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Sentinel Surveys 1995-2020 – Catch rates and biological information on Atlantic Cod (*Gadus morhua*) in NAFO Subdivision 3Ps

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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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TABLE OF CONTENTS

ABSTRACT	iv
INTRODUCTION	1
MATERIALS AND METHODS	1
INDICES OF PHYSIOLOGICAL CONDITION	1
SENTINEL CATCH RATES	2
STANDARDIZED SENTINEL CATCH RATES	2
RESULTS	2
SENTINEL CATCH RATES	3
STANDARDIZED SENTINEL CATCH RATES	4
BIOLOGICAL INFORMATION	5
Length	5
Indices of physiological condition	5
SENTINEL SURVEY REMOVALS	6
DISCUSSION	6
ACKNOWLEDGEMENTS	8
REFERENCES CITED	8
APPENDIX I: TABLES	10
APPENDIX II: FIGURES	18

ABSTRACT

Catch rates and biological information for Atlantic Cod from the Sentinel survey Program in the Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps are updated for 2019, and preliminary results presented for 2020. Temporal trends in gillnet (small 3¼ inch mesh, large 5½ inch mesh) and linetrawl unstandardized catch rates were similar for all gears, with the highest values at the beginning of each time-series, sharp declines after 1997, and oscillations around or below the series' mean catch rate thereafter. Age-disaggregated standardized catch rates for recent year-classes were generally weaker than those in the past. Age-aggregated catch rates were higher at the beginning of each time-series for both gears, declined over the mid-to-late 1990s, then remained at their lowest levels; decreasing below the series' mean of 6.4 fish/net (large mesh gillnet) in 1999, and 86 fish/1,000 hooks in 2009 (linetrawl). Gillnet and linetrawl catch rates for 2019 were 3.4 fish/net and 92 fish/1000 hooks (control sites), and 2.5 fish/net and 114 fish/net (experimental sites), respectively.

Length frequencies of Atlantic Cod measured in Sentinel surveys indicated that the small mesh gillnet was the least selective gear (retaining small and large fish from multiple length-classes), whereas large mesh gillnet and linetrawl captured larger fish in specific size ranges and few overlapping length-classes. Fish lengths from small mesh gillnet showed several modes ranging between 37-43 cm and 53-60 cm throughout the time-series, while those of fish from large mesh gillnet and linetrawl ranged between 60-68 cm and 42-61 cm, respectively. Indices describing the physiological condition of Atlantic Cod varied at both seasonal and annual scales. Total annual removals of Atlantic Cod by Sentinel harvesters peaked at 38 t (2001), then declined to a minimum of 9.9 t (2016), prior to increasing to 14.3 t in 2019. At least 15 fish species have been recorded as Sentinel bycatch over 2005-19, with American Plaice and Redfish been the most common in gillnet and linetrawl, respectively.

INTRODUCTION

The Sentinel fisheries survey of Atlantic Cod (*Gadus morhua*) has been conducted in NAFO Subdivision 3Ps since 1995. The Sentinel survey for 2020 was ongoing at the time of the present assessment, and its data will be reviewed in subsequent years.

Sentinel survey data were collected by trained fish harvesters at various inshore sites along the south coast of Newfoundland. The main goals of the Sentinel survey include: the development of indices of relative abundance (i.e. catch rates) for resource assessments; to incorporate knowledge of inshore fish harvesters in the resource assessment process; to evaluate inter-annual variability in resource distribution over inshore areas; and to collect information on key biological parameters used in the stock assessment (i.e. fish length, sex, maturity stage, and otoliths to determine fish age), as well as biological samples used for genetic, physiological, and toxicological analyses, and along with stomach contents for food and feeding studies.

MATERIALS AND METHODS

Fishing enterprises extending from St. Bride's to Burgeo have participated in the Sentinel fisheries survey in NAFO Subdivision 3Ps (Fig. 1). Participants in the Sentinel surveys are trained in scientific sampling methods and equipment, computer use, and principles of resource assessment.

Sentinel harvesters fish one control and one experimental site: with the location of the control site being fixed, and based on historical fishing areas and gear-use patterns; whereas the experimental site changes only within a designated area. For each fishing day, up to half of the fishing gear is deployed at the control site, and the remaining gear is deployed at the experimental site at the discretion of Sentinel harvesters.

Sentinel surveys are usually conducted for 9-12 weeks, except in 1999 (6 weeks), and 2003-04 (8 weeks each). Since 2005, an average of 10 weeks was maintained. Large mesh gillnet (5½ inch mesh size) crews deploy a maximum of six 50-fathom monofilament nets (rigged 2-3 to a fleet), and up to three fleets per fishing day. Linetrawl crews fish two tubs of bait hooks (approximately 500 hooks per tub) per fishing day. In addition, one small-mesh gillnet (3¼ inch mesh size) is deployed at selected sites a minimum of one day per week.

Data recorded after each fishing set include: set location (Latitude, Longitude), set start and soak times, bycatch fish and invertebrates species, and several environmental parameters (wind direction and speed, percent cloud cover, tidal conditions, in addition to water salinity and temperature at depth at selected sites). All fish (i.e. Atlantic Cod, as well bycatch species) caught by gillnet and linetrawl at control and experimental sites are kept separate and sampled on land. Each catch is sorted by species, and total number of individuals and total length (TL) (cm) by sex are recorded. Atlantic Cod otoliths are sampled using a length-stratified protocol, and up to 100 whole specimens are frozen bi-weekly and transported to DFO Northwest Atlantic Fisheries Center laboratory (St. John's, NL) for detailed biological measurements, including TL (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) is calculated by applying a standard weight-length relationship to the length data.

INDICES OF PHYSIOLOGICAL CONDITION

Body weight (gutted), liver and gonad weights are used to calculate three indices that reflect the physiological condition of individual Atlantic Cod (Lambert and Dutil 1997; Mello and Rose

2005a): Fulton's condition factor (K); Hepatosomatic Index (HSI); and Gonadosomatic Index (GSI).

$$K_i = (w_i / l_i^3)$$

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

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

where w_i is gutted weight (g), l_i is TL (cm), h_i is liver weight (g), and g_i is gonad weight (g) of fish i .

SENTINEL CATCH RATES

Sentinel catch rate for gillnets and linetrawl are 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 weigh scales are not available to the Sentinel fisheries survey.

STANDARDIZED SENTINEL CATCH RATES

As in previous assessments, both age-aggregated and age-disaggregated standardized catch rates were estimated for large mesh gillnet and linetrawl, but data were insufficient to do so for small mesh gillnet. Moreover, the 2019 aging data associated with the weight analysis were not available, except for the aging data estimated from otoliths collected by Sentinel harvesters; therefore the 2019 estimates of Sentinel standardized indices were conducted using a mixture of 2018 (i.e. aging data associated with the otolith and weight analyses) and 2019 aging data (i.e. aging data associated with the otolith analysis only).

Sentinel catch rates were standardized using Generalized Linear Models (GLM; McCullagh and Nelder 1989), in order 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 data to the model. Poisson models with a logarithmic link were fitted with the variables *Month* and *Age* as "nested effects": *Month* was nested within *Fishing Site*, and *Age* was nested within *Year*. The generic form of the age-disaggregated model is:

$$CPUE = \text{Month (Fishing Site)} \times \text{Age (Year)}$$

and the age-aggregated model:

$$CPUE = \text{Month (Fishing Site)} \times \text{Year}$$

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

RESULTS

Sentinel survey data were gathered annually from between eight and seventeen fishing enterprises/locations since 1995 (Fig. 2); although the number of enterprises participating in this survey has decreased to twelve or less during the last decade. In 1995-2019, the annual number of fishing sets ranged from 2 to 80, 149 to 760, and 52 to 1172 for small mesh gillnet, large mesh gillnet, and linetrawl, respectively (Tables 1-3). In 2019, nine communities participated in the Sentinel survey in Subdivision 3Ps, predominantly fishing small mesh gillnet (3¼ inch mesh) in Garden Cove and Little Paradise (Table 1), large mesh gillnet (5½ inch

mesh) in Garden Cove, Fox Harbour, and Grand Bank (Table 2), and linetrawl in Harbour Breton and Red Harbour (Table 3). Preliminary data from 204 sets in 2020 (all gears combined) indicate a similar pattern.

The number of sets conducted with large mesh gillnet declined from 760 in 1995 to 234 in 1999, and then fluctuated between 224 (the lowest value of the time-series) and 499 sets per year thereafter; for small mesh gillnet, the number of fishing sets was initially low, ranging between 2-29 sets annually (1995-99), increased to 40-88 sets annually between 2000-17 and then declined to 24 sets in 2019; the number of fishing sets for linetrawl was highest in 1995 (1172 sets), declined from 594 to 195 sets annually between 1996-99, and then fluctuated between 141 and 418 sets annually thereafter (Fig. 3, top panel).

Consistent with the reduction of fishing effort using large mesh gillnet, the number of fish measured for length declined by more than ten-fold: from 31,000-45,000 annually in 1995-98 to 1,600-4,000 fish in 2002-19; for small mesh gillnet, the number of fish measured was in general less variable, ranging between 460-2544 annually, except in 1995, 1999, 2011 and 2019 (34-342 fish/year); similarly to large mesh gillnets, the substantial reduction in fishing effort by linetrawl harvesters at the start of the time-series was reflected in the total number of fish measured, declining from roughly 77,000 in 1995 to 9,500 fish in 1999, then fluctuating mostly between 11,300-22,300 fish during the 2000's and 4,400-9,600 fish during the last decade (Fig. 3, middle panel).

The percentage of sets with no cod catch ranged between 1-28% for large mesh gillnet; 0-19% for small mesh gillnet; and 0-10% for linetrawl (Fig. 3, bottom panel); no trend over time was observed for any of the gear types, however the percentage of sets with no cod catches increased substantially over the last decade for large mesh gillnet, ranging from 17 to 28% compared to < 16% between 1996-2008.

Sentinel survey coverage by small mesh gillnet was centred in Placentia Bay throughout the time-series, mainly during the summer and early fall (St. Bride's, Little Paradise, Red Harbour, Lawn and Lord's Cove), but a few sites located at the head of the bay (Little Harbour East, North Harbour and Garden Cove) also fished during late fall and early winter (Fig. 4). Trends in Sentinel survey coverage by large mesh gillnet were similar to those observed for small mesh gillnet (Fig. 5), occurring mostly in summer and early fall on both sides of Placentia Bay (St. Bride's, Fox Harbour, Monkstown, Little Paradise, Red Harbour, Lawn, and Lord's Cove), and in late fall and early winter at sites located at the head of the bay; survey coverage by large mesh gillnet in Fortune Bay was limited to Grand Bank in summer and through most of the year in Seal Cove during the period 1999-2004. The most comprehensive Sentinel survey coverage in Subdivision 3Ps was conducted by linetrawl harvesters, including several sites in Placentia Bay (Arnold's Cove, Little Paradise, and Red Harbour), Fortune Bay (Grand Bank, Rencontre East, Harbour Breton, and Seal Cove), and the southwest coast (Ramea, François, and Burgeo) (Fig. 6); Sentinel surveys took place mostly in late summer and fall in Placentia Bay, late fall and early winter in Fortune Bay, and through most of the year in the southwest coast.

SENTINEL CATCH RATES

Mean annual catch rate for small and large mesh gillnet were similar and showed little variability between most fishing enterprises/communities, with a few exceptions in the case of small mesh gillnet (e.g. North Harbour, Little Harbour East), whereas catch rate for linetrawl tended to be more variable among enterprises/communities (Fig. 7). Mean catch rate for small mesh gillnet ranged mostly between 10-28 fish/net, but those from North Harbour and Little Harbour East were considerably higher, peaking at 169 fish/net (1998) and 160 fish/net (1997), respectively. Mean catch rate for large mesh gillnet fluctuated around 11 fish/net for most fishing

enterprises/communities; however catch rates were highest once more for enterprises in Little Harbour East, and North Harbour, peaking at 92 fish/net (1996) and 100 fish/net (1997), respectively. Mean catch rate for linetrawl fluctuated around 120 fish per 1,000 hooks, with the largest ranges from Arnold's Cove, Little Paradise, Harbour Breton, François, and Burgeo (200-320 fish per 1000 hooks); of note mean catch rates remained relatively higher in Burgeo, François, Ramea and Harbour Breton during the last 10-15 years, contrasting with the catch rates observed in the communities located further east, particularly in Placentia Bay.

Trends in mean annual catch rate (all enterprises/communities combined) were similar for all gears: the highest values were observed at the beginning of the time-series, followed by sharp declines after 1997; then values oscillated around or below the time-series mean catch rate of 28 fish/net for small mesh gillnet, 10 fish/net for large mesh gillnet, and 106 fish per 1000 hooks for linetrawl (Fig. 8). Large mesh gillnet yielded the lowest mean annual catch rate of all three gears: declining from 48 fish/net in 1997 to an average of 5 fish/net after 1999. Mean catch rate for small mesh gillnet was consistently higher than that of large mesh gillnet: peaking at 142 fish/net in 1996, then averaging 20 fish/net after 1997 (except for 6 fish/net in 2011). For linetrawl, mean catch rate peaked at 221 fish per 1,000 hooks in 1996, fluctuated around 110 fish per 1,000 hooks until 2012, then declined to its lowest value of 60 fish per 1,000 hooks in 2014. However, an increase in mean catch rate has been observed for linetrawl between 2018-20, ranging from 61 fish per 1000 hooks in 2018 to 115 fish per 1000 hooks in 2020. The variability of mean catch rate estimates (95% CIs) was generally small, with a few exceptions, notably for those associated with high catch rate values for small mesh gillnet at the beginning of the time-series.

STANDARDIZED SENTINEL CATCH RATES

Both age-disaggregated and age-aggregated models for standardized catch rate of Atlantic cod from the large mesh gillnet, and linetrawl Sentinel surveys (control and experiments 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; the variable *Year*, and the nested effect of *Month (Fishing Site)* in the age-aggregated model were also highly significant in all cases. (Tables 4-5). No trends were apparent in the distribution of model residuals versus the estimated linear predictors *Year*, *Month*, *Fishing Sites*, or *Fishing Effort* (Figs. 9-12). These results suggested that overall model parameterization of standardized catch rate from the Sentinel survey was appropriate for both fishing gears, and no systematic issues regarding model fit were detected. The age-disaggregated and age-aggregated models of the small mesh gillnet Sentinel survey (both sites) failed the convergence diagnostics (Hessian convergence criterion), therefore the validity of the model fit was questionable and not considered in further analyses.

For large mesh gillnet, standardized annual catch rate-at-age (control sites) increased from 1995 to 1996, remained relatively high until 1998 (comprised mostly of 5-8 year-old fish), then declined rapidly and remained stable at low levels since 1999 (Fig. 13). Estimates for 2015-16 were the lowest for most age groups; estimates for 2017 through 2019 have improved slightly each year, notably for 6-8 year-old fish. Several year-classes were well-represented over 1995-98, but were replaced by mainly weaker year-classes since then; the 2010 year-class was well-represented as 3 year-old fish in 2013 but the same year-class was not tracked in catches during subsequent years. Catch rates and year-class composition for estimates from the experimental sites mirrored those from the control sites to a large extent (Fig. 14). Moreover, the 1997 and 1998 year-classes contributed significantly to the fishery for several years (Rideout et al. 2016). However, these year-classes did not increase the magnitude of Sentinel gillnet

catch rate over 2002-06 (i.e. when they would have been in the peak selection range of large mesh gillnet), while being a major contributor to inshore fisheries.

