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The Status of Yellowtail Flounder (*Limanda ferruginea*) in NAFO Division 4T to 2020

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Foreword

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

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ABSTRACT

Yellowtail Flounder (*Limanda ferruginea*) tends to be distributed in shallow, near shore areas of the southern Gulf of St. Lawrence (sGSL; NAFO Division 4T). Yellowtail Flounder have been fished primarily for bait since 1995 and this fishery is mainly located off the Magdalen Islands. A Total Allowable Catch (TAC) of 300 tonnes (t) was established in 2000 but was revised down to 225 t in 2016. This document provides an assessment of the status of Yellowtail Flounder in the sGSL. Trends in abundance and biomass have differed markedly between commercial (≥ 25 cm) and pre-commercial (< 25 cm) lengths. The survey abundance index for fish < 25 cm increased 10-fold from 1985 to 2013. In contrast, the index for fish ≥ 25 cm declined by 94% from 1981 to 2011 and has since remained near this low level. Based on a population model, natural mortality of large, old Yellowtail Flounder (ages 6+) increased from 21% annually in the late 1980s to 86% annually in 2009-2020. For younger Yellowtail Flounder (ages 1-3) estimated natural mortality declined from 34% annually in 1985-1990 to 15% in 2003-2008, increasing to 34% in 2015-2020. In contrast to natural mortality, fishing mortality was estimated to be low for all ages over the entire time series. Thus changes in the abundance and biomass of the 4T Yellowtail Flounder stock appear to have been driven by changes in natural mortality since 1985. Natural mortality of the older, larger fish is currently unusually high. Predation by grey seals appears to be an important cause of this elevated mortality. Estimated spawning stock biomass (SSB) has declined by 50% from its peak biomass in the early 2000s, considerably less than the 95% decline in the abundance of large (≥ 25 cm) or old (6+ years) fish. This reflects a large change in the composition of the spawning stock. Size at 50% maturity has declined steadily in this stock. The spawning stock has changed from one dominated by fish aged 7 years and older to one now composed almost entirely of fish 4 years and younger. The Limit Reference Point (LRP) for this stock is estimated to be 5,710 t in the commercial length class (≥ 25 cm). The stock was estimated to be 39% of the LRP in 2020 and the probability that the stock was below the LRP was estimated to be 99% in 2016 to 2020. The population was projected forward 10 years assuming that current productivity conditions would persist over this period. Fishery catch was assumed to be 0, 100 or 300 t. Estimated SSB declined more than 50% over the 10-year projection with negligible impact of the catch level on the trajectory. The estimated biomass of the large length class was also projected over 10 years. The probability that the stock was below the LRP was 100% in all projection years. In conclusion, this stock is well below the LRP and is expected to continue to decline even with no fishing. The current status of this stock appears to be driven by high natural mortality rather than fishing mortality. However, this assessment is for the entire sGSL stock. Fishing is now confined to the Magdalen Islands region. Fishing may play a more important role in this region than over the sGSL as a whole.

1. INTRODUCTION

Yellowtail Flounder (*Limanda ferruginea*) is a righteye flounder from the Eastern Atlantic Ocean whose distribution ranges from Chesapeake Bay to the southern Labrador Shelf (Scott and Scott 1988). Little is known of their biology and population dynamics in the southern Gulf of St. Lawrence (sGSL), which is designated as division 4T (Fig. 1) by the Northwest Atlantic Fisheries Organization (NAFO). In the sGSL, Yellowtail Flounder tends to be distributed in shallow, near shore areas, where they have been harvested in localized fisheries. Yellowtail Flounder in NAFO Div. 4T have been fished primarily for bait, and were not under quota management until 2000. The first stock status reports for this stock were produced in 1997 and in 2002 (Poirier and Morin 2002). The most recent stock assessment was produced in 2016 (Surette and Swain 2016) and concluded that this population was experiencing high natural mortality and that no perceived difference in stock trends over the next five years was projected at catch projections of 0 t, 100 t, and 300 t. A quota of 300 t for Yellowtail Flounder in NAFO Div. 4T was established in 2000 but was revised down to 225 t in 2016.

