Assessment of Atlantic Herring in NAFO Div. 3KLPs to 2021

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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.

Correct citation for this publication:

Bourne, C.M., Herbig, J., Sutton, J., Young, C., and Zabihi-Seissan, S. 2025. Assessment of Atlantic Herring in NAFO Div. 3KLPs to 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2025/079. iv + 48 p.

Aussi disponible en français :

Bourne, C.M., Herbig, J., Sutton, J., Young, C., et Zabihi-Seissan, S. 2025. Évaluation du hareng de l'Atlantique dans les divisions 3KLPs de l'OPANO jusqu'en 2021. Secr. can. des avis sci. du MPO. Doc. de rech. 2025/079. iv + 52 p.

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ABSTRACT

The assessment of Newfoundland east and south coast Atlantic Herring (*Clupea harengus*) stock complexes considered data to the spring of 2021. During this assessment, stock status indices were updated for Bonavista Bay-Trinity Bay and Fortune Bay using data from the spring research gillnet program; the results of a similar short-term program in Placentia Bay were also presented. Results of recent acoustic surveys in White Bay-Notre Dame Bay, Bonavista Bay-Trinity Bay, St. Mary's Bay-Placentia Bay and Fortune Bay were reviewed. There was not enough recent data to provide an update for Conception Bay-Southern Shore.

Inshore acoustic surveys of northeast and south coast herring stock complexes were used to produce biomass indices from 1983 to 2001. These surveys were reinstated in 2019, and the results were presented at this assessment. For White Bay-Notre Dame Bay, the acoustic survey biomass index for 2020 (13,219 t) was similar to what was observed in the last survey in 1998 but much lower than the 1980s; samples collected during the survey were comprised of small herring indicating potential strong recruitment. Catch rates in the spring research gillnet program in Bonavista Bay-Trinity Bay increased substantially in 2021, after being well below the reference period (1990–2005) mean for the previous five years. The stock status index increased after decreasing in 2019 and 2020. Catch rates in the recent short-term research gillnet program in Placentia Bay were below the reference period mean from 2018 to 2021, but were slightly higher than those observed in the early 2000s. The biomass index from the winter 2021 St. Mary's Bay-Placentia Bay acoustic survey (2,407 t) was the second lowest in the time series, slightly higher than what was observed in 2000 (2,000 t). Catch rates in the spring research gillnet program in Fortune Bay increased slightly in 2020 but declined in 2021, remaining well below the reference period mean. The biomass index for Fortune Bay (5,425 t), derived from the winter 2020 acoustic survey, was higher than the last survey index value in 2001 (3,452 t) but significantly lower than the two previous (18,885 t and 30,408 t in 1997 and 1999, respectively).

INTRODUCTION

Atlantic Herring occurring along the south and northeast coasts of Newfoundland are largely found inshore, migrating between bays throughout the year to feed, spawn and overwinter (Wheeler and Winters 1984). Five stock complexes have been identified in NAFO Divisions 3K, 3L and 3Ps based on spawning location, as tagging studies showed that these populations displayed strong homing tendencies and returned to the same bay to spawn each year (Wheeler and Winters 1984). These stock complexes are: White Bay-Notre Dame Bay (WBNDB), Bonavista Bay-Trinity Bay (BBTB), Conception Bay-Southern Shore (CBSS), St. Mary's Bay-Placentia Bay (SMBPB), and Fortune Bay (FB) (Fig.1). Herring also occur along the south coast of Newfoundland and southern Labrador, the stock affinity of these populations is currently unknown.

Within each spawning complex there are both spring spawners and fall spawners. Historically, spring spawners comprised the majority (>90%) of all five stock complexes, however a shift to fall spawner prevalence occurred during the early 2000s in all areas except FB (Bourne et al. 2018). Shifts in spawning stock composition occurred in most stocks in the Northwest Atlantic during that time, with increasing recruitment of fall spawners which was correlated with increasing sea temperatures (Melvin et al. 2009).

ECOSYSTEM CONSIDERATIONS

Ecosystems in the NL bioregion were subject to overfishing from at least the 1960s to the 1980s. This fishing pressure, in conjunction with the environmental changes, led to a regime shift in the early 1990s. The structure of these ecosystems changed, with the collapse of the groundfish community and Capelin, a key forage species, and significant increases in shellfish, leading to a shellfish-dominated community structure on the Newfoundland Shelf (2J3K). These increases in shellfish did not compensate for the loss of groundfish biomass.

Consistent signals in the annual offshore multispecies surveys of groundfish rebuilding and a return to a groundfish-dominated community started in the mid- 2000s, coinciding with modest improvements in Capelin, and the beginning of the shellfish decline. The finfish biomass build-up plateaued in the early 2010s and showed declines around 2014–15. While some improvement has become apparent since the lows in 2016–17, current total biomass has yet to return to the 2010–15 level and remains well below the pre-collapse levels. Even though these recent signals appear promising, the ecosystems in the NL bioregion still remain at a low overall productivity state at the present time.

There has been a warming trend on the Newfoundland Shelf since 2018, with 2021 being one of the warmest years on record (Cyr et al. 2022). Since the mid-2010s, there has been a general trend toward earlier spring blooms. In addition, there was a shift in the zooplankton community on the northeast Newfoundland Shelf and the Grand Banks around the mid-2000s characterized by a decrease in the abundance of large, energy-rich calanoid copepods (*Calanus finmarchicus, C. glacialis, C. hyperboreus*) concurrent with an important increase in the abundance of small copepod taxa such as *Pseudocalanus* spp., *Oithona* spp. and *Temora longicornis*. These changes in the size structure of copepod assemblages resulted in a general decrease in total zooplankton biomass, which has remained mostly below the long-term (1999–2020) average since 2010.

Overall ecosystem dynamics appear mostly driven by bottom-up mechanisms, likely associated with the availability of key forage species, like Capelin and shrimp, and environmental conditions. The overall pattern of change observed at the broad ecosystem scale is generally

coherent with the changes observed inshore with herring, like declines in stock sizes since the late 1980s and early 1990s, and reduced sizes at age. This consistency further supports the hypothesis that ecosystem productivity in the NL bioregion is largely regulated by bottom-up processes.

SIZE AT AGE AND MATURITY

Historically, spring spawner lengths at age peaked in the late 1970s, declined through the 1990s and stabilized in the early 2000s (Wheeler et al. 2009). The stabilized trend continued in the 2010s, however there is an apparent decrease in fish length at age in the 2020s (based on data from 2020 and 2021). This is more apparent in younger fish (<6 years), with a slight dip in older aged fish in the south coast (SMBPB and FB) area (Fig. 2 and 3). There was no significant difference in length at age between spawning stock components or stock areas. Although the decadal averages are showing an overall decline in length at age, there has been an increase in length at age for most age classes from 2019 to 2021 (Fig. 2 and 3) with the notable exception of age 4s.

Determining the length and age at 50% maturity (L50 and A50) for these stock complexes has been a challenge in recent years due to low sample sizes of small, immature herring required to conduct the analyses. The last L50 update was done in 2017 to include the 2009 to 2011 year classes (Bourne et al. 2018). For this assessment it was possible to update the L50 of the spring spawners for the 2013 and 2017 year classes. Both the L50 and A50 of the spring spawners were updated using a generalized linear model (GLM) with a logit-link function and binomial error distribution in R. The L50 for the fall spawners is not presented since sample sizes are not large enough in most years. Analyses were completed using data from samples collected in the research gillnet program, acoustic surveys, bait fishery, and commercial fishery. Fish were grouped by age, spawning type, and year class; if there were less than 30 individuals in a group, it was excluded from the analysis. For the A50 analysis, age was converted into a continuous value based on the month fish were caught. Sample sizes were insufficient to estimate L50 for each stock area for most years, but comparisons between years when possible did not show a significant difference so all regions were combined. Similar trends were noted by Wheeler et al. (2009) when a previous L50 analysis was conducted. The L50 of the 2017 year class decreased significantly to a time series low of 233 mm (total length) from 258 mm (total length) in 2013. As an exercise during the assessment, the L50 was also calculated for years where the number of fish was between 10–30. (Fig. 4). The A50 increased from a time-series low in the late 1990s of less than 2.5 years to over 3.5 years in 2017, a value closer to what was observed during the 1980s and through the late 2000s (Fig. 4).

FISHERY

FISHERY OVERVIEW

Atlantic Herring are fished along the coasts of Newfoundland and southern Labrador, both commercially and for bait. The commercial herring fishery peaked in the late 1970s at over 30,000 t total catch, when the presence of several strong year classes and the introduction of purse seiners allowed intensive exploitation. All stocks were placed under quota regulation by the early 1980s as landings decreased sharply. The total allowable catch (TAC) is comprised of a commercial quota and bait allocation (note that bait landings have not been included in commercial landing statistics since 1996 – see "Bait Fishery and Phone Survey" below); the 2021 combined TAC from southern Labrador to FB was 14,342 t (12,342 t commercial quotas and 1,500 t bait allocations) (Fig. 5).

Commercial fisheries generally occur in both spring and fall in all stock areas except FB, where there is no fall fishery. Because spring and fall spawners do not separate, the fishery targets mixed aggregations. The commercial fishery is carried out using a variety of gear types, with purse seines accounting for the majority of landings (Fig. 6), except in Labrador and FB where there is no mobile gear fishery and other types of seines (bar in FB and tuck in Labrador) account for most landings. There is currently a minimum size provision for the fishery (excluding gillnets) which allows a maximum 20% of landed herring to be under 24.76 cm fork length per fishing trip (DFO 2022), which is intended to give immature herring the opportunity to spawn at least once before exploitation (Bourne et al. 2018). This regulatory measure has led to decreased fishing activity and lower landings at times when strong cohorts of herring occur and lead to a high percentage of undersized fish.

COMMERCIAL FISHERY LANDINGS

Total commercial landings were approximately 4,000 t (31% of the TAC) in 2020 and 2,500 t in 2021 (20% of the TAC), the lowest landings since the early 1980s (Fig. 5). The impacts of the COVID-19 pandemic and a high percentage of undersized herring (below the minimum size allowed in the commercial fishery) contributed to the lower landings in recent years.

There has been a commercial (fixed gear) fishery in Labrador since 2013, with a 500 t quota. Landings increased substantially from 2017 to 2018 and have continued to increase, with the entire TAC being taken in 2021. Most landings occur in the fall. The stock affiliation of these herring is currently unknown. Landings were relatively high in WBNDB from 2017 to 2020, with most of the 2,568 t TAC taken; however, landings decreased in 2021. In BBTB landings remained fairly high from 2004 to 2016, with >60% of the TAC taken on average (the TAC increased several times during that period, from 3,000 t in 2004 to 5,990 t in 2017); however, landings decreased in recent years with less than 15% of the TAC taken over the past 4 years, and very low landings in 2021 (Fig. 7). Overall, commercial landings in CBSS increased in the 2010s compared to the previous decade; however, while most of the 895 t TAC was taken in 2020, there were no landings in 2019 or 2021 (Fig. 7). In SMBPB landings increased overall during the 2010s, with 90% of 2,100 t TAC landed in 2019; SMBPB took the greatest proportion of overall TAC in 2021 (Fig.7). Landings in FB were high in 2018 and 2019 with the entire 789 t TAC taken, but declined in 2020 and 2021 with 45% and 55% of the TAC landed respectively.

COMMERCIAL FISHERY CATCH AT AGE

Commercial catch at age is calculated using samples collected from processors; an effort is made to collect a sample of 55 randomly selected herring per 500 t of landings by gear, month, and bay. When these criteria cannot be met, samples from different gear types, bays and/or seasons may be applied to landings (see Wheeler et al. 2009 for detailed methods), as was the case for several stock areas when calculating catch at age for the 2019, 2020 and 2021 fisheries (Table 1a-c). Bait estimates from the annual telephone survey (see below) are also added to total landings (gillnet) to account for all fishery removals.

An annual commercial catch numbers-at-age vector, by stock area and spawning type, is calculated by converting the catch weight to fish numbers using the mean whole weight from the sample being applied to that portion of the catch. Those numbers are then apportioned by age using the sample numbers-at-age. Age and spawning type are determined through otolith examination and maturity stage; at the time of this assessment, ages and spawning type designations were available for all samples up to and including those collected in 2021 (except for 2018, where only FB samples had been aged – these samples will be processed prior to the next assessment and added to existing catch at age datasets). While the commercial catch at age provides information about the composition of herring caught in the fishery, the catch at age

obtained from the research gillnet program (see below) is considered to be more representative of the population as it is derived from a standardized sampling program.

There were no commercial samples collected from Labrador in 2019 and 2020; one sample was collected in 2021 (Table 1c). This sample was comprised of 67% fall spawners and 40% age one herring (Fig.8a) which is very atypical of the commercial fishery given the size selectivity of gear and minimum size restrictions, therefore this catch at age may not be reflective of what was seen throughout the fishery. In WBNDB, there were too few samples obtained in 2019 (3) or 2020 (1) to meet the criteria noted above (Table 1a and 1b); adequate samples (2) were collected in 2021 (Table 1c). The percentage of fall spawners in the commercial catch samples was near 10% in 2021 and the age distribution was broadly distributed, with ages 3, 4 and 5 dominating the catch (Fig. 8b). In BBTB, the age distribution of commercial samples was well distributed in 2019 and 2020, with fall spawners comprising approximately 70% of the catch in both years; in 2021, age 4 herring (the 2017 cohort) was composed of 75% percent spring spawners and comprised over 40% of the catch, indicating the presence of a strong year class recruiting into the fishery (Fig. 8b). In CBSS, there were no commercial landings in 2019 or 2021. The 2020 commercial catch at age based on commercial samples was broadly distributed, with ~70% percent fall spawners (Fig. 8a). The commercial catch at age of commercial samples in SMBPB was largely dominated by age 7 herring in 2019 but was more well distributed with a range of year classes present in 2020 and 2021. The distribution of spring and fall spawners has remained fairly even, with 60% spring spawners in 2021 (Fig. 8b). In FB the 2012 year class continued to dominate the catch in samples collected in 2019, 2020 and 2021, with that cohort comprising 84% of the catch; spring spawners still dominate in this stock area (99% in 2021) (Fig. 8b).

BAIT FISHERY AND ESTIMATED REMOVALS

A herring gillnet bait fisher telephone survey has been conducted annually since 2006 (with the exception of 2010) to provide estimates of bait removals, which have not been included in commercial landings data since 1996. The survey is also used to get fishers' perceptions of changes in abundance in their areas (see Cumulative Change Index below) and collect information about bycatch in the herring bait fishery. Logbooks are also issued to fishers with bait licenses; however, the Science telephone survey currently has a higher response rate, so logbook data were not included in this assessment.

Each fall, a random subset of herring fixed gear licence and bait permit holders are selected for the survey within each stock area (CBSS was added in 2016). The estimated number of bait fishers has declined in all stock areas since the survey began, as has the number of bait licence holders – there were an estimated 391 active bait fishers in 2021. Most bait fishing occurs in the spring and early summer, however in 2020 and 2021 more fishers surveyed (8–10 vs 1–2 in previous years) on the northeast coast (WBNDB and BBTB) indicated that they will also be fishing bait nets in the fall.

During the survey fishers are asked to estimate the amount of bycatch they had, and these estimates are used to extrapolate total bycatch for the 3KLPs herring bait fishery. In 2020 mackerel accounted for most of the reported bycatch (estimated ~2,500 kg from WBNDB and BBTB combined), whereas Atlantic Cod and other cod species comprised the majority in 2021 (~1,600 kg from all areas combined) (Fig. 9). There were also reports of seal bycatch in 2020 (6 seals in WBNDB) and 2021 (20 seals in SMBPB).

The number of active bait fishers declined in all areas in the early 2000s but has remained relatively consistent over the past decade, with an estimated total of 336 in 2020 and 391 in 2021. Total bait removal estimates were 407 t in 2020 and 560 t in 2021; bait removals were at

or near time series lows in 2020 in BBTB, SMBPB and FB, but increased in all areas except CBSS in 2021 (Table 2a-2e; Fig 10a-b). Estimated bait landings in WBNDB have not exceeded the 500 t bait allocation since the telephone survey began in 2006 and have remained well below for the past several years, accounting for a small proportion of total removals (Table 2a, Fig. 10a). There have been five years in which estimated bait landings in BBTB exceeded the 300 t allocation since the survey began, but estimates have been below 200 t for the past four years; bait landings generally comprise a small proportion of total removals in this stock area, with the exception of 2021 when there were no commercial landings (Table 2b, Fig. 10a). Estimated bait landings in CBSS have met or exceeded the 50 t allocation in most years since the survey began in the stock area in 2016 but were just 27 t in 2021 (Table 2c, Fig. 10a). In SMBPB estimated bait landings have fluctuated, exceeding the 150 t allocation in four instances since the survey began in 2006; generally, bait removals comprise a small portion of commercial landings (Table 2d, Fig. 10b). Estimated bait landings have remained well below the 400 t allocation in FB since 2013 (Table 2e, Fig. 10b).

During the phone survey fishers are also asked to (voluntarily) provide comments on stock/fishery. Most fishers expressed concerns about their stocks and the perceived impacts of commercial fishing (particularly seining) through excess mortality. In all areas except FB fishers commented that herring have been small for the past several years, however most fishers who commented in FB noted that herring were larger in 2021.

ACOUSTIC SURVEYS

SURVEY BACKGROUND

Thirty-two inshore acoustic herring surveys were conducted in the Newfoundland region between 1983 and 2000 to provide fisheries independent estimates of biomass for the WBNDB, BBTB, SMBPB and FB stock complexes. However, these surveys were discontinued due to limited funding and low herring abundance, which made it difficult to locate and sample herring in later years (Wheeler et al. 2010). In 2019, acoustic surveys were reinstated through funding under the new Fish Stock Provisions, to provide further data to aid in the development of limit reference points for 3KLPs herring.

SURVEY METHODOLOGY

Acoustic Surveys

To keep biomass estimates comparable between acoustic time series, acoustic survey design was similar to those conducted from 1983 to 2001 (Wheeler et al. 2001). Stock areas were divided into strata and the sampling intensity (total transects length) was allocated to each stratum on a 2:6:11 ratio (for low, medium and high density strata) based on herring distribution patterns observed in previous acoustic surveys and (historical) commercial fishery observations (Wheeler et al. 1999). The acoustic surveys followed a random parallel design where transects were placed perpendicular to the coastline with a minimum separation of 500 m between them with transects extending from inshore waters (as shallow as vessel can safely survey) to the 120 m depth contour line. Prior to 1989 the maximum transect depth had been 90 m but based on the 1988 acoustic surveys of WBNDB and BBTB, it was found that all herring were detected within the 140 m contour and that greater than 95% were within the 100 m contour, so the maximum depth was increased to 120 m for subsequent surveys (Wheeler et al. 1989).

