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Sentinel Surveys 1995-2020 – Catch rates and biological information on Atlantic Cod (*Gadus morhua*) in NAFO Divisions 2J3KL

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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

Catch rates and biological information of Atlantic Cod (*Gadus morhua*) from the Sentinel gillnet and linetrawl surveys in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 2J3KL are updated for 2020. Catch rates for all gears were considerably variable among communities. Catch rates were relatively low and stable in most communities from the North stratum prior to 2005. In contrast, catch rates from the communities located in the South stratum were higher at the beginning of the time-series, and then declined by ten-fold in the mid 2000s. In the Central stratum, catch rates for most communities remained relatively high throughout the time-series. Catch rates increased steadily in communities from the North stratum since the mid 2000s and were relatively high thereafter but remained stable at low levels in the communities from the South stratum during the same period. Similar patterns were observed in catch rates from the small mesh gillnet (all strata) and linetrawl (Central and South strata) surveys.

Standardized age-disaggregated catch rate for large mesh gillnet was higher at the beginning of the time-series, peaking in 1998 and dominated by 5–8 year-old fish. Catch rates declined rapidly to the lowest estimate in 2002, then increased during most of the 2003–14 period, before declining once more in the following years. In the case of small mesh gillnet (experimental sites), catch rate declined from 1996 to 2001, then fluctuated during 2002–16, before declining by 50% or more in 2017–20. Most fish caught were 3–7 year-old until 2015, but the contribution of younger year-classes, notably 3 and 4 year-old fish, was reduced thereafter.

Large mesh gillnet and linetrawl surveys captured larger fish from specific size ranges, whereas the small mesh gillnet survey retained small and large fish from multiple length-classes. Indices of physiological condition for both male and female cod (Fulton's condition factor, Hepatosomatic Index, and Gonadosomatic Index) varied seasonally and annually.

Total removals (control plus experimental sites, all gears combined) of Atlantic Cod caught in Divs. 2J3KL Sentinel surveys (1995–2020) peaked at 388 t in 1998, declined to 92 t in 2003, reached 270 t annually over 2012–15, and then declined thereafter, reaching 71 t in 2020. Several fish species were recorded as Sentinel bycatch in 2005–20, American Plaice and Winter Flounder were the most common in large mesh gillnet survey.

INTRODUCTION

The Sentinel survey for Atlantic Cod (*Gadus morhua*) has been conducted in NAFO Divs. 2J3KL since 1995. Sentinel survey data are collected by trained fish harvesters at various inshore sites along the East and Northeast coasts of Newfoundland, and the South coast of Labrador. The goals of the Sentinel survey are to develop indices of relative abundance (i.e. catch rates) to be used in resource assessments; to incorporate inshore fish harvesters' knowledge in the resource assessment process; to evaluate inter-annual variability in resource distribution in inshore areas; to collect information on key biological parameters used in stock assessments (i.e. fish length, sex, maturity stage, and otoliths to determine age), and to collect biological samples for genetic, physiological, and toxicological analyses, and stomach contents for food and feeding studies.

In the present assessment, we review the Sentinel survey's data from 1995 to 2020. The 2021 survey was ongoing at the time of the present assessment; its data will be reviewed in subsequent years.

MATERIAL AND METHODS

Fish harvesters operating between Black Tickle and Point Lance have participated in the Sentinel survey in NAFO Divs. 2J3KL since 1995 (Fig. 1). The surveyed area was subdivided into three inshore strata after 2005: North (including NAFO Unit Areas 2Jm, 3Ka, 3Kd); Central (3Kh, 3Ki, 3Lb); and South (3Lf, 3Lj, 3Lq).

Participants in the Sentinel surveys were trained in scientific sampling methods and equipment, and in the principles of resource assessment. Sentinel harvesters fished one control site and one experimental site. The location of the control site was fixed and based on historical fishing areas and gear types, while the location of the experimental site changed but only within a designated area. During each fishing day, up to half of the fishing gear was deployed at the control site, and the remaining gear was deployed at the experimental site at the discretion of Sentinel harvesters. Sentinel surveys were conducted in summer and fall in all years, coinciding with traditional fishing times in the study area.

In general gillnets and linetrawls were used, although cod traps were periodically employed in 1998–2002. Sentinel harvesters fishing with large mesh gillnets (5½ inch mesh size) deployed a maximum of six 50-fathom monofilament nets (rigged two or three to a fleet), and up to three fleets per fishing day. Sentinel harvesters fishing with linetrawls fished two tubs of baited hooks (approximately 500 hooks per tub) per fishing day. In addition, each harvester deployed one small mesh gillnet (3¼ inch mesh size) at selected sites for a minimum of one day a week.

Set location (latitude and longitude), start and soak times, bycatch of fish and invertebrates species, and environmental parameters (wind direction and speed, percent cloud cover, tidal conditions, water salinity and temperature) were recorded for each fishing site. Atlantic Cod and bycatch fish species caught using each gear type under each condition (i.e., control and experimental sites) were kept separate and sampled on land. Each catch was sorted by species, and individual fish length (cm), sex, and the total number of individuals were recorded. Atlantic Cod otoliths were collected using a length-stratified protocol, and up to 100 whole specimens were frozen bi-weekly and transported to the Fisheries and Oceans Canada (DFO) Northwest Atlantic Fisheries Center (NAFC, St. John's, NL) for detailed biological measurements. This included total length (cm), gutted weight (g), and liver and gonad weights (g). Total annual removal (t) of Atlantic Cod from Sentinel surveys (control and experimental

sites combined) was calculated by applying a standard weight-length relationship to the length data.

INDICES OF PHYSIOLOGICAL CONDITION

Body weight (gutted), liver weight and gonad weight were used to calculate three indices reflective of the physiological condition of individual Atlantic Cod (Lambert and Dutil 1997, Mello and Rose 2005): Fulton's condition factor (K); Hepatosomatic Index (HSI); and Gonadosomatic Index (GSI), respectively.

$K_i = (w_i / l_i^3)$

$HSI_i = ((h_i / w_i) \times 100)$

$GSI_i = ((g_i / w_i) \times 100)$

where w_i is gutted weight (g), l_i is total length (cm), h_i is liver weight (g), and g_i is gonad weight (g) of cod *i*.

SENTINEL CATCH RATES

Catch rates for gillnet and linetrawl were estimated for each fishing day and fishing community as the number of fish per gillnet, and number of fish per 1,000 hooks, respectively. Catch weight per unit effort was not estimated, because weight scales were not available to all Sentinel harvesters over the years.

STANDARDIZED SENTINEL CATCH RATES

Age-aggregated and age-disaggregated standardized catch rates were estimated for large and small mesh gillnet surveys, but data were insufficient to do so for the linetrawl survey. Moreover, the 2020 aging data associated with the detailed biological analysis were not available (due to work restrictions at NAFC imposed by the COVID-19 pandemic), except for the aging data estimated from otoliths collected by Sentinel harvesters. Accordingly, the 2020 estimates of Sentinel standardized indices were calculated using a mixture of 2019 (i.e., aging data associated with the otolith and weight analysis) and 2020 aging data (i.e., aging data associated with the otolith analysis only).

Sentinel Catch per Unit Effort (CPUE) from June to November were standardized using Generalized Linear Models (GLM; McCullagh and Nelder 1989) to remove the effects of site selection and season. In addition, only gillnets with soak times of 12–32 hours and linetrawls with soak times of 24 hours or less were used in this analysis. Zero catches were generated for ages not observed in a set, as sets with effort but no catch were considered valid input to the model. Poisson models with a logarithmic link were fitted with the variables *Month* and *Age* as nested effects: *Fishing Site* was nested within *Month*, and *Year* was nested within *Age*. The generic form of the age-disaggregated model is:

CPUE = Month (Fishing Site) x Age (Year) + Error

and the age-aggregated model:

CPUE = Month (Fishing Site) x Year + Error

Overall model fit was examined using the statistical significance of the effects included, and the distribution of residuals.

RESULTS

In 1995–2020, the annual number of fishing enterprises who participated in the Sentinel survey in the North, Central, and South strata respectively ranged from 10–16, 15–28, and 6–18 for large mesh gillnet; 1–13, 2–15, and 2–6 for small mesh gillnet; and 0–11, 1–20, and 1–17 for linetrawl. However, the number of enterprises who participated in the program has decreased since 2002, notably for linetrawl fishing (Fig. 2).

The annual number of fishing sets in the North, Central, and South strata respectively ranged from 295–911, 473–1,476, and 110–803 for large mesh gillnet; 4–206, 18–160, and 5–63 for small mesh gillnet; and 0–228, 7–709, and 8–522 for linetrawl (Fig. 3). The number of large mesh gillnet sets increased between 1995 and the early 2000s, reaching a time-series high in 2000–01, before declining to the lowest value in 2020 (all strata). The number of small mesh gillnet sets peaked in 2001 (North) and 2004 (Central) and have been in decline since; the number of small mesh gillnet sets varied without trend in the South stratum. The number of linetrawl sets were greatest in 1995 (Central and South) and 1996 (North), but have been in decline since, dropping to the lowest values in 2020 (all strata).

Most Atlantic Cod were caught in the Central stratum by large mesh gillnets, followed by small mesh gillnets and then by linetrawls (except in 1995–98, when linetrawl catches in the Central and South strata surpassed small mesh gillnets) (Fig. 4). The number of fish caught by large mesh gillnets in the Central and South strata increased from 18,000 to 62,000, and from 10,000 to 56,000 between 1995 and 1998, respectively; the number of fish caught then declined by three and six-fold in the early 2000s in those two strata. This decline reversed in the Central stratum; catches increased annually and were above 50,000 fish during 2007–15, before declining in recent years to 20,000 fish in 2020. In contrast, catches in the South stratum continued to decline after 2005, reaching its lowest value in 2020 (480 fish). In the North stratum, annual catches were initially low (<10,000 fish) until 2004, but increased almost every year until 2015, when catches reached 30,000 fish, before declining in recent years. Small mesh gillnet catches were less variable in all three strata and typically ranged from 4,000 to 5,000 fish annually in the Central stratum, 2,000 to 3,000 fish in the North stratum, and 1,000 fish or less in the South stratum. Linetrawl catches were relatively high until 1998, ranging from 30,000 to 45,000 fish annually in the Central stratum, and 18,000 to 25,000 in the South stratum. Catches have since declined by ten-fold; catch in the North stratum averaged 2,700 fish annually between 1995 and 2001.

The percentage of large mesh gillnet sets with no Atlantic Cod ranged from 2% to 20% in the Central and South strata until 2006, and between 41% and 59% in the North stratum until 2004. From 2007 onwards this proportion increased during most years in the South stratum, and reached 60% in 2020 (Fig. 5). In the Central stratum the percentage of sets with no catch remained below 10% annually, except in 2020 (14%). The percentage of sets with no catch declined to 24% in the North stratum in 2005, and ranged between 18% and 37% thereafter. In the case of small gillnets, less than 10% of sets in the Central stratum had no catch of Atlantic Cod, except in 2019 (16%); however, in both the North and South strata, percentages increased from 7–10% in the late 1990s to 60–72% in recent years. No trends over time in the percentage of sets with no Atlantic Cod catch were observed for linetrawl in all three strata.

SENTINEL CATCH RATES

Mean annual catch rates for all gear types were variable among communities, but were consistently higher in the Central stratum (Figs. 6–8). The mean catch rate for the large mesh gillnet survey was 5 fish/net or less for most communities in the North stratum prior to 2006, increasing from 10 to 30 fish/net or higher thereafter, notably during 2019–20 in the most

northern communities (e.g., Black Tickle, Williams Harbour). The mean catch rate for most communities in the Central stratum was 20 to 30 fish/net during 1995–99, decreasing to 10–15 fish/net in 2000–05, and then increasing by three-fold (33 to 60 fish/net); however, catch rates in most communities declined during 2019–20. Trends in catch rate in the South stratum were initially similar to those observed in the Central stratum. Catch rates ranged from 20 to 40 fish/net in 1995–99 in most communities. Catch rates decreased by two to three-fold during 2000–05 (0 to 15 fish/net) and remained largely unchanged since, with a few exceptions (notably in those communities near the boundary with the Central stratum, e.g., Carbonear, Bay de Verde), thus contrasting with the trend observed in the other two strata. In the small mesh gillnet survey, the mean catch rate fluctuated with no clear trend in most communities (all strata) and were consistently higher than those observed for the large mesh gillnet survey, ranging mostly from 20 to 30 fish/net in the North and South strata to 50 to 80 fish/net in the Central stratum. Mean catch rate for the linetrawl survey was very low (<70 fish/1,000 hooks) in the North stratum and no data were collected from 2003 onwards. Catch rate ranged from 100 to 400 fish/1,000 hooks in most communities from the Central stratum, and less than 100 fish/1,000 hooks in most communities from the South stratum. No spatial or temporal trends in catch rate are evident for the linetrawl survey throughout the study area. Moreover, only two communities from the Central stratum (Coachman's Cove and Shoe Cove), and one community from the South stratum (Foxtrap) participated in the linetrawl survey since 2015.

Time-series mean catch rates were similar among communities within each stratum and gear type, with a few exceptions (Fig. 9). In the case of the large mesh gillnet survey, catch rates from communities in the North stratum were in general less than 10 fish/net, and less than 20 fish/net in the Central and South strata; relatively higher catch rates (33 to 62 fish/net) were observed in St. Anthony (North), Happy Adventure, Bonavista, Little Catalina, and Heart's Content (Central), as well Bay de Verde and St. Shott's (South). Catch rates for the small mesh survey were higher than those from the large mesh gillnet survey (all strata) Catch rates from communities in the North stratum ranged mostly between 16 to 26 fish/net, 30 to 48 fish/net in the Central stratum and 26 to 32 fish/net in the South stratum. The highest catch rates per stratum were observed in the communities of Great Brehat (47 fish/net, North), Happy Adventure (81 fish/net, Central), and St. Shott's (45 fish/net, South). In the linetrawl survey, catch rates from communities in the Central stratum ranged mostly between 100 to 200 fish/1,000 hooks, and 100 fish/1,000 hooks in the South stratum. The highest catch rates (316 to 350 fish/1,000 hooks) were observed in Lumsden, Wesleyville, and Bonavista in the Central stratum; the two communities from the North stratum had catch rates of 16 fish/1,000 hooks or less.