For linetrawl, standardized annual catch rate-at-age at the control sites was higher at the beginning of the time-series, and dominated by 4-8 year-old fish (Fig. 15). Catch rate declined by more than 50% during the period 1995-99, and then increased in 2000-03 due mostly to improved recruitment of 3 year-old fish, but overall those for older fish continued to decline until 2015; the index increased slightly in 2016 prior to declining once more in 2017-18; however catch rate more than doubled in 2019 compared to 2017-18 and was the highest since 2006, resulting mainly from the increased contribution of 6-10 year-old fish to Sentinel linetrawl fishery. Several year-classes were well-represented over 1995-98: the 1997 year-class, and especially the 1998 year-class, were consistently caught by Sentinel linetrawl. In addition, the 1999 year-class also appeared relatively strong as 4-5 year-old fish, but was generally below average at older ages. Catch rates and age composition of catches from the experimental sites also followed the same patterns as observed at the control sites but were in general higher than catch rates from control sites at any given year (Fig. 16).

Age-aggregated standardized annual catch rate for large mesh gillnet from both control and experimental sites declined rapidly from 29 and 32 fish/net respectively in 1997 to 4 fish/net 1999, then remained stable at low levels (< 5 fish/net) in 1999-2019 (Fig. 17). For linetrawl, catch rate from control and experimental sites decreased over 1995-99, from 181 and 200 to 75 and 81 fish per 1000 hooks respectively; remained relatively stable until 2008, then declined to its lowest value (36 fish per 1000 hooks) in 2018 (both at control and experimental sites), prior to increasing in 2019 to 92 and 114 fish per 1000 hooks from control and experimental sites, respectively (Fig.18). In most cases the variability of mean standardized catch rate (95% CI) was small, with a few exceptions, notably for those associated with high catch rate values (gillnet), or with estimates from recent years (linetrawl).

BIOLOGICAL INFORMATION

Length

Length frequency distributions of Atlantic Cod from Sentinel surveys indicated that large mesh gillnet and linetrawl tended to capture larger fish from specific size ranges, whereas the small mesh gillnet was the least selective gear: retaining small and large fish from multiple length-classes (Fig. 19). TL of fish retained in large mesh gillnet and linetrawl were 19-120 cm and 16-120 cm, respectively, with modal lengths for any particular year ranging between 60-68 cm (large mesh gillnet) and 42-61 cm (linetrawl). Atlantic Cod retained in small mesh gillnet were 20-115 cm (TL), with smaller bi-modal lengths ranging between 37-43 cm and 53-60 cm for the first and second modal-class, respectively. Of note, the length frequency distributions of fish retained by both small and large mesh gillnets in 2019 and 2020 are very similar to distribution from previous years, whereas in the case of linetrawl, modal length increased from 50 cm prior to 2018 to 55 cm in the last two years of the time-series.

Indices of physiological condition

All three indices (K, HSI, GSI) that reflect the physiological condition of Atlantic Cod varied seasonally and annually (Fig. 20). Fulton's K and HSI covaried: showing minimum values in April (HSI) and May (K) for females and May (HSI, K) for males; these indices remained high during the summer and fall and then peaked in December (K and HSI) for females, and October (K) and December (HSI) for males. The temporal trend in GSI contrasted with those of the other two indices: peaking in June for females and May for males, then reaching minimum values in

October for females and September for males. Inter-annual trajectories in K and HSI also covaried: peaking in 2003 (K) and 2004 (HSI) for females, and 2004 (K and HSI) for males, then declining and reaching minimum values in 2012 (HSI) and 2013 (K) for females, and 2014 (K) and 2016 (HSI) for males. Female and male GSI fluctuated without any clear pattern over the time-series: their lowest GSI occurred in 2009 and 2003 for females and males, respectively; the GSI for females increased since 2010 and remained above the levels of previous decades, whereas for males the index has remained the same (i.e. no clear pattern) until 2017; the index increased in 2018-19 in both cases. Of note, HSI increased from 2016 to 2017 and then declined in 2018 for both males and females, but increased in 2019 for females and continued to decline further in the case of males, whereas K increased for females from 2016 to 2018, and from 2016 to 2017 for males prior to declining in 2018 for males; the index declined in 2019 for both males and females. It should be noted that the data used for estimating the indices of physiological condition (as well length frequency distribution) were pooled from fish captured in all fishing communities/fishing enterprises, and that many of these enterprises 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 the unbalanced spatio-temporal design had a limited effect on the precision of the estimated indices.

SENTINEL SURVEY REMOVALS

Total removals (control plus experimental sites, all gears combined) of Atlantic Cod caught in Subdivision 3Ps Sentinel surveys over 2001-19 was highest in 2001-02 (38 t), declined by half during the period 2003-05 and then increased to 33 t in 2006; removals declined thereafter until 2011 and have since then fluctuated around 14 t annually (Fig. 21). At least 15 fish species have being recorded as bycatch in Sentinel surveys over 2005-19, and between 46-633 and 15-1593 individual fish have been recorded annually as bycatch by large mesh gillnet and linetrawl, respectively (Fig. 22). Bycatch species in the gillnet fishery consisted of: American Plaice (*Hippoglossoides platessoides*) which was the most common, followed by Winter Flounder (*Pseudopleuronectes americanus*) and Redfish (*Sebastes* sp.). Bycatch species in the linetrawl fishery consisted of: American Plaice, Redfish and Wolffish (*Anarhichus lupus* and *Anarhichus* sp.) which were the most common between 2002-11, with Redfish becoming the most common bycatch species thereafter. Other species reported infrequently as Sentinel bycatch were Haddock (*Melanogrammus aeglefinus*), Atlantic Halibut (*Hippoglossus hippoglossus*), Lumpfish (*Cyclopterus lumpus*), Pollock (*Pollachius virens*), Thorny Skate (*Amblyraja radiata*), Greenland Halibut (*Reinhardtius hippoglossoides*), White Hake (*Urophycis tenuis*), Witch Flounder (*Glyptocephalus cynoglossus*), and Yellowtail Flounder (*Limanda ferruginea*).

DISCUSSION

Sentinel survey coverage by small and large mesh gillnet is centered in Placentia Bay, mainly during the summer and early fall (east and west sides of the bay), and in late fall and early winter in sites located at the head of the bay (large mesh gillnet). Coverage by large mesh gillnet in Fortune Bay is limited to Grand Bank in summer and through most of the year in Seal Cove (1999-2004). The most comprehensive Sentinel survey coverage in Subdivision 3Ps is conducted by linetrawl harvesters, including several sites in Placentia Bay, Fortune Bay, and the southwest coast. Linetrawl surveys take place mostly in summer and fall in Placentia Bay, late fall and early winter in Fortune Bay, and through most of the year along the southwest coast.

The analysis of Sentinel catch rates aggregated by community and gear type indicated that the highest catch rates by gillnet harvesters were observed in Placentia Bay during the period 1995-98, whereas catch rates in Fortune Bay were considerably lower during the same period; catch rates declined by one order of magnitude in Placentia Bay since then and have remained

unchanged. For linetrawl, trends in catch rate for communities in Placentia Bay were similar to those observed for gillnets, but for communities from Fortune Bay and along the southwest coast, catch rates remained relatively high over the years. These findings suggest that an important component of the 3Ps Atlantic Cod stock was centred in Placentia Bay in the years immediately after the end of the moratorium (1997 onwards); and that component became depleted after a few years, likely resulting from the intense pressure from commercial fisheries and the concentration of fishing effort in the bay (Rideout et al. 2016). Commercial landings of Atlantic Cod in Placentia Bay comprised between 30% and 40% of the total reported annual landings from Subdivision 3Ps in most years since 1997, whereas annual landing from Fortune Bay and the southwest coast amounted to < 20% and < 10%, respectively (Healey et al. 2013, Ings et al. 2019). Sentinel catch rates by linetrawl harvesters indicate that the stock components found in Fortune Bay and the southwest coast were more resilient to depletion as the result of a less intense pressure from commercial fisheries in those areas over the years.

The standardized age-disaggregated catch rate from large mesh gillnet was comprised mostly of 6-8 year-old fish during the period of high relative abundance; 5-6 year-old fish accounted for most of the large gillnet catch during the period of low relative abundance, except in 2018-19, when the proportion of 7-8 year-old fish increased. The same age-classes contributed to the catch rate from linetrawl during the periods of high and low relative abundance, in addition the contribution of 3-5 year-old fish was higher for linetrawl over the years. Of note, catch rates from linetrawl in 2019 were considerably higher in relation to estimates from the previous 2-3 years, and were dominated by older age-classes, ranging between 6-10 years-old. It is unclear if the observed pattern from the 2019 estimates represent a real change in relative abundance and age composition of 3Ps Atlantic Cod in inshore areas, or the introduction of bias resulting from the limited aging data in 2019 and its impact on model performance. Moreover, estimates from the experimental sites mirrored those from the control sites to a large extent (both gears), suggesting that trends observed in standardized catch rates are representative of this stock in inshore waters during the summer and fall.

Temporal trends in independent indices such as inshore catch rates from Science logbooks and exploitation rates determined from tagging studies (Bratley and Healey 2006, Healey et al. 2012) are similar to those observed in the Sentinel indices. However, trends in Sentinel indices do not track well with the DFO spring multispecies survey abundance index for this stock (Mello et al. 2019). This may result from differences in the portion of the stock available to each survey. Subdivision 3Ps Atlantic Cod form part of a stock complex comprised of inshore and offshore populations that intermingle at periods other than spawning (Templeman, 1974 and 1979). This stock complex includes local coastal populations (Templeman 1979, Lawson and Rose 2000a, Robichaud and Rose 2001 and 2002, Mello and Rose 2005b), local offshore populations centered on the St. Pierre and Burgeo Banks and along the shelf edge (Bratley 1996, Bratley et al. 1999, Lawson and Rose 2000b), as well as Atlantic Cod from the Grand Bank and Northern Gulf of St. Lawrence populations which may seasonally occupy inshore and offshore areas of Subdivision 3Ps (Bratley 1996, 2000, and 2013). The movement and mixing of resident and non-resident fish, in addition to the existence of inshore components that are outside the coverage area at the time of the multispecies spring survey, have been identified as key sources of uncertainty impacting the index of relative abundance derived from this survey (DFO 2004, Ings et al. 2019). In contrast, Sentinel indices of relative abundance are estimated using data collected in inshore areas during the summer and fall.

Finally, while the number of enterprises participating in the Sentinel surveys has decreased over the years, this program constitutes an independent source of information that can be readily incorporated in resource assessments of commercial fish stocks like the Subdivision 3Ps

Atlantic Cod (Varkey et al. in press¹). It also engages stakeholders (e.g. inshore fish harvesters) to participate in the shared responsibilities of resource conservation and sustainable exploitation.

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APPENDIX I: TABLES

Table 1. Number of Sentinel survey sets (Gillnet 3¼ inch mesh) per fishing enterprise/community in Subdivision 3Ps, 1995-2020 (including sets with no catches). Data for 2020 are preliminary.

Community	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
St. Bride's	0	0	1	11	0	7	9	20	9	11	11	10	10
Little Hr. East	1	5	7	8	1	19	15	0	0	0	0	0	0
North Hr.	1	5	7	4	1	18	13	8	8	5	11	10	11
Garden Cove	0	0	0	0	0	0	0	0	0	0	0	0	0
Little Paradise	0	0	0	0	0	0	6	6	6	6	6	8	10
Red Hr.	0	0	0	0	0	0	0	6	2	4	0	0	1
Lawn	0	0	7	6	4	4	19	20	10	18	16	18	11
Lord's Cove	0	0	0	0	0	0	0	20	12	16	16	15	20
Total	2	10	22	29	6	48	62	80	47	60	60	61	53

Table 1 Continued

Community	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
St. Bride's	9	7	0	0	0	0	0	0	0	0	0	0	0
Little Hr. East	0	0	0	0	0	0	0	0	0	0	0	0	0
North Hr.	9	9	12	10	10	2	0	0	0	0	0	0	0
Garden Cove	0	0	0	0	0	7	9	10	9	10	9	10	3
Little Paradise	6	10	12	10	10	14	14	15	11	14	12	12	0
Red Hr.	0	0	8	2	2	0	0	2	0	0	0	0	0
Lawn	10	0	0	0	0	0	0	0	0	0	0	0	0
Lord's Cove	20	20	20	20	20	20	20	20	20	20	2	0	0
Total	54	46	52	49	42	43	43	47	40	44	23	24	3

Table 2. Number of Sentinel survey sets (Gillnet 5½ inch mesh) per fishing enterprise/community in Subdivision 3Ps, 1995-2020 (including sets with no catches). Data for 2020 are preliminary.

Community	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
St. Bride's	160	84	69	69	2	42	54	59	50	38	50	54	60
Fox Hr.	145	88	71	71	36	48	60	60	48	54	54	54	60
Little Hr. East	156	31	44	40	9	37	52	0	0	0	0	0	0
Arnold's Cove	4	0	8	21	2	20	0	0	0	0	0	0	0
North Hr.	111	63	59	44	18	55	42	34	37	25	44	40	43
Garden Cove	0	0	0	0	0	0	0	0	0	0	0	0	0
Monkstown	145	69	72	72	36	57	60	60	0	0	0	0	0
Little Paradise	0	6	17	29	24	30	30	24	18	36	30	36	48
Red Hr.	0	0	12	24	15	21	16	23	6	18	24	18	23
Lawn	0	32	62	65	32	60	59	60	26	54	52	54	48
Lord's Cove	39	39	40	48	36	48	60	58	35	54	53	53	60
Grand Bank	0	0	0	0	0	0	24	23	18	24	23	18	18
Rencontre East	0	0	2	18	0	0	0	0	0	0	0	0	0
Seal Cove	0	0	3	24	23	6	40	27	8	0	0	0	0
Total	760	412	459	525	233	424	497	428	246	303	330	327	360

Table 2 Continued

Community	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
St. Bride's	54	42	30	32	36	35	36	40	36	40	28	40	24
Fox Hr.	5260	60	60	60	57	60	58	60	59	59	60	60	35
Little Hr. East	00	0	0	0	0	0	0	0	0	0	0	0	0
Arnold's Cove	00	0	0	0	0	0	0	0	0	0	0	0	0
North Hr.	34	37	49	42	39	8	0	0	0	0	0	0	0
Garden Cove	0	0	0	0	0	54	54	60	53	60	54	72	18
Monkstown	0	0	0	0	0	0	0	0	0	0	0	0	0
Little Paradise	36	41	36	42	30	42	42	48	42	42	42	36	0
Red Hr.	11	16	16	14	10	4	8	8	4	24	20	20	20
Lawn	44	40	16	6	0	0	0	0	0	0	0	0	0
Lord's Cove	60	59	60	57	60	59	60	40	40	40	4	0	0
Grand Bank	18	18	30	12	31	16	14	25	14	0	16	52	52
Rencontre East	0	0	0	0	0	0	0	0	0	0	0	0	0
Seal Cove	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	317	313	317	265	263	278	272	282	248	265	224	280	149

Table 3. Number of Sentinel survey sets (Linetrawl) per fishing enterprise/community in Subdivision 3Ps, 1995-2020 (including sets with no catches). Data for 2020 are preliminary.

Community	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Arnold's Cove	147	63	61	6	5	22	0	0	0	0	0	0	0
Little Paradise	60	44	34	22	12	19	33	34	18	16	16	12	8
Red Hr.	41	36	28	13	5	11	17	28	14	11	12	16	17
Lord's Cove	15	9	21	2	0	0	1	4	0	0	0	0	0
Grand Bank	0	0	0	0	0	0	36	36	20	20	20	24	24
Rencontre East	174	96	64	56	36	90	71	60	20	32	40	36	36
Hr. Breton	154	39	27	28	31	45	31	53	34	30	33	40	30
Seal Cove	199	71	41	18	10	52	6	21	1	0	0	0	0
Ramea	201	46	96	60	38	88	92	88	46	36	44	44	49
Francois	181	66	74	68	30	52	35	22	25	10	42	38	28
Burgeo	0	46	60	62	28	36	64	45	36	24	28	44	40
Total	1172	516	506	335	195	415	386	391	214	179	235	254	232

Table 3 Continued

Community	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Arnold's Cove	0	0	0	0	0	0	0	0	0	0	0	0	0
Little Paradise	16	12	0	12	0	0	12	12	8	12	16	16	0
Red Hr.	23	16	16	18	18	28	17	30	8	24	20	20	16
Lord's Cove	0	0	0	0	0	0	0	0	0	0	0	0	0
Grand Bank	28	28	16	15	16	25	24	16	17	36	24	22	8
Rencontre East	36	36	36	36	40	40	40	40	40	40	40	40	0
Hr. Breton	38	34	37	36	36	32	40	38	32	44	40	43	4
Seal Cove	0	0	0	0	0	0	0	0	0	0	0	0	0
Ramea	50	48	48	48	48	46	48	48	0	0	0	0	0
Francois	32	22	27	0	0	0	0	0	0	0	0	0	0
Burgeo	36	41	40	40	24	34	32	32	36	40	34	26	24
Total	259	237	220	205	182	205	213	216	141	196	174	167	52

Table 4. Model information and results of fitting age-disaggregated and age-aggregated standardized Sentinel catch rates for large mesh (5½ inch) gillnets, using data from control and experimental sites in Subdivision 3Ps, 1995-2019.