Transects were surveyed using chartered purse seine vessels (*Fiddler's Green* for fall surveys, *Sweet Caroline* for winter surveys) equipped with a SIMRAD EK60 echo sounder with a split

beam 120 kHz transducer with a 7° beam width. The transducer was mounted on a towed body, which was deployed on the side of the ship during the surveys. The towed body was replaced by a blister mounted directly on the stabilizing fin of the chartered vessels starting in fall 2022. The ping interval varied from 400–500 ms, pulse duration was set to 1.024 ms in 2019 or 0.256 ms in subsequent years, and the power was 500 W in 2019 and 250 W in subsequent years. The acoustic system was calibrated yearly using the standard sphere method (Demer et al. 2015). To calculate the speed of sound in water and the coefficient of absorption required for acoustic analyses, Conductivity–Temperature–Depth (CTD) profiles were collected after each successful purse seine set (Simmonds and MacLennan 2008).

Each stock area (except for CBSS) is surveyed every second year, with a south coast area (SMBPB or FB) surveyed in late winter/early spring, and a northeast coast area (WBNDB or BBTB) surveyed each fall. Survey timing is based on historical migration patterns, meant to intercept herring near the end of their migration to begin overwintering (for fall surveys) or during overwintering/prior to spawning (winter surveys) (Wheeler et al. 1999).

Surveys are conducted for 12 hours each day, for up to 30 days (or as long as it takes to complete all transects) during daytime hours (largely during daylight hours but depending on the time of year, some transects/sampling sets can occur in dark conditions). Surveying in both day and night results in a detectability issue since Atlantic Herring are known to undergo diel vertical migration where they come up to the surface during the day and go to deeper waters at night (Brawn 1960; Huse et al. 2012). Although problematic, these surveys have always had the same daily schedule to minimize hazards while navigating in shallow coastal areas with minimally accurate navigation charts. During the survey, a detailed log record was maintained for each transect and inter-transect. Transect start and end times were also annotated as marker regions and embedded within the raw acoustic files using the SIMRAD event log feature.

To validate the source of acoustic signal and for target strength calculations, herring samples of 50–100 fish were collected whenever possible when aggregations were encountered. Samples were collected primarily using a purse seine – if this was not possible due to depth limitations or adverse conditions (weather or rocky bottom), hook and line was used. When possible, an underwater camera was used to verify species before sampling or if the purse seine net could not be deployed. All observed fish concentrations, CTD casts, and purse seine deployments were recorded in the logbook. Atlantic Herring samples were used to calculate the average length of fish for biomass estimates.

Acoustic Data Processing

Hydroacoustic data were processed using Echoview® (Echoview Software Pty. Ltd). A first editing pass was conducted using an Echoview® template which excluded the top 5 m of the water column from analyses to avoid near-field and ring-down noise. The template also excluded the backscatter within 0.1–1 m of the bottom from analyses to remove the acoustic dead zone. Finally, the template also incorporated the depth of the transducer.

After the initial first editing pass using the Echoview® template, the next step consisted of echograms being visually assessed for non-biological noise. If the boat accidently surveyed an area deeper than 120 m, the signal below 120 m was removed. Echograms were visually assessed and manually edited so that non-biological noise was removed, any schools of fish along the bottom were re-included if screened by the template, and any major surface washdown under 5 m were also removed.

All fish detected during the survey were considered to be herring, unless samples collected on site proved otherwise. The Nautical Area Scattering Coefficient (NASC m^2 nmi^{-2}) values were used to evaluate the abundance of fish. Transects were visually examined for high NASC

values to confirm that the high values were due to fish and not due to inaccurate bottom delineations.

Biomass Estimates

Atlantic Herring biomass estimates were calculated for each acoustic survey. To estimate biomass, the weight-based target strength function (TS_W; dB re 1 m^2 g^{-1}) was used (Simmonds and MacLennan 2008; Benoit et al. 2008) (Table 3):

$$TS_W = TS_N - 10 \log(\overline{W}) \qquad (1)$$

where, TS_N is the estimated target strength (dB re 1 m^2) and $\overline{W}$ is the average weight (g). Using $\overline{W}$ accounts for the non-linear relationship between weight and length.

Estimated TS_N was based on the average Atlantic Herring length from each survey region (Table 3) and was calculated using the following equation (Wheeler et al. 1994):

$$TS_N = 20 \log(\overline{L}) - 65.5 \qquad (2)$$

where, TS_N is the target strength per individual (dB re 1 m^2) and $\overline{L}$ is the mean length (cm) of Atlantic Herring from each survey (Table 3).

The estimated average weight ($\overline{W}$) was calculated using the following equation from Benoit et al. (2008) (Table 3):

$$\overline{W} = a_f \sum_j n_j \frac{\left\{ (L_j + \Delta L/2)^{b_f+1} - (L_j - \Delta L/2)^{b_f+1} \right\}}{(b_f+1)\Delta L} \qquad (3)$$

where, a and b are parameters from a length-weight regression and L_j is the mean length of length class j contributing the fraction of n_j of the total length-frequency distribution of the population, and ΔL is the interval between successive length classes (ΔL = 1 cm). Values for a_f (4.15 x 10^{-3}) and b_f (3.147) are estimated from a length-weight regression combining all Atlantic Herring caught during acoustic surveys from 2019–21 (Fig. 11).

Due to low sample size (Table 3), fish were combined from each study area during each survey to calculate $\overline{L}$ and $\overline{W}$ rather than calculating $\overline{L}$ and $\overline{W}$ by stratum (Wheeler et al. 2001).

Echoview® files were integrated by transect region to give a single Nautical Area Scattering Coefficient (NASC m^2 nmi^{-2}) value per transect. Biomass per transect in each stratum was then calculated using the NASC and the previously calculated TS_W:

$$B_{hi} = \frac{NASC}{4\pi \cdot 10^{\frac{TS_W}{10}} \cdot 1852^2} \qquad (4)$$

Each transect was weighted based on the mean transect length within each strata (O'Boyle and Atkinson 1989):

$$K_{hi} = \frac{L_{hi}}{\overline{L}h} \qquad (5)$$

where, K_{hi} is the weighting factor for transect *i* in the hth stratum, L_{hi} is the length of transect *i* in the hth stratum and $\overline{L}_h$ is the mean length of all transects within the hth stratum. Mean biomass per strata was then calculated using an adapted equation from O'Boyle and Atkinson (1989), where B_{hi} is the biomass for transect *i* in the hth stratum. n_h corresponds to the number of transects in the hth stratum:

$$\overline{B} = \sum (K_{hi} * B_{hi})/n_h \qquad (6)$$

Variance in biomass within a strata was then calculated using the following equation (O'Boyle and Atkinson 1989):

$$\sigma^2{}_{Bh} = \frac{\sum K_{hi}{}^2 (B_{hi} - \overline{B_{hi}})^2}{n_h(n_h - 1)} \qquad (7)$$

To obtain total biomass estimates for the whole study area, mean biomass per stratum was first multiplied by the stratum area (A_h):

$$B_h = A_h * \overline{B_h} \qquad (8)$$

Next, biomass from each stratum was summed for the whole study area:

$$B_{total} = \sum B_h \qquad (9)$$

and an associated variance for the whole survey area was calculated.

$$\sigma^2{}_B = \sum A_h{}^2 \cdot \sigma^2{}_{Bh} \qquad (10)$$

All biomass calculations were performed in R 3.6.3 (R Core Team 2019) and figures were made using ggplot2 (Wickham 2016) and ggmap (Kahle and Wickham 2013) packages. A resampling technique may be considered moving forward for future assessments to account for potential intra-transect autocorrelation (Mowbray 2014).

SURVEY RESULTS

Five acoustic surveys were completed from fall 2019 through 2021 – the planned winter 2022 survey of FB had to be cancelled due to COVID-19 and weather-related issues. BBTB was surveyed in fall 2019 and 2021, FB in the winter of 2020, WBNDB fall of 2020, and SMBP in winter 2021. During these five surveys a total of 2,179 transects were completed covering 2,408 nmi.

The 2019 fall BBTB survey was conducted from November 5th to December 19th. During this survey 478 transects were surveyed, covering a distance of 541 nmi (Fig. 12); six successful purse seine sets were completed during the survey and two additional aggregations were sampled using hook and line. A biomass estimate of 26,589 t was derived from the survey area, a value similar to those obtained in the 1990s (Table 4 and 5a, Fig. 14). Herring were detected throughout the survey area, composed primarily of small (age 2) fish.

The 2021 fall BBTB survey commenced on November 2nd and finished on November 25th. During this survey 632 transects were surveyed covering 659 nmi (Fig 13) and two samples were obtained using hook and line (four purse seine sets were attempted but none were successful as herring aggregations were beyond the depth of the seine or in areas where seine could not be deployed). A biomass estimate of 9,970 t was derived from the survey area (Table 4 and 5e, Fig. 14). While the distribution of biomass in 2021 was similar to 2019, the estimated total was significantly smaller, representing the lowest value in the time series (Fig. 14).

The 2020 winter FB survey commenced on February 25th and finished on March 10th. During this survey 324 transects were surveyed covering 265 nmi (Fig 15) and there were two samples collected – one with a purse seine and the other hook and line. A biomass estimate of 5,425 t was derived from the survey area (Table 4 and 4b, Fig. 14), 49% of which was detected in a single stratum (Stratum 11) (Fig 15). The 2020 biomass estimate was higher than the last survey completed in 2001 but significantly less than the two previous (Fig. 14).

The 2020 fall WBNDB survey was conducted from November 30th to December 19th. During this survey 360 transects were surveyed covering 455 nmi (Fig. 16) and four samples were collected, one from a purse seine set and the others by hook and line and dipnet (when herring were aggregated at surface). A biomass estimate of 13,219 t was derived from the survey area (Table 4 and 4c, Fig. 14), 33% of which was detected in a single stratum (Stratum 5) located in

White Bay (Fig. 16). This is the third lowest biomass estimate of the time series (Table 4 and 4c, Fig. 14), however it should be noted that WBNDB had the smallest fish of the recent acoustic surveys (average length=10 cm), but relatively high biomass and therefore highest abundance compared to other regions.

The 2021 winter SMBPB survey had a delayed start due to COVID-19 Public Health restrictions and was conducted from March 13th to March 31st. During this survey 385 transects were surveyed over 488 nmi, concentrating on the inner portions of the bay where more herring were historically encountered (Fig. 17); there was one successful purse seine set. A biomass estimate of 2,407 t was derived from the survey area (Table 4 and 4d, Fig. 14), 55% of which was detected in a single stratum (Stratum 60) (Fig. 17). This biomass estimate is very similar to the last acoustic survey in 2000 (2,000 t), which was the lowest in the time series. At the time there were concerns that the timing of the 2000 survey (also in March) was an issue as the survey had typically been conducted in January-February, but it was felt that based on industry reports the biomass estimate was reflective of abundance at the time (Wheeler et al. 1999). However, an acoustic survey of Placentia Bay was conducted in February 2016 as part of the Laurentian Channel MPA development program which found biomass of almost 20,000 (t) using similar methodology (Bourne et al. 2018) indicating that it may still be advantageous to have this survey take place in January-February.

RESEARCH GILLNET PROGRAMS

PROGRAM OVERVIEW AND METHODOLOGY

The spring research gillnet (RGN) program provides a fishery independent index of abundance which has formed the basis for stock status advice for the past two decades. The program currently takes place in BBTB and FB; previously there were RGN programs in the other three stock areas (see Bourne et al. 2015 for details), but these were discontinued due to funding restrictions. However, in 2018 short term funding was obtained through the Ocean Protection Program's Environmental Baseline study in Placentia Bay. With these funds, the RGN program was reinstated in PB only (not SMB) for five years (2018 to 2022).

The RNG program involves contracting 8 fishers in BBTB, 4 in PB and 4 in FB each spring to fish a standardized fleet of 5 gillnets of varying size (2, 2.25, 2.5, 2.75 and 3 inches stretched mesh) for a 45-day period between April 1 and July 31 each year. The timing of the program is intended to intercept spring spawners during their annual inshore spawning migrations. Though over the past 20 years fall spawner numbers have increased significantly, the timing and methodology of the RGN program was not changed as limited funding and challenges contracting fishers in the fall did not allow the program to be expanded or shifted.

During the 45-day fishing period, fishers set their nets in the same location and, when possible, at the same time of year each spring. The same fishers are contracted each year; if a fisher can no longer take part in the program, efforts are made to replace them with another local fisher who is able to set the fleet of gillnets in the same general location to preserve the integrity of the historical time series. Fishers keep detailed logbooks and collect 2 samples of 55 fish per week.

Logbook data is used to calculate catch rates (total catch numbers/average days fished) for each fisher, these are then averaged for each stock area. Biological data from samples is then used in conjunction with catch rates to calculate mesh-disaggregated catch rates at age by spawning type, and to derive a recruitment index based on catch rates of age 4 fish. In addition, relative year class strength is calculated based on catch at age.

PROGRAM RESULTS

In BBTB the combined catch rate (both spring and fall spawners) in 2021 was the highest since 2007 (the fourth highest in the time series); this was only the second time that catch rates were above the reference period (1995–2005) mean in the last 10 years (Fig. 18). Most of the catch in 2021 occurred in Trinity Bay (Fig. 19), with one fisher having significantly higher catch rates than the others; when this fisher's catch is removed from the analysis catch rates in 2021 are up slightly from 2020 but still below the reference period and decadal mean (Fig. 18). The proportion of fall spawners in the catch increased through the early 2000s and peaked in 2014 at 76%; the catch in 2021 was comprised of 65% spring spawners, the highest proportion since 2003 (Fig. 18). The catch at age in 2019 and 2020 was well distributed with an even mix of spring and fall spawners; the 2021 catch at age was heavily dominated by the age 4 (2017) cohort which comprised almost 70% of the total catch (Fig. 20). The year class strength of the 2014 and 2015 fall cohorts were average, with the 2014 spring cohort just above average and 2015 just below; the fall 2016 cohort was well above average based on age 4 and 5 catch rates, and the spring was just above average (Fig. 21). Recruitment of the 2017 spring and fall year class was the highest in the time series for both spring and fall spawners (Fig. 21).

From 1982 to 2012 the spring RGN program operated in SMBPB, with 4 fishers per bay. This time series was continued from 2018 to 2022, but only in PB (with 4 fishers). The commercial fishery is concentrated in PB in this stock area, so it is hoped that the gillnet index still provides an adequate stock status evaluation. When catch rates from SMB are removed from the RGN catch rate time series, rates increase in the early 80s, decrease through the 90s, but remain much the same in the 2000s (Fig. 22). Catch rates in SMBPB remained below the reference period (1990–2005) mean throughout the 2000s, including the most recent data obtained through the Coastal Baseline program (Fig. 22). SMBPB has had a higher proportion of fall spawners (20–50%) than the other stock areas during the 1980s and 1990s, and as seen with the stock complexes on the northeast coast, there was an increase in the proportion of fall spawners in SMBPB during the 2000s, peaking at 75% in 2020 (Fig. 22). The catch at age in this stock area tends to vary from year to year more than the other stock complexes, with strong year classes not always tracking. This was the case for the past three years, with age 7s dominating the catch in 2019, age 4 and 11+ in 2020, and age 4 in 2021 (Fig. 23). The 2014 and 2015 fall year class strength was above average, but the 2016 was well below; all the recent (2014-16) spring spawning year classes have been well below average strength. Recruitment of the 2017 spring and fall year classes were above average (Fig. 24).

In FB the combined catch rates have been well below the reference period (1990–2005) mean since 2004; there was a slight increase in 2020 but another decline back down to the decadal mean in 2021 (Fig. 25). Unlike the other stock areas, after spring spawners declined in the late 1990s, fall spawner recruitment did not increase significantly in FB; spring spawners comprised 85% of the catch in 2021 (Fig. 25). The catch at age in FB has been dominated by the 2012 year class for the past several years, with it accounting for over 70% of the catch in 2019 and 2020; however, in 2021 it comprised just under 50% with age 4 herring (2017 year class) accounting for over 30% of the remaining catch (Fig. 26). Numbers of fall spawners caught in the RGN program in FB have been too low to provide adequate estimates of year class strength or recruitment so only spring spawners are considered when updating stock status. Throughout the 2000s, recruitment in FB has been relatively weak with only two year classes (2002 and 2012) of above average recruitment and relative year class strength (Fig. 27). Subsequently, these year classes each sustained the fishery for a decade. While the year classes currently recruited to the fishery are below average with the exception of 2012, the high recruitment of the 2017 year class is promising.

STOCK STATUS EVALUATION

OVERVIEW

During 3KLPs herring stock assessments in the 2000s, performance tables were compiled for stock complexes with a research gillnet program which included information on the fishery, commercial landings, telephone survey observations, and research gillnet program results; however, only the data from the research gillnet program (the only fisher independent index of abundance) was used to update the stock status index and provide advice (see Bourne et al. 2018). For this assessment, the stock status indices have been updated where possible, but performance tables are not provided as there was inadequate data given poor response rates to the annual purse seine telephone survey (no results were presented at this assessment due to inadequate sample size), and low samples sizes for some commercial catch at age calculations. Performance tables were implemented when acoustic surveys ceased, and data became more limited; it is hoped that going forward acoustic biomass estimates will be incorporated into stock status evaluation to provide a more robust evaluation of stock status.

The stock status index is calculated using three metrics from the spring research gillnet program: overall catch rates as a percentage of the reference period mean, catch rates of ages 7–10 as a percentage of the reference period mean, and the number of mature year classes above the reference period mean. Each metric is scored and all three are equally weighted to calculate the stock status index value. In BBTB, this is done for both spring and fall spawners, then the values are weighted according to the proportion of each spawning component in the catch to give a combined stock status value. In FB, only spring spawners are evaluated, and the low number of fall spawners does not provide sufficient data to update research gillnet indices for that spawning component. The stock status index could not be updated for SMBPB given the break in the RGN time series and resulting lack of data on mature year class strength (catch rates are required to track cohorts through ages 4–11+).

STOCK STATUS EVALUATION

The stock status index could not be updated for WBNDB given that there is no longer a RGN program in the stock area. The commercial catch at age was based on few samples for 2019–20 but showed a broad age distribution (Fig. 8b). The acoustic survey biomass index for 2020 was below the last estimate in 1998 and much lower than the 1980s (Fig. 14). However, samples collected during that survey were comprised of small/young herring indicating potential strong recruitment, but without a standardized index of recruitment this cannot be quantified. Given the limited data for this stock area an evaluation of stock status cannot be provided for this assessment.