Finally, the time-series mean catch rate for each survey showed declines during the mid-1990s, reaching minimum values in the early 2000s in all strata; and then either increased (large mesh gillnet, Central and North strata), continued to decline (large mesh gillnet, South strata) or fluctuated about the time-series historical mean catch rate (small mesh gillnet and linetrawl, surveys, all strata) thereafter (Fig. 10). The mean catch rate for the large mesh gillnet survey remained above the historical mean during 2007–19 and 2012–20 in the Central and North strata, respectively; mean catch rate peaked in 2014 (40 fish/net) in the Central stratum and in 2015 (31 fish/net) in the North stratum, but have declined since, reaching half of those peaks by 2020 in both cases. Mean catch rate in the South stratum peaked in 1998 (43 fish/net) but have since declined by three-fold, reaching the lowest value in the time-series in 2020 (<2 fish/net). Mean catch rate for small mesh gillnets peaked at 118 fish/net in 1996 (Central), then declined and fluctuated about the time-series' historical mean in all strata (20 fish/net, North and South; 47 fish/net, Central) after 1999. In the linetrawl survey, mean catch rates in Central and South strata fluctuated about the time-series' historical mean (193 and 100 fish/1,000 hooks, respectively), but increased to 357 fish/1,000 hooks in 2015 (Central), and 246 fish/1,000 hooks

(South) in 2017, prior to declining in both areas in 2018–20. The mean linetrawl catch rate in the North stratum was the lowest among all strata (2 to 70 fish/1,000 hooks), and only available for 1995–2002.

Confidence intervals of mean catch rate estimates for all gears, either aggregated by community or year, were generally small, with a few exceptions.

STANDARDIZED SENTINEL CATCH RATES

Both age-disaggregated and age-aggregated models for standardized catch rate of Atlantic Cod from the large mesh gillnet survey (control and experiments sites), as well as from the small mesh gillnet survey (experimental sites) provided a good fit to the data. The nested effects *Month* (*Fishing Site*) and *Age* (*Year*) in the age-disaggregated model were highly significant ($P < 0.0001$) in all cases. Likewise, the variable *Year*, and the nested effect of *Month* (*Fishing Site*) in the age-aggregated model were also highly significant in all cases. (Tables 1–2). No trends were apparent in the distribution of model residuals versus the estimated linear predictors *Year*, *Month*, *Fishing Sites*, or *Fishing Effort* (Figs. 11–13). These results suggest that overall model parameterization of standardized Sentinel survey catch rate was appropriate for both gears, and no systematic issues regarding model fit were detected. The age-disaggregated and age-aggregated models of the linetrawl survey (both sites), and of the small mesh size gillnet survey (control sites) failed the convergence diagnostics (Hessian convergence criterion), therefore the validity of the model fit was questionable and not considered in further analyses.

For the large mesh gillnet survey, the temporal trend and magnitude of change in the age-disaggregated standardized catch rate were very similar at both the control and experimental sites (Fig. 14). Catch rate was higher at the beginning of the time-series, peaking in 1998 (13 and 16 fish/net, control and experimental sites, respectively) and was dominated by 5–8 year-old fish, but declined rapidly to the lowest estimate in 2002 (3 fish/net). Catch rate increased during most of the 2003–14 period (up to 19 fish/net in 2014), prior to declining once more in the following years, reaching 11 fish/net in 2020. However, a larger proportion of the catch rate was comprised of 9–10 year-old fish in 2010–20. Several year-classes were well-represented over the time-series, notably in 2013–20, except for younger year-classes (3–5 year-old fish), which have been poorly tracked in the large mesh gillnet survey since 2016.

The temporal trend in the age-disaggregated standardized catch rate from the small mesh gillnet survey corresponded well to the trend in catch rate from the large mesh gillnet survey, however the magnitude of change over time was in general less pronounced (Fig. 15). The catch rate declined from 34 fish/net in 1996 to 15 fish/net in 2001, then fluctuated around 22 fish/net during the period 2002–11, and 28–32 fish/net in 2012–16, prior to declining by 50% or more in 2017–20. Small mesh gillnet caught mostly 3–7 year-old fish until 2015, but the contribution of younger year-classes, notably 3 and 4 year-old fish, was reduced thereafter and not well tracked in the survey, which coincided with a sharp reduction in catch rate during the same period.

Age-aggregated catch rates for the corresponding gears and sites showed patterns and values similar to those of age-disaggregated model estimates, respectively (Figs. 16–17). Confidence intervals of estimates were generally small, with a few exceptions.

BIOLOGICAL INFORMATION

Length

Length frequency distributions of Atlantic Cod from the Sentinel survey indicated that large mesh gillnet and linetrawl tended to capture larger fish from specific size ranges with few

overlapping length-classes, whereas small mesh gillnet retained small and large fish from multiple length-classes (Fig. 18). Atlantic Cod retained by large mesh gillnet and linetrawl were 16–120 cm and 16–119 cm, respectively, with modal lengths for any particular year ranging between 60–64 cm (large mesh gillnet) and 53–60 cm (linetrawl). Fish from small mesh gillnet were 17–114 cm, with bi-modal length frequencies ranging between 37–50 cm and 51–63 cm for the first and second modal-classes, respectively.

Indices of Physiological Condition

All three indices (K, HSI, GSI) that reflect the physiological condition of Atlantic Cod varied seasonally and annually (Fig. 19). Fulton's K and HSI covaried: showing minimum values in April (K) for both males and females, then peaking in October for females and November for males. HSI was minimum in April and May and peaked in August and November for females and males, respectively. The seasonal trend in GSI contrasted with those of the other two indices: peaking in March for males and June for females, and then reaching minimum values in September for males and November for females. Inter-annual trajectories in K and HSI also covaried: peaking in 1996 for both males and females, declined over the late 1990s, and fluctuated without trend until the mid-2010s; Fulton's K and HSI declined afterwards, reaching minimum values for both male and female in 2016 (HSI) and 2017 (Fulton's K). Female and male GSI increased from minimum values in 1995 and peaked in 2014, before declining until 2017; the index improved in 2018–19 for both males and females, contrasting with the trajectories of K and HIS during the same period.

It should be noted that the data used for estimating the indices of physiological condition (as well for length frequency distributions) were pooled from fish captured in all fishing communities, and that many of these communities participated in the Sentinel survey over different periods of time. Notwithstanding confidence intervals for these three indices were usually small, suggesting that the impact of such unbalanced spatio-temporal sampling scheme had limited effect on the precision of the estimated indices.

SENTINEL SURVEY REMOVALS

Total removal (control plus experimental sites, all gears combined) of Atlantic Cod caught in Divs. 2J3KL Sentinel surveys during 1995–2020 peaked at 388 t in 1998, then declined to 92 t in 2003. This trend reversed afterwards: removals reached approximately 270 t annually in 2012–15, then declined every year since, reaching 71 t in 2020 (Fig. 20).

Several fish species were recorded as Sentinel bycatch in large mesh gillnet survey during 2005–20 (Fig. 21): American Plaice (*Hippoglossoides platessoides*) and Winter Flounder (*Pseudopleuronectes americanus*) were the most common species, followed by Yellowtail Flounder (*Limanda ferruginea*) and Redfish (*Sebastes* sp.). Other species reported infrequently in the Sentinel surveys were: Witch Flounder (*Glyptocephalus cynoglossus*), Greenland Halibut (*Hippoglossus hippoglossus*) and Wolffish (*Anarhichus* sp.). Overall the amount of bycatch fish recorded during the Sentinel surveys declined by five-fold between 2005 and 2017. However, the number of bycatch fish recorded annually has been on the rise since 2018. Bycatch data are not available for the other two gears.

DISCUSSION

The large mesh gillnet Sentinel survey provided the most comprehensive coverage of NAFO Divs. 2J3KL; it corresponded to 79% of the fishing sets and 75% of the Atlantic Cod catch during 1995–2020. The analysis of temporal and spatial variability in catch rate detected shifts in relative abundance and distribution of Atlantic Cod across the study area. Catch rates were

relatively low and stable in most communities from the North stratum prior to 2005. In contrast catch rates from the communities located in the South stratum were higher at the beginning of the time-series, and then declined by ten-fold in the mid 2000s. In the Central stratum, catch rates for most communities remained relatively high throughout the time-series. Catch rates increased steadily in communities from the North stratum since the mid 2000s and were relatively higher thereafter, but remained stable at low levels in the communities from the South stratum during the same period. These estimates suggest that the center of the stock distribution (in inshore waters) was located in Div. 3K during both periods of low and high relative abundance; and that the distribution range of the stock has contracted along the southern boundary (Div. 3L), as the relative abundance declined during the first part of the time-series, and expanded towards the northern boundary (Div. 2J) during the most recent period, coinciding with a period of stock recovery.

Moreover, the trend in standardized catch rate of Atlantic Cod for large mesh gillnet (both age-disaggregated and age-aggregated models) from control sites corresponded well to the estimates from experimental sites, indicating that the observed patterns are representative of the abundance across the distributional range of this stock in inshore waters of Divs. 2J3KL during summer and fall.

Likewise, the standardized age-disaggregated catch rate for large mesh gillnet showed that most Atlantic Cod caught during the Sentinel survey was comprised of 6–9 year-old fish throughout the time-series. However, the standardized catch rate for small mesh gillnet showed a larger proportion of younger fish (≤5 year-old) during the periods of relative abundance increase (2005–07, 2012–15). The opposite was observed during periods of abundance decline (2016–20). These findings support the view that recruitment and survival of younger fish are among the main drivers of the population dynamics of Atlantic Cod in inshore areas of Divs. 2J3KL.

Of note, the estimate of catch number at age for Divs. 2J3KL Atlantic Cod derived from the DFO Multi-Species Survey (MSS) time-series indicated that most fish caught in 2016–20 were 2 to 5 year-old (unpublished data). The MSS targets mostly the offshore component of the stock during the fall season. Nevertheless, the trend in the MSS abundance index for this stock over the last 10–15 years mirrored to a large extent the Sentinel survey standardized catch rate for large mesh gillnet. These findings suggest that the data collected by the Sentinel survey for Divs. 2J3KL Atlantic Cod in inshore areas can be useful in estimating some of the most critical metrics of stock status, such as the age-structure of catch, and trends in stock abundance and distribution.

In conclusion, the Sentinel survey constitutes an independent source of information that can be readily incorporated in resource assessment of commercial fish stocks like the Divs. 2J3KL Atlantic Cod (DFO 2019, DFO 2021). It also engages stakeholders such as the inshore fish harvesters, and enables them to participate in the shared responsibility of resource conservation and sustainable exploitation.

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TABLES

Table 1. Model information and results of fitting age-disaggregated and age-aggregated standardized Sentinel catch rate of Atlantic Cod from the large mesh gillnet (5½ inch) survey, using data from control and experimental sites in Divs. 2J3KL, 1995–2020.

Class	Level	Values
Fishing Site	87	1 2 2.5 3 4 5 6 6.5 7 9 9.5 10 10.5 11 12 13 13.5 14 15 15.25 15.5 16 16.5 17 18 19 20 21 22 22.5 23 24 25 25.5 26 27 27.5 27.75 28 29 29.5 30 30.5 31 32 33 33.5 33.75 34 35 35.5 36 36.5 37 38 38.5 38.75 39 40 41 41.5 42 43 44 45 45.5 46 47 48 49 50 51 51.5 52 53 54 55 56 57 58 58.5 59 59.5 60
Month	6	6 7 8 9 10 11
Year	26	1995–2020
Age	8	3 4 5 6 7 8 9 10

LR Statistics for Type 3 Analysis

Age-disaggregated – Control Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	393	26,903	84.38	<.0001	33,161.2	<.0001
Age (Year)	207	26,903	313.43	<.0001	64,880.1	<.0001

Age-aggregated – Control Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	393	3,019	13.41	<.0001	5,269.06	<.0001
Year	25	3,019	56.47	<.0001	1,411.77	<.0001

Age-disaggregated – Experimental Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	404	27,420	70.75	<.0001	28,584.4	<.0001
Age (Year)	207	27,420	360.12	<.0001	74,545.9	<.0001

Age-aggregated – Experimental Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	404	3,074	11.62	<.0001	4,694.43	<.0001
Year	25	3,074	64.15	<.0001	1,603.87	<.0001

Table 2. Model information and results of fitting age-disaggregated and age-aggregated standardized Sentinel catch rate of Atlantic Cod from the small mesh gillnet (3 1/4 inch) survey, using data from experimental sites in Divs. 2J3KL, 1996–2020.

Class	Level	Values
Fishing Site	51	1 2 2.5 3 4 5 6 6.5 7 9 10 11 13 13.5 14 15 15.25 15.5 16 16.5 18 22 22.5 23 25 25.5 26 27 28 29 30 33 33.5 33.75 35.5 36 36.5 38 39 41 42 43 47 48 50 51 51.5 53 55 56 59
Month	6	6 7 8 9 10 11
Year	25	1996–2020
Age	9	2 3 4 5 6 7 8 9 10

LR Statistics for Type 3 Analysis

Age-disaggregated – Experimental Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	203	15,169	41.64	<.0001	8,453.04	<.0001
Age (Year)	224	15,169	114.67	<.0001	25,686.8	<.0001

Age-aggregated – Experimental Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	203	1,505	8.11	<.0001	1,646.07	<.0001
Year	24	1,505	6.72	<.0001	161.27	<.0001