Class	Level	Values
Fishing Site	16	61 61.5 63 63.5 64 65 66 66.5 67 68 69 70 71 71.5 73 75
Month	6	6 7 8 9 10 11
Year	25	1995-2019
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)	59	3741	88.36	<.0001	5213.38	<.0001
Age (Year)	199	3741	104.02	<.0001	20699.2	<.0001

Age-disaggregated - Experimental Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	63	3769	70.52	<.0001	4442.73	<.0001
Age (Year)	199	3769	117.01	<.0001	23284.1	<.0001

Age-aggregated - Control Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	59	416	13.20	<.0001	778.71	<.0001
Year	24	416	49.93	<.0001	1198.33	<.0001

Age-aggregated - Experimental Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	63	416	10.71	<.0001	674.68	<.0001
Year	24	416	55.01	<.0001	1320.22	<.0001

Table 5. Model information and results of fitting age-disaggregated and age-aggregated standardized Sentinel catch rates for linetrawl, using data from control and experimental sites in Subdivision 3Ps, 1995-2019.

Class	Level	Values
Fishing Site	16	62 65 68 69 70 71 71.5 73 74 75 76 76.5 76.75 77 77.5 78
Month	6	6 7 8 9 10 11
Year	25	1995-2019
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)	69	2923	29.63	<.0001	2044.59	<.0001
Age (Year)	199	2923	38.19	<.0001	7599.98	<.0001

Age-disaggregated - Experimental Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	68	2932	24.58	<.0001	1671.51	<.0001
Age (Year)	199	2932	40.59	<.0001	8077.80	<.0001

Age-aggregated - Control Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	69	305	6.19	<.0001	427.40	<.0001
Year	24	305	7.96	<.0001	190.93	<.0001

Age-aggregated - Experimental Sites

Source	Num DF	Den DF	F Value	Pr > F	Chi-Square	Pr > ChiSq
Month (Fishing Site)	68	307	5.19	<.0001	353.26	<.0001
Year	24	307	8.22	<.0001	197.35	<.0001

APPENDIX II: FIGURES

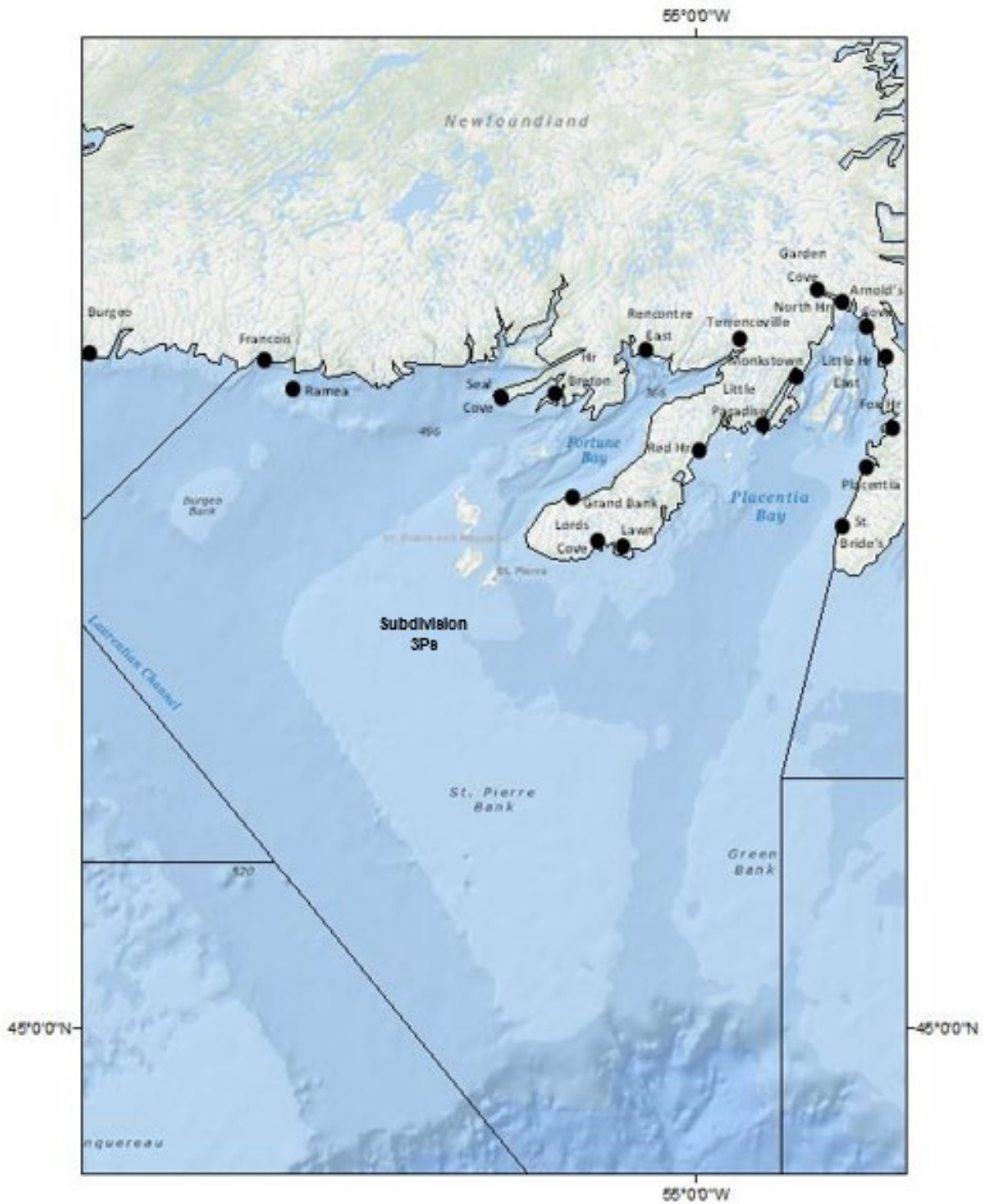


Figure 1. Map of NAFO Subdivision 3Ps indicating the communities that have participated in Sentinel fisheries survey, 1995-2020.

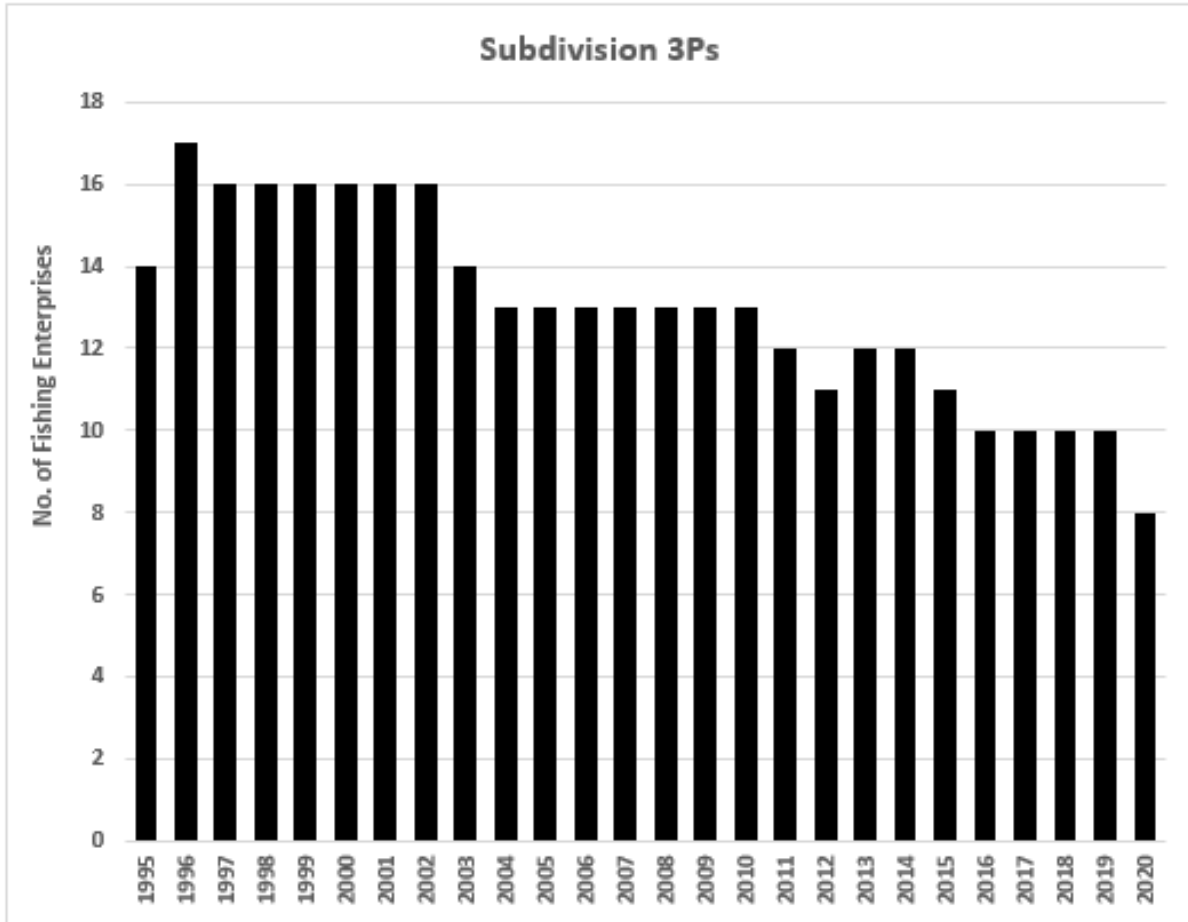


Figure 2. Number of fishing enterprises that have participated in the Sentinel fisheries survey annually between 1995 and 2020.

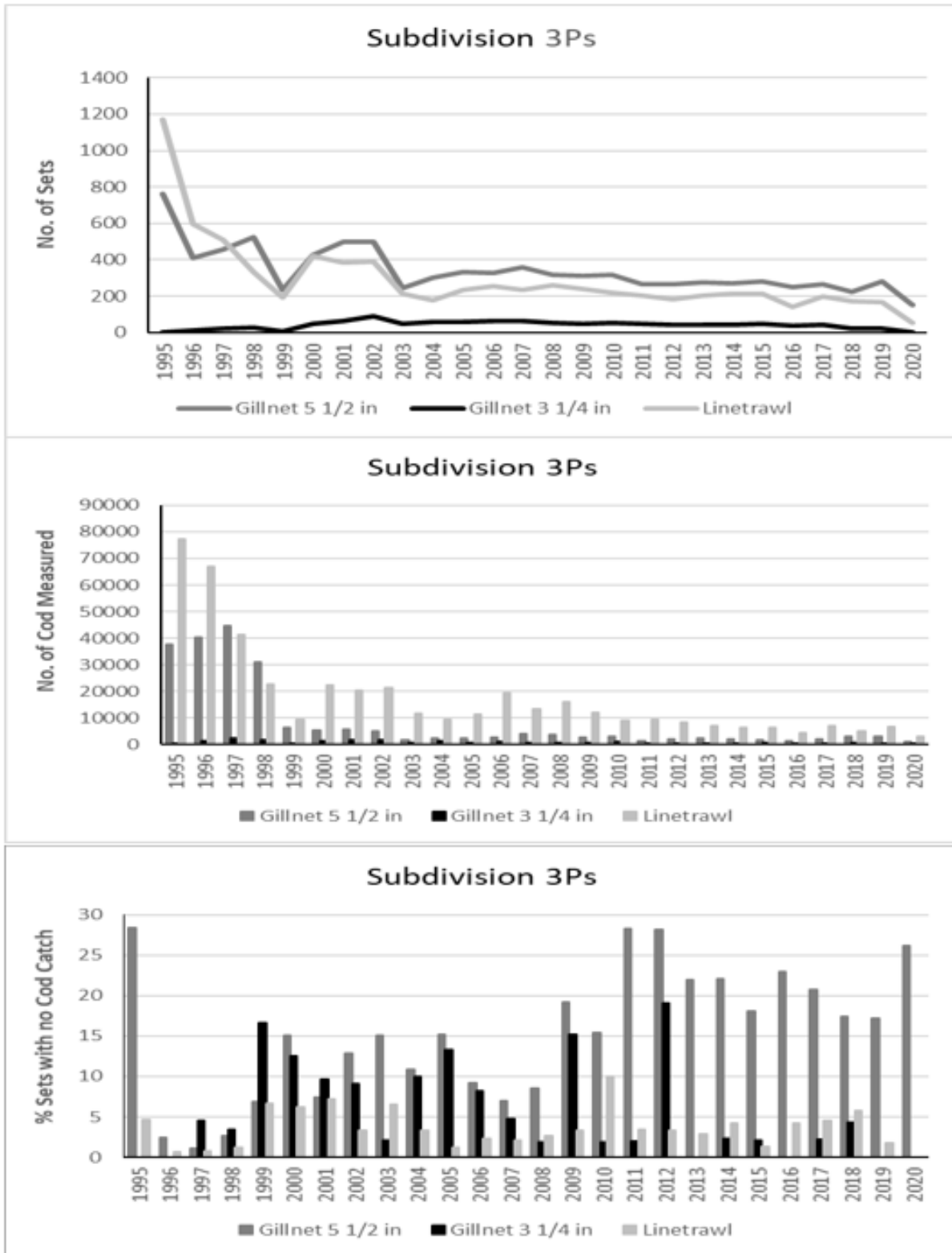


Figure 3. Annual Sentinel survey number of sets by gear type (top panel), the number of Atlantic Cod caught by gear type (middle panel), and the percentage of sets with no cod catch (bottom panel) in Subdivision 3Ps, 1995-2020. Data for 2020 are preliminary.