Research gillnet program catch rates in BBTB increased significantly in 2021, well above the decadal and reference period mean (Fig. 18). This increase in catch rates was largely driven by high numbers of age 4 (2017 year class) herring that were recruiting into the fishery; the recruitment index for this year class was at a time-series high for both spring and fall spawners (Fig. 21). This recruitment pulse also led to an increase in the stock status index after a slight decrease in 2020 (Fig. 28). Based on this data, stock status evaluation for BBTB is positive. However, it should be noted that the catch of a single fisher in Trinity Bay was responsible for the significant increase observed in catch rates, without this fisher's data catch rates in 2021 increased but not above the decadal or reference period mean (Fig. 18).

Stock status for CBSS is not evaluated as there is no fishery independent index of abundance for this stock area and in recent years little commercial fishing activity.

The stock status index for SMBPB could not be updated, however 4 years of data from the short term RGN program in that area and the results of a recent acoustic survey were available at the time of this assessment. The RGN program over the past 5 years has taken place in PB only, but catch rates for SMBPB through the early 2000s did not change significantly when SMB data was removed (Fig. 22) so it is likely that data from only PB can be applied to the entire stock area. Catch rates in PB have remained below the reference period mean from 2018 to 2021, but are slightly higher than those observed in the early 2000s (Fig. 22). The age distribution in the RGN program has been broadly distributed with a strong age 4 (2017) cohort comprising over 30% of the catch in 2021 (Fig. 23); cohorts do not tend to track as well in PB as other stock areas. Year class strength of recent fall spawning cohorts (2014 and 2015) was above average in PB, but the spring spawners were well below average; recruitment of the 2017 cohort was above average for both spawning components (Fig. 24). The biomass estimate from the winter 2021 acoustic survey was the second lowest in the time series, but timing may have been an issue (Fig. 14). Based on these data (reduced catch rates, good recruitment, low survey biomass) the stock status evaluation for this area is uncertain.

The age composition of herring in FB has been dominated by a single year class for the past 20 years (the 2002 year class in the early 2000s and the 2012 year class over the past decade). This trend continued in 2019 and 2020, but in 2021 the age 4 year class (2017) comprised over 30% of the catch (Fig. 26). This was the first time two strong year classes have been present in the RGN catch since the early 2000s. Overall catch rates in the RGN program remain low compared historical catches, well below the reference period mean. There was a slight increase in catch rates in 2020, but this declined again in 2021 (Fig. 25). The 2012 cohort was the only mature year class fully recruited to the program in 2021 of above average strength (Fig. 27). The recruitment of the 2017 year class was above average (Fig. 27). The stock status index for FB increased consistently since 2016 but declined again in 2020, largely due to low catch rates (Fig. 29). The acoustic survey biomass index from the winter 2020 survey was relatively low but higher than the last survey in 2001 (Fig. 14). Based on this information the stock status evaluation for FB remains negative, but the above average recruitment of the 2017 year class is a positive sign for future prospects.

AREAS OF UNCERTAINTY

The inability to estimate spawning stock biomass and exploitation rates continues to be a major source of uncertainty for this stock assessment.

The lack of a fishery-independent abundance index in one of the five stock areas makes it impossible to update the standardized stock status index until further data is collected during acoustic surveys, otherwise only biological updates could be provided, based on limited data from the commercial fishery.

The timing of the current acoustic surveys are taking place based on historical timing of past surveys and it is uncertain if the migration patterns and timing of herring have changed. The timing of the acoustic surveys may no longer be appropriate and may be missing herring.

The lack of ecosystem information in the inshore creates challenges in trying to apply an ecosystem approach to managing the herring stocks. Currently there is a reliance on offshore ecosystem data to gather relevant ecosystem information although there is also a lack in understanding the link between offshore and inshore ecosystem dynamics.

RESEARCH RECOMMENDATIONS

- Investigate the linkages among trophic levels in the inshore and how that relates to offshore dynamics.

- Investigate links of environmental drivers between herring growth, changes in herring condition, and recruitment.

- Investigate the relationship between weight and age in herring, as well as causes of mortality of herring.

- Determine if recruitment and length at age between fall and spring spawners are the same, and identify how recruitment relates to strong year classes.

- Investigate using neighbouring year classes to bolster sample sizes for L50 and A50 calculations and investigate gear selectivity on L50 values for both fall and spring spawners.

- Collect acoustic tagging data, alongside genetic work, to confirm there has been no significant change in the stock composition and boundaries since the studies done in the 1970–80s.

- Re-examine aspects of the acoustic herring surveys such as the current maximum depth and timing of the surveys to avoid missing overwintering herring.

- Calculate biomass estimates for acoustic survey dead zones to determine if large amounts of biomass are being missed.

- Compare cohort strength estimate between the research gillnet program and acoustic survey. Catch rates can be changed into weights per net/tow to make acoustic surveys and the gillnet research program more comparable.

- Investigate modifying gillnet research program to account for gear selectivity and size at age in the catch rate estimates.

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APPENDIX 1: TABLES

Table 1a. Allocation of samples for 2019 commercial landings with the months and gear type for sample allocations.

Area	Bay	Month Sampled	Gear Fished	Number of Fish	Total Allocated Landings (t)	Months Allocated	Gear Allocated
WBNDB	NDB	June	Gillnet	48	267.7	May, Aug., Sept.	Gillnet and Trap
	NDB	August	Tuck Seine	50	3,124.92	May, Aug.–Dec.	Purse Seine and Tuck Seine
BBTB	TB	April	Gillnet	49	236.37	May–June, Aug.–Sept.	Gillnet and Trap
	TB	May	Bar Seine	50	573.78	May, Aug., Dec.	Bar Seine, Purse Seine, and Tuck Seine
SMBPB	PB	February	Purse Seine	50	894.16	Feb.–Mar.	Purse Seine
	PB	April	Bar Seine	50	866.39	Apr.–May	Bar Seine
	PB	March	Gillnet	49	47.25	Mar.–Apr.	Gillnet
	PB	May	Gillnet	50	287.48	May, July	Gillnet
FB	FB	January	Gillnet	50	77.87	May	Gillnet
	FB	March	Bar Seine	100	662.35	Mar.	Bar Seine
	FB	April	Trap	50	207.11	Apr.–May	Trap
	FB	December	Gillnet	50	77.87	May	Gillnet

Table 1b. Allocation of samples for 2020 commercial landings with the months and gear type for sample allocations. Gillnet landings in July[1] and May[2,3] were not included because there were no gillnet samples collected in the area.

Area	Bay	Month Sampled	Gear Fished	Number of Fish	Total Allocated Landings (t)	Months Allocated	Gear Allocated
WBNDB[1]	NDB	December	Tuck Seine	50	1,971.48	July–Dec.	Purse Seine and Tuck Seine
BBTB	TB	June	Trap	49	12.37	Aug.–Sept.	Trap
	TB	July	Purse Seine	48	162.15	Jan., Dec.	Purse Seine
	TB	July	Tuck Seine	50	29.47	Dec.	Tuck Seine
	TB	July	Gillnet	50	94.07	May–June, Aug.–Sept.	Gillnet
CBSS[2]	CB	May	Purse Seine	50	495.53	May, Sept.– Oct.	Purse Seine
	CB	May	Tuck Seine	50	157.41	May, Sept.	Tuck Seine
SMBPB	PB	January	Purse Seine	50	189.01	Jan.	Purse Seine
	PB	December	Purse Seine	50	189.01	Jan.	Purse Seine
	PB	December	Purse Seine	50	290.28	Mar.	Purse Seine
	PB	April	Gillnet	50	24.51	May	Gillnet
	PB	March	Gillnet	50	24.51	May	Gillnet
FB[3]	FB	May	Bar Seine	50	266.95	May	Bar Seine
	FB	May	Tuck Seine	50	95.05	Mar., May	Tuck Seine and Trap

Table 1c. Allocation of samples for 2021 commercial landings with the months and gear type for sample allocations.

Area	Bay	Month Sampled	Gear Fished	Number of Fish	Total Allocated Landings (t)	Months Allocated	Gear Allocated
WBNDB[1]	NDB	November	Gillnet	50	85.49	Aug.	Gillnet
	NDB	December	Gillnet	50	85.85	Aug.	Gillnet
BBTB	TB	April	Gillnet	50	42.85	Aug.	Gillnet
	TB	May	Gillnet	50	42.85	Aug.	Gillnet
	TB	May	Gillnet	50	42.85	Aug.	Gillnet
	TB	June	Gillnet	50	43.15	Aug.	Gillnet and Trap
	TB	July	Tuck Seine	50	5.52	Dec.	Purse Seine
SMBPB	PB	January	Purse Seine	50	419.19	Dec.	Purse Seine
	PB	January	Purse Seine	50	419.19	Dec.	Purse Seine
	PB	January	Purse Seine	50	257.35	Jan., Feb.	Purse Seine
	PB	March	Purse Seine	40	257.35	Jan., Feb.	Purse Seine
	PB	April	Gillnet	50	0.68	Apr.	Gillnet
	PB	May	Gillnet	50	139.10	May	Gillnet
FB	FB	January	Gillnet	50	21.91	Apr.	Gillnet
	FB	April	Bar Seine	50	183.49	Mar.–Apr.	Bar Seine
	FB	April	Bar Seine	50	257.22	Apr.–May	Bar Seine
	FB	May	Gillnet	49	21.91	Apr.	Gillnet
	FB	December	Gillnet	50	21.91	Apr.	Gillnet
LAB	LAB	November	Purse Seine	48	508.89	Aug., Oct.	Tuck Seine

[1]A total of 655.63 t purse and tuck seine landings were not included for WBNDB because only gillnet samples were collected.

Table 2a. Results of the annual herring bait fisher telephone survey in White Bay-Notre Dame Bay.

Year	Response Rate (%)	% of Fishers Actively Fishing Bait Nets	Estimated Number of Bait Fishers	Estimated Bait Landings (t) for Stock Area
2008	81	35	334	474
2009	84	39	362	408
2010	-	-	-	282
2011	71	32	282	165
2012	82	41	343	242
2013	77	29	226	248
2014	80	28	213	272
2015	75	28	189	151
2016	87	27	166	121
2017	79	35	203	259
2018	69	47	180	297
2019	71	29	110	103
2020	69	41	160	129
2021	52	47	178	160

Table 2b. Results of the annual herring bait fisher telephone survey in Bonavista Bay-Trinity Bay.

Year	Response Rate (%)	% of Fishers Actively Fishing Bait Nets	Estimated Number of Bait Fishers	Estimated Bait Landings (t) for Stock Area
2008	87	47	262	431
2009	84	49	270	511
2010	-	-	-	392
2011	83	44	233	274
2012	84	41	214	281
2013	80	51	244	424
2014	85	39	182	162
2015	80	43	199	291
2016	74	45	189	281
2017	81	33	137	338
2018	85	33	92	128
2019	49	37	102	180
2020	55	34	94	90
2021	48	43	117	171

Table 2c. Results of the annual herring bait fisher telephone survey in Conception Bay-Southern Shore.

Year	Response Rate (%)	% of Fishers Actively Fishing Bait Nets	Estimated Number of Bait Fishers	Estimated Bait Landings (t) for Stock Area
2016	62	12	38	51
2017	79	10	31	37
2018	85	19	34	60
2019	82	29	47	60
2020	53	20	34	114
2021	62	15	25	27

Table 2d. Results of the annual herring bait fisher telephone survey in St. Mary's Bay-Placentia Bay.

Year	Response Rate (%)	% of Fishers Actively Fishing Bait Nets	Estimated Number of Bait Fishers	Estimated Bait Landings (t) for Stock Area
2008	76	22	97	127
2009	85	22	92	123

Year	Response Rate (%)	% of Fishers Actively Fishing Bait Nets	Estimated Number of Bait Fishers	Estimated Bait Landings (t) for Stock Area
2010	-	-	-	148
2011	77	33	125	172
2012	73	21	75	134
2013	80	17	57	103
2014	78	15	51	29
2015	81	16	51	19
2016	89	38	117	193
2017	70	26	80	226
2018	80	30	36	68
2019	55	17	18	224
2020	60	12	14	47
2021	60	21	80	137

Table 2e. Results of the annual herring bait fisher telephone survey in Fortune Bay.

Year	Response Rate (%)	% of Fishers Actively Fishing Bait Nets	Estimated Number of Bait Fishers	Estimated Bait Landings (t) for Stock Area
2008	89	60	181	395
2009	81	62	184	301
2010	-	-	-	277
2011	91	64	178	252
2012	72	60	165	540
2013	63	47	123	100
2014	74	35	90	53
2015	100	35	83	70
2016	79	41	94	140
2017	76	48	109	333
2018	58	42	54	122
2019	65	56	66	156
2020	37	28	34	27
2021	61	38	47	64

Table 3. Mean lengths and the weighted mean weight ($\overline{W}$) used to calculate the estimated target strength (TSN) and weight-based target strength (TSW) to estimate biomass.

Survey	Number of Fish	Average Length (cm)	$\overline{W}$	TS_N	TS_W
BBTB fall 2019	350	18.78	46.20	-40.08	-56.72
FB winter 2020	105	22.40	82.33	-38.55	-57.70
WBNDB fall 2020	167	9.85	9.68	-45.68	-55.54
SMBPB winter 2021	100	25.74	127.57	-37.34	-58.40
BBTB fall 2021	52	17.98	41.53	-40.45	-56.64

Table 4. Biomass (t) and SE (t)* estimates for spring and fall spawners combined from hydroacoustic surveys.

Year	WBNDB		BBTB		SMBPB		FB	
	Biomass	SE	Biomass	SE	Biomass	SE	Biomass	SE
1983	81,919	na	-	-	-	-	-	-
1984	91,460	na	59,793	na	-	-	-	-

Year	WBNDB		BBTB		SMBPB		FB	
	Biomass	SE	Biomass	SE	Biomass	SE	Biomass	SE
1985	119,460	na	99,916	na	-	-	23,345	na
1986	75,963	na	25,672	na	36,336	na	-	-
1987	114,567	na	38,658	na	-	-	-	-
1988	98,945	31,071	134,914	63,707	-	-	-	-
1989	-	-	-	-	-	-	-	-
1990	-	-	34,601	18,059	97,521	86,292	36,959	25,150
1991	-	-	-	-	-	-	-	-
1992	113,479	111,685	-	-	8,665	4,026	7,328	6,196
1993	-	-	24,362	7,314	-	-	-	-
1994	2,164	na	-	-	43,949	na	-	-
1995	-	-	13,047	4,312	-	-	2,803	na
1996	-	-	36,849	-	29,418	30,664	-	-
1997	-	-	-	-	-	-	16,885	na
1998	19,529	3,319	-	-	11,572	4,361	-	-
1999	-	-	22,674	4,103	-	-	30,408	17,448
2000	312	121	-	-	2,000	3,810	-	-
2001	-	-	-	-	-	-	3,452	1,844
2016	-	-	-	-	19,834**	-	-	-
2017	-	-	-	-	-	-	-	-
2018	-	-	-	-	-	-	-	-
2019	-	-	26,589	396	-	-	-	-
2020	13,219	136	9,770	56	-	-	5,425	295
2021	-	-	-	-	2,407	71	-	-

*some SE values were unavailable from historical datasets

**SMBPB 2016 biomass estimate for Placentia Bay only (Bourne et al. 2018)

Table 5a. Strata, area (m²), and biomass estimates (t) from fall 2019 BBTB acoustic survey.

Stratum	Area (m^2)	Biomass (t)
26	3.92E+08	12.88
27	2.34E+08	2,178.48
28	2.15E+08	2,042.28
29	2.16E+08	703.88
30	3.35E+08	2,323.25
31	1.56E+08	951.18
32	1.05E+08	193.83
33	7.40E+07	78.09
34	1.59E+08	165.06
35	3.67E+08	171.06

Stratum	Area (m²)	Biomass (t)
36	6.41E+08	5,401.68
37	3.34E+08	4,691.62
38	9.00E+07	937.70
39	8.10E+07	334.67
40	8.50E+07	1,069.09
41	5.20E+07	809.26
43	1.16E+08	811.37
44	1.64E+08	516.47
45	1.03E+08	541.82
46	1.72E+08	241.26

Table 5b. Strata, area (m²), and biomass estimates (t) from winter 2020 FB acoustic survey

Stratum	Area (m²)	Biomass (t)
1	2.52E+08	84.65
2	2.80E+07	24.35
3	4.70E+07	36.22
4	6.90E+07	69.59
5	3.40E+08	77.95
6	1.33E+08	226.07
7	7.50E+07	1,532.86
8	6.70E+07	393.68
9	3.03E+08	86.06
10	9.70E+07	146.28
11	9.30E+07	2,645.05
12	3.10E+07	38.22
13	5.10E+07	64.28

Table 5c. Strata, area (m²), and biomass estimates (t) from fall 2020 WBNDB acoustic survey.

Stratum	Area (m²)	Biomass (t)
1	1.04E+09	236.21
2	1.12E+09	187.27
3	3.40E+08	77.14
4	2.34E+08	51.60
5	2.55E+08	4,351.52
6	1.29E+08	12.96
7	3.17E+08	977.58
8	2.82E+08	120.11
9	6.30E+07	680.32
10	1.47E+08	494.02

Stratum	Area (m²)	Biomass (t)
11	9.20E+07	176.66
12	9.80E+07	207.19
13	1.61E+08	98.41
14	1.25E+08	732.30
15	9.30E+07	60.64
16	1.93E+08	532.53
17	1.76E+08	805.70
18	2.73E+08	880.61
19	2.20E+08	557.40
20	1.32E+08	329.74
21	2.99E+08	145.55
22	3.98E+08	160.56
24	5.18E+08	113.82
25	7.82E+08	45.69
23A	6.01E+08	85.63
23B	2.89E+08	1,097.53

Table 5d. Strata, area (m²), and biomass estimates (t) from winter 2021 SMBPB acoustic survey.

Stratum	Area (m²)	Biomass (t)
54	3.92E+08	81.52
55	2.34E+08	45.14
56	2.15E+08	66.47
57	2.16E+08	41.66
58	3.35E+08	19.54
60	1.05E+08	1,313.53
61	7.40E+07	12.81
62	1.59E+08	34.90
63	3.67E+08	55.77
64	6.41E+08	203.31
65	3.34E+08	103.47
66	9.00E+07	37.81
67	8.10E+07	34.20
68	8.50E+07	22.17
69	5.20E+07	32.33
70	2.34E+08	18.15
71	1.16E+08	77.90
72	1.64E+08	206.19

Table 5e. Strata, area (m²), and biomass estimates (t) from fall 2021 BBTB acoustic survey.