FIGURES

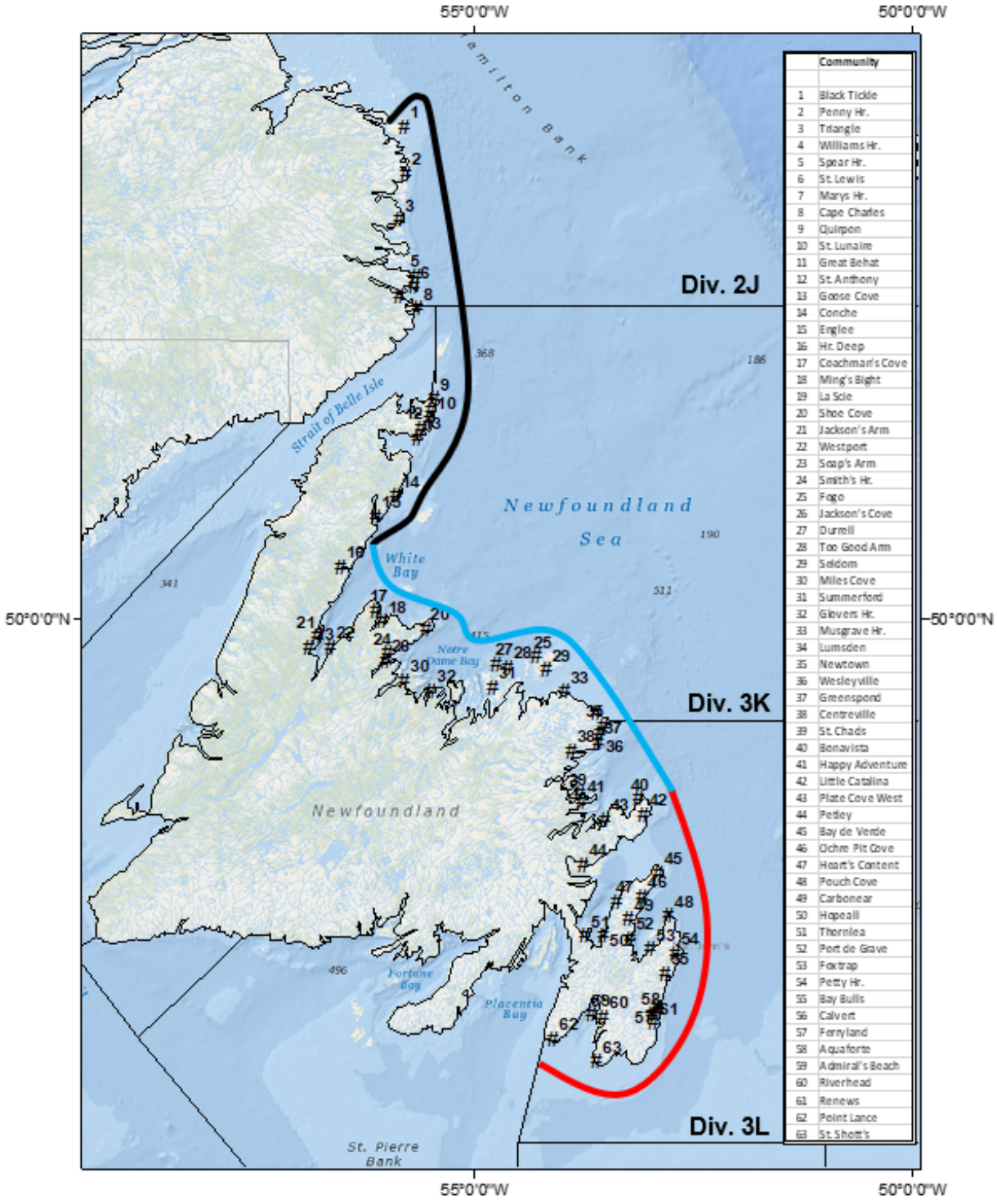


Figure 1. Map of NAFO Divs 2J3KL indicating the Sentinel survey study area and the three inshore strata used: (1) North (NAFO unit areas 2Jm, 3Ka and 3Kd, black line), (2) Central (3Kh, 3Ki, and 3Lb, blue line), and (3) South (3Lf, 3Lj, and 3Lq, red line), 1995–2020.

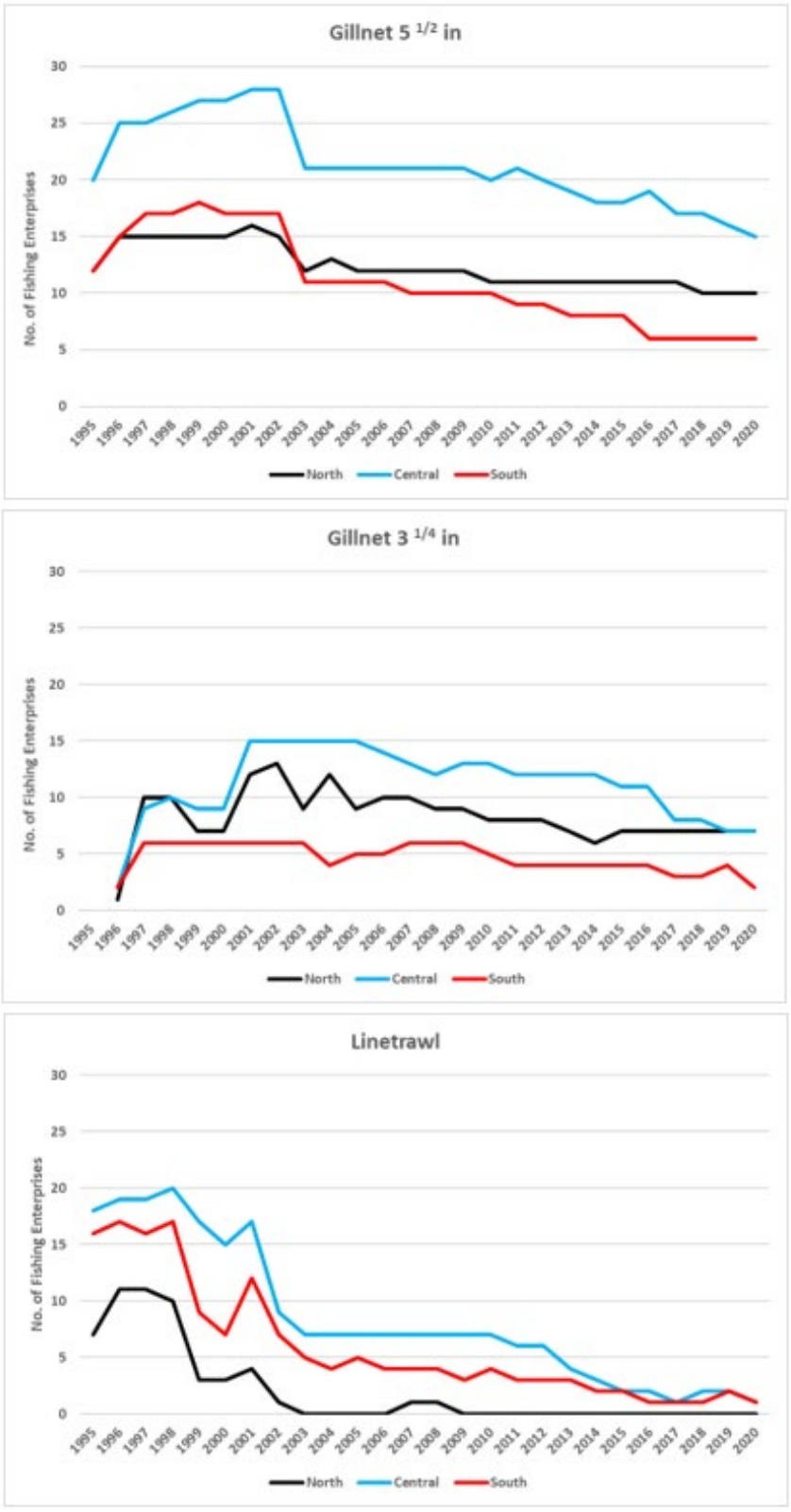


Figure 2. Annual number of fishing enterprises participation in the Sentinel survey by gear type and stratum (North, Central and South) in NAFO Divs. 2J3KL, 1995–2020.

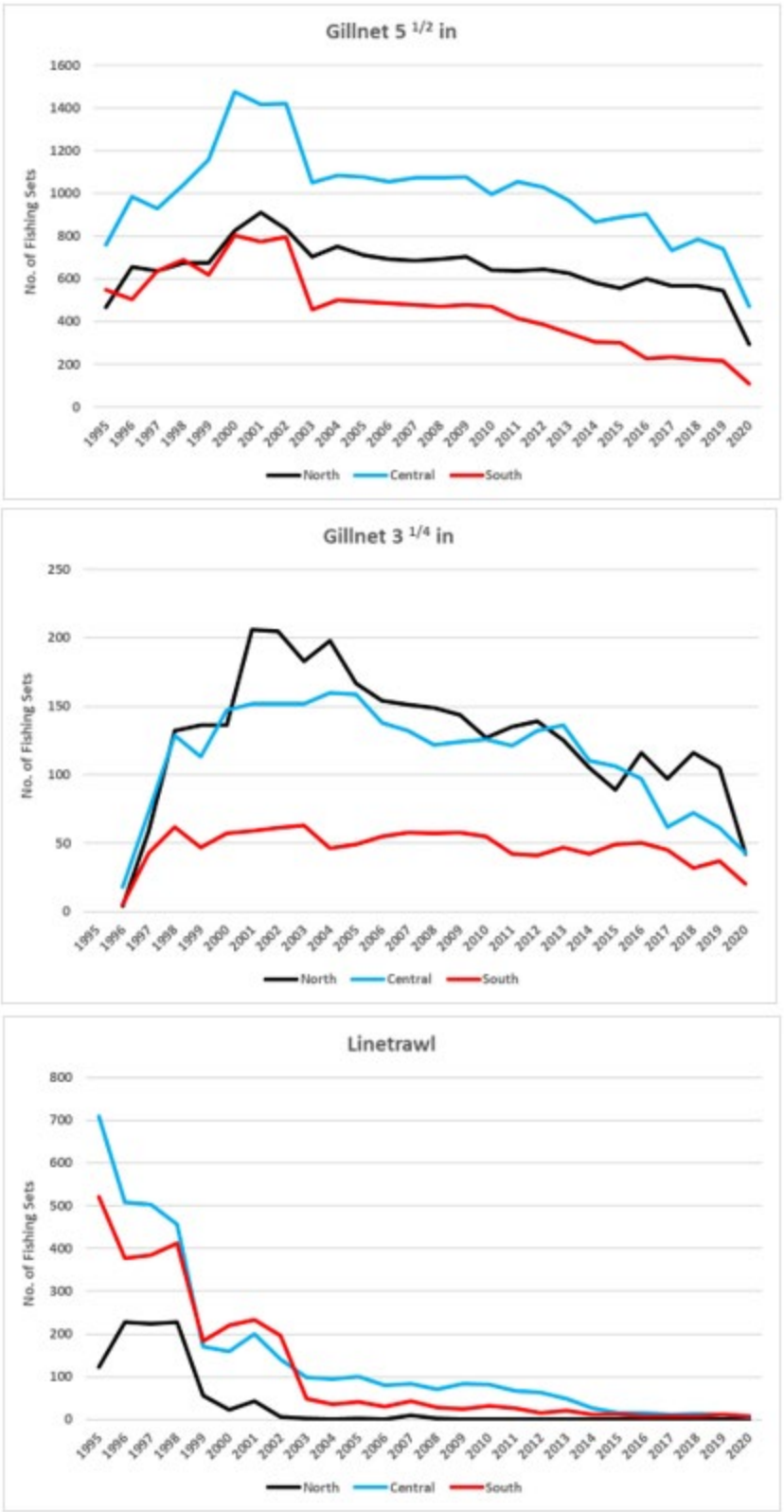


Figure 3. Annual number of fishing sets in the Sentinel survey by gear type and stratum (North, Central and South) in NAFO Divs. 2J3KL, 1995–2020.

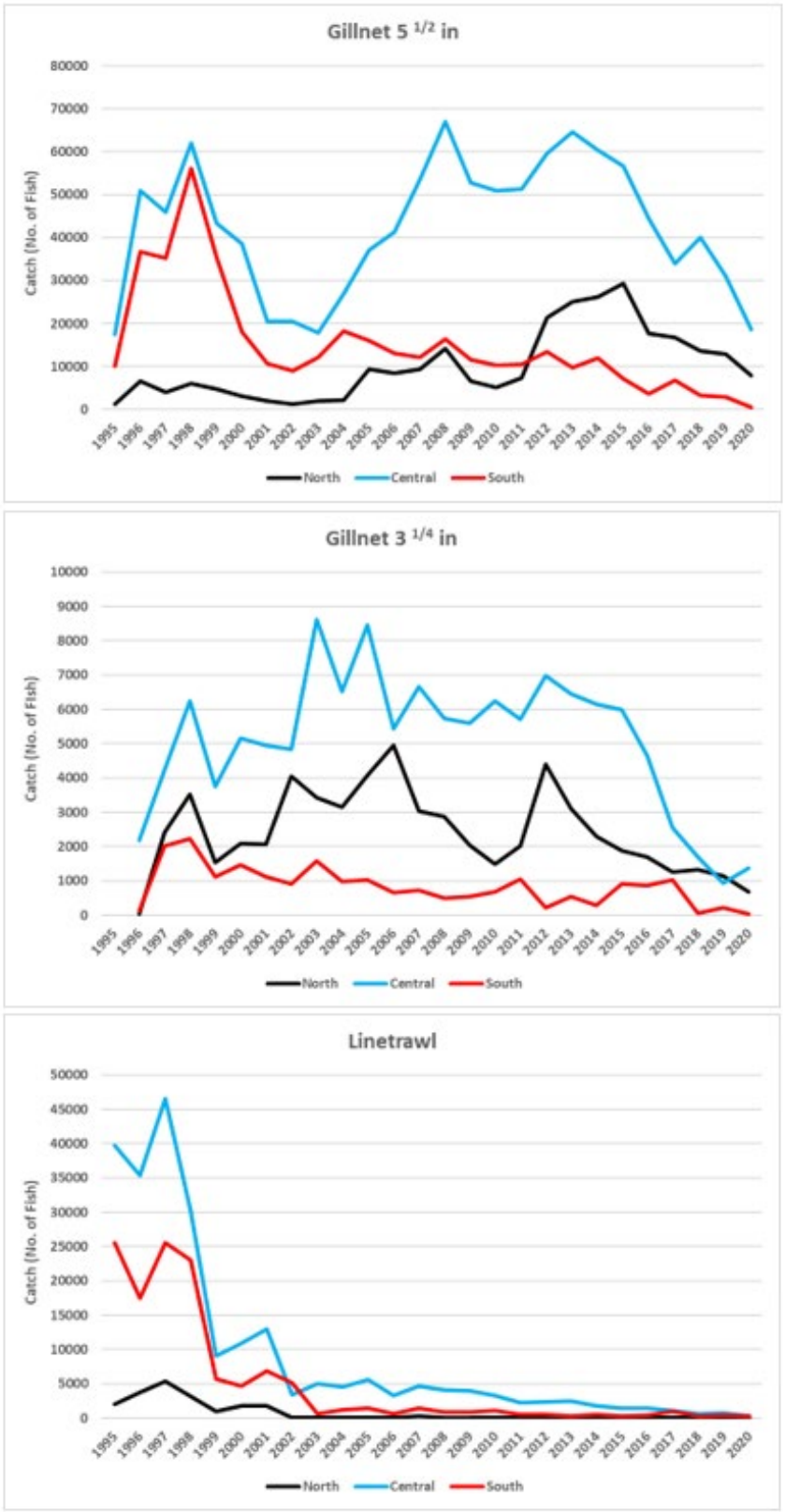


Figure 4. Annual number of Atlantic Cod caught in the Sentinel survey by gear type and stratum (North, Central and South) in NAFO Divs. 2J3KL, 1995–2020.