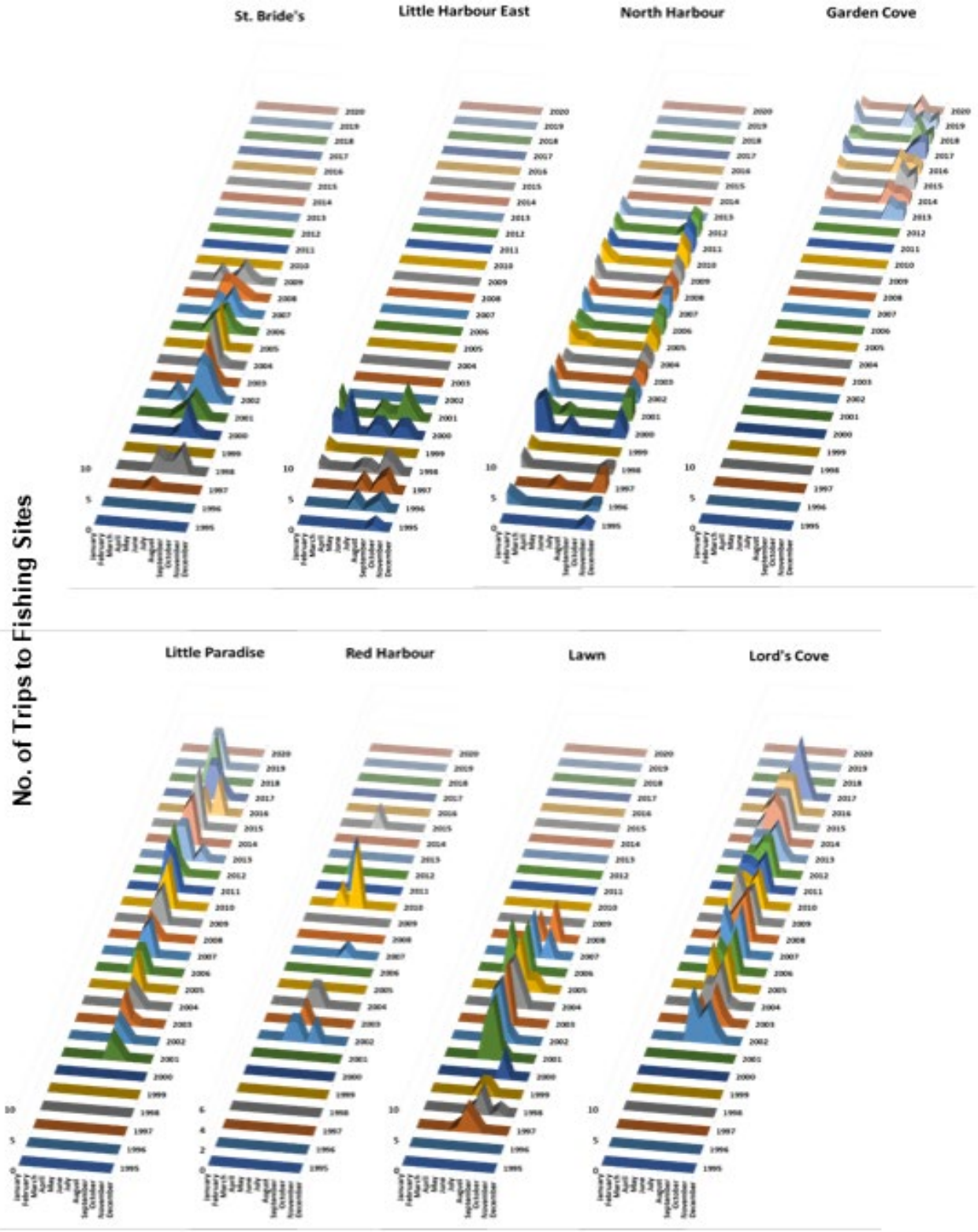


Figure 4. Monthly Sentinel survey coverage per community (No. of Trips to Fishing Sites) by small mesh gillnet harvesters in Subdivision 3Ps, 1995-2020. Data for 2020 are preliminary

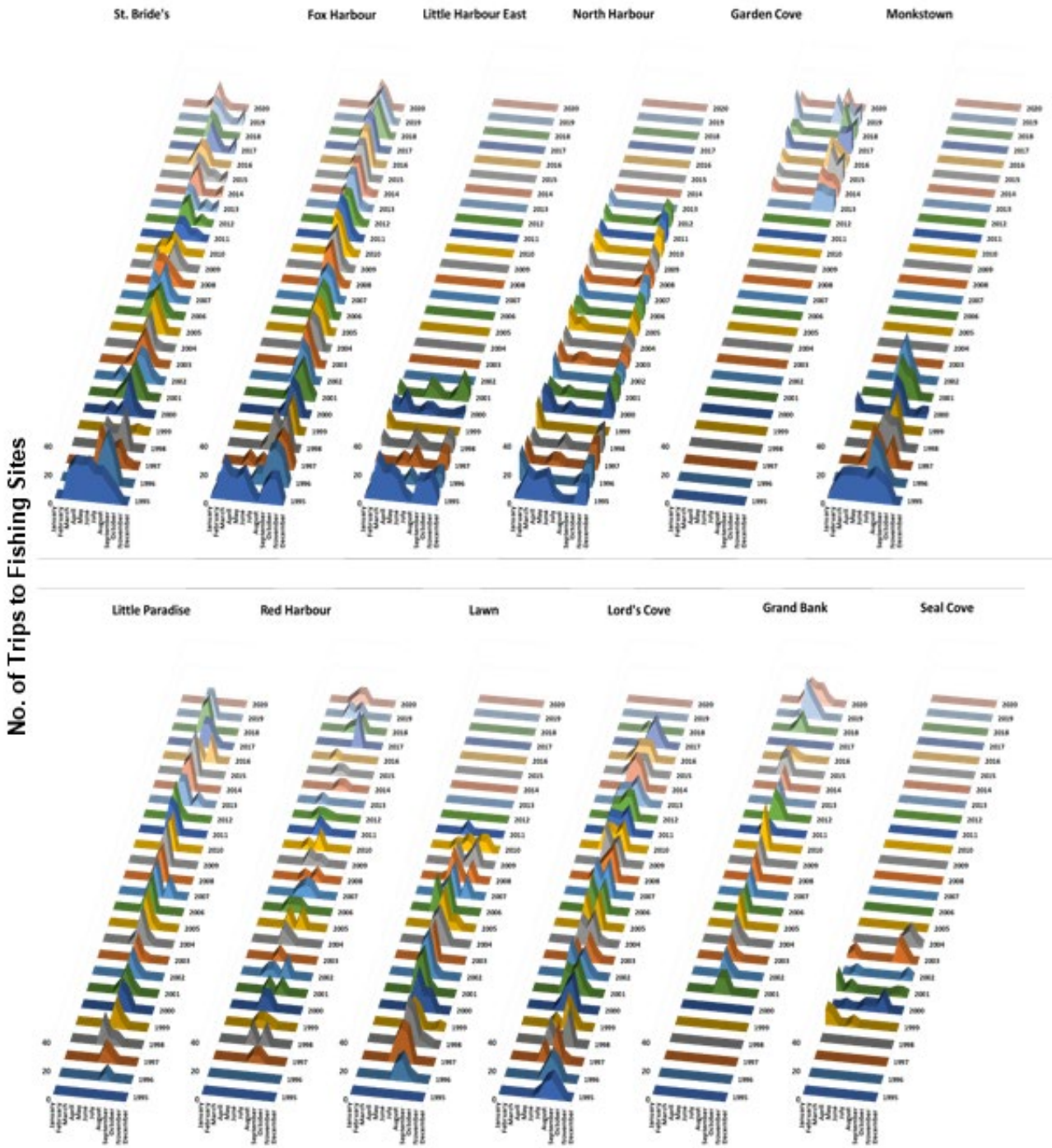


Figure 5. Monthly Sentinel survey coverage per community (No. of Trips to Fishing Sites) by large mesh gillnet harvesters in Subdivision 3Ps, 1995-2020. Data for 2020 are preliminary.

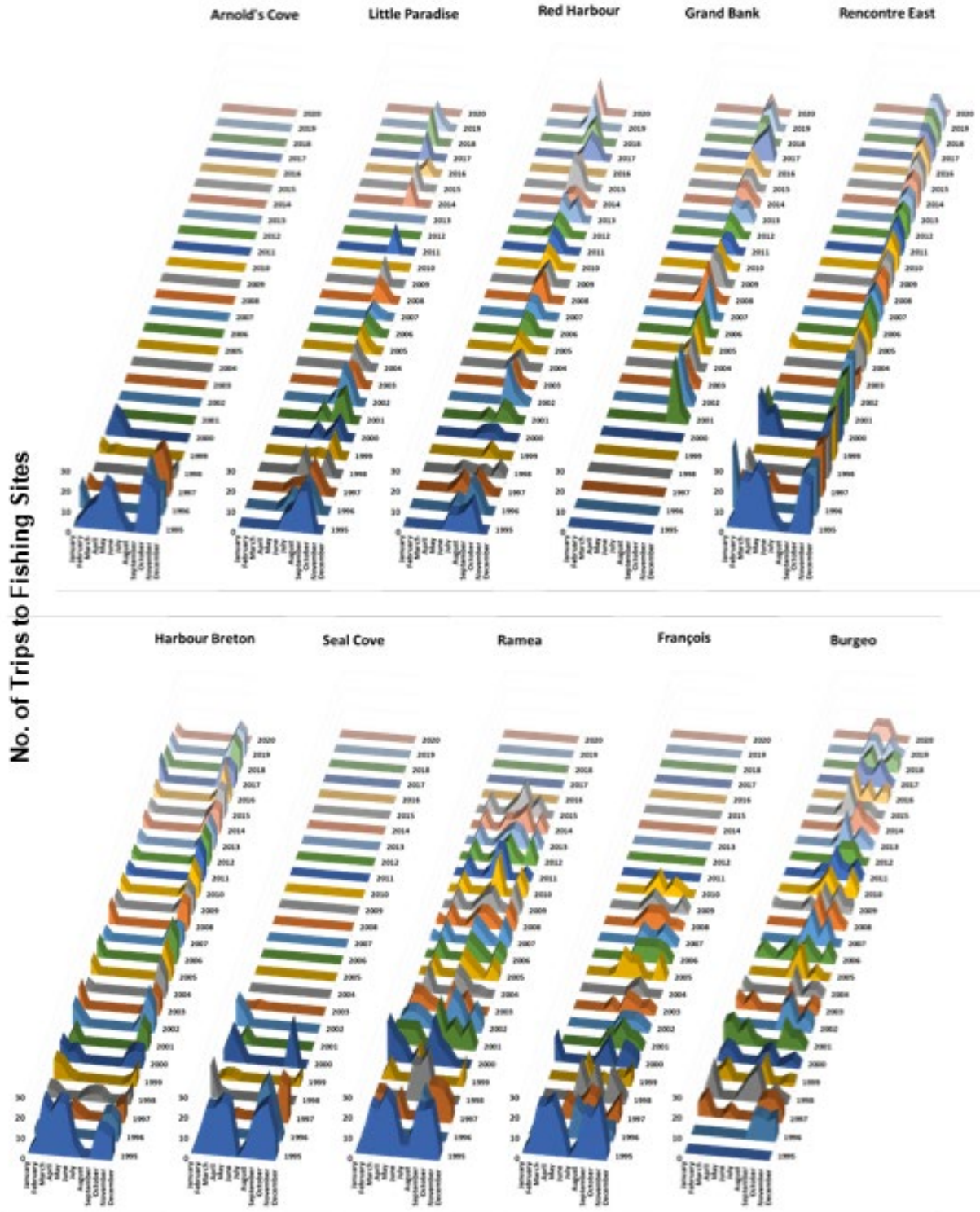


Figure 6. Monthly Sentinel survey coverage per community (No. of Trips to Fishing Sites) by linetrawl harvesters in Subdivision 3Ps, 1995-2020. Data for 2020 are preliminary.

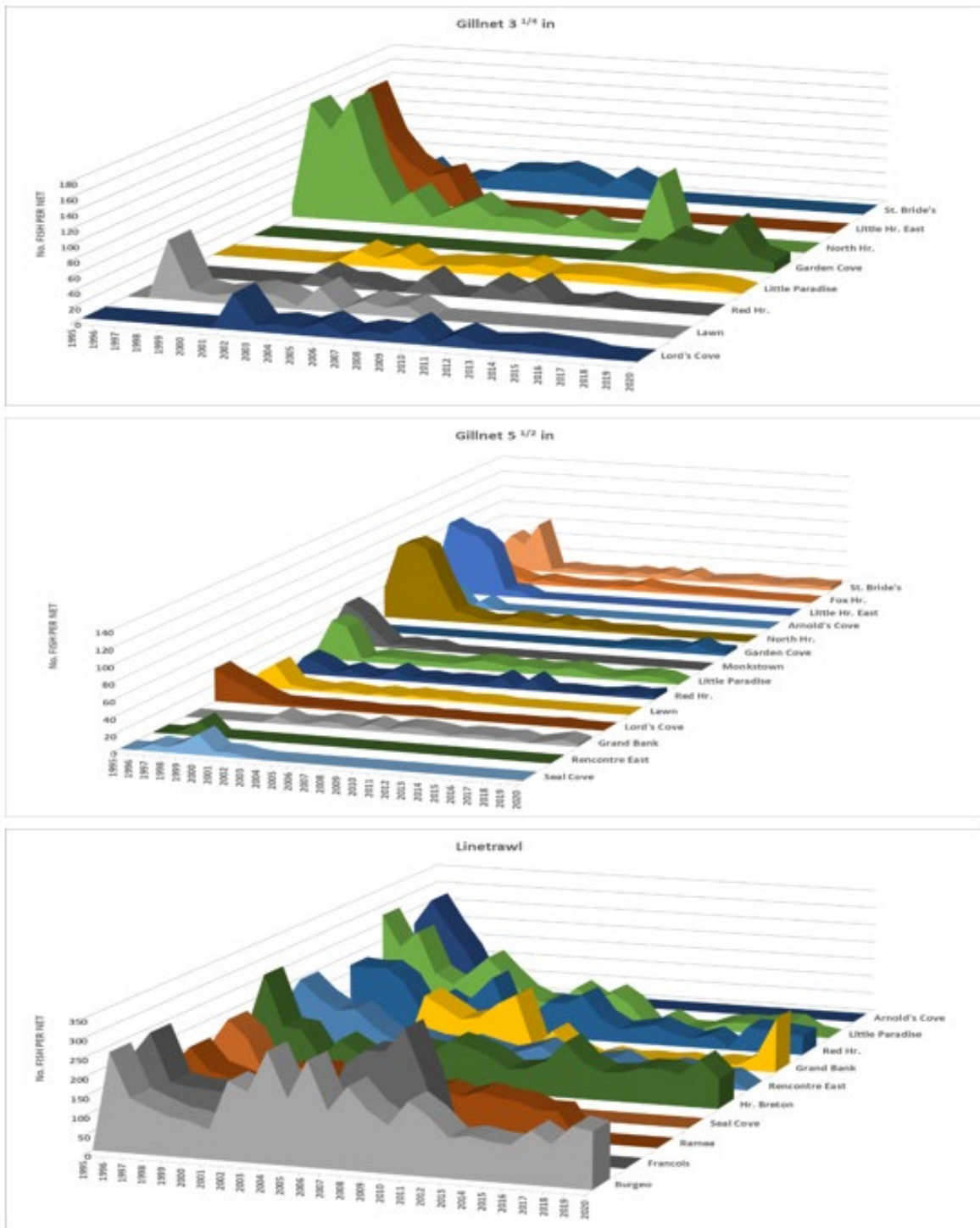


Figure 7. Distribution of mean annual catch rates of Atlantic Cod from small and large mesh gillnet and linetrawl (1995-2020), aggregated by fishing communities of Sentinel surveys in Subdivision 3Ps (control and experimental sites combined). Data for 2020 are preliminary.