Stratum	Area (m²)	Biomass (t)
26	3.92E+08	568.89
27	2.34E+08	255.44
28	2.15E+08	276.53
29	2.16E+08	154.77
30	3.35E+08	924.90
31	1.56E+08	197.58
32	1.05E+08	30.62
33	7.40E+07	72.03
34	1.59E+08	65.91
35	3.67E+08	845.86
36	6.41E+08	2,743.46
37	3.34E+08	975.78
38	9.00E+07	198.34
39	8.10E+07	233.43
40	8.50E+07	245.32
41	5.20E+07	158.60
42	2.34E+08	1,124.80
43	1.16E+08	235.43
44	1.64E+08	180.23
45	1.03E+08	143.41
46	1.72E+08	338.78

APPENDIX 2: FIGURES
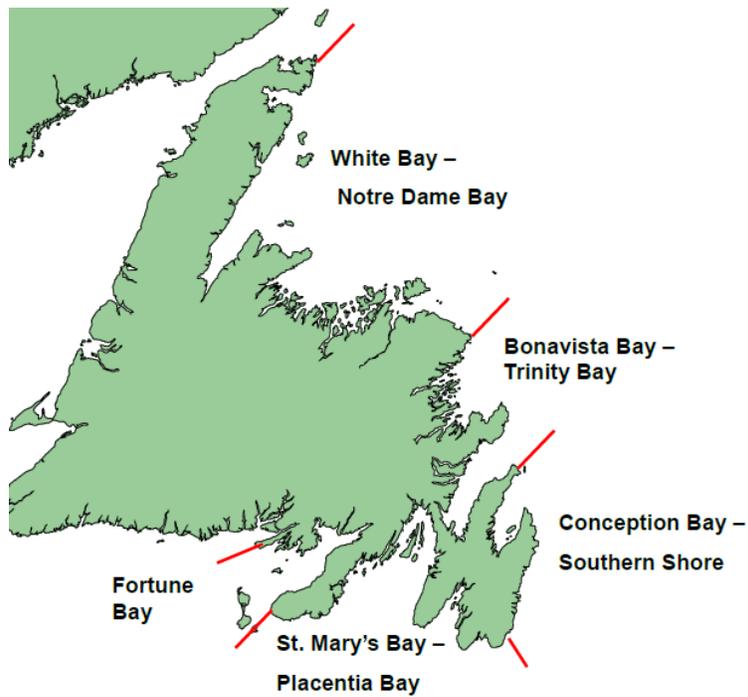
Figure 1. Map of Newfoundland east and south coast Atlantic Herring stock complexes.
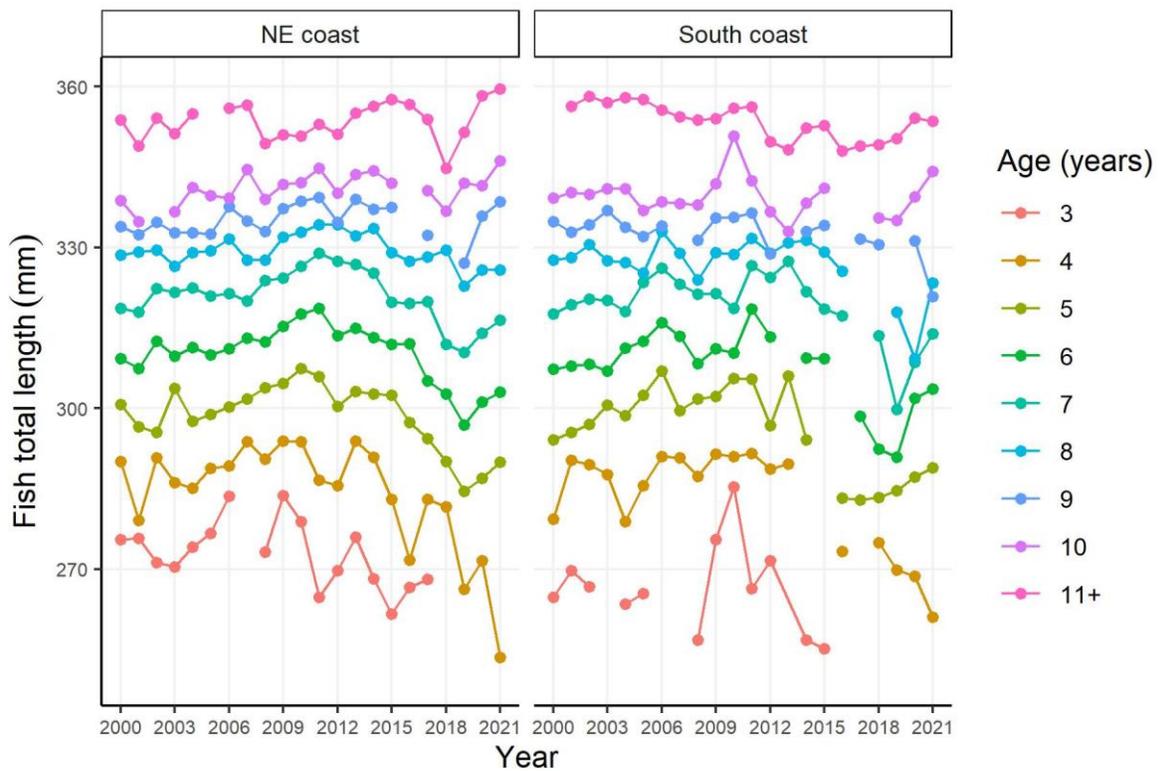
Figure 2. Mean length at age (total length in mm) for combined spring and fall spawning herring stock components for the northeast (NE) and South coast stock areas by year.
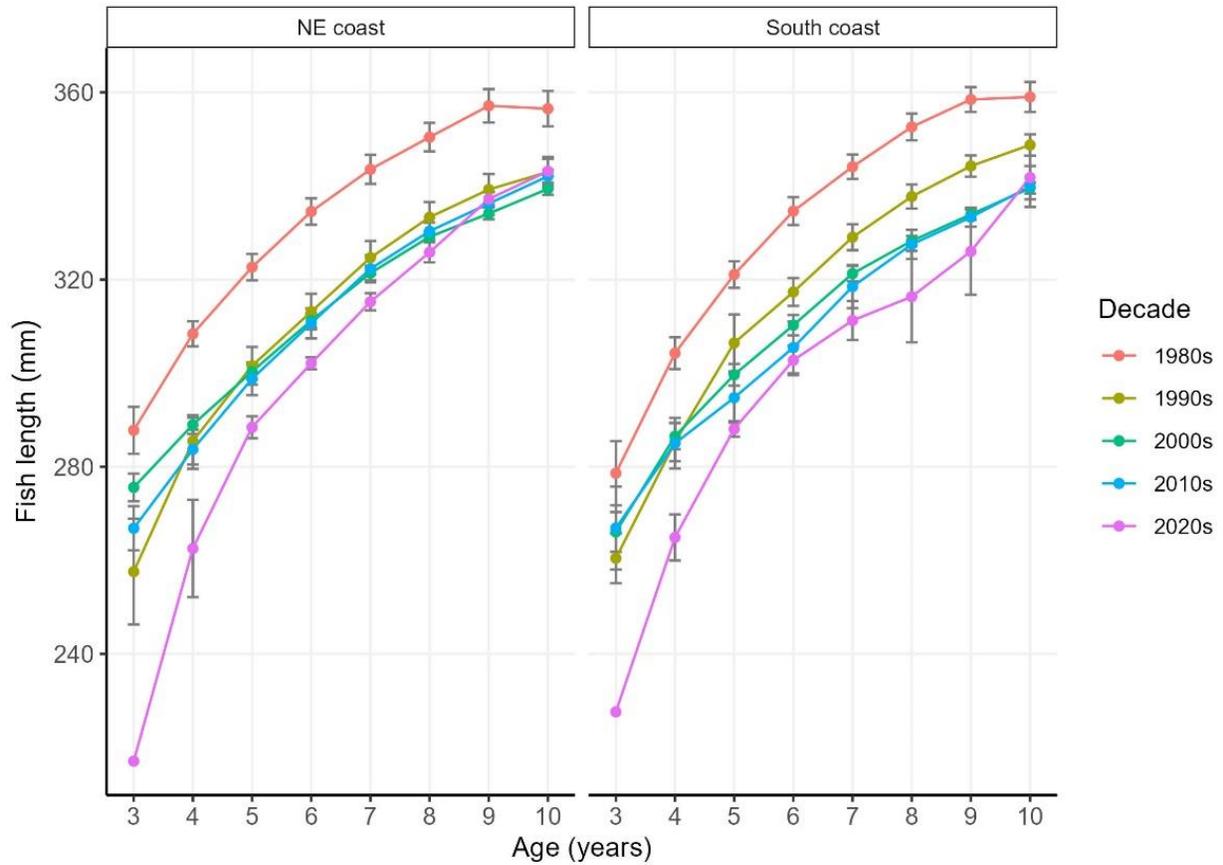
Figure 3. Mean length at age by decade (total length in mm and error bars representing 95% confidence intervals) for combined spring and fall spawning herring stock components for the northeast (NE) and South coast stock areas.
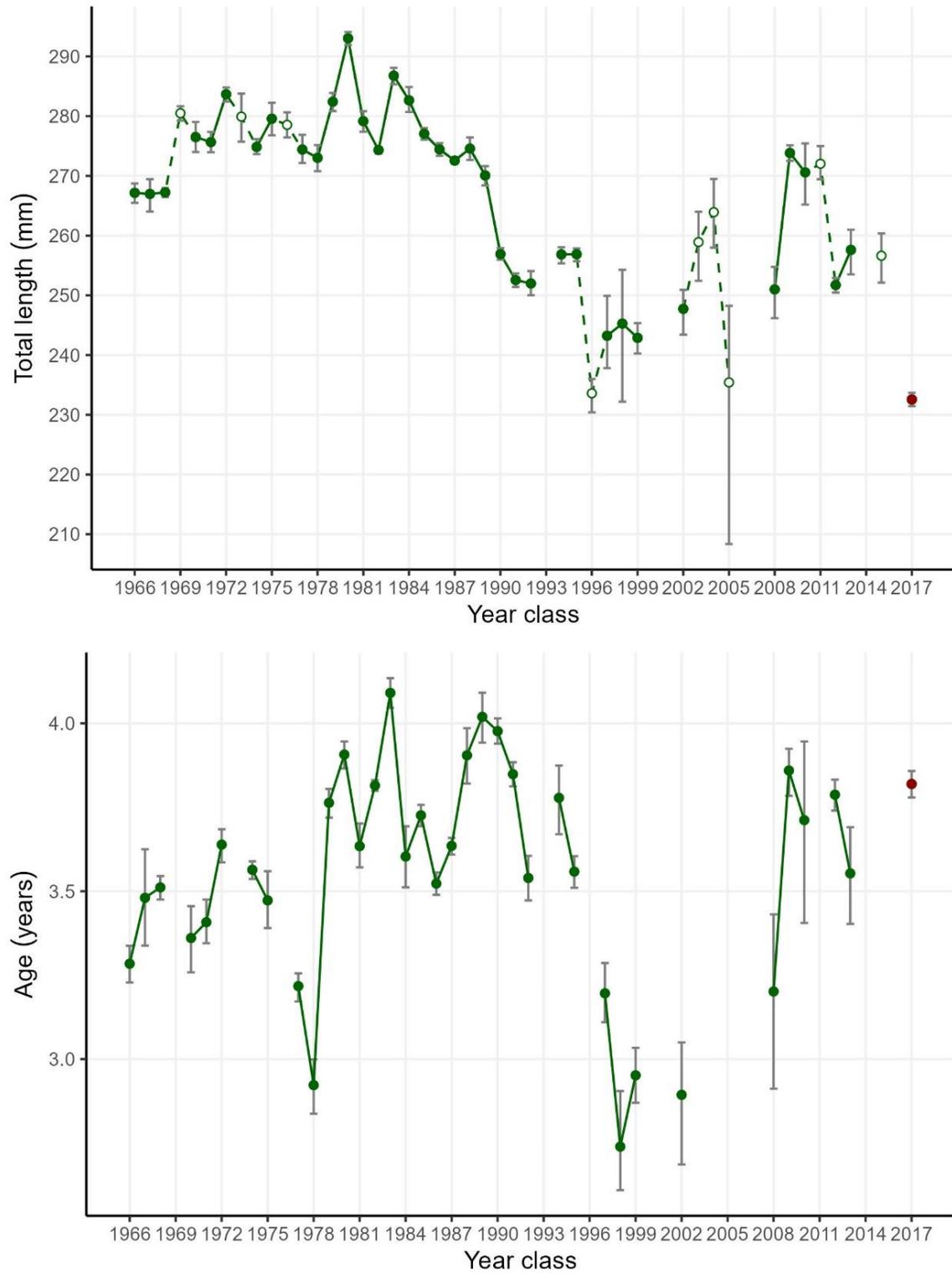
Figure 4. Length (L50, top panel) and Age (A50, bottom panel) at 50% maturity of spring spawners (total length in mm). The red point corresponds to the most recent year class available (2017), solid green points correspond to year classes with 30 or more fish, and hollow points correspond to L50 values calculated with less than 30 fish (minimum 10) sampled in a group.
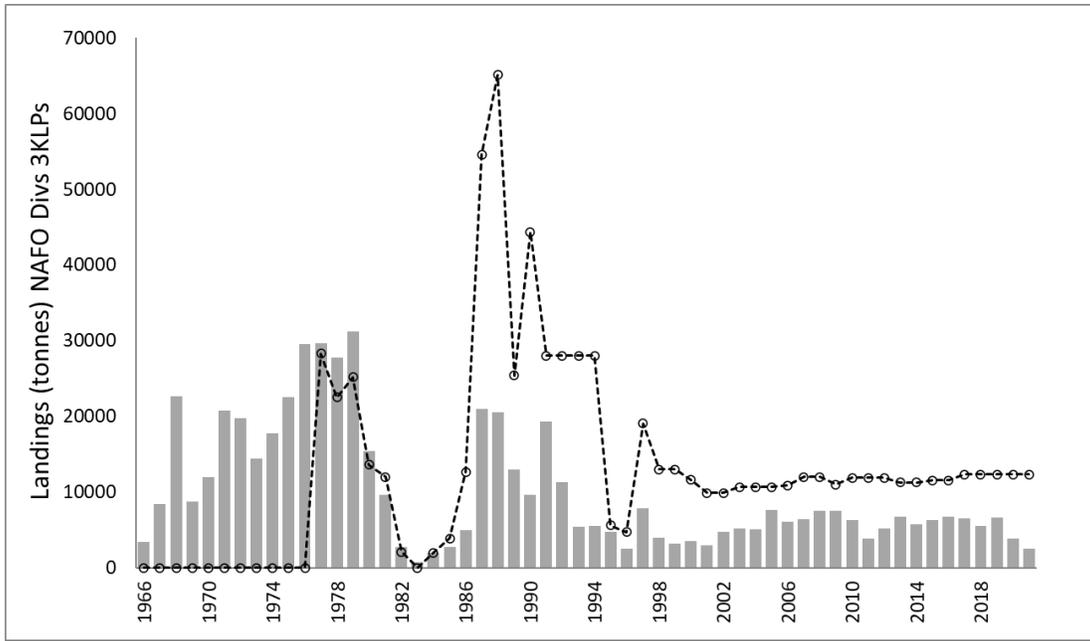