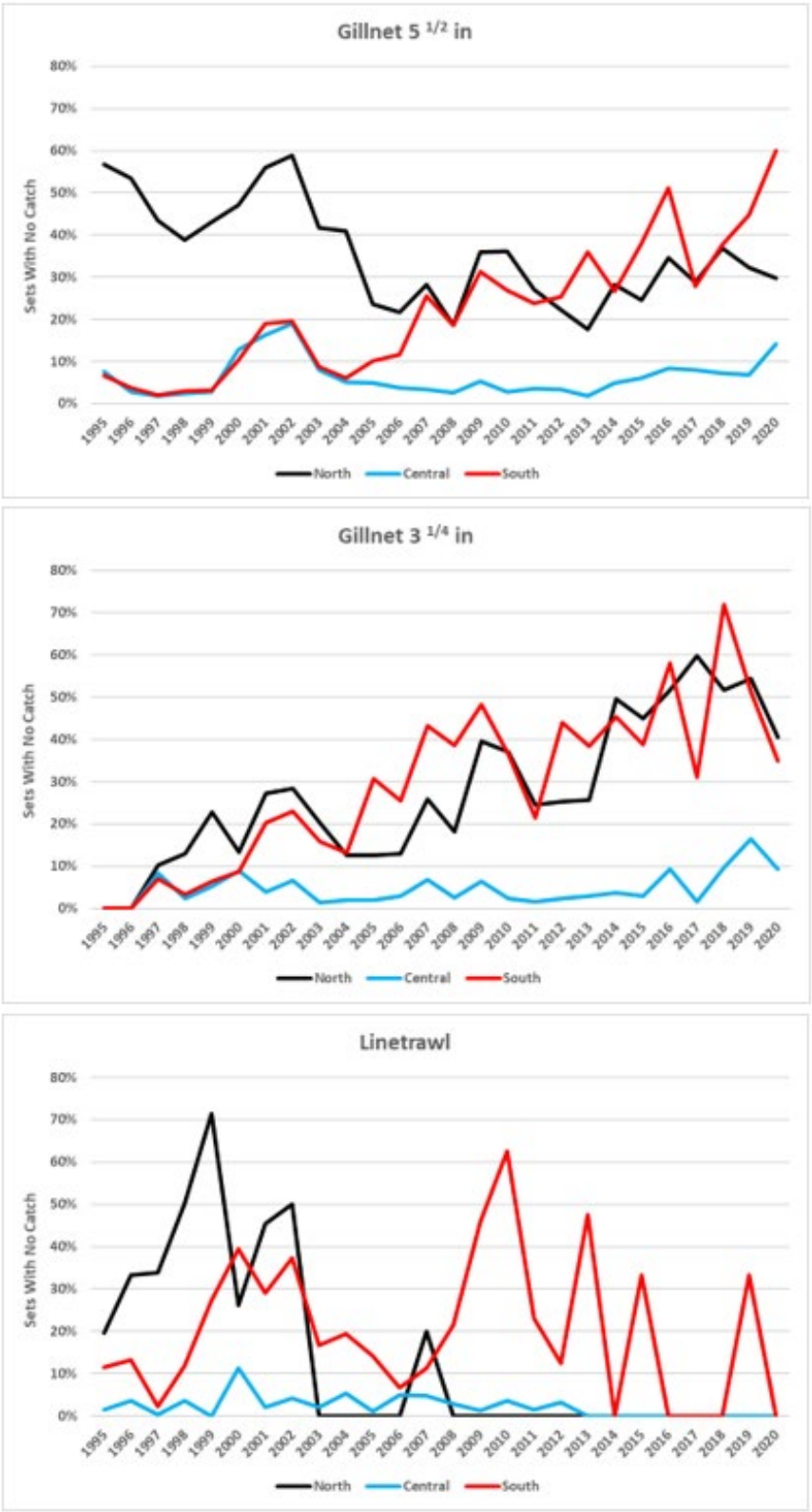


Figure 5. Percentage of sets with no catch of Atlantic Cod by gear type and stratum (North, Central and South) in NAFO Divs. 2J3KL, 1995–2020.

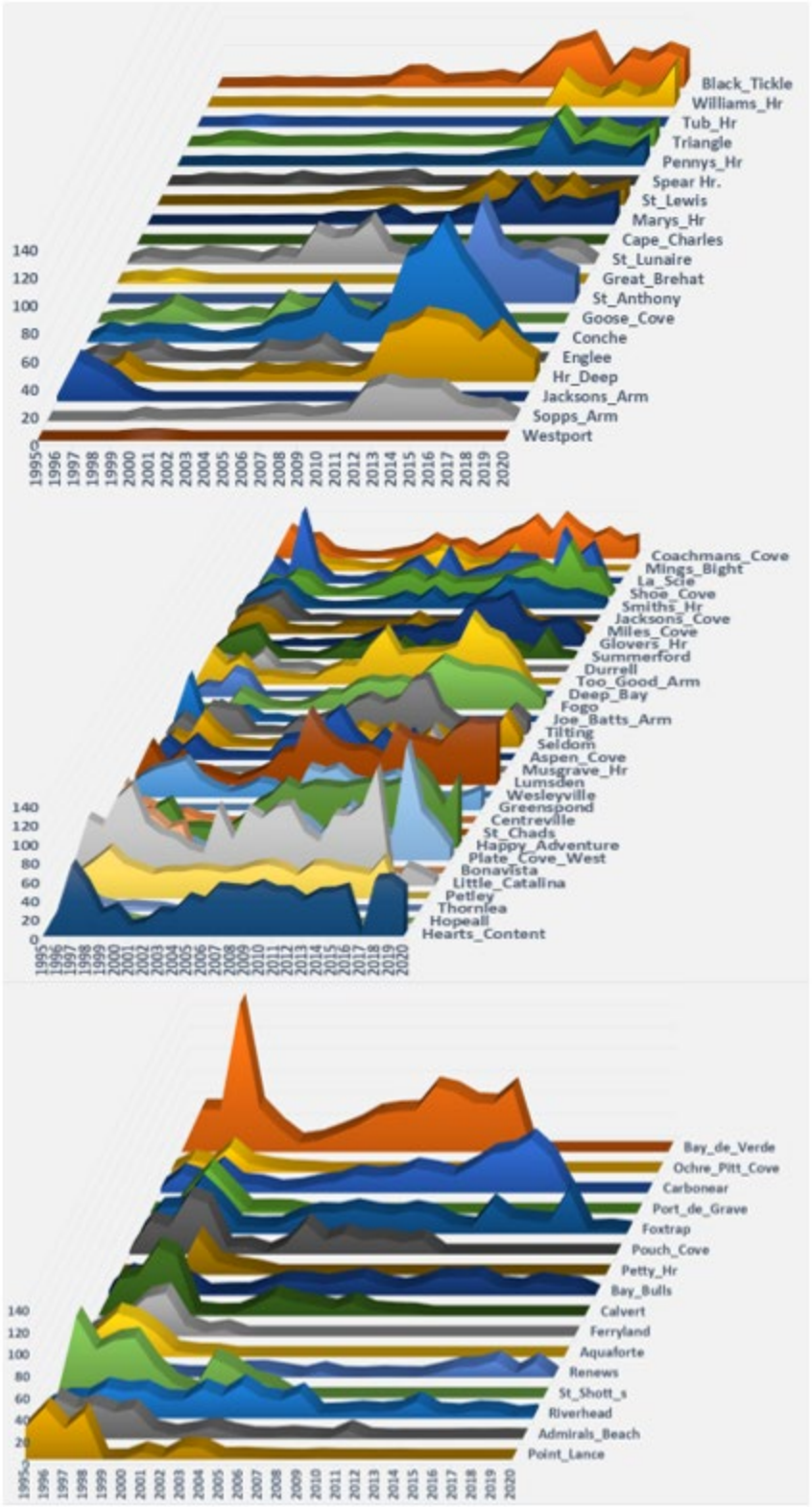


Figure 6. Distribution of mean annual catch rate of Atlantic Cod from large mesh gillnet, aggregated by fishing communities of Sentinel surveys in North (top panel), Central (middle panel), and South strata (bottom panel) of Divs. 2J3KL, 1995–2020.

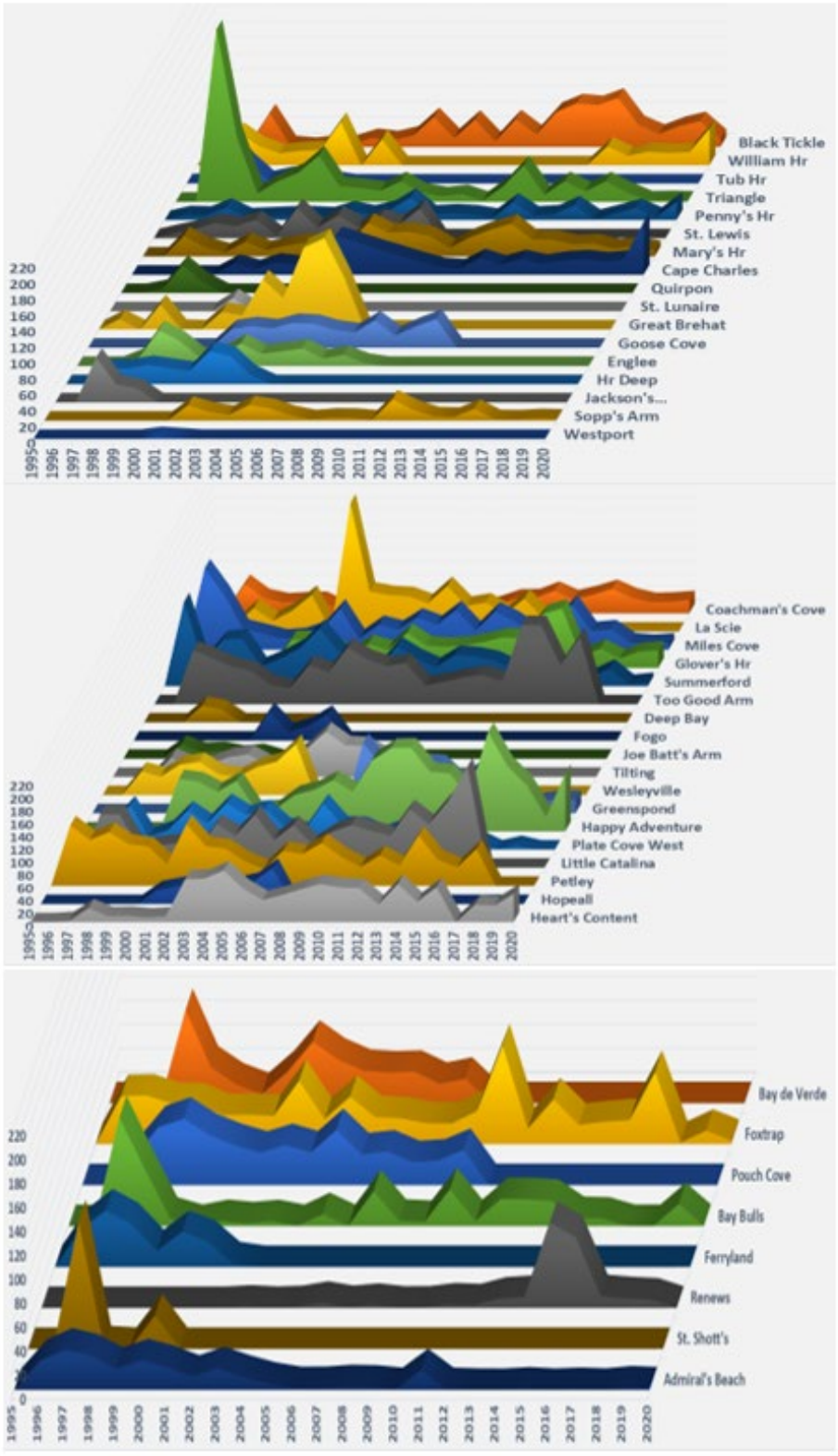


Figure 7. Distribution of mean annual catch rate of Atlantic Cod from small mesh gillnet, aggregated by fishing communities of Sentinel surveys in North (top panel), Central (middle panel), and South strata (bottom panel) of Divs. 2J3KL, 1996–2020.

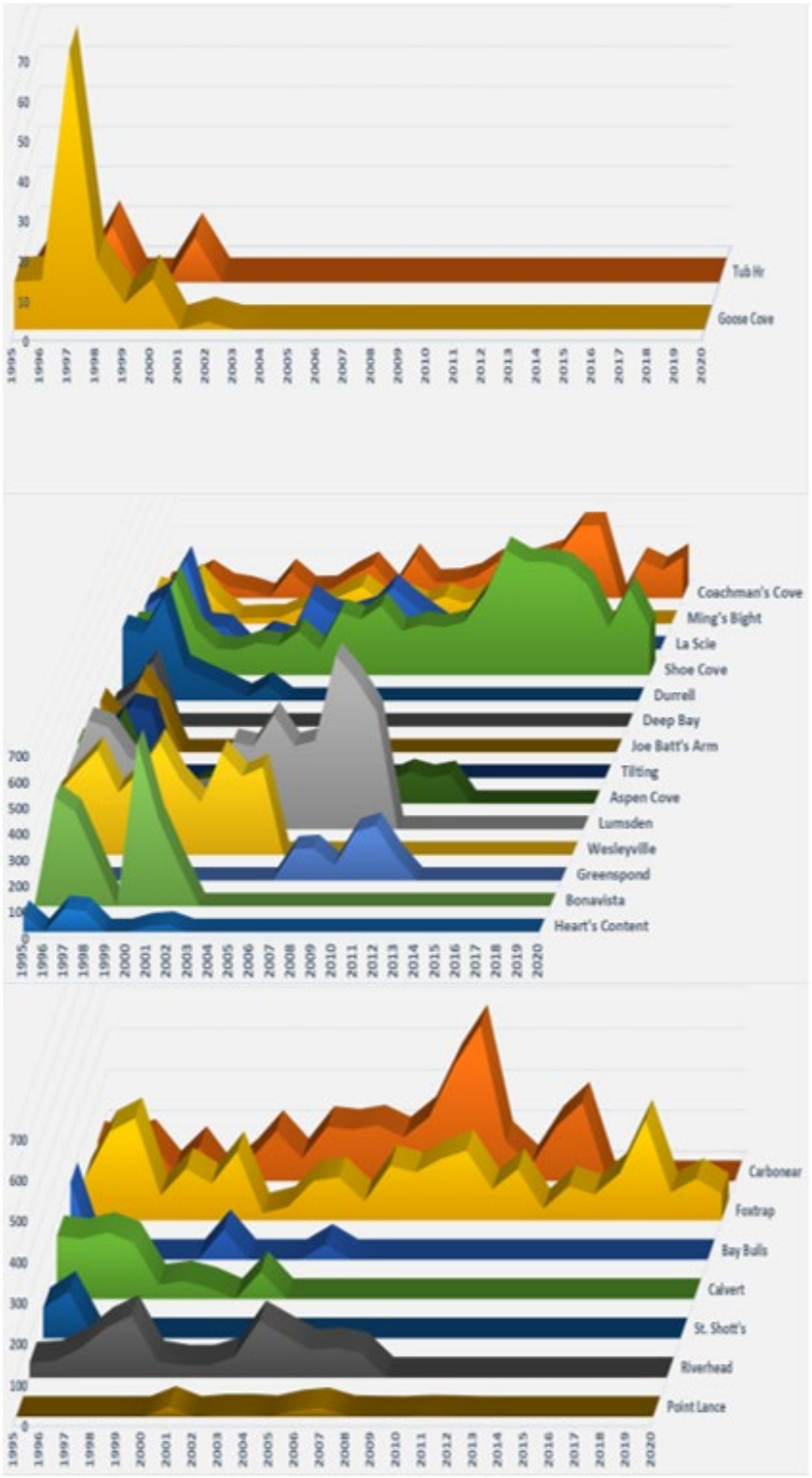


Figure 8. Distribution of mean annual catch rate of Atlantic Cod from linetrawl, aggregated by fishing communities of Sentinel surveys in North (top panel), Central (middle panel), and South strata (bottom panel) of Divs. 2J3KL, 1995–2020.