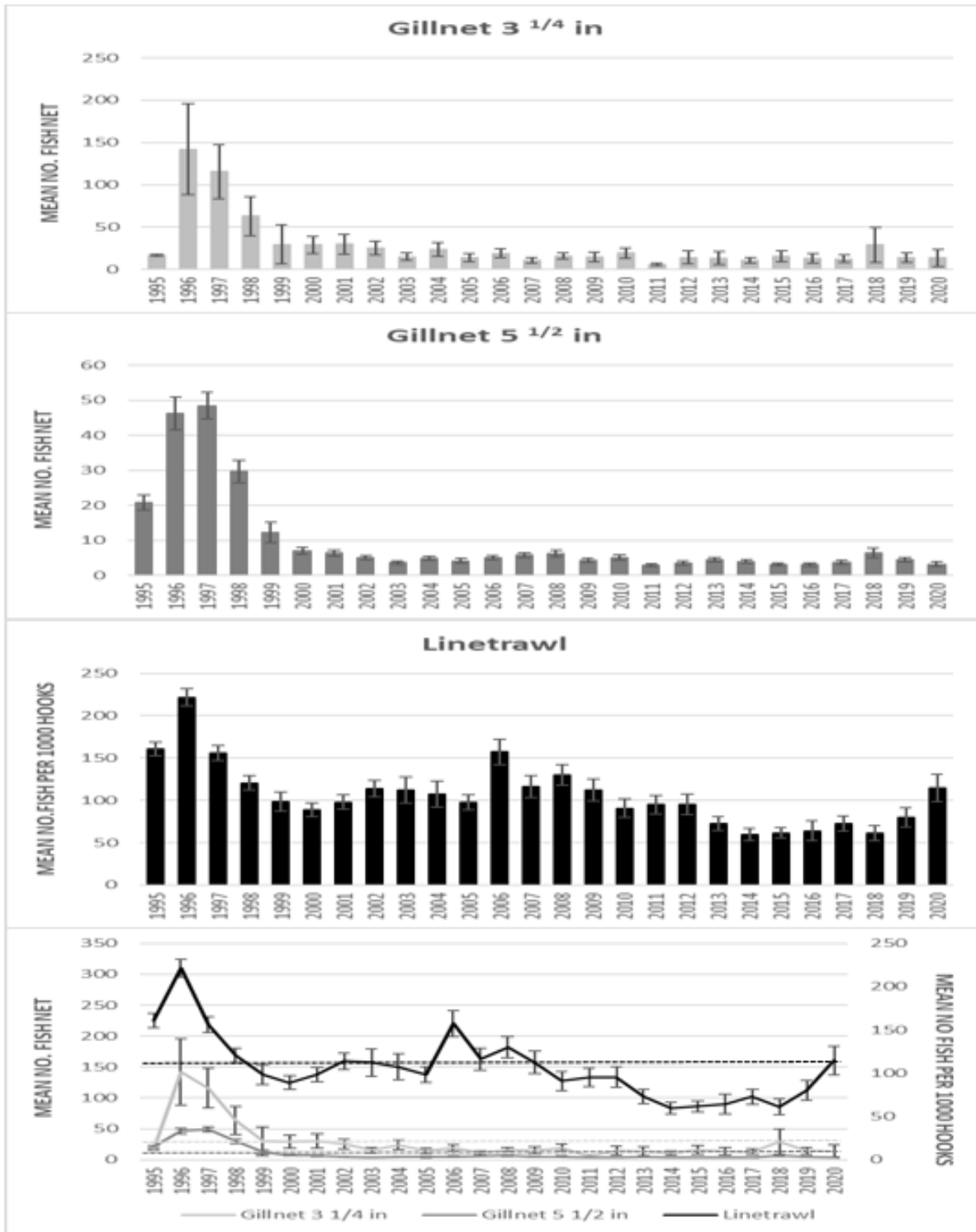


Figure 8. Mean annual catch rate of Atlantic Cod from small and large mesh gillnets and linetrawl, as well as all gears combined in a single plot from Sentinel surveys in Subdivision 3Ps (control and experimental sites combined). Dotted line = time-series mean, T-bars = +/- 95% CI. Data for 2020 are preliminary.

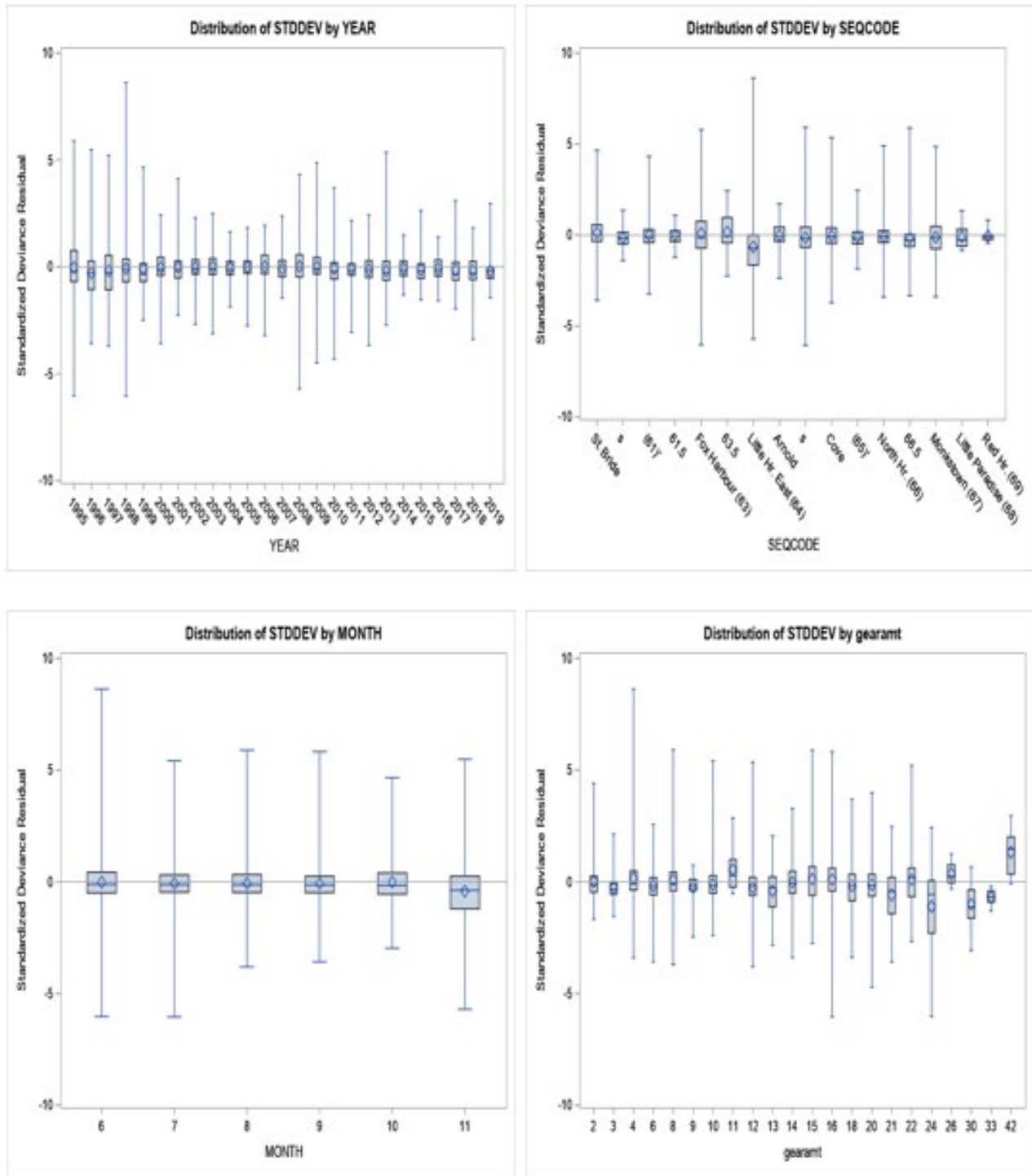


Figure 9. Deviance residuals ($\pm 95\%$ CI) from the standardized catch rate model (control sites) for large mesh gillnet in Subdivision 3Ps, 1995-2019. Panels show residuals plotted by Year, Month, Fishing Site (SEQCODE), and Fishing Effort (gearamt).

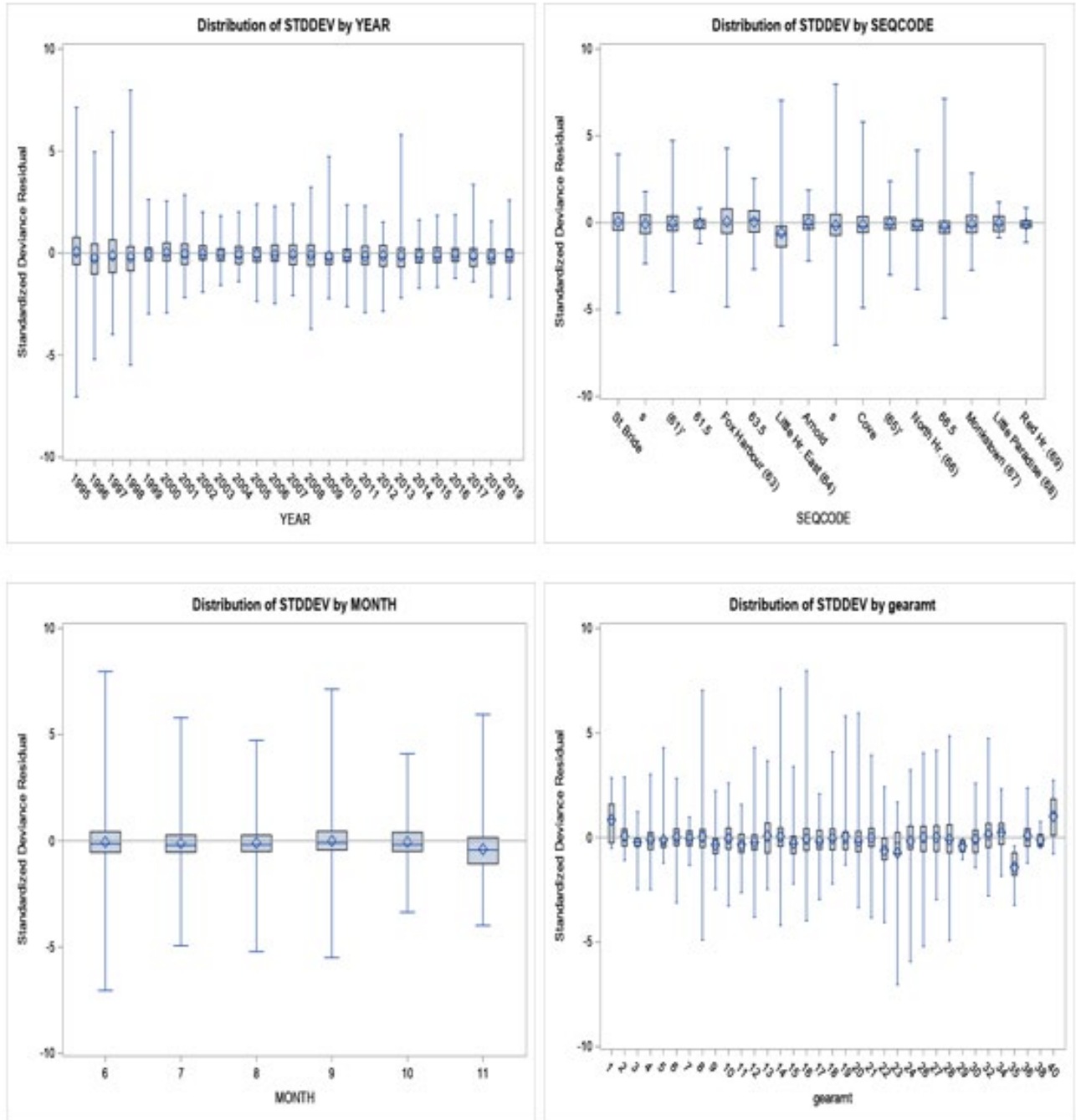


Figure 10. Deviance residuals ($\pm 95\%CI$) from the standardized catch rate model (experimental sites) for large mesh gillnet in Subdivision 3Ps, 1995-2019. Panels show residuals plotted by Year, Month, Fishing Site (SEQCODE), and Fishing Effort (gearmt).

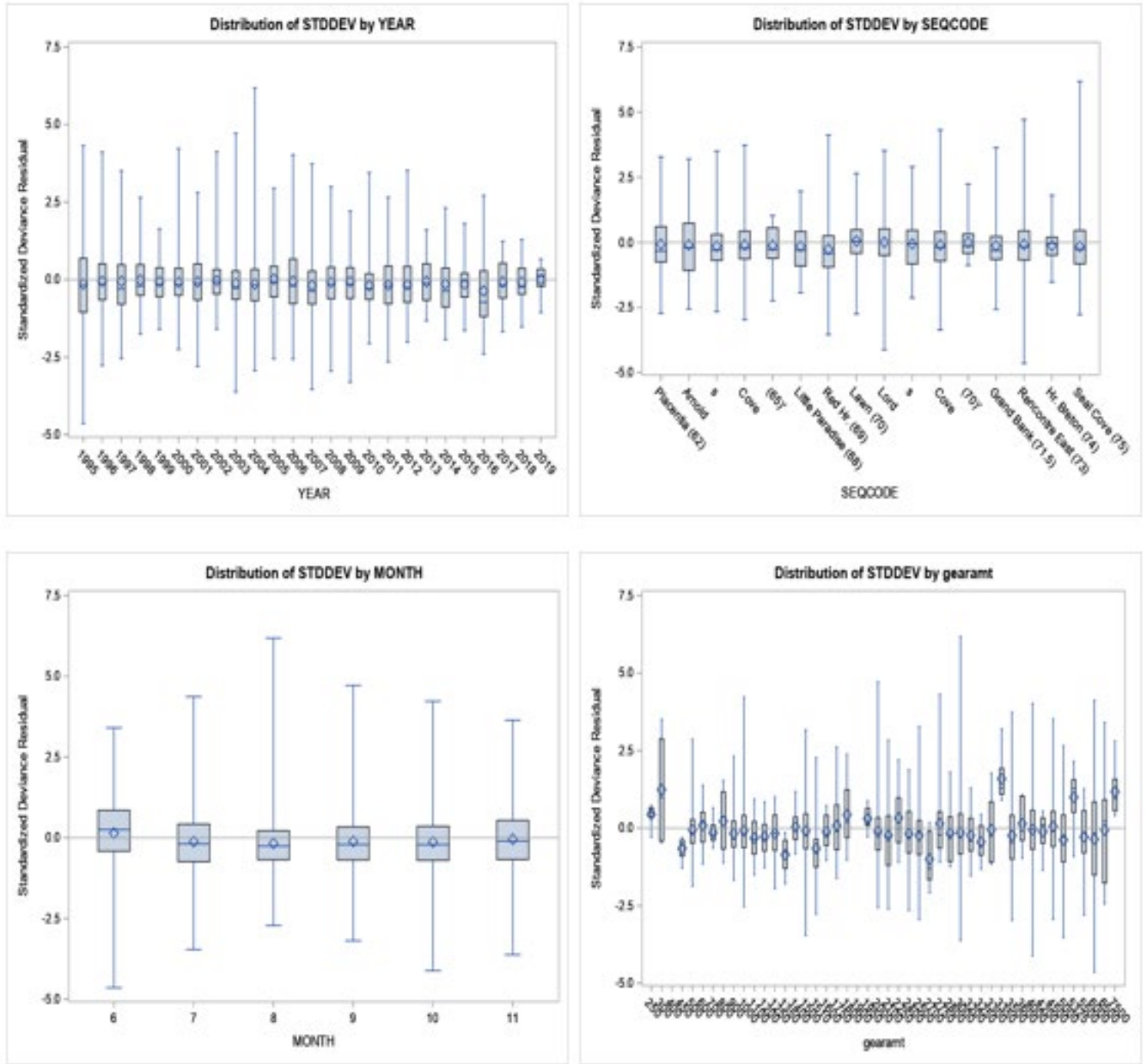


Figure 11. Deviance residuals ($\pm 95\%$ CI) from the standardized catch rate model (control sites) for linetrawl in Subdivision 3Ps, 1995-2019. Panels show residuals plotted by Year, Month, Fishing Site (SEQCODE), and Fishing Effort (gearamt).