Figure 5. Commercial landings (tonnes) and total TAC (dashed line) for all stock areas combined from 1966 to 2021* (*note 3 most recent years' data is considered preliminary).
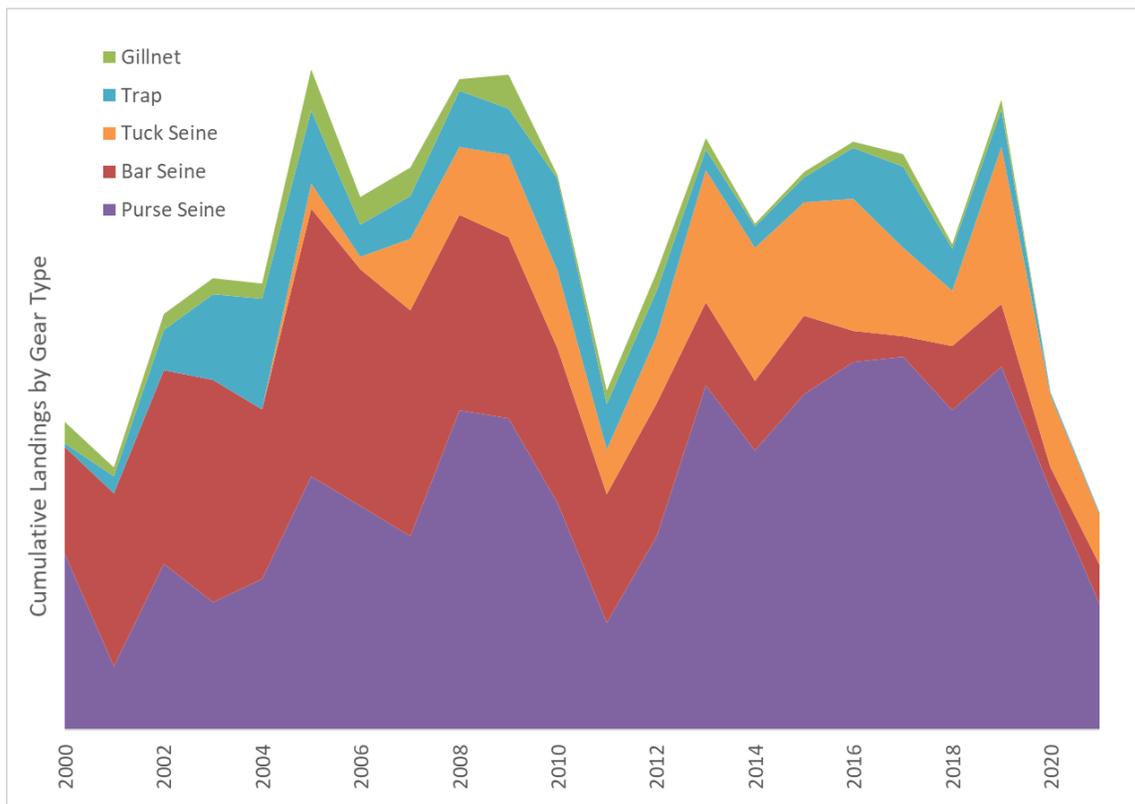
Figure 6. Proportion of total landings (all stock areas combined) from 2000 to 2021 by gear type.
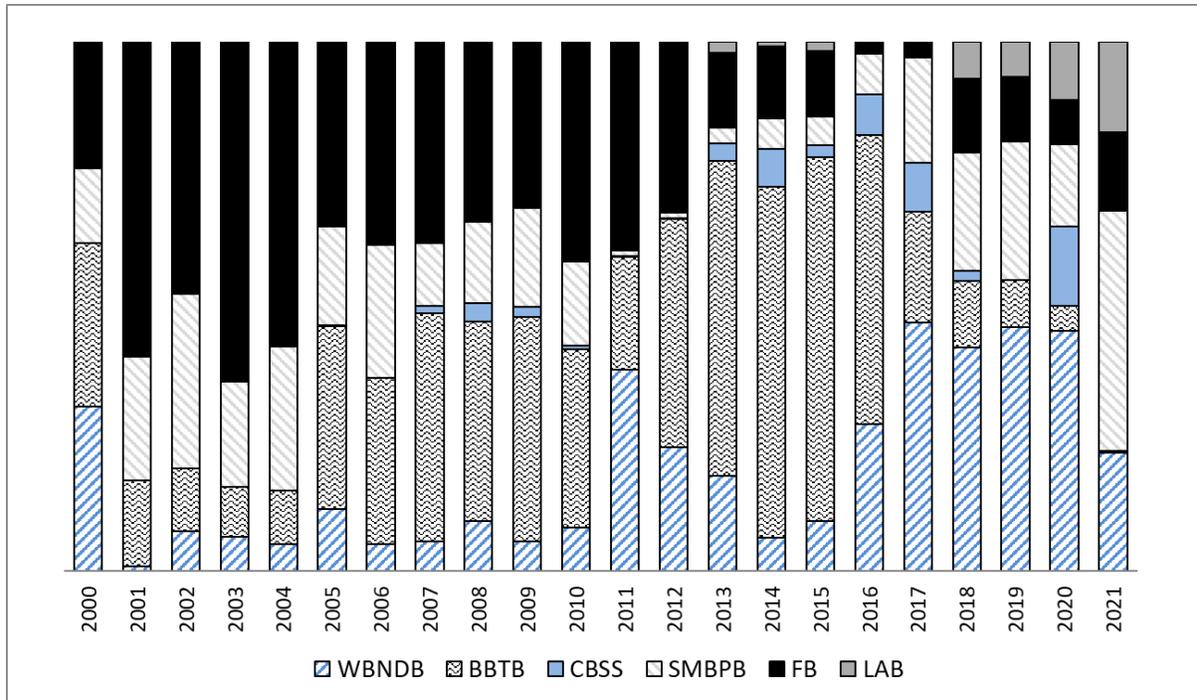
Figure 7. Proportion of total landings from 2000 to 2021 by stock area.
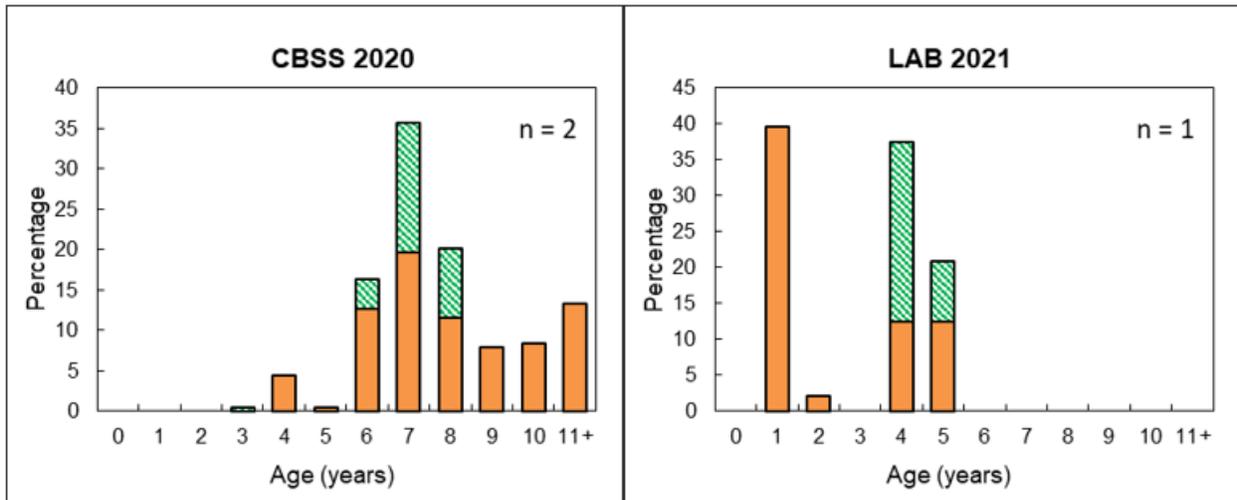
Figure 8a. Age and spawning type (orange = fall spawners, green = spring spawners, n = number of samples) composition of commercial sample collected in CBSS 2020 and Labrador 2021.
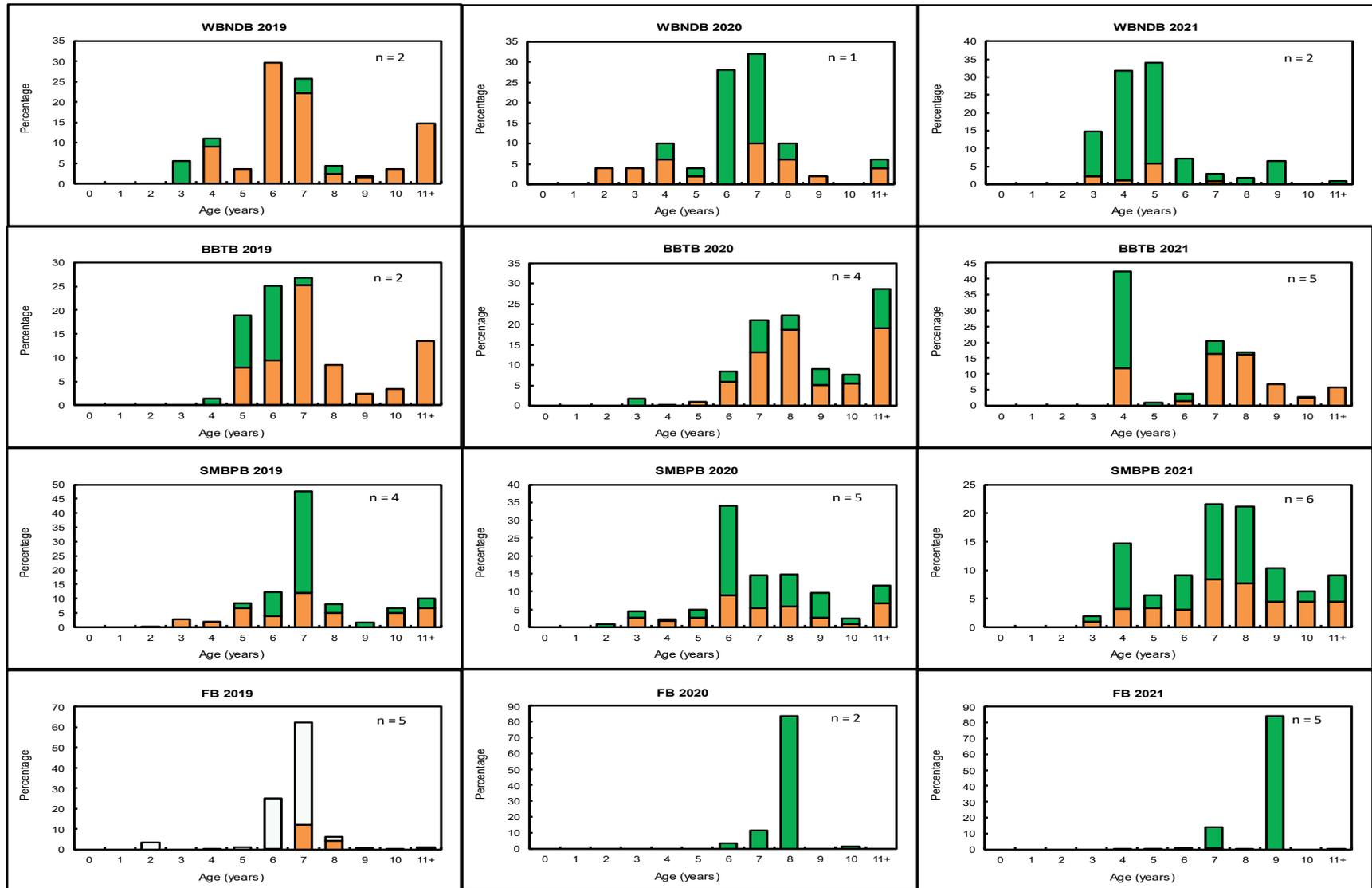
Figure 8b. Age and spawning type (orange bars = fall spawners, green bars = spring spawners, n = number of samples) composition of commercial samples collected in WBNDB, BBTB, SMBPB, and FB in 2019, 2020 and 2021.
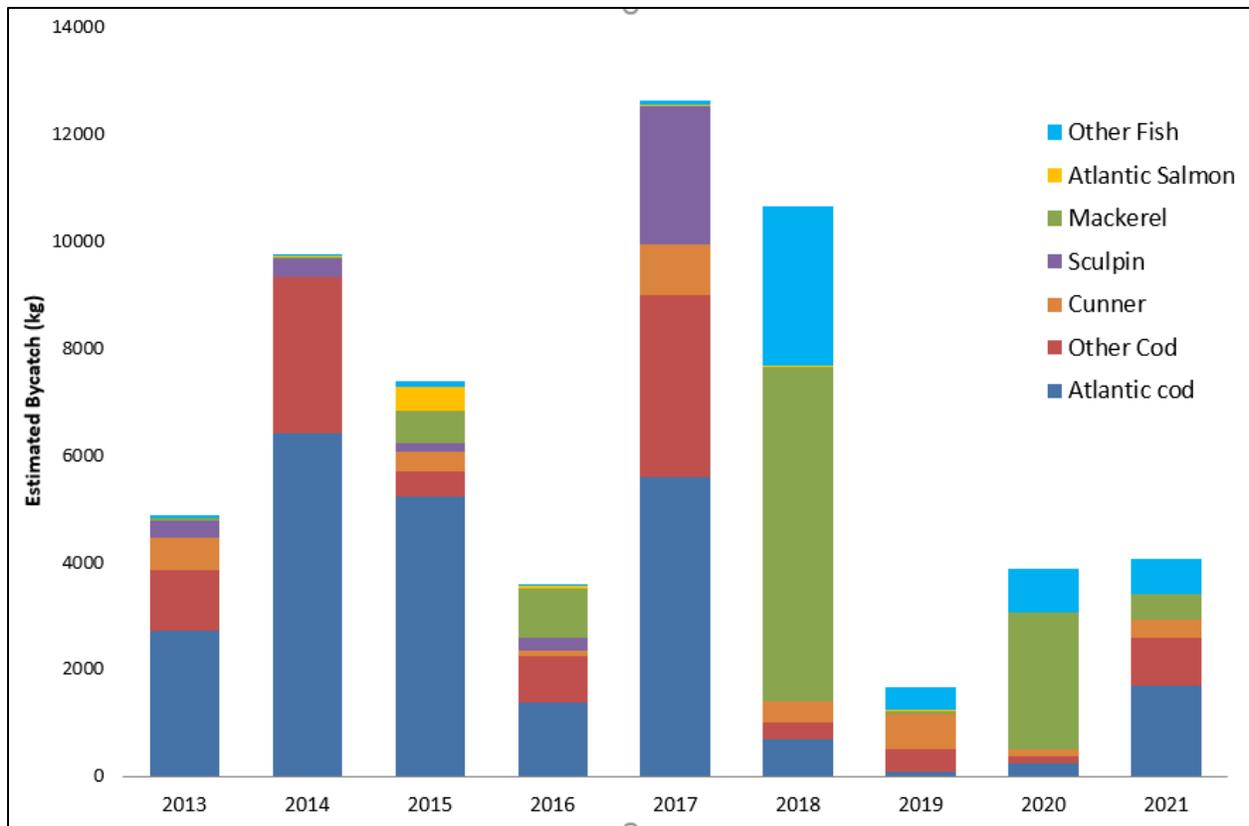
Figure 9. Estimated herring bait (gillnet) fishery bycatch (kg) for all stock areas combined based on the annual telephone survey.
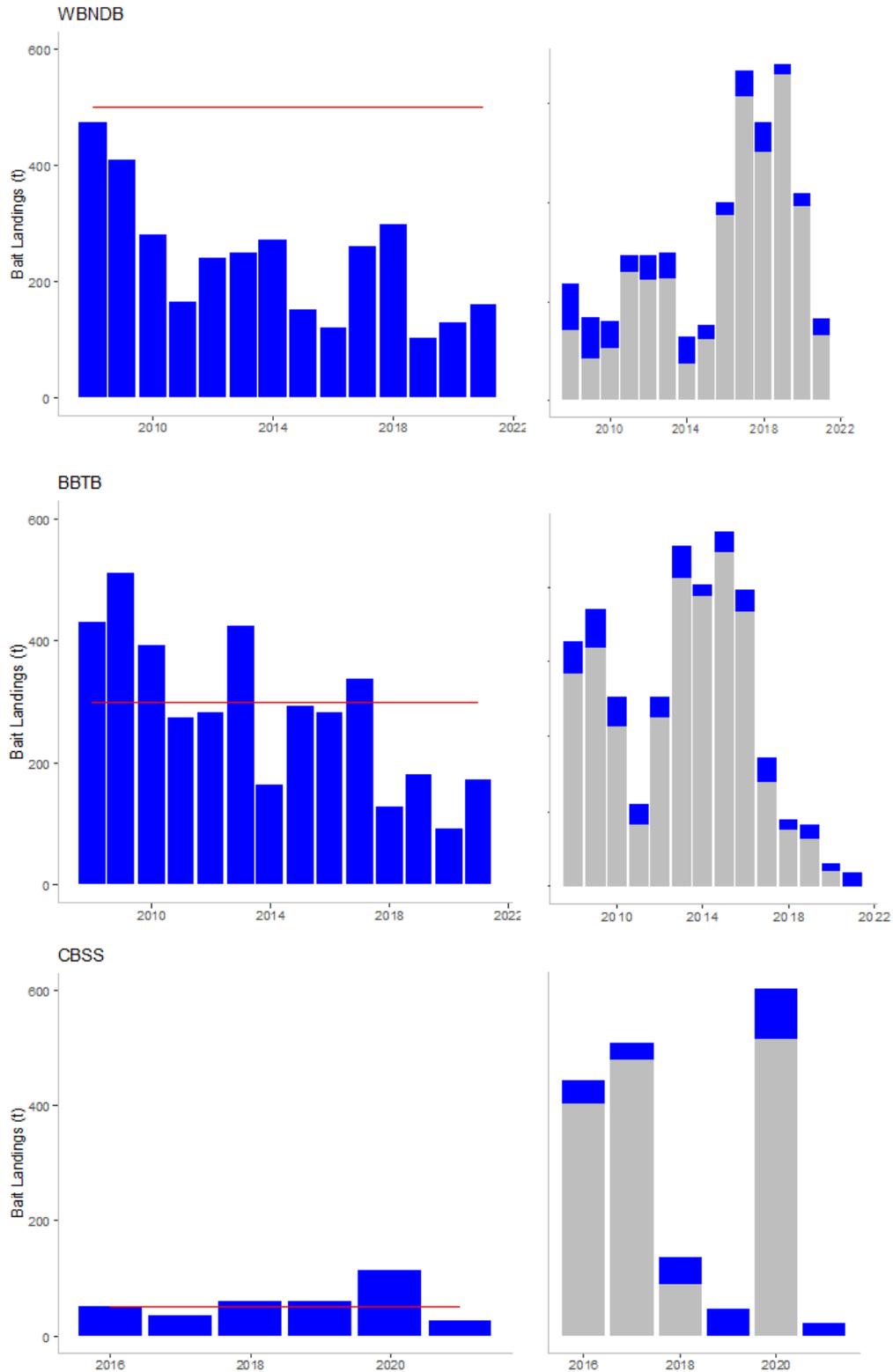
Figure 10a. Estimated herring bait landings (blue bars) and bait allocation (red line) (left panels); and total removals including commercial landings (grey bars) and estimated bait landings (blue bars) (right panels) in WBNDB, BBTB and CBSS.
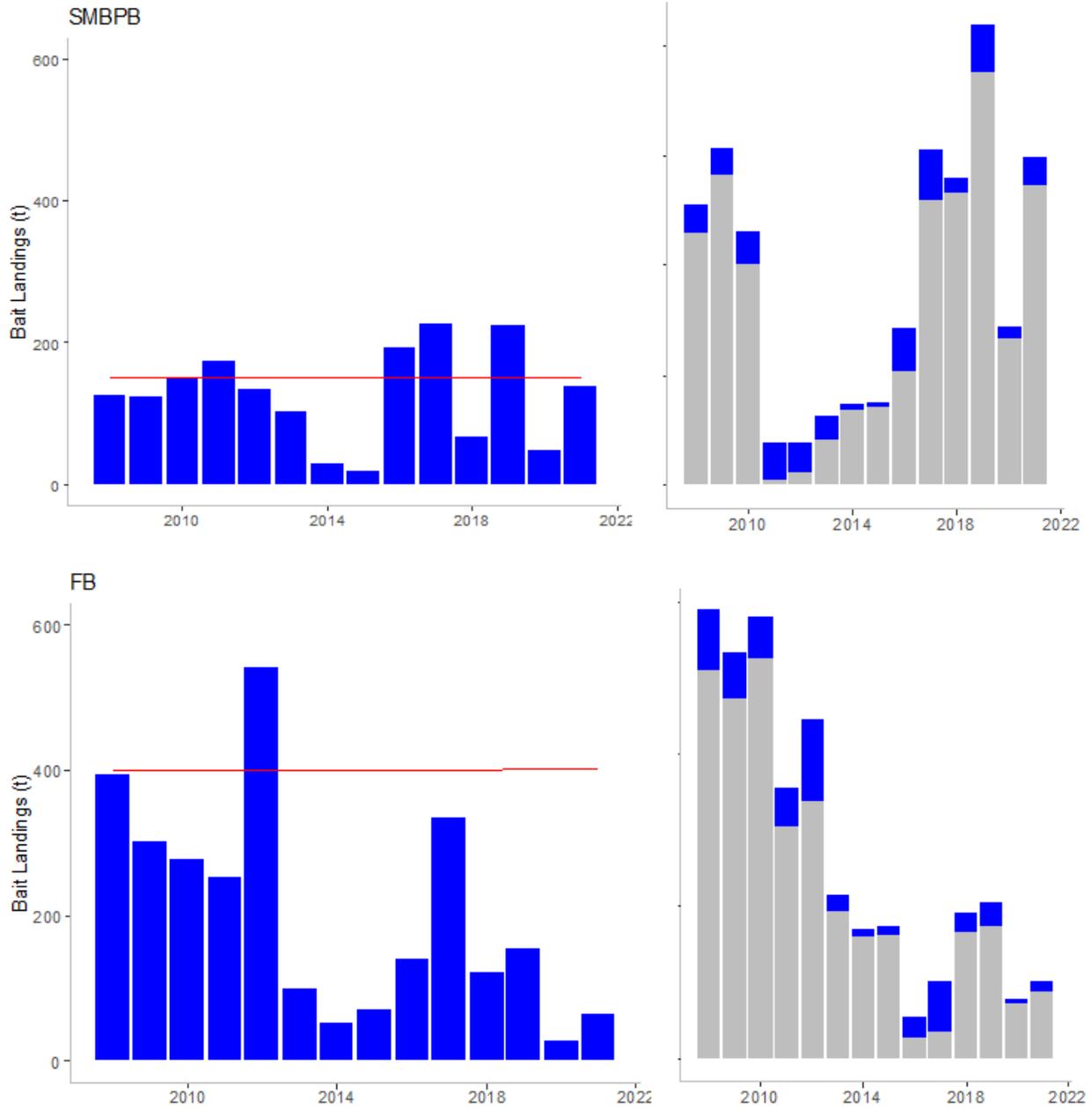
Figure 10b. Estimated herring bait landings (blue bars) and bait allocation (red line) (left panels); and total removals including commercial landings (grey bars) and estimated bait landings (blue bars) (right panels) in SMBPB and FB.