This research document updates information on landings, fishery data, survey indices, catch-at-length from the fishery and various annual surveys. It also presents a population model that estimates the temporal evolution of the stock and also derives reference points for the stock.

2. FISHERY DESCRIPTION

2.1. MANAGEMENT MEASURES

Historically, gear mesh size and fishing season were the key management measures on sGSL flatfish stocks, before quota restrictions came into effect. The closure of the 4T Atlantic cod fishery in 1993 brought into effect a number of measures to protect the cod stock, as well as other groundfish species. Some of these measures included limits on by-catch and the capture of fish below a minimum size, area closures to protect cod spawning, expanded coverage by observers and dockside monitoring. The size limit for Yellowtail Flounder has been 25 cm in the 4T fisheries since 1995.

Clay et al. (1984) reported that up to 1976, the minimum cod-end mesh size for trawl fishing gear was between 105 and 114 mm, depending upon the type of twine. In 1977, the minimum mesh size became 120 mm for most twine materials, and in 1981, it became 130 mm. The Conservation Harvest Plan for 1998 set the minimum cod-end mesh size for Yellowtail Flounder at 140 mm throughout 4T. From 2001 to 2012, trawlers in the Magdalen Islands (4T2a) bait fishery were permitted with cod-end meshes of 120 and 130 mm. Nowadays, minimum cod-end mesh size is 145 mm square; however, on the Magdalen Islands (4T2a), a minimum square mesh of 140 mm is permitted when directing for Yellowtail Flounder. Table 1 summarizes the management measures in effect for 4T2a Yellowtail fisheries.

2.2. LANDINGS

Preliminary landings of Yellowtail Flounder for NAFO Div. 4T in 2019 and 2020 were 120 and 136 t, respectively. These records represent an increase of about 35% over the value observed in 2015 and almost 68% over the lowest recorded levels of the time series that was observed in 2016 (Table 2; Fig. 2).

Table 1. Management measures in effect for 4T2a Yellowtail fisheries

Management measures	Specifics
Authorized Fishing Gear	Otter trawl, Danish seine, Scottish seine
Gear, minimum mesh size	Square 140 mm or diamond 130 mm. The minimum length for the cod end and the lengthening piece is 50 meshes from the cod line.
Departure hail-out required	Yes
Observer coverage	10%
Dockside monitoring	100%
Vessel Monitoring System (VMS)	100%, every 15 minutes.
Incidental catches	Return any Halibut with a length less than 85 cm, any Yellowtail Flounder with a length less than 23 cm, any Winter Flounder with a length less than 25 cm and any Skate to the place from which it was taken; and where it is alive, in a manner that causes it the least harm. Release any Dogfish, Lumpfish, Sculpin, Atlantic hagfish and Atlantic wolffish to the place from which it was taken and where it is alive, in a manner that causes it the least harm.

Yellowtail Flounder catches have fluctuated widely through time, however the landings information from the early period is deemed to be unreliable due the practice of reporting unspecified flatfish from 1960 to 1984. In 1973, the International Commission on North Atlantic Fisheries (ICNAF, or the precursor of NAFO) requested advice from participating countries on allocating unspecified flounder to species (ICNAF 1974). Morin et al. (1998) reported that from 1965 to 1971, annual landings of 4T American Plaice were corrected by adding 90% of the reported landings of unspecified flounder. This 90% criterion, based on research survey data, probably overestimated the contribution of American Plaice to unspecified flounder catches at the expense of Winter Flounder, Yellowtail Flounder and other flatfishes. From 1972 to 1985, unspecified flounder continued to appear in landing statistics, but these were no longer apportioned by species. In addition, the landings of American Plaice and other flatfishes were considered to have been underestimated over this period (Morin et al. 1998).