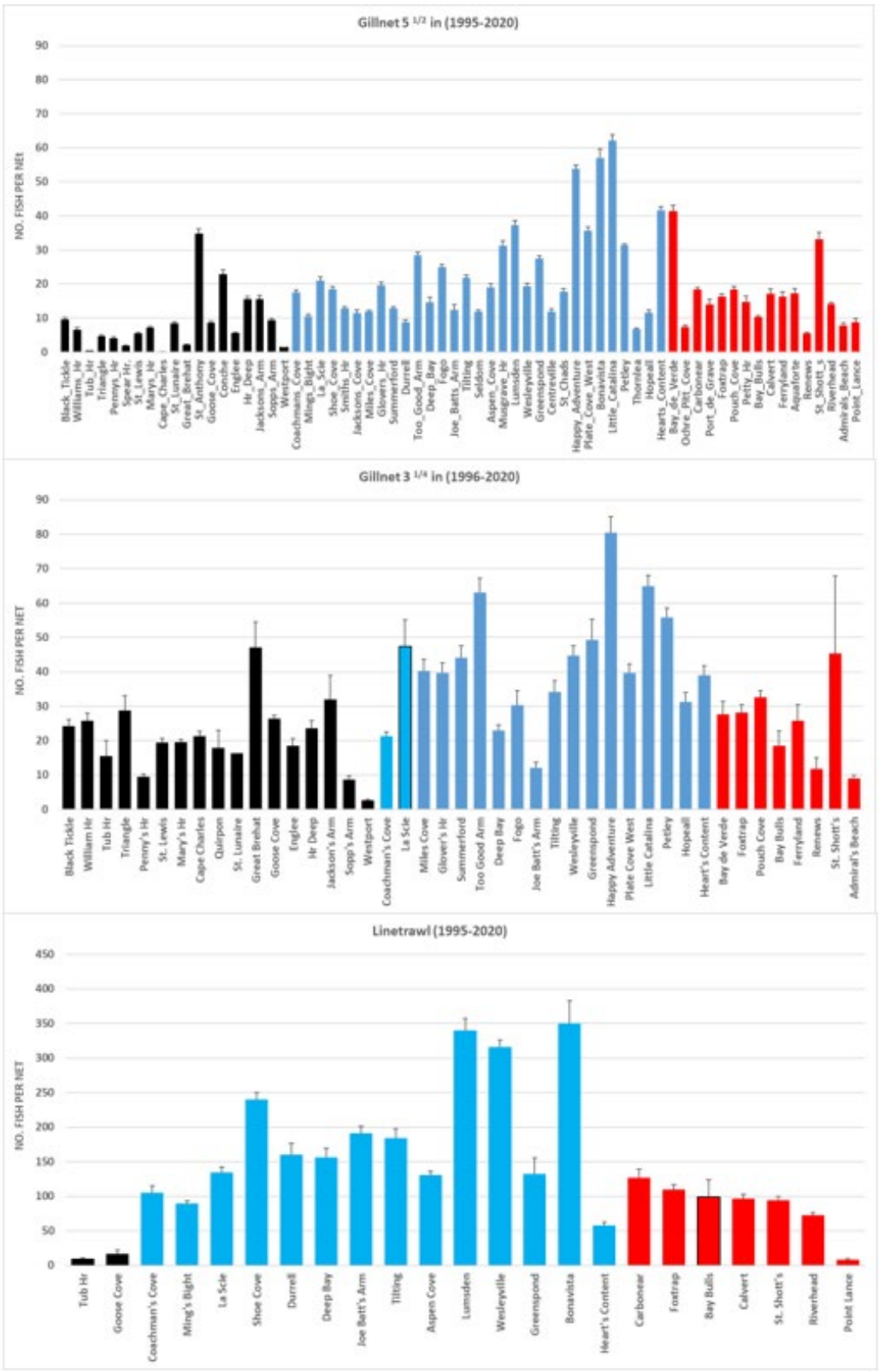


Figure 9. Distribution of the time-series mean catch rate of Atlantic Cod from large and small mesh gillnet and linetrawl, aggregated by fishing communities of Sentinel surveys in North (black bars), Central (blue bars), and South (red bars) strata of Divs. 2J3KL, 1995–2020. T-bars = +95% CI.

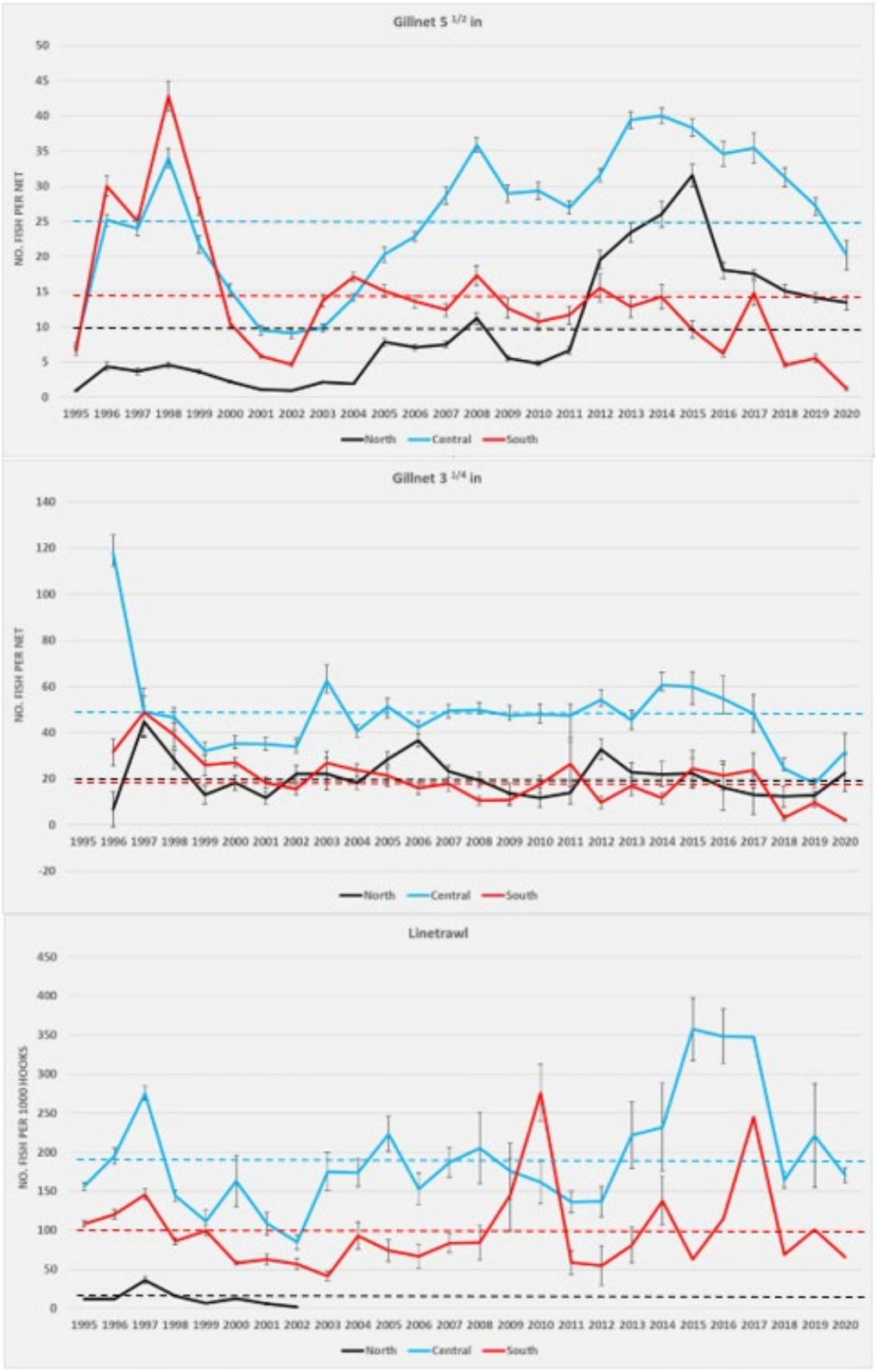


Figure 10. Distribution of the time-series mean annual catch rate of Atlantic Cod from large and small mesh gillnet and linetrawl, aggregated by strata of Sentinel surveys in Divs. 2J3KL, 1995–2020.The dotted lines represent the time-series' historical mean for each gear and stratum. T-bars = +/-95% CI.

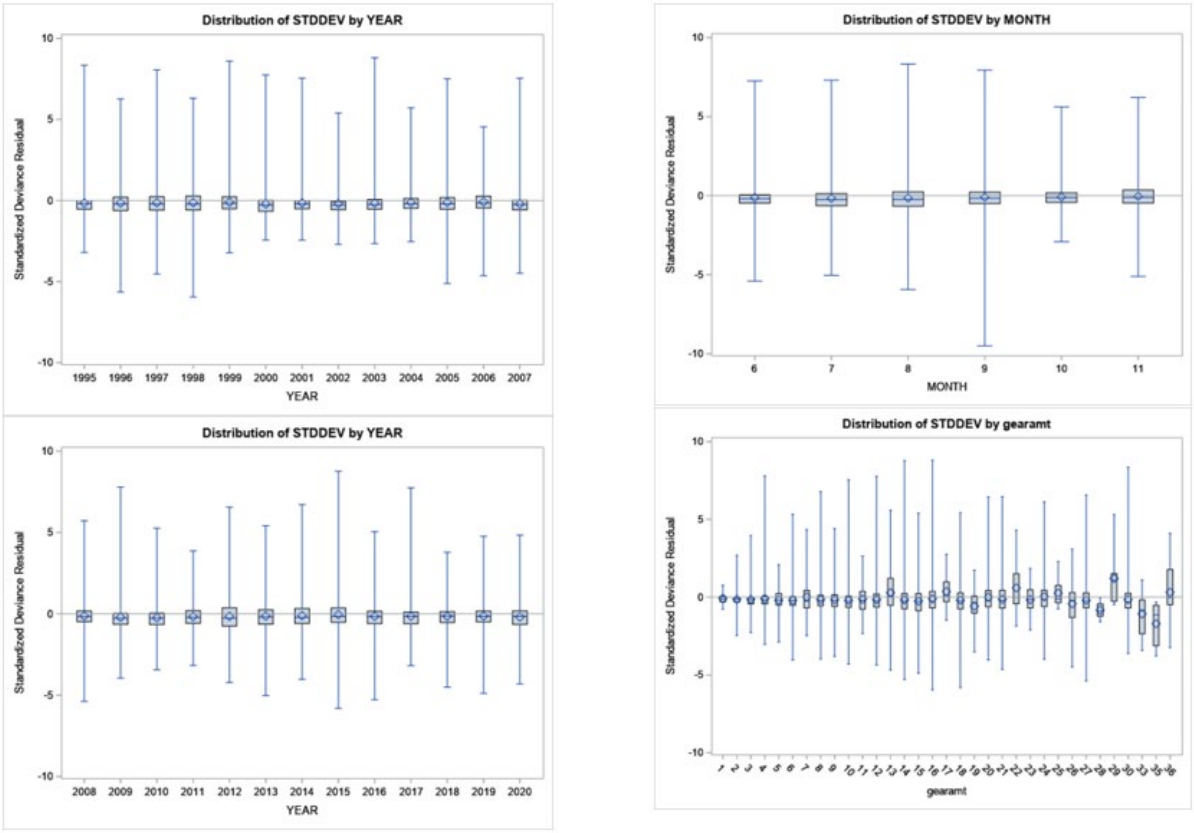


Figure 11. Distribution of model residuals versus the estimated linear predictors Year, Month, Fishing Site (SEQCODE), and Fishing Effort (gearamt) from the standardized catch rate model (control sites) for large mesh gillnet (5½ inch) in Divs. 2J3KL,1995–2020.