$$W = 4.5 \times 10^{-3} \times SL^{3.147}$$
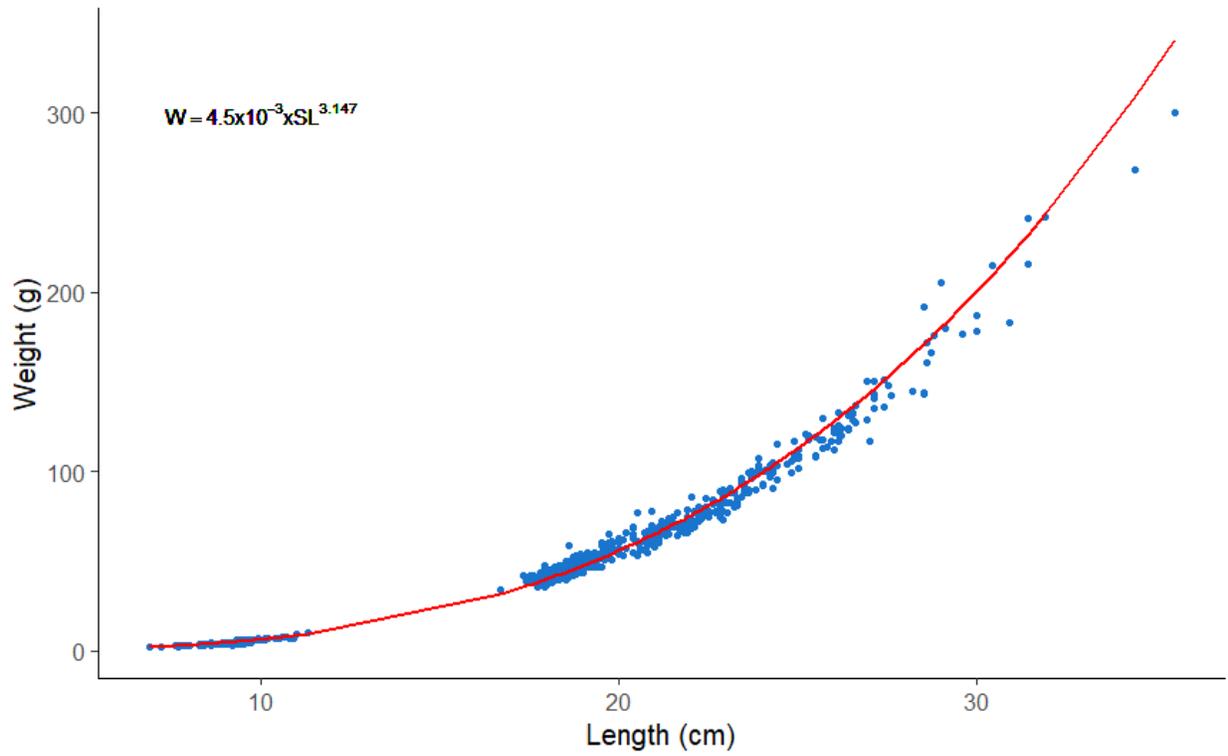
Figure 11. Weight-length regression calculated using Atlantic Herring sampled during hydroacoustic surveys from 2019 through 2021.
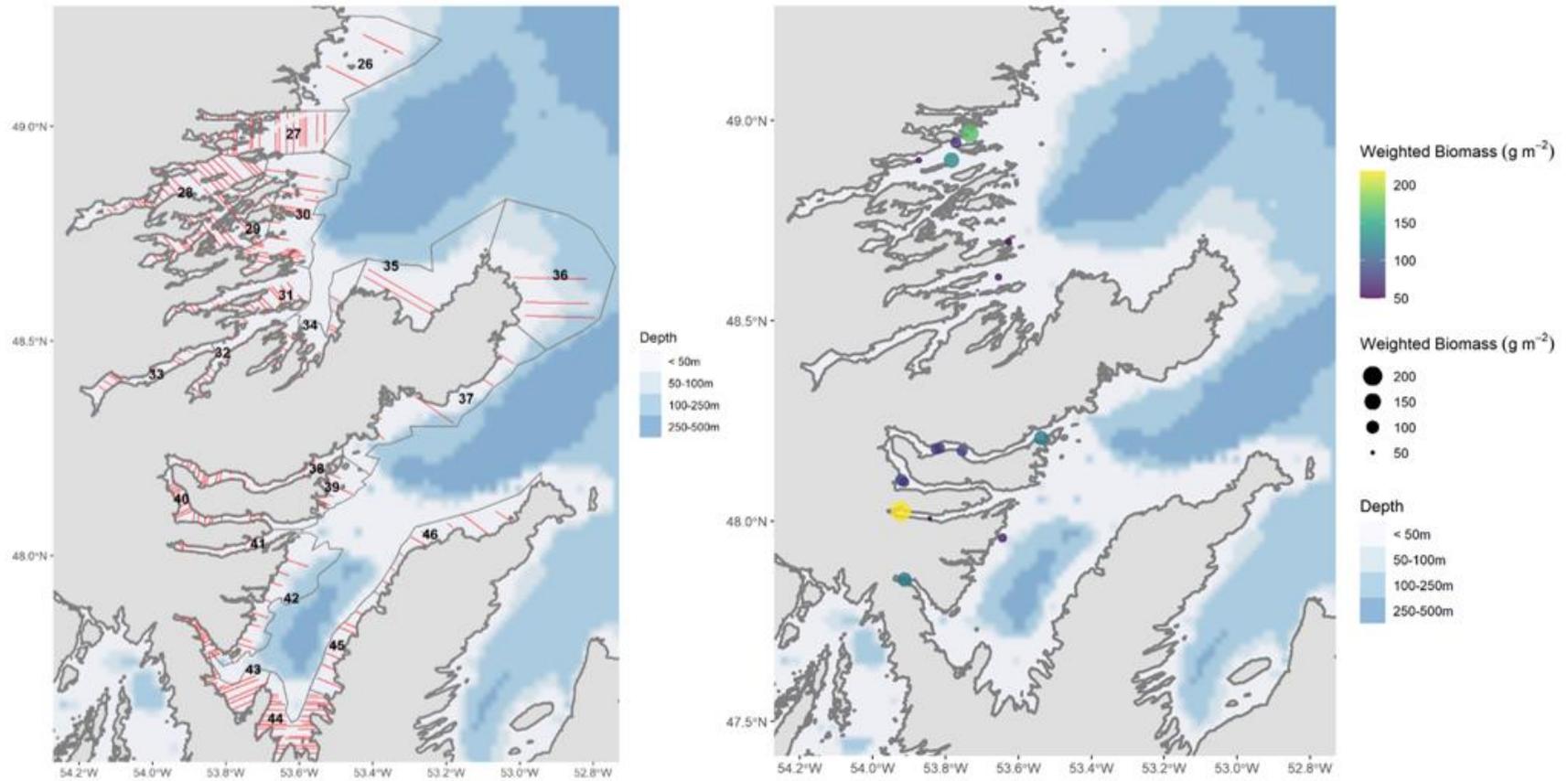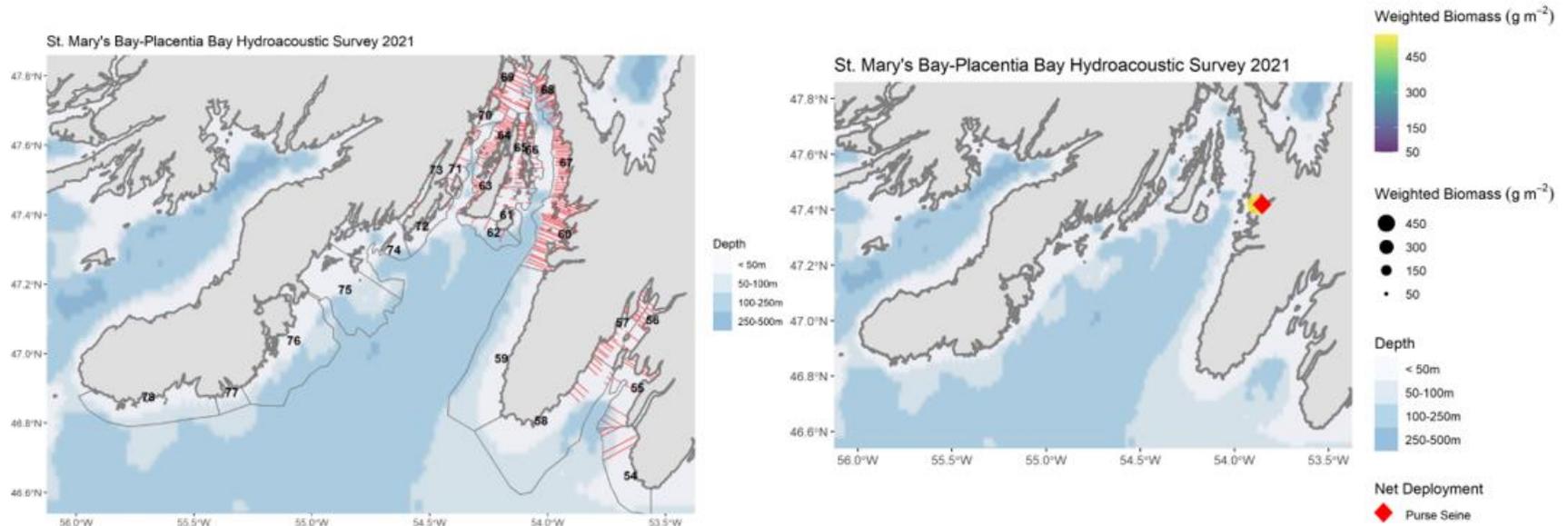
Figure 12. Bonavista Bay-Trinity Bay survey strata (grey lines) and transects (red lines) for the fall 2019 inshore acoustic survey (left panel) and distribution of the weighted transect biomass with the smallest weighted biomass values (<50 g m⁻²) removed and fishing set (net deployment) location (right panel).
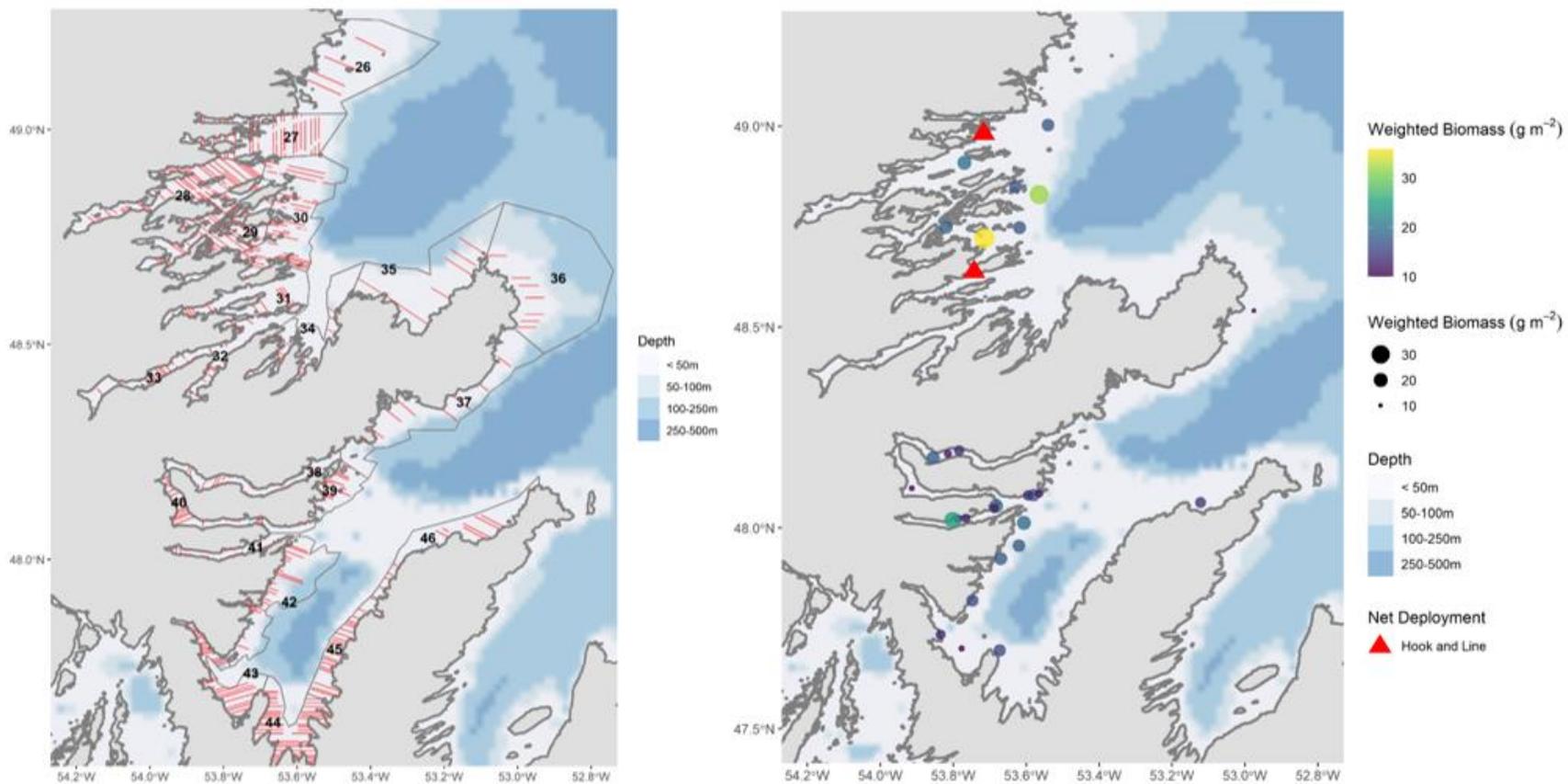
Figure 13. Bonavista Bay-Trinity Bay survey strata (grey lines) and transects (red lines) for the fall 2021 inshore acoustic survey (left panel) and distribution of the weighted transect biomass with the smallest weighted biomass values (< g m⁻²) removed and fishing set (net deployment) location (right panel).
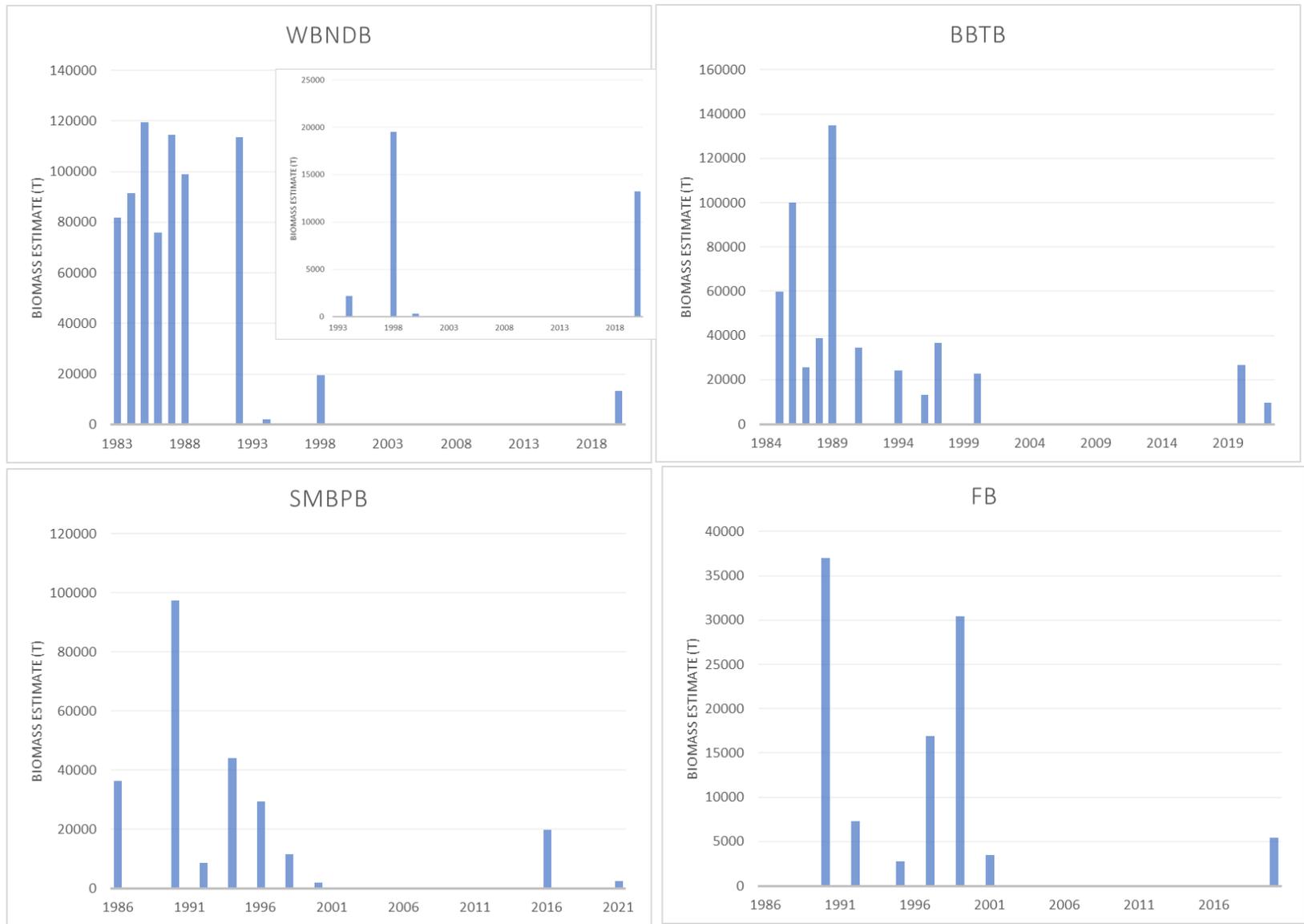
Figure 14. Herring biomass estimates (t) from inshore hydroacoustic surveys for spring and fall spawners combined. (Note: 2016 SMBPB was PB only; low estimate from 2000 WBNDB not visible due to scale, see inset).
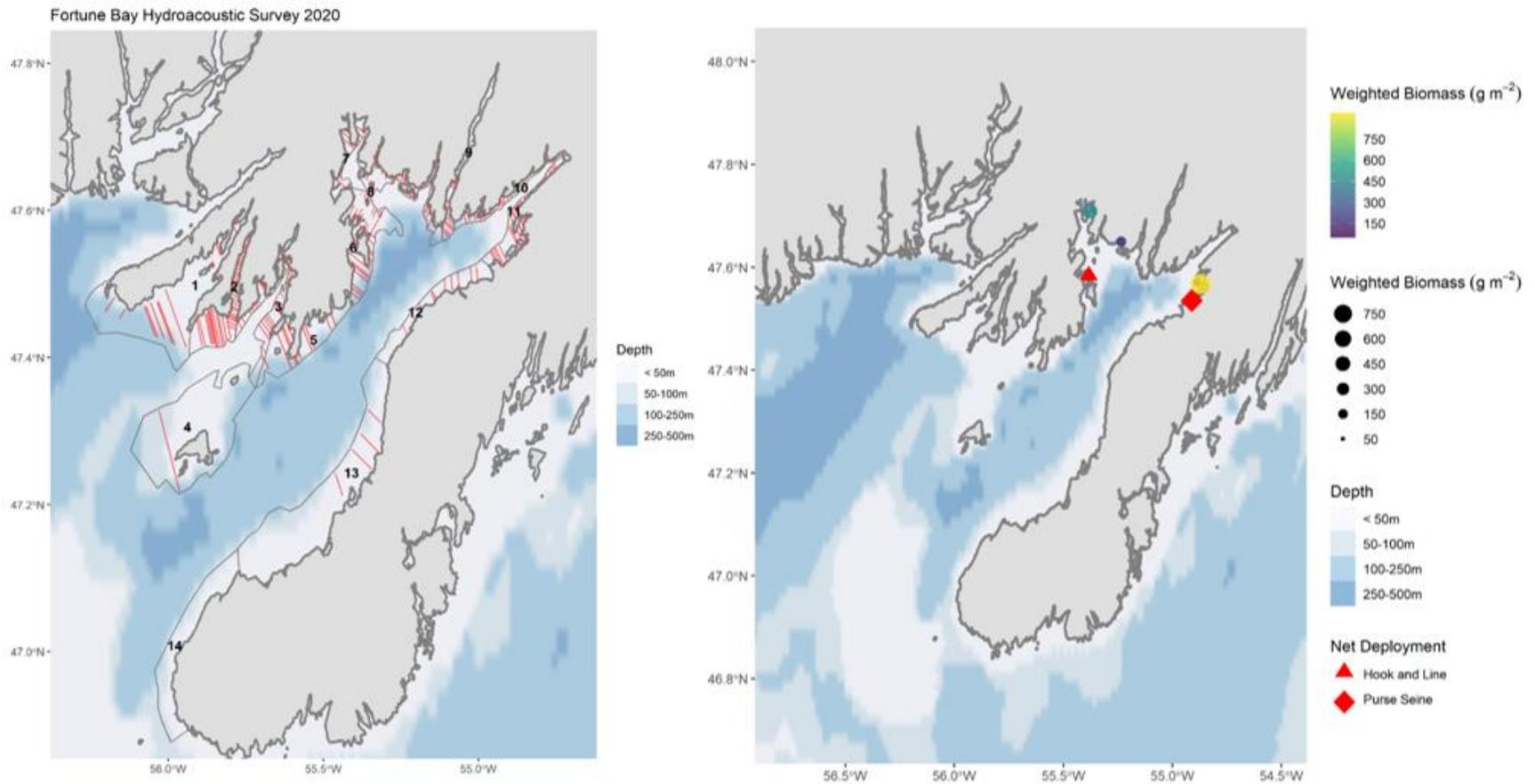
Figure 15. Fortune Bay survey strata (grey lines) and transects (red lines) for the winter 2020 inshore acoustic survey (left panel) and distribution of the weighted transect biomass with the smallest weighted biomass values (<50 g m^{-2}) removed and fishing set (net deployment) location (right panel).
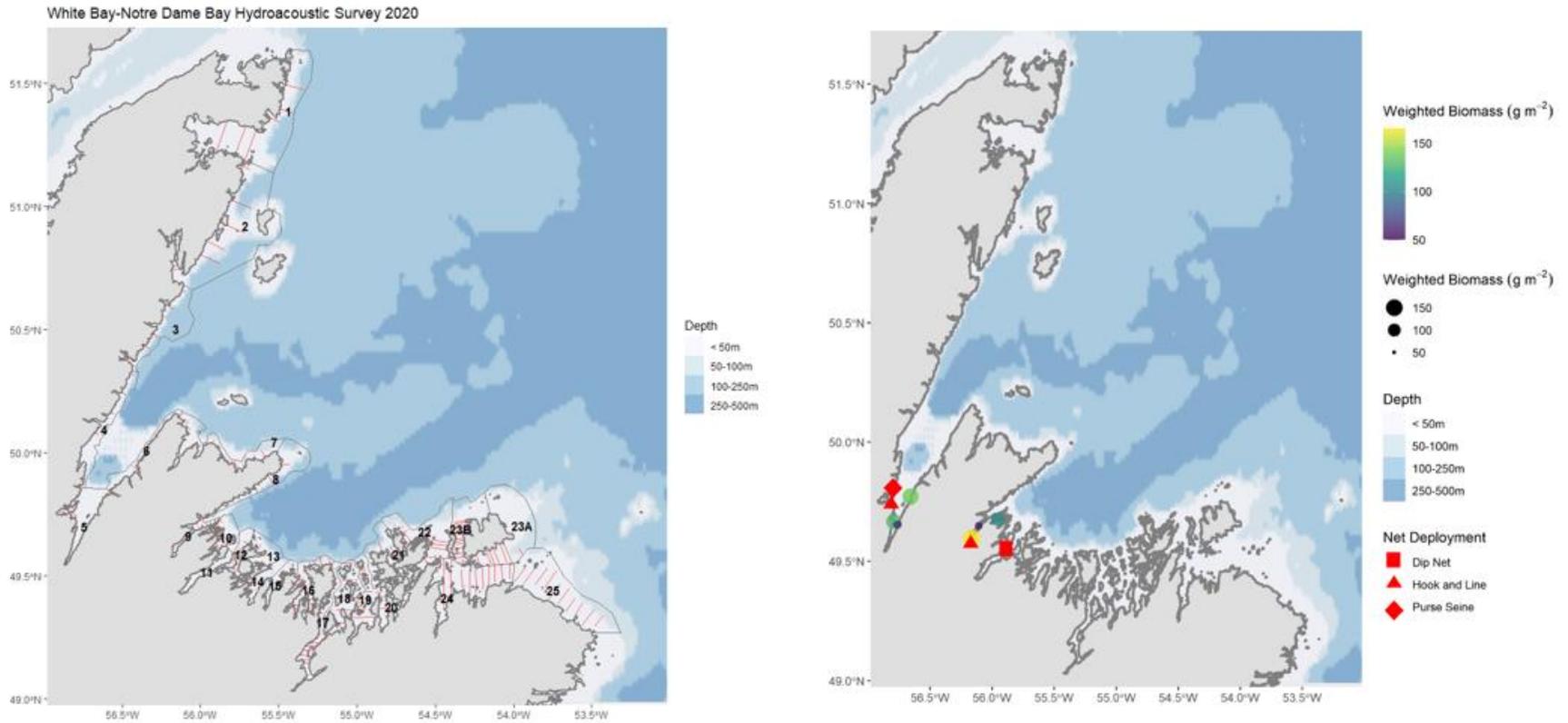
Figure 16. White Bay-Notre Dame Bay survey strata (grey lines) and transects (red lines) for the fall 2020 inshore acoustic survey (left panel) and distribution of the weighted transect biomass with the smallest weighted biomass values (<50 g m^{-2}) removed and fishing set (net deployment) location (right panel).

