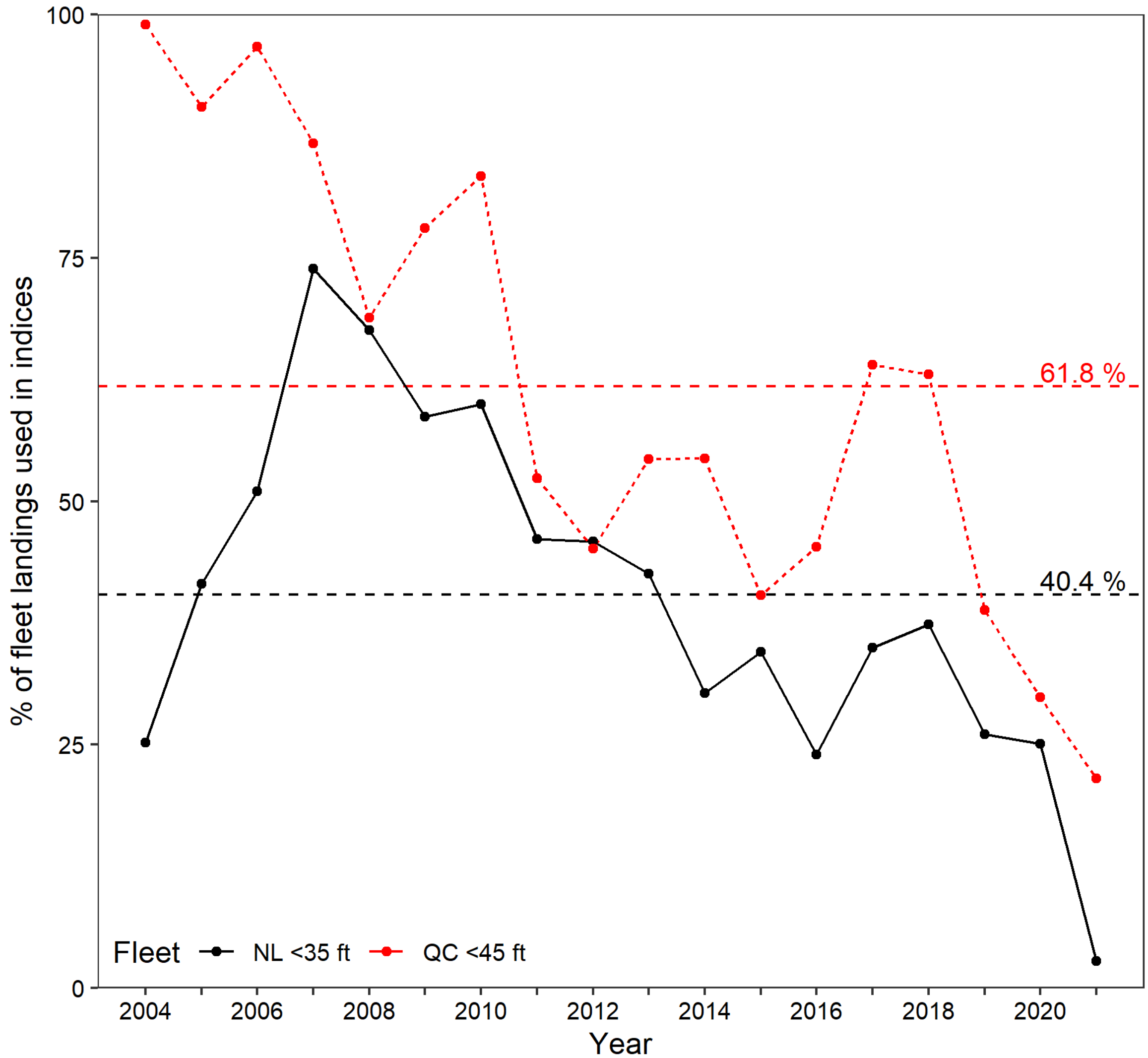

Figure 29. Percentages of cod landings for which commercial fishing logbook data from Quebec (QC, < 45 ft) and Newfoundland and Labrador (NL, < 35 ft) vessels were completed during the period 2004–2021. Only cod landings for which the target species was cod and the gear was longline or gillnet are considered. The hatched horizontal lines are the 2004–2021 series means for each fleet.

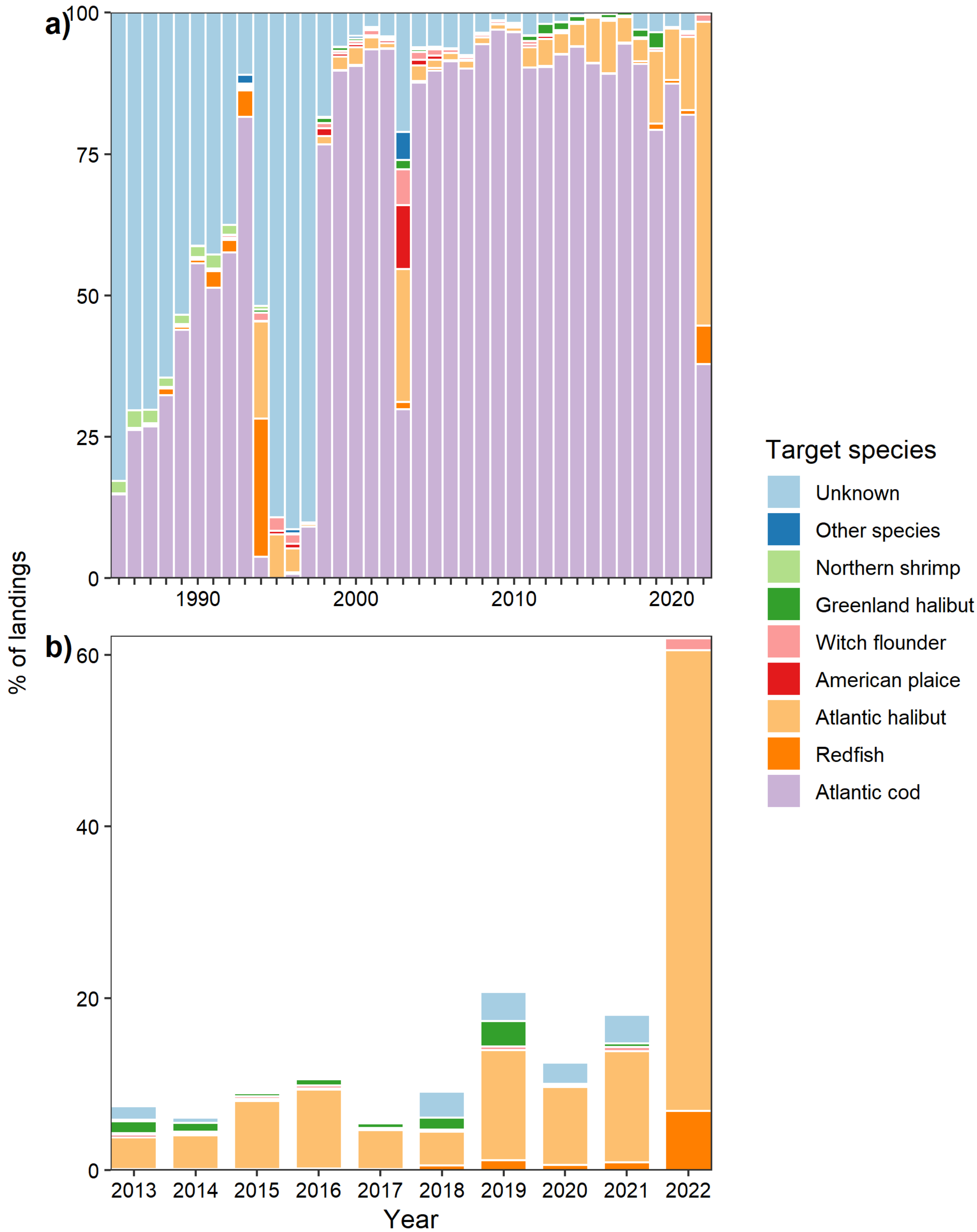

Figure 30. Percentage of annual cod landings by target species for the a) period 1985-20221 and b) last ten years and excluding landings where cod was targeted. Data source: NAFO 21B and ZIFF.

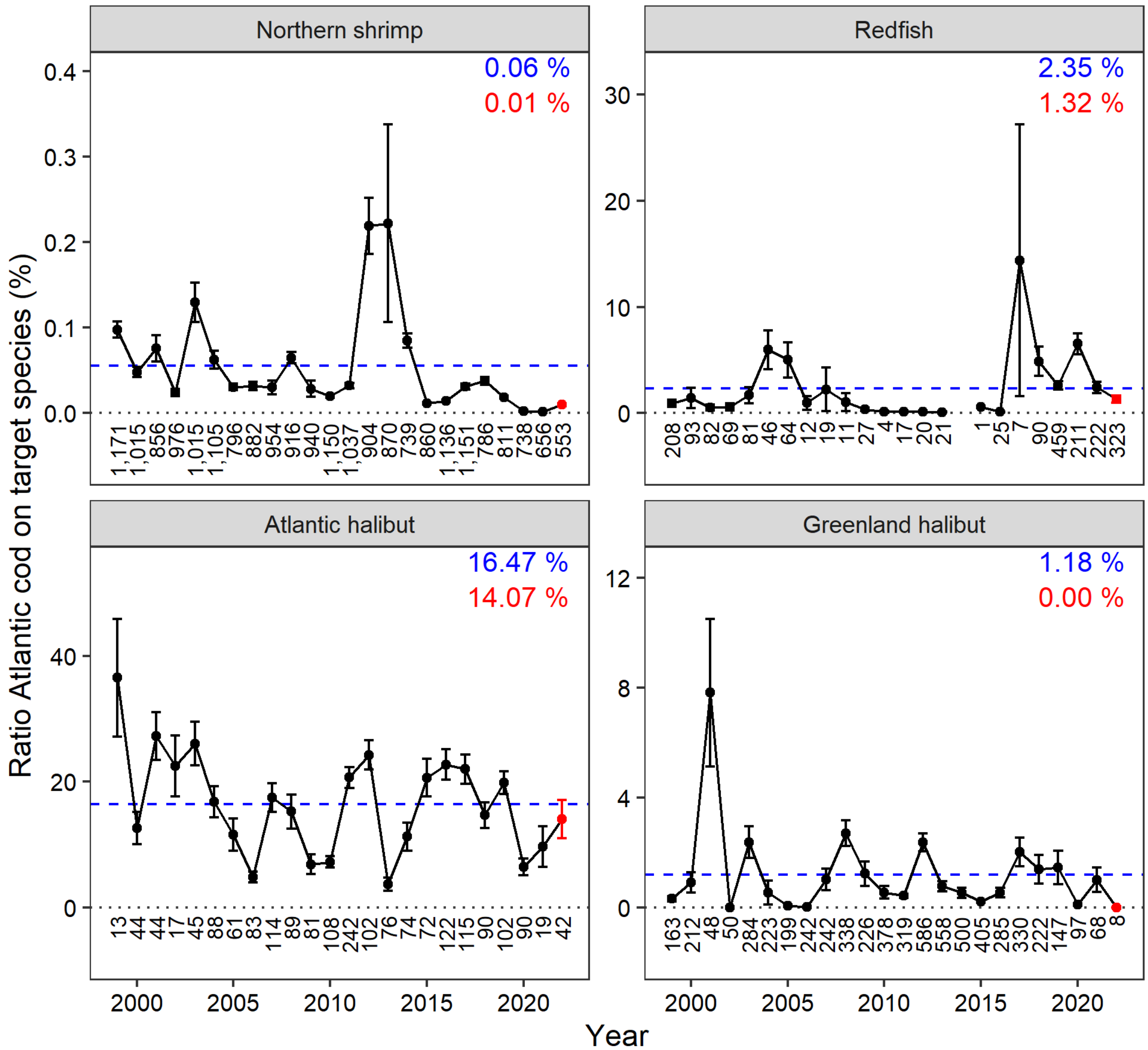

Figure 31. Ratio of the catch weight of cod to that of the target species (panels) during the period 1999–2022 based on at-sea observer data. Each point represents the annual mean (± the standard error) of all fishing activities monitored by at-sea observers for which the target species was caught. The blue value and the horizontal hatched line represent the average annual ratio during the 1999–2022 series. The value of 2022 is provided in red. Below each point, the number of monitored activities used in the calculations is provided.

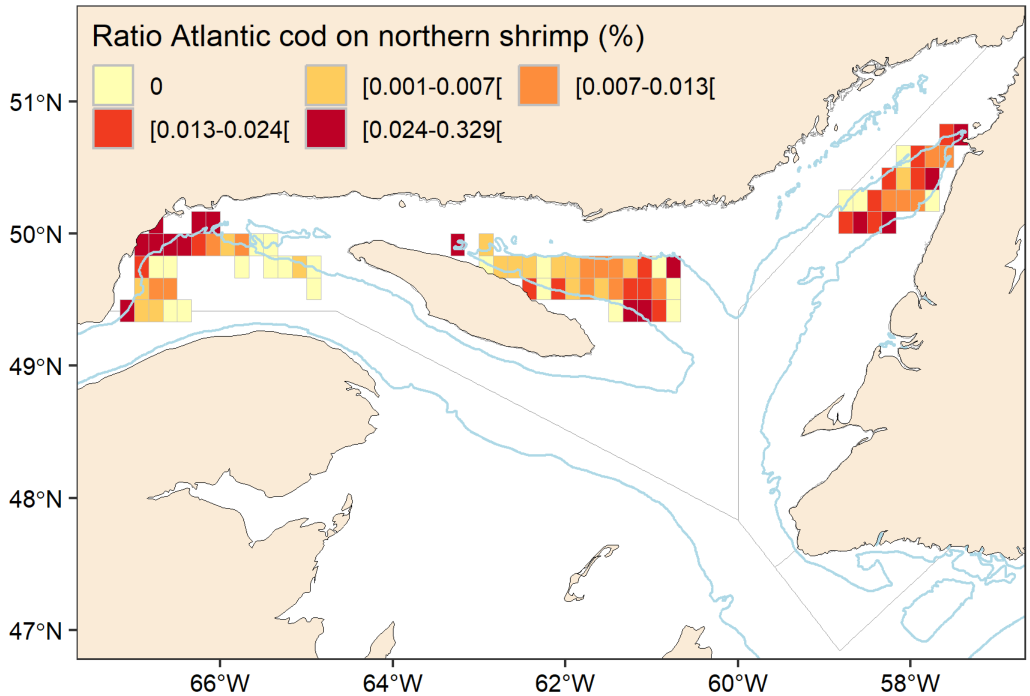

Figure 32. Ratio of the catch weight of cod to that of northern shrimp during the period 2018–2022 in the directed northern shrimp fishery, based on data from at-sea observers. The average ratio associated with a statistical square was calculated from the ratio of each monitored fishing activity found in the latter. For statistical squares whose average ratio is not 0, the ratio categories are based on the observed quartiles. Only statistical squares with at least two monitored activities are shown. The 200 m isobath is shown.

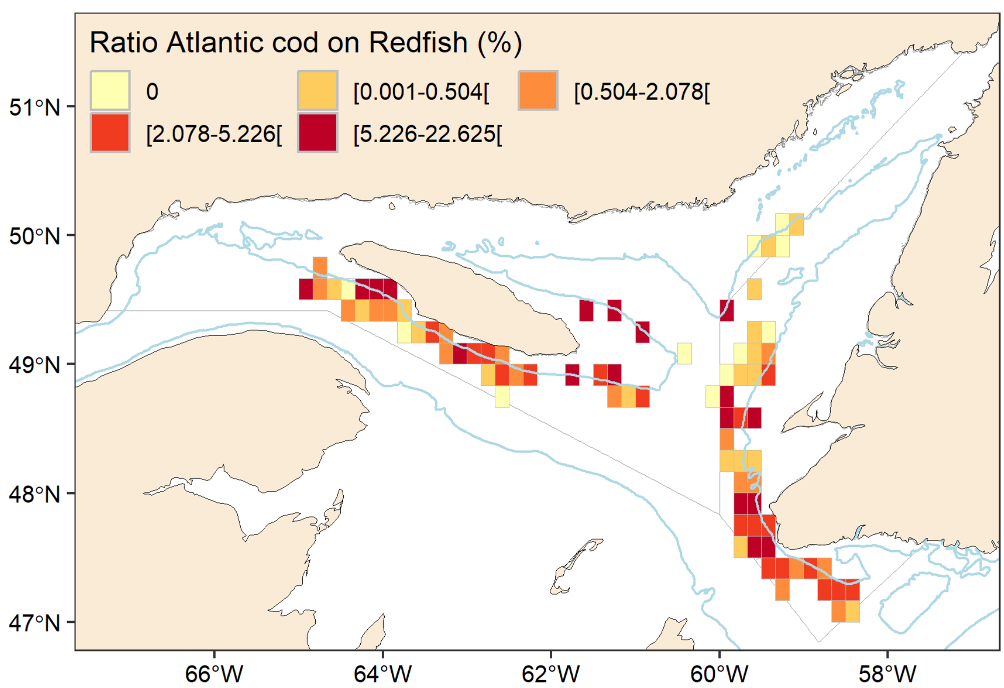

Figure 33. Ratio of the catch weight of cod to that of redfish during the period 2018–2022 in the directed redfish fishery, based on data from at-sea observers. The average ratio associated with a statistical square was calculated from the ratio of each monitored fishing activity found in the latter. For statistical squares whose average ratio is not 0, the ratio categories are based on the observed quartiles. Only statistical squares with at least two monitored activities are shown. The 200 m isobath is shown.

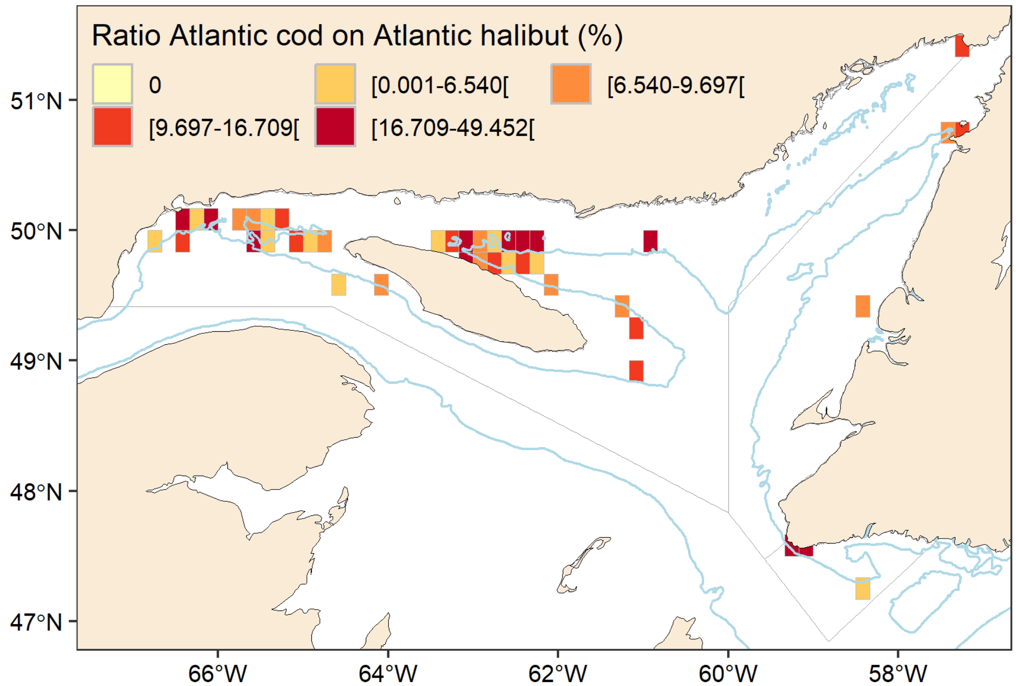

Figure 34. Ratio of the catch weight of cod to that of Atlantic halibut during the period 2018–2022 in the directed Atlantic halibut fishery, based on data from at-sea observers. The average ratio associated with a statistical square was calculated from the ratio of each monitored fishing activity found in the latter. For statistical squares whose average ratio is not 0, the ratio categories are based on the observed quartiles. Only statistical squares with at least two monitored activities are shown. The 200 m isobath is shown.

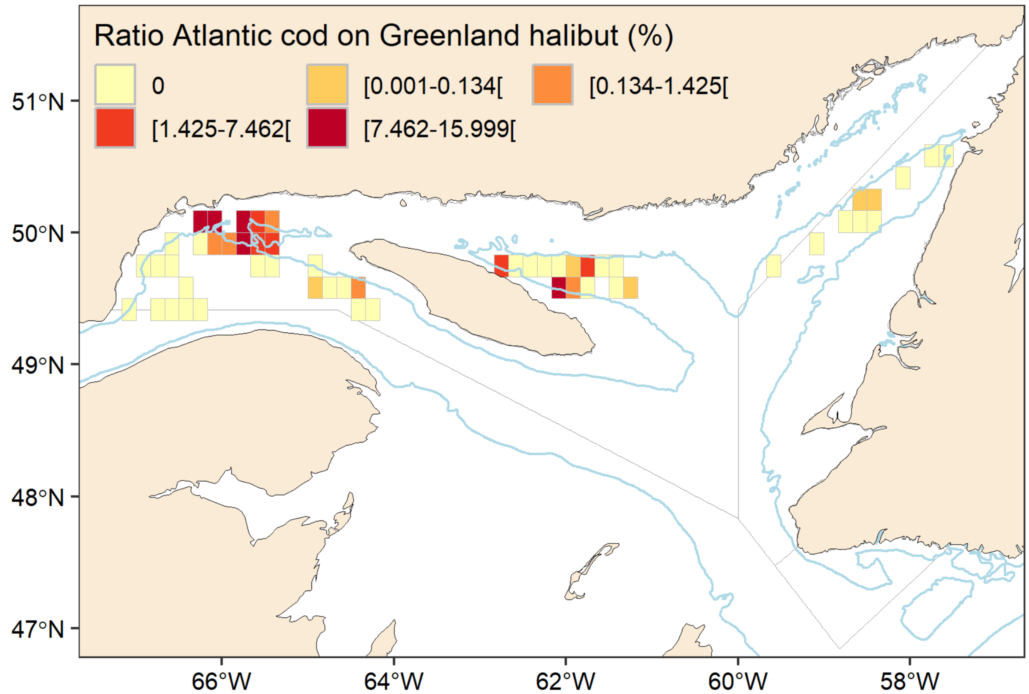

Figure 35. Ratio of the catch weight of cod to that of Greenland halibut during the period 2018–2022 in the directed Greenland halibut fishery, based on data from at-sea observers. The average ratio associated with a statistical square was calculated from the ratio of each monitored fishing activity found in the latter. For statistical squares whose average ratio is not 0, the ratio categories are based on the observed quartiles. Only statistical squares with at least two monitored activities are shown. The 200 m isobath is shown.

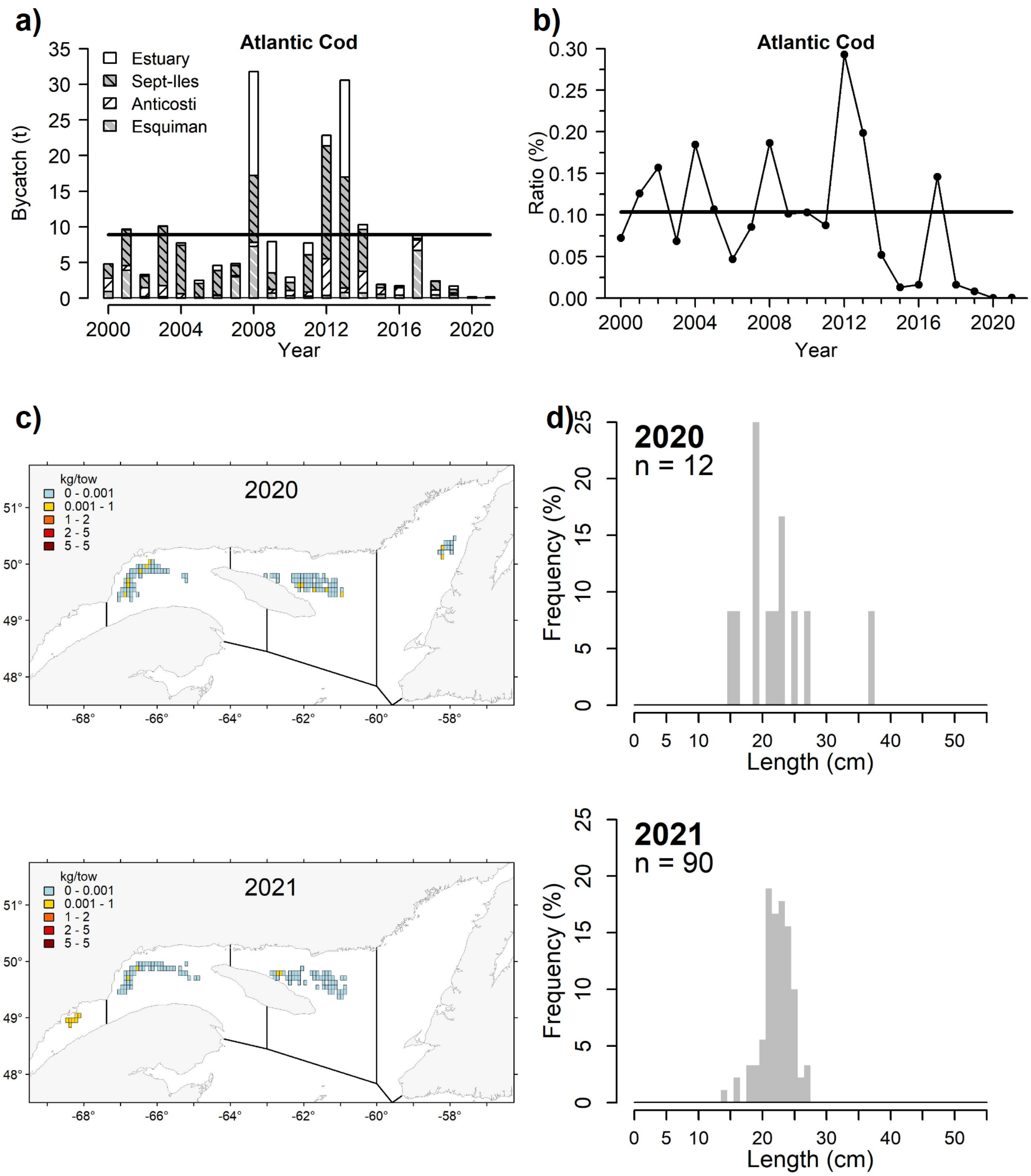

Figure 36. Estimated Atlantic cod bycatch in the northern shrimp fishery by year and fishing area from the at-sea observers program (a). b) Ratio (%) of the bycatch on the biomass estimate from the DFO survey (solid line indicates the average for the years 2000-2019). c) Geographical distribution of bycatch averaged per 5-minute square. d) Length frequency distributions of sampled fish (number (n) of specimens measured is indicated). Figure from Bourdages et al. (2022).

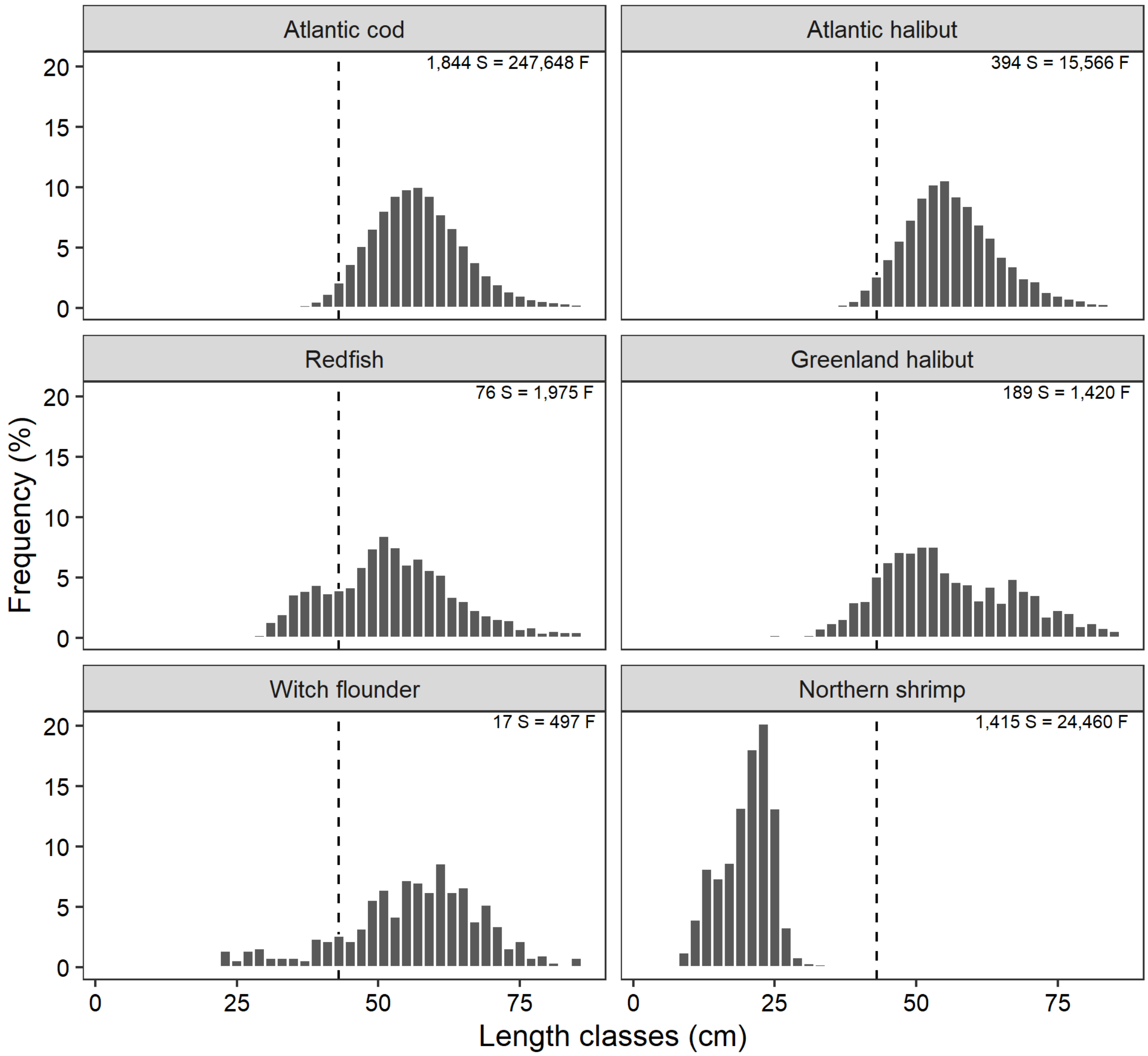

Figure 37. Length frequency distribution of the 3Pn4RS Atlantic cod stock measured since 1999 by the at-sea observer program, by target species (panels). The vertical dotted line represents the 43 cm minimum size of cod relative to the small fish protocol. For each target species, the number of samples (S) from which the fish (F) were measured is indicated. The x-axis is truncated to the right (85 cm) to only show the length classes ≤ 99th percentile.

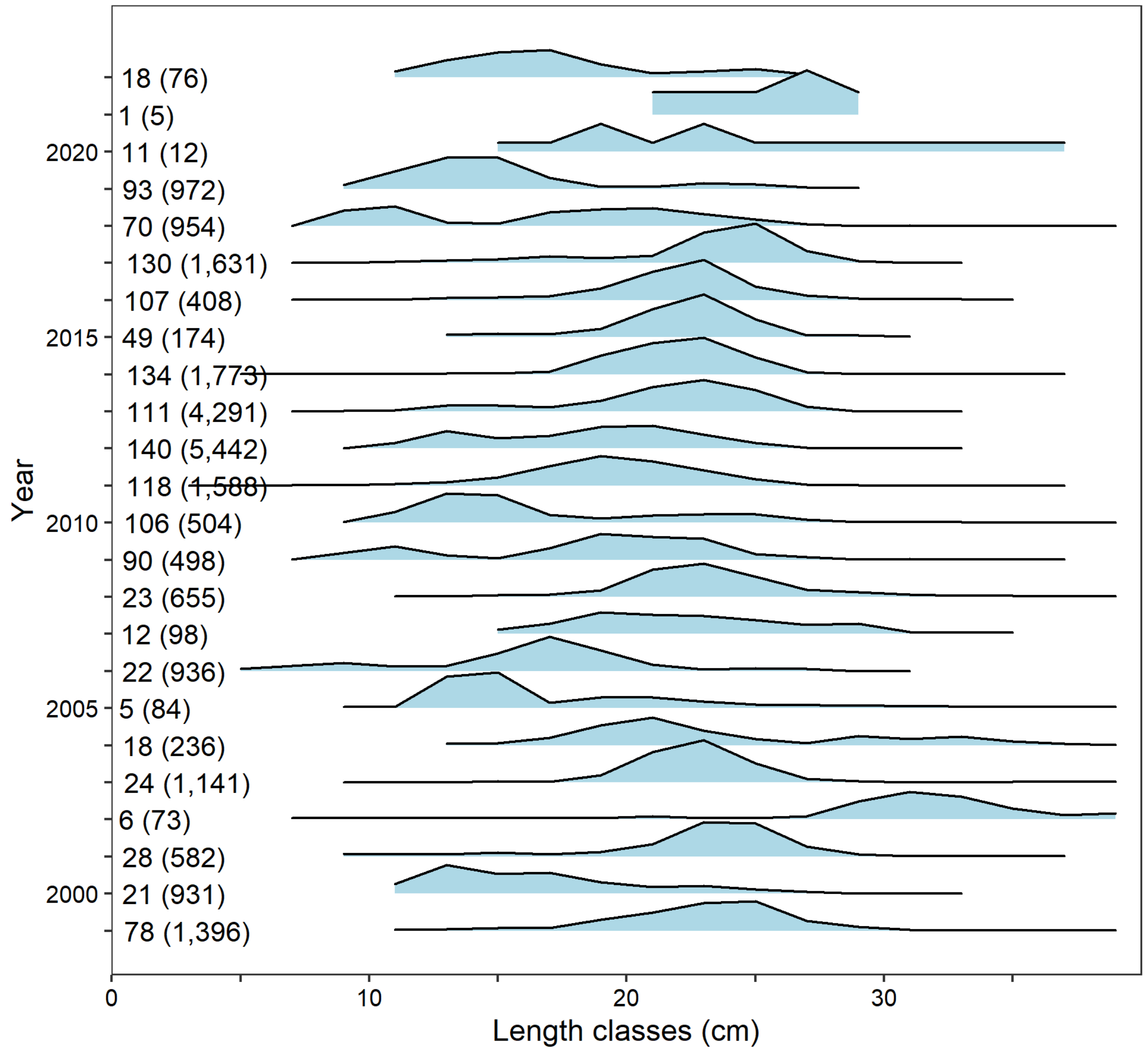

Figure 38. Atlantic cod length frequencies from fishing activities targeting northern shrimp and monitored by at-sea observers. The numbers shown are the annual number of activities monitored where cod lengths were taken and in parentheses the number of cod measured.

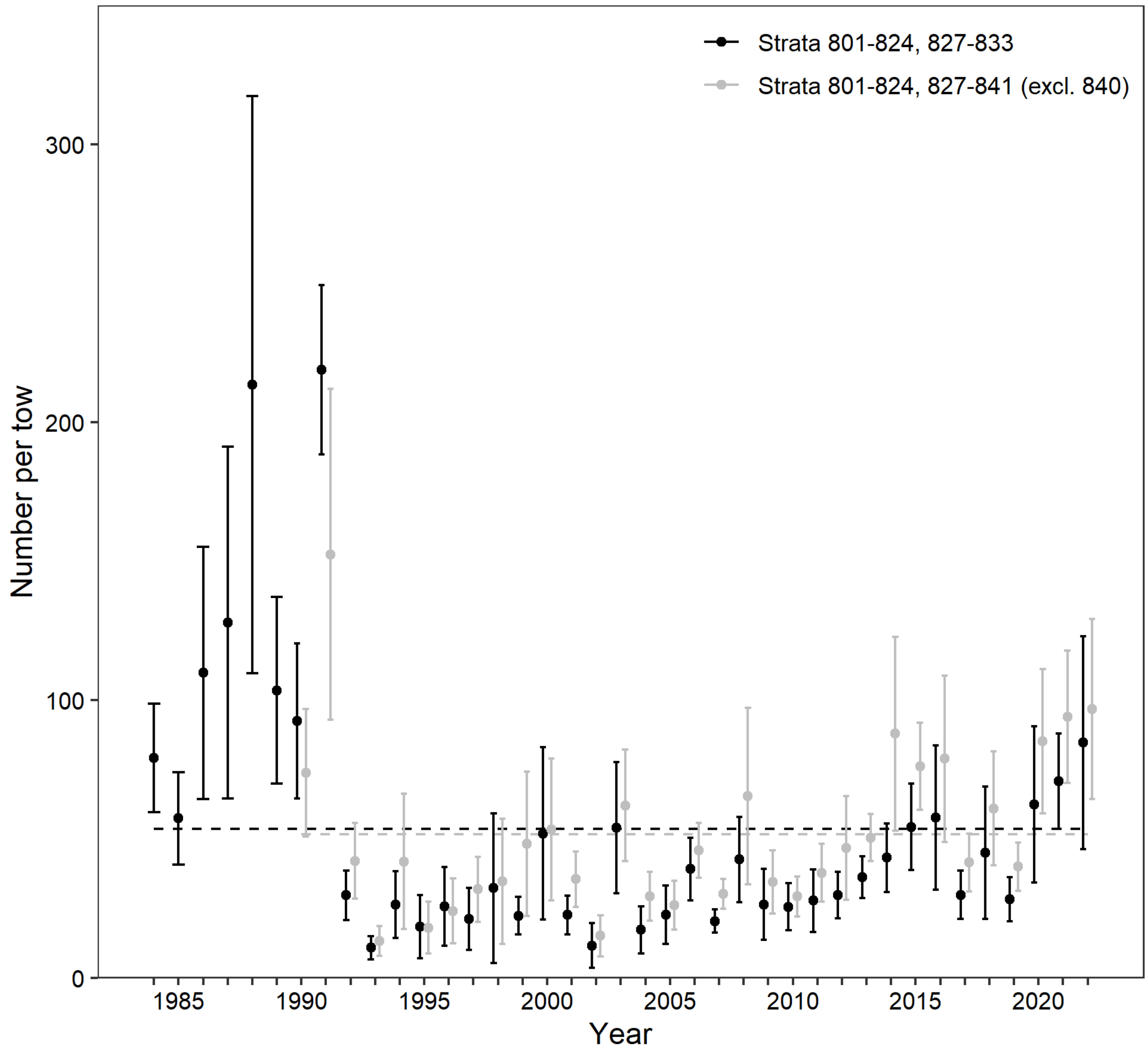

Figure 39. Age-aggregated abundance index with 95% confidence intervals for cod from the DFO August survey for 1984-2022 based on the reduced suite of strata (black dots) and for 1990-2022 based on all consistently sampled strata (grey dots). The stratum numbers are indicated in the legend. The dashed horizontal lines represent the average of each series (1984–2022 and 1990–2022).

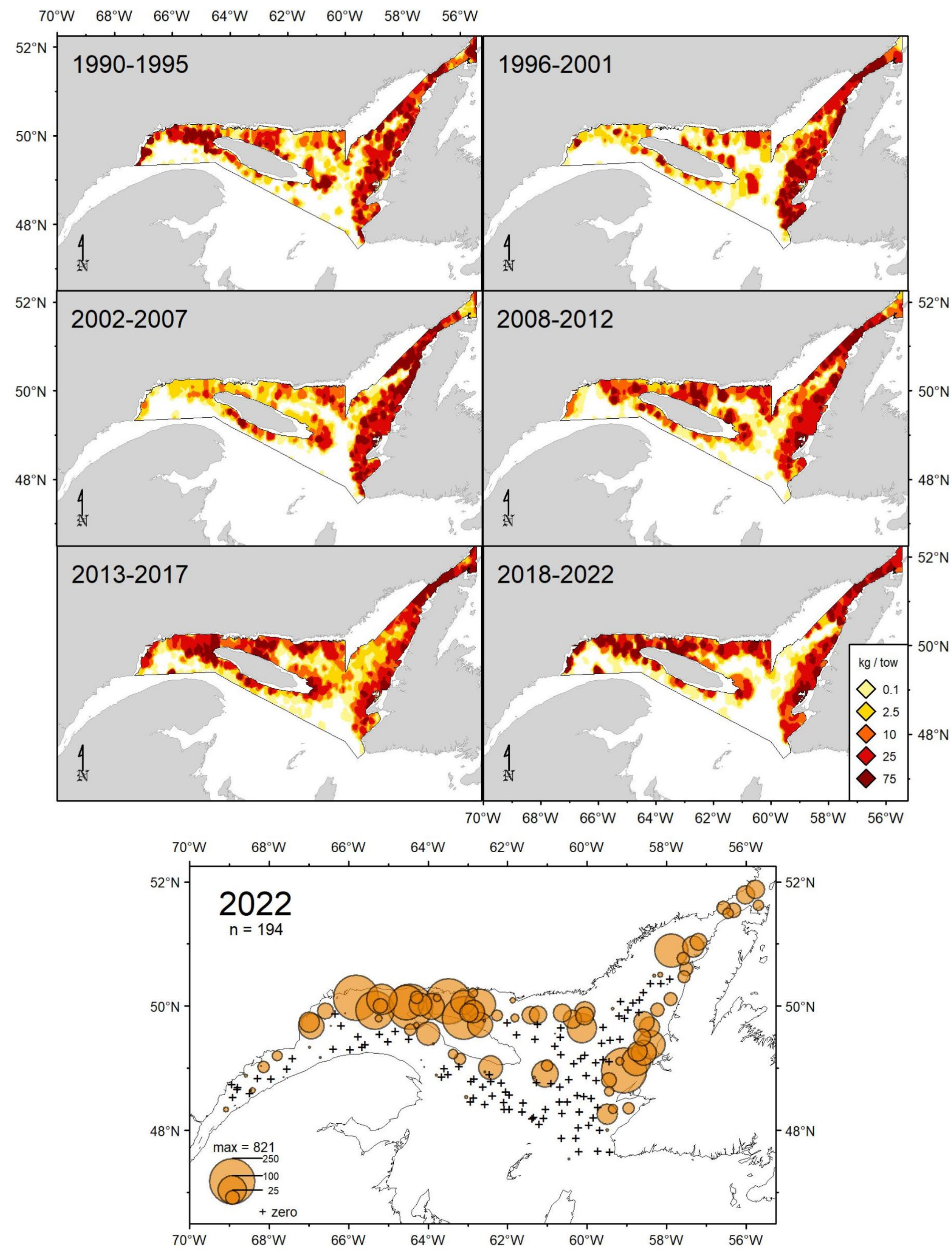

Figure 40. Distribution of cod catch rates (kg per 15 min tow) during the DFO August survey in NAFO Divisions 4RS.

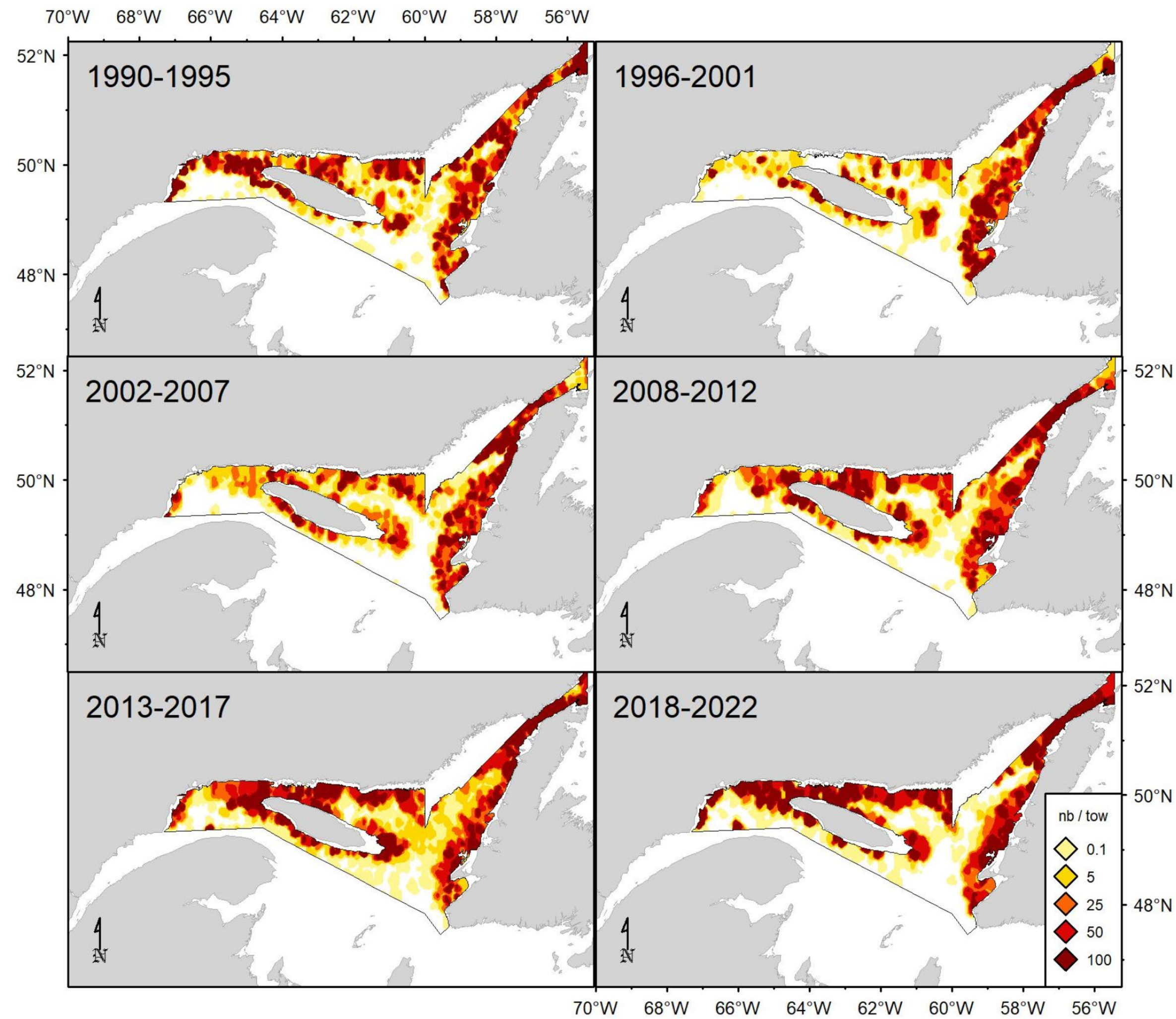

Figure 41. Distribution of cod catch rates (number per 15 min tow) in the DFO August survey in NAFO Divisions 4RS.

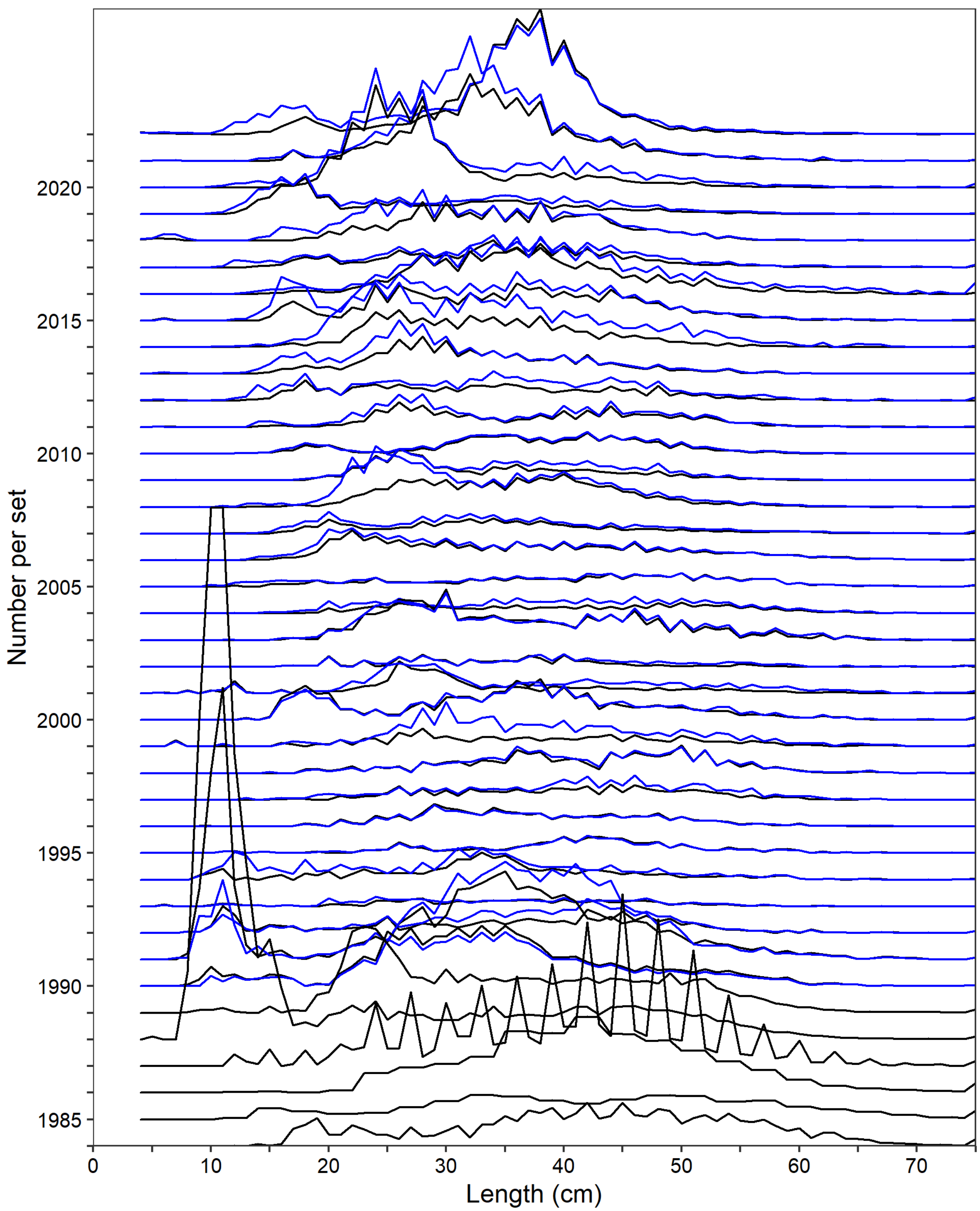

Figure 42. Annual DFO August survey length frequencies in numbers per tow for 1984-2022 based on the reduced suite of strata (black lines) and for 1990-2022 based on all consistently sampled strata (blue lines).