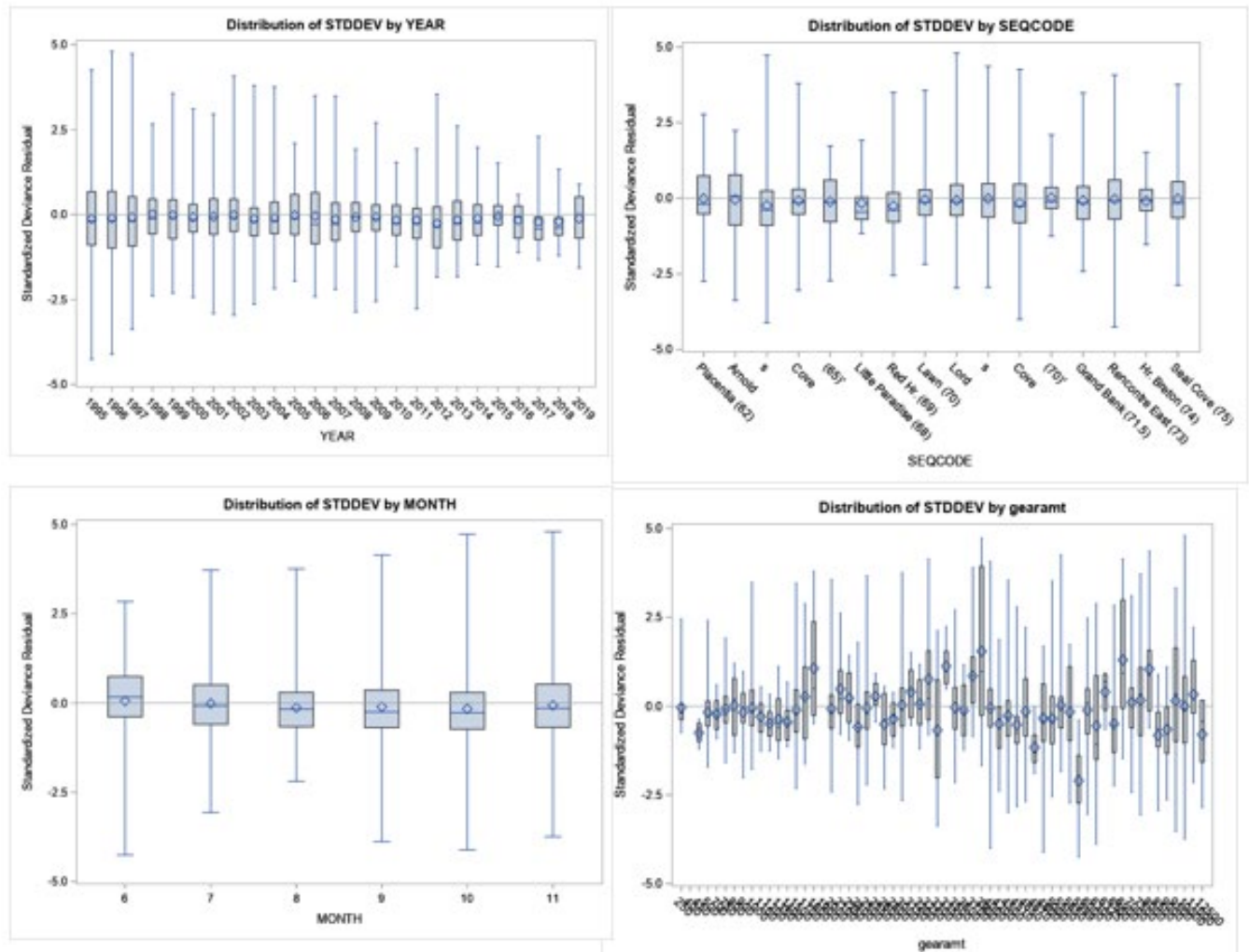


Figure 12. Deviance residuals ($\pm 95\%CI$) from the standardized catch rate model (experimental sites) for linetrawl in Subdivision 3Ps, 1995-2019. Panels show residuals plotted by Year, Month, Fishing Site (SEQCODE), and Fishing Effort (gearamt).

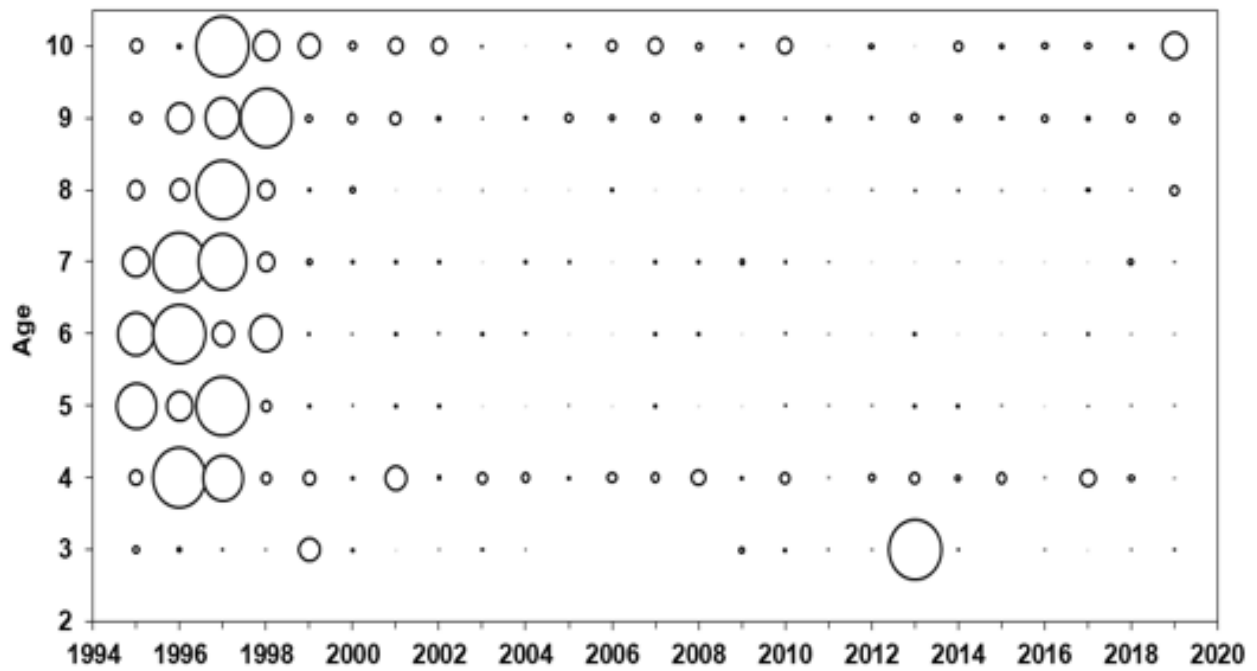
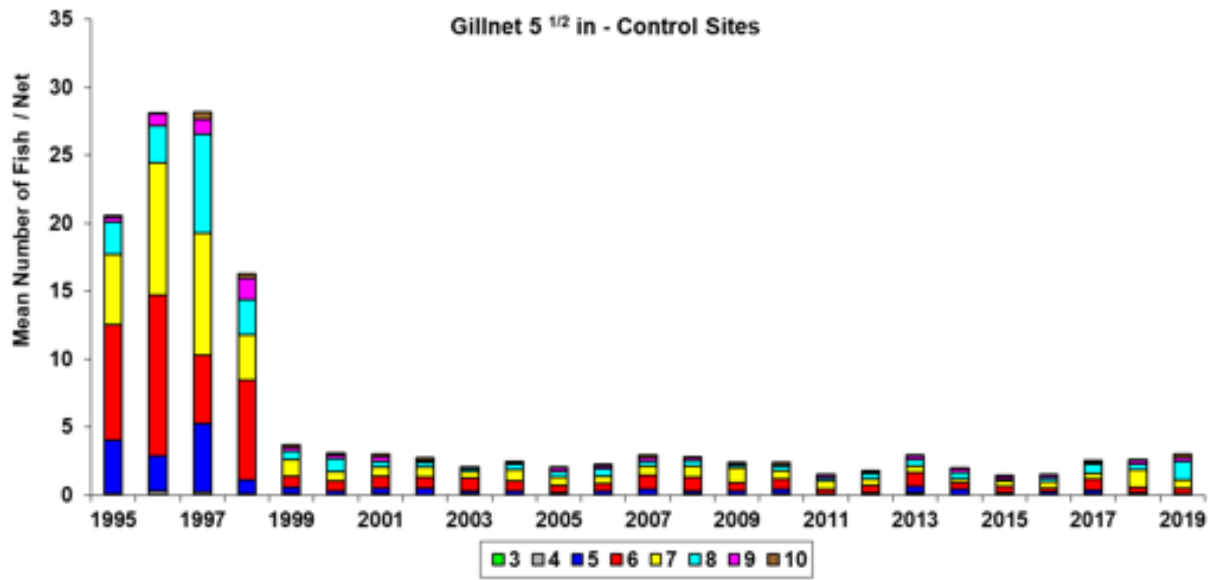


Figure 13. Standardized age-disaggregated catch rate for large mesh gillnet (top panel), and the proportions of catch rate-at-age (bottom panel) using data from Sentinel survey control sites in Subdivision 3Ps, 1995-2019.

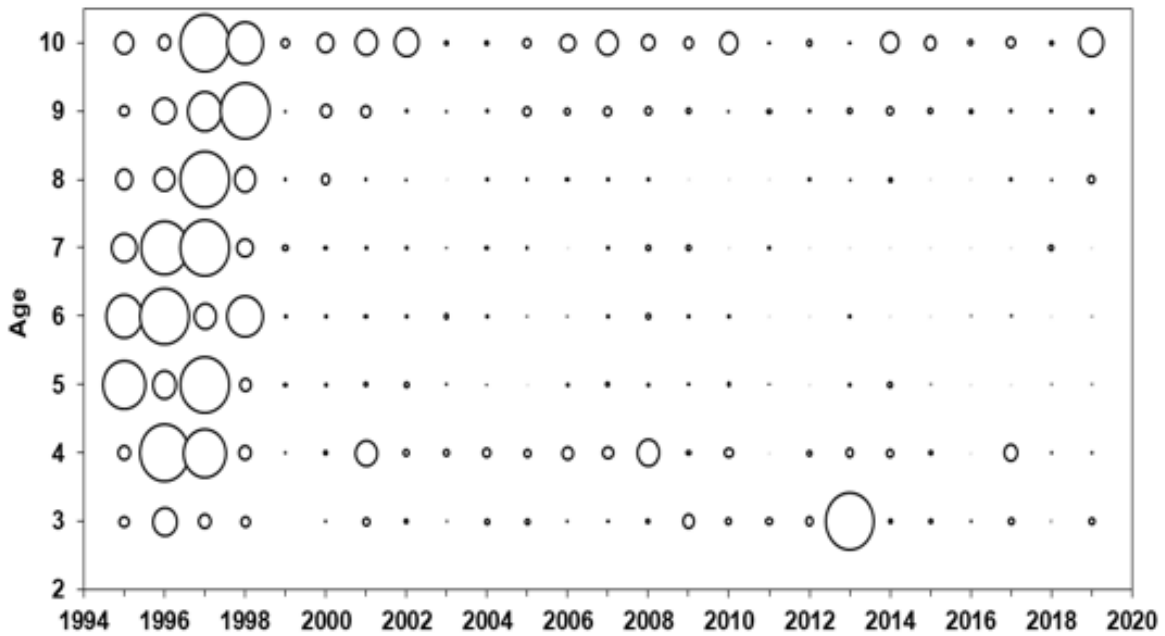
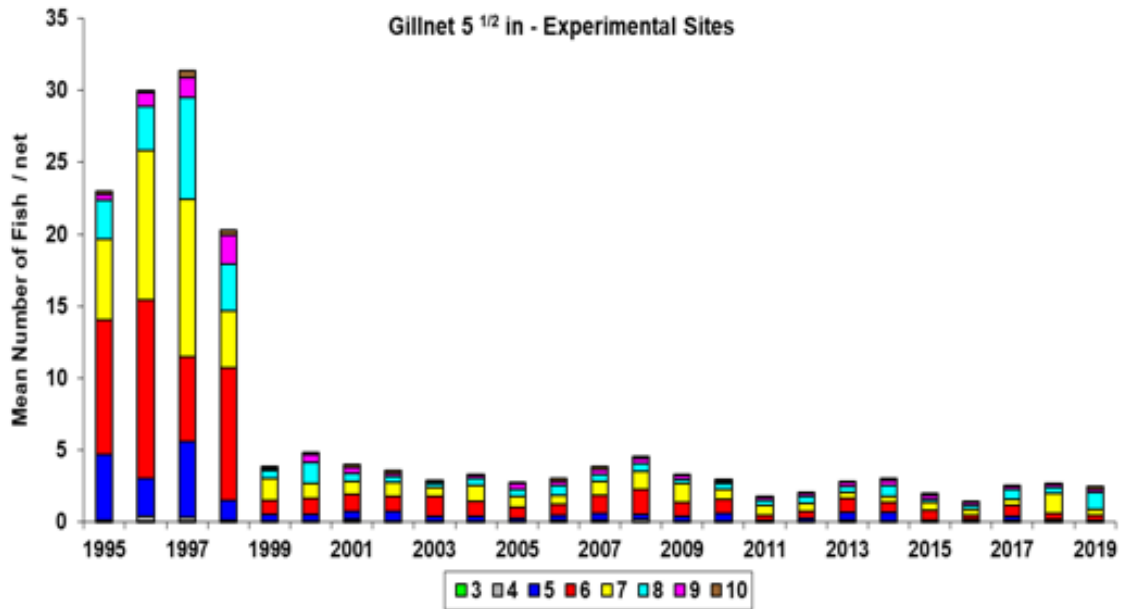


Figure 14. Standardized age-disaggregated catch rate for large mesh gillnet (top panel), and the proportions of catch rate-at-age (bottom panel) using data from Sentinel survey experimental sites in Subdivision 3Ps, 1995-2019.

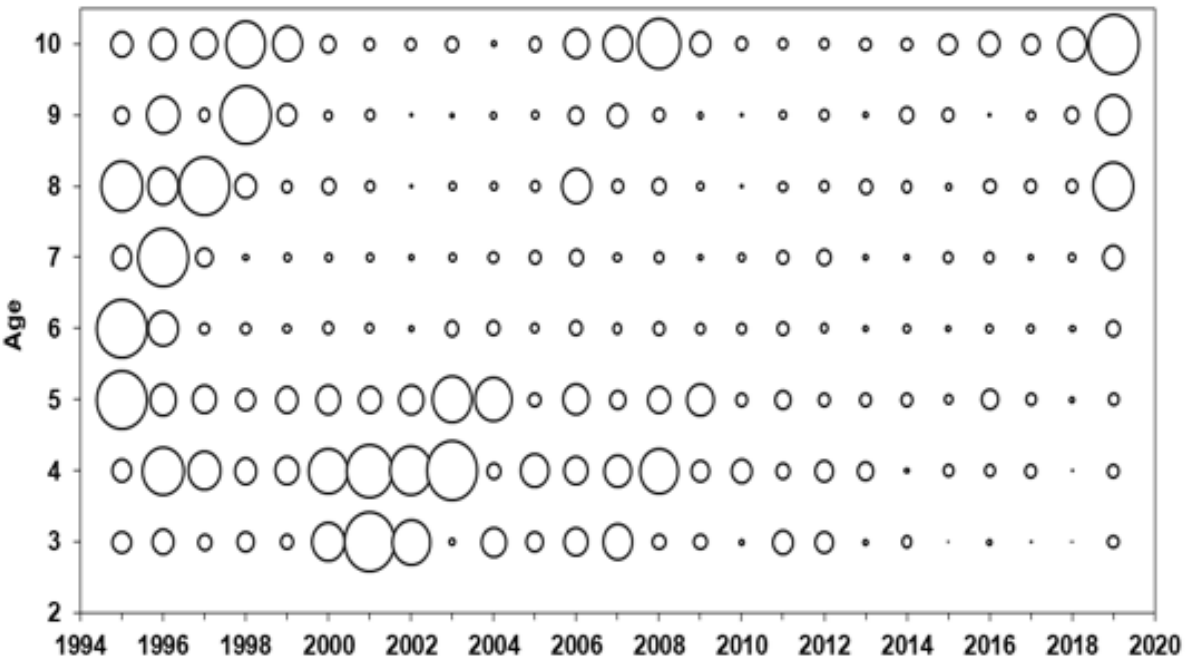
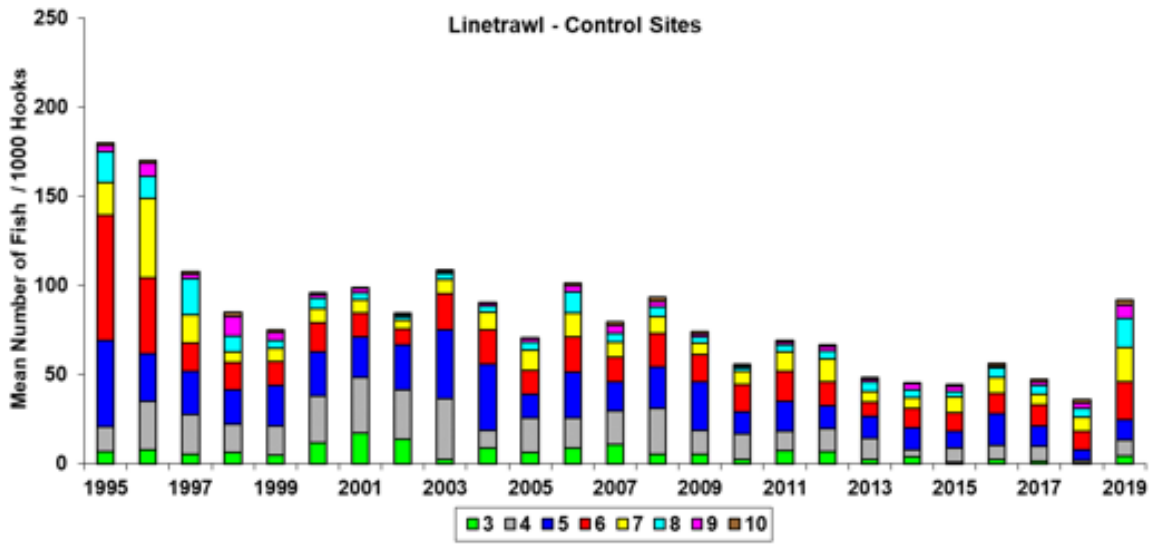


Figure 15. Standardized age-disaggregated catch rate for linetrawl (top panel), and the proportions of catch rate-at-age (bottom panel) using data from Sentinel survey control sites in Subdivision 3Ps, 1995-2019.