Figure 17. St. Mary's Bay-Placentia Bay survey strata (grey lines) and transects (red lines) for the winter 2021 inshore acoustic survey (top panel) and distribution of the weighted transect biomass with the smallest weighted biomass values (<50 g m-2) removed and fishing set (net deployment) location (bottom panel).
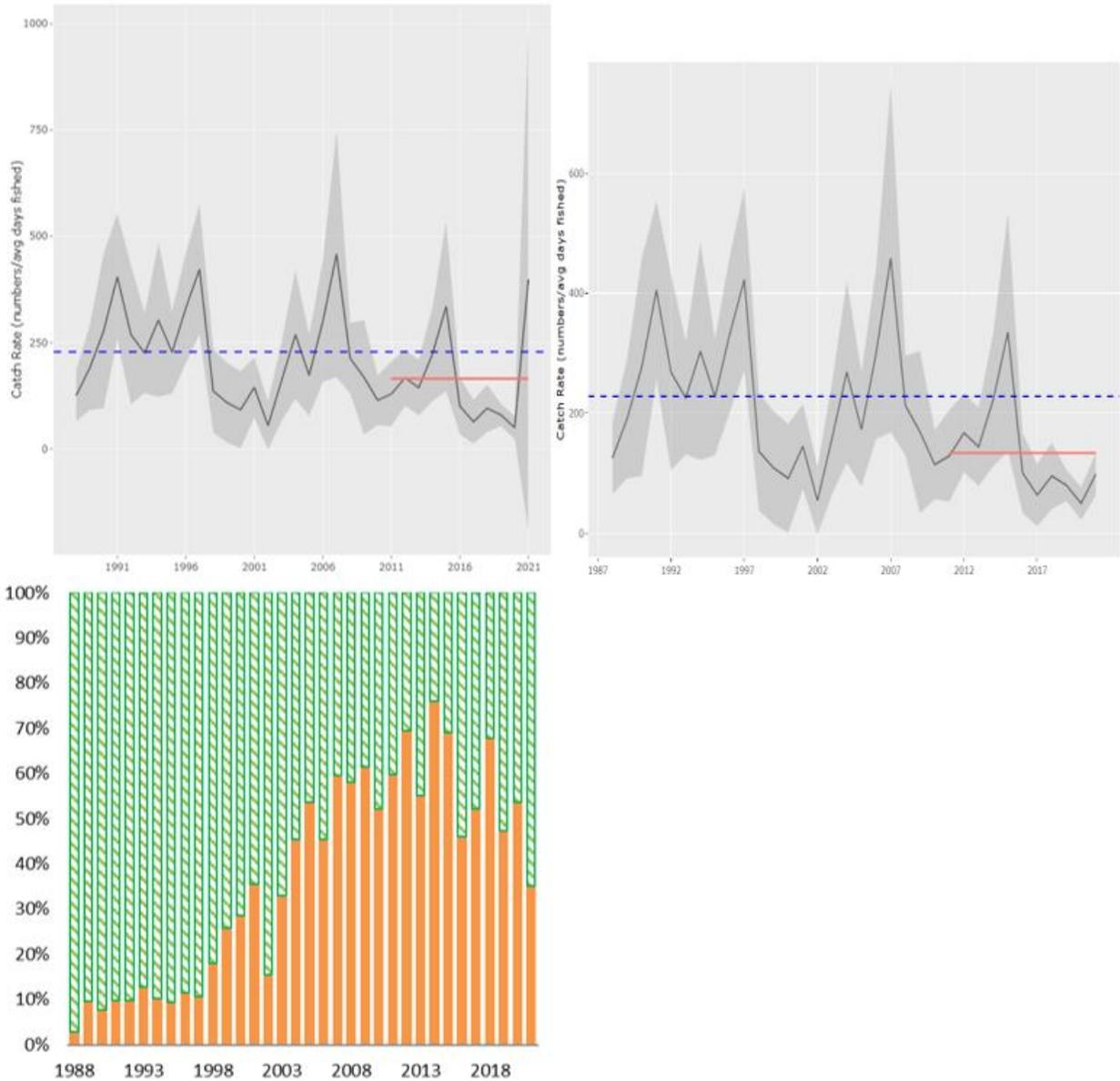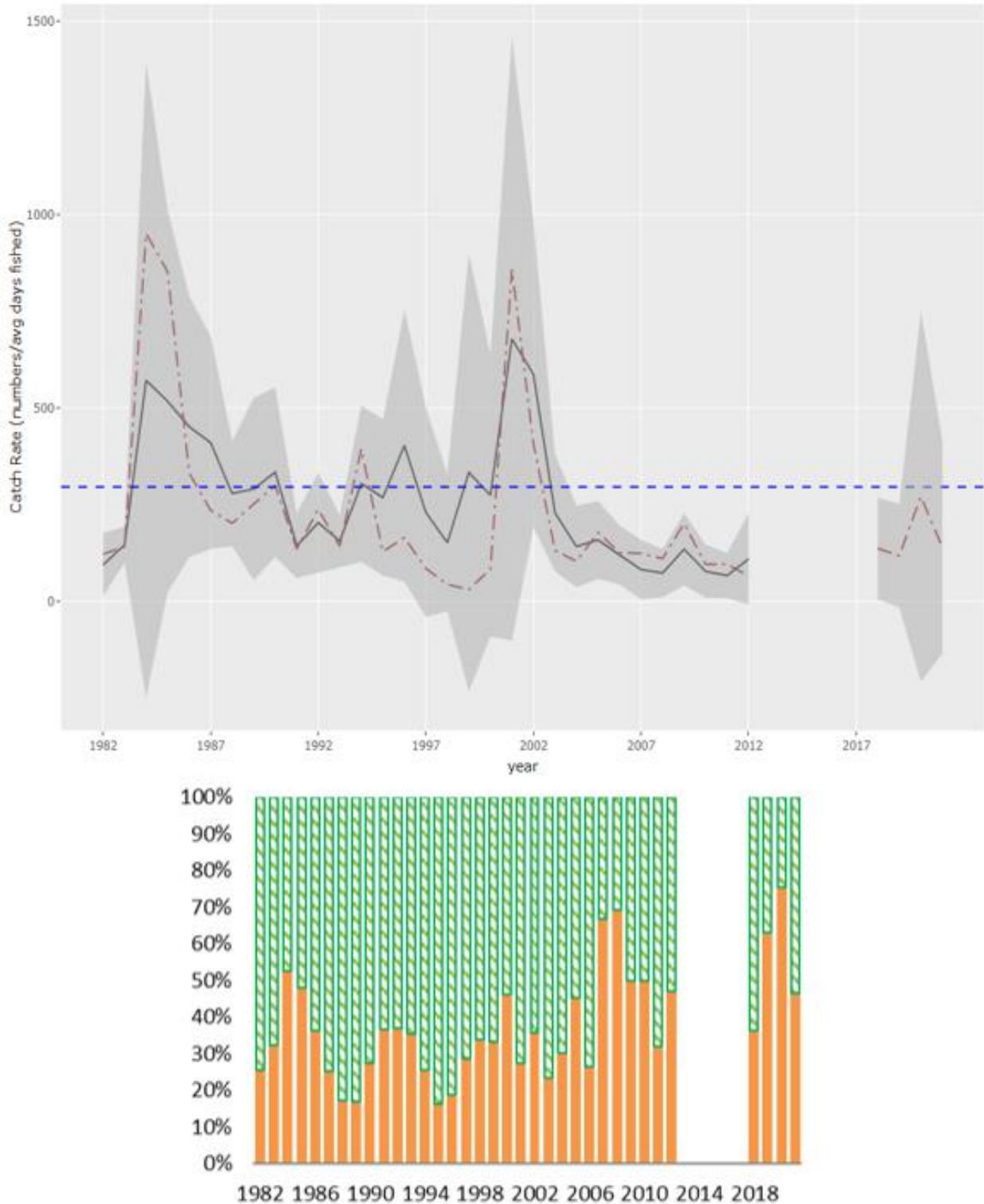
Figure 18. Combined catch rate (number of herring caught/average days fished) for the BBTB spring research gillnet program with reference period mean (1990–2005; broken blue line) and decadal mean (solid red line) including all fishers (top left) and without fisher in 2021 who had anomalously high catch rate (top right); and the proportion of spring (green bars) and fall (orange bars) spawning herring in the RGN catch (bottom panel).

Figure 19. Total daily catch numbers (not catch rates) for the BBTB research gillnet program by bay in 2021.