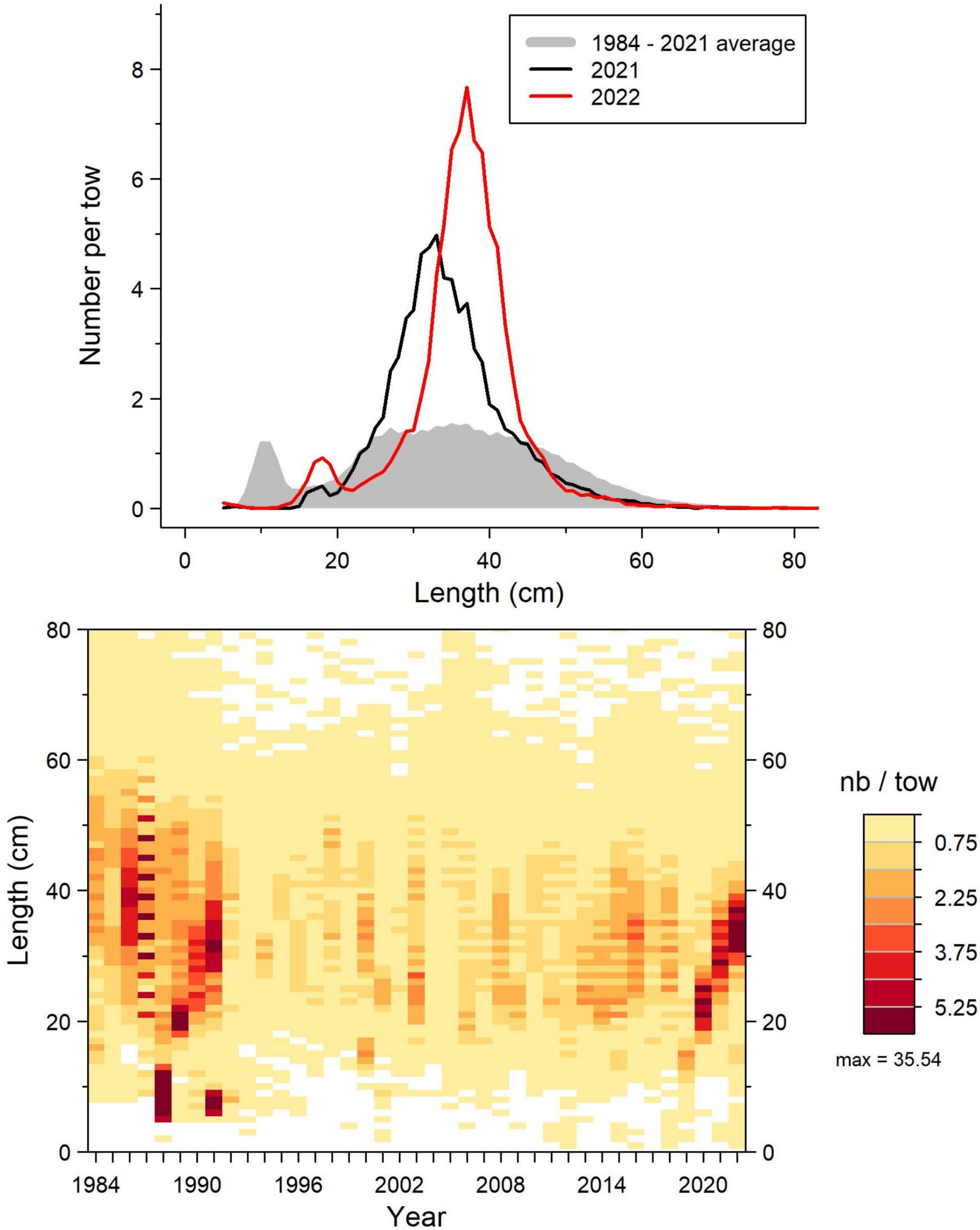

Figure 43. Cod length frequency distributions (mean number per 15 min tow) in the DFO August survey in NAFO Divisions 4RS for the 1984–2021 series average and individually for 2021 and 2022, based on the reduced suite of strata.

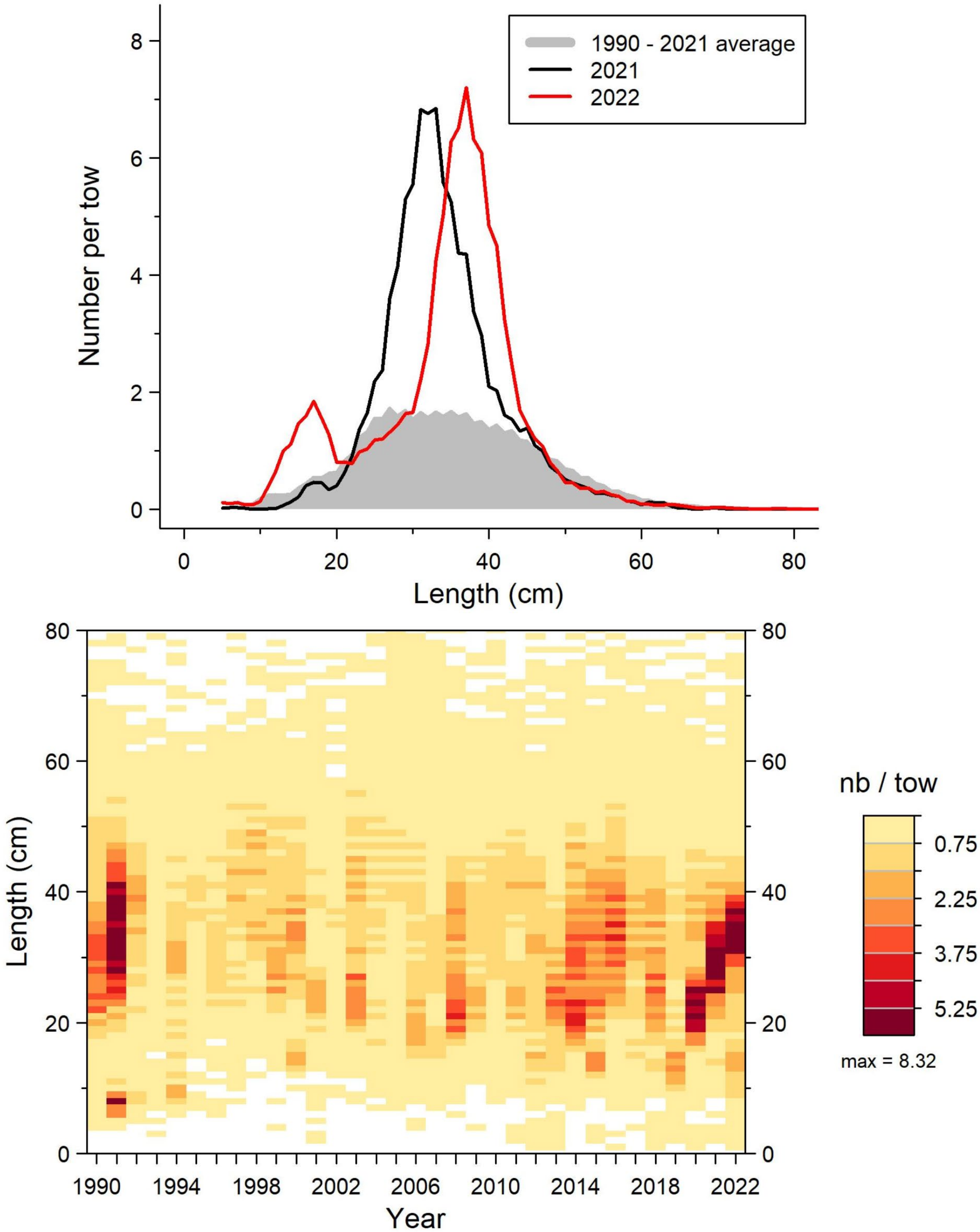

Figure 44. Cod length frequency distributions (mean number per 15 min tow) in the DFO August survey in NAFO Divisions 4RS for the 1990–2021 series average and individually for 2021 and 2022, based on all consistently sampled strata.

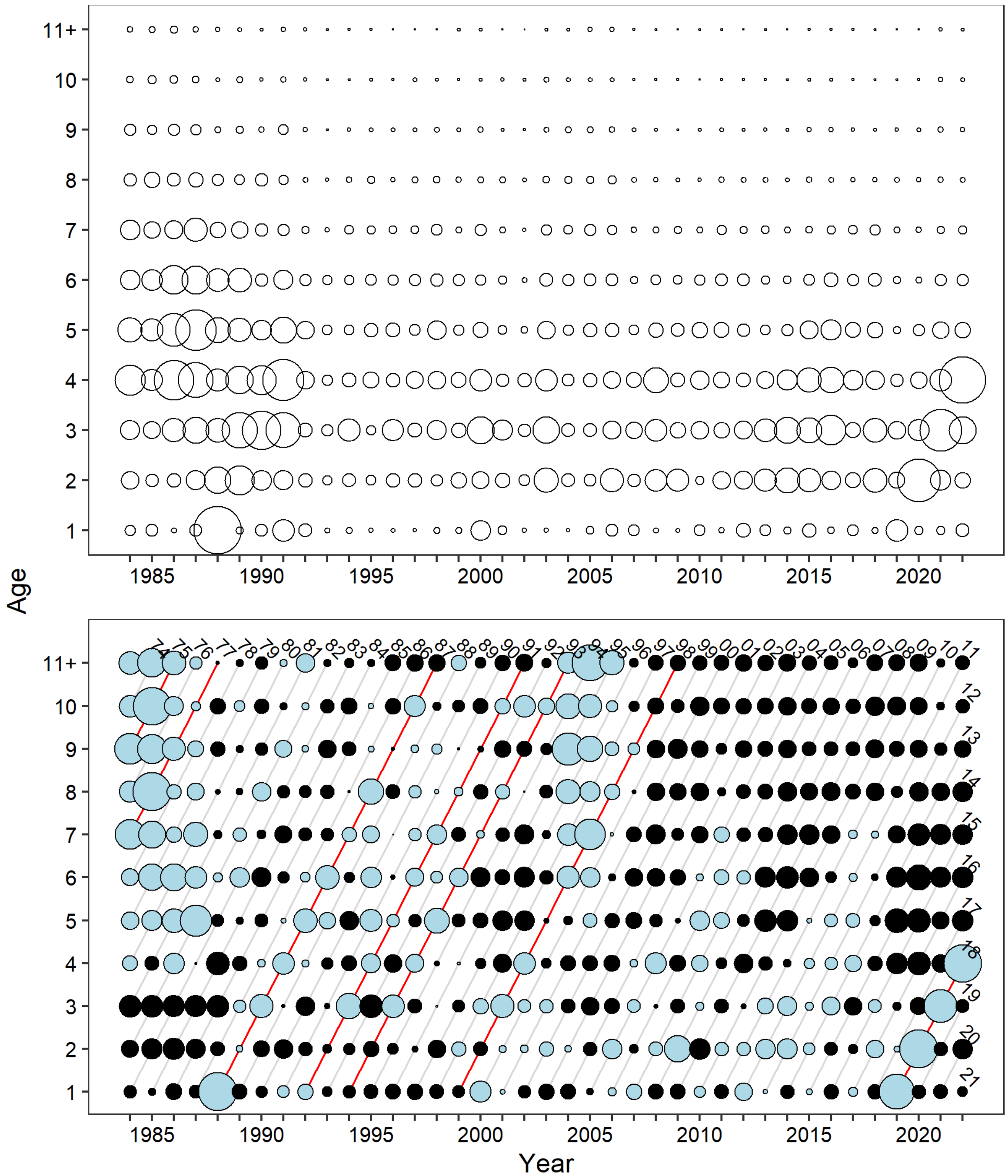

Figure 45. Numbers at age in the DFO August survey for 1984–2022 based on the reduced suite of strata. The top figure shows numbers proportional to circle diameter, while the bottom one shows standardized proportions at age and year (SPAY) with blue and black bubbles indicating above and below average, respectively. The bubble diameter is indicative of the SPAY value. The red lines indicate some consistently tracked above average cohorts in the DFO August survey. Cohort years' last two digits are indicated above bubbles from oldest ages and the ones from the most recent year.

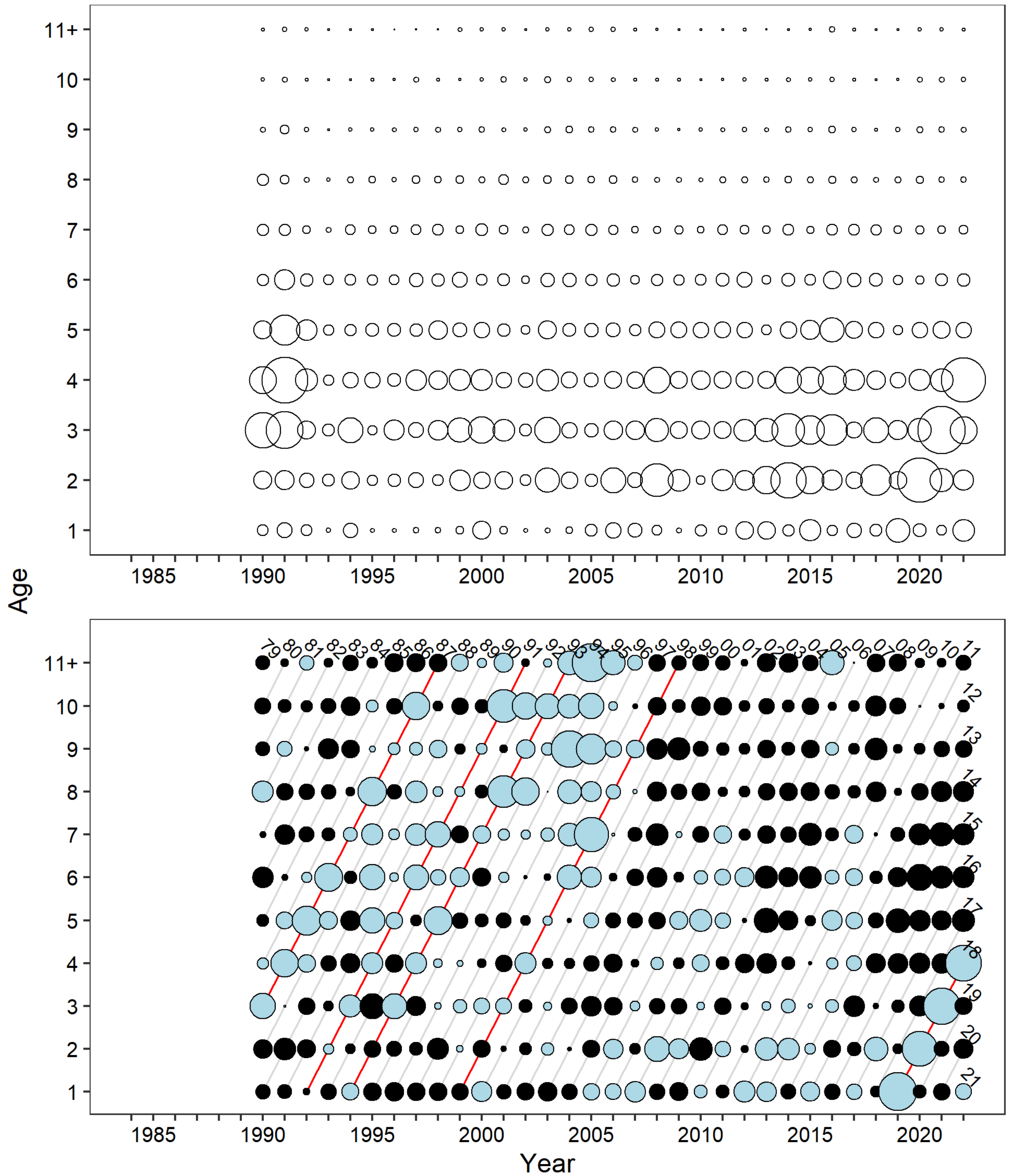

Figure 46. Numbers at age in the DFO August survey for 1990–2022 based on all consistently sampled strata. The top figure shows numbers proportional to circle diameter, while the bottom one shows standardized proportions at age and year (SPAY) with blue and black bubbles indicating above and below average, respectively. The bubble diameter is indicative of the SPAY value. The red lines indicate some consistently tracked above average cohorts in the DFO August survey. Cohort years' last two digits are indicated above bubbles from oldest ages and the ones from the most recent year.

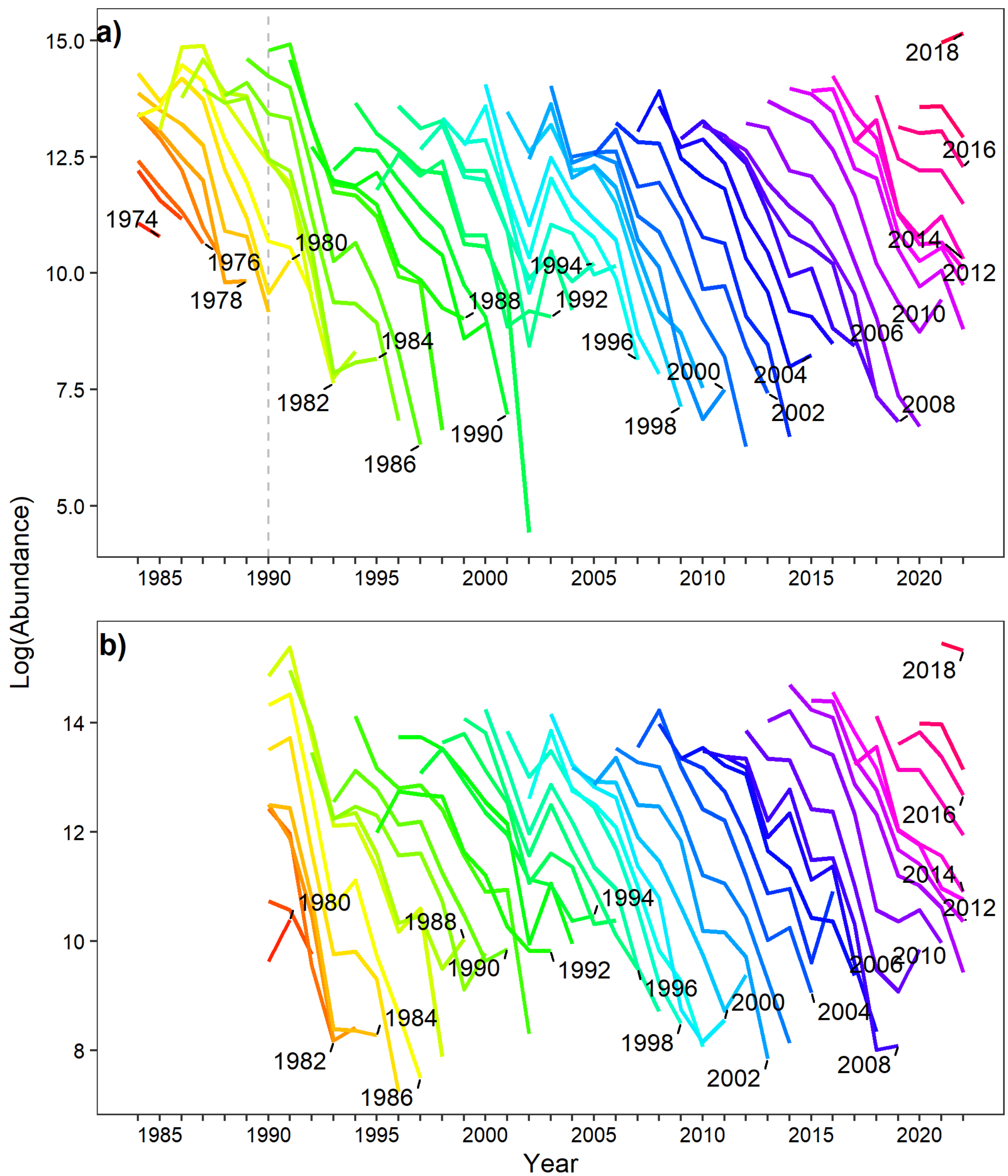

Figure 47. Log-abundance of individual cohorts (ages 3 to 11+) from the DFO August survey catch at age for a) 1984-2022 based on the reduced suite of strata and b) 1990-2022 based on all consistently sampled strata. The year of the 1990 comparative fishing experiment is indicated by a vertical dashed line in a). Cohorts are identified by birth year for every 2nd year.

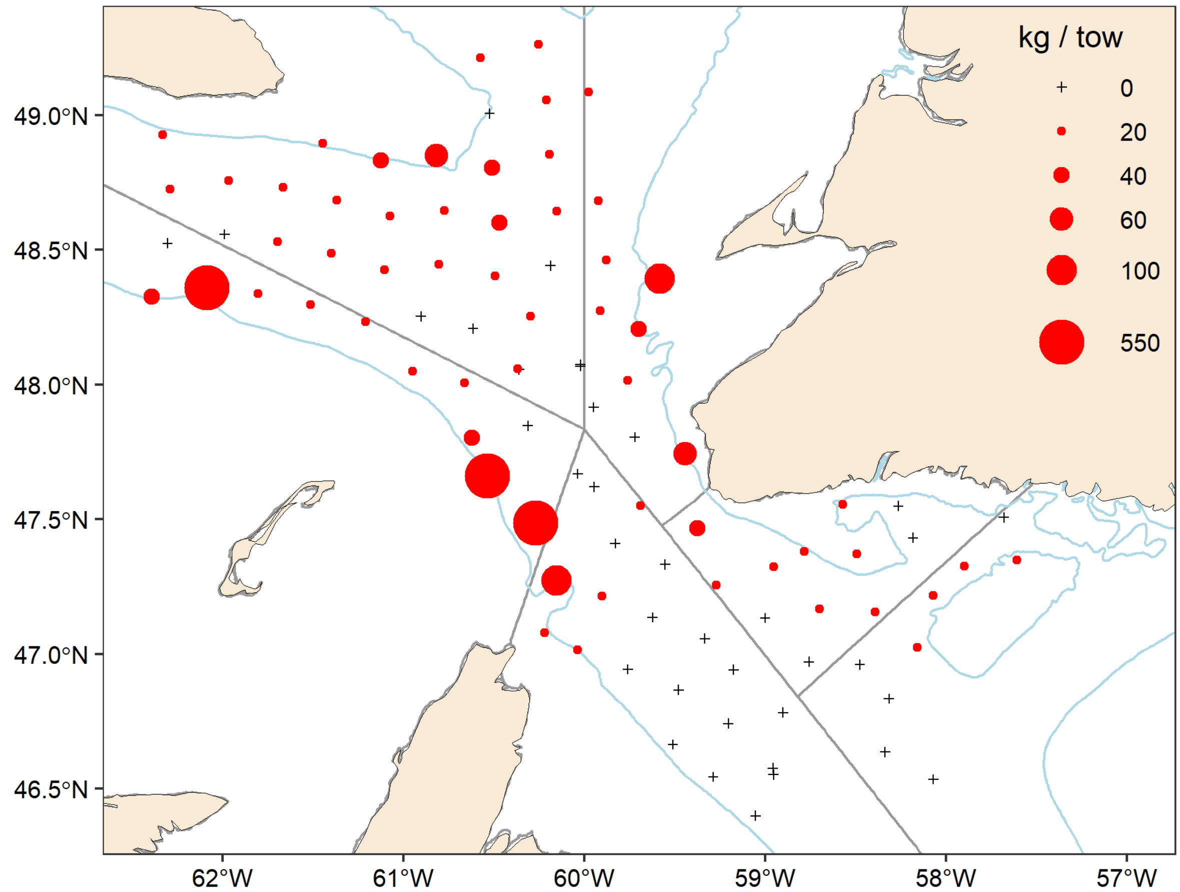

Figure 48. Distribution of catch rates (kg per tow) during the 2022 winter survey. The 200 m isobath is shown in light blue, as is the delineation of the various NAFO Divisions/Subdivisions overlapping the study area in gray.

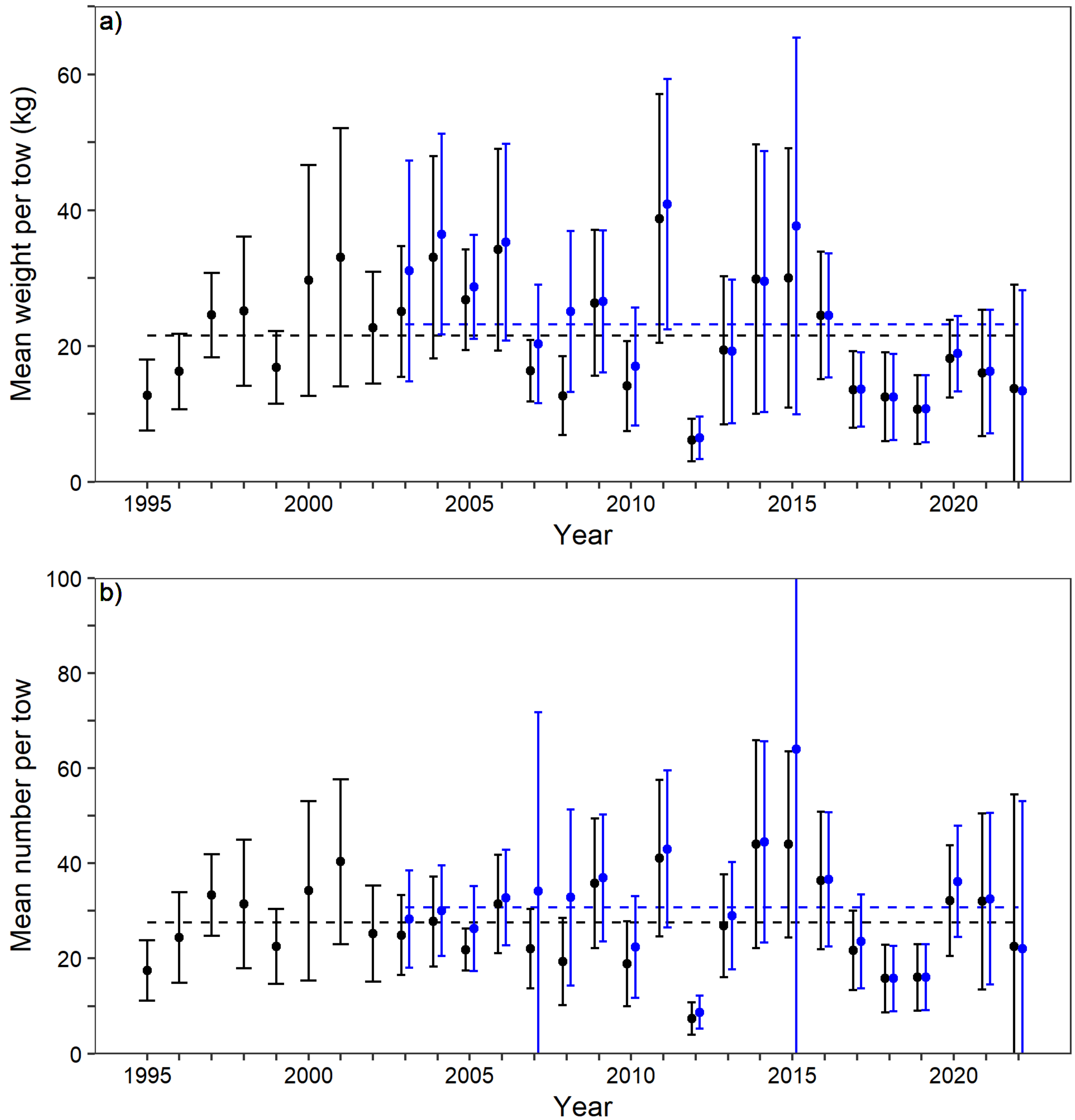

Figure 49. Mean a) weight and b) number per tow in the July mobile gear sentinel survey for the two series considered in the assessment. Error bars represent the 95% confidence intervals. The dashed line represents the average of each series (1995–2022 and 2003–2022).

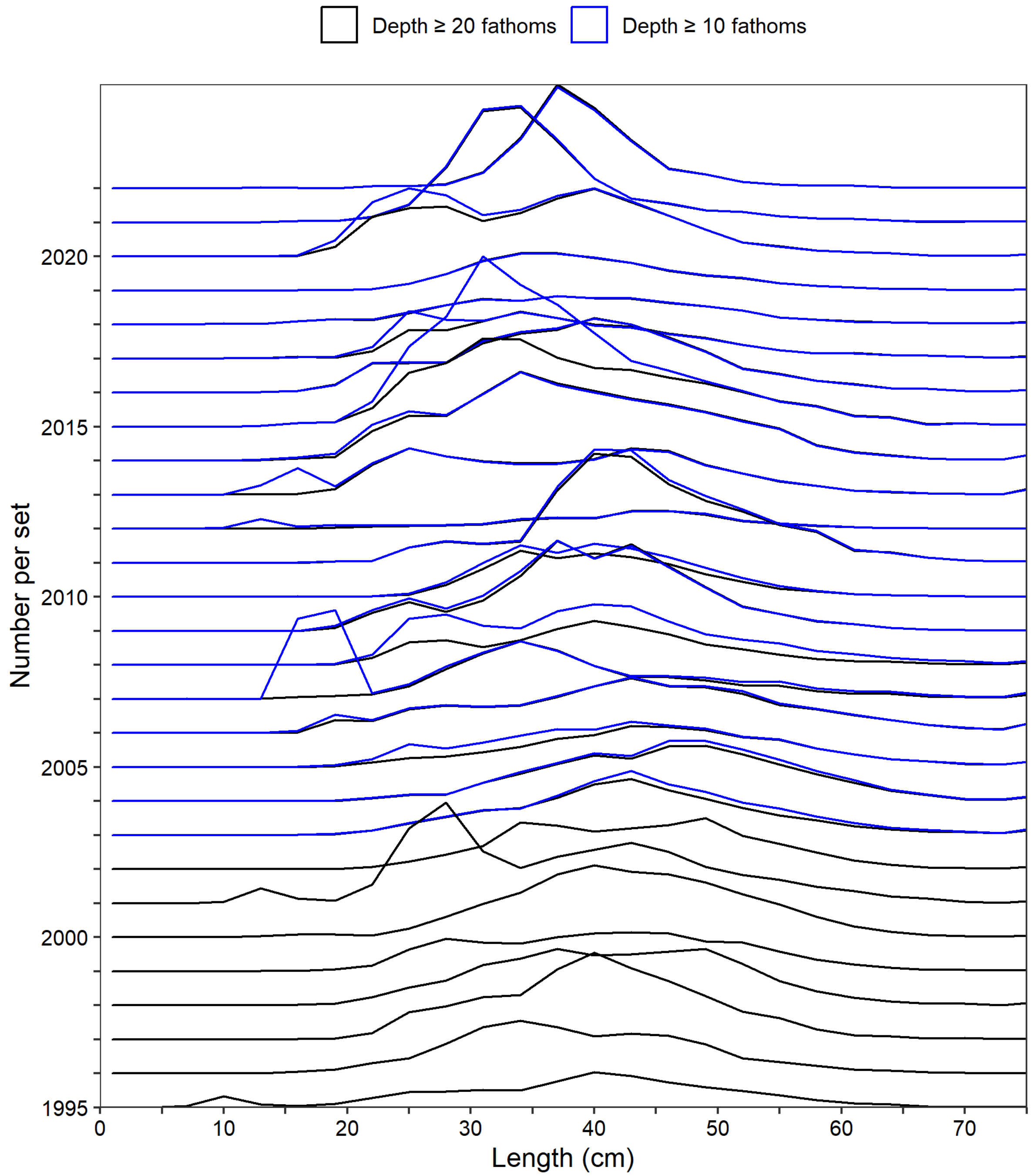

Figure 50. Length frequency distributions (in mean numbers per tow) during the July sentinel mobile gear survey for the two series considered in the assessment model. 3-cm length classes were used for the calculations. Starting in 2003, 10-20 fathom strata were added to the sampling design.

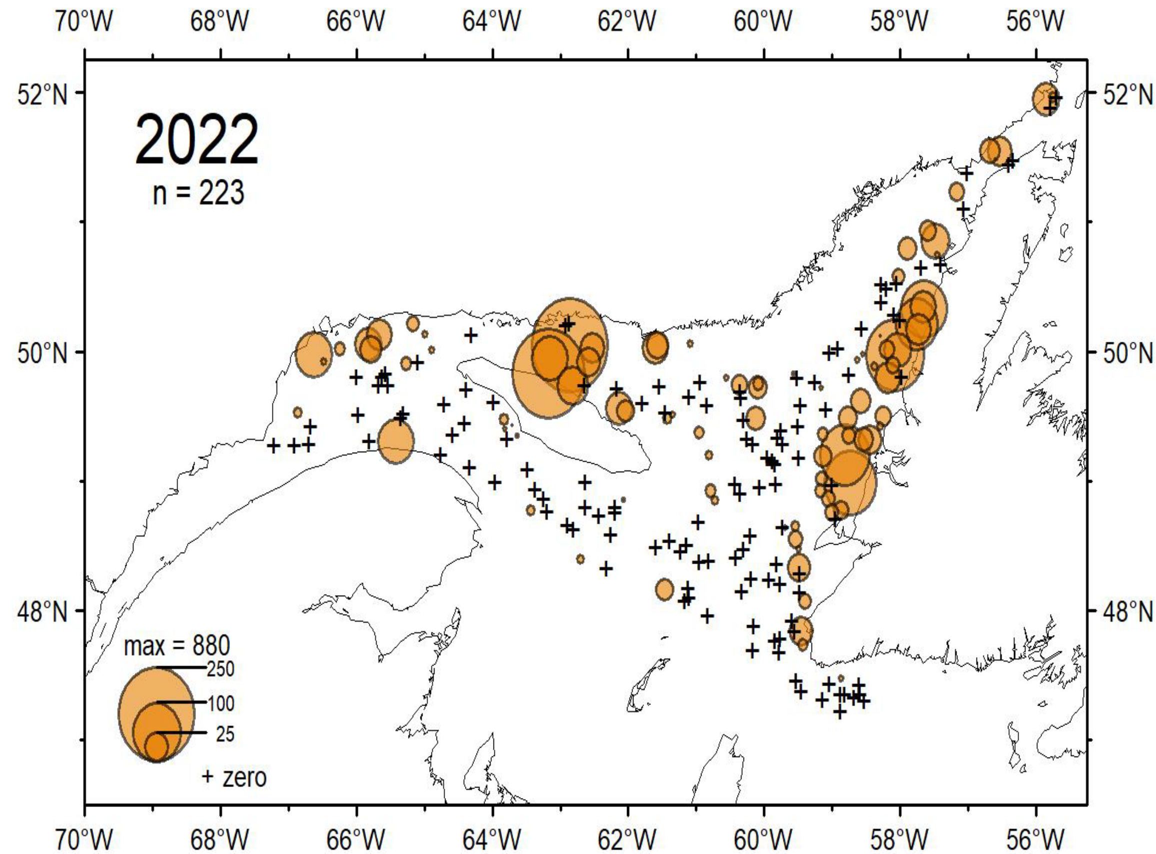

Figure 51. Distribution of catch rates (kg per 30 min tow) of cod during the 2022 sentinel mobile gear survey.

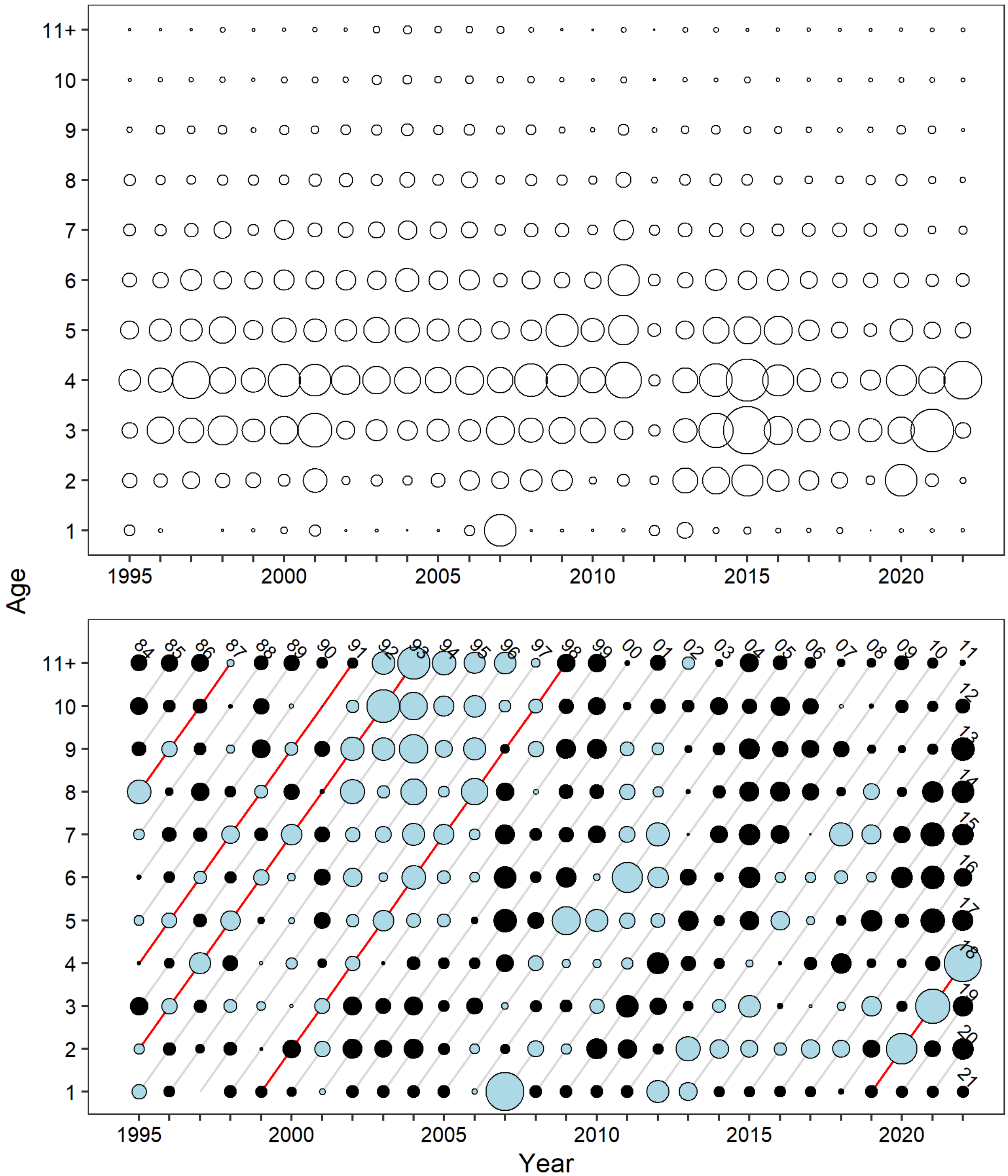

Figure 52. Numbers at age in the sentinel mobile gear survey for 1995–2022. The top figure shows numbers proportional to circle diameter, while the bottom one shows standardized proportions at age and year (SPAY) with blue and black bubbles indicating above and below average, respectively. The bubble diameter is indicative of the SPAY value. The red lines indicate some consistently tracked above average cohorts in the DFO August survey. Cohort years' last two digits are indicated above bubbles from oldest ages and the ones from the most recent year.

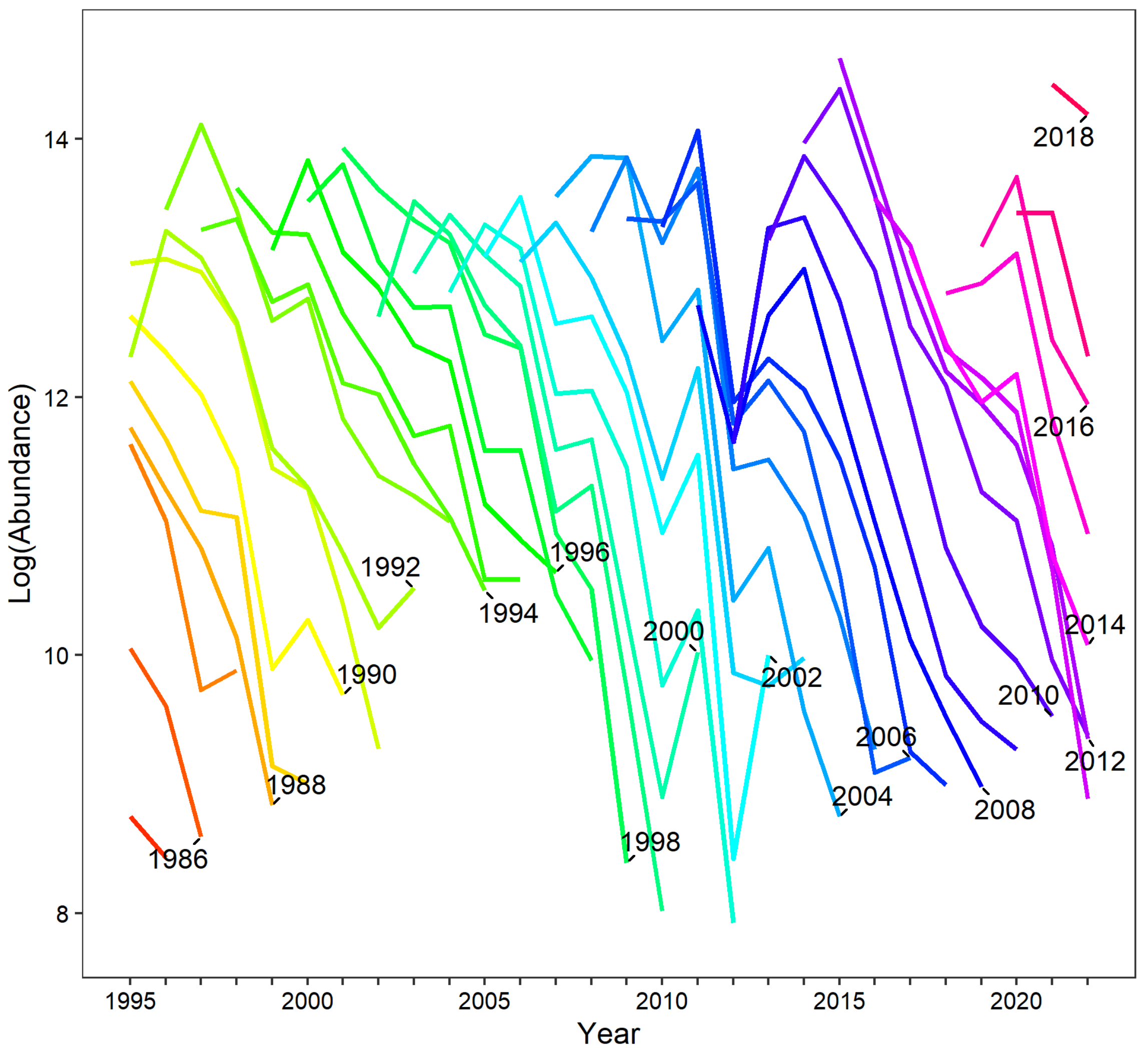

Figure 53. Log-abundance of individual cohorts (ages 3+) from the sentinel mobile gear survey catch at age, 1995-2022. Cohorts are identified by birth year for every 2nd year.

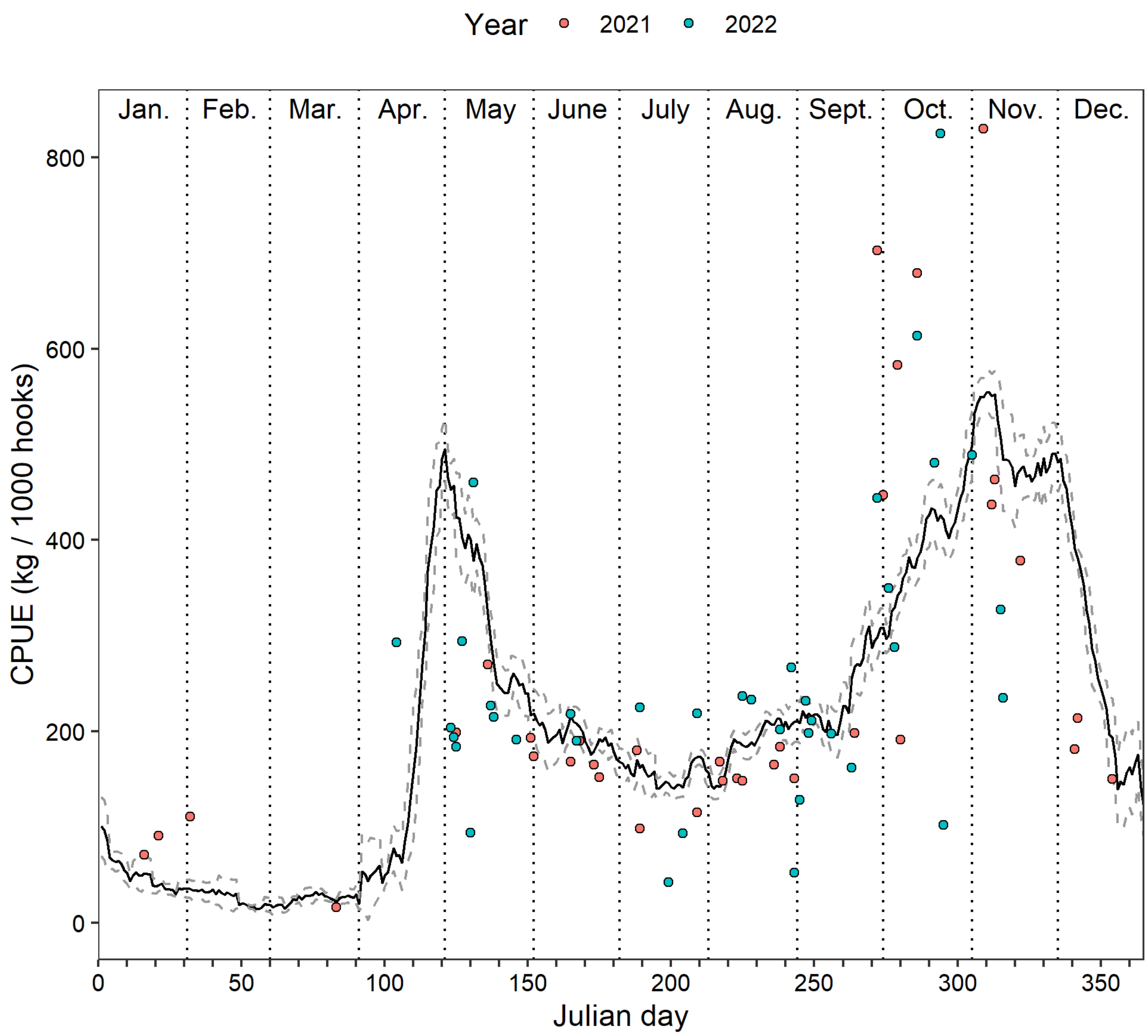

Figure 54. Average daily longline CPUE (kg/1000 hooks) for the sentinel survey program in zone 1 (3Pn) for year 2021 and 2022. The solid line is a 7-day running average of the daily averages for the 1995-2020 series and the dotted lines represent ± ½ standard deviation around this average.

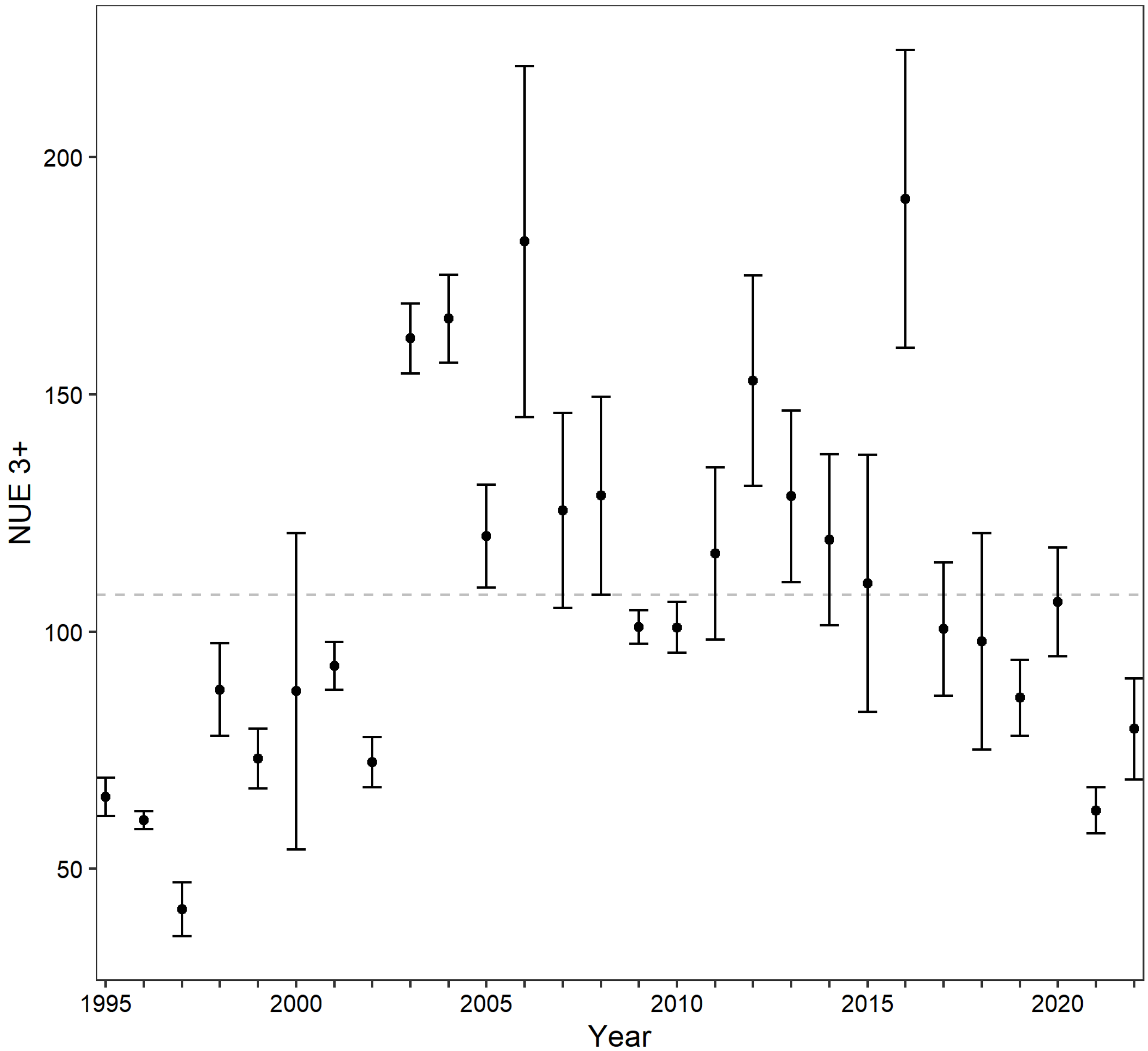

Figure 55. Age 3+ aggregated summer abundance index (number per unit effort [NUE], per 1,000 hooks) with 95% confidence intervals for the sentinel longline program, 1995–2022. The hatched horizontal line represents the average of the 1995–2022 series.