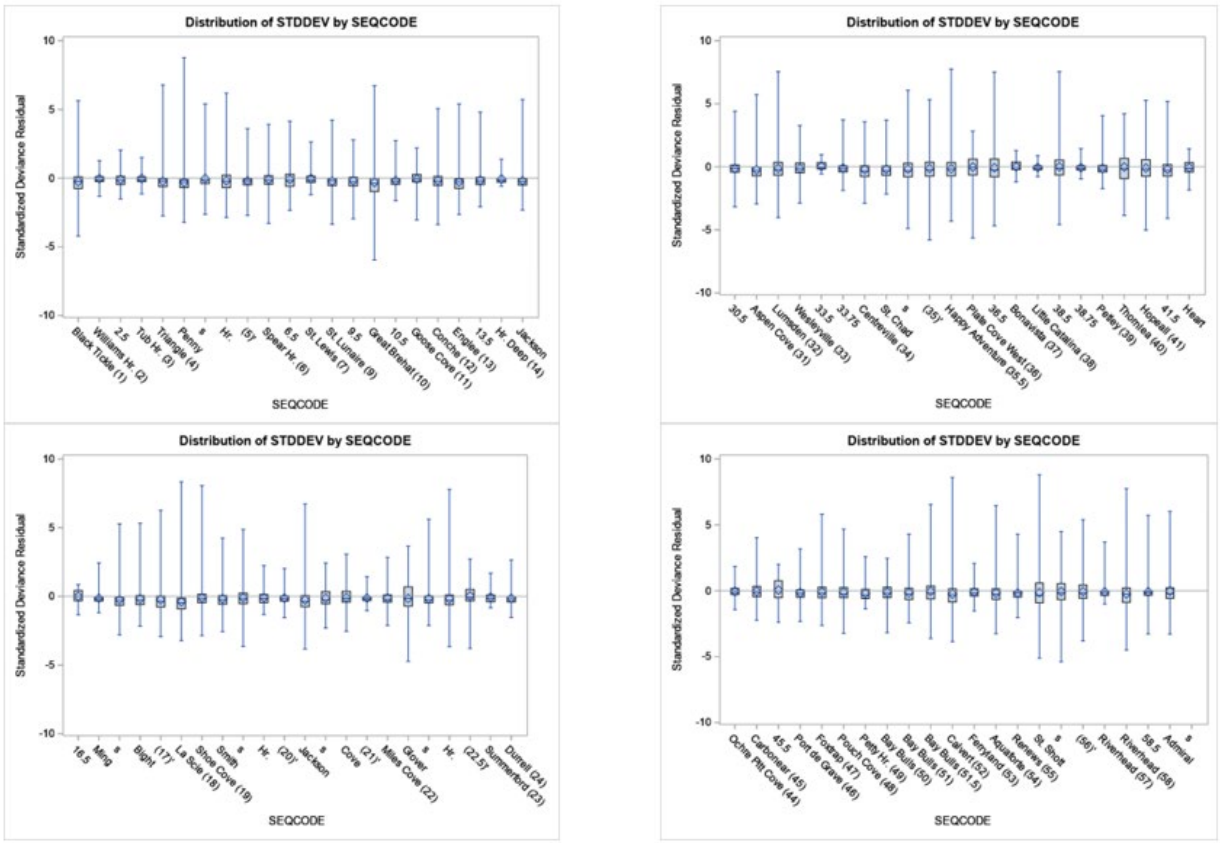


Figure 11 continued. Distribution of model residuals versus the estimated linear predictors Year, Month, Fishing Site (SEQCODE), and Fishing Effort (gearamt) from the standardized catch rate model (control sites) for large mesh gillnet (5½ inch) in Divs. 2J3KL,1995–2020.

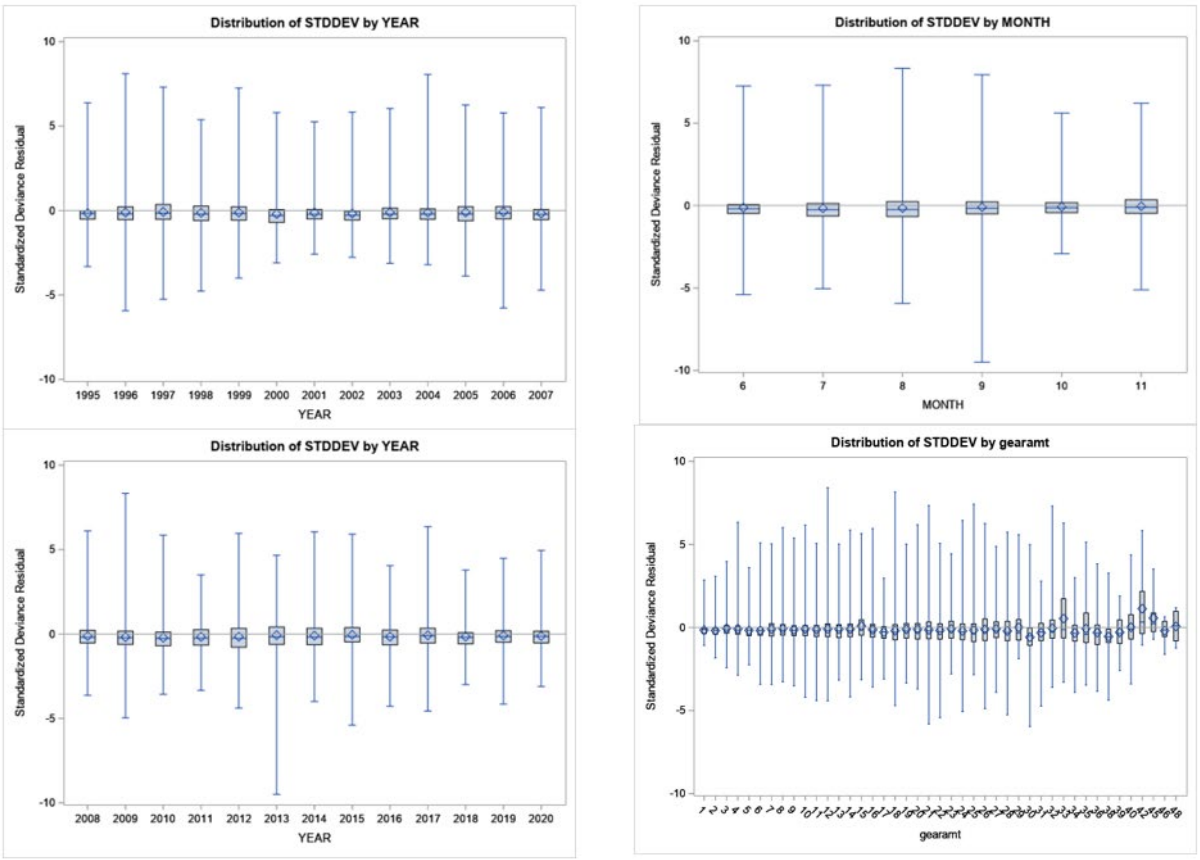


Figure 12. Distribution of model residuals versus the estimated linear predictors Year, Month, Fishing Site (SEQCODE), and Fishing Effort (gearamt) from the standardized catch rate model (experimental sites) for large mesh gillnet (5½ inch) in Divs. 2J3KL,1995–2020.

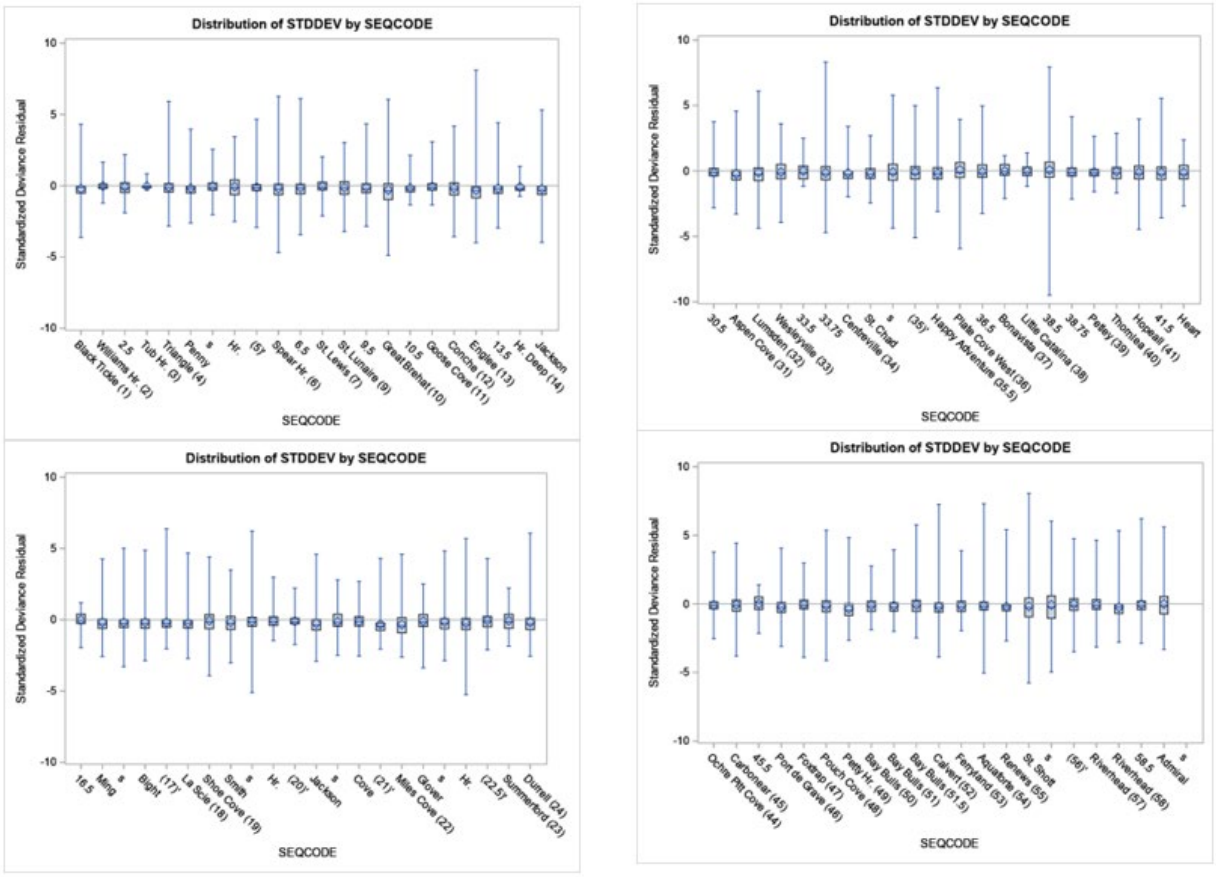
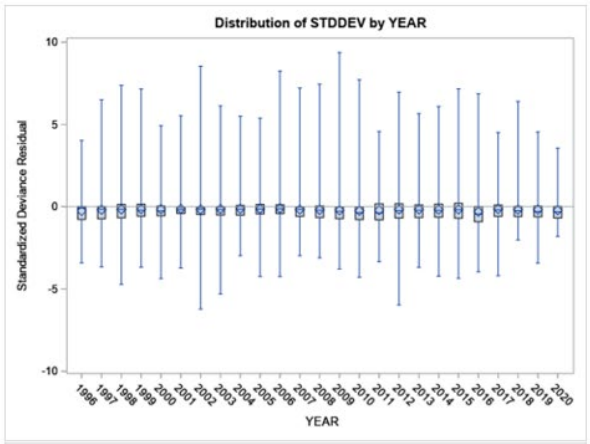
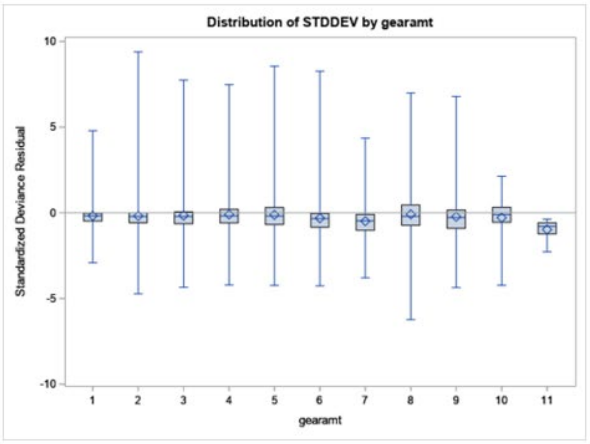


Figure 12 continued. Distribution of model residuals versus the estimated linear predictors Year, Month, Fishing Site (SEQCODE), and Fishing Effort (gearamt) from the standardized catch rate model (experimental sites) for large mesh gillnet (5½ inch) in Divs. 2J3KL,1995–2020.





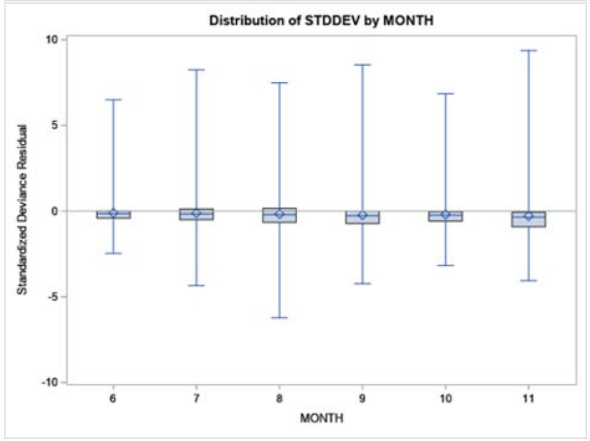


Figure 13. Distribution of model residuals versus the estimated linear predictors Year, Month, Fishing Site (SEQCODE), and Fishing Effort (gearamt) from the standardized catch rate model (experimental sites) for small mesh gillnet (3¼ inch) in Divs. 2J3KL,1996–2020.