Figure 20. Catch at age in the BBTB research gillnet program with percentage of spring (green bars) and fall (orange bars) spawners 2019–21.
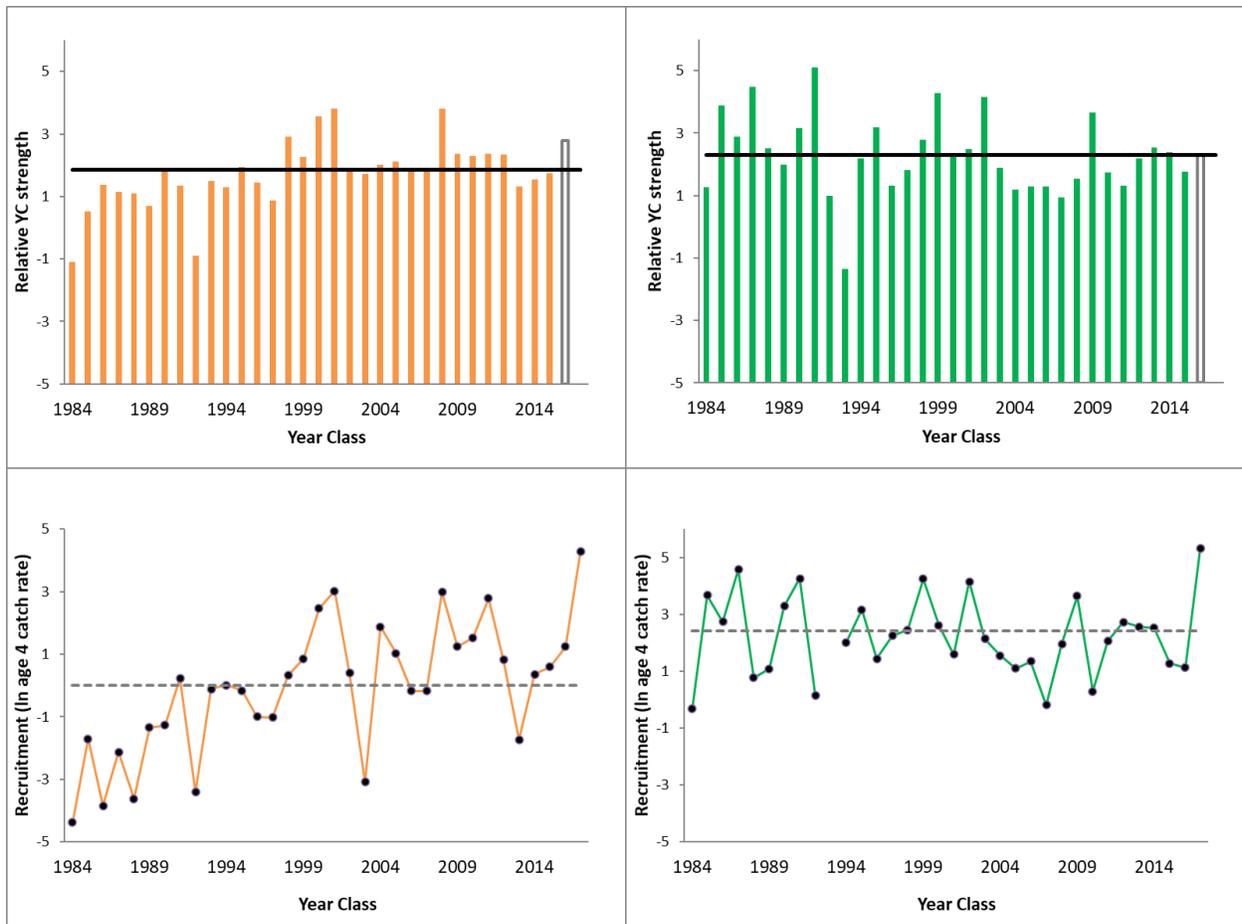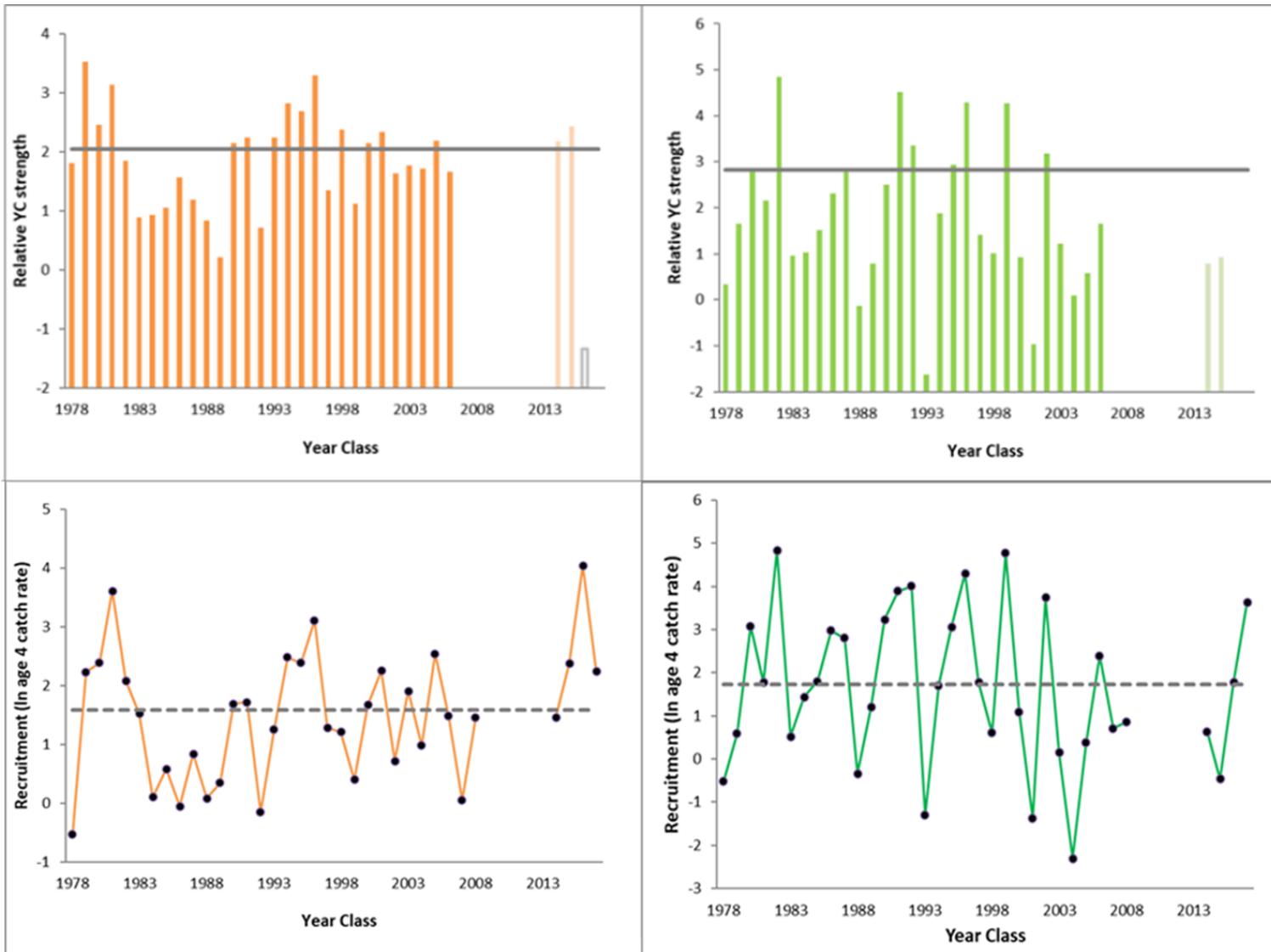
Figure 21. Relative year class strength (average of ln catch rates at age 4–6, preliminary year class strength based on ages 4–5, hollow bars) (top panels) and recruitment rates (ln age 4 catch rates, bottom panels) of fall spawners (left panels) and spring spawners (right panels) in the BBTB spring research gillnet program.
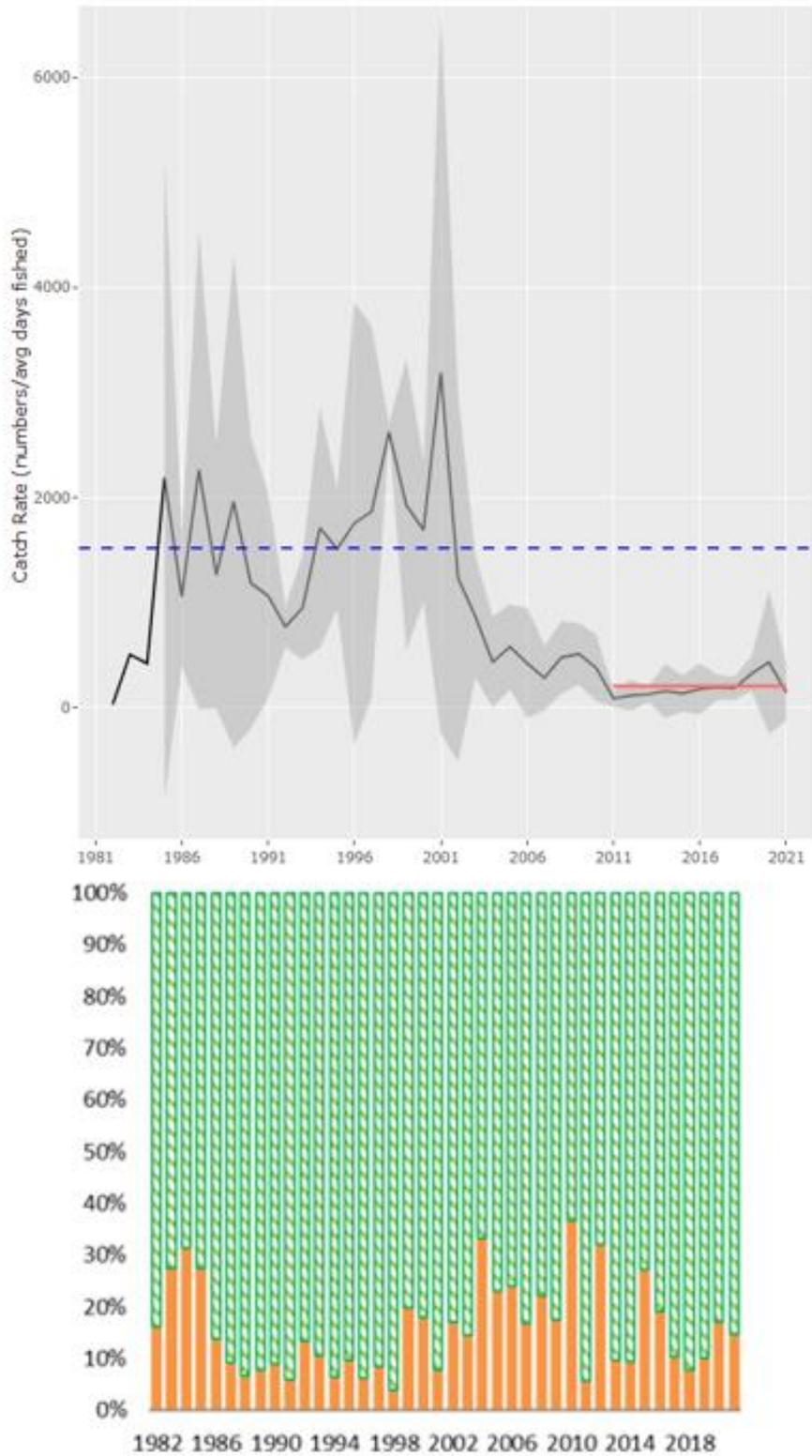
Figure 22. Combined catch rate (number of herring caught/average days fished) for the SMBPB spring research gillnet program with reference period mean (1990–2005; broken blue line) for SMBPB from 1982–2012 (black line) and just PB for the time series (red broken line) (top panel) and the proportion of spring (green bars) and fall (orange bars) spawning herring in the RGN catch (bottom panel).

Figure 23. Catch at age in the PB research gillnet program with percentage of spring (green bars) and fall (orange bars) spawners 2019–21.
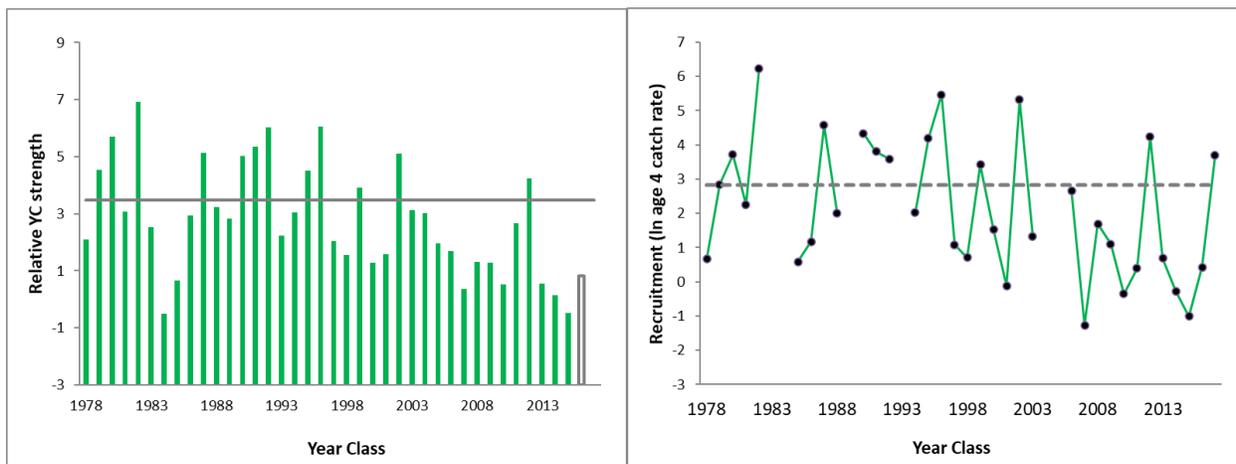
Figure 24. Relative year class strength (average of ln catch rates at age 4–6, preliminary year class strength based on ages 4–5, hollow bars) (top panels) and recruitment rates (ln age 4 catch rates, bottom panels) of fall spawners (left panels) and spring spawners (right panels) in the SMBPB spring research gillnet program (1978–2008) and PB program (2014–17).

Figure 25. Combined catch rate (number of herring caught/average days fished) for the FB spring research gillnet program with reference period mean (1990–2005; broken blue line) and decadal mean (solid red line) (top panel) and the proportion of spring (green bars) and fall (orange bars) spawning herring in the RGN catch (bottom panel).

Figure 26. Catch at age in the FB research gillnet program with percentage of spring (green bars) and fall (orange bars) spawners 2019-21.

Figure 27. Relative year class strength (average of ln catch rates at age 4–6, preliminary year class strength based on ages 4–5, hollow bars) (left panels) and recruitment rates (ln age 4 catch rates, right panel) of spring spawners in the FB spring research gillnet program.
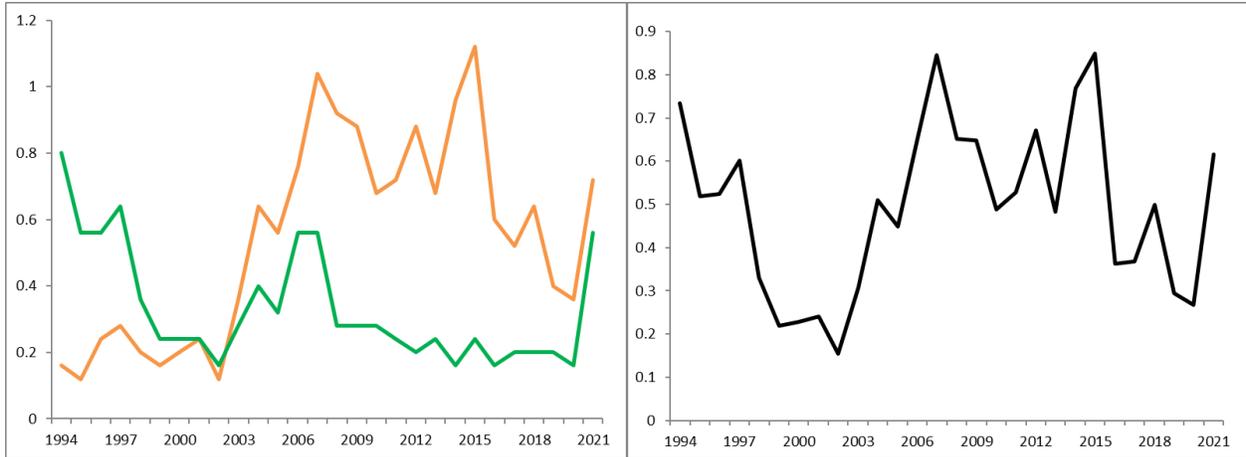
Figure 28. Stock status index for spring (green line) and fall (orange line) spawning components (left panel) and the weighted average of both spawning types combined (right panel) for BBTB.
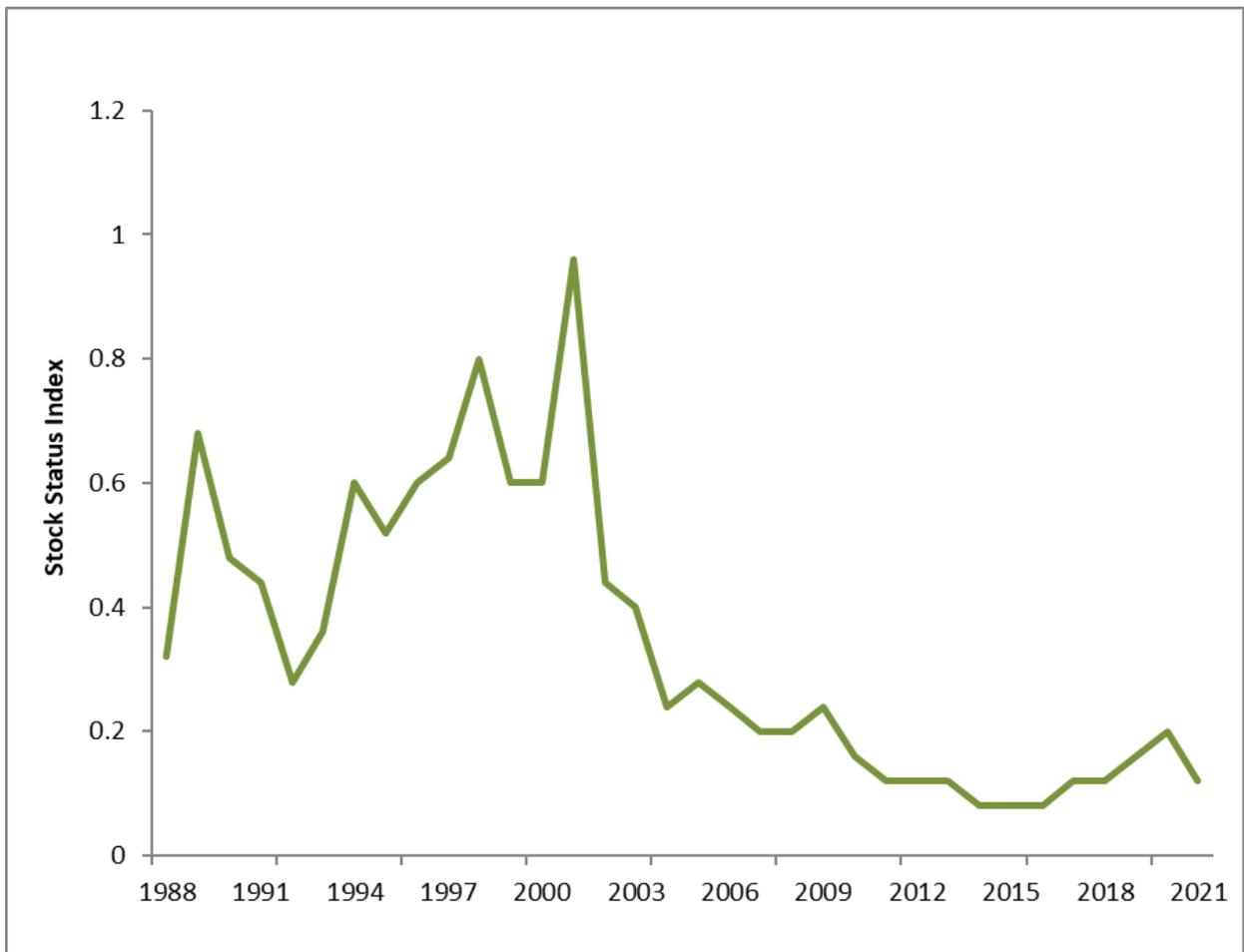

Figure 29. Stock status index for spring spawners in FB.