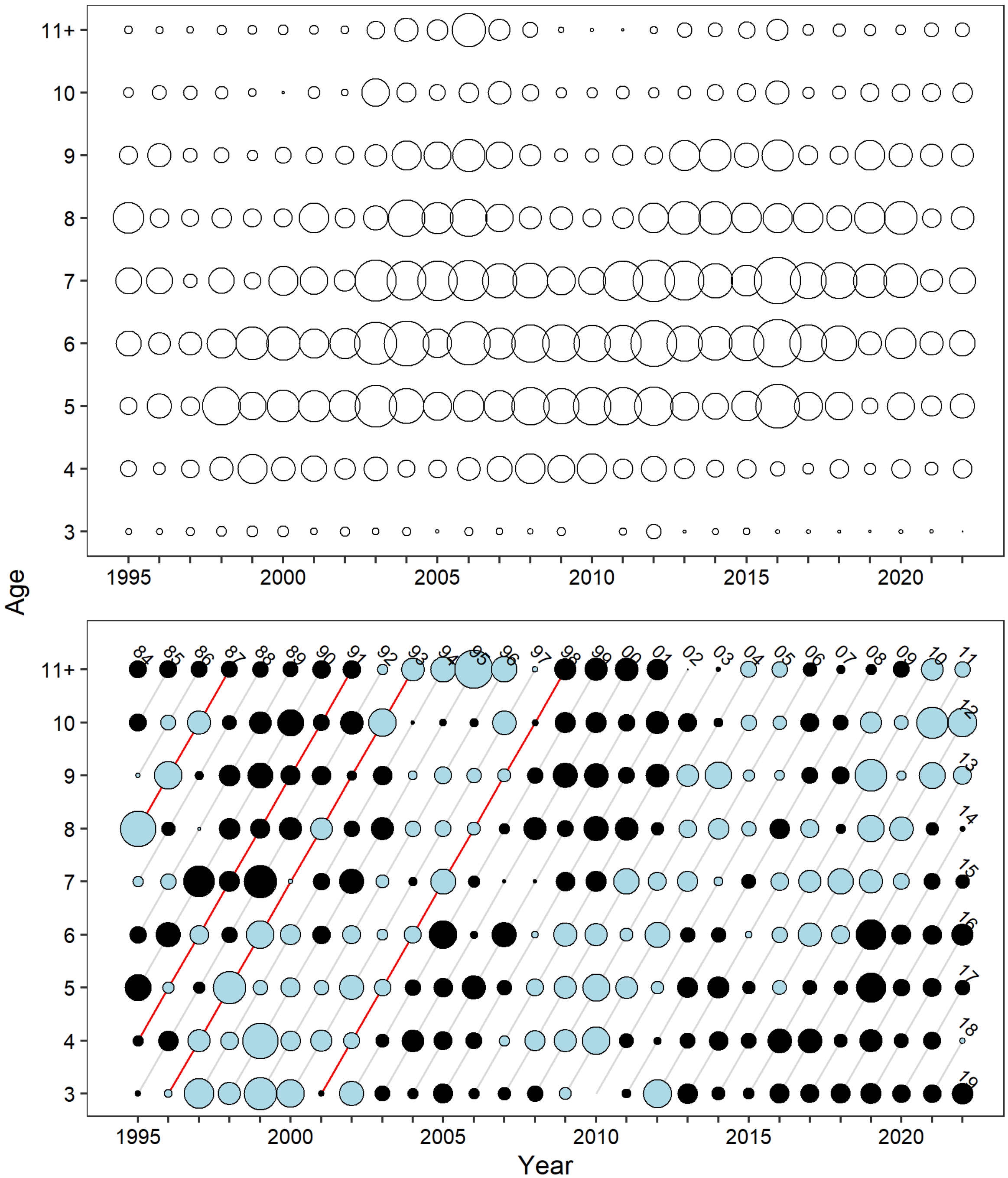

Figure 56. Numbers at age in the sentinel longline survey (summer index) 1995–2022. The top figure shows numbers proportional to circle diameter, while the bottom one shows standardized proportions at age and year (SPAY) with blue and black bubbles indicating above and below average, respectively. The bubble diameter is indicative of the SPAY value. The red lines indicate some consistently tracked above average cohorts in the DFO August survey. Cohort years' last two digits are indicated above bubbles from oldest ages and the ones from the most recent year.

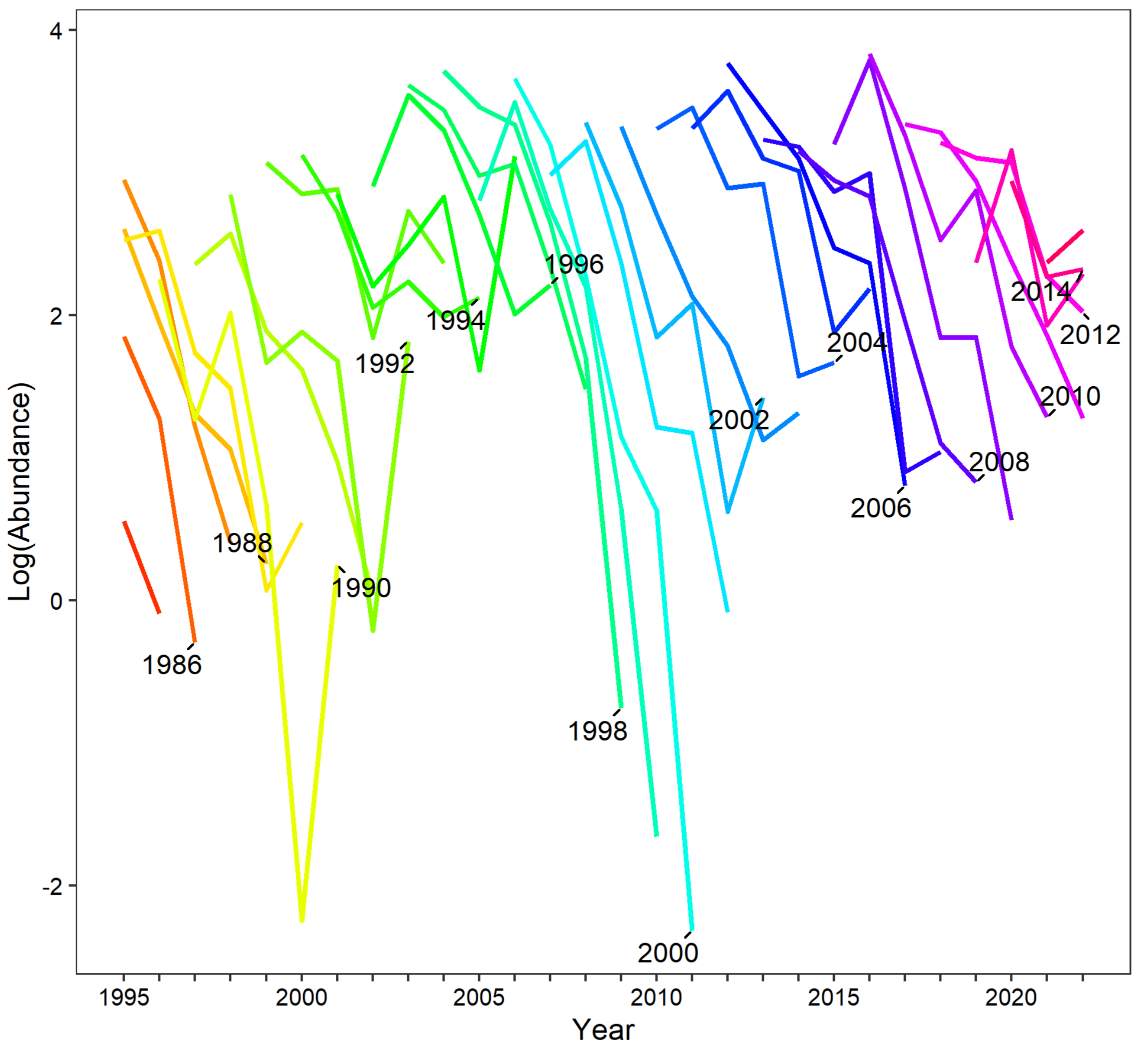

Figure 57. Log-abundance of individual cohorts (ages 6 to 11+) in the sentinel longline survey (summer index) catch at age, 1995–2022. Cohorts are identified by birth year for every 2nd year.

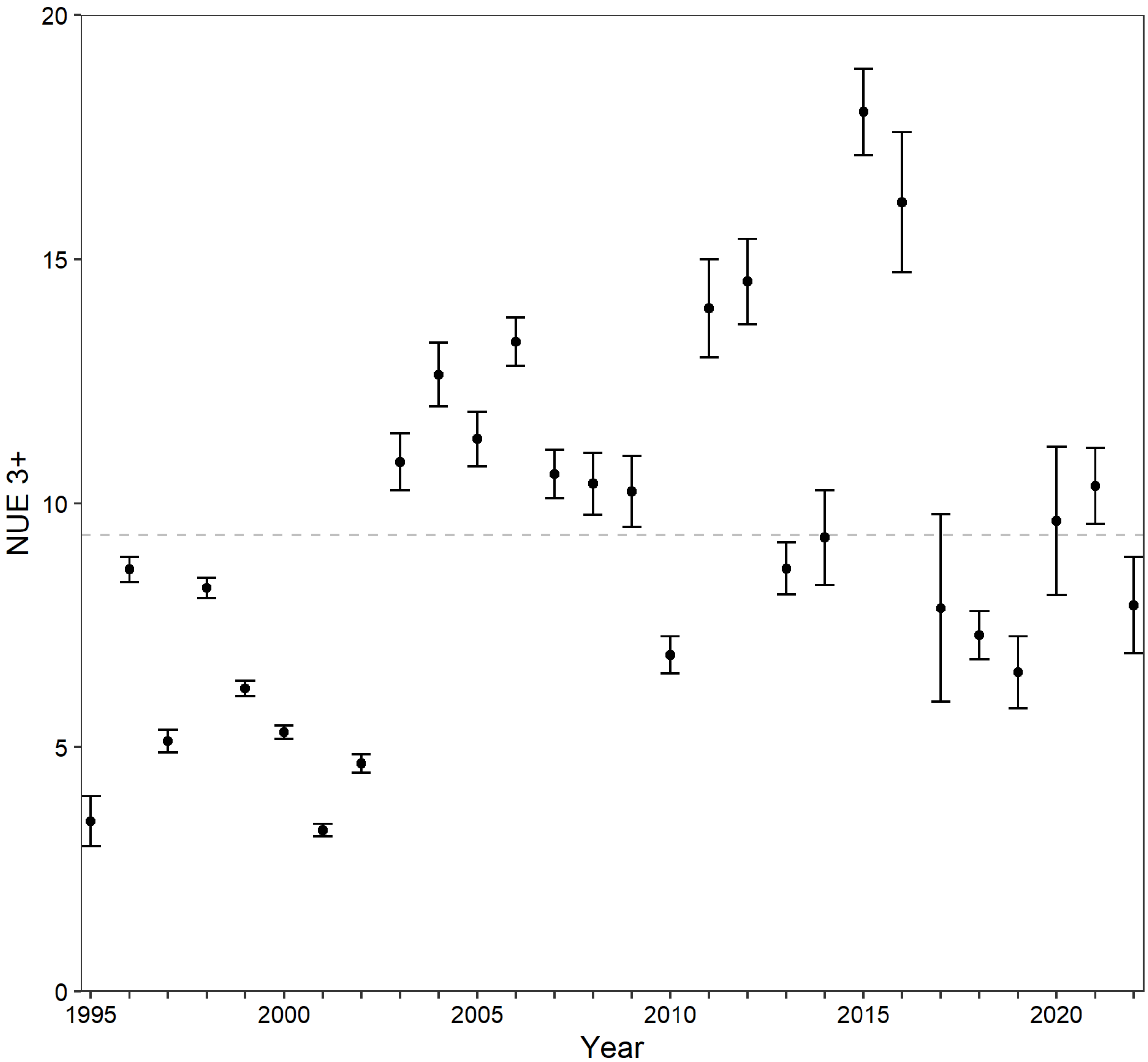

Figure 58. Age 3+ aggregated abundance index (number per unit effort [NUE], per net) with 95% confidence intervals for the sentinel gillnet program, 1995–2022. The hatched horizontal line represents the average of the 1995–2022 series.

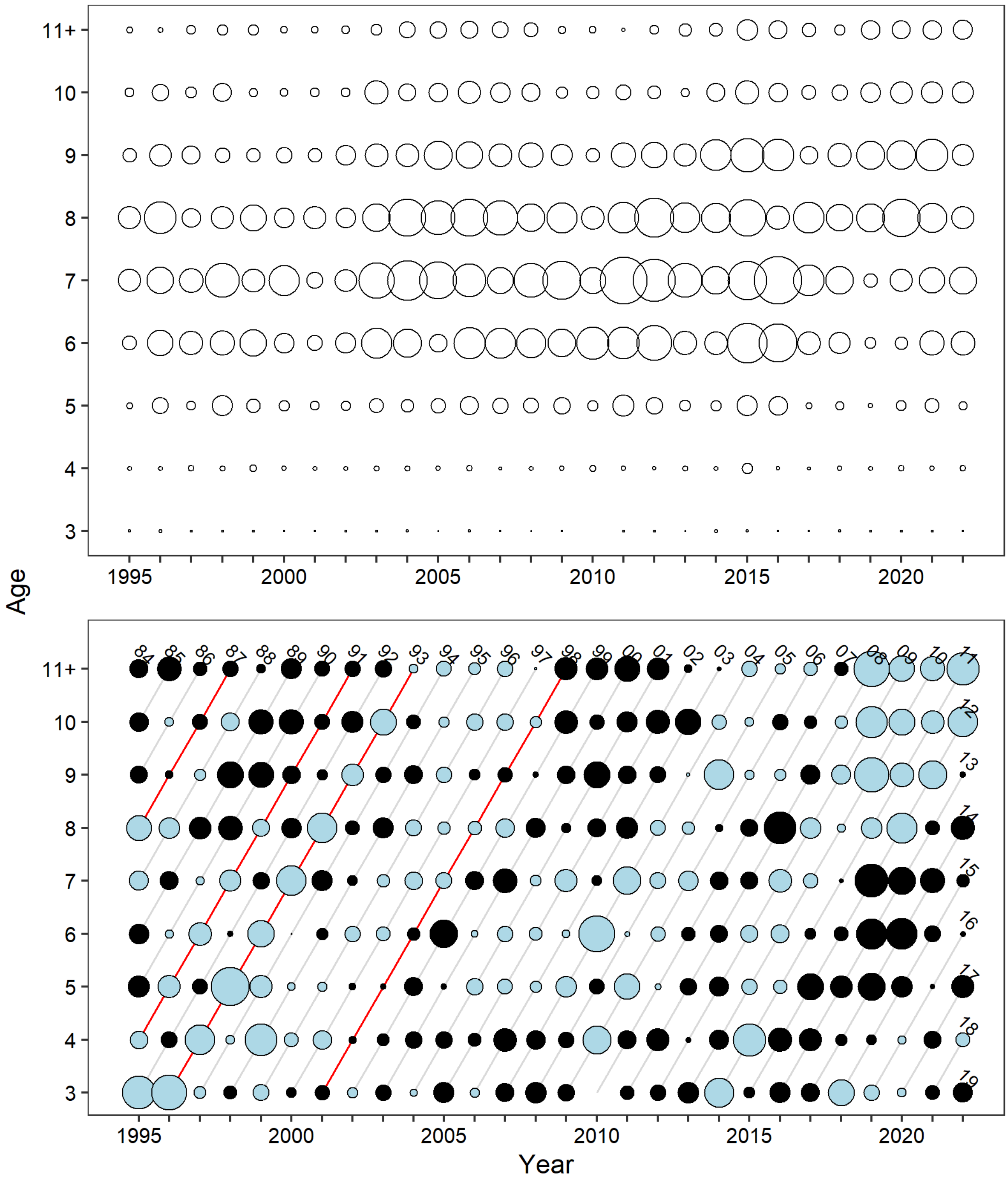

Figure 59. Numbers at age in the sentinel gillnet survey for the period 1995–2022. The top figure shows numbers proportional to circle diameter, while the bottom one shows standardized proportions at age and year (SPAY) with blue and black bubbles indicating above and below average, respectively. The bubble diameter is indicative of the SPAY value. The red lines indicate some consistently tracked above average cohorts in the DFO August survey. Cohort years' last two digits are indicated above bubbles from oldest ages and the ones from the most recent year.

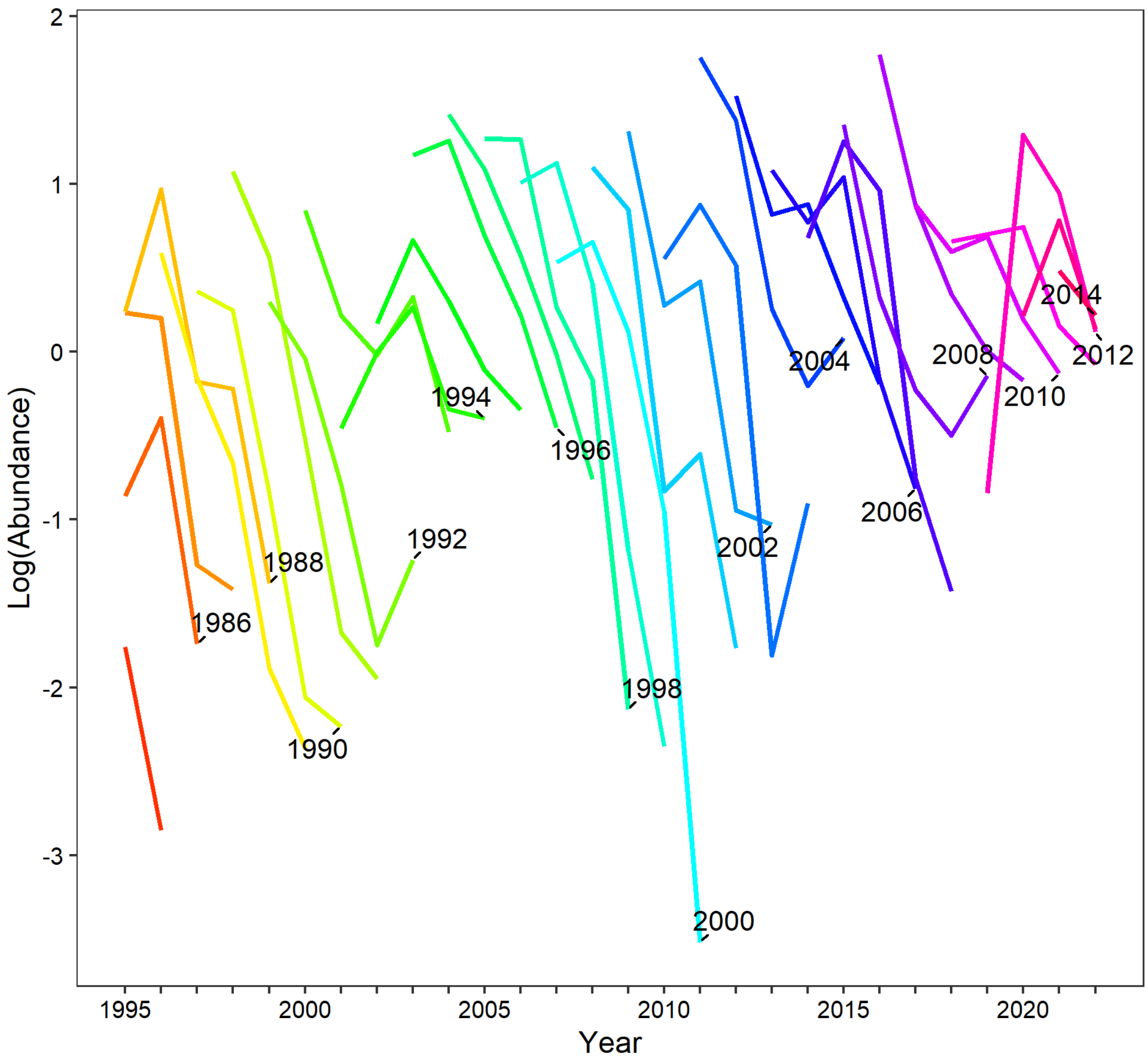

Figure 60. Log-abundance of individual cohorts (ages 7 to 11+) in the sentinel gillnet survey catch at age, 1995–2022. Cohorts are identified by birth year for every 2nd year.

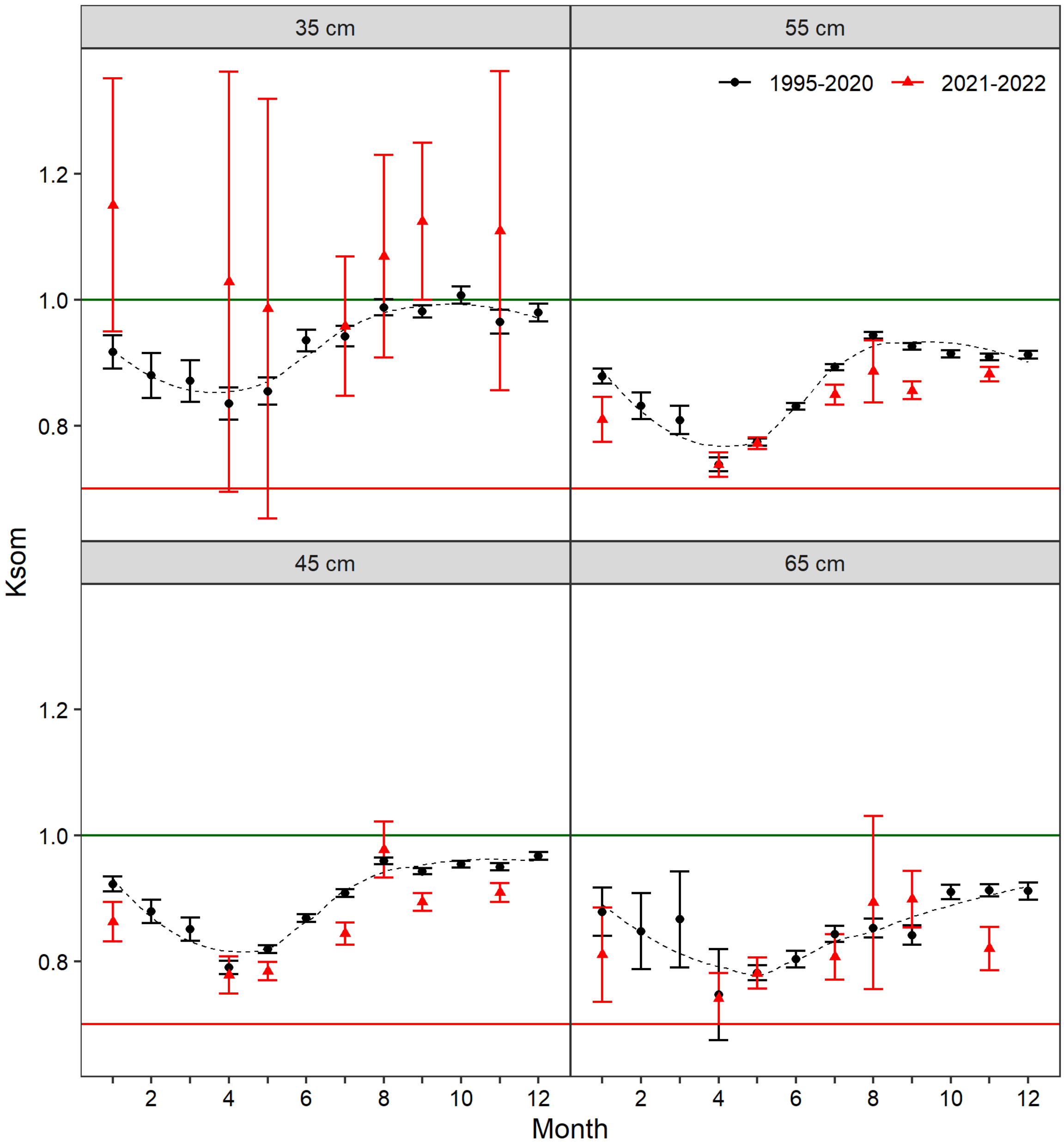

Figure 61. Seasonal changes in mean condition (Fulton Index, Ksom, ±95% CI) of cod sampled during 2021–2022 compared to 1995–2020 at different fish sizes (panels), based on the fixed gear sentinel survey program. The hatched line represents a smoothing of the monthly averages for the 1995-2020 series. Based on Dutil et al. (1995), Ksom values > 1, between 0.7 and 1 and < 0.7 represent cod in excellent, good and critical condition respectively.

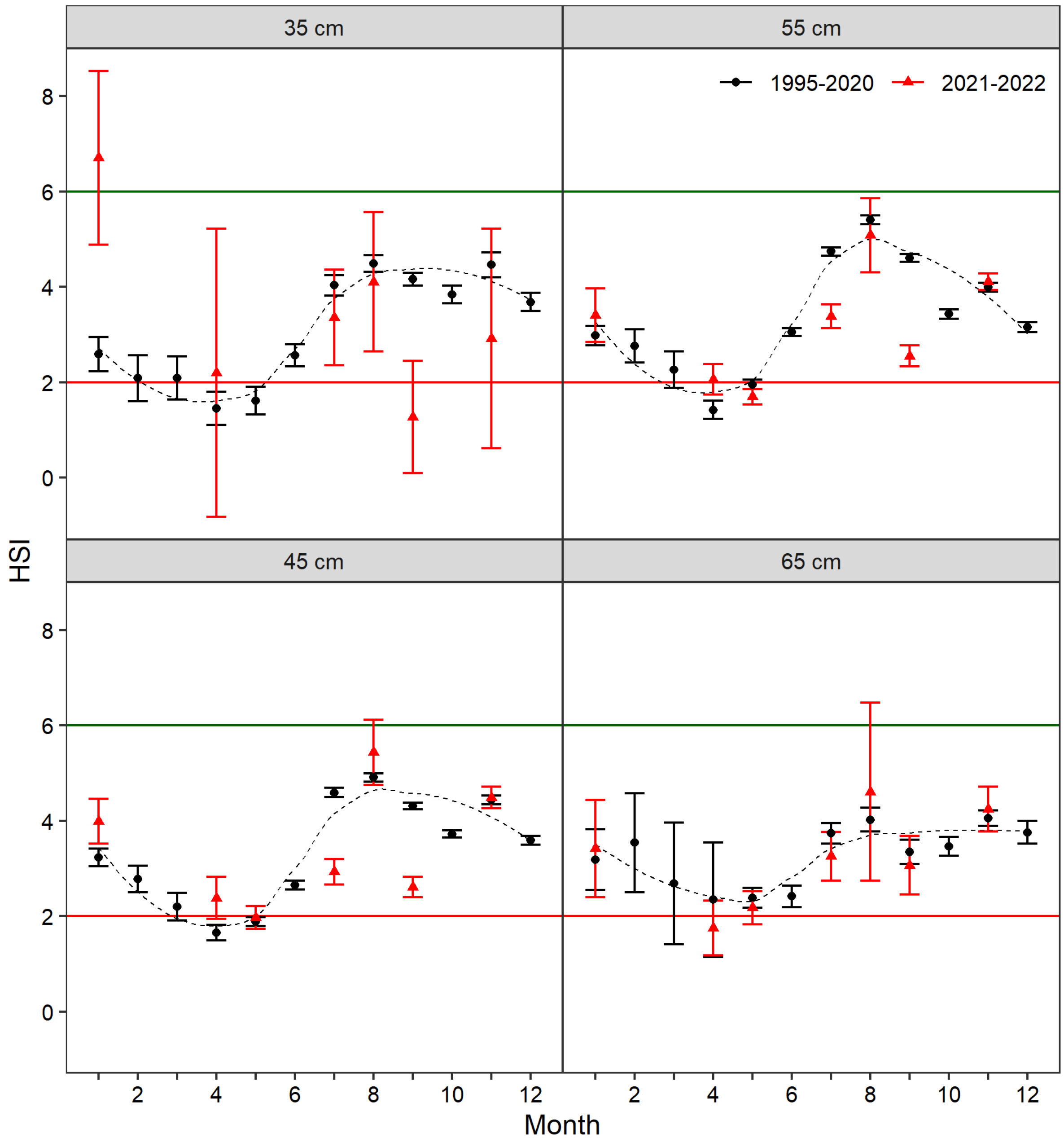

Figure 62. Seasonal changes in mean condition (hepato-somatic index, HSI, Ksom, ±95% CI) of cod sampled during 2021–2022 compared to 1995–2020 at different fish sizes (panels), based on the fixed gear sentinel survey program. The hatched line represents a smoothing of the monthly averages for the 1995-2020 series. Based on Dutil et al. (1995), HSI values > 6, between 2 and 6 and < 2 represent cod in excellent, good and critical condition respectively.

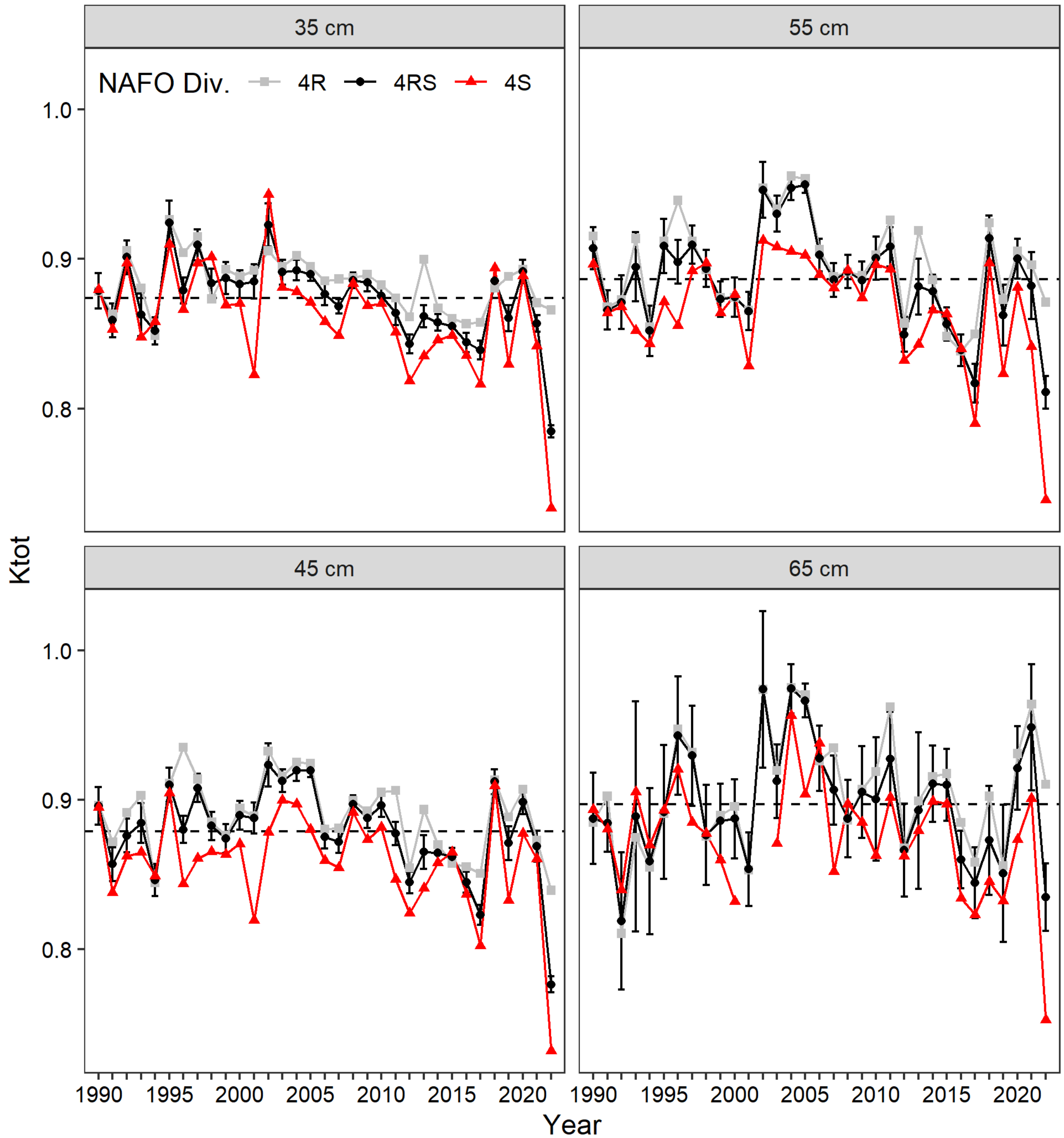

Figure 63. Condition of cod sampled during the DFO August survey, by NAFO Division. Each point represents the annual mean (± 95% CI for the 4RS series only) of the Fulton condition index (Ktot). The horizontal hatched line represents the average of the 4RS 1990–2022 series. Based on Dutil et al. (1995), Ktot values > 1, between 0.7 and 1 and < 0.7 represent cod in excellent, good and critical condition respectively.

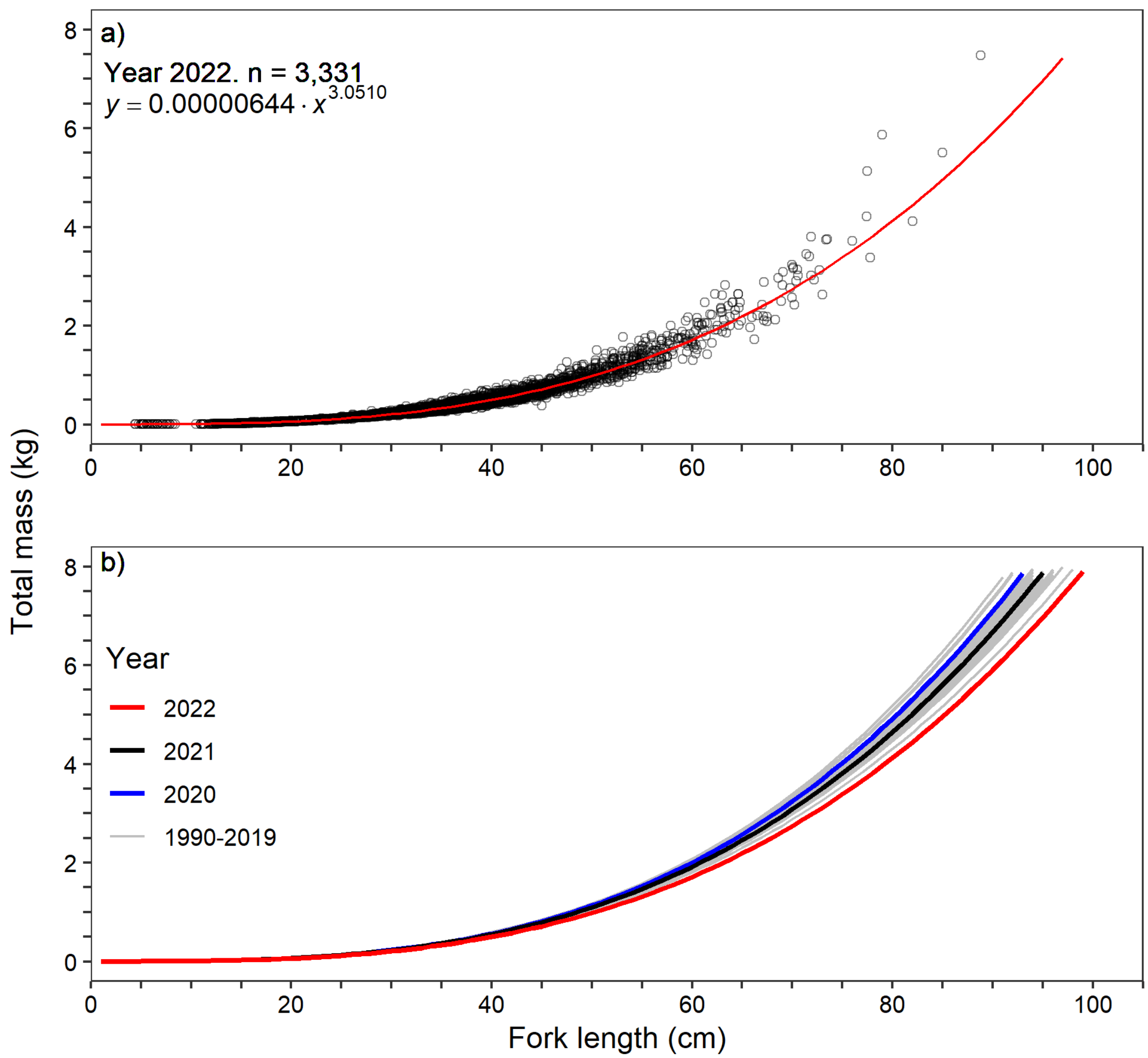

Figure 64. Mass-length relationship from the DFO August survey for a) year 2022 and b) all years in the series (1990-2022).

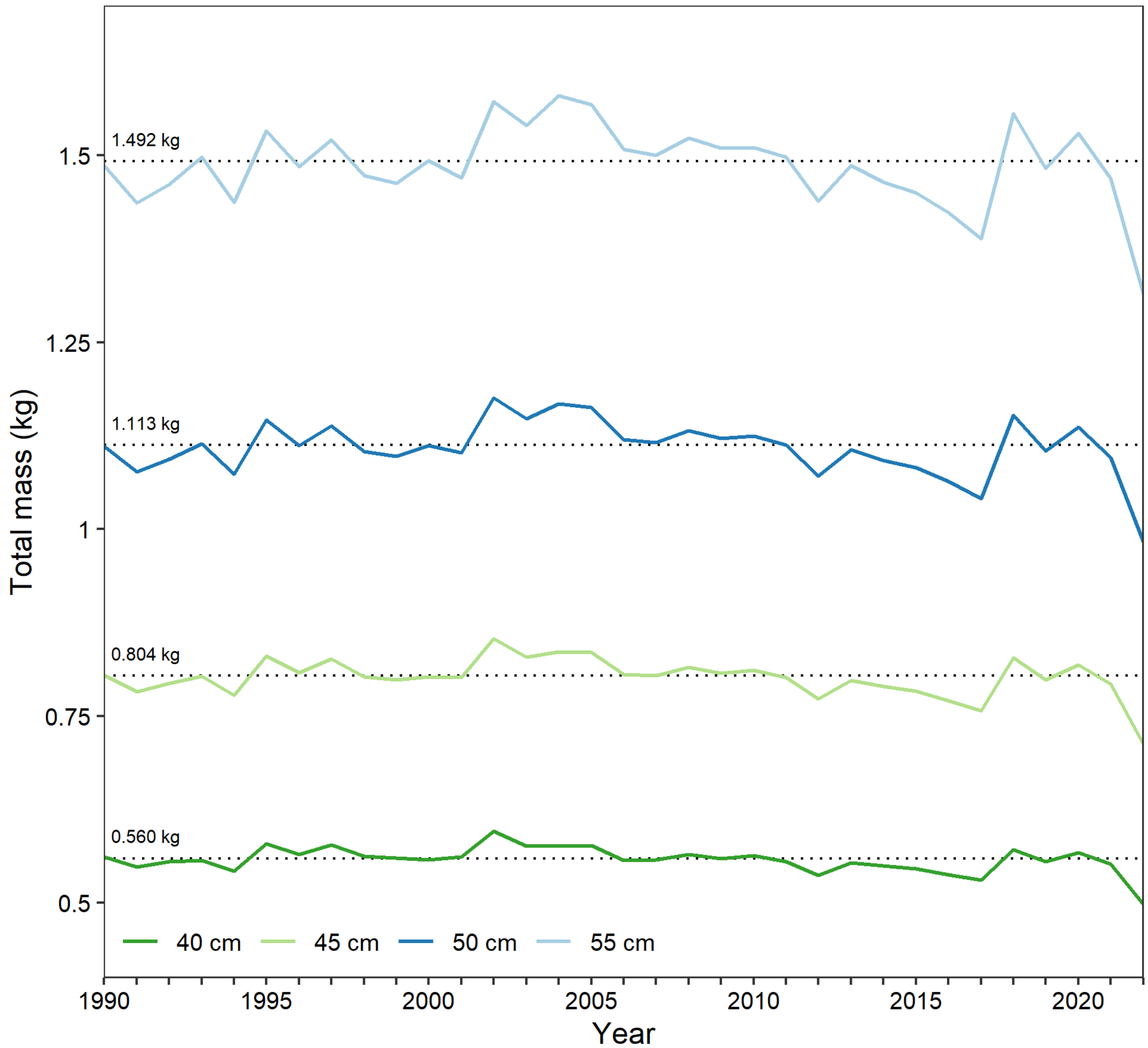

Figure 65. Evolution of total mass of Atlantic cod of different lengths as a function of year. Masses are calculated from mass-length relationships obtained from the DFO August survey. The dotted horizontal lines represent the average of the 1990-2022 series for each displayed length. For each length, the average total mass is provided.

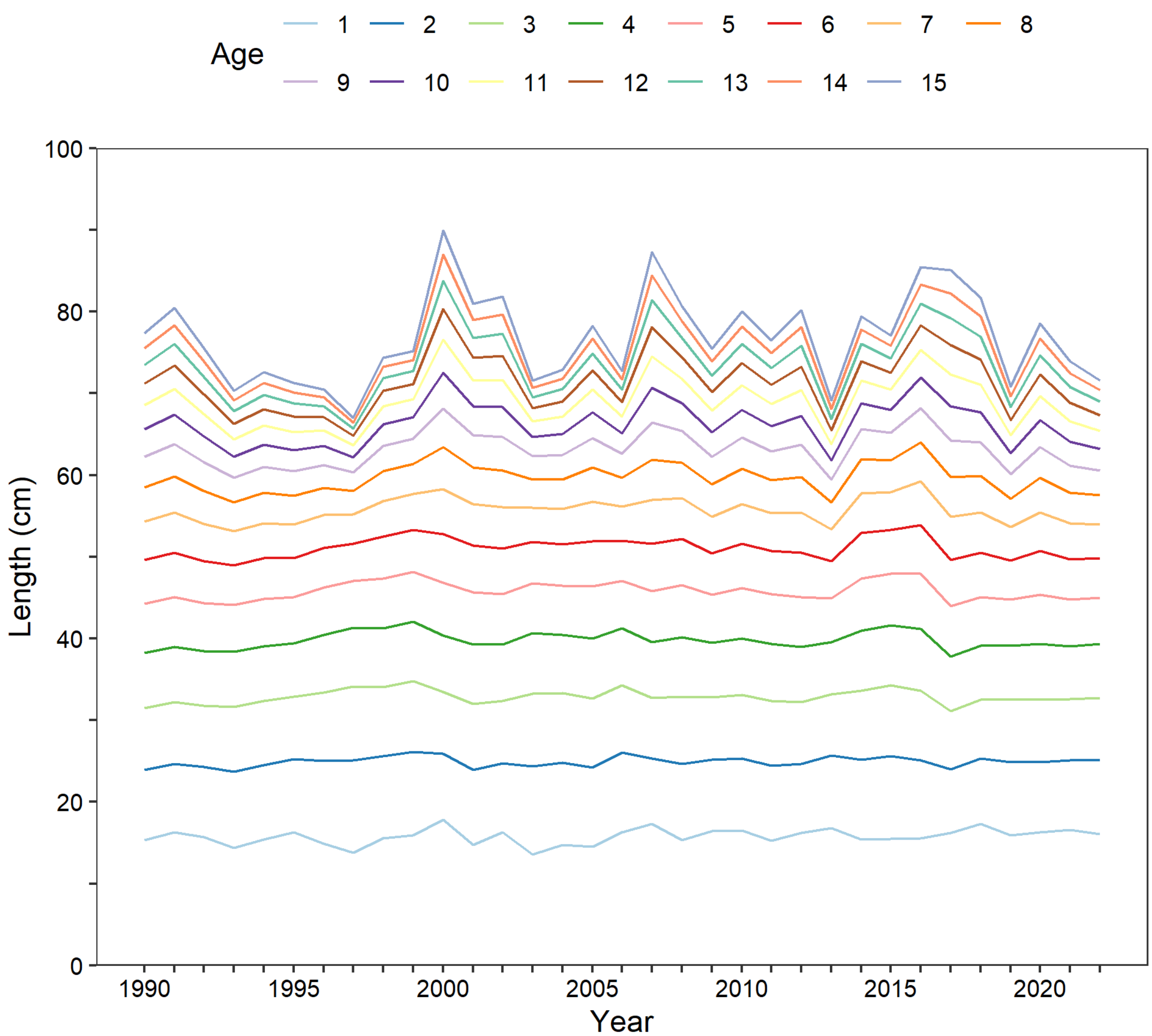

Figure 66. Evolution of lengths calculated from the von Bertalanffy growth curve for the period 1990-2022 using the data from the DFO August survey.

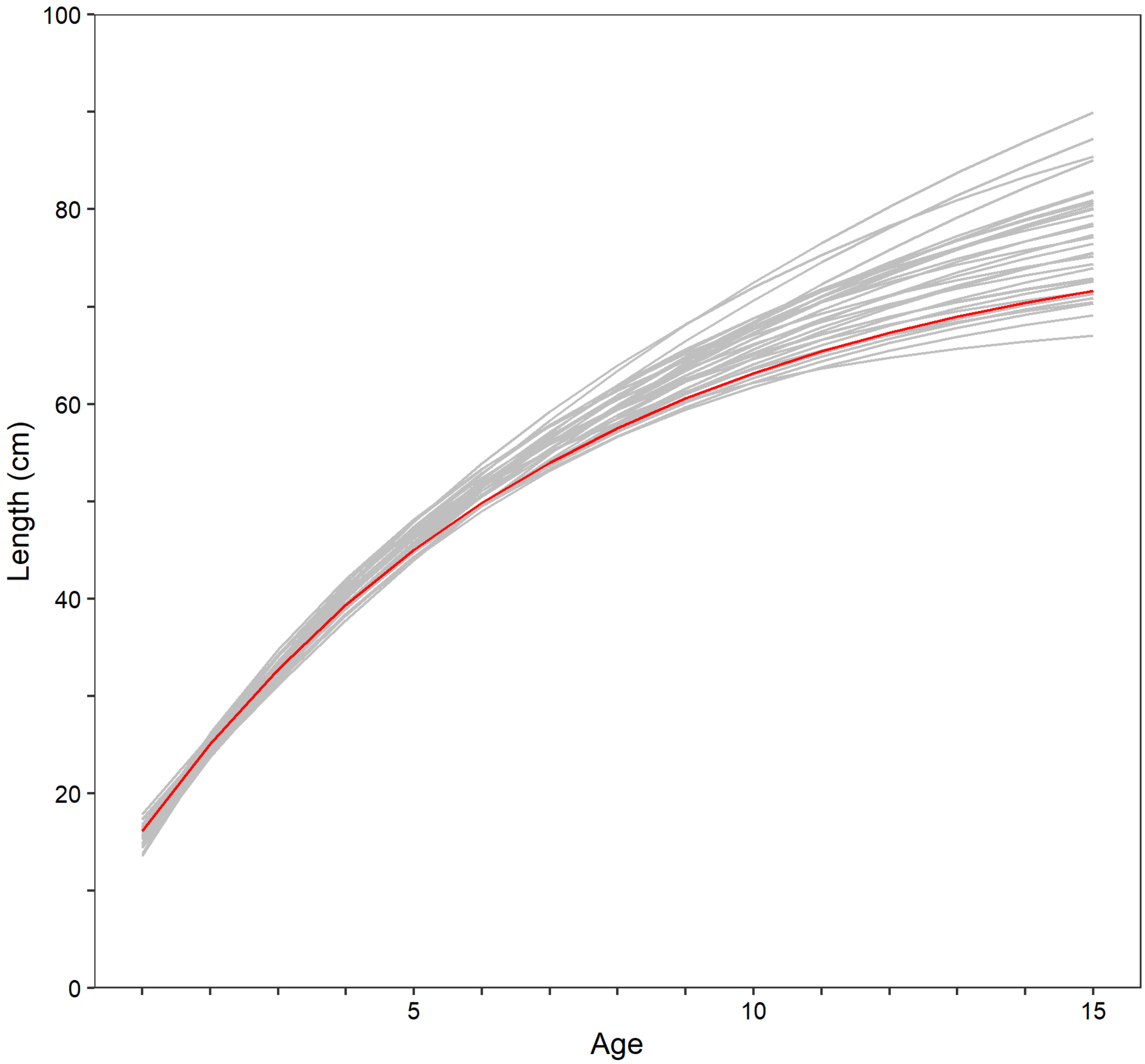

Figure 67. Evolution of annual von Bertalanffy growth curves for the period 1990-2022 from the DFO August survey. The year 2022 is in red and those of the period 1990-2021 in grey.

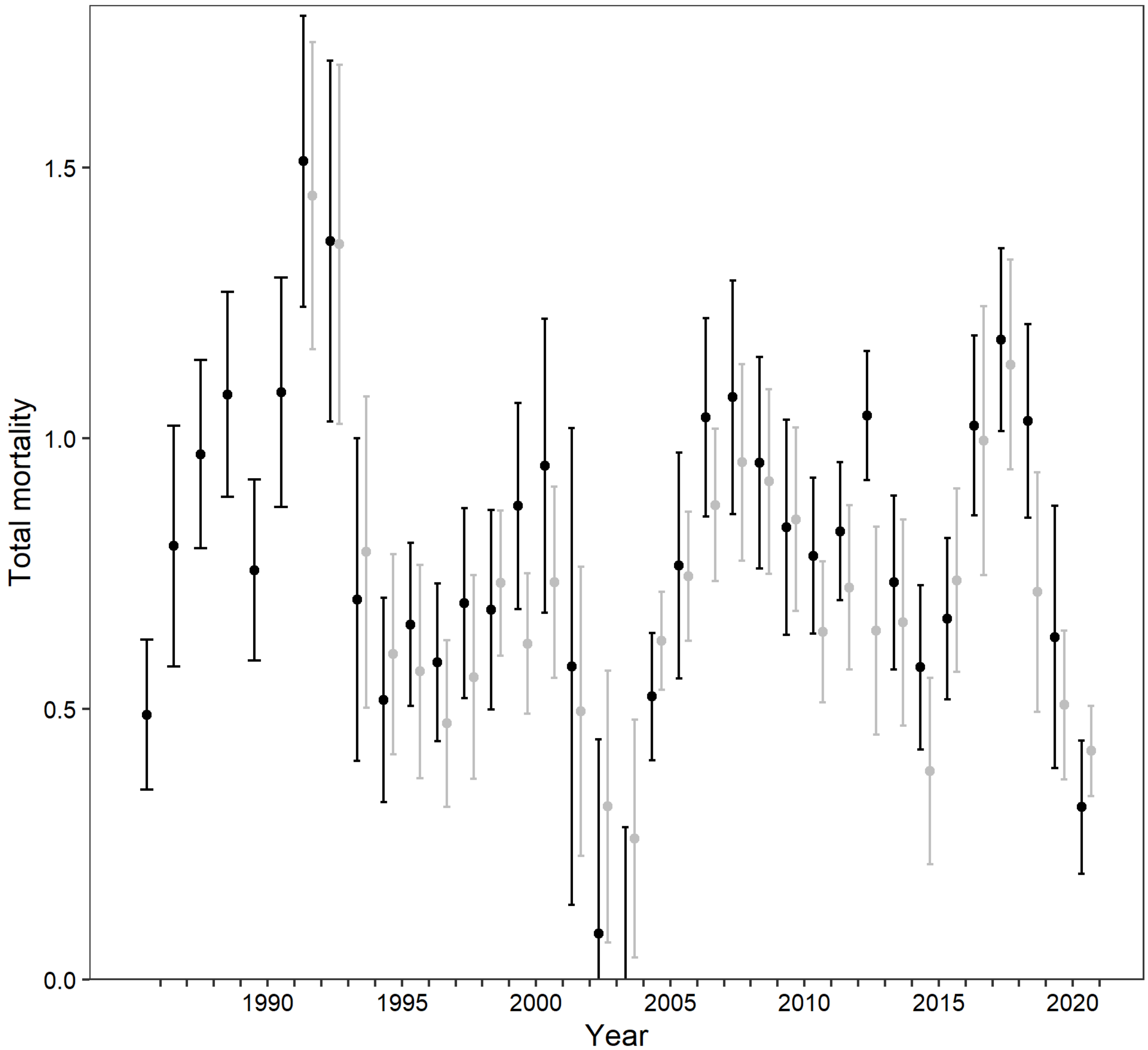

Figure 68. Estimates of total mortality (Z, with 95% confidence intervals) for ages 5 to 10 from the DFO August survey for 1984–2022 based on the reduced suite of strata (black) and 1990-2022 based on all consistently sampled strata (grey).