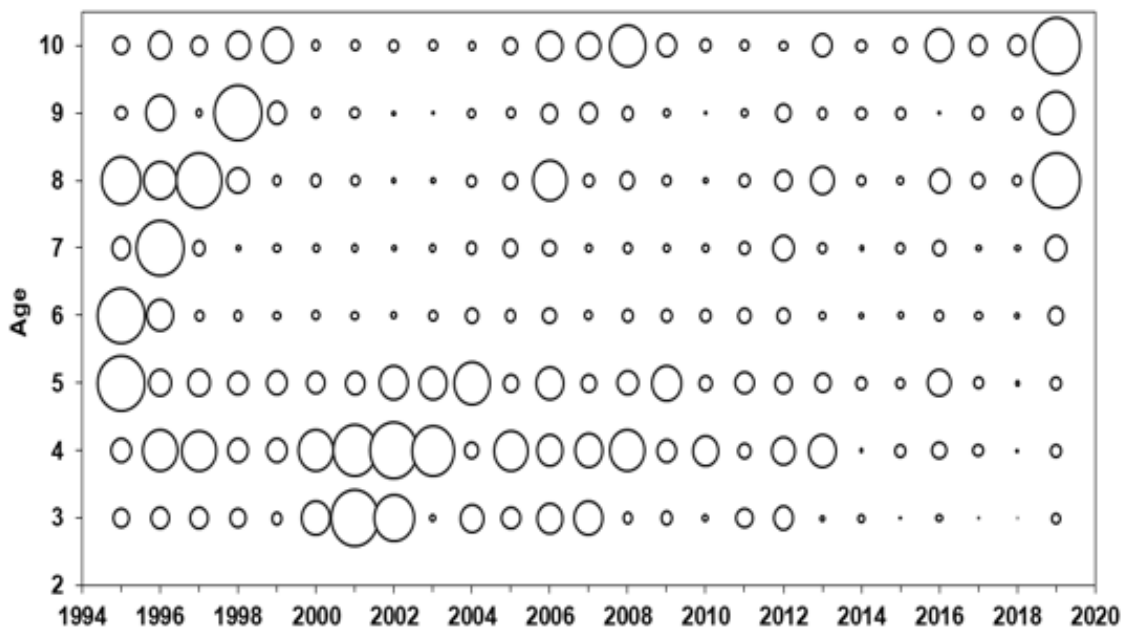
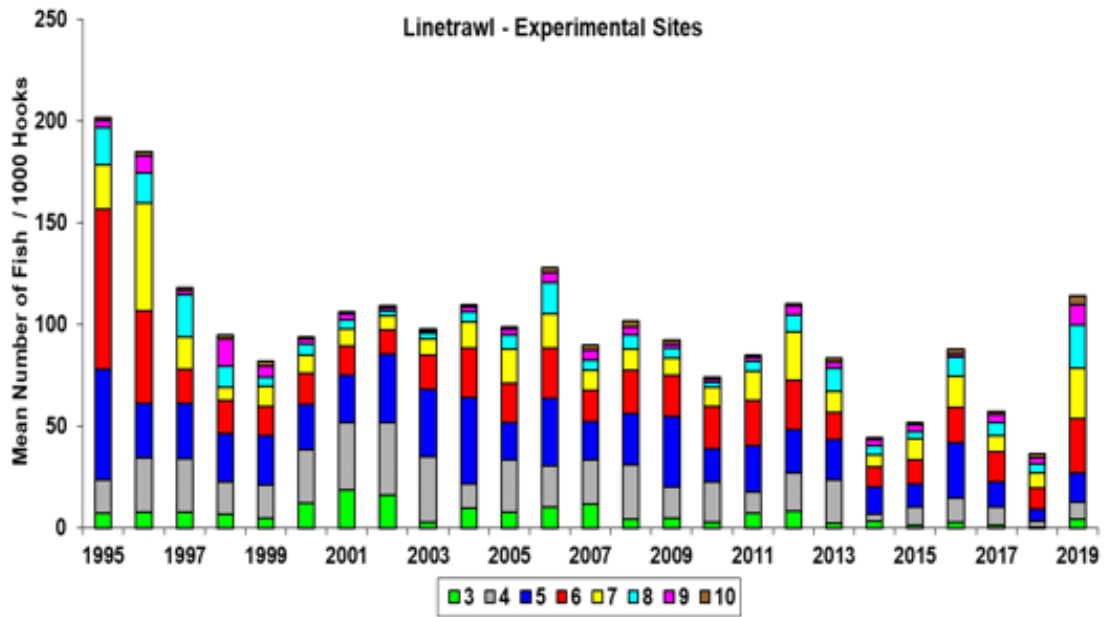


Figure 16. Standardized age-disaggregated catch rate for linetrawl (top panel), and the proportions of catch rate-at-age (bottom panel) using data from Sentinel survey experimental sites in Subdivision 3Ps, 1995-2019.

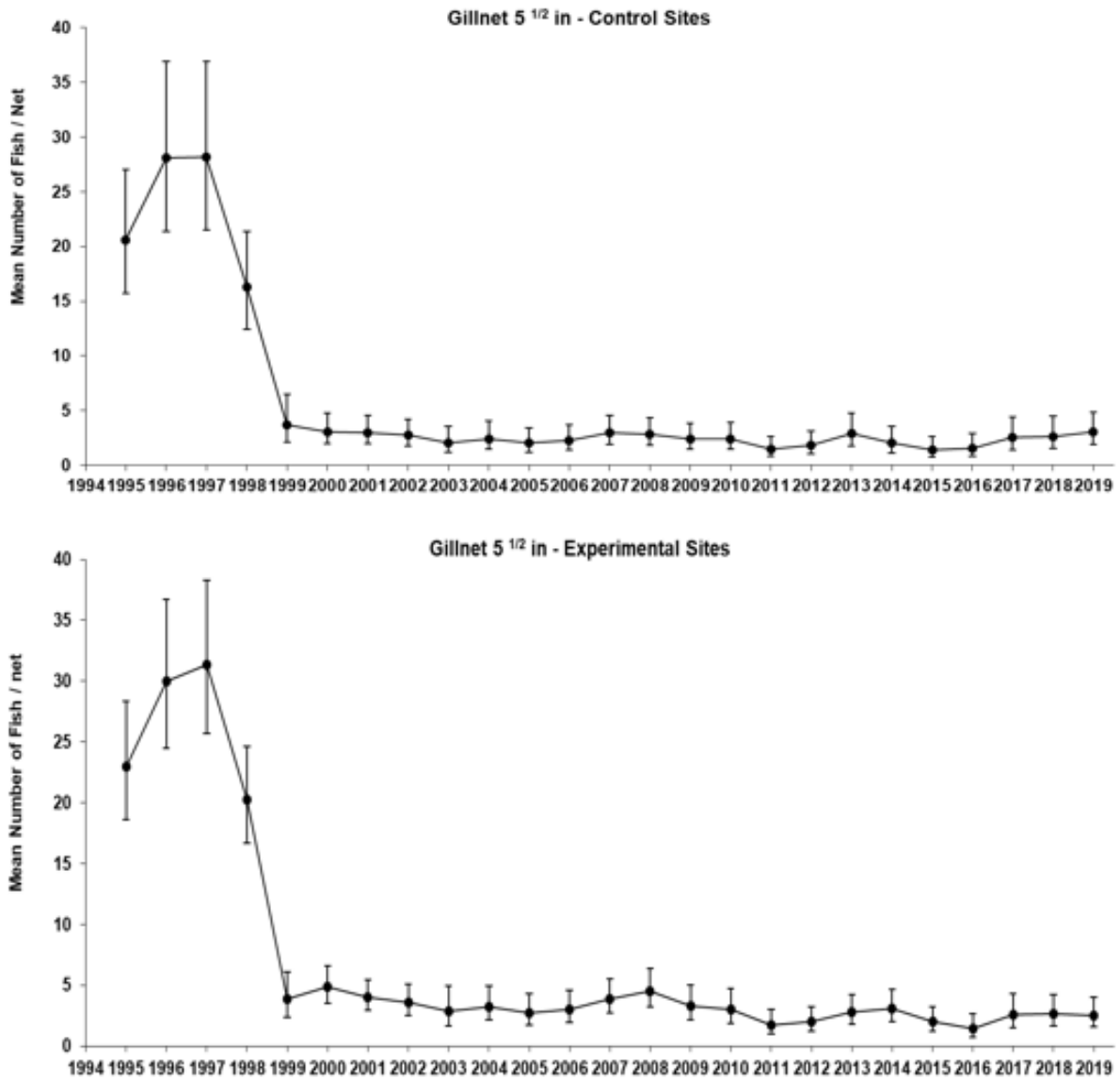


Figure 17. Standardized age-aggregated catch rate for large mesh gillnet (+/-95% CI), using data from Sentinel survey control (top panel) and experimental (bottom panel) sites in Subdivision 3Ps, 1995-2019.

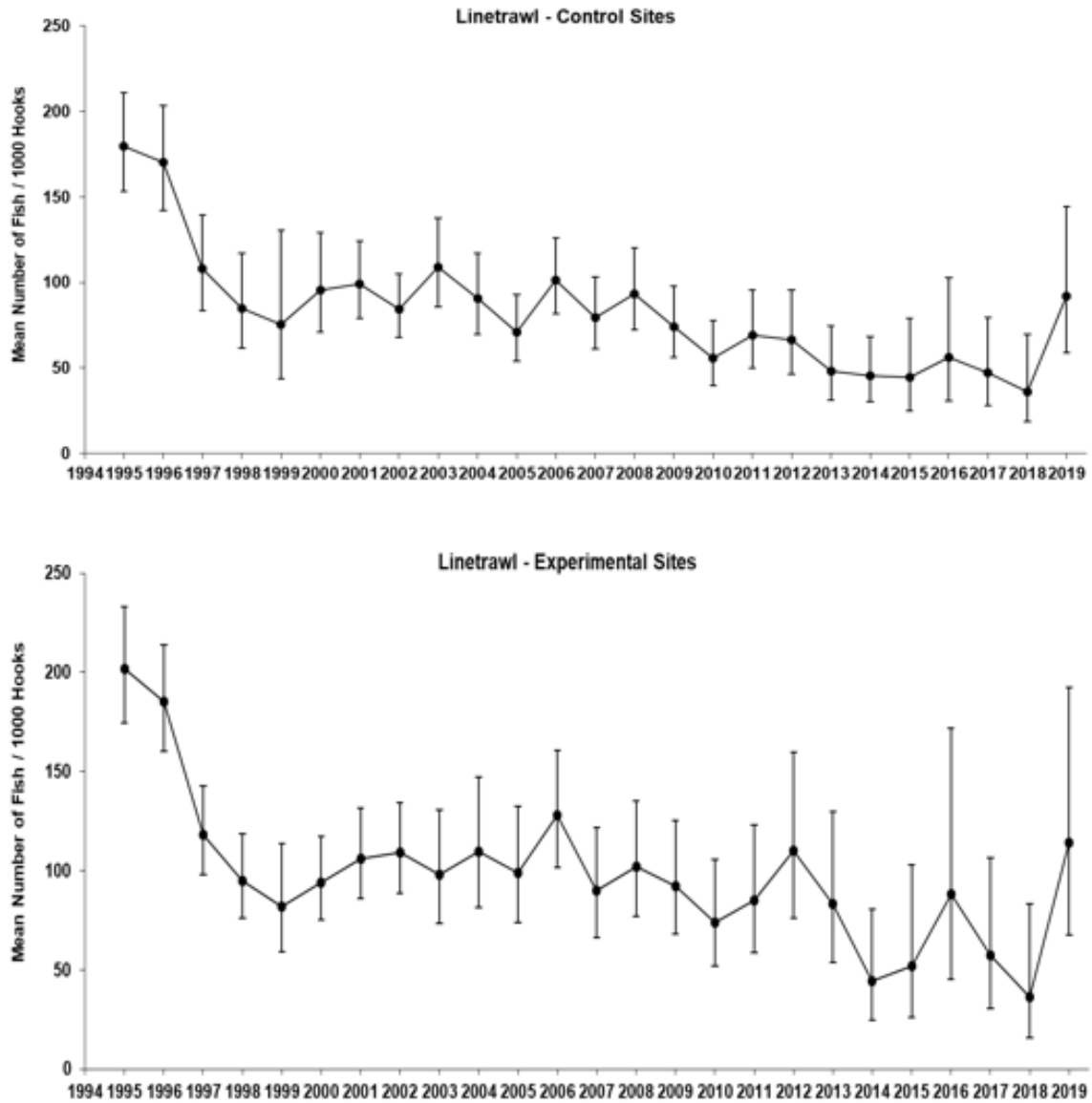


Figure 18. Standardized age-aggregated catch rate for linetrawl (+/-95% CI), using data from Sentinel survey control (top panel) and experimental (bottom panel) sites in Subdivision 3Ps, 1995-2019.