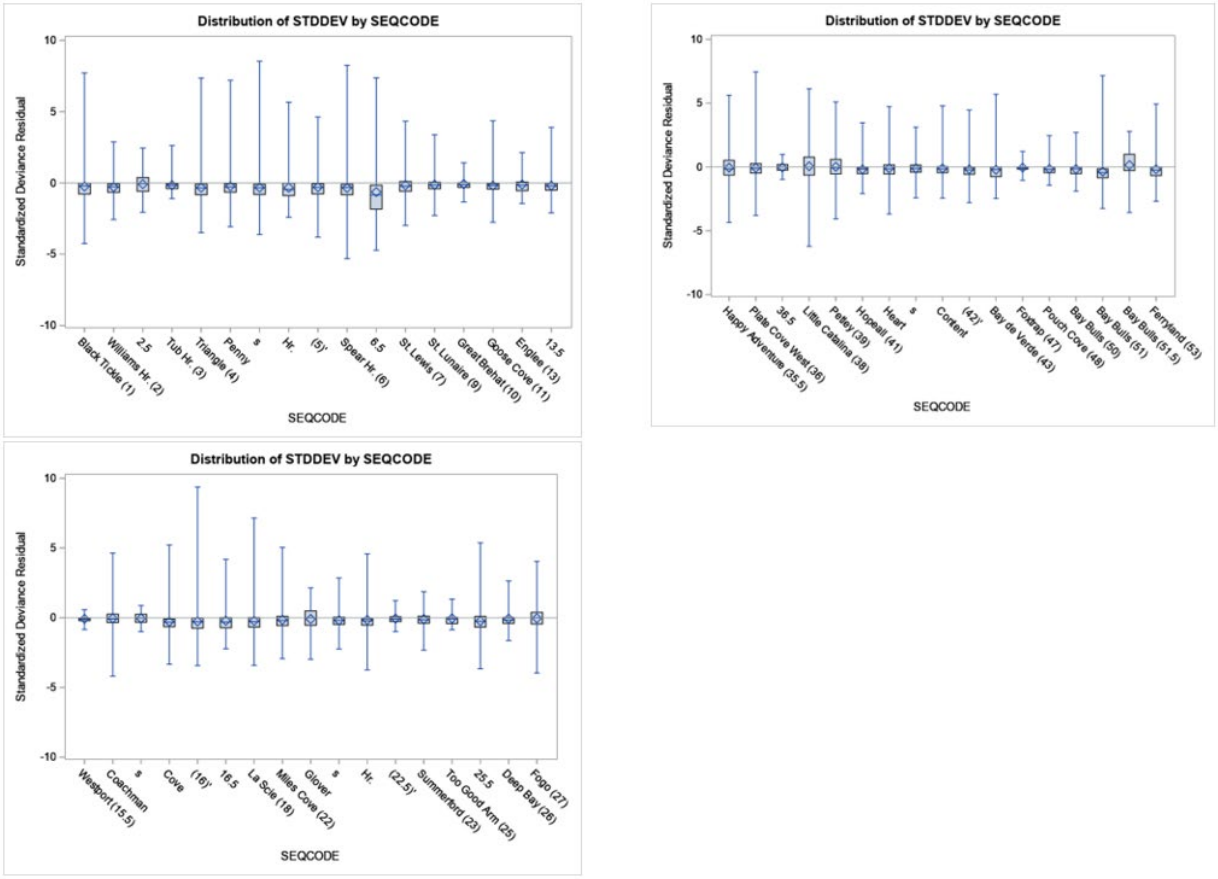


Figure 13 continued Distribution of model residuals versus the estimated linear predictors Year, Month, Fishing Site (SEQCODE), and Fishing Effort (gearamt) from the standardized catch rate model (experimental sites) for small mesh gillnet (3¼ inch) in Divs. 2J3KL,1996–2020.

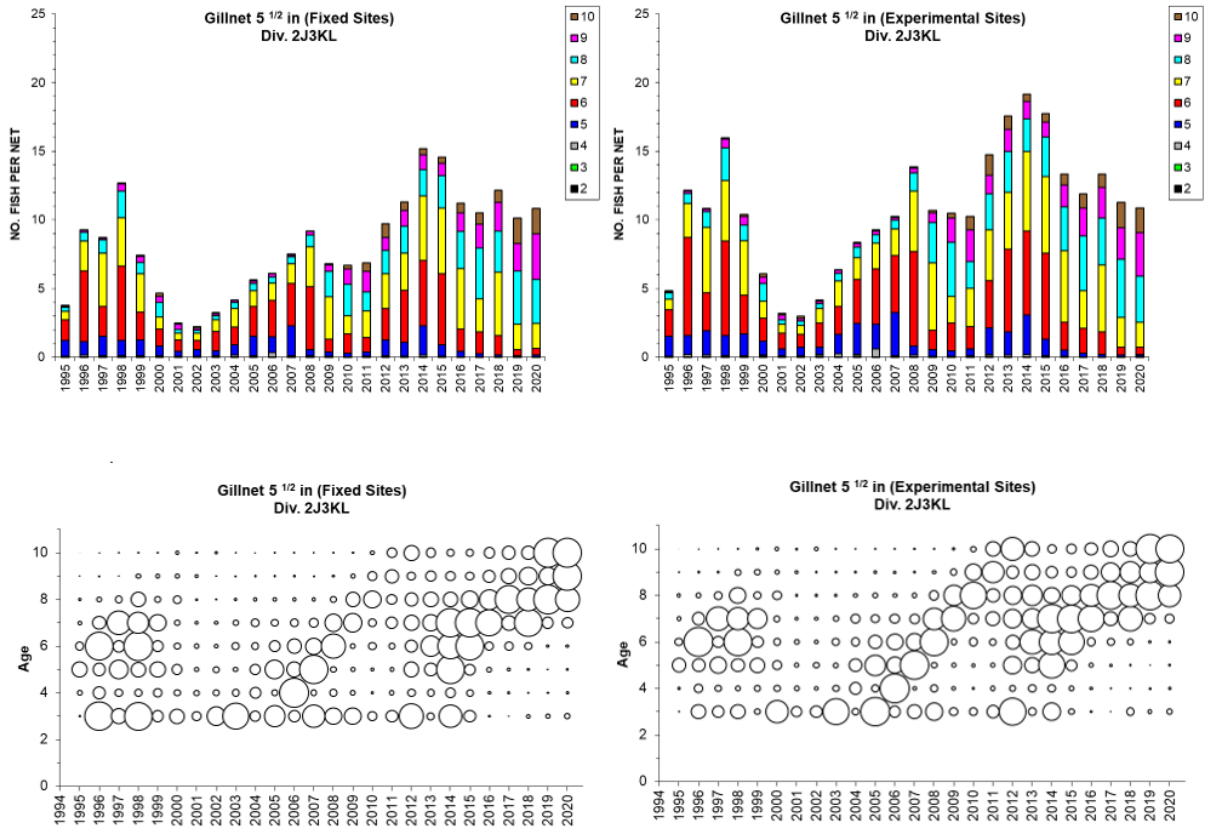


Figure 14. Standardized age-disaggregated catch rate of Atlantic Cod (top), and the proportions of Sentinel catch rate-at-age (bottom) for large mesh gillnet (5½ inch), using data from Sentinel survey control and experimental sites in Divs. 2J3KL, 1995–2020.

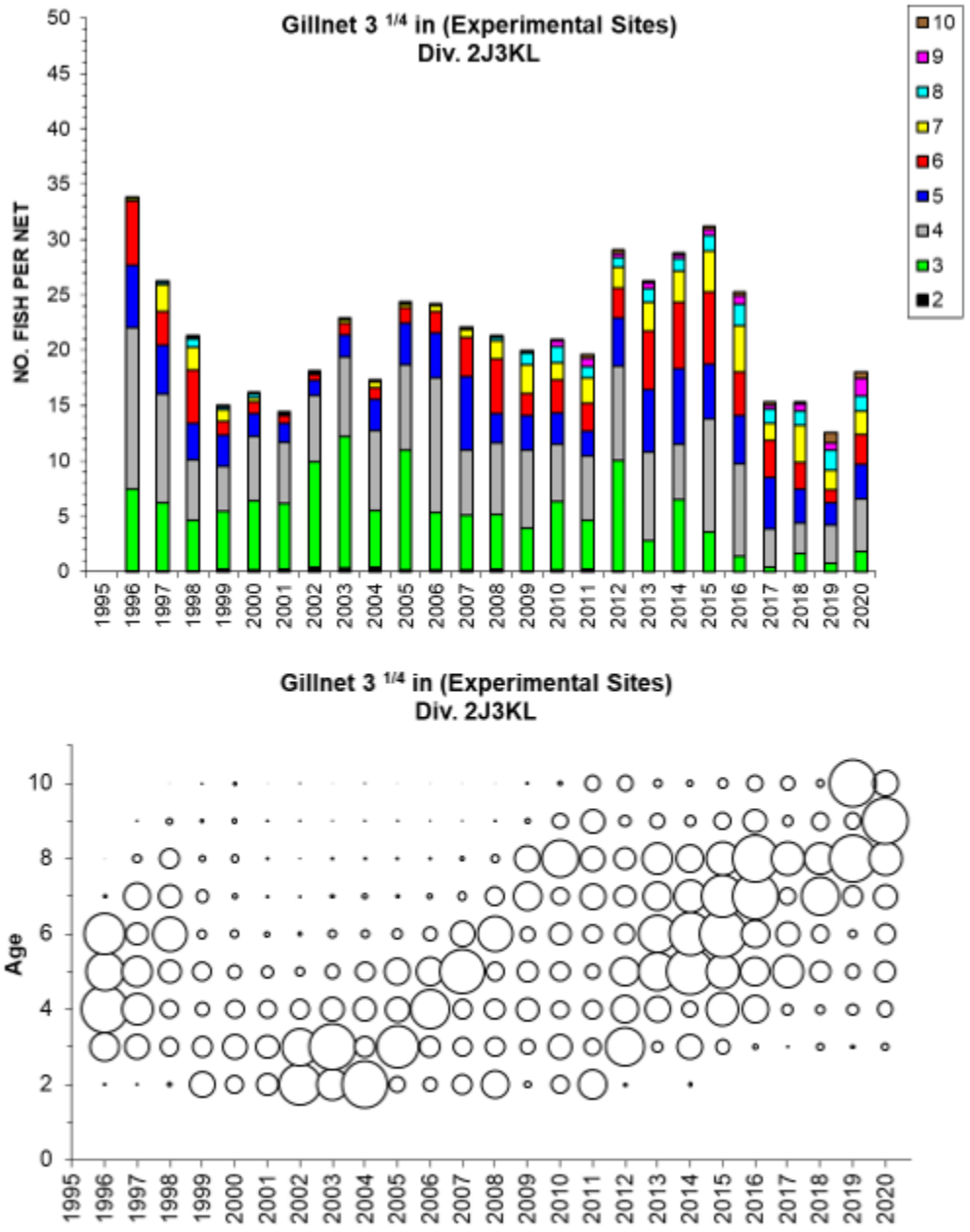


Figure 15. Standardized age-disaggregated catch rate of Atlantic Cod (top), and the proportions of Sentinel catch rate-at-age (bottom) for small mesh gillnet (3¼ inch), using data from Sentinel survey experimental sites in Divs. 2J3KL, 1996–2020.

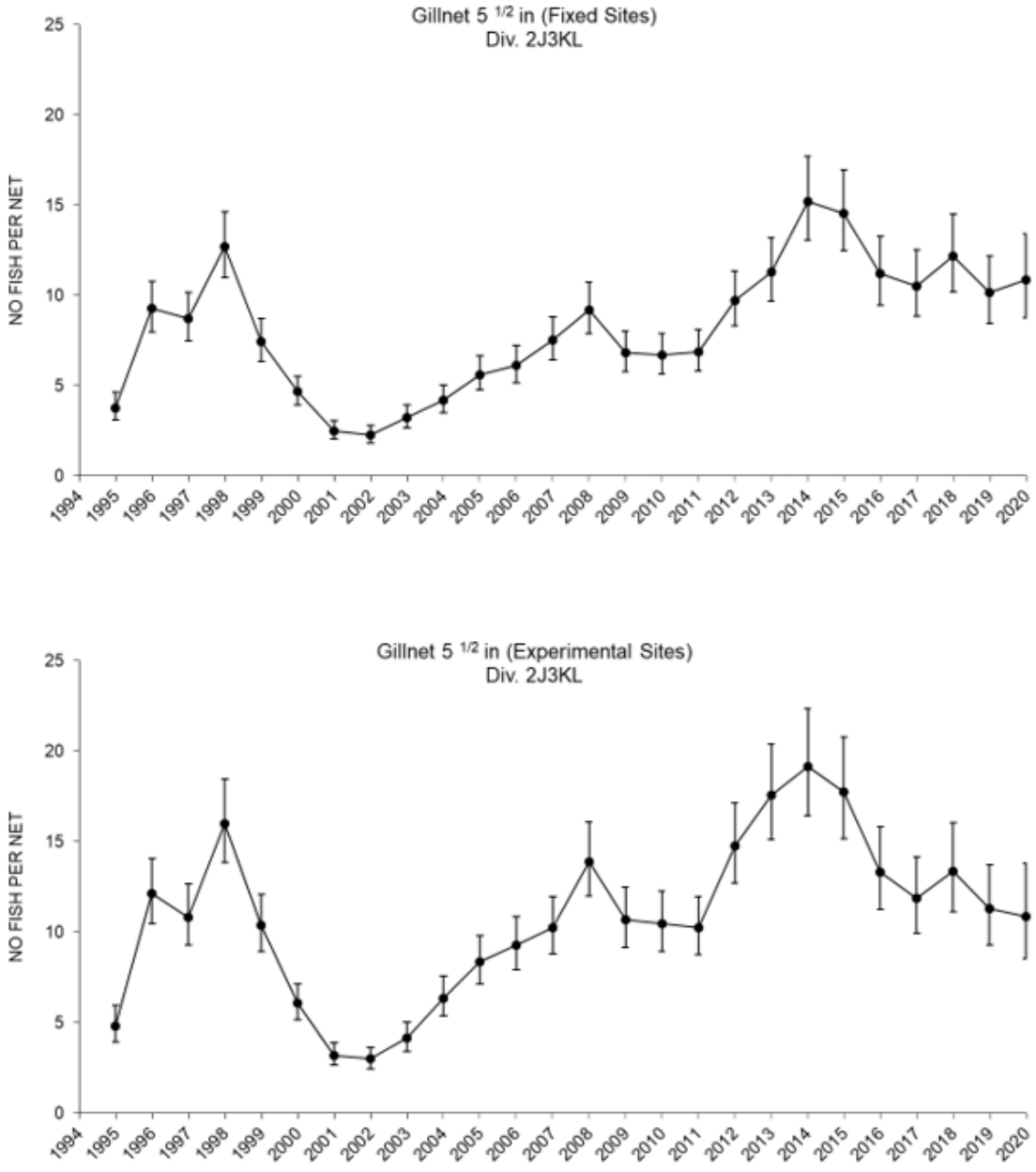


Figure 16. Standardized age-aggregated catch rate of Atlantic Cod for large mesh gillnet (5½ inch), using data from Sentinel survey control and experimental sites in Divs. 2J3KL, 1995–2020.