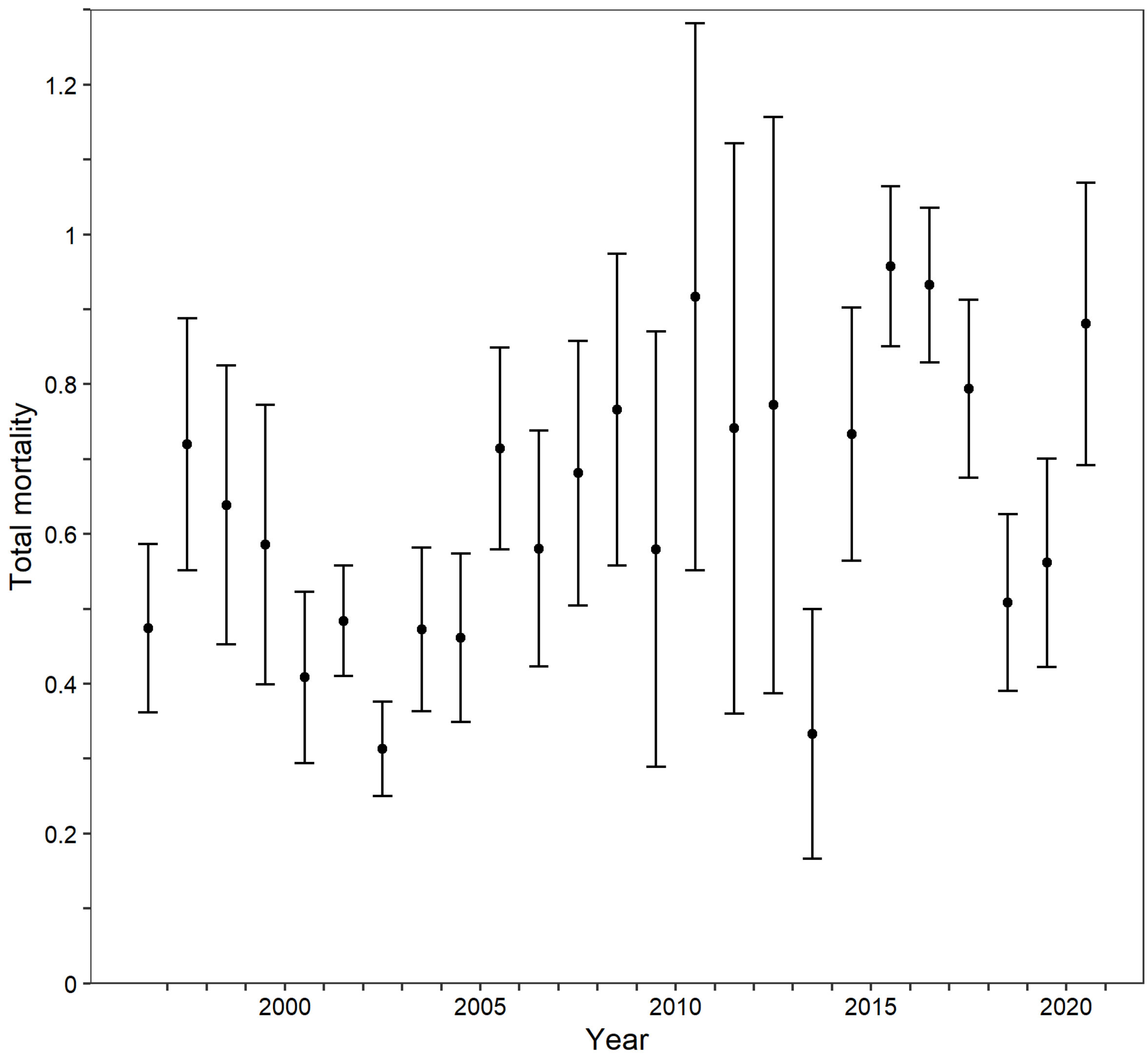

Figure 69. Estimates of total mortality (Z, with 95% confidence intervals) for ages 5 to 10 from the sentinel mobile gear survey, 1995–2022.

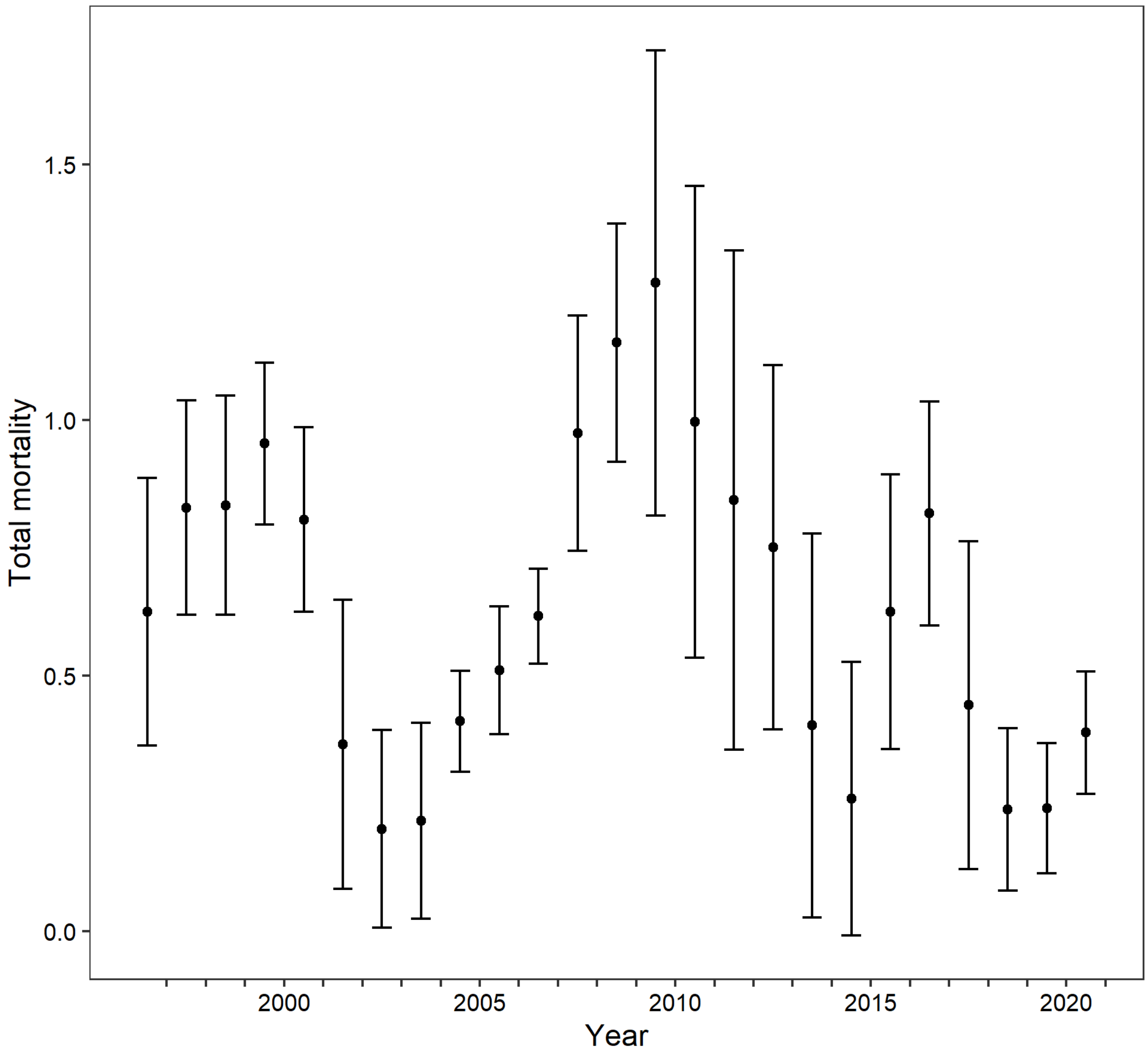

Figure 70. Estimates of total mortality (Z, with 95% confidence intervals) for ages 8 to 12 from the sentinel gillnet survey, 1995–2022.

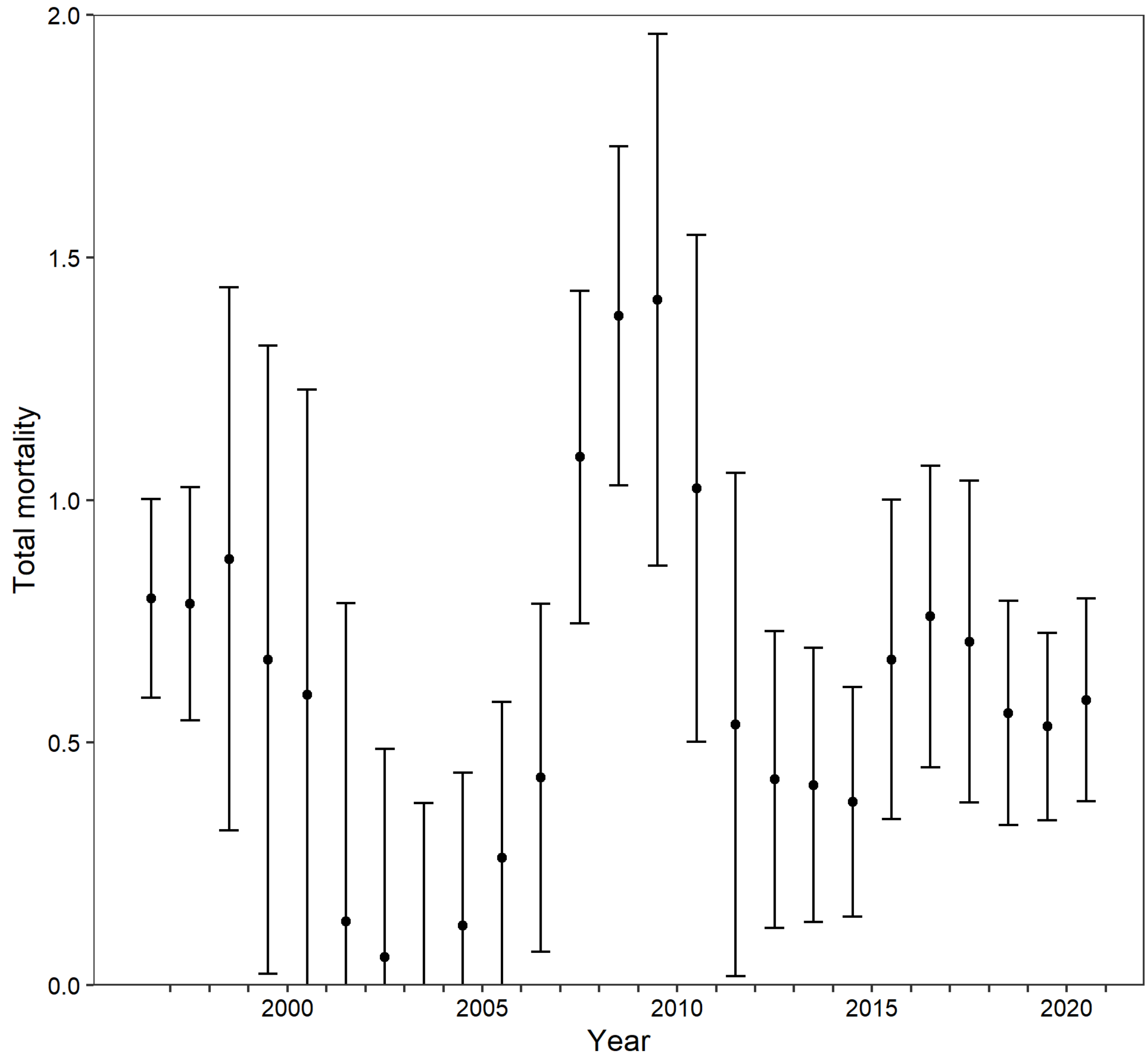

Figure 71. Estimates of total mortality (Z, with 95% confidence intervals) for ages 8 to 12 from the sentinel longline survey (summer index), 1995–2022.

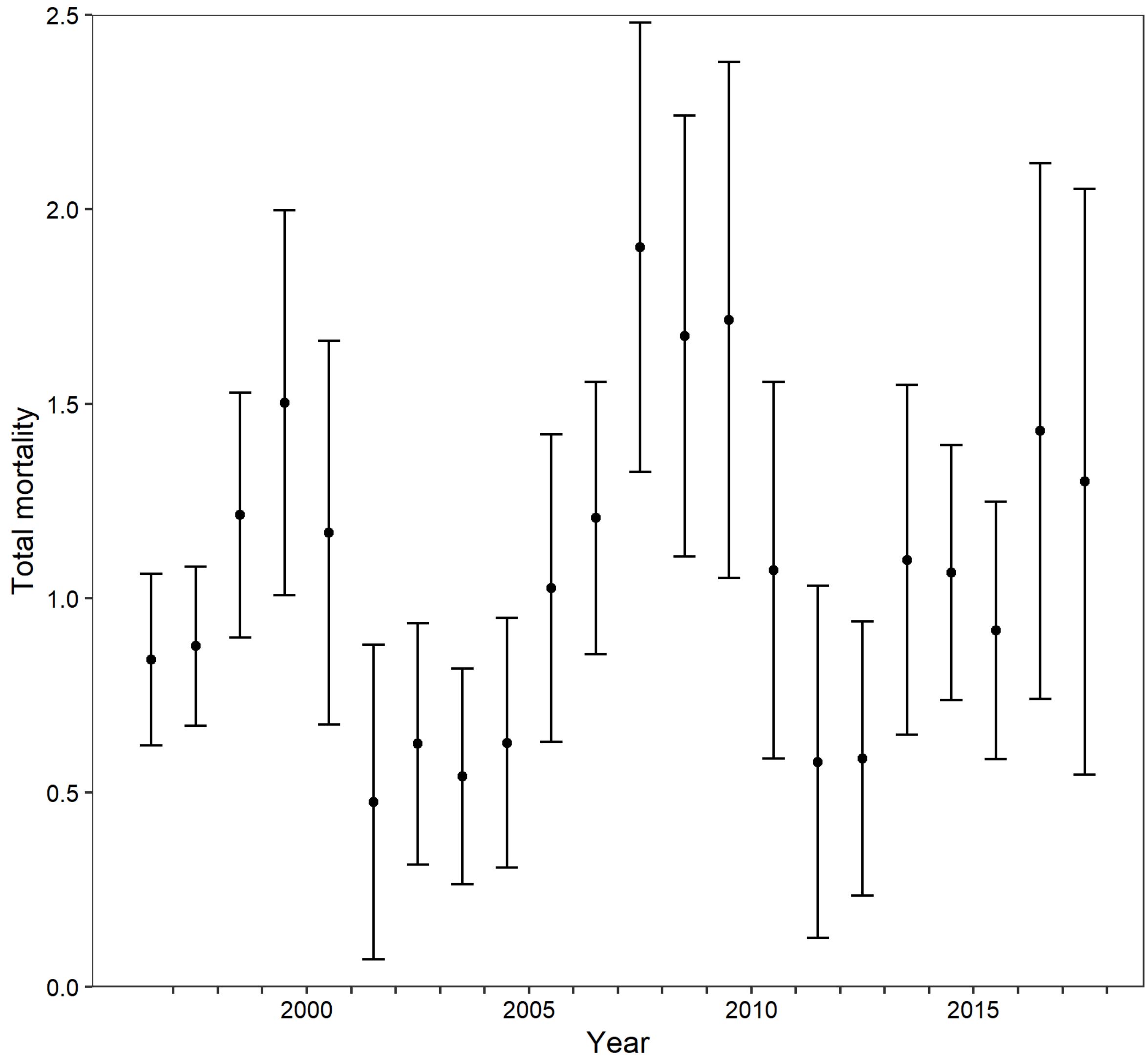

Figure 72. Estimates of total mortality (Z, with 95% confidence intervals) for ages 8 to 12 from the sentinel longline survey (zone 1 fall index), 1995–2019.

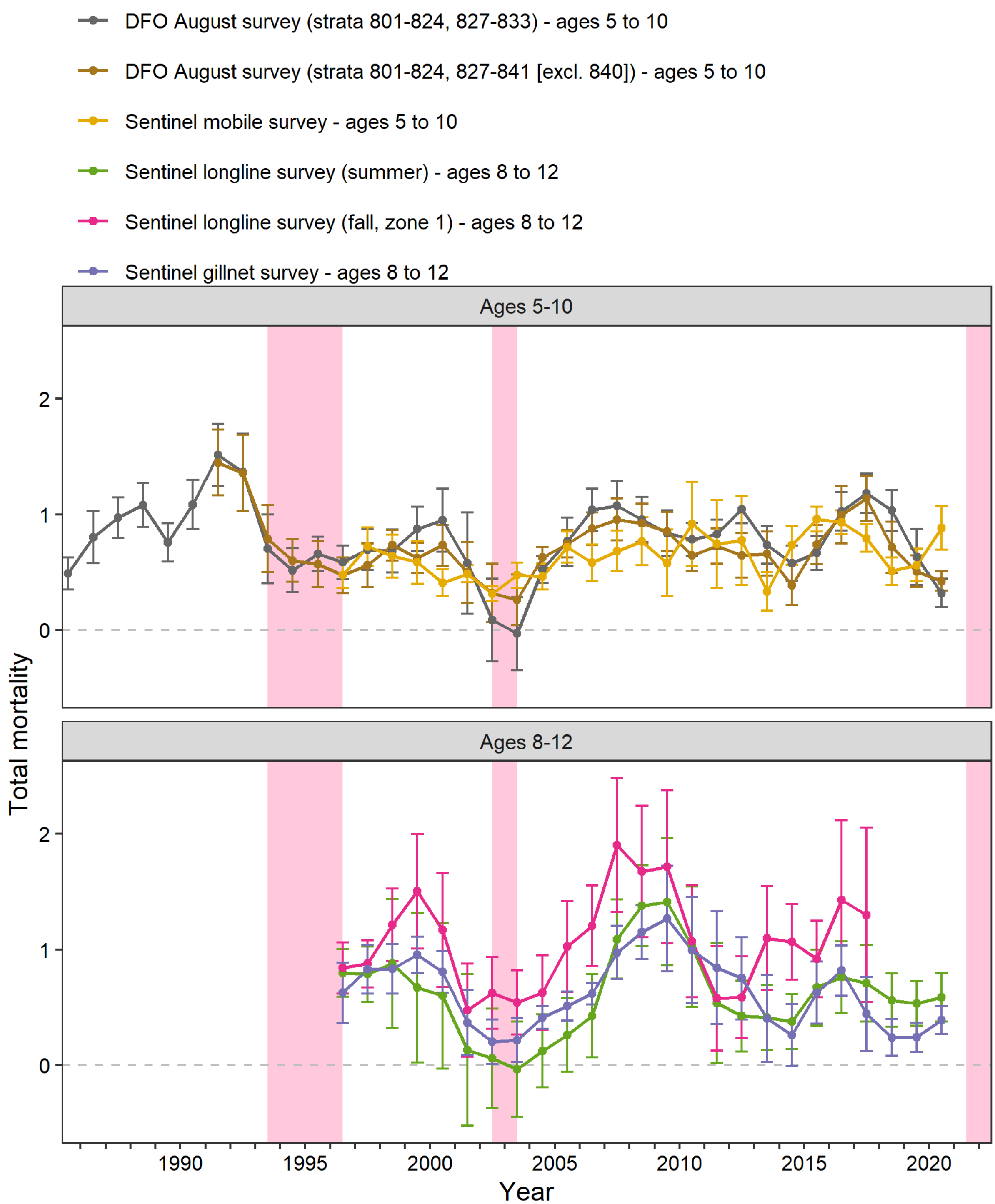

Figure 73. Comparison of total mortality estimates for each of the six principal fishery independent survey indices. Moratorium years are shaded in pink.

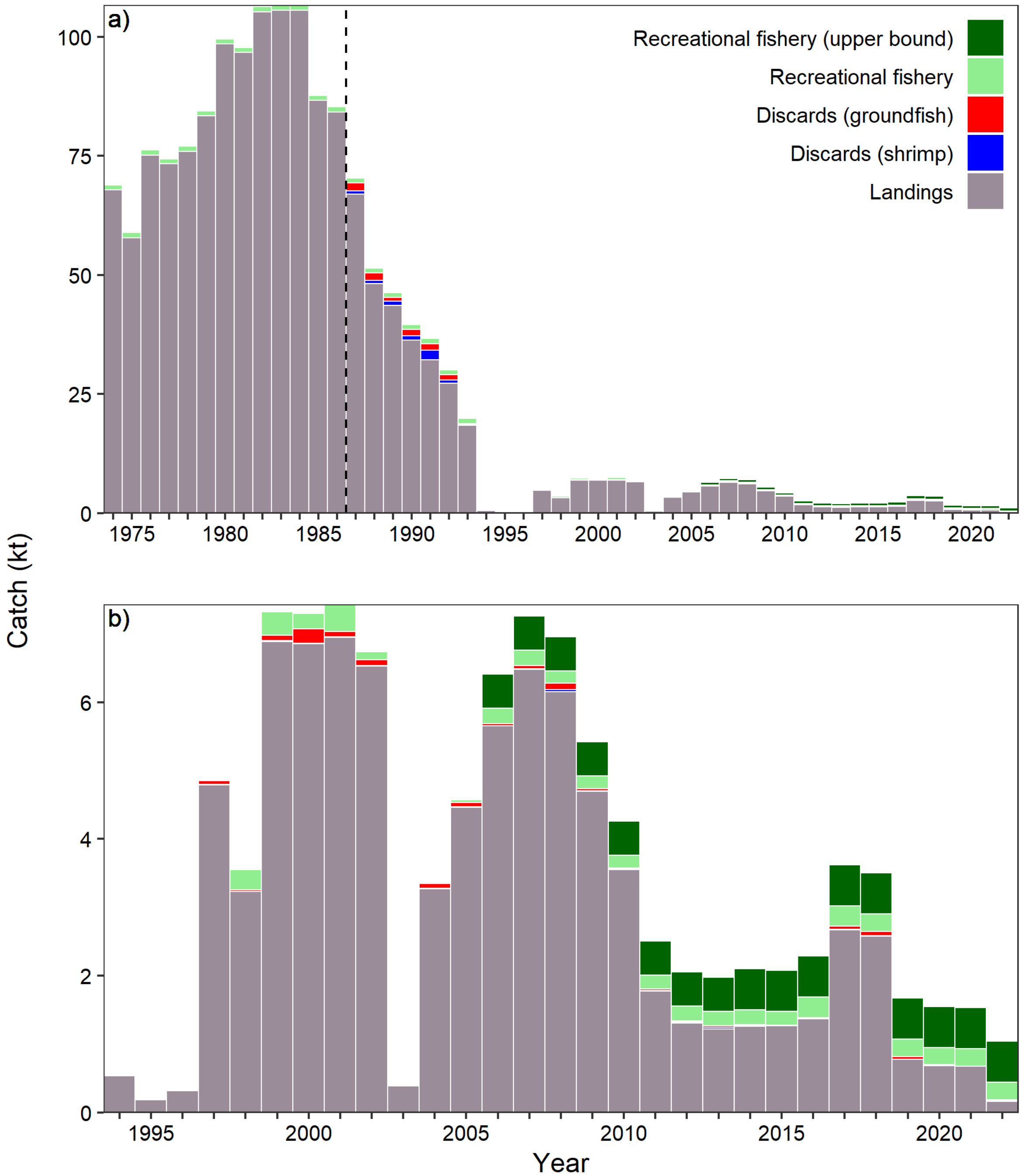

Figure 74. Estimates of annual cod removals in NAFO Divisions 3Pn4RS fisheries from reported landings, estimated discards in shrimp and groundfish fisheries (assuming no post-release survival) and from the recreational fishery. Discard estimates are available from 1987, indicated by the vertical dotted line. Estimated recreational fishery catches added to landings are indicated in light green, while a censored range for recreational fishery catches as of 2006 is indicated in dark green. The figure in b) emphasizes the 1994–2022 period.

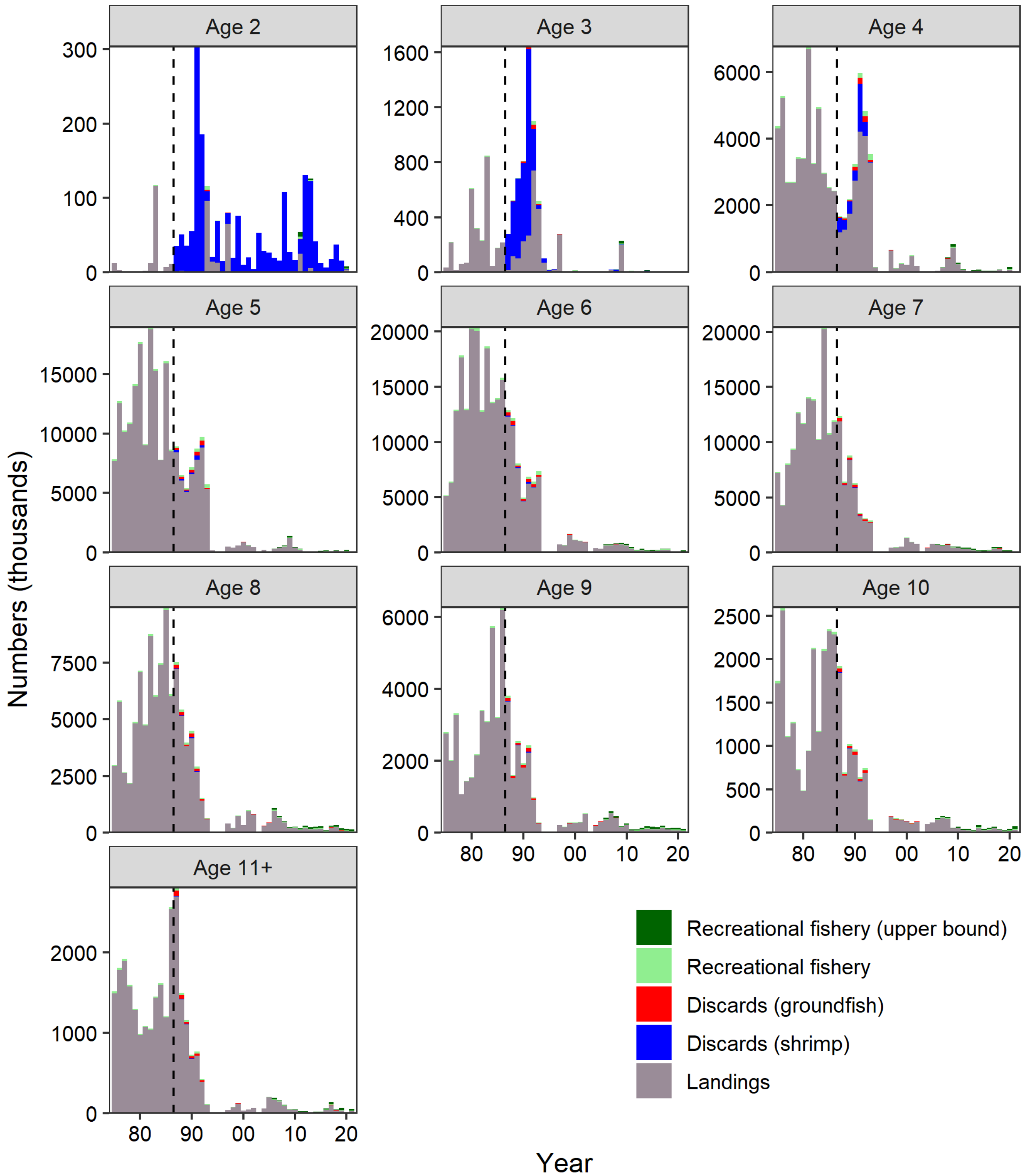

Figure 75. Age-specific estimates of annual cod removals in NAFO Divisions 3Pn4RS fisheries from reported landings, estimated discards in shrimp and groundfish fisheries (assuming no post-release survival), and from the recreational fishery, 1974–2022. Discard estimates are available from 1987, indicated by the vertical hatched line. Estimated recreational fishery catches are indicated in light green, while a censored range for recreational fishery catches as of 2006 is indicated in dark green.

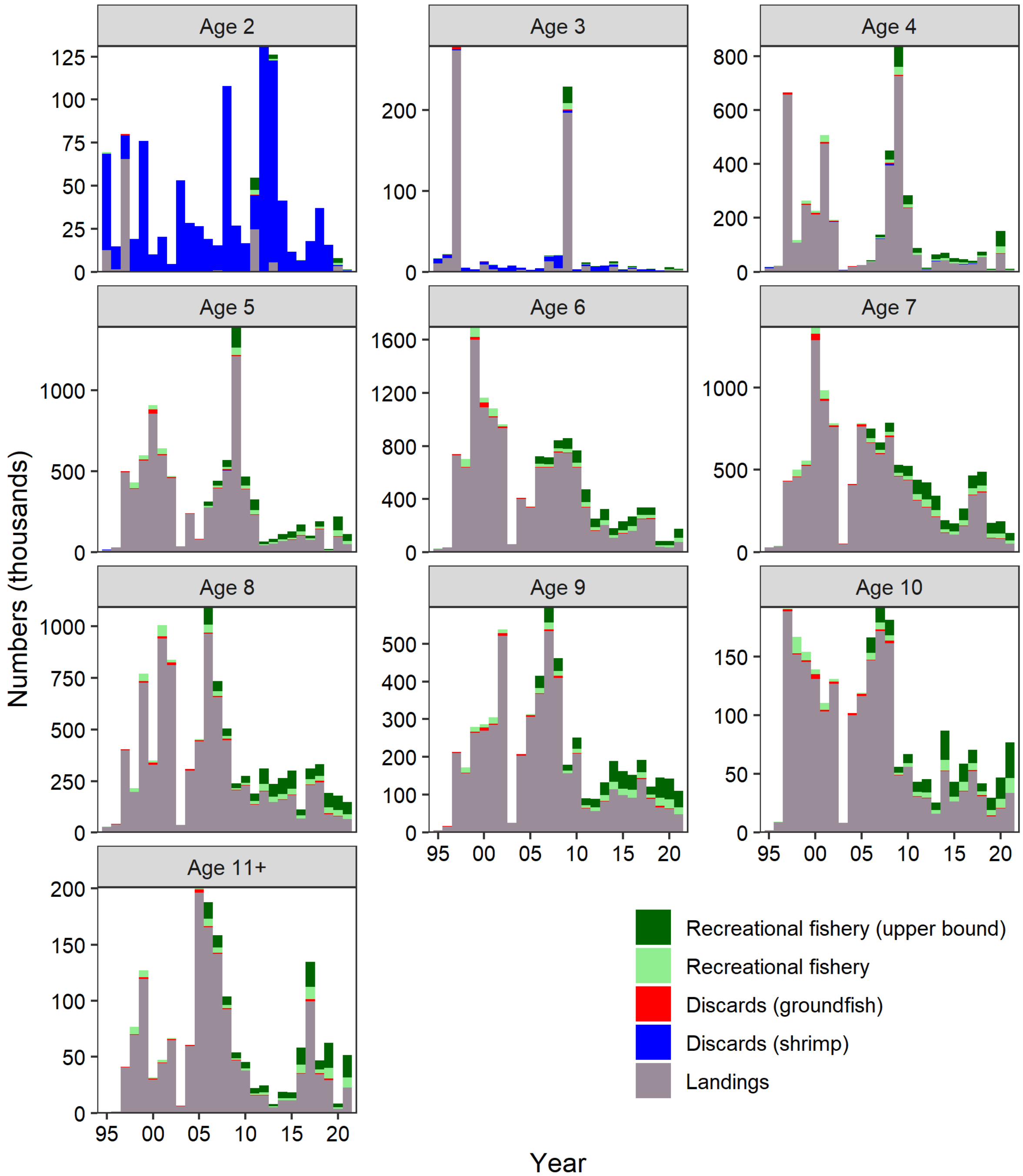

Figure 76. Same results and details as for the precedent figure, but for the 1994-2022 period.

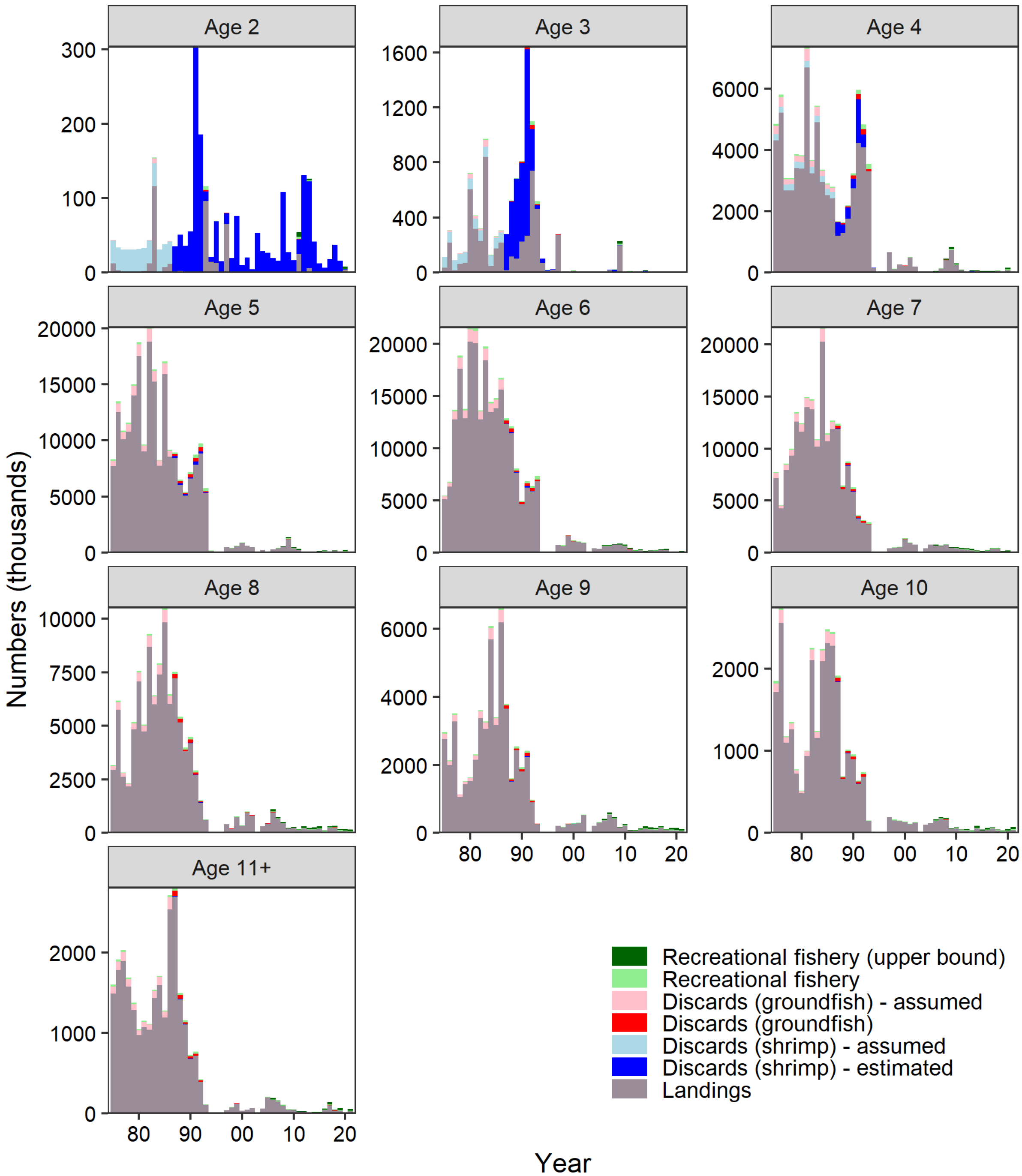

Figure 77. Age-specific estimates of annual cod removals in NAFO Divisions 3Pn4RS fisheries from reported landings, estimated and assumed discards in shrimp and groundfish fisheries (assuming no post-release survival) and estimated catch from the recreational fishery, 1974–2022.

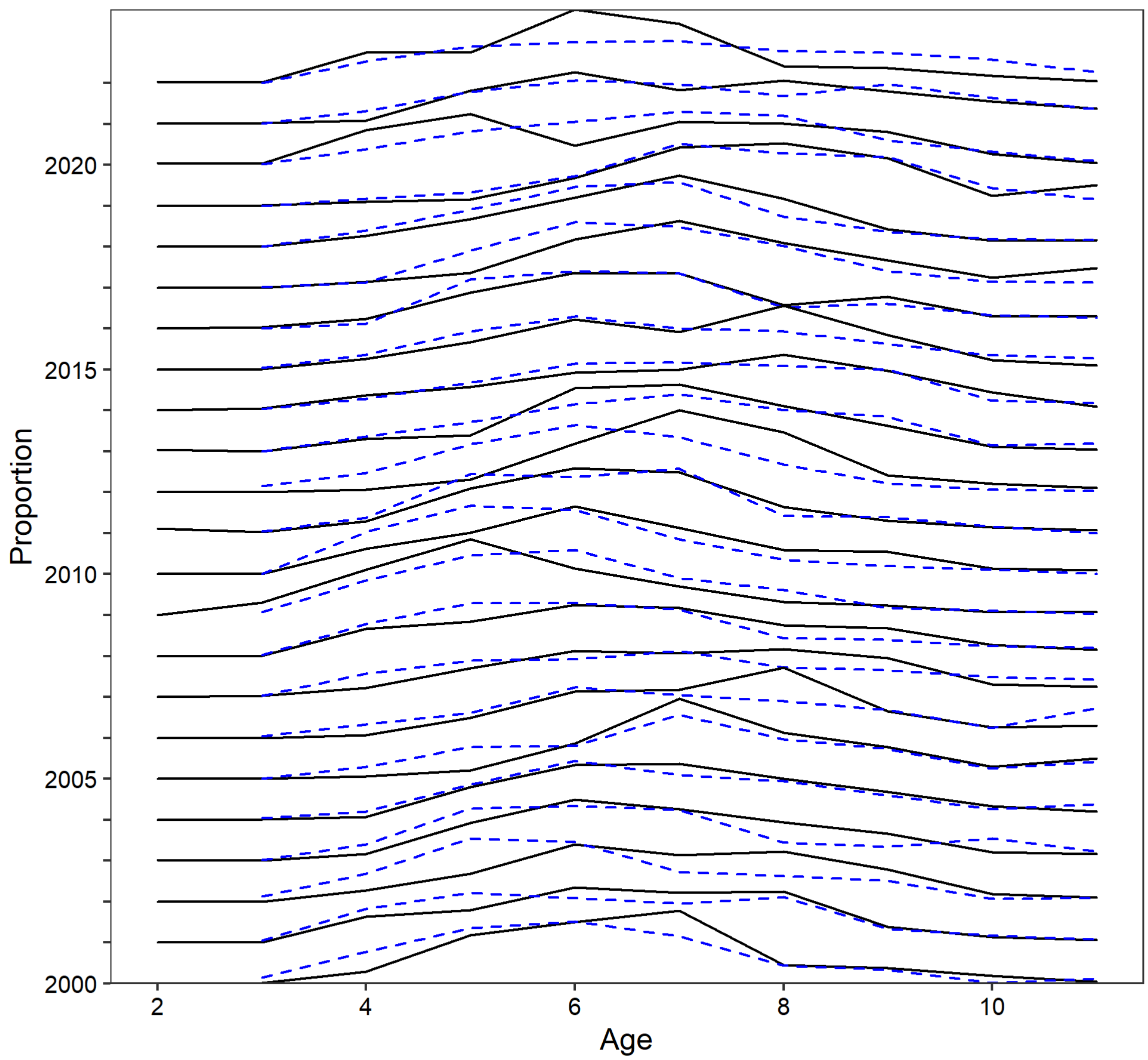

Figure 78. Catch-at-age composition (in proportion) of the commercial fishery (black) and the sentinel longline survey (summer, blue) for the period 2000–2022.

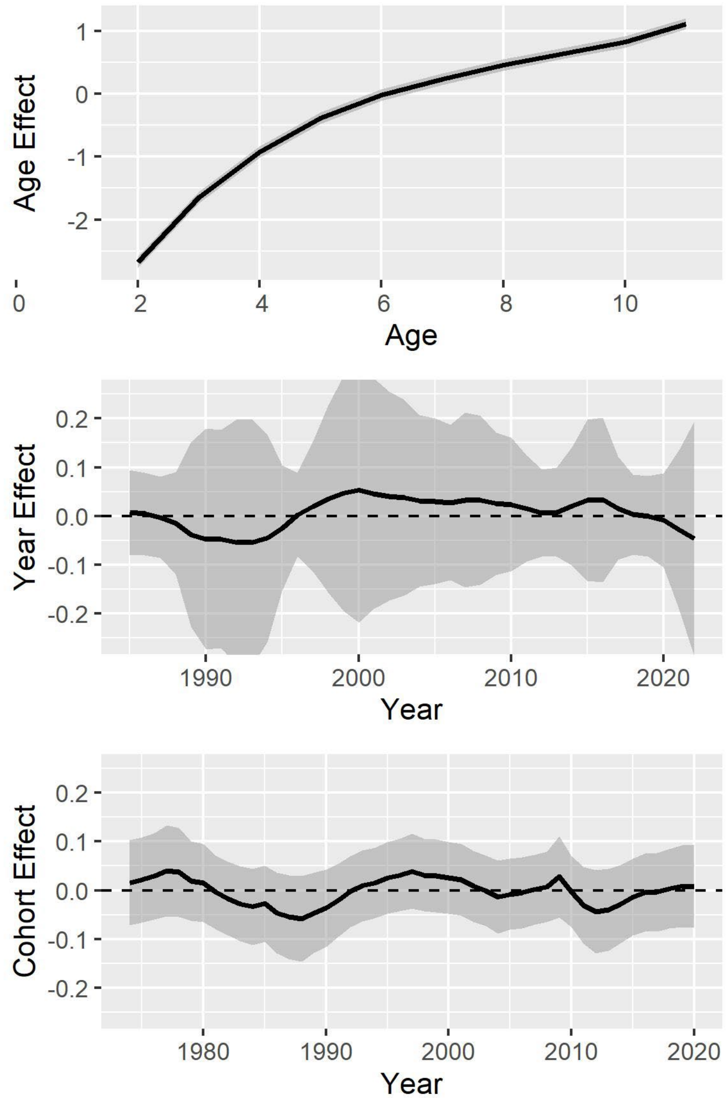

Figure 79. Estimates of the main effects in the weight-at-age model. Shaded regions indicate 95% confidence intervals. Age 11 represents 11+.

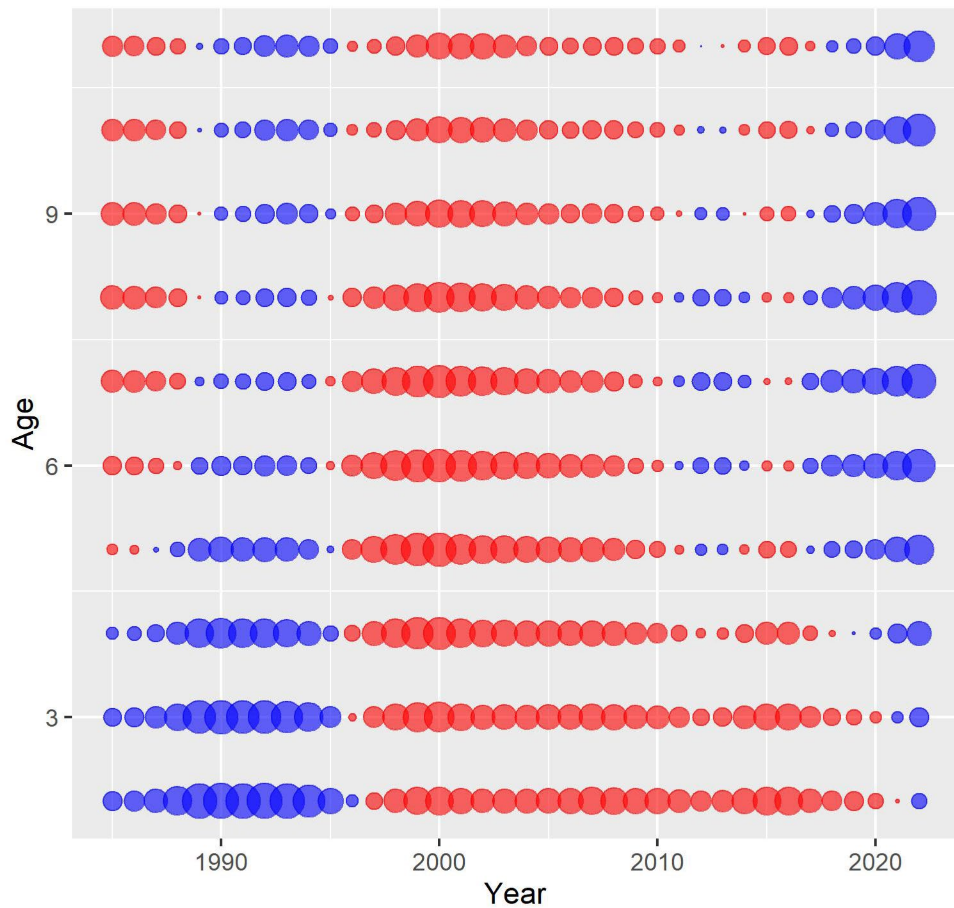

Figure 80. Estimates of the year-age interactions effects. The surface area of the circles is proportional to the absolute value of the effect, and the color indicates the sign (red +; blue -). Age 11 represents 11+.

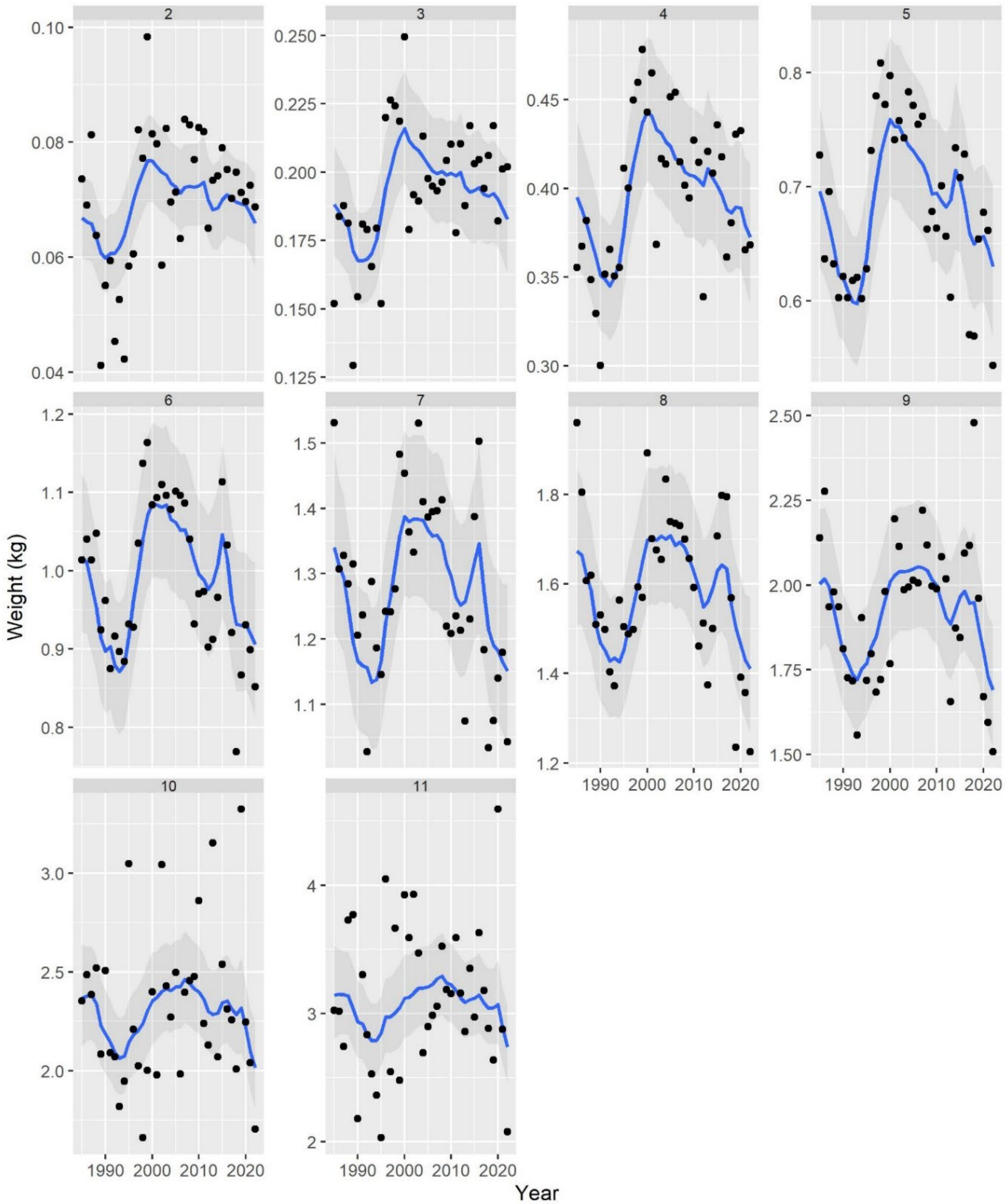

Figure 81. Time-series of 'observed' (points) and model-predicted (lines) average stock weights-at-age. Each panel is for an age class, where 11 represents 11+. Shaded regions indicate 95% confidence intervals.

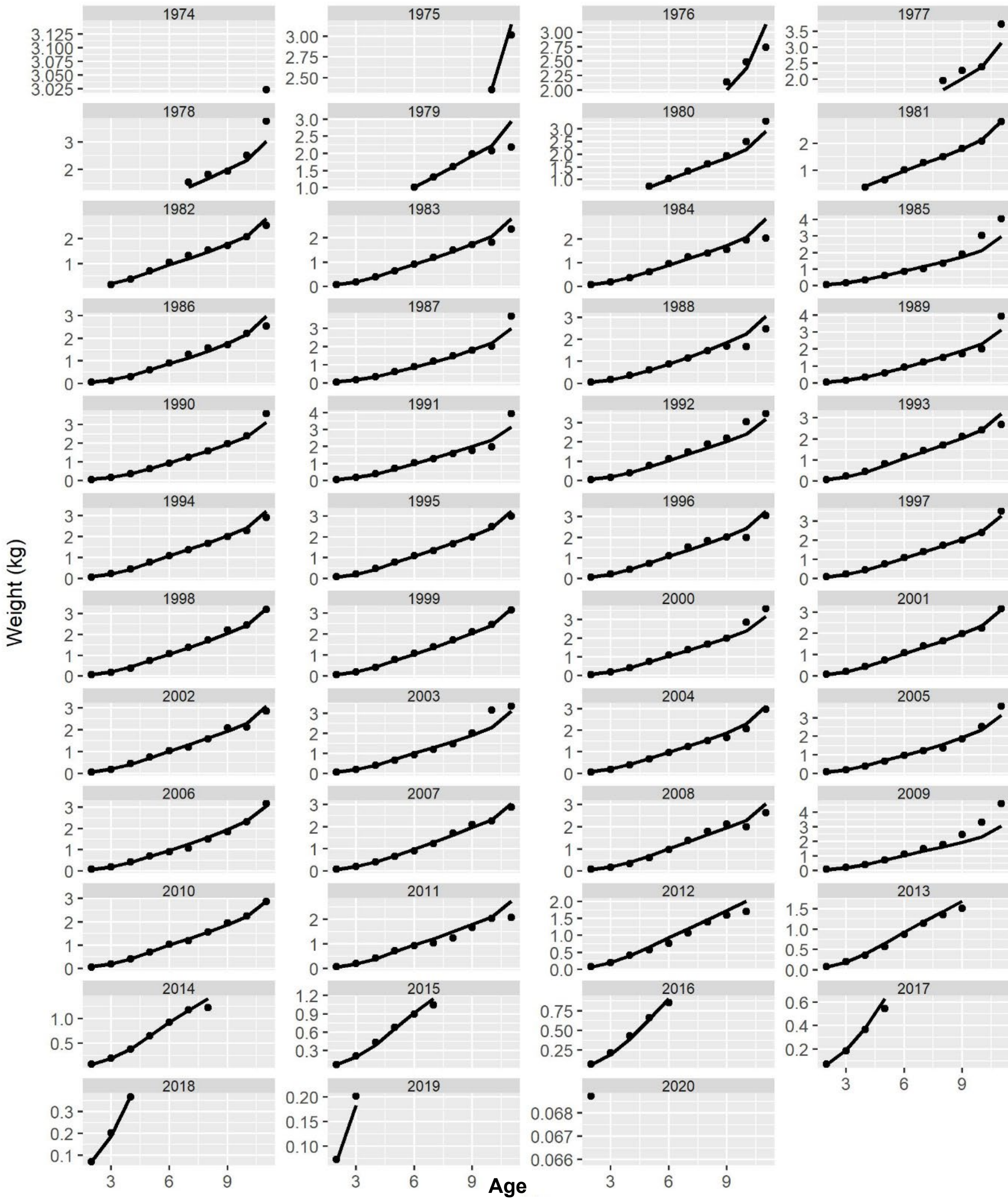

Figure 82. Observed (points) and model-predicted (lines) average stock weights-at-age. Each panel is for a cohort.