In 1991, it became a license condition for mobile gear captains to maintain a logbook. Until that year, vessel captains tended to not report the location of capture, including the NAFO unit area (note the catch levels in unreported unit area 4Tu until 1991; Table 3). The fishery has been increasingly dominated by boats originating from the Magdalen Islands in NAFO unit area 4Tf (Table 3, Fig. 2 and Fig. 3). Until the mid-1990s, Yellowtail Flounder were also caught off northern Prince Edward Island (PEI) and in Chaleur Bay (unit areas 4Tj and 4Tm) and, until 2005, off eastern PEI and in the Shediac Valley (4Tg and 4Ti; Table 3 and Fig. 3). The Magdalen Islands Yellowtail Flounder fishery is mainly destined for lobster bait in a near-shore fishery; elsewhere, it may also be fished as bait or occur as by-catch in other fisheries. Fishing coordinates were recorded more reliably in logbooks after 1997. The spatial distribution of logbook catches by time period is shown in Figure 4.

In the 1980s and 1990s, Yellowtail Flounder landings were reported mainly from August to November. Since then, most catches have tended to occur earlier, mainly in May and June, which average almost 90% of the total landings for 2019 and 2020, although in 2014 and 2015 one third of the total landings were made in July (Table 4, Fig. 3). The shift to early fishing coincided with the concentration of the Yellowtail Flounder fishery off the Magdalen Islands where the spring lobster fishery requires an early supply of fish bait and where there is no spring herring fishery to provide an alternate source of bait. Until the late 1990s, whenever the targeted species was indicated, Yellowtail Flounder was caught mainly as by-catch in fisheries directing for American Plaice and Winter Flounder. However, since the mid-1990s, Yellowtail Flounder are increasingly reported as the targeted species (Fig. 3).

Trawls and seines are the preferred gear type for fishing Yellowtail Flounder and the proportion of landings of each type has varied considerably through the years. Until 2006, the seine fleet contributed most of the Yellowtail Flounder landings in most years; since then, trawlers have been dominant, contributing 70 and 74% of the total landings in 2019 and 2020, respectively (Table 5; Fig. 3).

The importance of bait fishing cannot be over-emphasized in the development of the 4T Yellowtail Flounder fishery. An exception occurred in 1997 when a Japanese food market was developed, leading to a rapid increase in landings. The fishery was closed in the autumn when landings surpassed 800 t. The following year, a 300 t quota was established, which was raised to 375 t in 1999 and in from 2000 onward, a 300 t quota, revised at 225 t in 2016, has remained in effect. This level of harvest was insufficient to supply the Japanese market and the Yellowtail Flounder resource on the Magdalen Islands reverted to bait fishing.

From 2001 to 2012, the DFO Québec Region authorized an exploratory fishery for flatfish bait to supply the Magdalen Islands lobster fishery. A local bait fishery developed, composed mainly of small lobster boats fishing inshore with otter trawls targeting local stocks of Yellowtail Flounder, Winter Flounder and Windowpane. In 2001, roughly 20 vessels were active in the bait fishery, with reported catches of about 5 t of Yellowtail Flounder, or 6% of the local fishery (DFO 2010). This activity increased over time and, by 2008, 36 trawlers with bait licenses reported catches of 16 t of Yellowtail Flounder. The activity peaked in 2010 (72 t) and 2011 (62 t) and an agreement was reached to gradually reduce the number of bait permits and the days of fishing. Since 2012, fish bait is provided by the commercial fishery in the Magdalen Islands.

A commercial Catch-per Unit Effort (CPUE) analysis and an estimation of the fishing gear mean immersion time are presented in Appendix A.