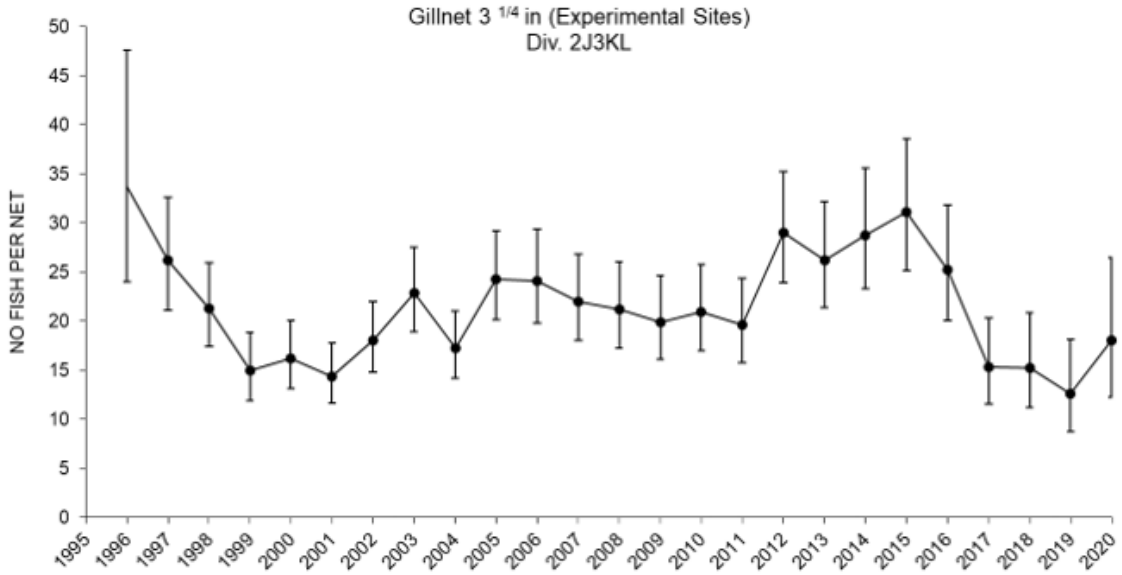


Figure 17. Standardized age-aggregated catch rate of Atlantic Cod for small mesh gillnet (3¼ inch), using data from Sentinel survey experimental sites in Divs. 2J3KL, 1996–2020.

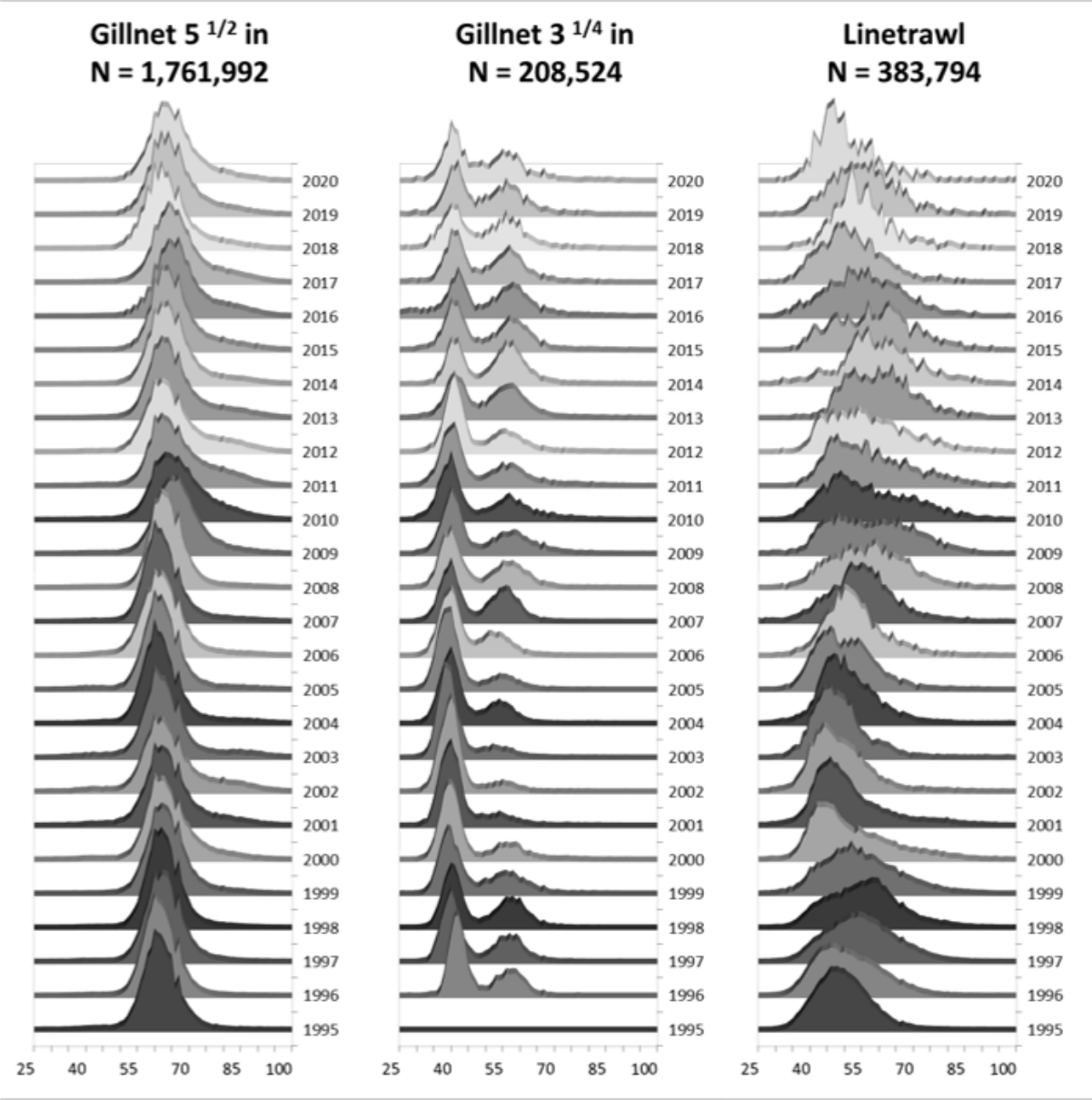


Figure 18. Length frequency distributions of Atlantic Cod (scaled to 1) by gear type from Sentinel surveys in Divs. 2J3KL (control and experimental sites combined), 1995–2020. N = number of fish measured.

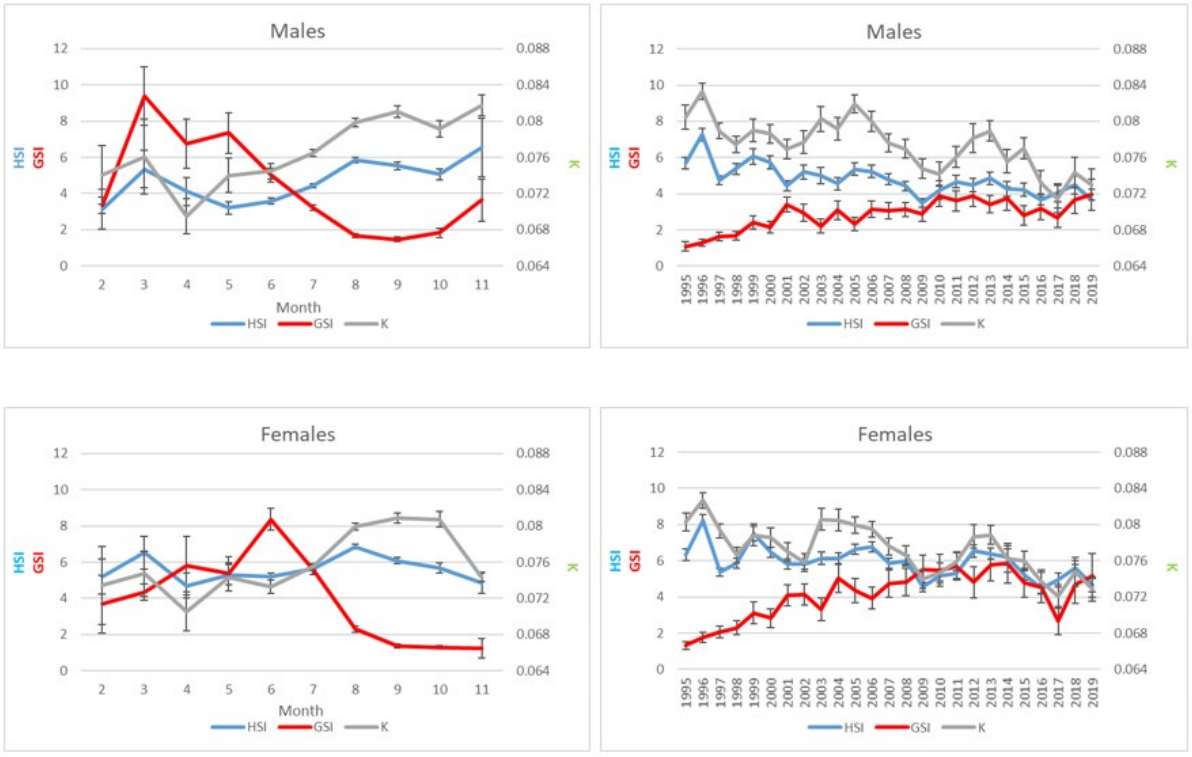


Figure 19. Temporal changes in mean Fulton's K condition factor (N=9,564 fish), mean Hepatosomatic Index (HSI; N=9,506 fish), and mean Gonadosomatic Index (GSI; N=9,516 fish) by sex for Atlantic Cod (all sizes combined) from Sentinel surveys in Divs. 2J3KL, 1995–2019. T-bars represent +/-95% CI. Data are not available for 2020.

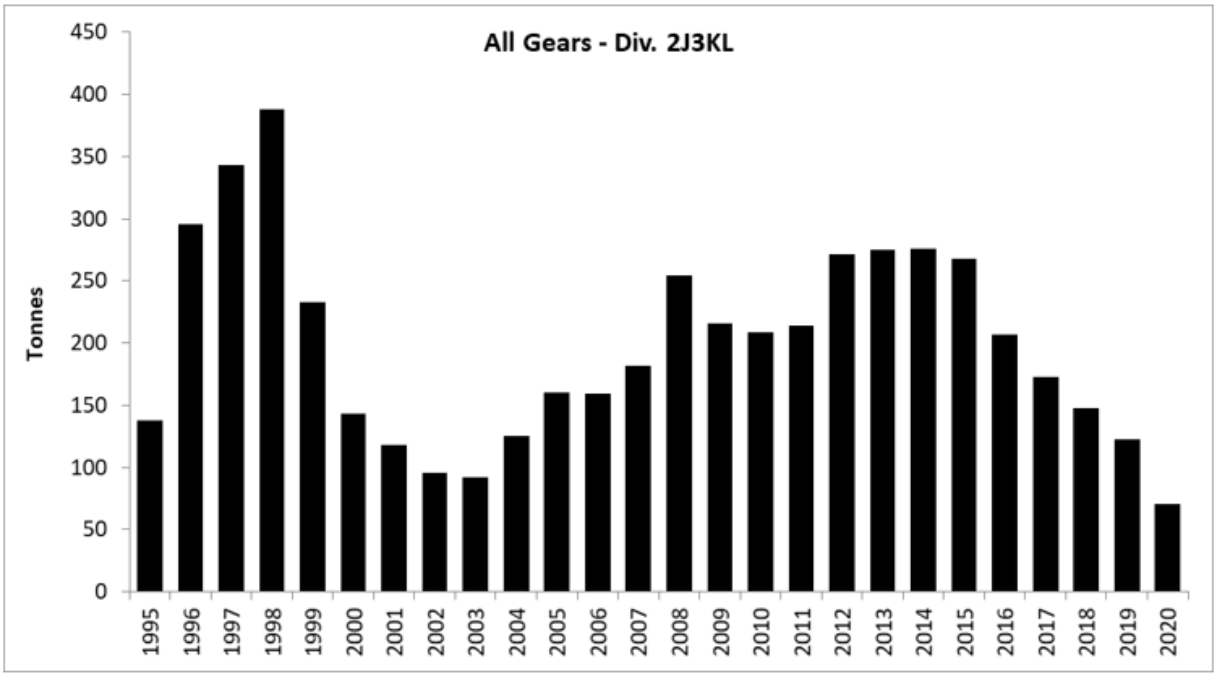


Figure 20. Total annual removal of Atlantic Cod from Sentinel surveys (control and experimental sites, all gears combined) in Divs. 2J3KL, 1995–2020.

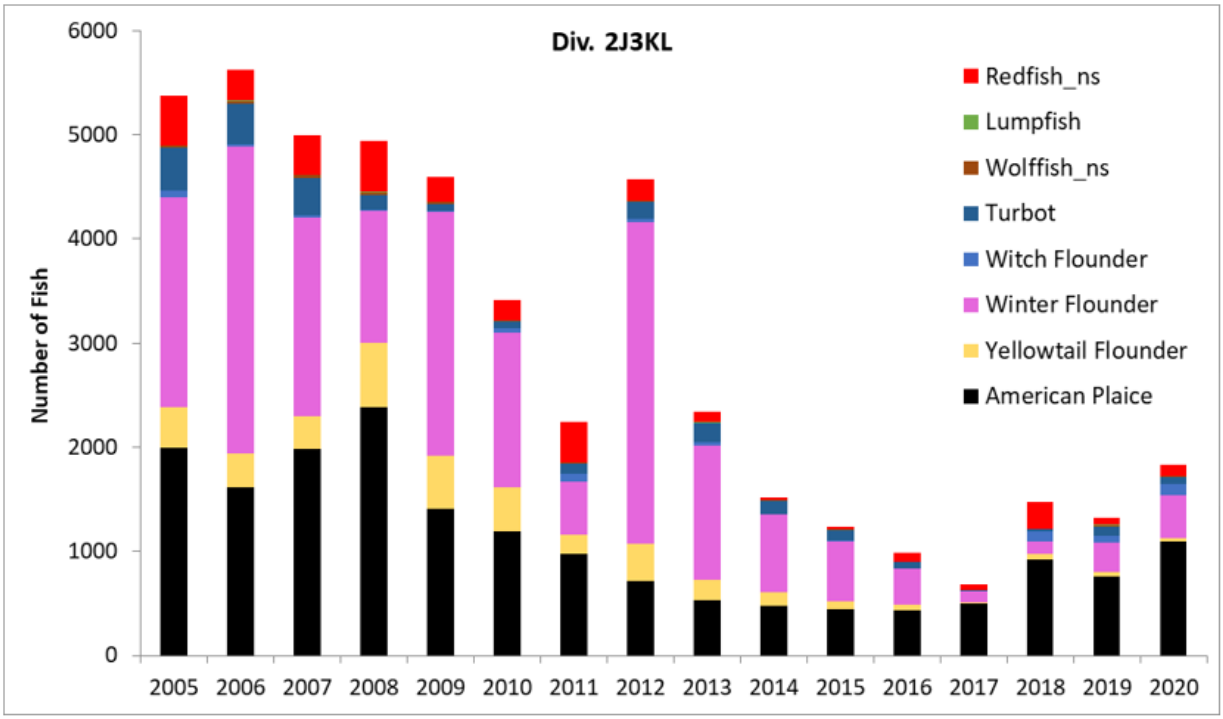


Figure 21. Total annual number of fish recorded as bycatch species from Sentinel surveys (control and experimental sites) in Divs. 2J3KL, 2005–20. Bycatch data are only available for the large mesh gillnet survey.