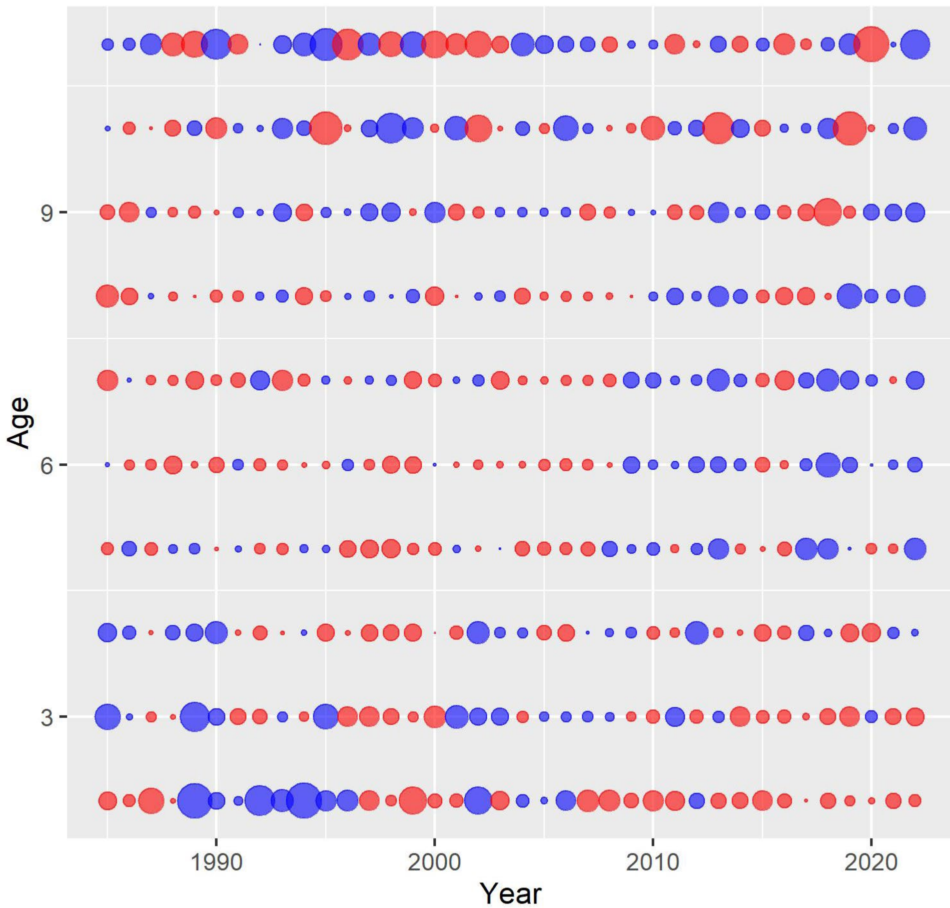

Figure 83. Model standardized residuals. The surface area of the circles indicates the relative value of the residual and the color indicates the sign (red +; blue -). Age 11 represents 11+.

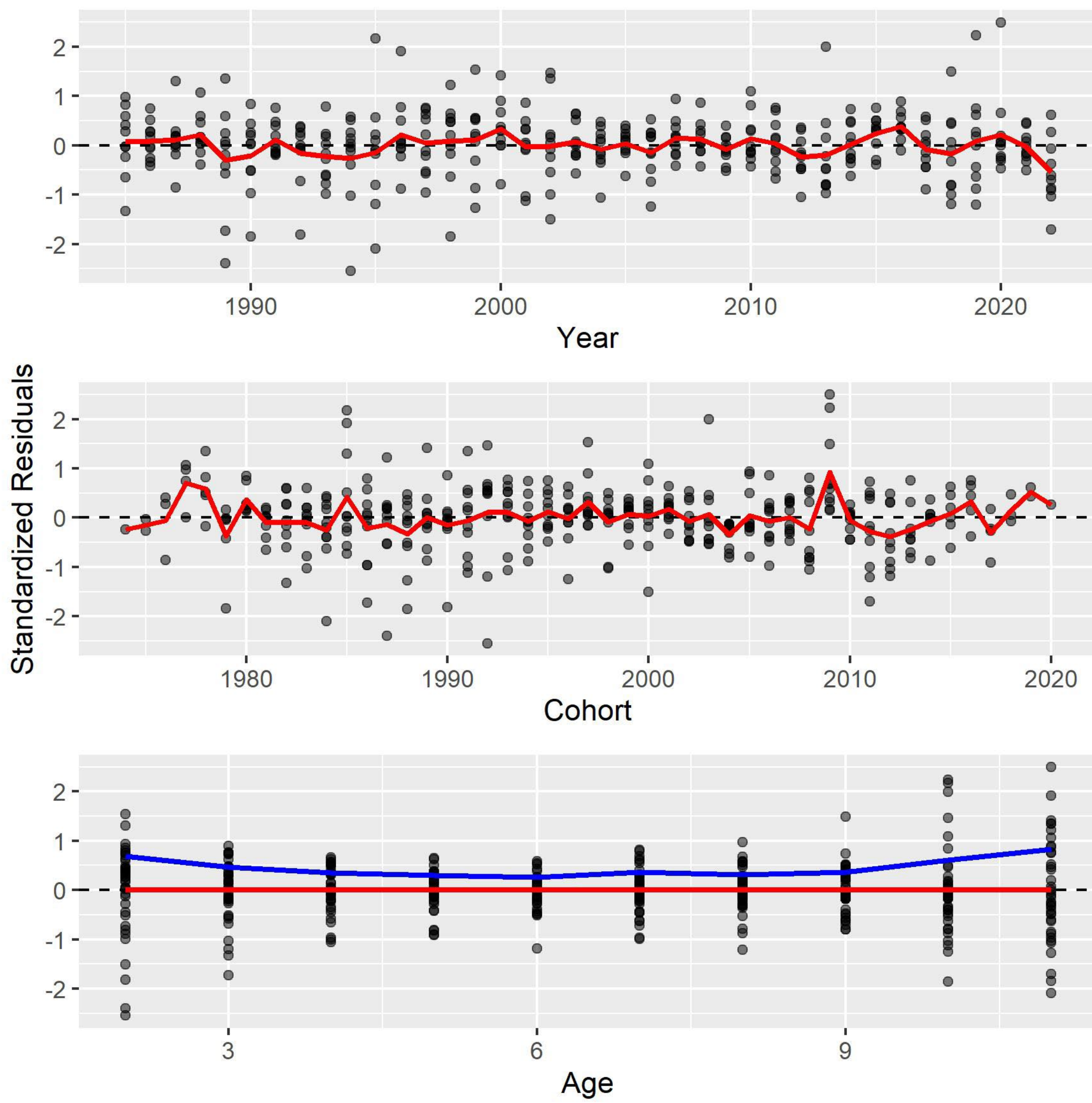

Figure 84. Standardized residuals versus year (top), cohort (middle), and age (bottom). Red lines indicate the average residual, and the blue line indicates the average absolute residual. Age 11 represents 11+.

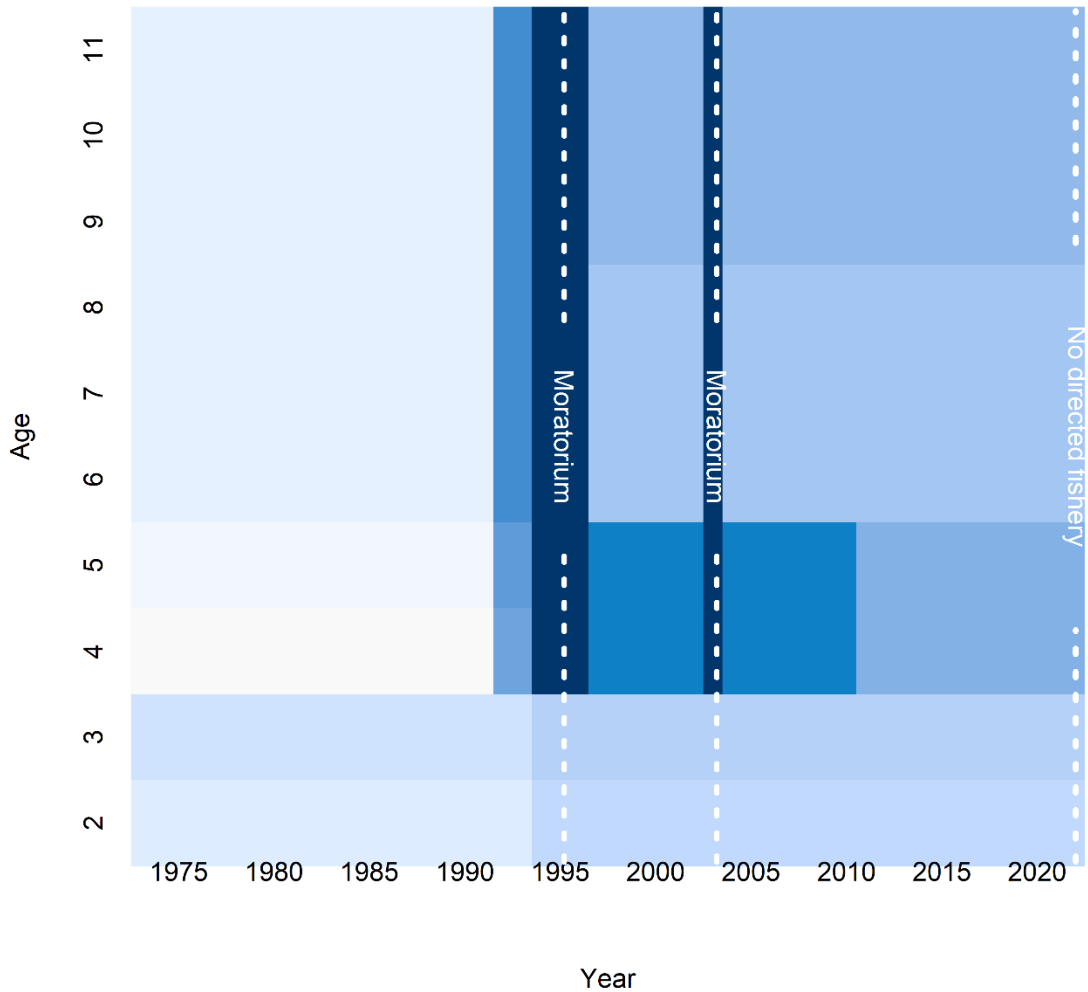

Figure 85. Fishing mortality main fixed effects. Each color represents a different group for which a parameter value is estimated.

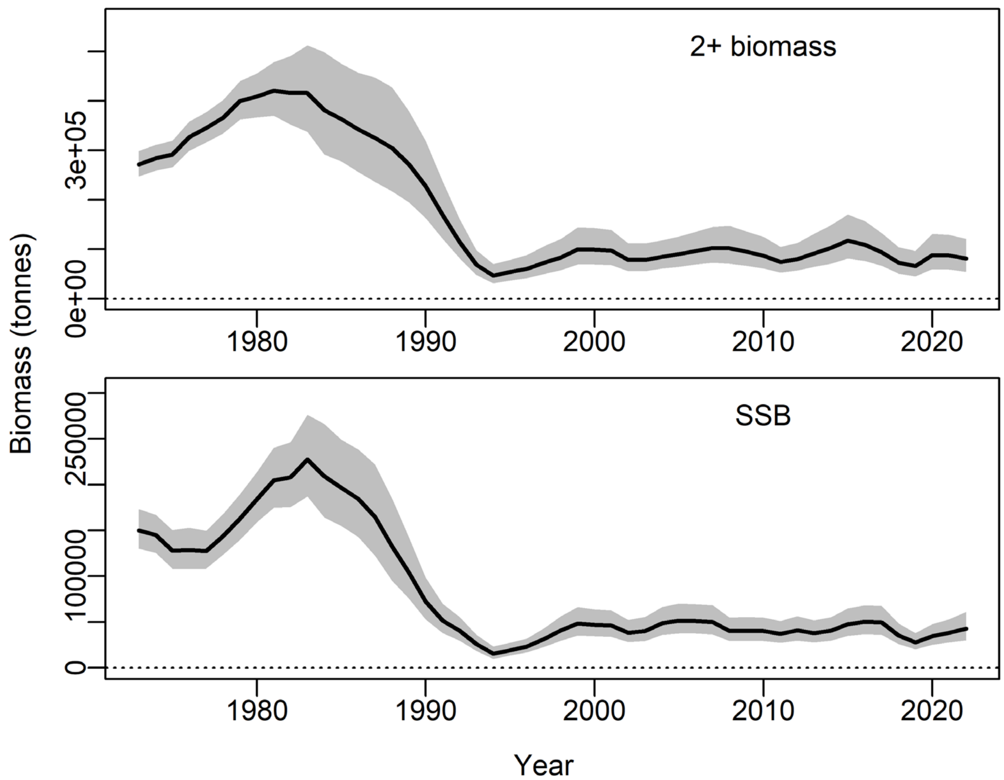

Figure 86. Model estimates of age 2+ biomass and spawning stock biomass (SSB), with 95% confidence interval (shaded region).

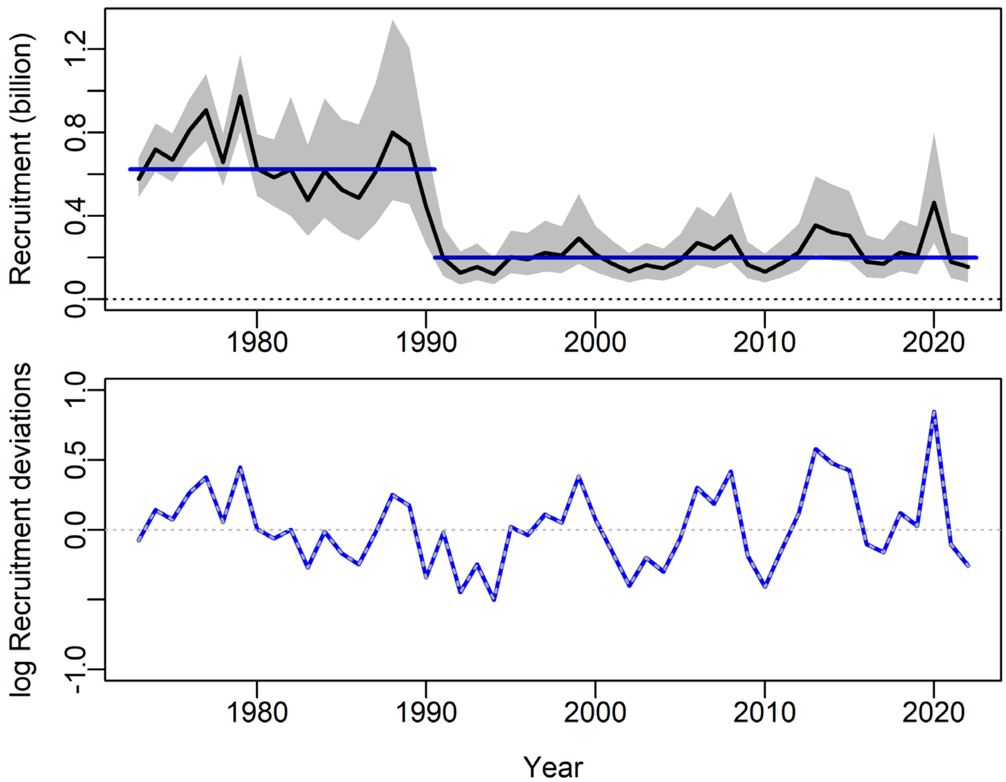

Figure 87. Top - Model estimates of recruitment at age 2 with 95% confidence interval (shaded region), along with the model estimated mean recruitment for years ≤ 1990 and > 1990 (blue lines). Bottom – Model estimated recruitment deviations.

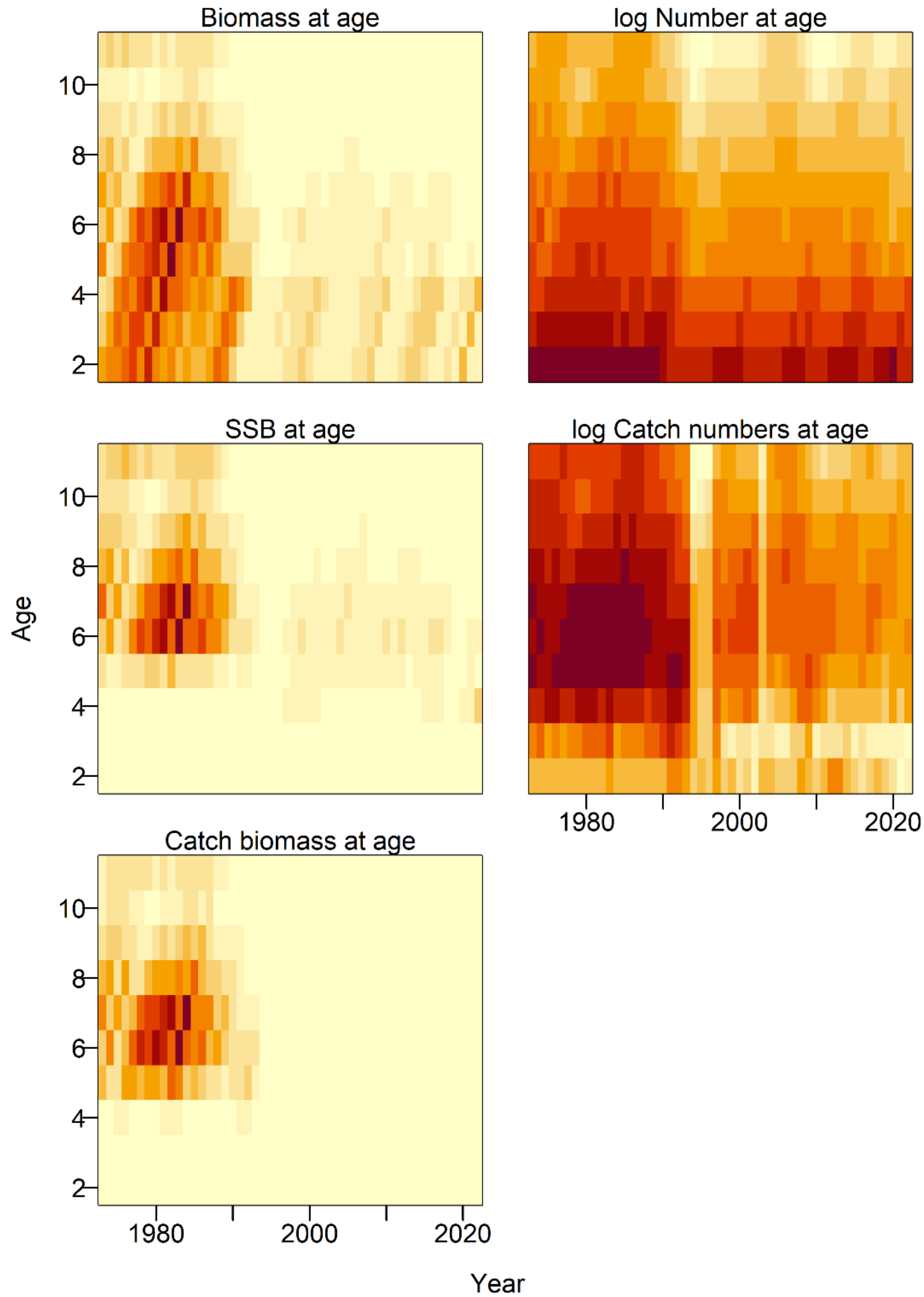

Figure 88. Model estimates of age-based quantities defined at the top of each panel. Darker colors indicate higher estimates. Catches are model predicted, not the input catch.

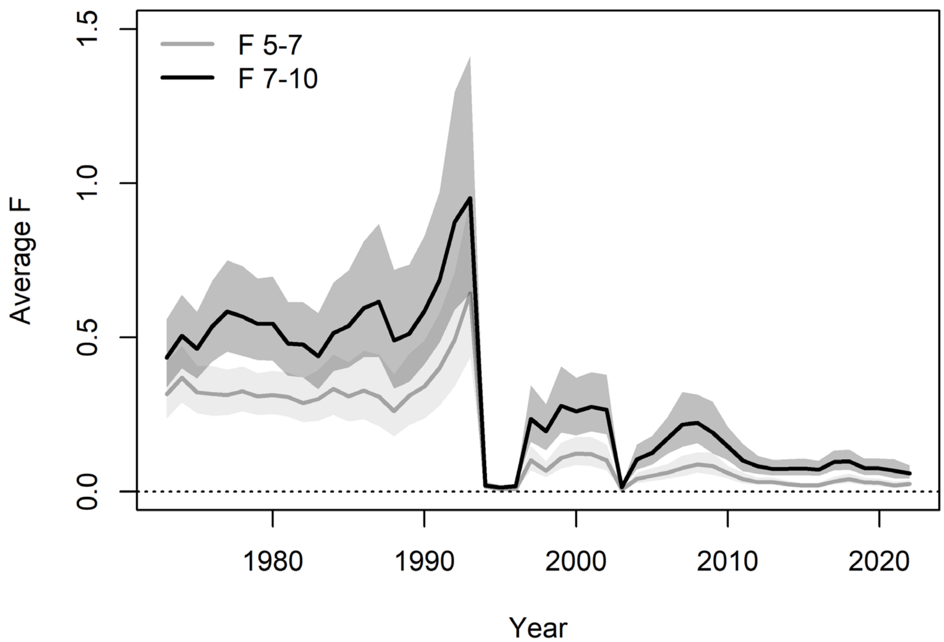

Figure 89. Model estimates of average fishing mortality F at ages 5-7 and 7-10, with 95% confidence interval (shaded region).

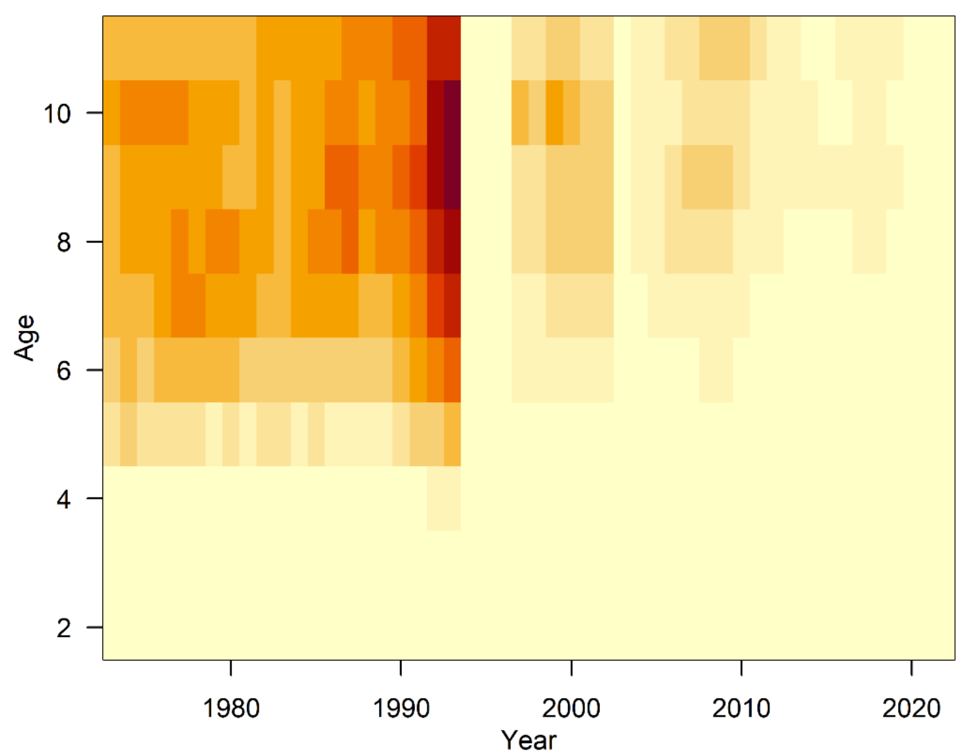

Figure 90. Illustration of model estimates of fishing mortality at age, where darker colours indicate higher values.

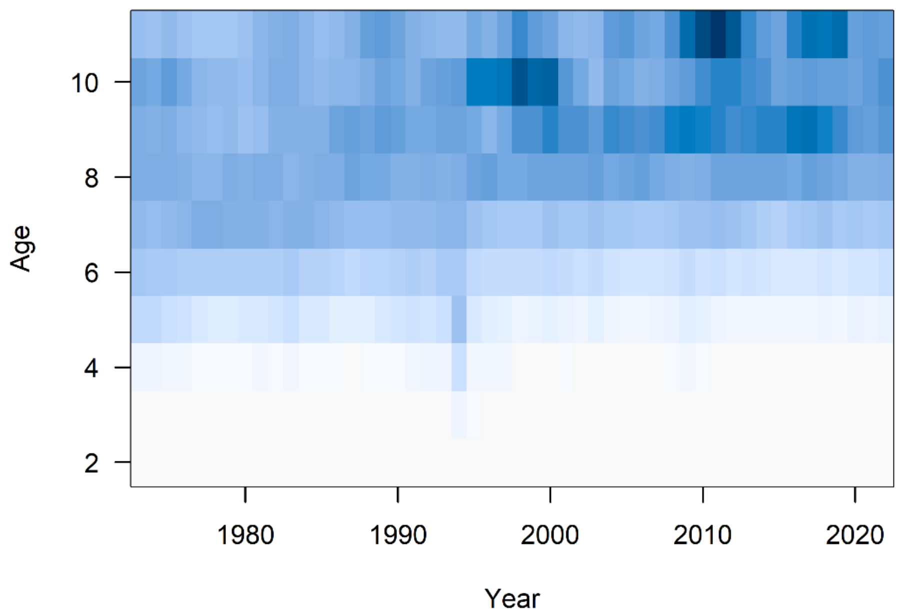

Figure 91. Fishery selectivity, calculated as age-specific F divided by the average F for ages 6-9. Darker colours indicate higher values.

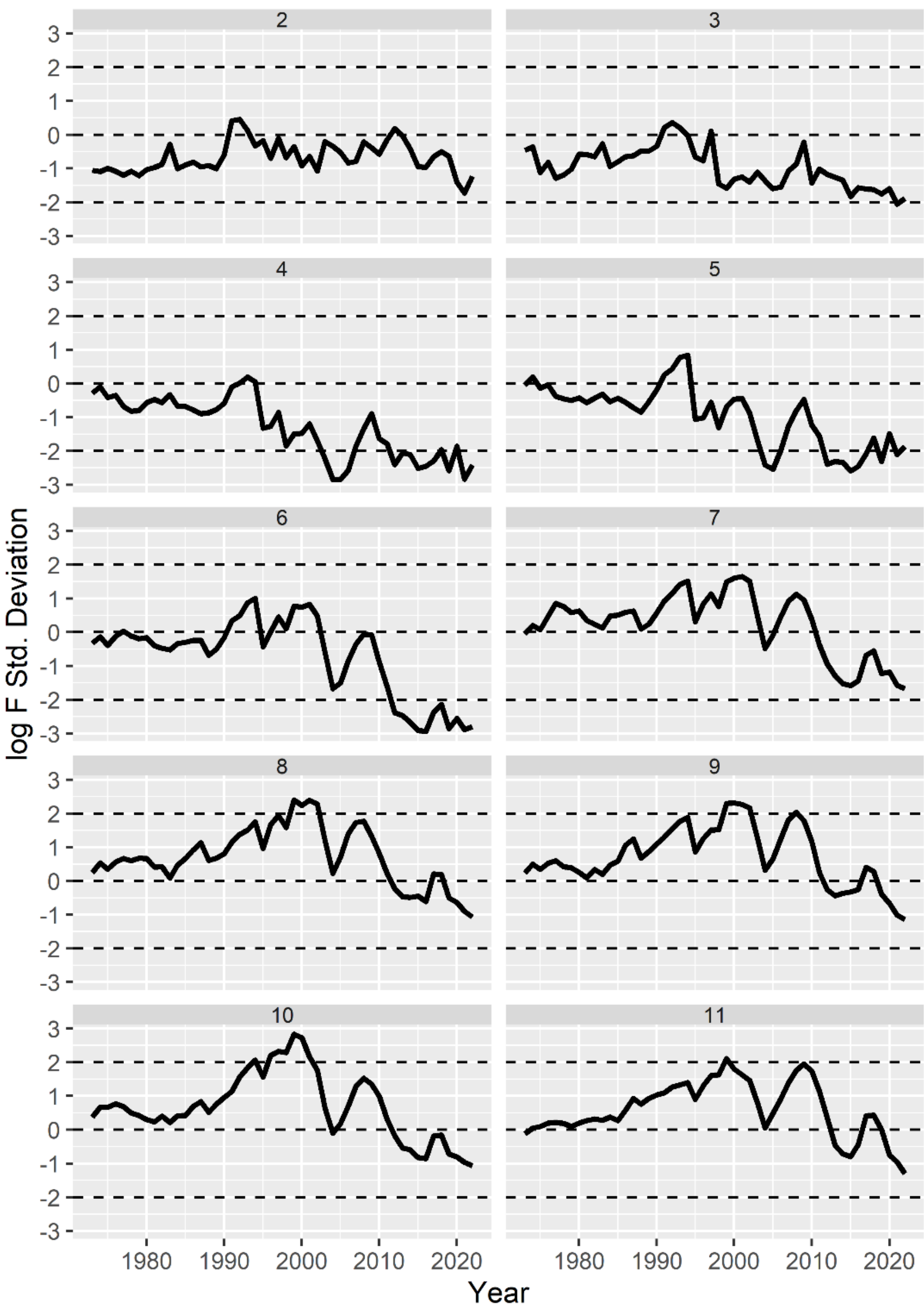

Figure 92. Estimates of standardized log F deviations (standardized Δ_F), by age (panels). Age 11 represents 11+.

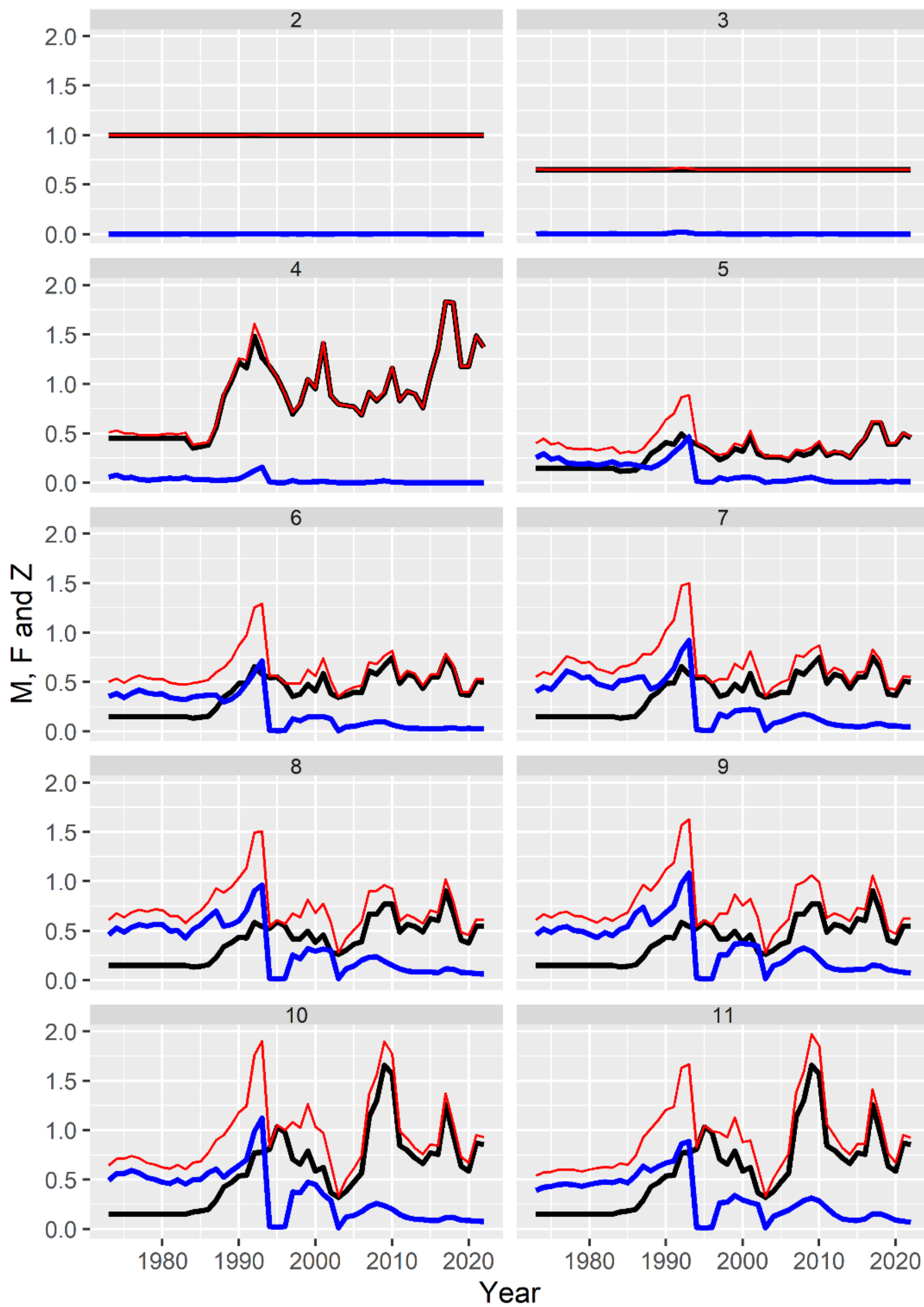

Figure 93. Estimates of age-specific fishing mortality (F, blue lines), natural mortality (M, black lines) and total mortality (Z= M+F; red lines). Age 11 represents 11+.

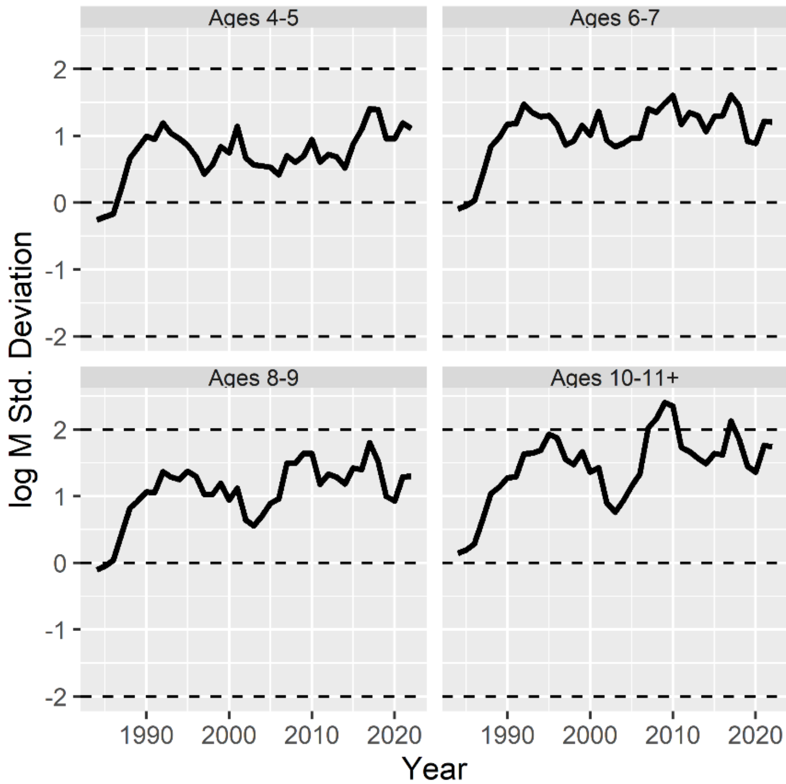

Figure 94. Estimates of standardized natural mortality process errors, log $\delta_{a,y}$, by age blocks (panels).

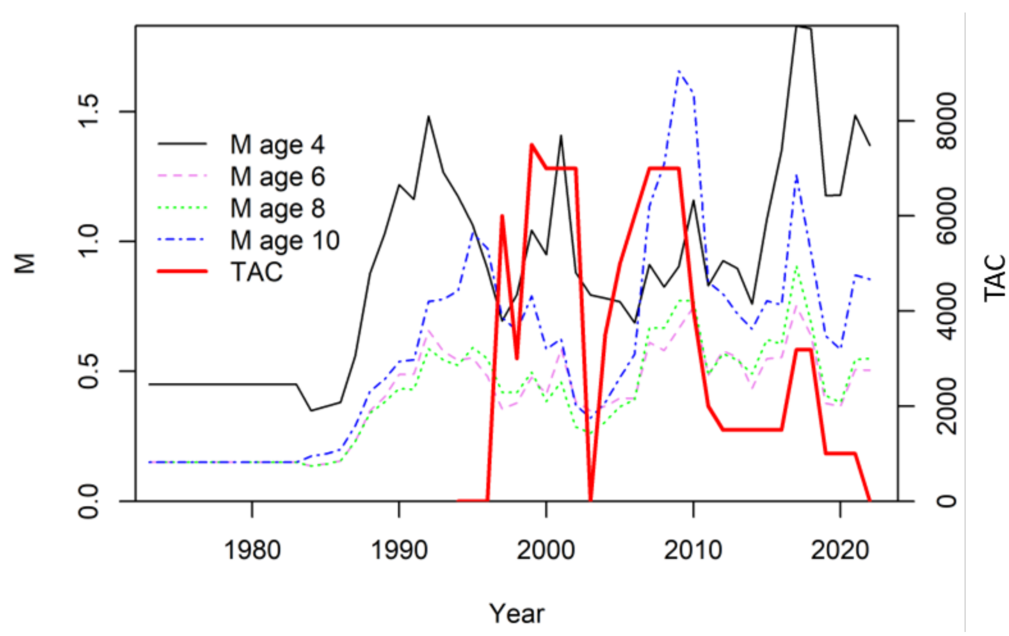

Figure 95. Estimates of natural mortality (M) for some ages along with the total allowable catch since 1994 (TAC, red line, secondary y-axis).

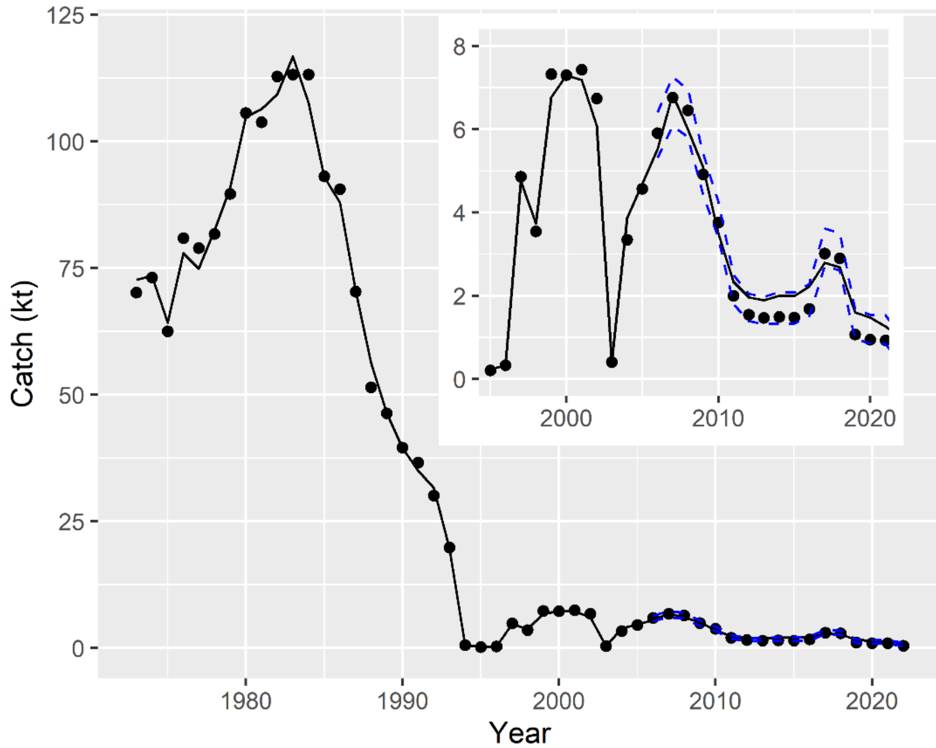

Figure 96. Model predicted catch (black line), compared to input catch (points) and the catch bounds assumed for 2006-2022 (dashed blue lines). The inset panel shows a close-up for 1995-2022.

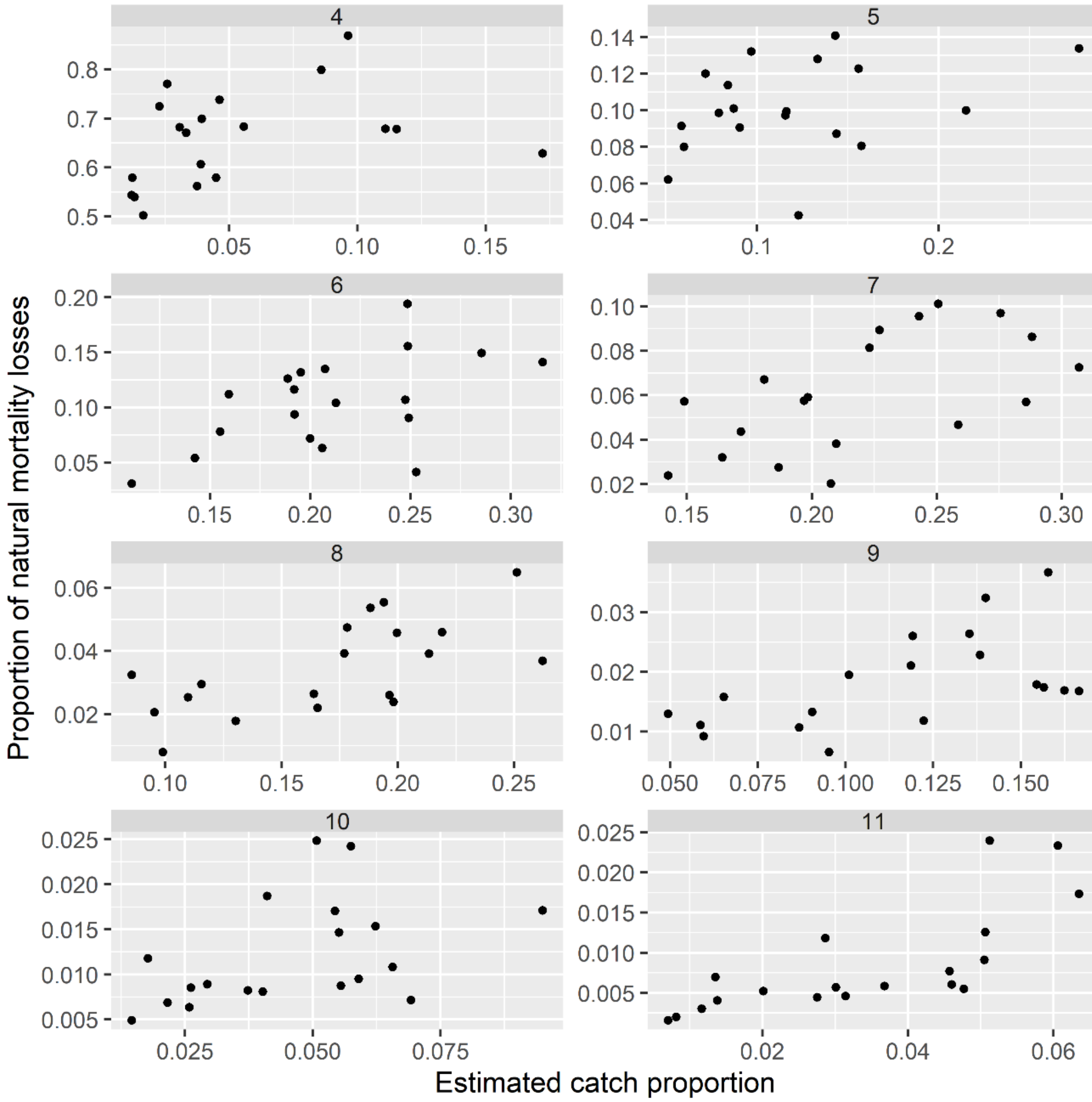

Figure 97. Annual age-composition (proportions) of estimated natural mortality losses relative to estimated fishery catch, faceted by age. Fishery catch proportions-at-age are the same as those presented later in Figure 109. Age 11 represents 11+.

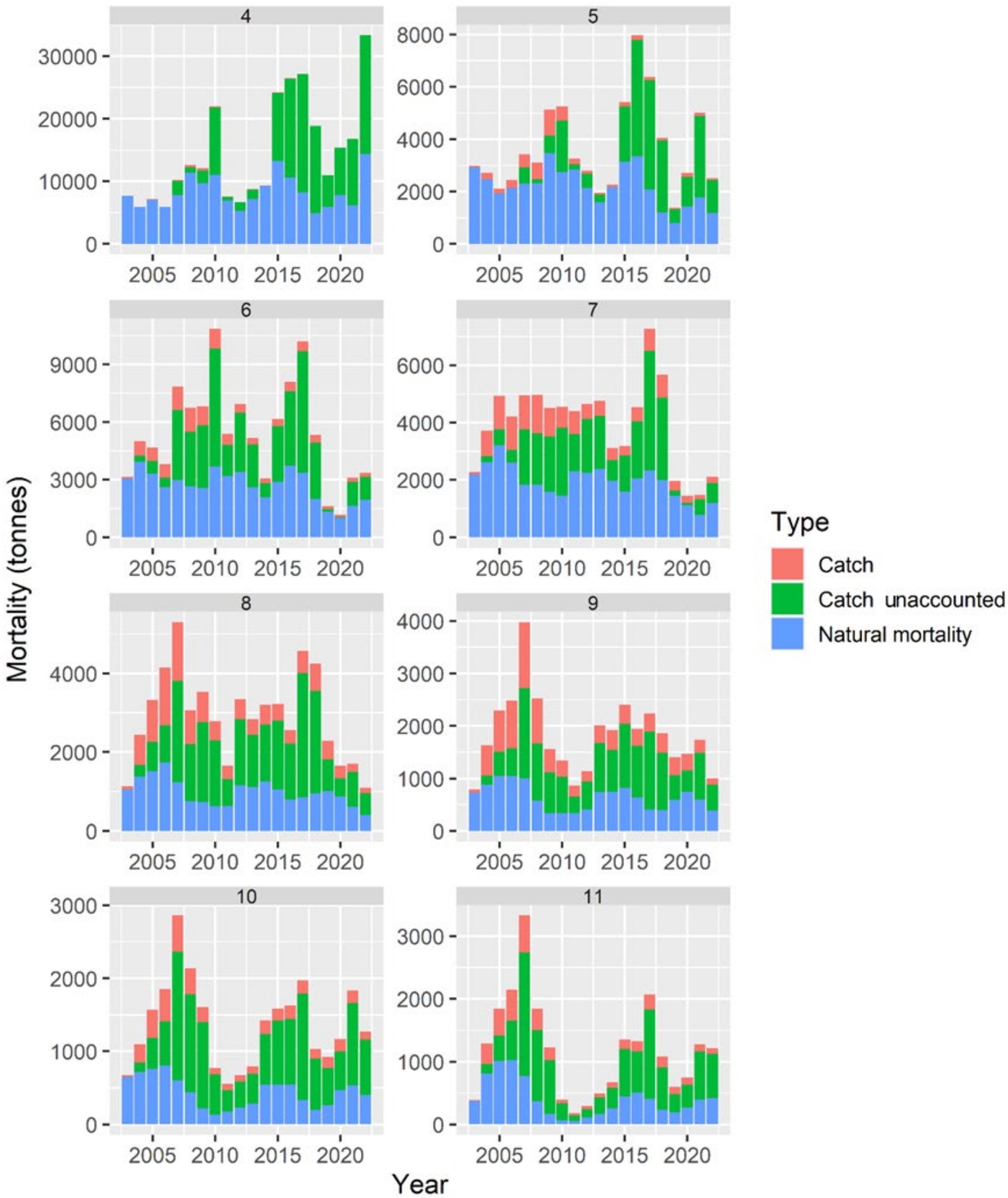

Figure 98. Estimated annual mortality losses (tonnes) associated with catch, hypothesized unaccounted catch and natural mortality by age for 2003-2022. Age-specific natural mortality rates in excess of 2003 values were assumed to constitute unaccounted catch, and losses attributable to each were estimated using the Baranov catch equation. Age 11 represents 11+.

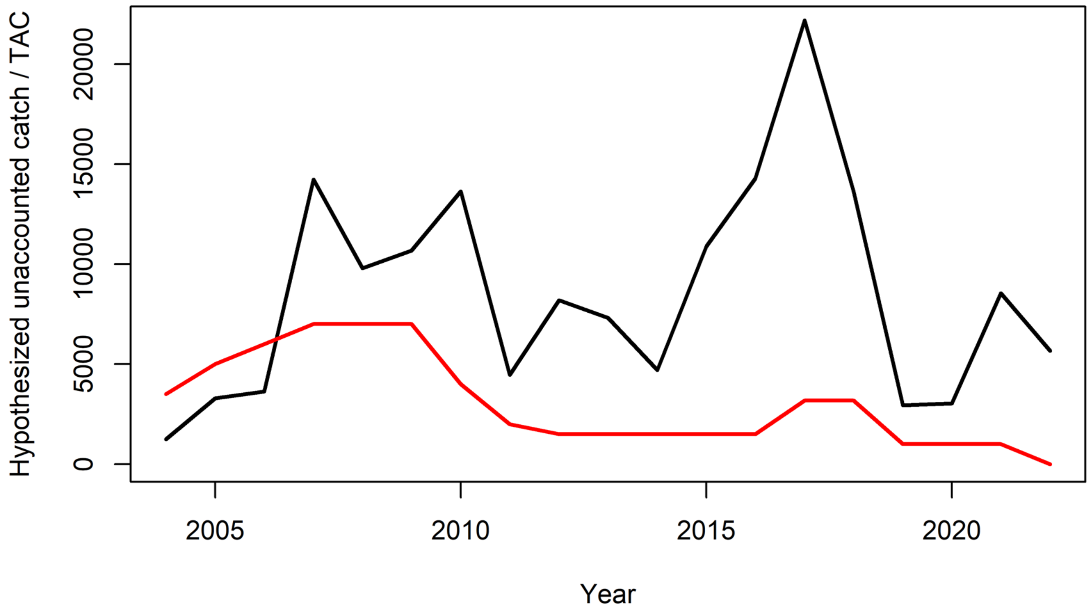

Figure 99. Hypothesized unaccounted catch of cod ages 5+ (black line) and total allowable catch (TAC, red line) in tonnes for 2004-2022.