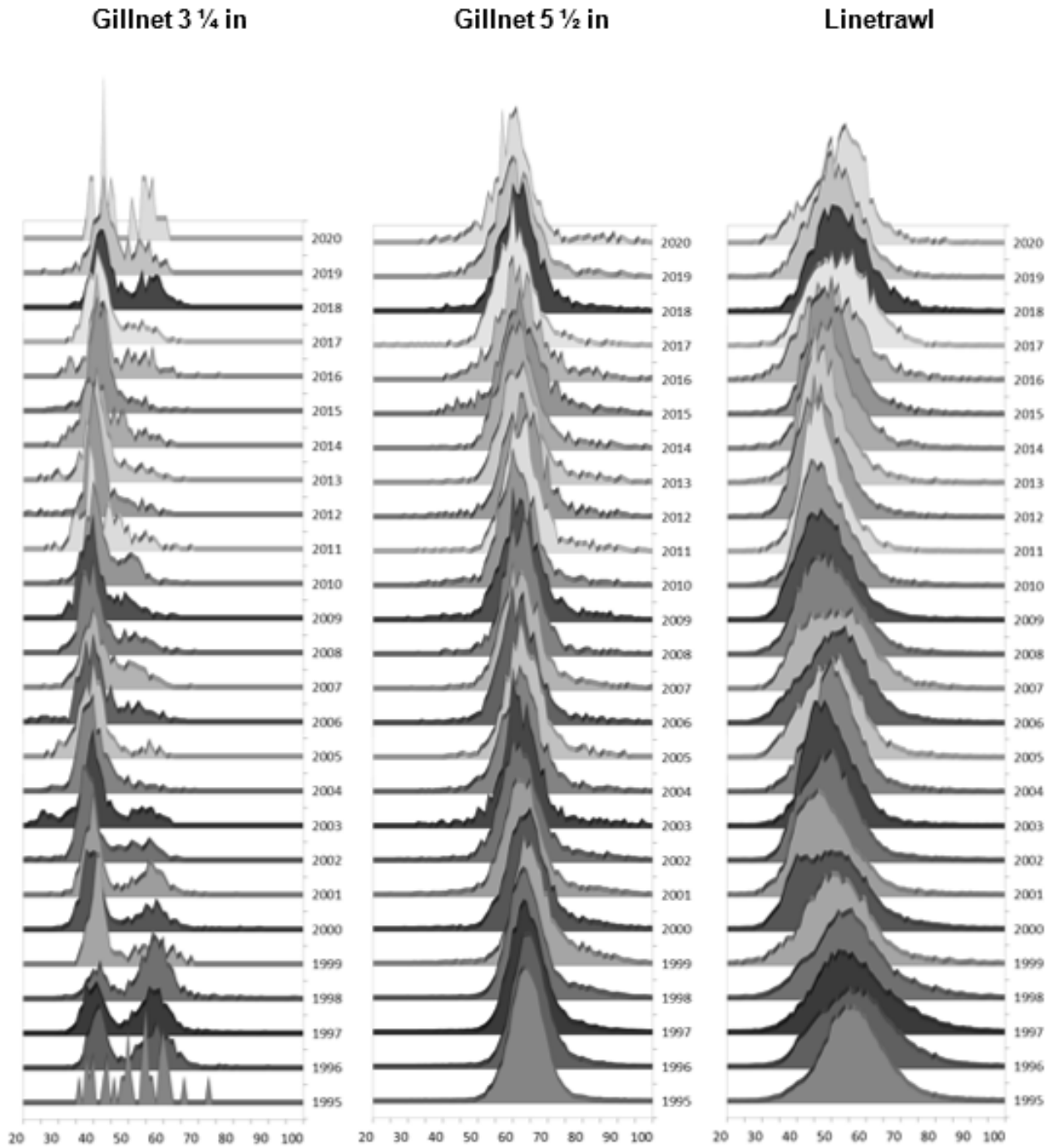


Figure 19. Length distributions ($N=692,456$ fish, number at length scaled to 1) of Atlantic Cod from Sentinel surveys in Subdivision 3Ps (control and experimental sites combined), 1995-2020. Data for 2020 are preliminary.

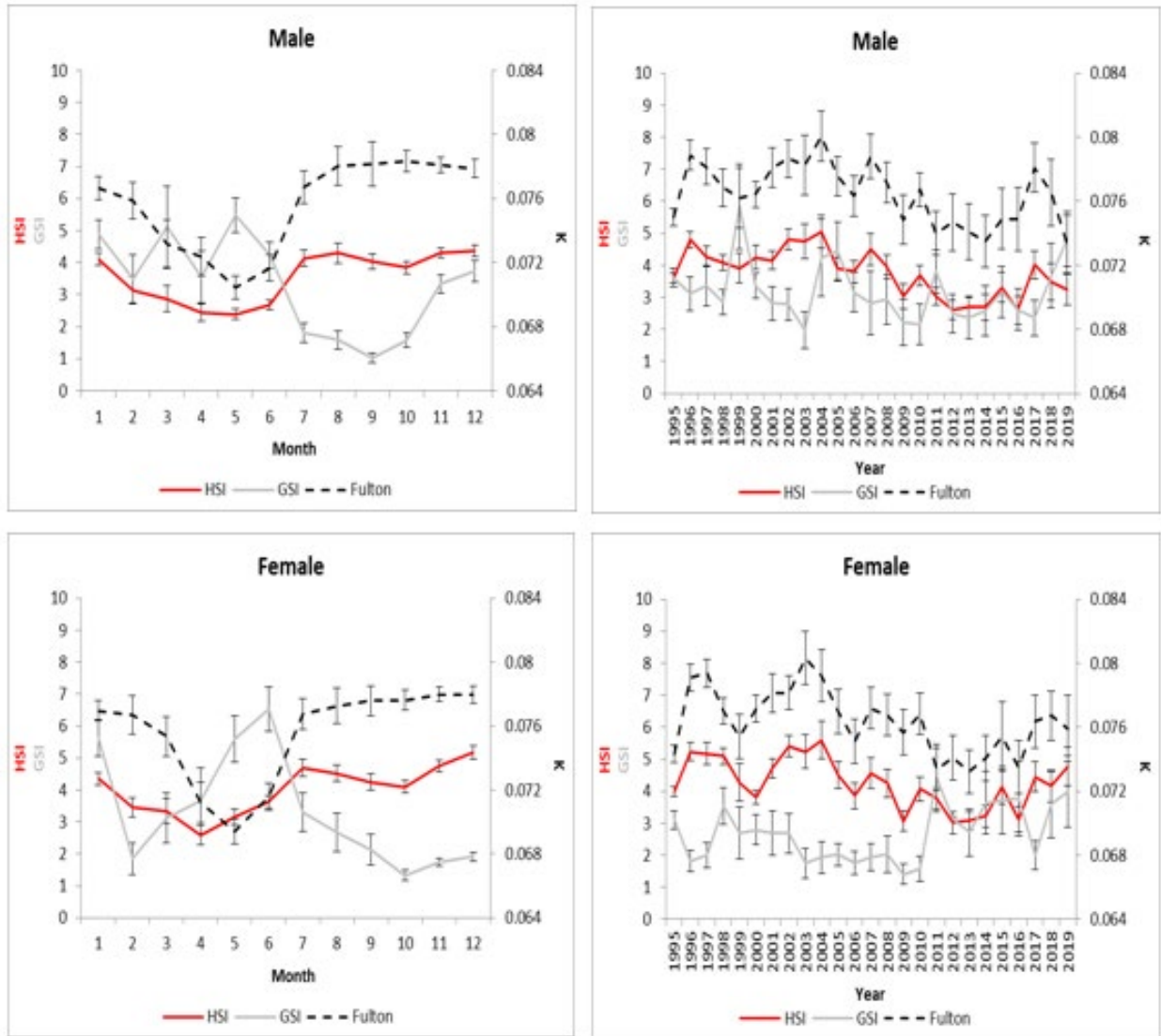


Figure 20. Temporal changes in mean Fulton's K condition factor (N=6,602 fish), mean Hepatosomatic Index (HSI; N=6,310 fish), and mean Gonadosomatic Index (GSI; N=6,454 fish) by sex for Atlantic Cod (sizes combined) from Sentinel surveys in Subdivision 3Ps, 1995-2019. T-bars represent +/-95% CI. Data for 2020 are not available.

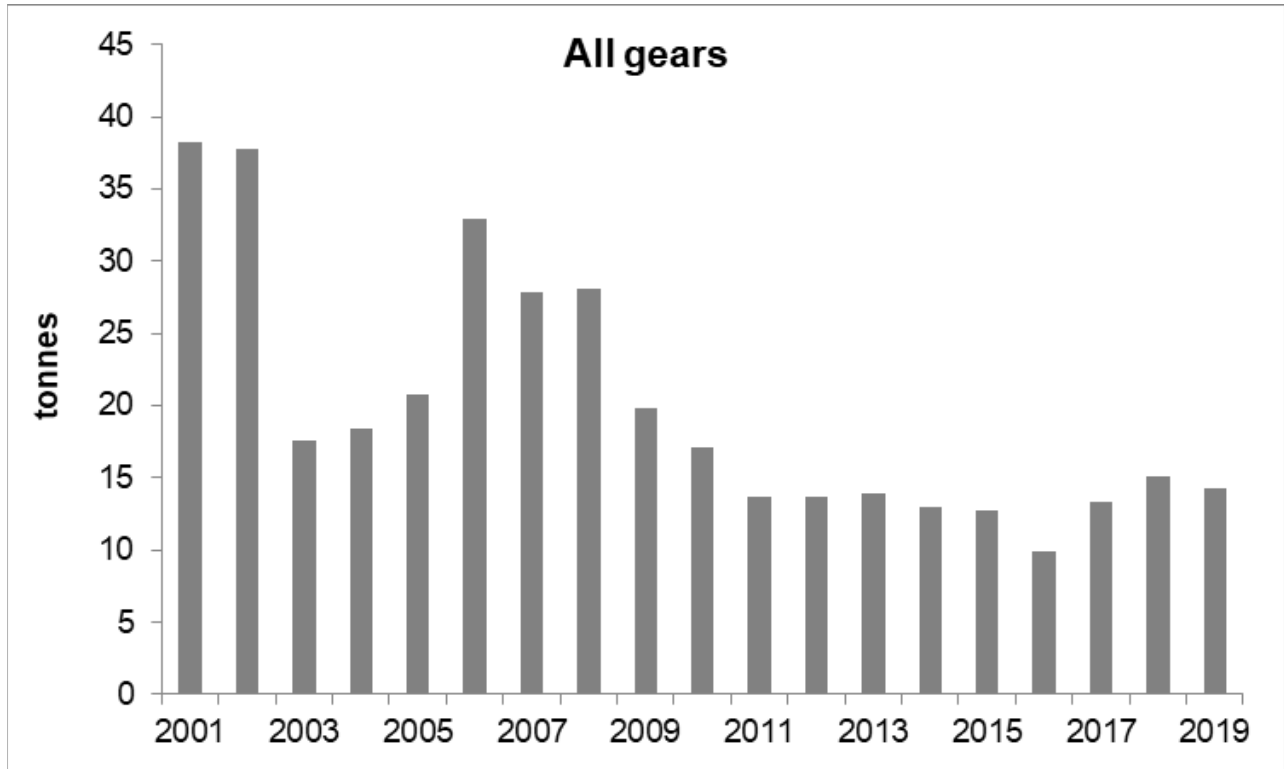


Figure 21. Total annual removals of Atlantic Cod (t) from Sentinel surveys (control and experimental sites; all gears combined) in Subdivision 3Ps, 2001-19. Data for 2020 are not available.

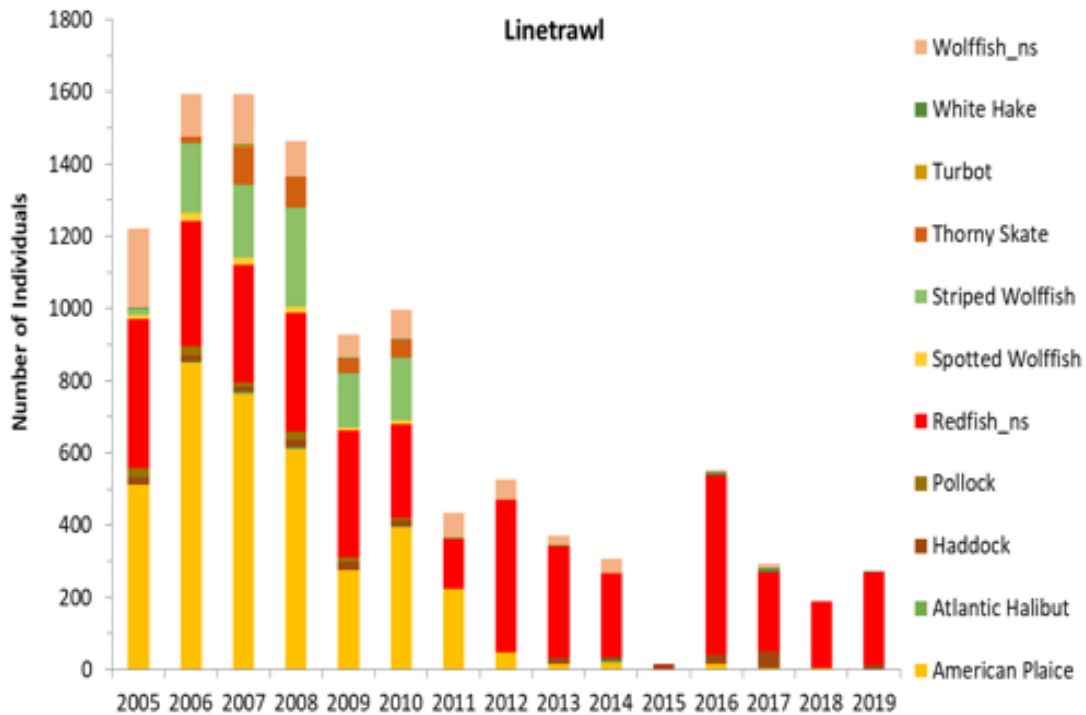
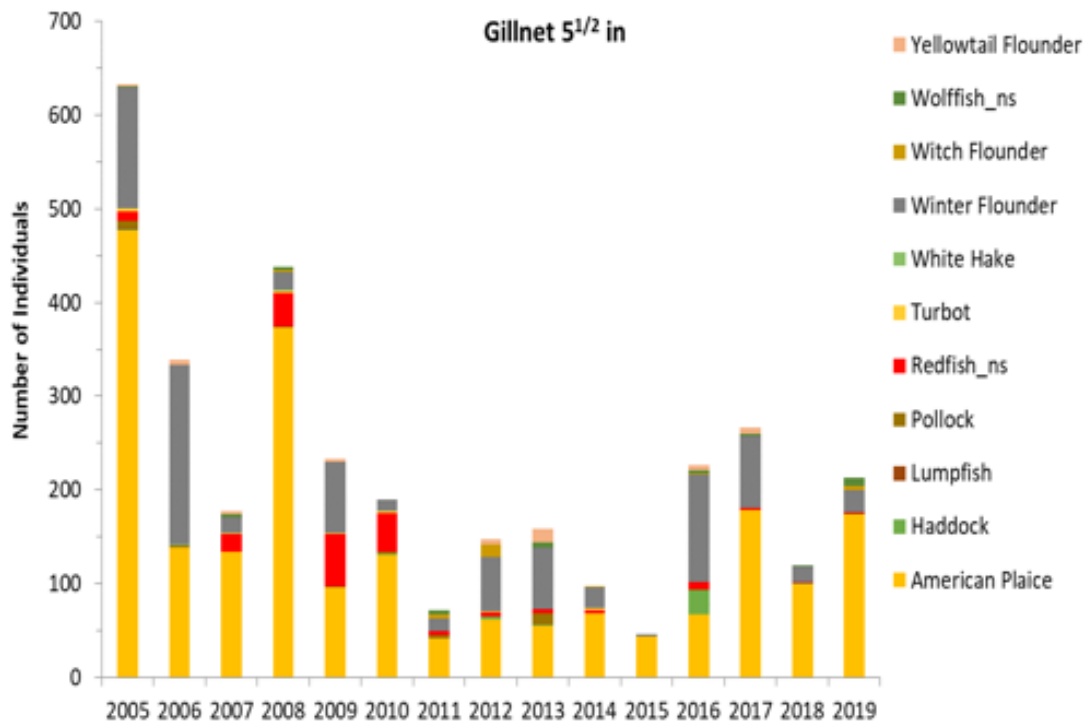


Figure 22. Total annual number of fish per bycatch species from Sentinel surveys (control and experimental sites) in Subdivision 3Ps, 2005-19. No data are available for small mesh gillnet, as well large mesh gillnet and linetrawl in 2020.