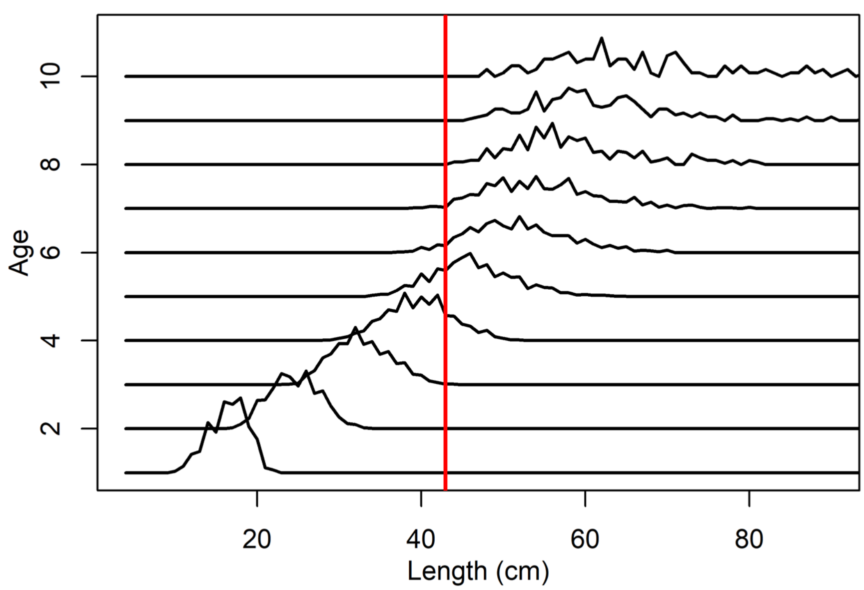

Figure 100. Length composition for cod of different ages in the DFO August survey, up to age 10. The 43 cm cut-off employed for the small fish protocol is indicated by the vertical red line.

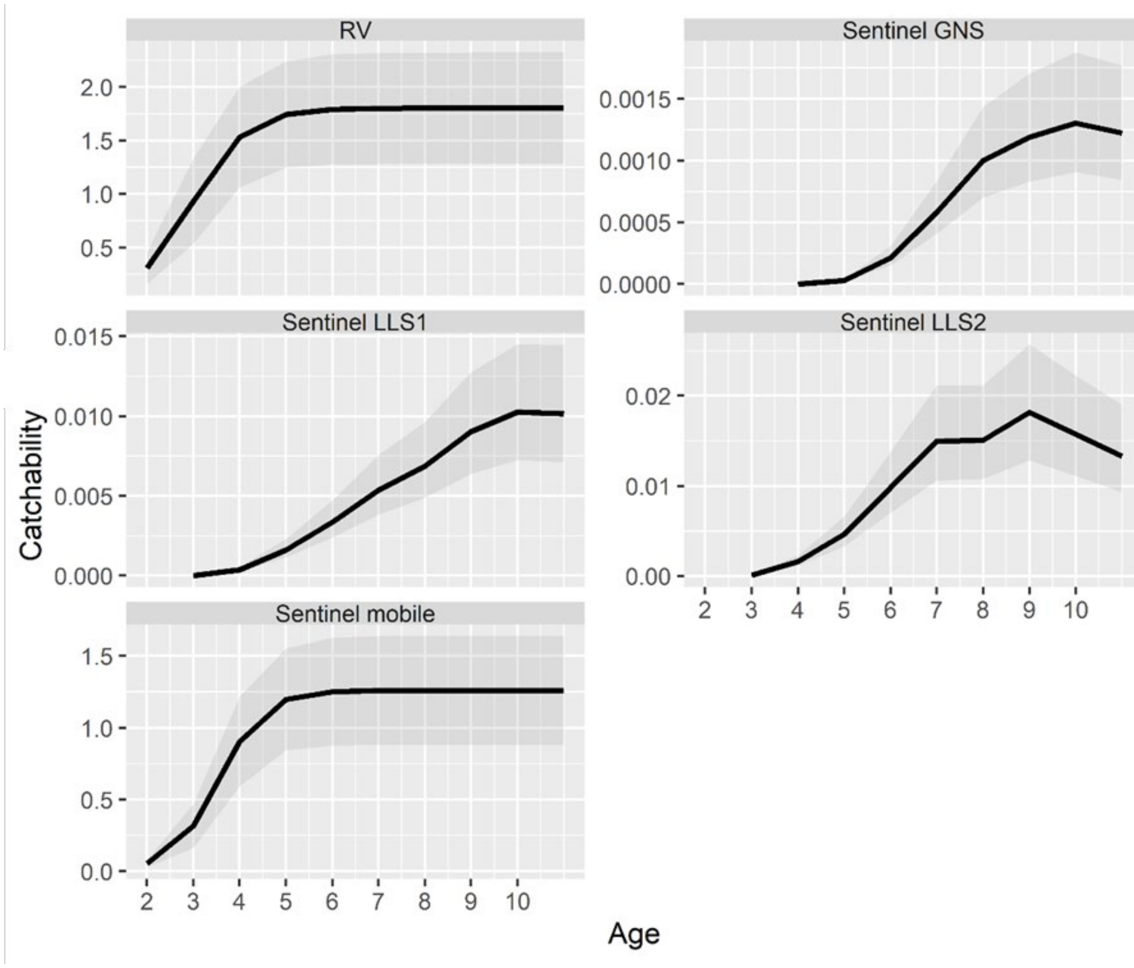

Figure 101. Estimated age-specific catchability to the five main surveys, with 95% confidence intervals (shaded regions). RV indicates the DFO August research vessel survey.

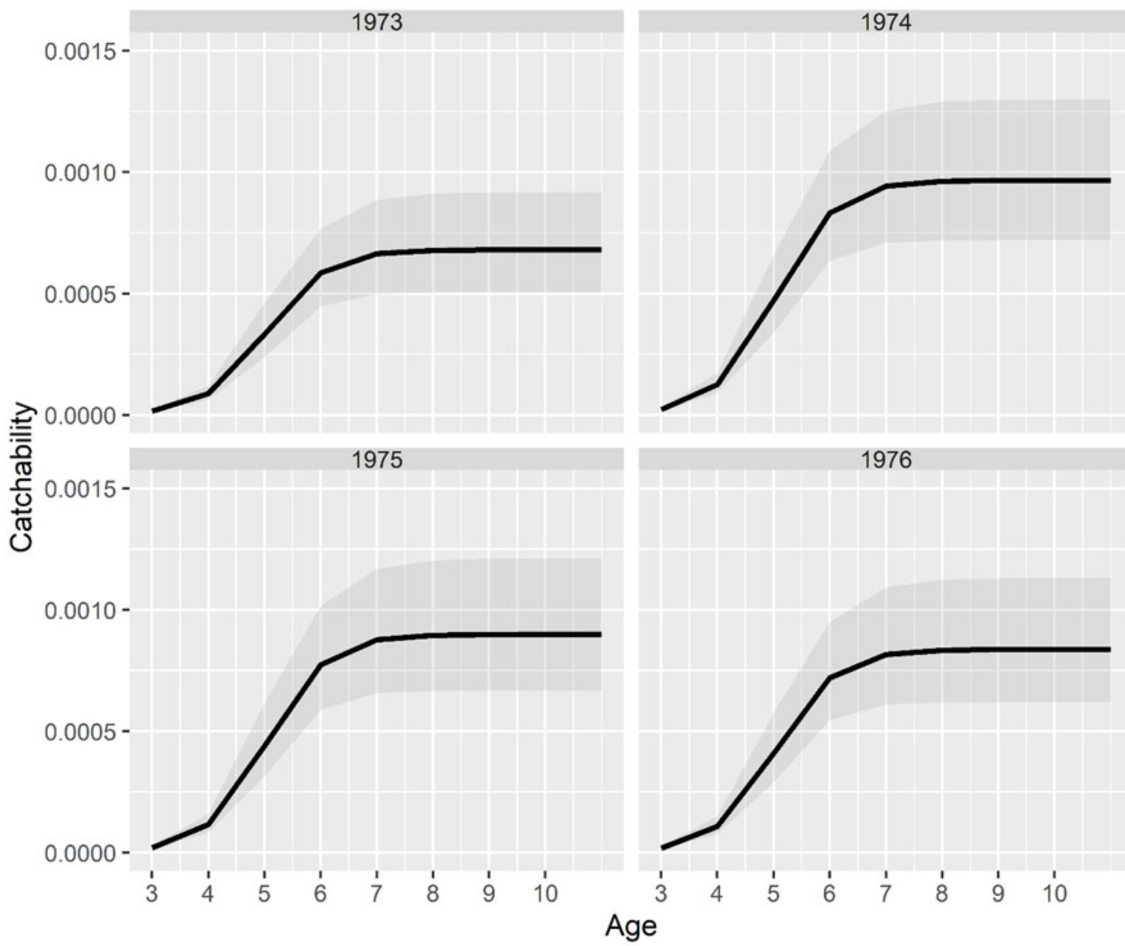

Figure 102. Estimated age and year-specific catchability to the Minet (1978) surveys, with 95% confidence intervals (shaded regions).

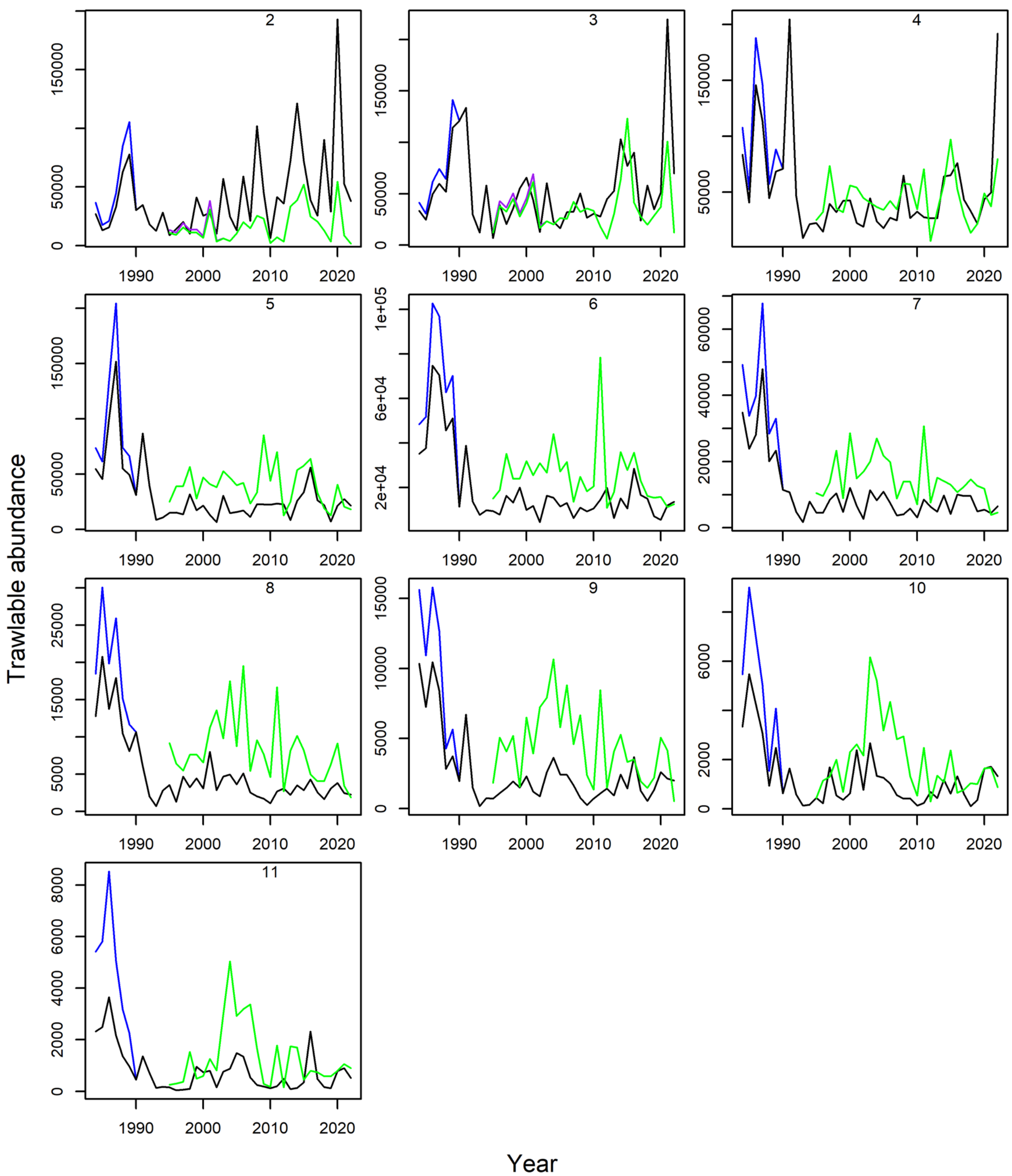

Figure 103. Age-specific (panels) survey abundance indices for the DFO August survey (black line) and the sentinel mobile survey (green line). The indices are also shown adjusted using the estimated correction for smaller survey coverage that occurred prior to 1990 in the DFO August survey (blue line) and prior to 2003 in the sentinel survey (purple line, ages 2 and 3 only). Note that the indices for the sentinel survey were multiplied by 3 for the plots for age 2 to 4 to put them on a scale comparable to that of the DFO August survey for visualization purposes only. Age 11 is 11+.

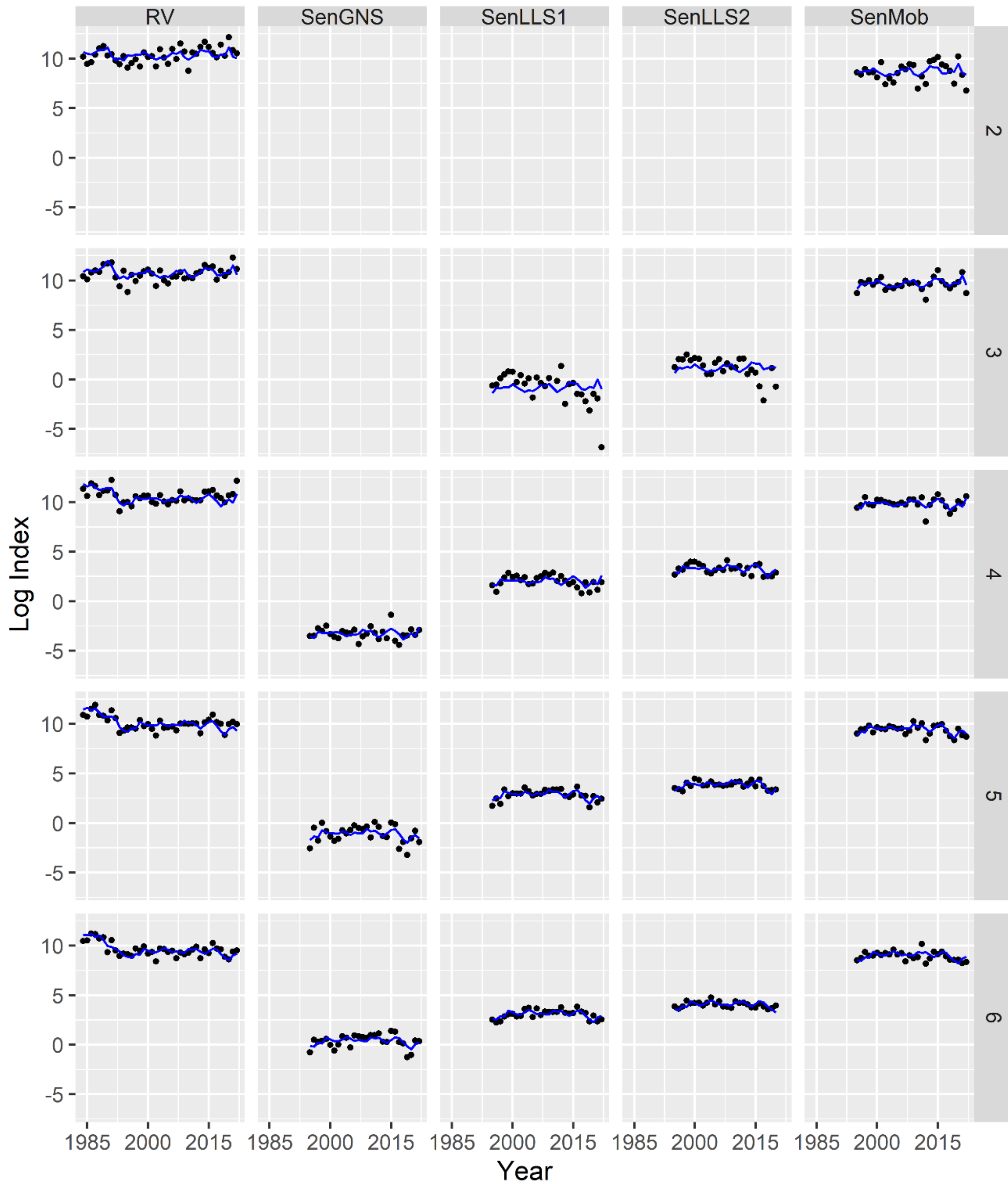

Figure 104. Model fits to the log indices at age (rows) for each of the five major survey indices (columns). Points represent the observations and the line the model fit. Panels are empty when an age was not included in the model for a particular survey. Age 11 is 11+. RV indicates the DFO August research vessel survey.

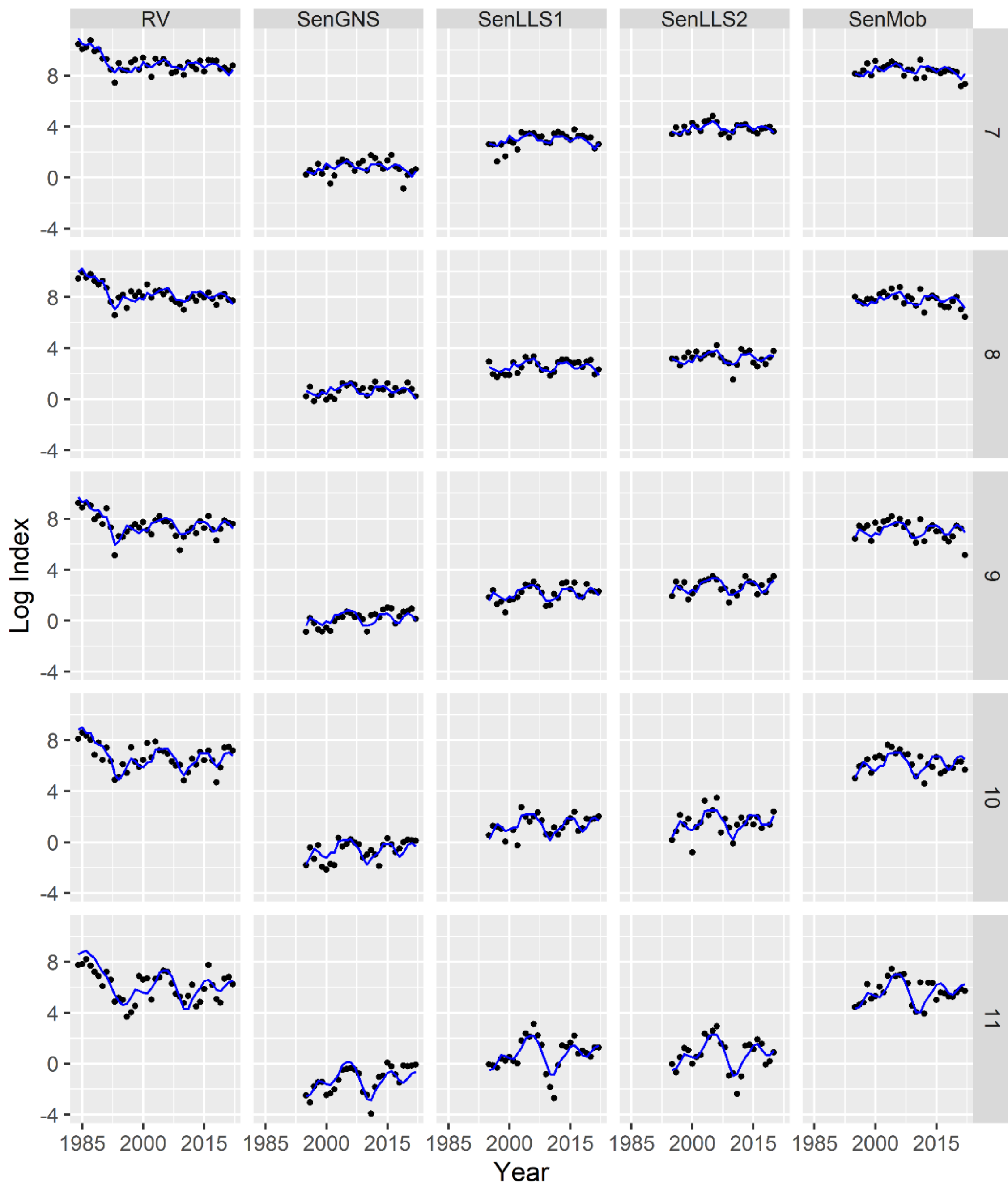

Figure 104 (continued).

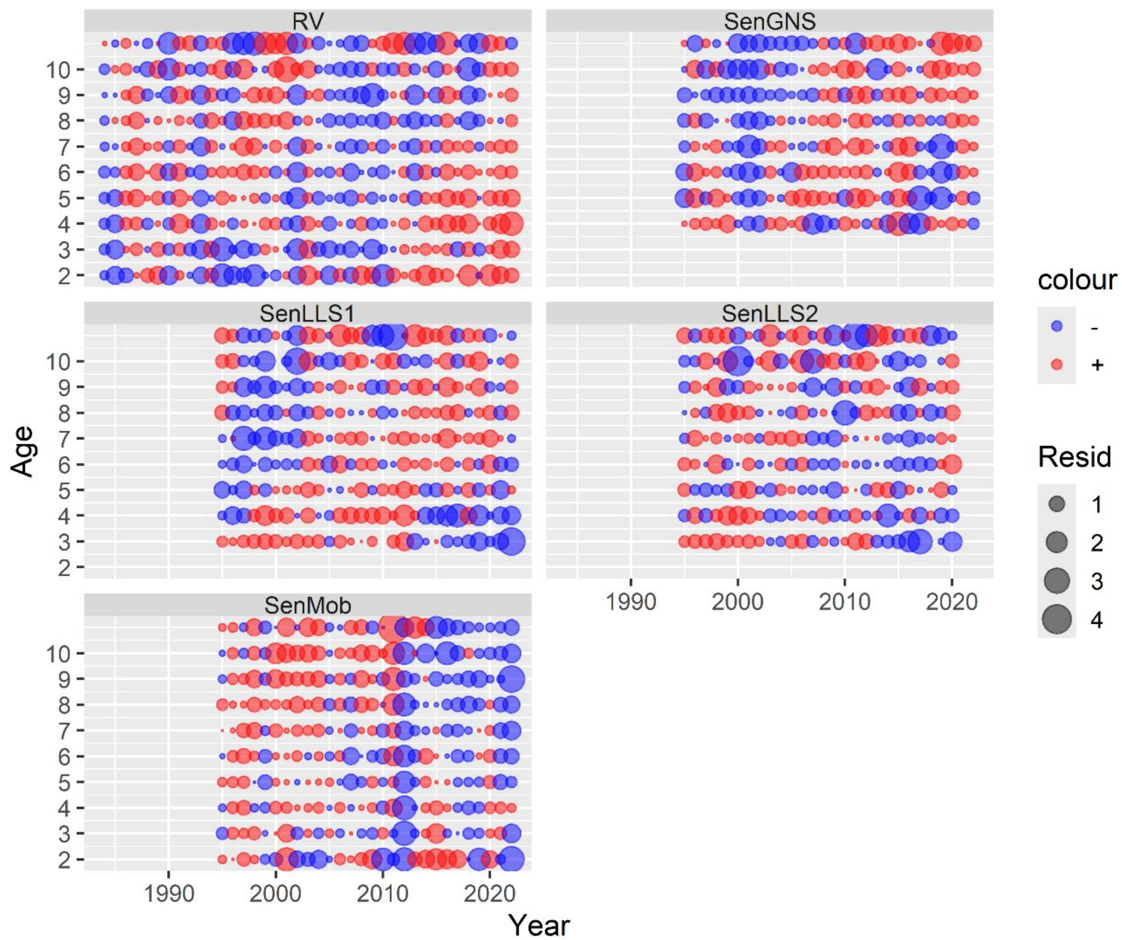

Figure 105. Model residuals for the age-specific abundance indices for each survey (panels). The surface area of a bubble is proportional to the absolute value. Red is positive and blue is negative. RV indicates the DFO August research vessel survey.

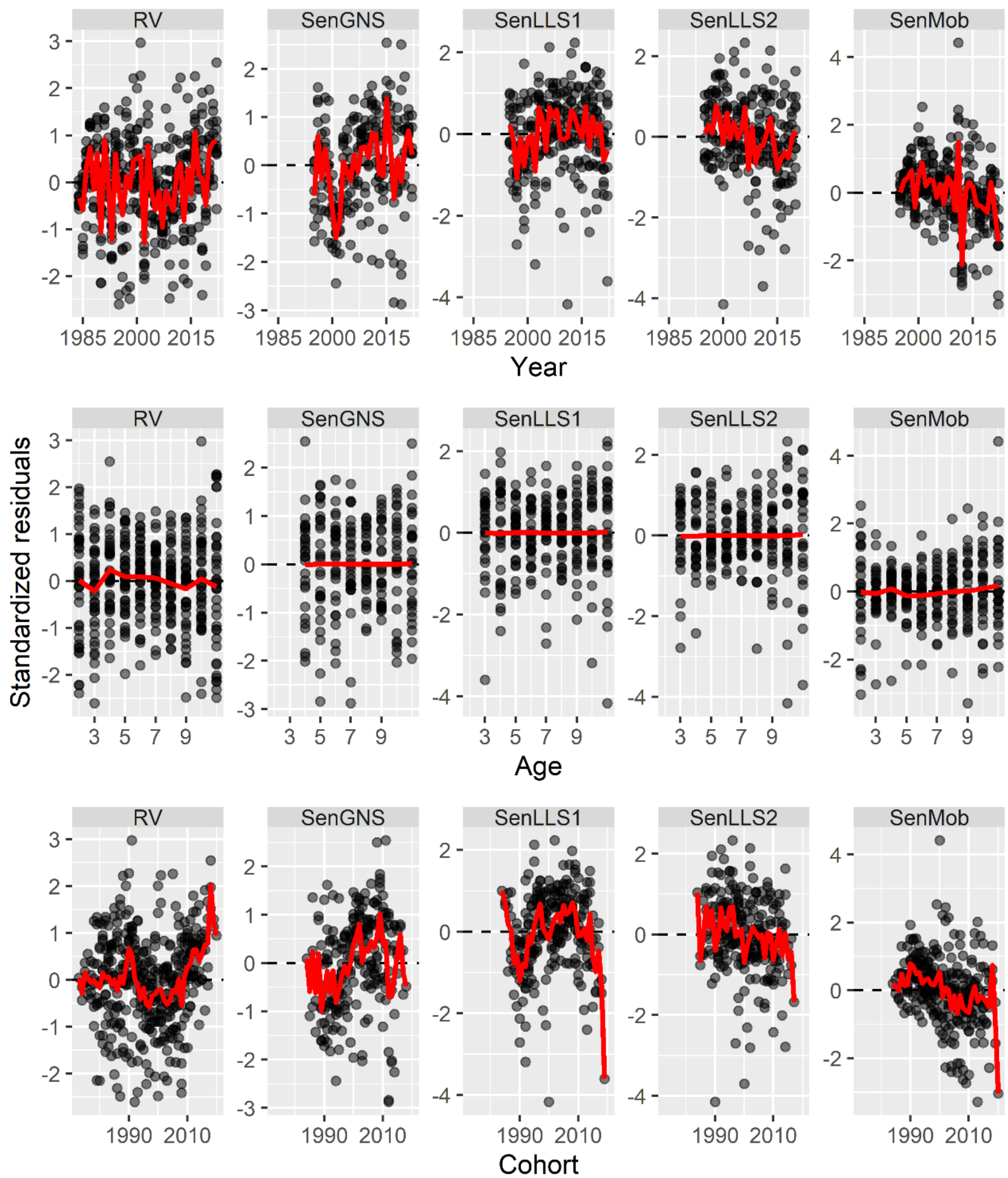

Figure 106. Model residuals for the age-specific abundance indices for each survey (columns) versus year (top row), age (middle row), and cohort (bottom row). Red lines connect the means for year/age/cohort. RV indicates the DFO August research vessel survey.

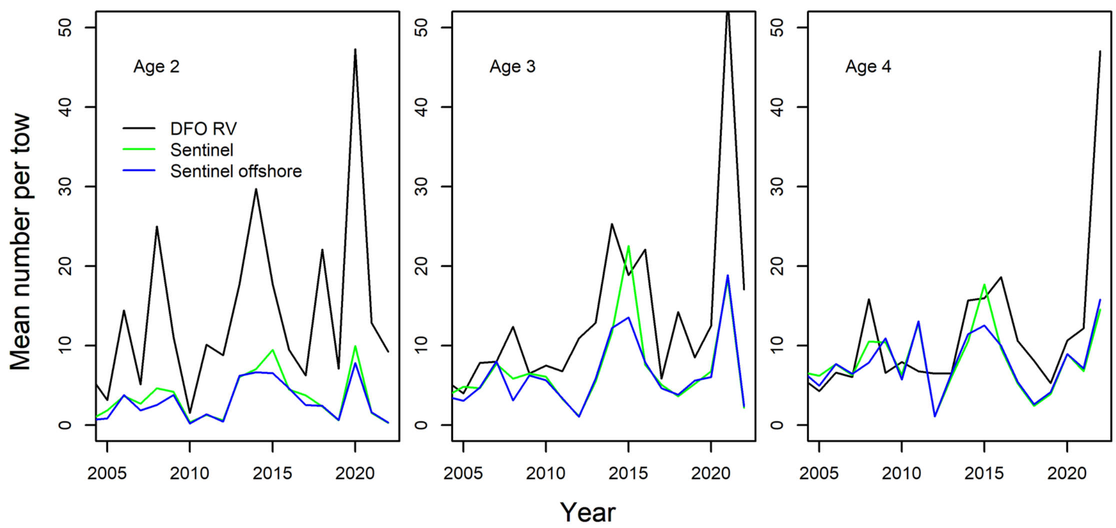

Figure 107. Abundance indices for the DFO August survey (black line), and the sentinel mobile survey based on the typical survey strata (green line) and excluding strata in NAFO 3Pn and coastal strata in 4R (blue line).

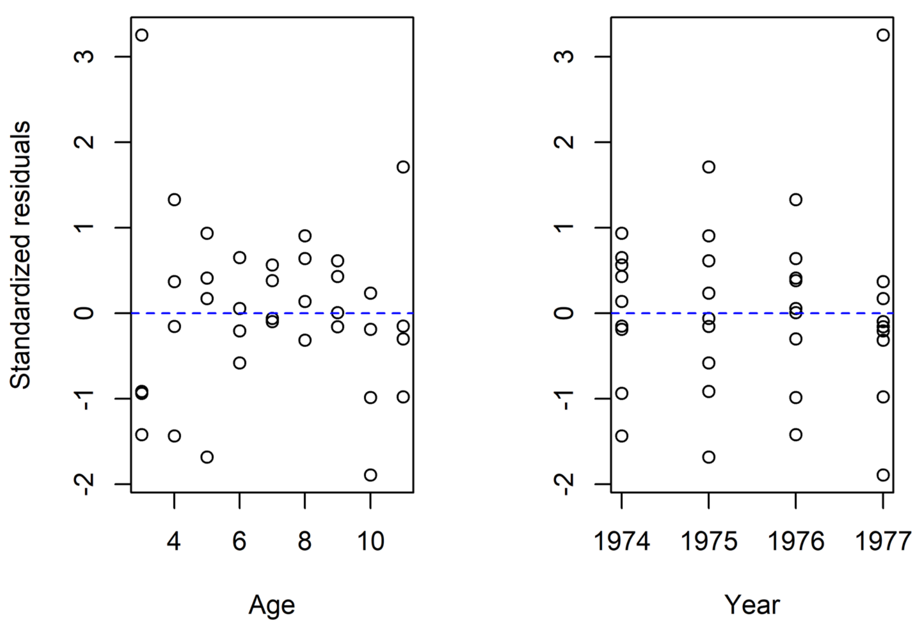

Figure 108. Model residuals for the Minet survey abundance indices as a function of age (left) and year (right).

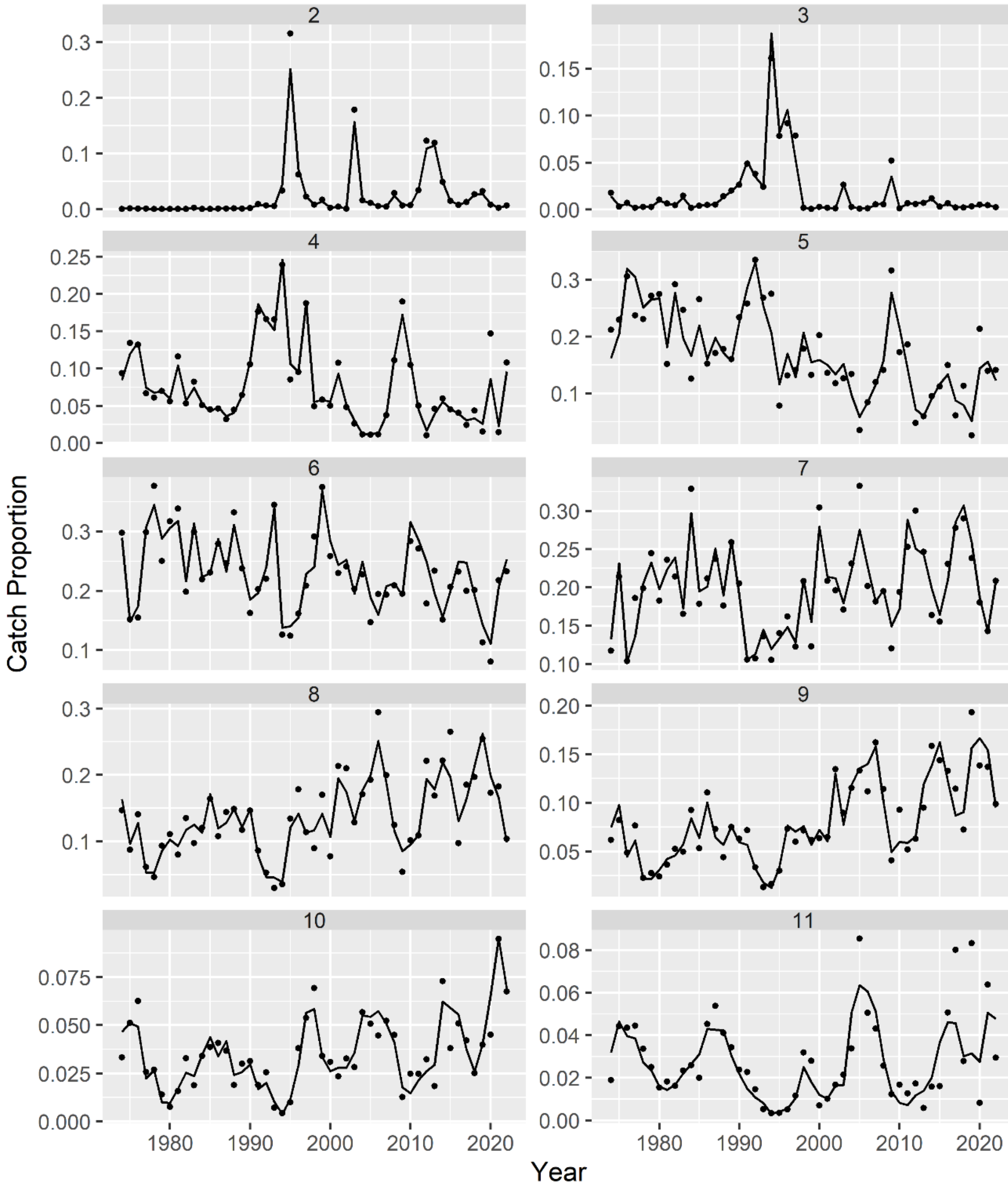

Figure 109. Observed (points) and model predicted (lines) catch proportion-at-age. Age 11 represents 11+.

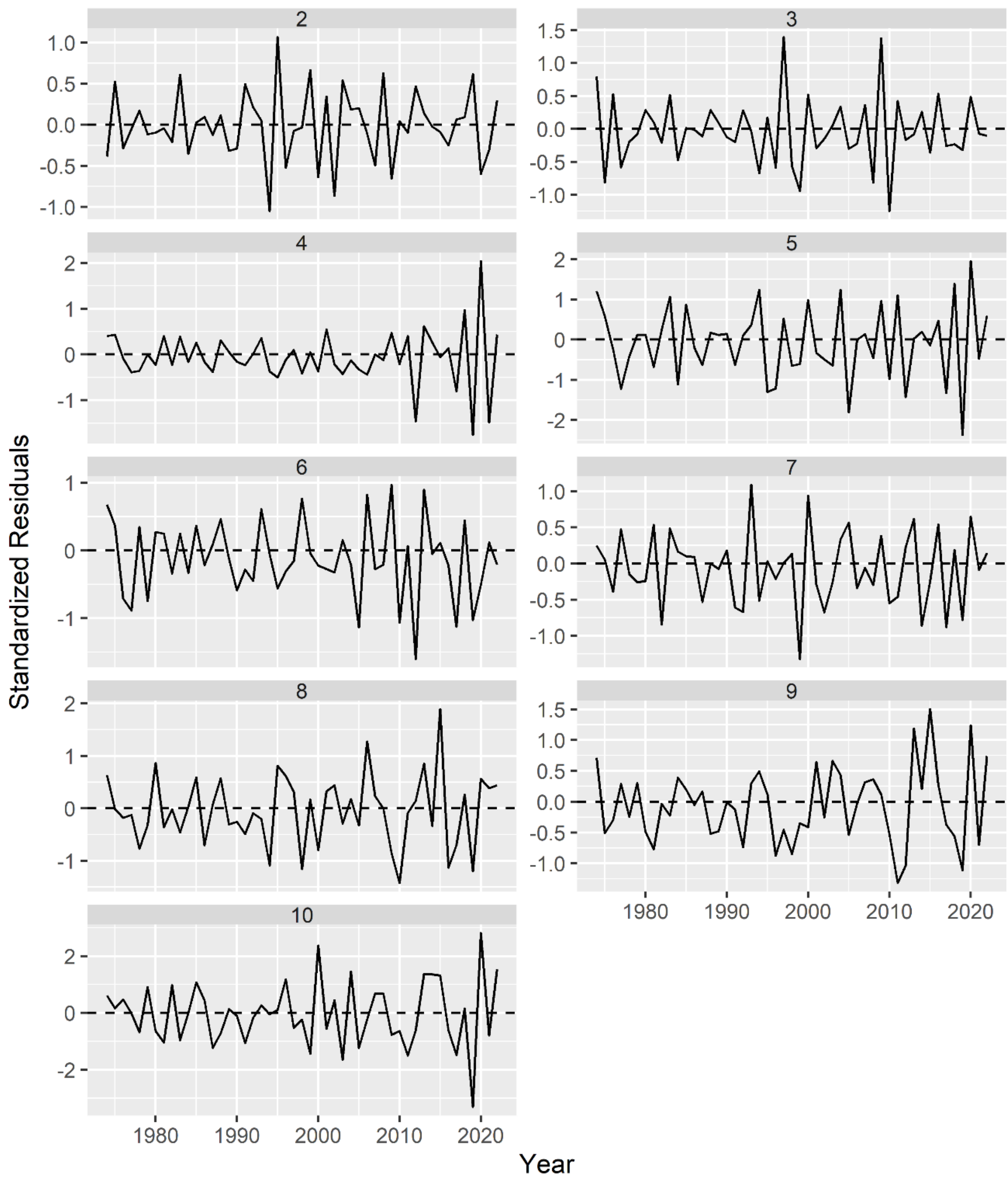

Figure 110. Time series of standardized catch proportions-at-age residuals, by age (panels). Note that the model fits to ages 2-10 only, and proportions for the age 11+ group are derived from the estimates for the other ages.

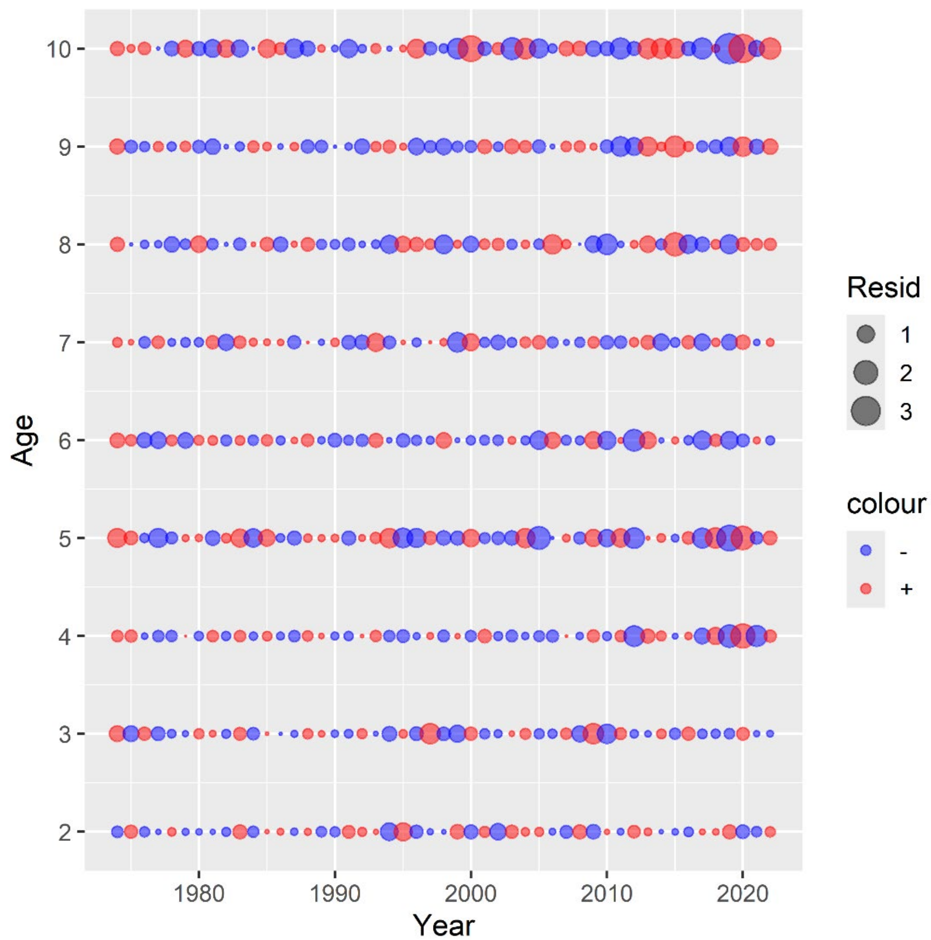

Figure 111. Model catch-at-age composition continuation ratio logit (crl) residuals. The surface area of a bubble is proportional to the absolute value. Red is positive and blue is negative.

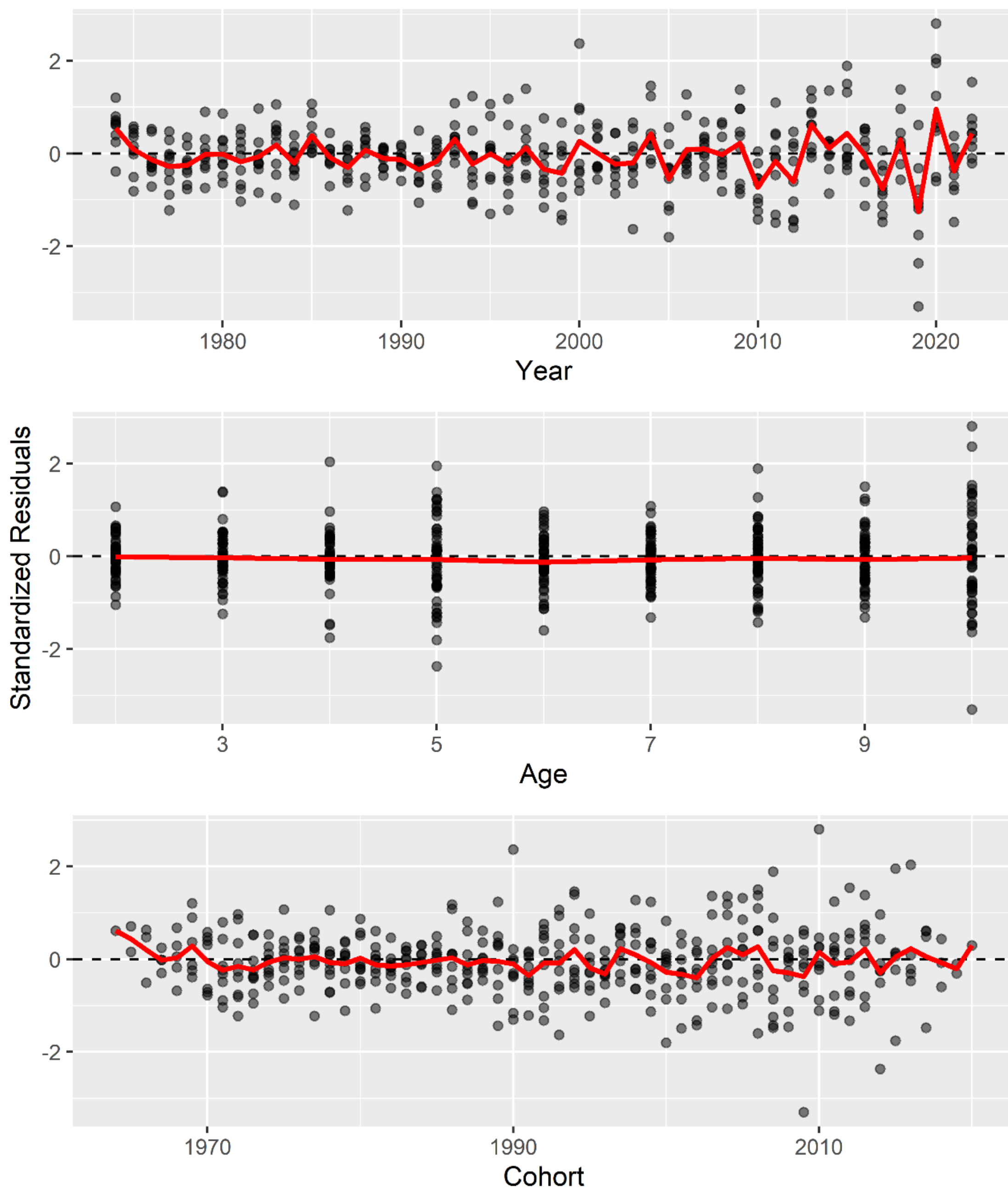

Figure 112. Model catch-at-age composition continuation ratio logit (crl) residuals versus year (top panel), age (middle panel), and cohort (bottom panel). Red lines connect the means for year/age/cohort.

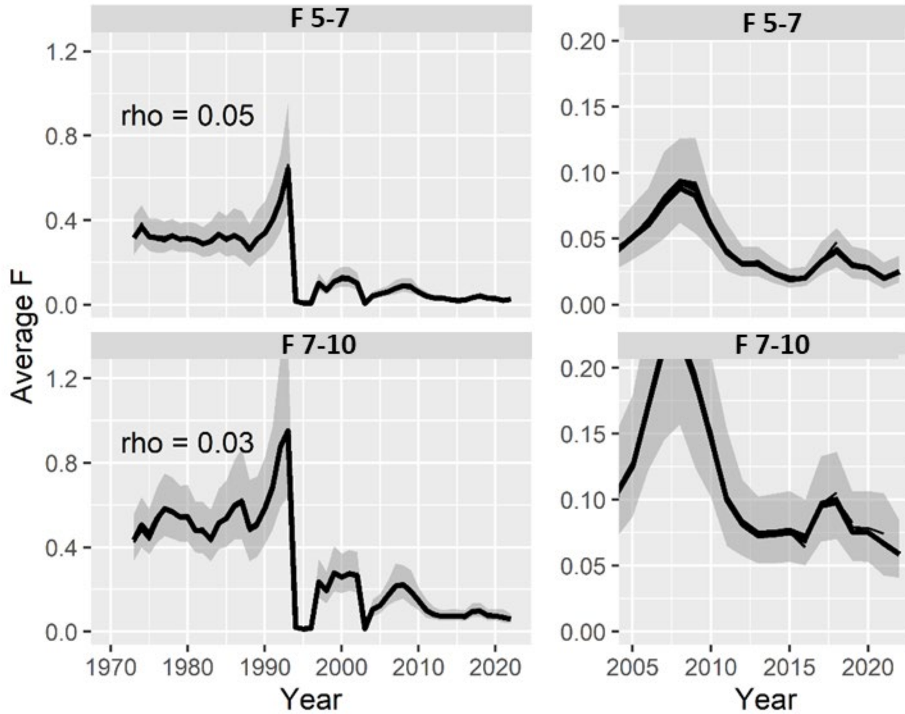

Figure 113. Retrospective estimates of average F at ages 5-7 (top panels) and 7-10 (bottom panels). Shaded regions indicate 95% confidence intervals based on the full time-series of data. The value of Mohn's rho is indicated in the panels. Rightmost panels show trends since 2005.

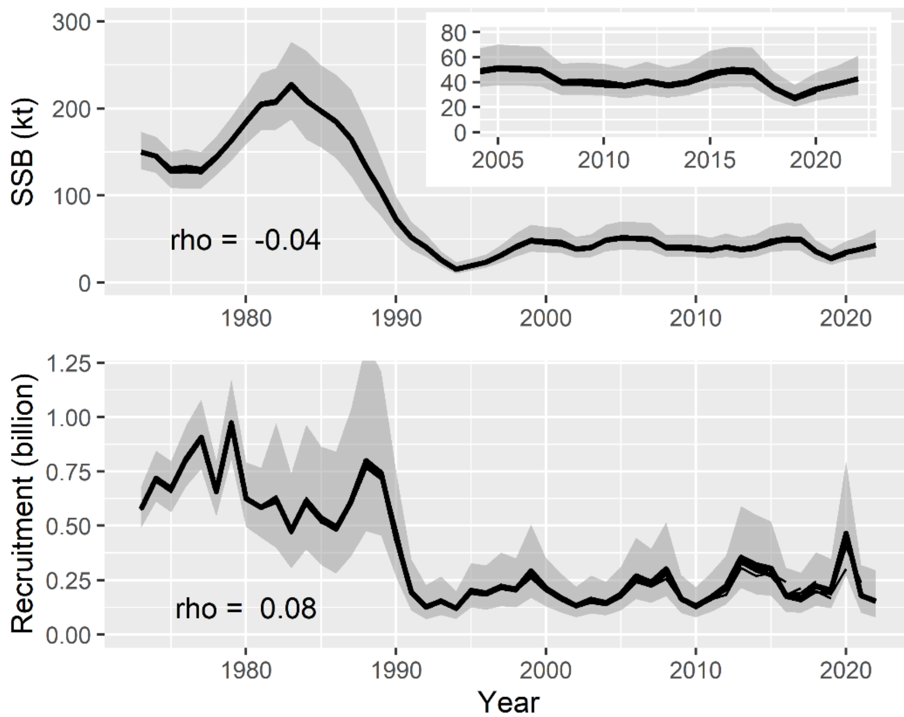

Figure 114. Retrospective estimates of spawning stock biomass (top panel) and recruitment (bottom panel) for the baseline model. Shaded regions indicate 95% confidence intervals based on the full time-series of data. The value of Mohn's rho is indicated in the panels. The inset panel shows the trend since 2005.

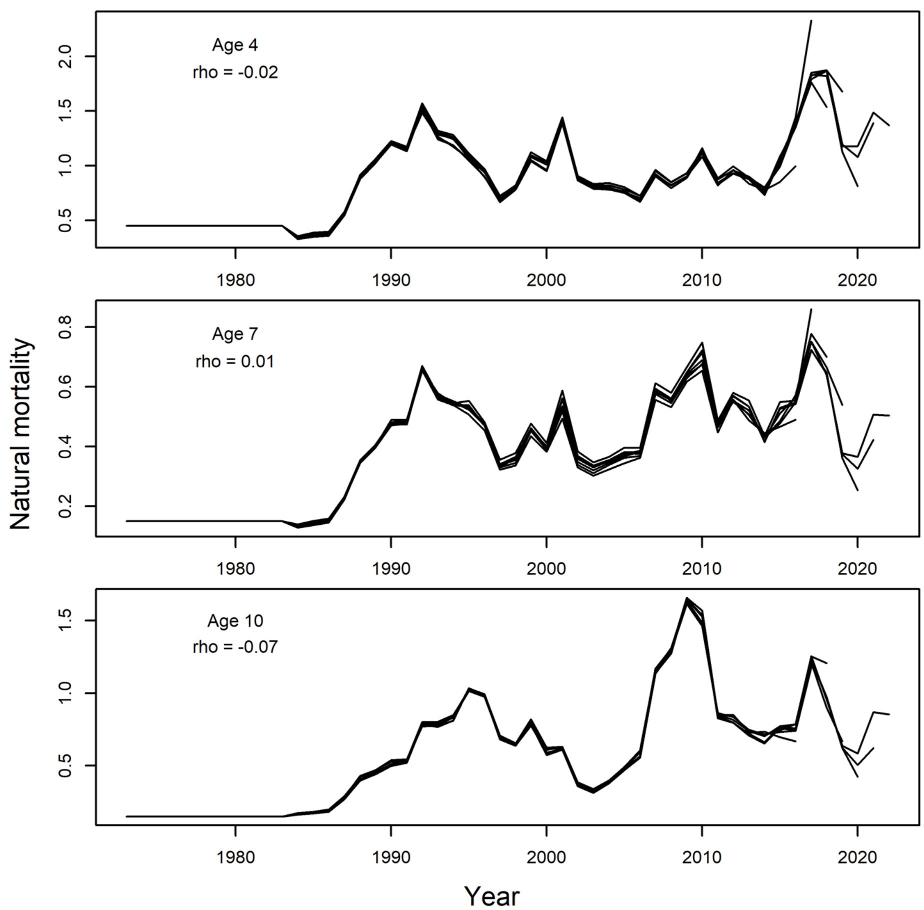

Figure 115. Retrospective estimates of natural mortality for three ages in the baseline model. The value of Mohn's rho is indicated in the panels.

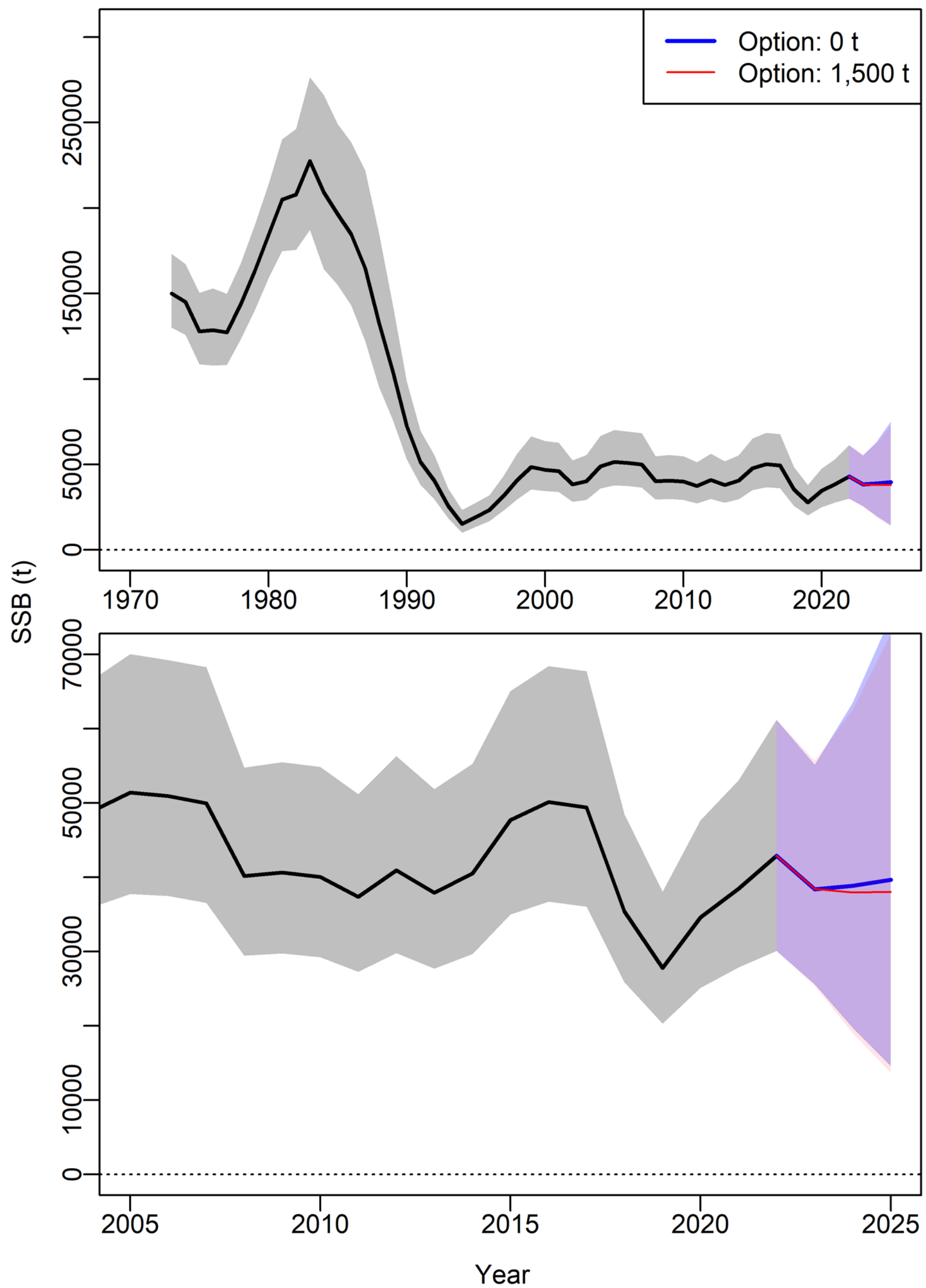

Figure 116. Model estimated spawning stock biomass (black line) and projected spawning stock biomass under total removals scenarios of 0 (blue line) and 1,500 tonnes (red line). The shaded areas represent the 95% confidence intervals, using the same colours as for the estimates. The bottom panel shows a close-up of results for the 2005-2025 period.

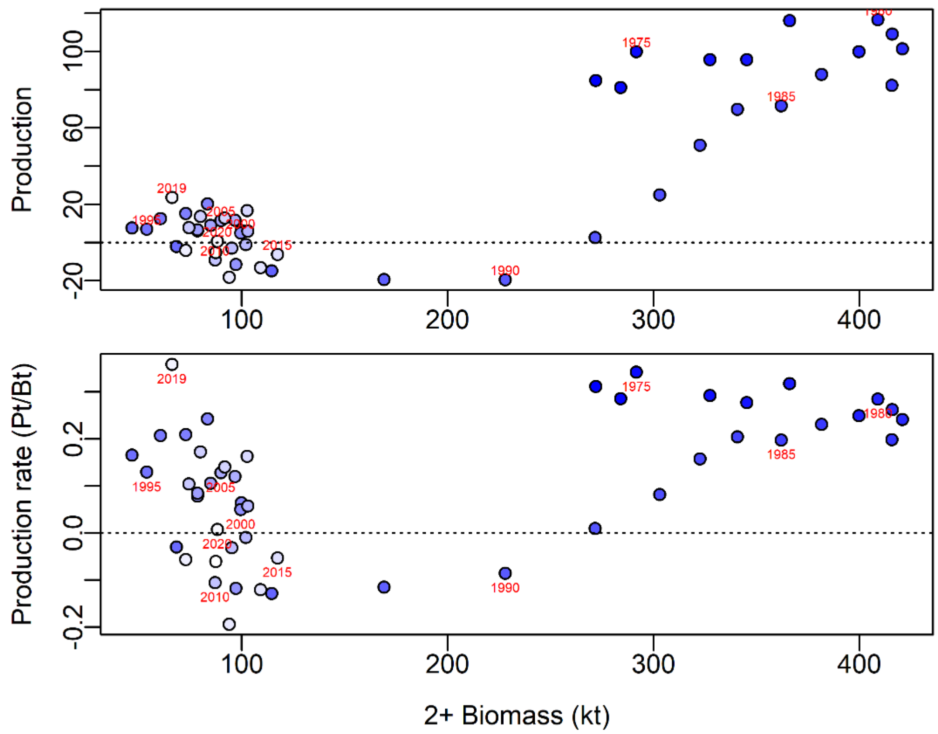

Figure 117. Estimated annual production (tonnes, top panel) and production rate (production over biomass, bottom panel) of age 2+ biomass, as a function of the standing 2+ biomass. Year is indicated by blue shading and every fifth year is labelled using red text.

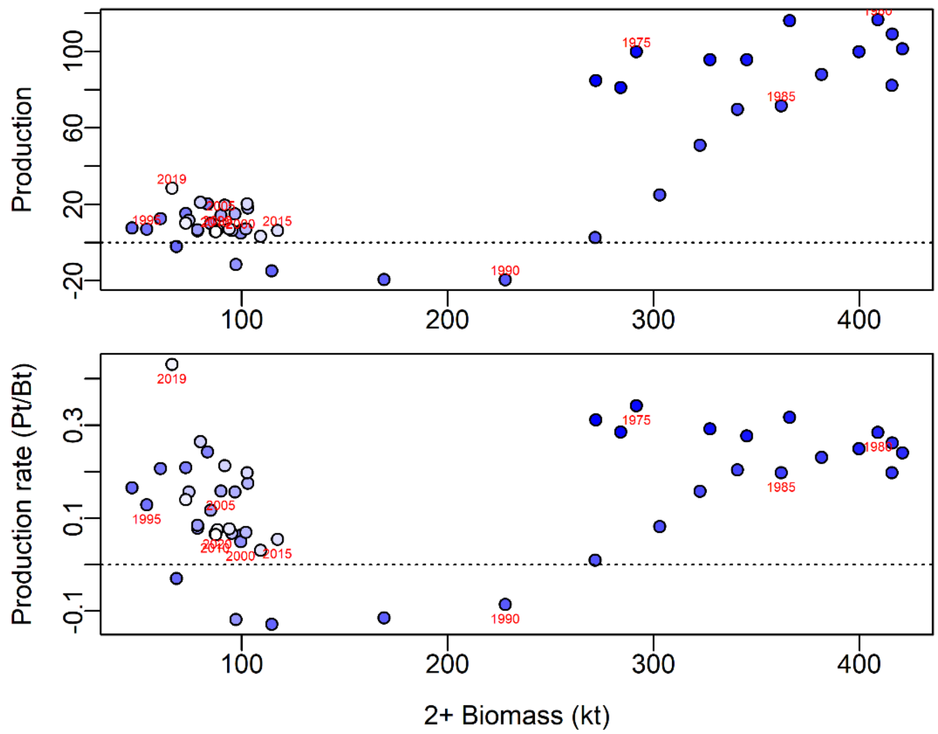

Figure 118. Estimated annual production and production rate, like in Figure 117, only assuming that rates of natural mortality that exceed age-specific 2003 values were instead hypothesized unaccounted catch mortality for years > 2003.

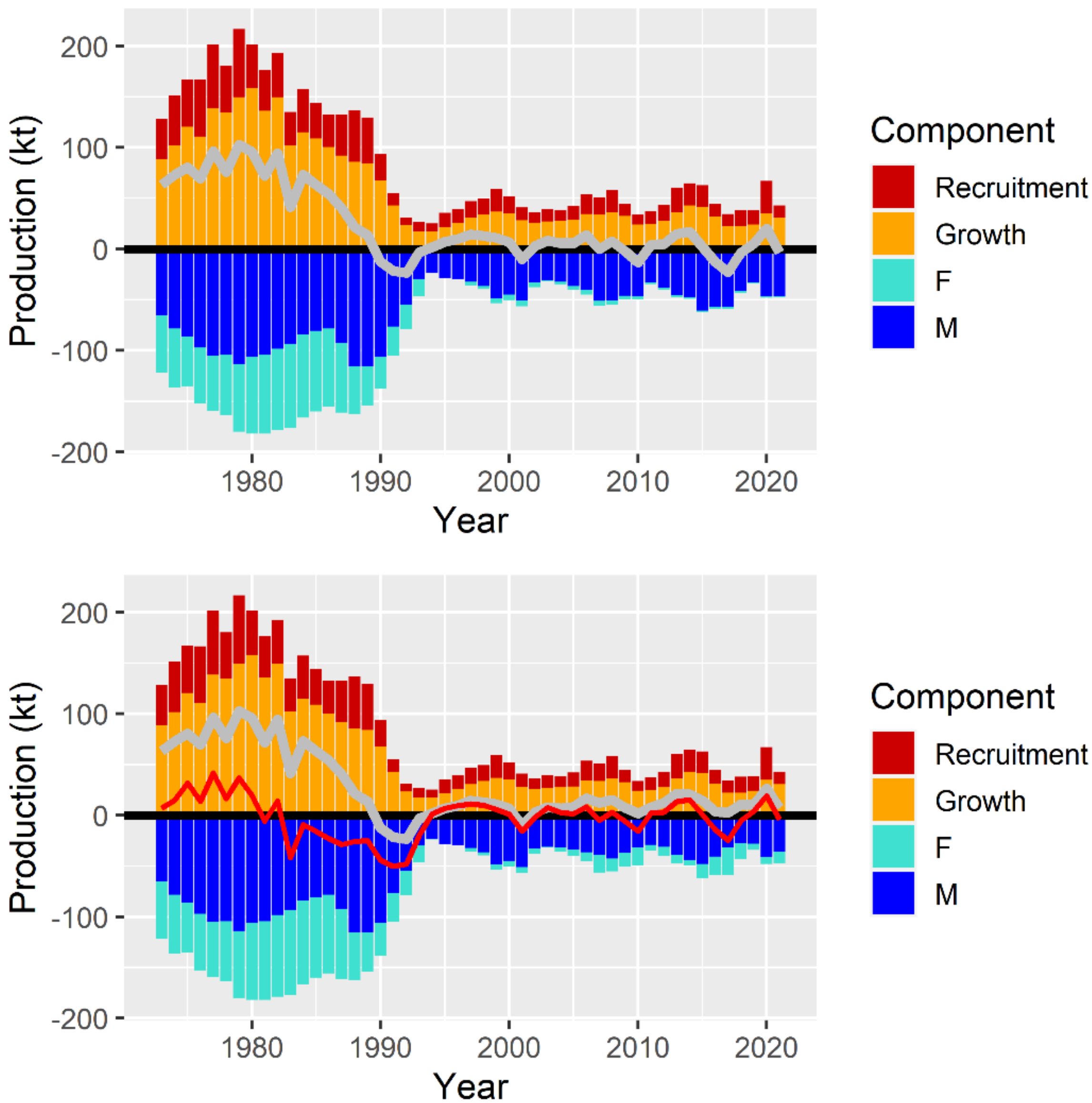

Figure 119. Components of age 2+ production (bars), along with the estimated surplus production (grey line) and net production (red line), based on model estimated rates (top) and assuming that rates of natural mortality that exceed age-specific 2003 values were instead hypothesized unaccounted catch mortality for years > 2003 (bottom).

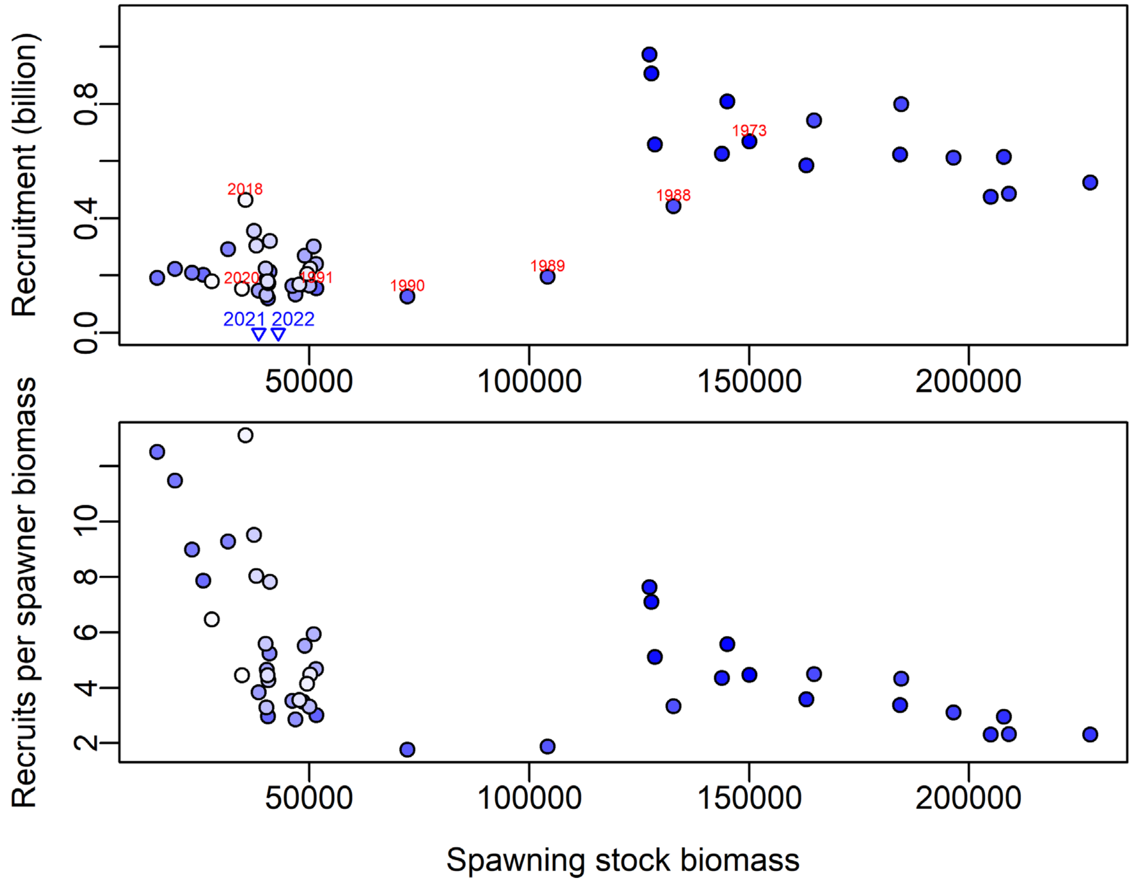

Figure 120. Top panel: Stock-recruitment relationship, with older years plotted in dark blue, turning to white for the most recent years. First, last and certain transitory years are labelled, recalling that the year 2020 of recruitment at age 2 is for the 2018 cohort. Estimated SSB values for 2021 and 2022, for which recruitment has yet to be observed/estimated, are indicated along the x-axis. Bottom-panel: Plot of recruit numbers per spawner biomass for estimates from the baseline model, using the same colour coding as the top panel.

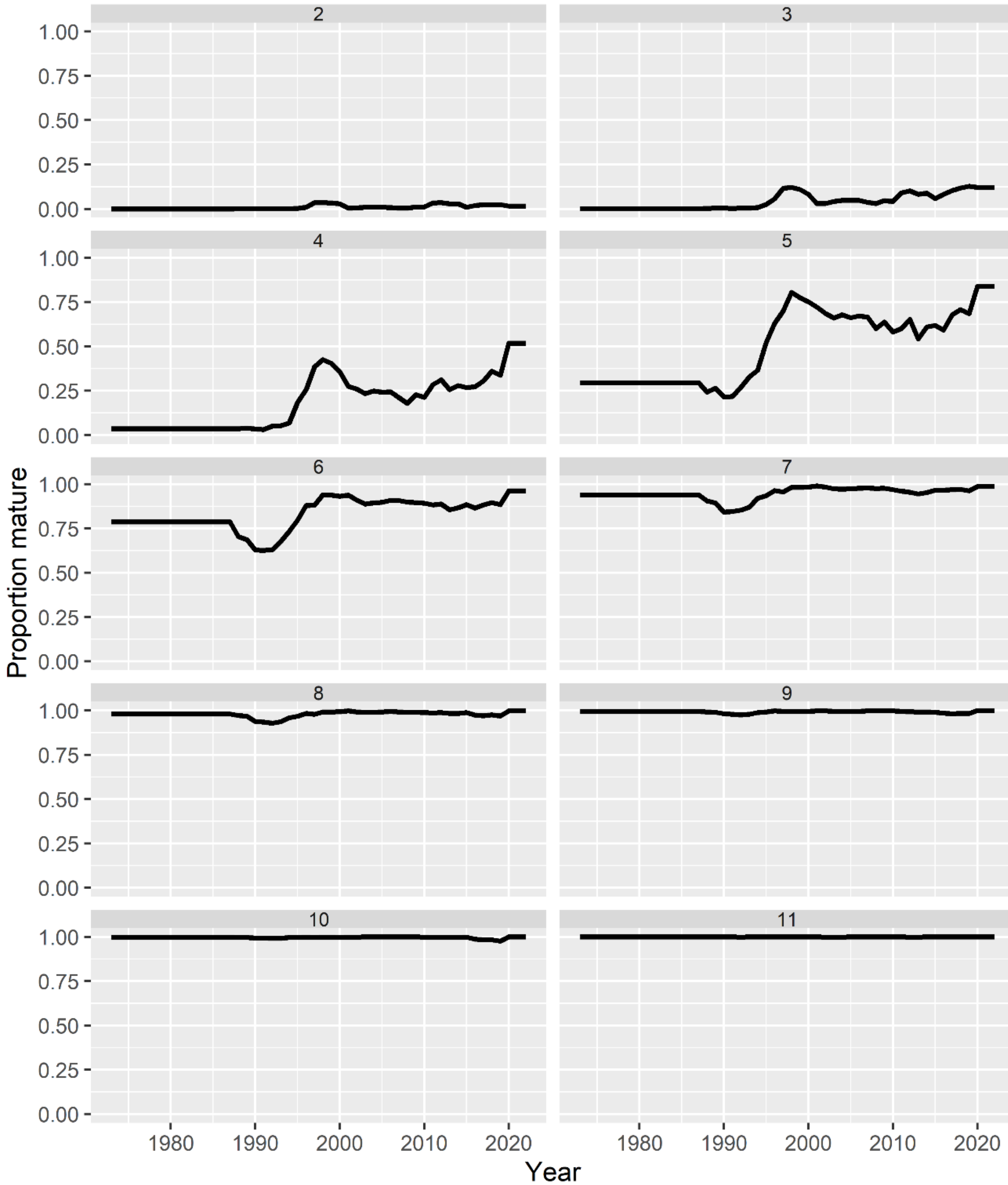

Figure 121. Age-specific plots of the proportion mature as a function of year, which is an input to the model. Age 11 represents 11+.

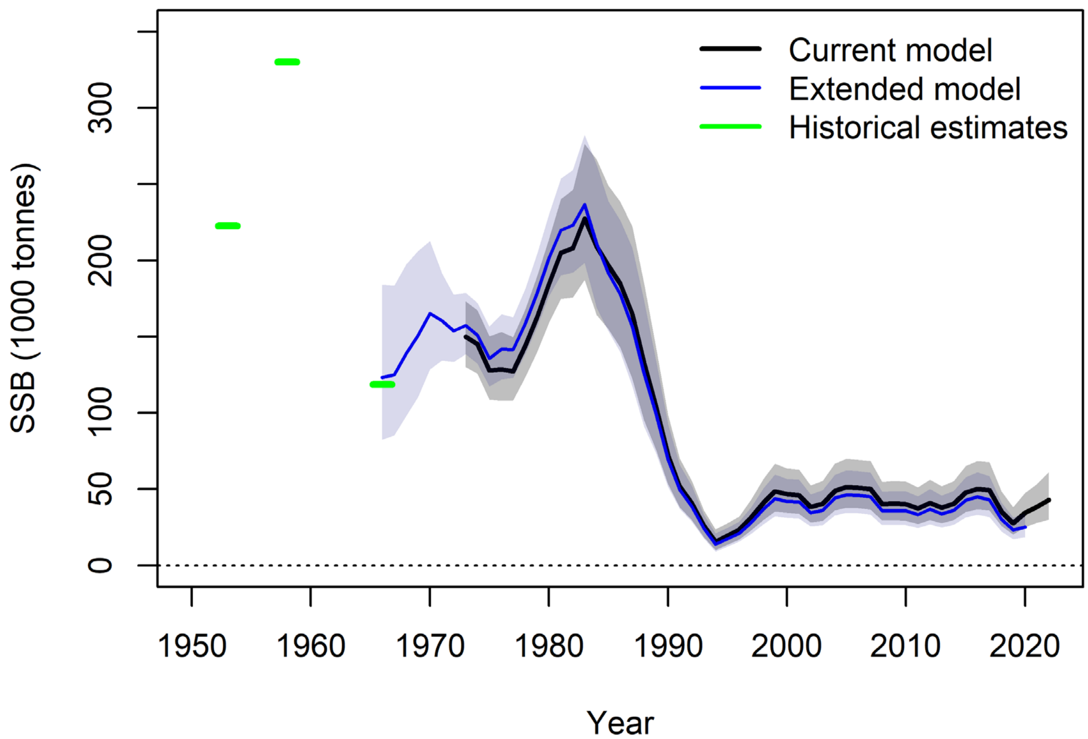

Figure 122. Estimates of spawning stock biomass from the extended model fit as part of the 2022 framework review with 95% confidence intervals (blue line and shaded area), along with the estimated SSB from the current assessment model (black line and grey shaded area). The green bars indicate the point estimates calculated for 1953 and 1958, and recalculated for 1966, using the stock weight and maturity information from Wiles and May (1968).

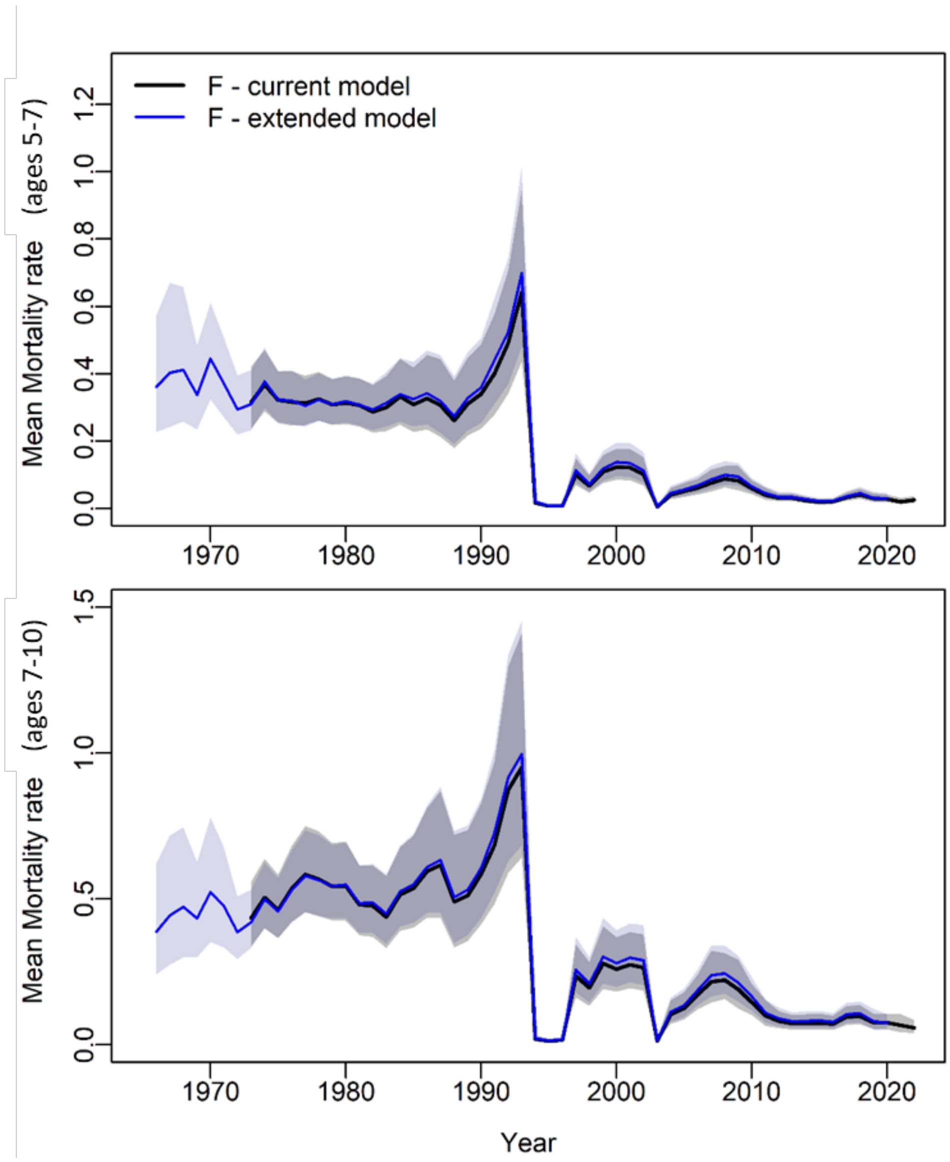

Figure 123. Estimates of average fishing mortality F at ages 5-7 and 7-10, with 95% confidence interval (blue line and shaded area) from the extended model fit as part of the 2022 framework review, along with estimates from the current assessment model (black line and grey shaded area).

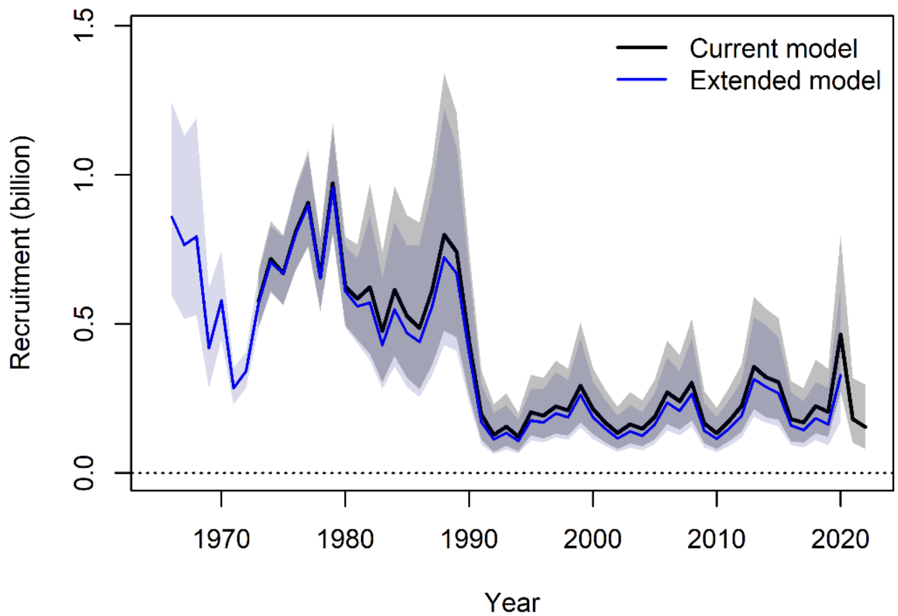

Figure 124. Estimates of recruitment from the extended model fit as part of the 2022 framework review with 95% confidence intervals (blue line and shaded area), along with the estimated recruitment from the current assessment model (black line and grey shaded area).

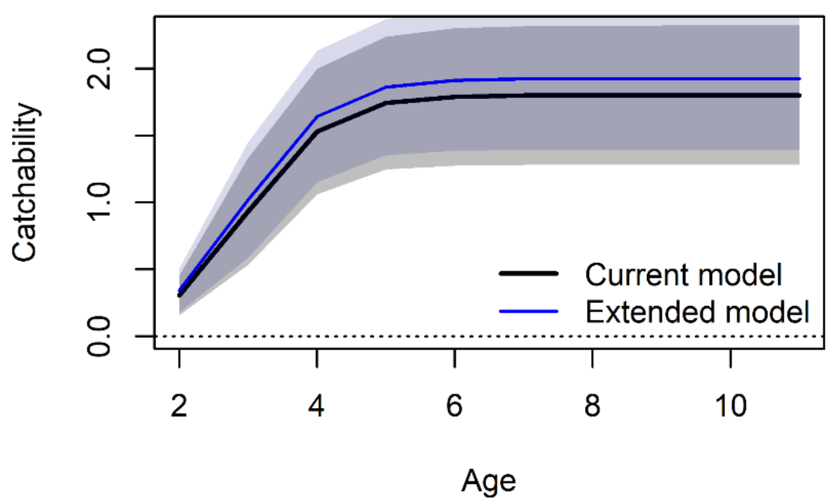

Figure 125. Estimated DFO August survey catchability function, with 95% confidence interval (shaded area) for the extended model fit as part of the 2022 framework review (blue) and for the current assessment model (black).

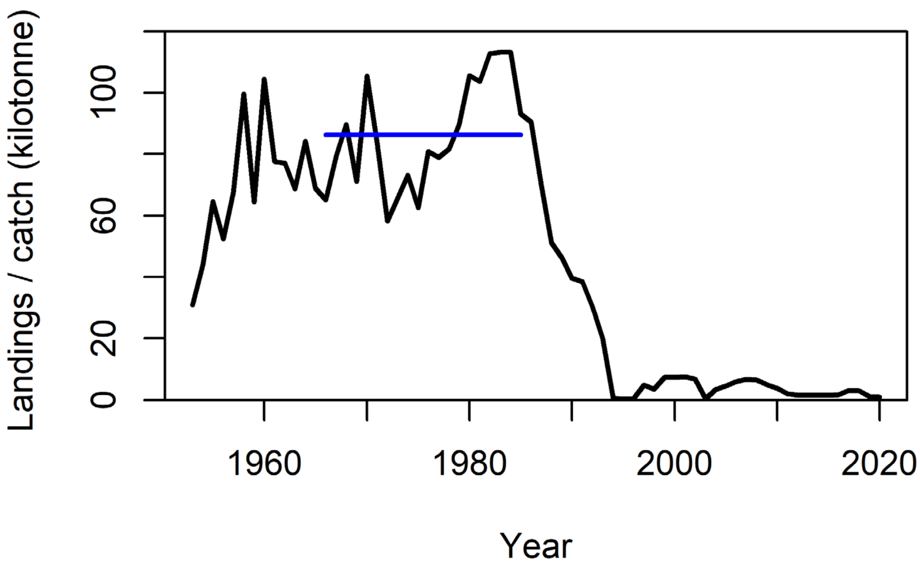

Figure 126. Time series of cod landings, or catch for the period in which censored catches were estimated by the model, used in the extended model, with the 1966-1985 mean indicated by the horizontal blue line.

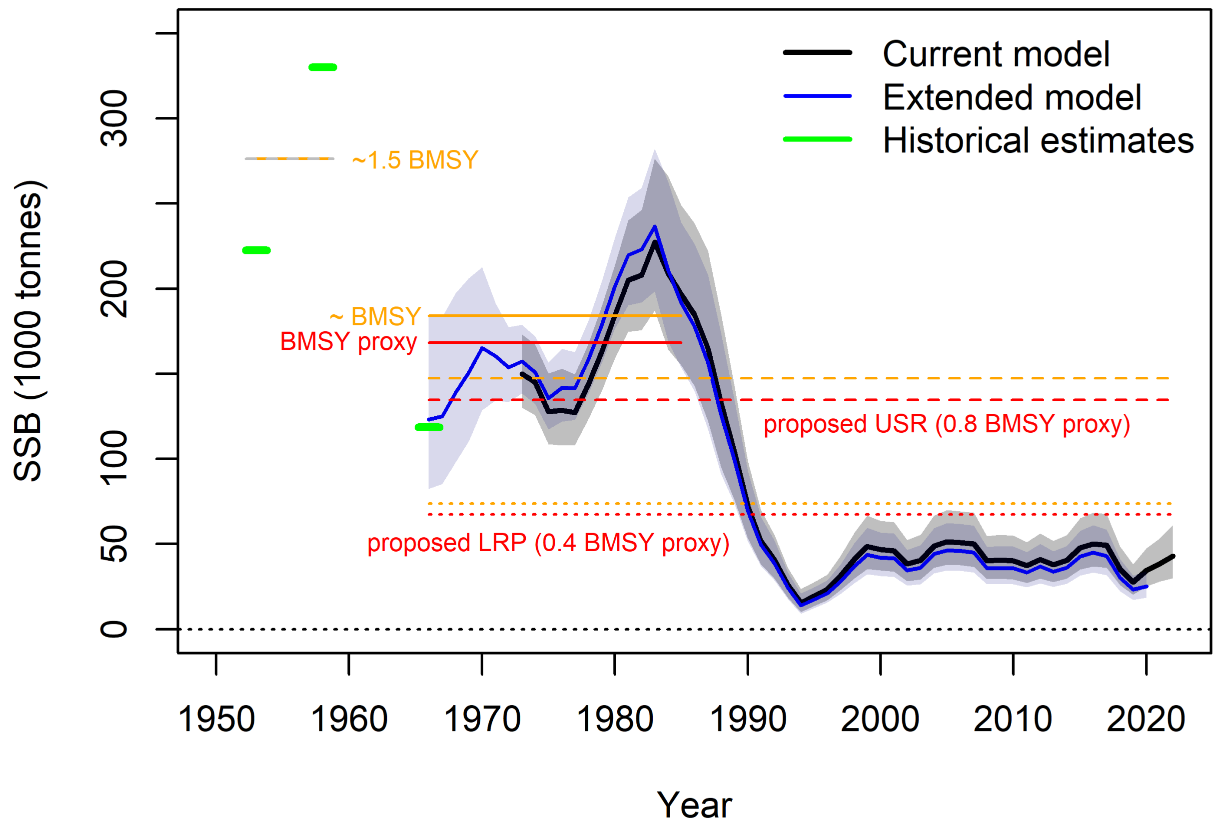

Figure 127. Estimates of spawning stock biomass from the extended model fit as part of the 2022 framework review with 95% confidence intervals (blue line and shaded area), along with the estimated SSB from the current assessment model (black line and grey shaded area). The green bars indicate the point estimates calculated for 1953 and 1958, and recalculated for 1966, using the stock weight and maturity information from Wiles and May (1968). Two candidate BMSY values are indicated, one based on the assumption that mean SSB values in the 1950s constituted 1.5 x BMSY , as has been estimated for NAFO 2J3KL cod (Schijns et al. 2021) (solid orange horizontal lines), and the other that assumes that the mean value of SSB during the period 1966-1985 constitutes a proxy for BMSY (solid red horizontal line). Proposed upper stock reference (USR) and limit reference point (LRP) values based on provisional DFO precautional approach guideline default values of 0.8 and 0.4 times BMSY are indicated using dashed and dotted lines, respectively.

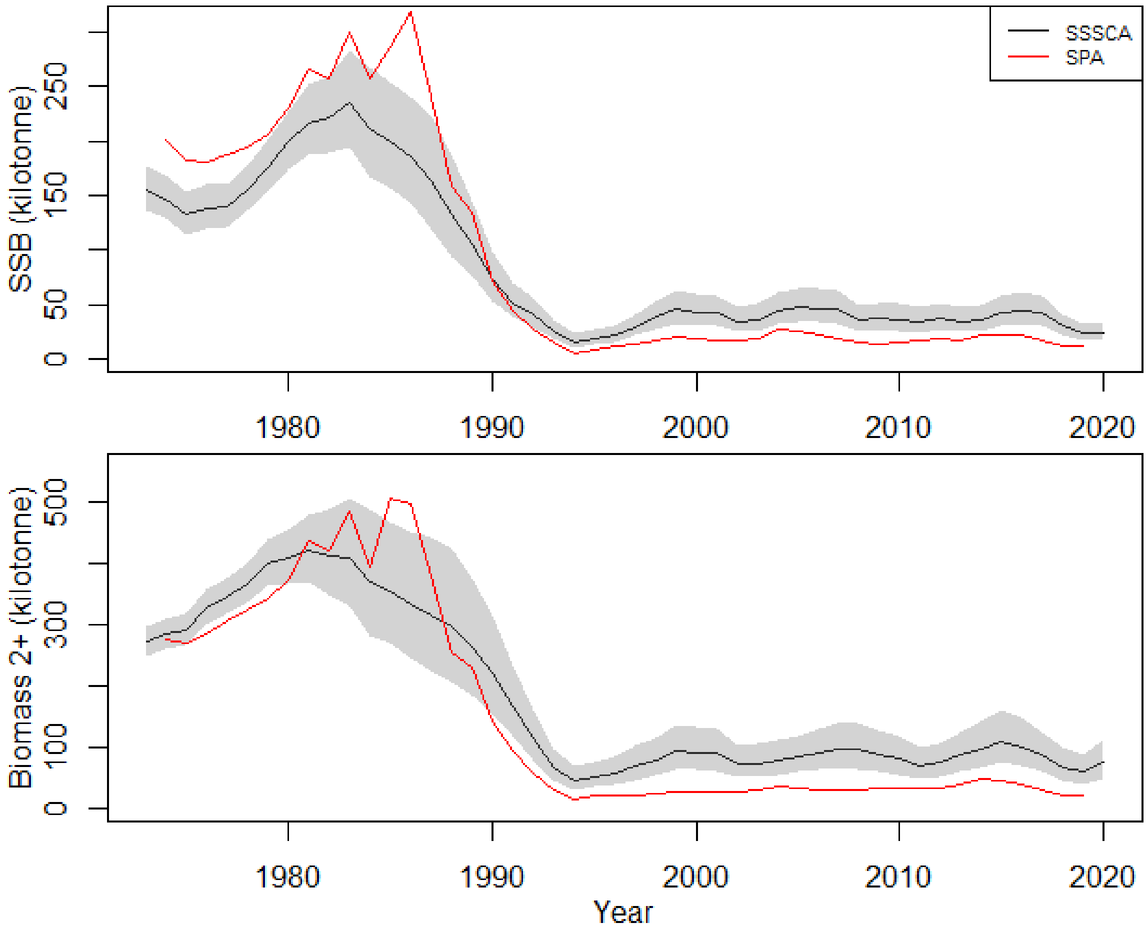

Figure 128. Estimates of spawning stock biomass (SSB) and ages 2+ biomass from the new assessment model (black line; 95% confidence interval shown using the shaded area) and the former sequential population analysis model (SPA; red line) (taken from Benoît et al. 2024a). This figure illustrates that the level of stock depletion between the early to mid 1980s and the post-1995 period was estimated to be considerably greater using the former model.

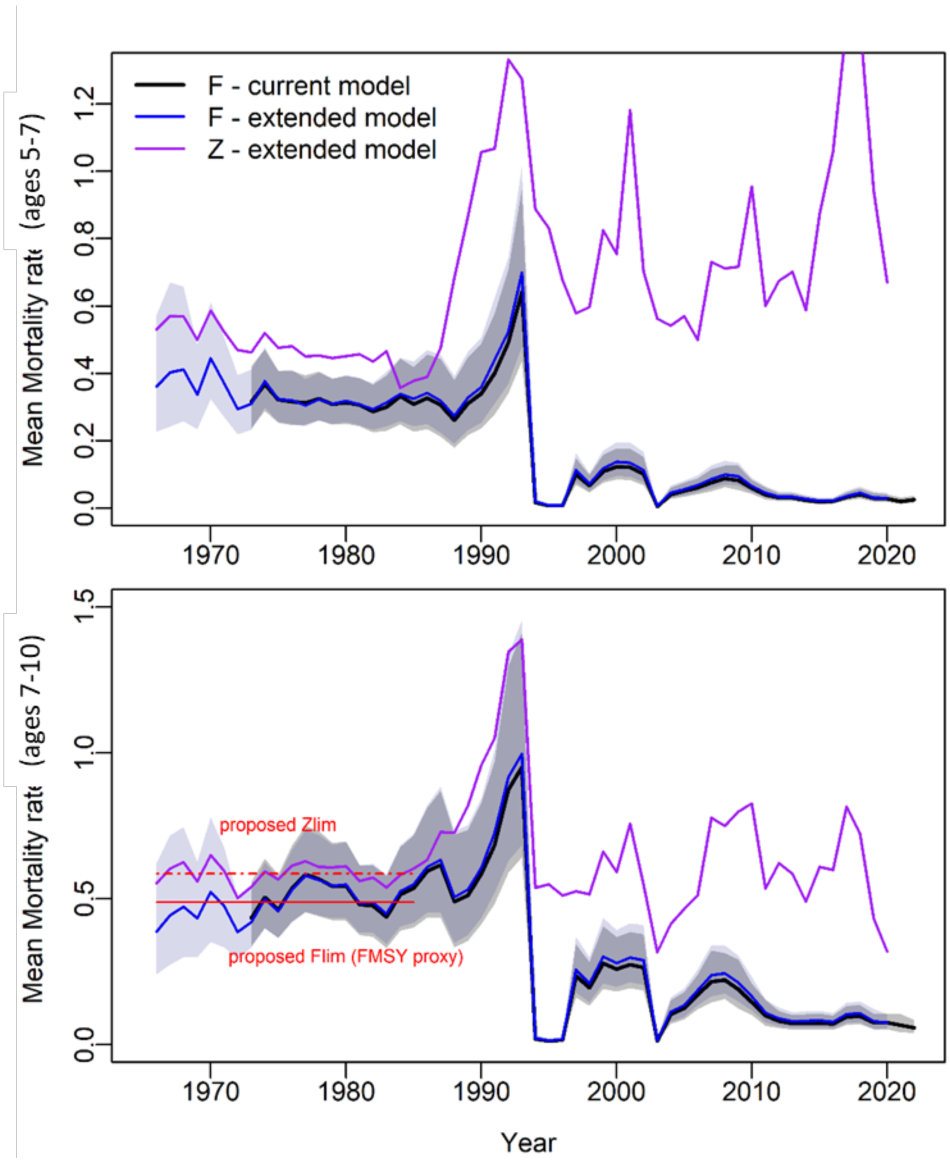

Figure 129. Same as Figure 123, but also showing the total mortality rate Z from the extended model (purple line), and the proposed values of F_{lim} and Z_{lim}, based respectively on the mean values of F and Z for ages 7-10 over the period 1966-1985.

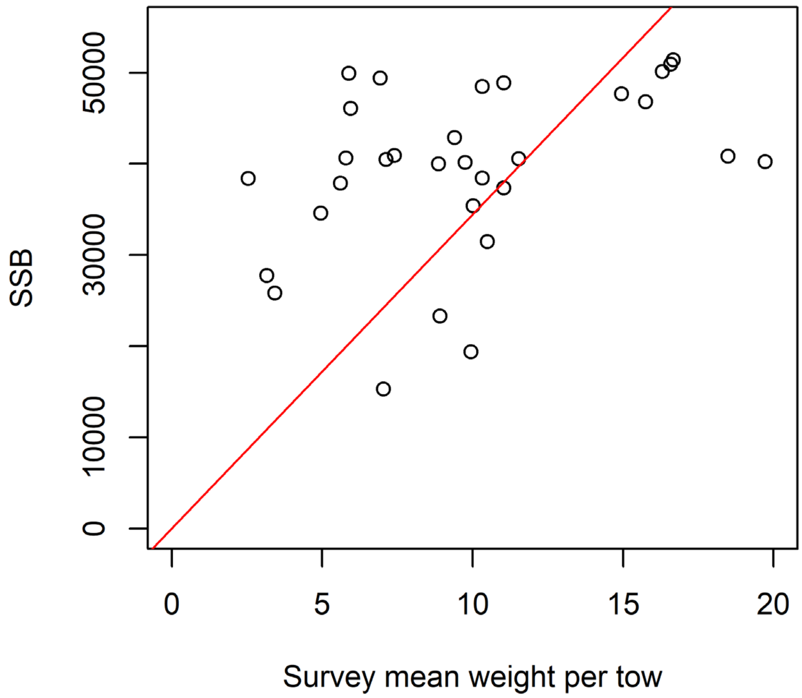

Figure 130. Relationship between model estimated spawning stock biomass (SSB) and the DFO August survey biomass index for cod ≥ 43 cm for 1992-2023. The red line indicates the best fitting linear regression line for a model assuming a nil intercept value.

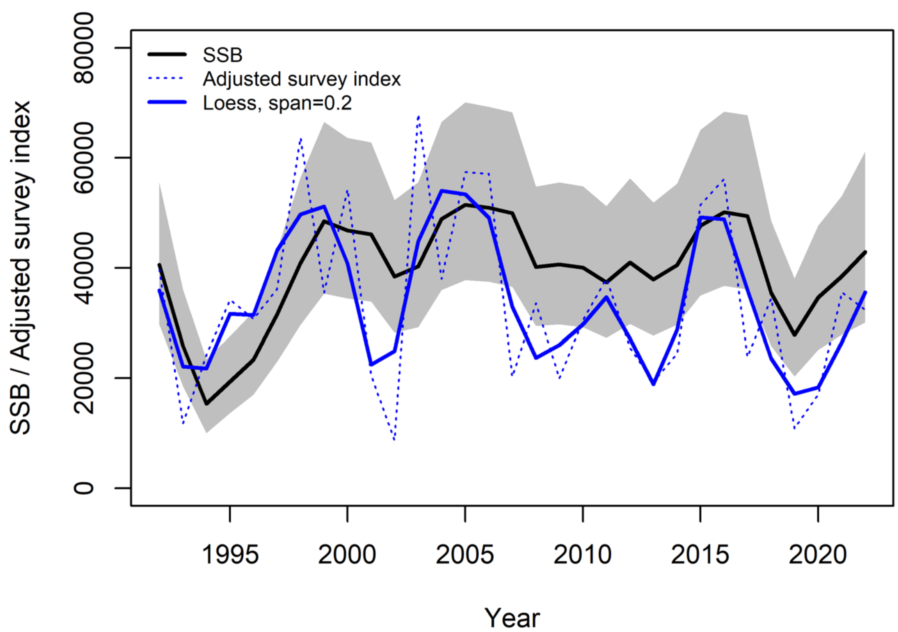

Figure 131. Model estimated spawning stock biomass (SSB; black line with 95% confidence interval), and the adjusted DFO August survey biomass index for cod ≥ 43 cm (dotted blue line) along with a loess smooth of the adjusted index using a span of 0.2 (solid blue line).

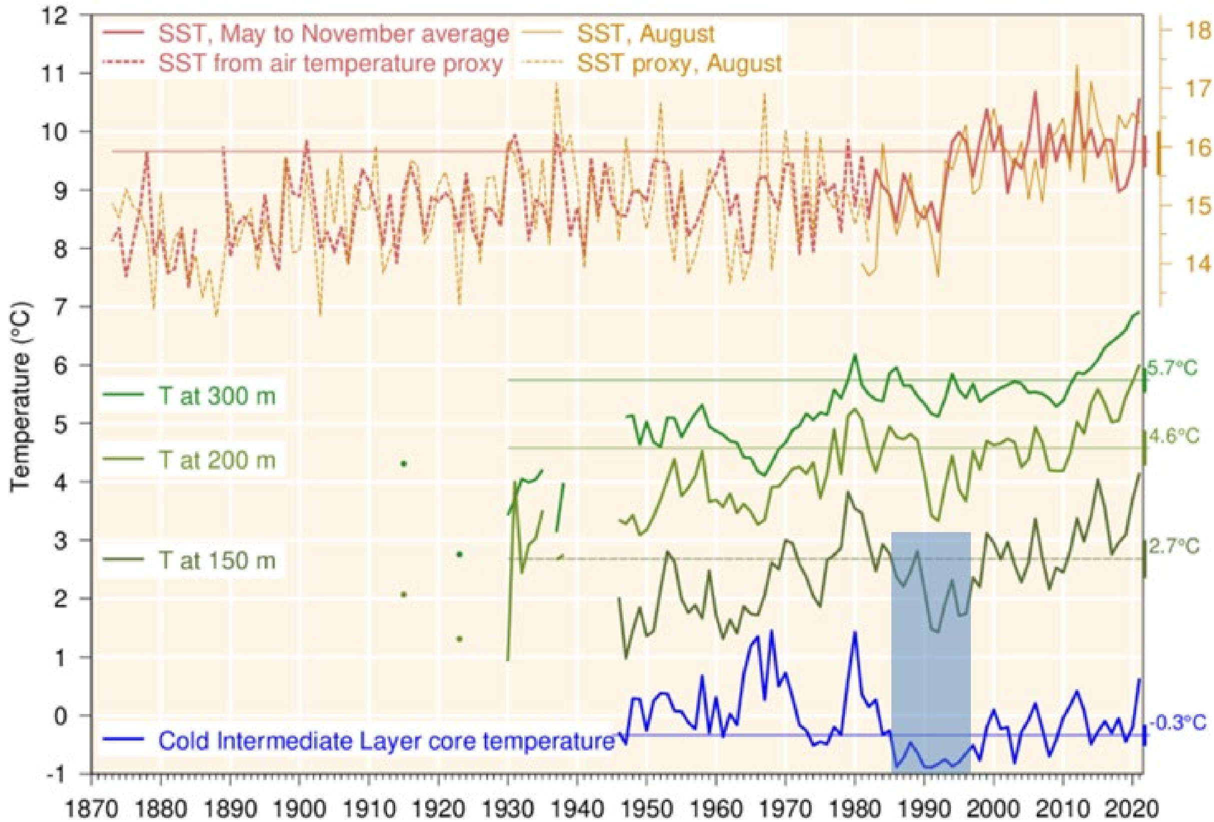

Figure 132. Water temperatures in the Gulf of St. Lawrence, taken from Figure 64 in Galbraith et al. (2022), with blue shading added here for emphasis for the 1986-1995 cold-water period. May–November SST averaged over the Gulf excluding the Estuary (1982–2021, red line), completed by a proxy based on April–November air temperature (1873–1981, red dashed line). August SST is shown using temperature scale offset by 6.3 °C; its proxy is based on the average air temperature in July and August. Layer-averaged temperature for the Gulf of St. Lawrence at 150 m, 200 m and 300 m (green lines). Cold intermediate layer minimum temperature index in the Gulf of St. Lawrence (blue line). Further details in Galbraith et al. (2022).

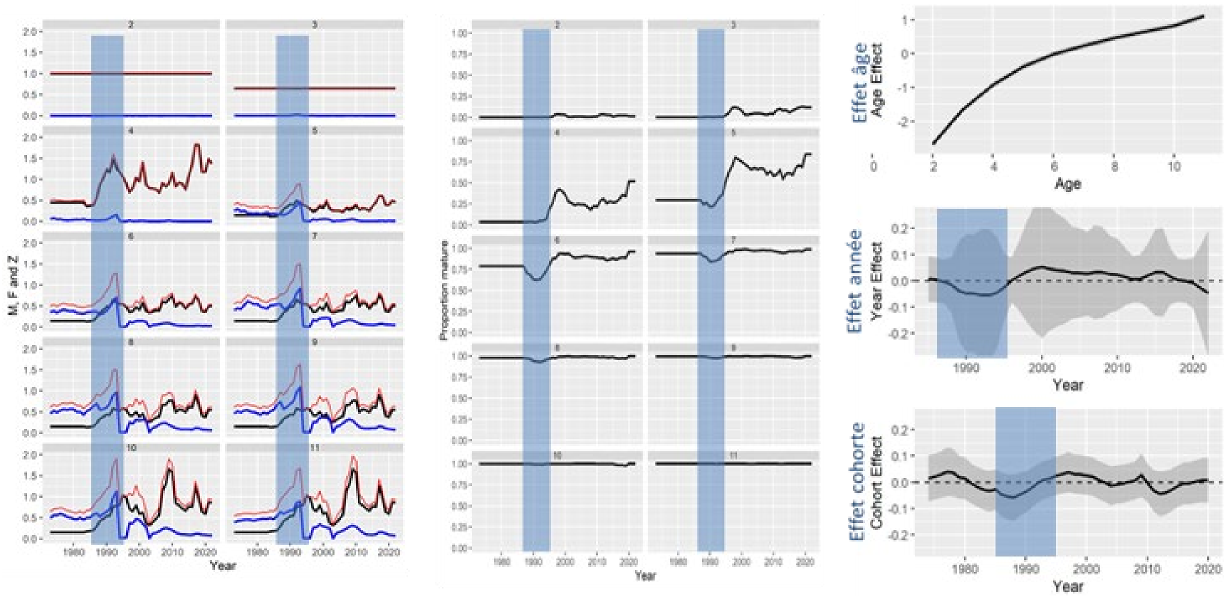

Figure 133. Composite plot of figures appearing previously in this document and in which blue shading is added for emphasis for the 1986-1995 cold-water period. From left to right, are shown Figures 93 (estimates of age-specific mortalities), 121 (age-specific proportion mature) and 79 (main effects of the weight-at-age model).

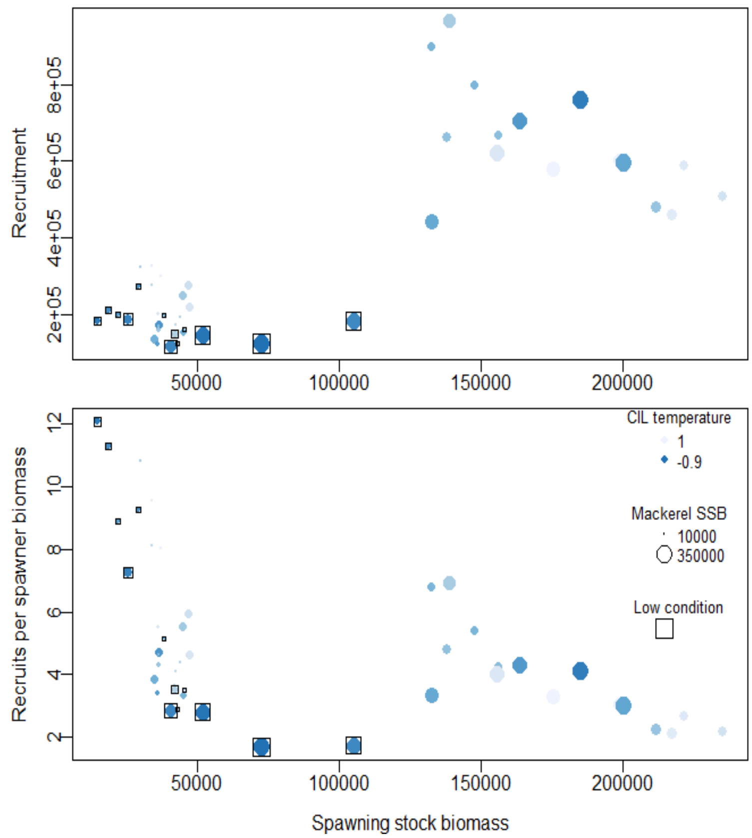

Figure 134. Top panel: Stock-recruitment relationship with symbols defining the conditions in the year the stock originated. Blue shading indicates the mean core temperature in the cold intermediate layer (CIL; from Galbraith et al. 2022), symbol size corresponds to the SSB for mackerel (from DFO 2021b) and boxes indicate years associated with low physiological condition in adults (from Lambert 2011). Bottom-panel: Plot of recruit numbers per spawner biomass, using the same symbol coding as the top panel.

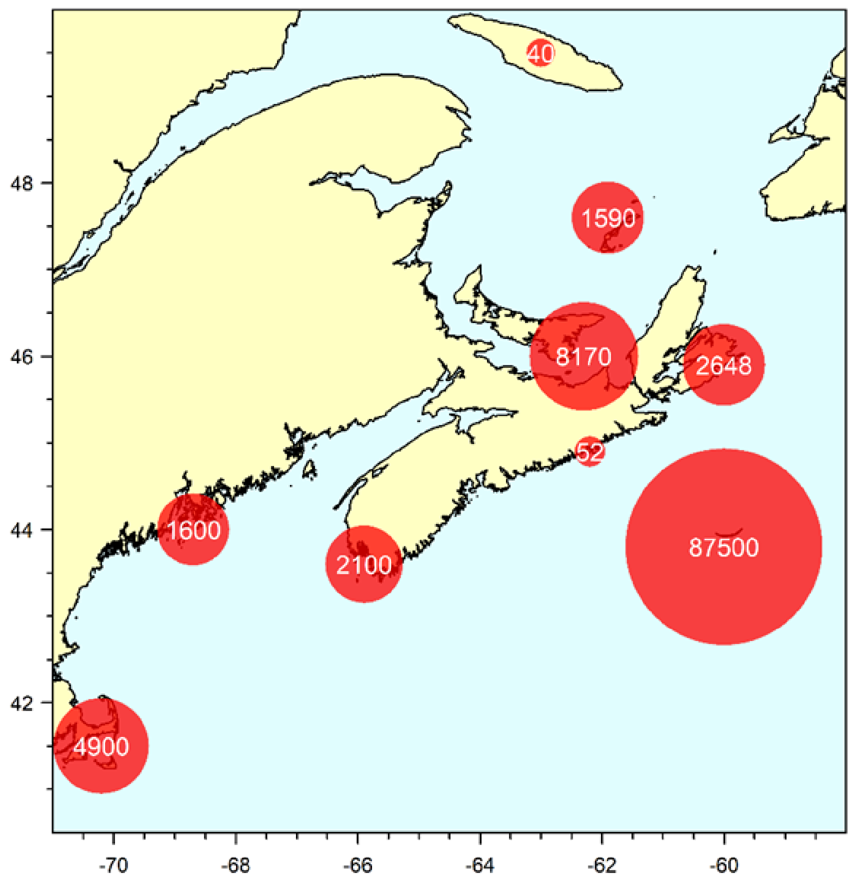

Figure 135. Map of estimated 2016 grey seal pup counts aggregated by geographic area, data from Table 1 of den Heyer et al. (2021). Circle size is proportional to the magnitude of the count, which is also directly indicated.

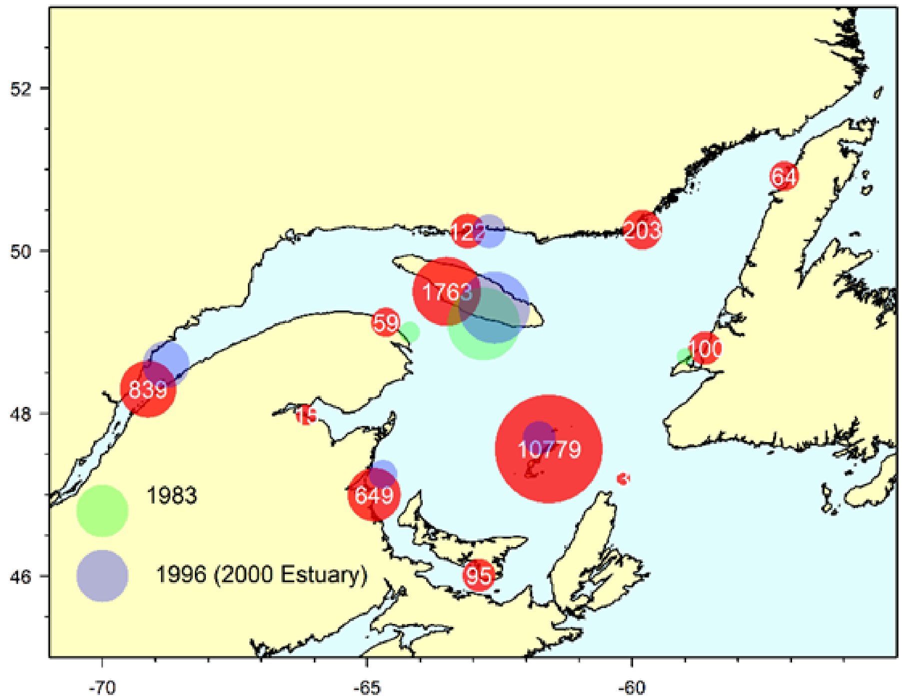

Figure 136. Map of hauled out grey seal counts during late spring and summer aggregated by geographic area from aerial surveys conducted in the Gulf of St. Lawrence in 1983-1984 (green circles; Clay and Nielsen 1985), in 1996 and 2000 (blue circles; Robillard et al. 2005) and in 2019 (red circles with numbers; Mosnier et al. 2023). Circle size is proportional to count and numbers in the red circles are the counts themselves.

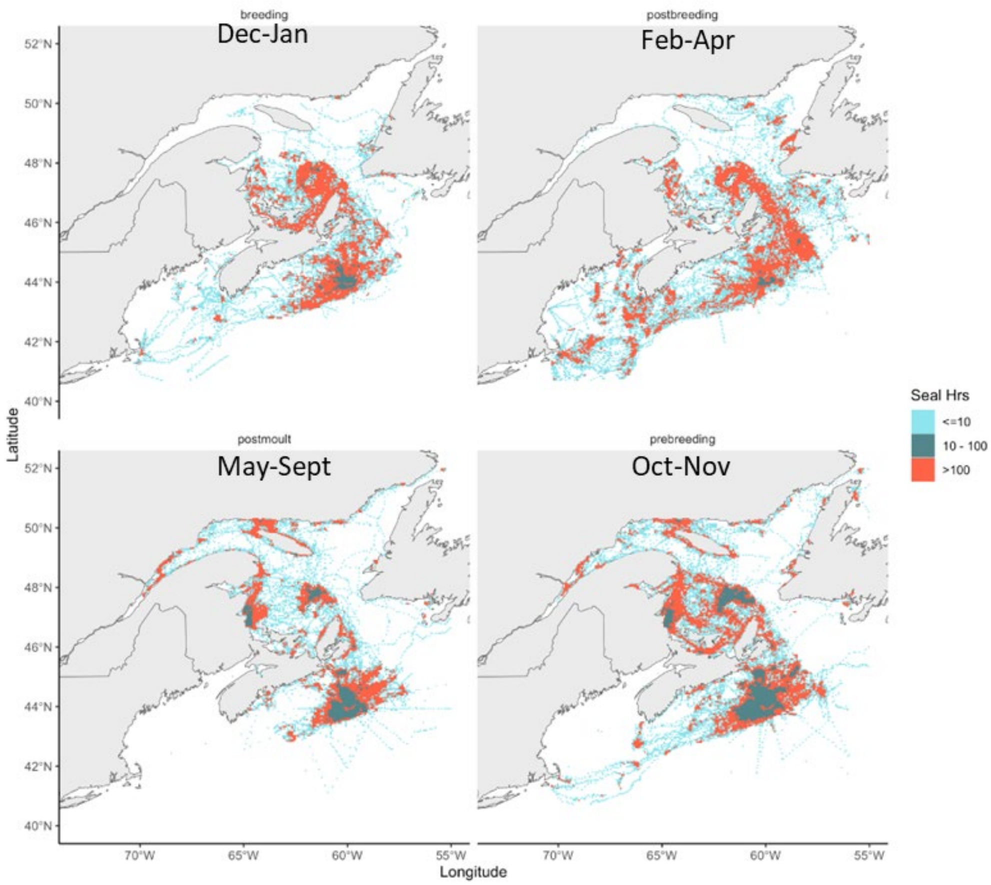

Figure 137. Summary of seasonal grey seal space use based on telemetry of tagged individuals in studies undertaken from 1993-2018 (Kim Whoriskey et al. unpublished document). Space use is summarized as the number of hours spent at a location by tagged seals (n=378). The telemetry data were pre-processed using a state-space movement model to filter-out unexpected movement patterns attributed to measurement errors.

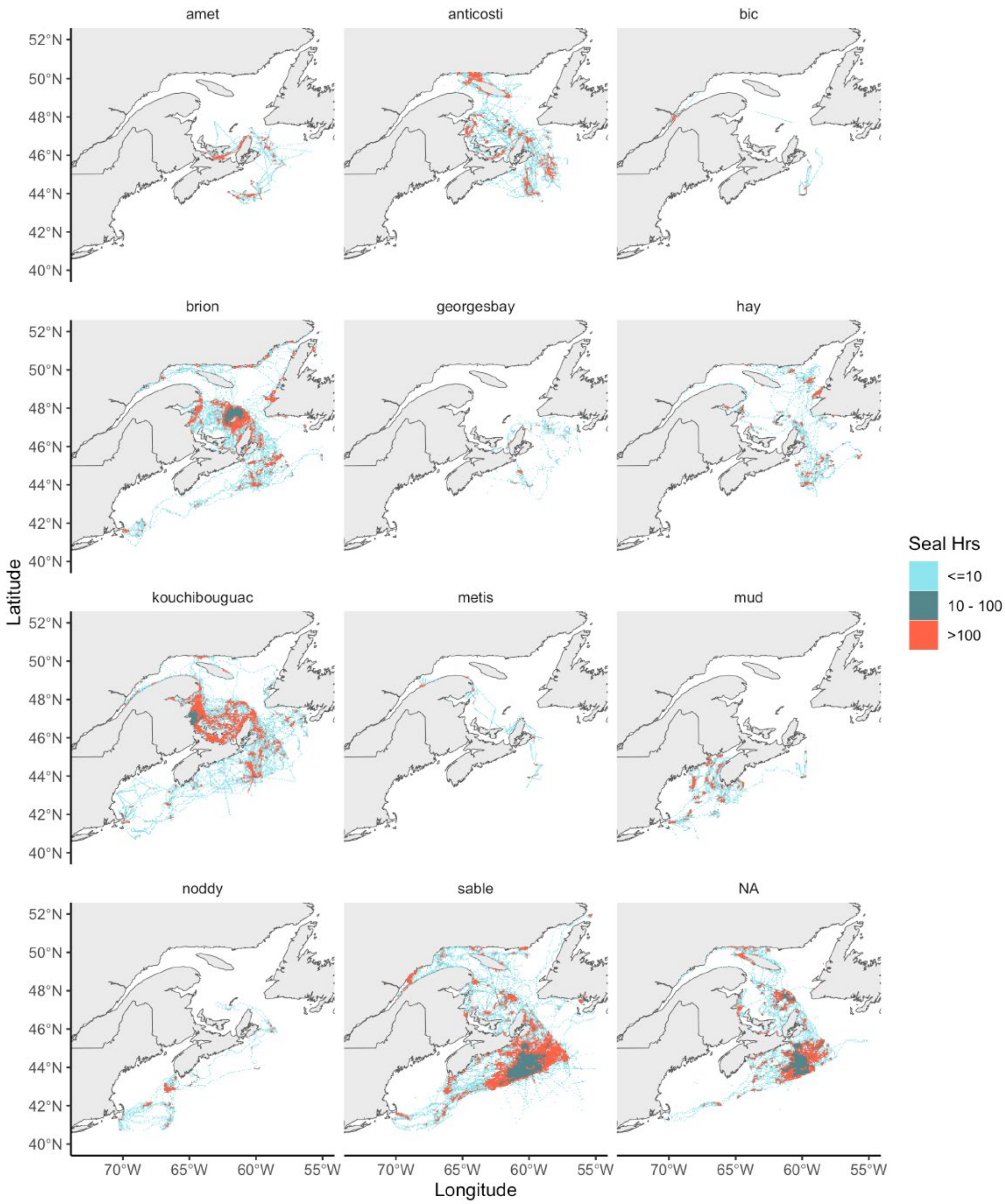

Figure 138. Summary of grey seal space use as a function of the tagging location and regardless of season, based on telemetry of tagged individuals in studies undertaken from 1993-2018 (Kim Whoriskey et al. unpublished document). Space use is summarized as the number of hours spent at a location by tagged seals (n=378 across all tagging locations). The telemetry data were pre-processed using a state-space movement model to filter-out unexpected movement patterns attributed to measurement errors.

10 APPENDIX A. COLLABORATORS 2019–2022

The following collaborators have been involved in work relevant to the assessment of Atlantic cod in the northern Gulf of St. Lawrence.

Industry partners

The sentinel projects and those from the FSCP Program could not have moved forward without the significant contribution of our industry partners:

Organization	Team
ACPG	Claudio Bernatchez, Marcel Denis and Samantha Bois
LNSFA	Frank Collier, Julie Monger, Maureen Collier and Paul Nadeau
Biorex	France Henry and Gabrielle Chapados
FFAW	Erin Carruthers, Jackie Baker, Jason Spingle, Monty Way and Myra Swyers

On the water, the captains and their crews assigned to the work contributed enormously to the various projects through their knowledge of the resource:

Field work	Captains
CRP	Brian Vautier and Jason Spence
FSCP	Jean Savage, Jean-Richard Joncas and Marty Etheridge
Sentinel - fixed gear	Barry Hart, Bernard Barter, Carl Bennett, Carl Hedderson, Colby Cullihall, Curtis Stubbert, Dennis Keats, Douglas Ryland, Dwight Anderson, Ian Anderson, Irené Marcoux, Jean-Yves Mercier, John C. Hardy, Joseph Brake, Kevin Hardy, Lester Combdon, Marty Etheridge, Norman Keats, Peter Francis, Randy Anderson, Randy Gould, Randy woodward, Steven Stagg, Troy Hardy and Wilfred Munden
Sentinel - mobile gear	Clément Samuel, Dan Genge, Jean-Pierre Élément, Leonard Warren, Marcel Roy, Martin Élément, Murray Lavers, Pierre-Luc Dupuis, Rémy Élément and Samuel Normand

DFO Colleagues

Finally, several DFO colleagues contributed data that were used in this stock assessment. By type of activity, these colleagues are:

Activity	Team
Commercial sampling	Alain Carpentier, André Chevrier, Benoît Chartier, Bernard Chouinard, Carole Turbide, Chantal Méthot, Denis Bernier, Jerry Lavers, Kloé Chagnon-Taillon, Marie-Claude Cormier, Marie-Hélène Armaly-St-Gelais, Michelle Langford, Mona Rochette, Renée Morneau, Samuel Naud, Sophie Boudreau, Suzie Jomphe, Sylvain Hurtubise, Terry Beaudoin and Yvon Dufresne
DFO August survey	Alain Carpentier, Andrew Smith, Anthony Ouellet, Bernard Chouinard, Brian Boivin, Camille Aubé, Caroline Chavarria, Caroline Senay, Chantal Méthot, Charlotte Gauthier, Charlotte Lemerre, Christine Drouin, Claude Brassard, Claude Nozères, Claudie Bonnet, David Leblanc, Denis Bernier, Félix St-Pierre, Gabriel Bardoxoglou, Geneviève Côté, Grégoire Cortial, Guillaume Mercier, Hugo Bourdages, Hugo Morin-Brassard, Hugues Benoît, Jade Paradis-Hautcoeur, Jean-François Lussier, Jean-Luc Shaw, Jean-Martin Chamberland, Johanne Gauthier, Jordan Ouellette-Plante, Joëlle Guitard, Julian Wilson, Jérôme Gagnon, Laurie Isabel, Lola Coussau, Manuelle Beaudry-Sylvestre, Marie-Claude Marquis, Marie-Maude Rondeau, Marie-Pier Boulanger, Mathieu Boudreau, Mathieu Desgagnés, Mona Rochette, Myranda Blouin, Mélanie Boudreau, Nicolas Coulombe, Pierre-Marc Scallon-Chouinard, Safouane Khamassi, Sarah Brown-Vuillemin, Shani Rousseau, Tanya Hansen, Tom Bermingham, Valérie de Carufel, Émilie Simard, Éric Parent and Éveline Sigouin

Activity	Team
FSCP	Marie-Julie Roux, Mathilde Girard-Robert, Pierre-Marc Scallon-Chouinard and Émilie Simard
Logbooks	Marty Snooks
Resource management	Magalie Hardy and Shelley Dwyer
Winter survey	Bruno Comeau, Caroline Chavarria, Caroline Senay, François Turcotte, Jean-François Lussier, Jean-Patrick Bourbonnière, Joeleen Savoie, Jordan Ouellette-Plante, Marie-Claude Marquis, Marie-France Robichaud, Marie-Maude Rondeau, Pierre-Marc Scallon-Chouinard and Émilie Simard

To all, a huge thank you!

11 APPENDIX B. SUPPLEMENTAL FIGURES

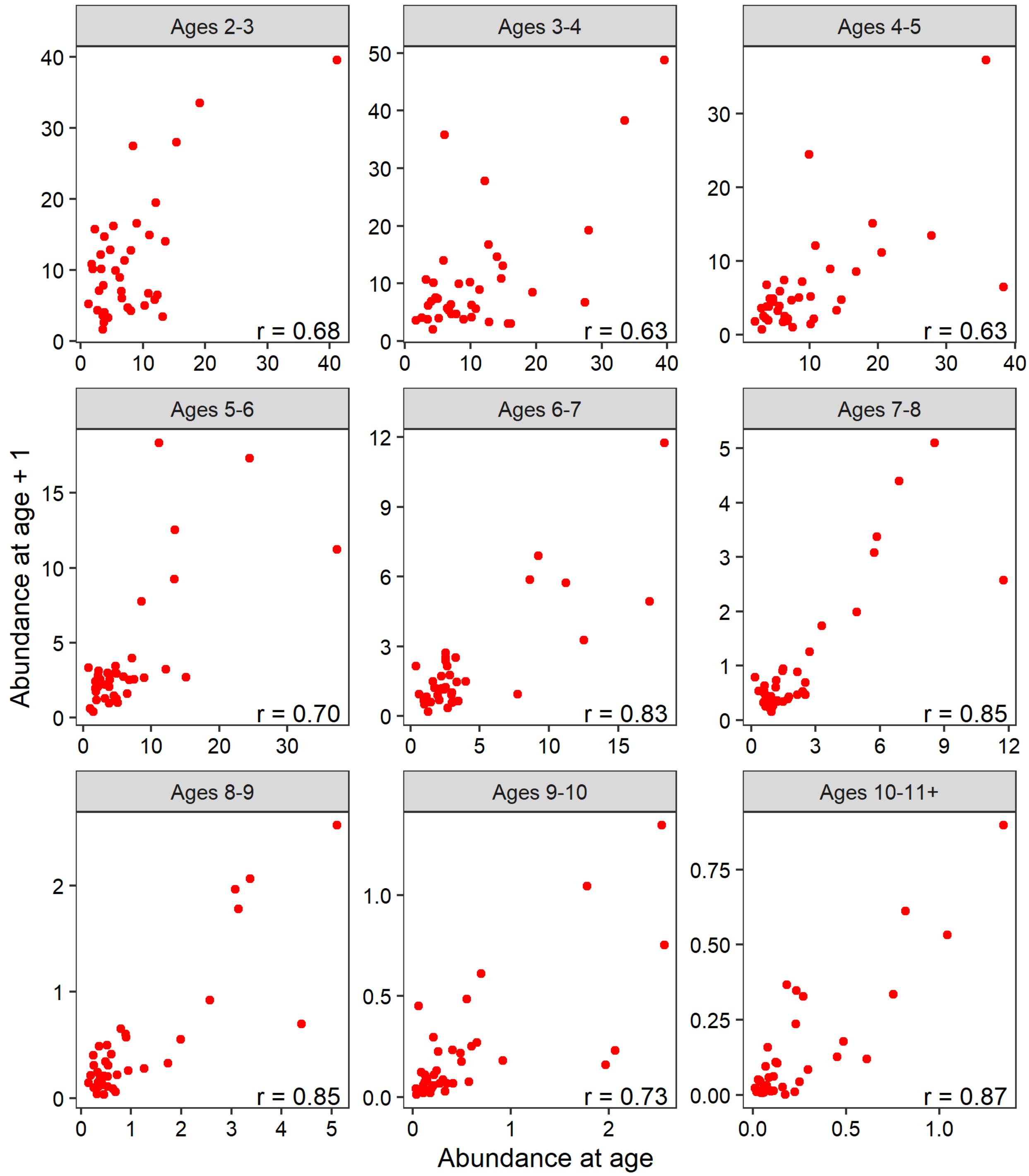

Figure A1. Age-specific abundance of cohorts at a given age and year, as a function of their abundance one year later in the DFO August survey, for 1984-2022. The correlation between the two sets of estimates is indicated in each panel.

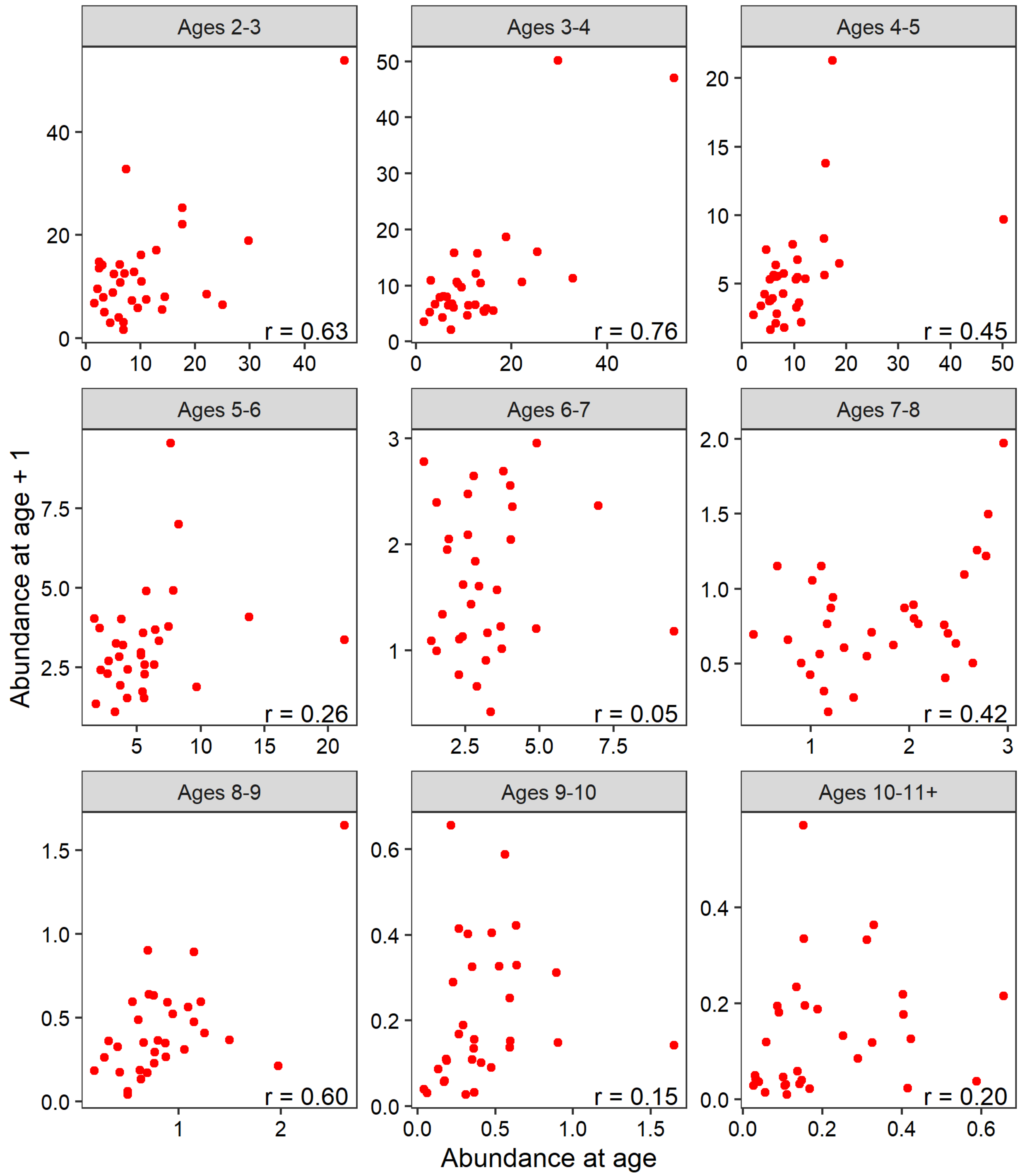

Figure A2. Age-specific abundance of cohorts at a given age and year, as a function of their abundance one year later in the DFO August survey, for 1990-2022. The correlation between the two sets of estimates is indicated in each panel.

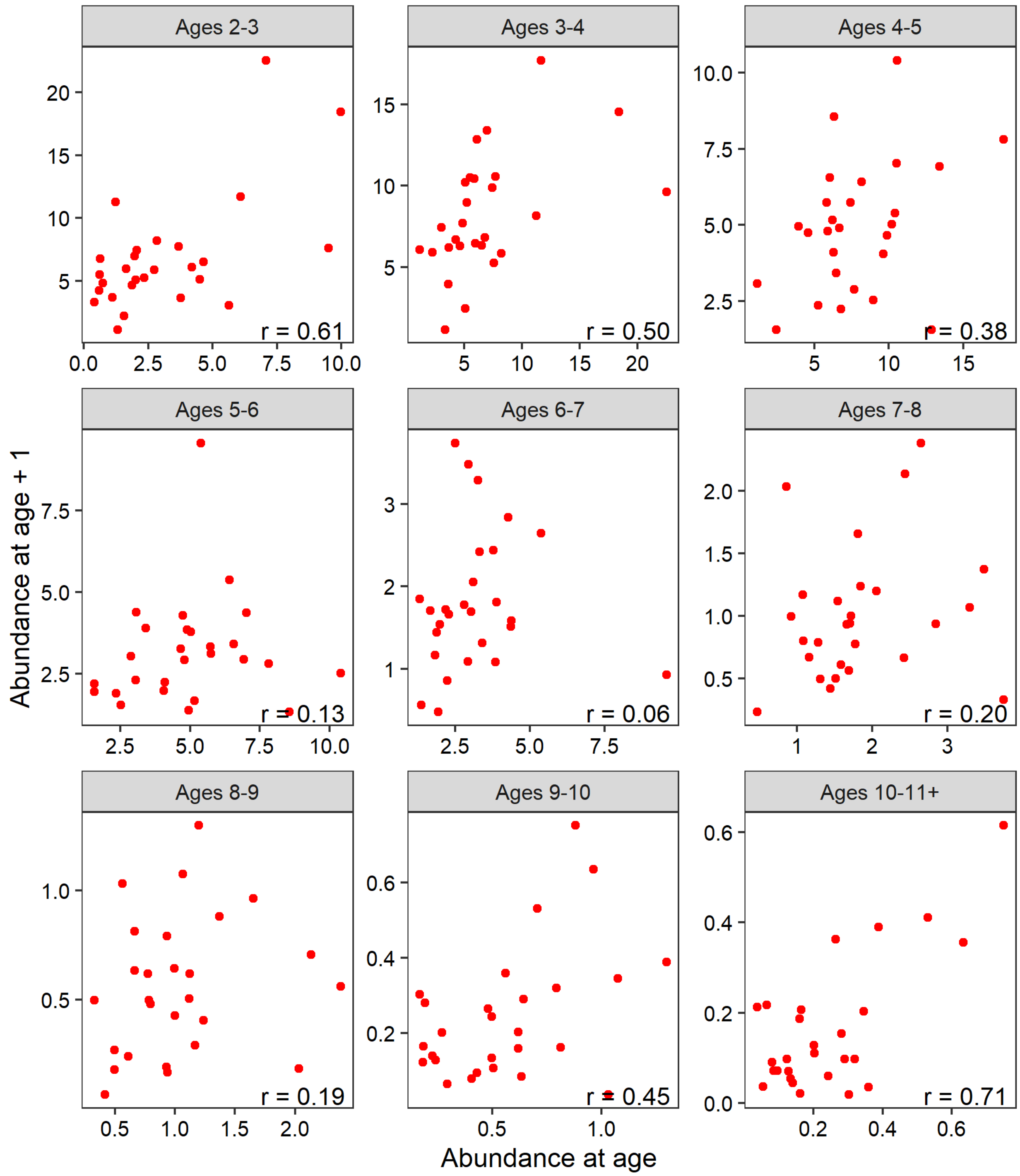

Figure A3. Age-specific abundance of cohorts at a given age and year, as a function of their abundance one year later in the sentinel mobile gear survey, for 1995-2022. The correlation between the two sets of estimates is indicated in each panel.

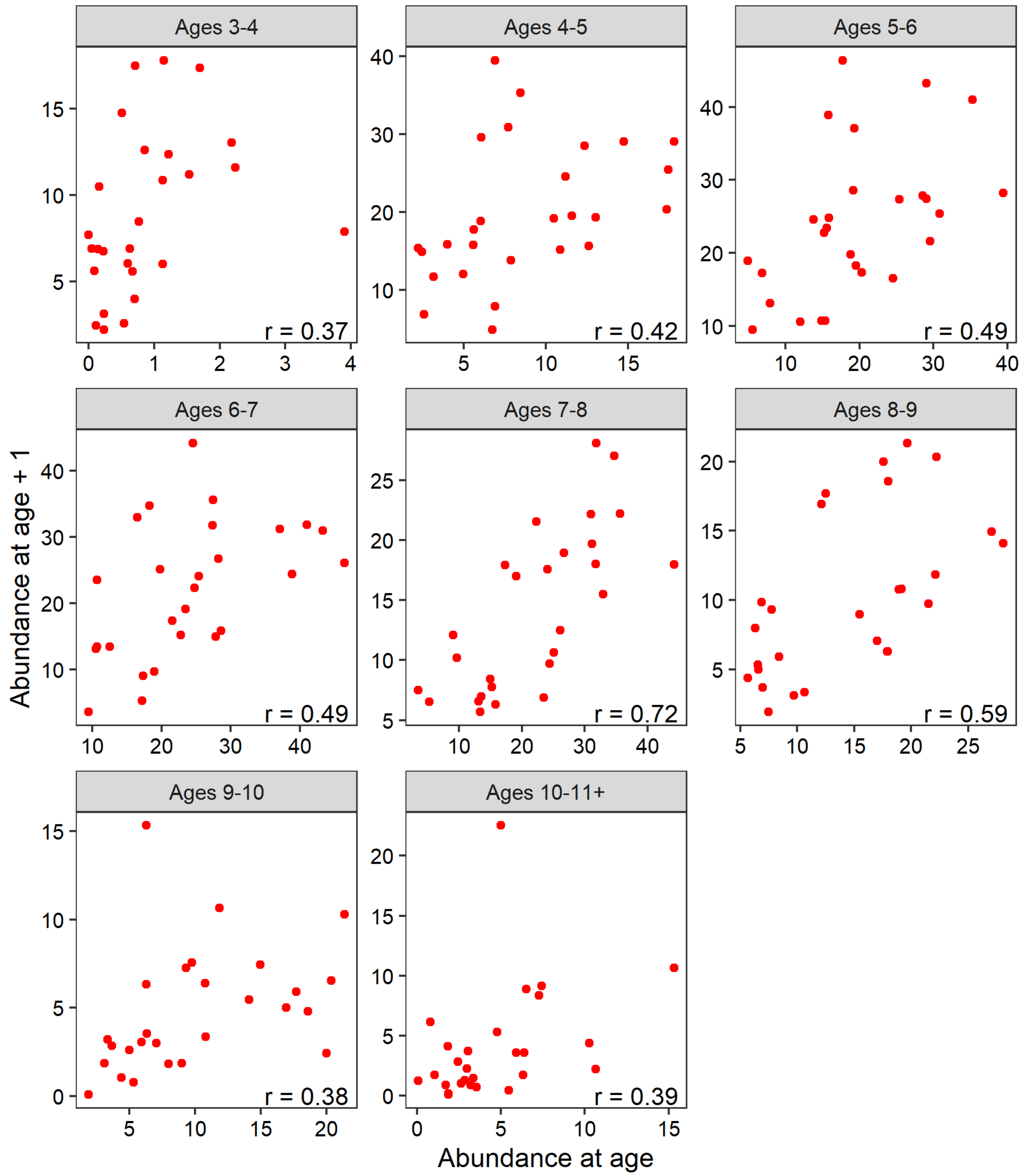

Figure A4. Age-specific abundance of cohorts at a given age and year, as a function of their abundance one year later in the sentinel longline survey (summer index), for 1995-2022. The correlation between the two sets of estimates is indicated in each panel.

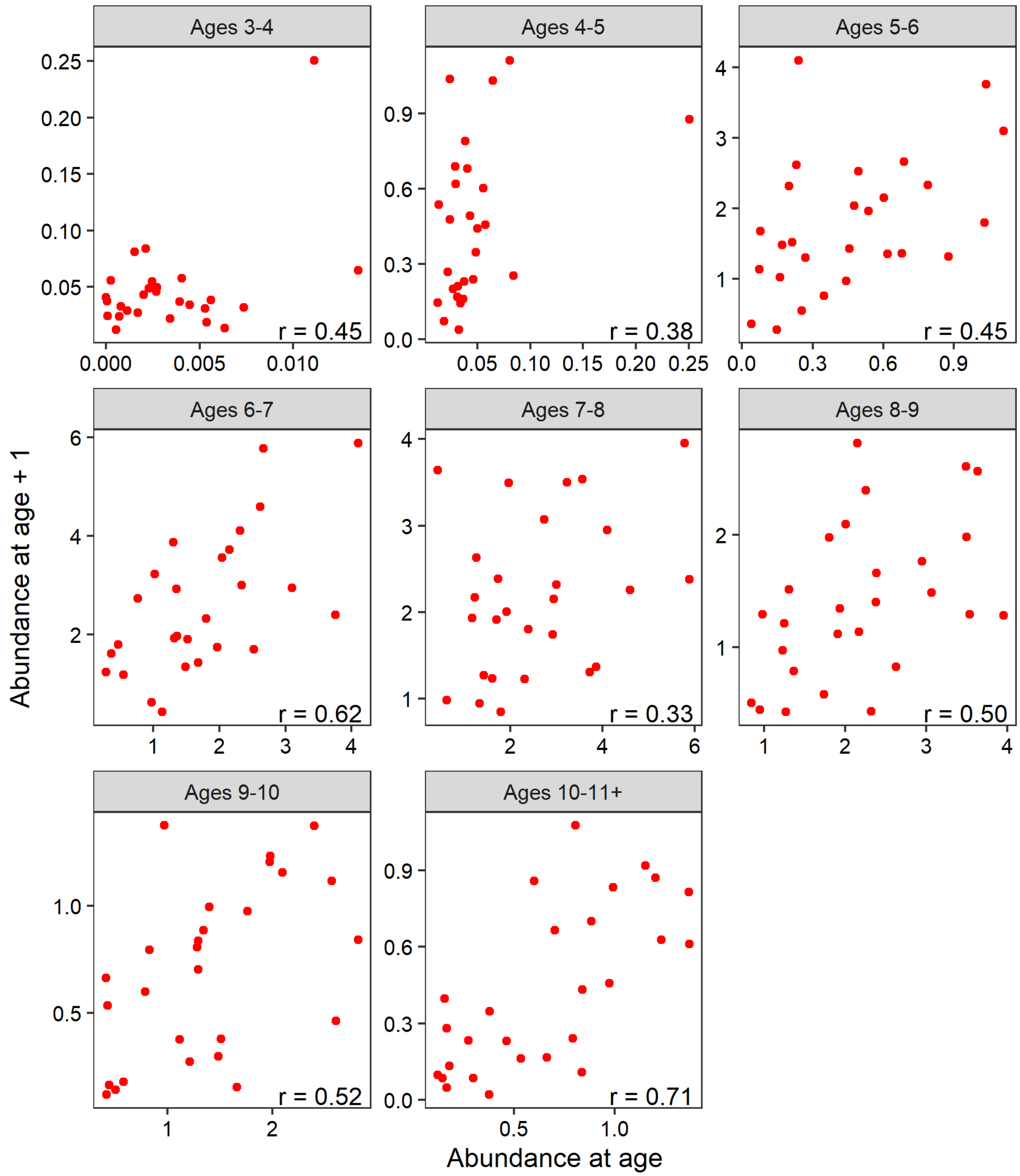

Figure A5. Age-specific abundance of cohorts at a given age and year, as a function of their abundance one year later in the sentinel gillnet survey, for 1995-2022. The correlation between the two sets of estimates is indicated in each panel.

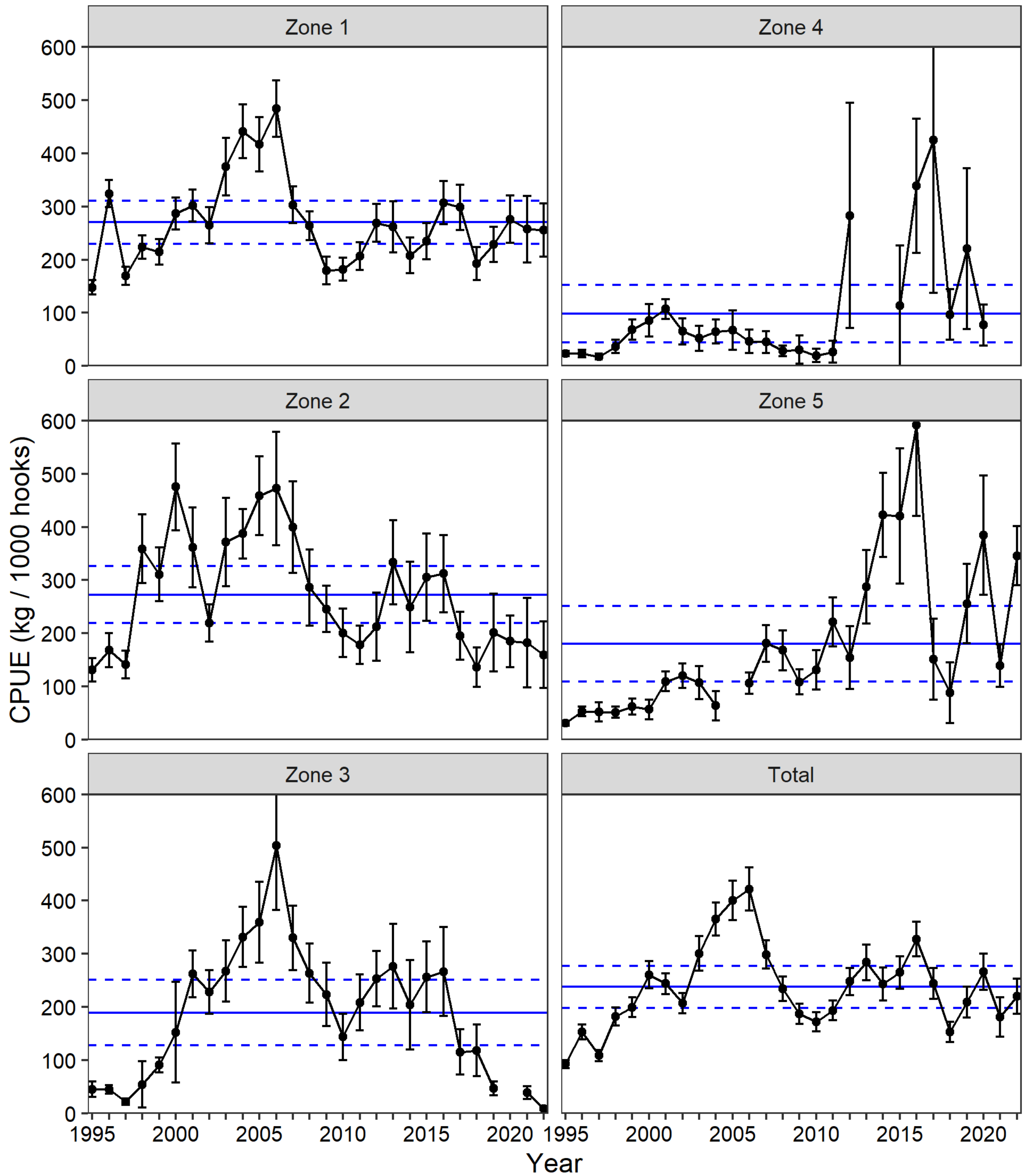

Figure A6. sentinel longline survey CPUE (average ± 95% CI) from 1995 to 2022, by fishing zone. The solid horizontal line represents the 1995-2022 average and the hatched lines ± ½ standard deviation.

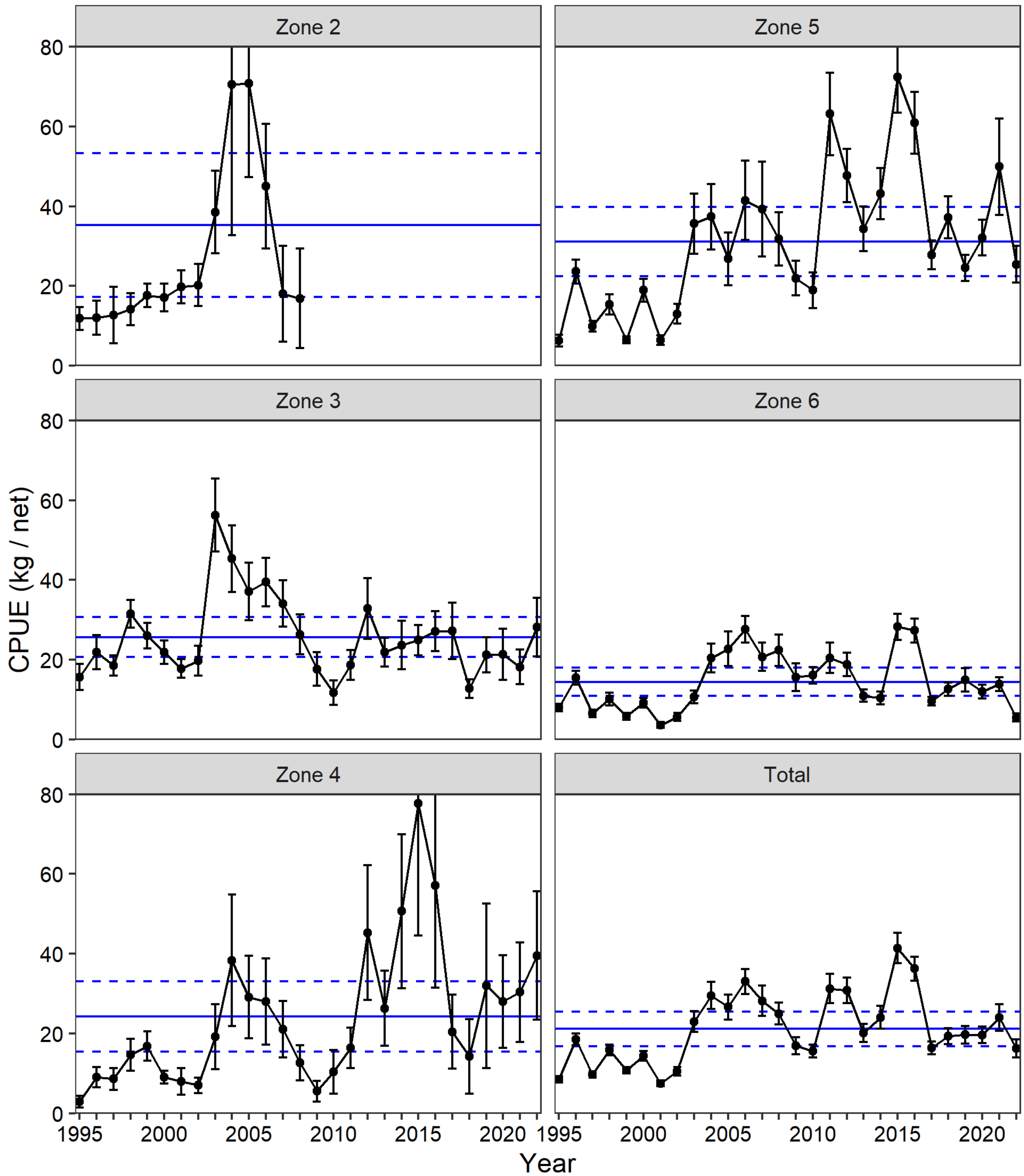

Figure A7. sentinel gillnet survey CPUE (average ± 95% CI) from 1995 to 2022, by fishing zone. The solid horizontal line represents the 1995-2022 average and the hatched lines ± ½ standard deviation.