2.3. VESSEL MONITORING SYSTEM

Since 2019, fishing licences require all vessels to be equipped with a Vessel Monitoring System (VMS) set at a minimum sampling interval of 15 min. Using the Geosphere R package (Hijmans 2019), the spherical distance between each continuous recording was calculated and a travel speed (in knots (kn)) was derived from that distance and the time difference between each recording. Speed was classified into four categories: ≤ 0.1 kn (stationary), $0.1 > \text{kn} \leq 2.0$ kn (fishing activity #1), $2.0 > \text{kn} \leq 4.0$ kn (fishing activity #2), and > 4.0 kn (travel). Both categories considered as fishing activities could potentially include setting and towing gear.

The 2019 season gathered 109,427 spatial coordinates that were used to evaluate the fishing intensity and its spatial distribution throughout the season (Fig. 5). Most of the fishing activities occurred in the eastern portion of the Magdalen Island, more precisely in the bay located in front of Havre-Aubert, in the channel between Havre-Aubert and the Île d'Entrée, and finally north-east from Grande-Entrée. Some activities were also recorded alongside the coast, west of Étang-du-Nord, Fatima, Pointe-aux-Loups and Grosse-Île. The largest proportion (51%) of all the recordings fall

under the category of fishing activity #2, while 26% were categorized as fishing activity #1. The remaining quarter was considered to be travel (21%) and stationary (2%) (Fig. 6). On average, 69% of all the spatial coordinates were logged during day time from 06h00 in the morning to 18h00 in the evening.

3. FISHERY-DEPENDENT DATA

3.1. CATCH-AT-LENGTH

Annual catch-at-length estimates for Yellowtail Flounder in NAFO Div. 4T were generated from samples of commercial catches obtained by port samplers and observers-at-sea, gathered from 1985 to 2020. Table 6 and Table 7 show the number of length-frequency samples obtained by port samplers and observers-at-sea, presented by year, gear and season, as well as the total number of fish measured by reported grouping.

Prior to calculating the catch-at-length, individual length-frequency samples obtained by port samplers were first scaled to the level of the total fisherman's catch. For observer-at-sea samples, samples were first scaled to the level of each individual fishing activity, summed, and then scaled to the level of the total catch for the fishing trip. Sample-weights were calculated from length-frequency values and length-weight regression parameters estimated from the September multi-species survey data from each corresponding year. These conversions were sex-specific when sex was recorded in the samples. Samples were separated by fishing gear type, namely trawler and seiners, which represent the majority of landings over the 1985 to 2020 period (Fig. 7). Samples for all months and all geographic locations within NAFO division 4T were pooled to generate annual estimates.

Total catch-at-length estimates were obtained by scaling available samples to the level of annual NAFO Div. 4T landings by fishing gear type, then summing over sampled gear types. Landings from unsampled gear types were assumed to have the same catch-at-length profile as sampled gear.

Certain years had deficient sampling. In such cases, the relative length-distribution was assumed to be an average of those from adjacent years. Thus 1997 is an average of 1996 and 1998. Trawl length-frequencies for 1999, 2000 and 2001 were calculated as averages of 1998, 2002 and 2003. Relative length-frequencies were then scaled to trawl landings for catch-at-length estimates.

Figure 7 shows the commercial catch-at-length, standardized to proportions-at-length, for NAFO Div. 4T estimated from port samples and observer samples for years 1986 to 2020. Only preliminary data was available for 2020. The proportions by trawlers and seiners are shown by blue and red lines, respectively. With few exceptions, catch-at-length distributions are all unimodal, with a modal shift from 31 cm in the late 1980s to 28-29 cm in the late 1990s, to a mode of 25 cm in the late 2000s. There was a slight increase of 33 to 35 cm fish in catches in 2015 relative to previous years however this event was short lived and fish larger than 30 cm were almost absent in 2019-2020 (< 5%), with over 90% of the proportion at length being observed between 20 and 30 cm.

The length distributions between trawlers and seiners are generally similar prior to 2010, with the exception of 2002, though this may be due to small sample size. Starting in 2009, a large increase in catch of smaller fish occurred through to 2012. Figure 8 shows that the proportion of catches below 25 cm reached levels of approx. 80% in 2010, 2011 and 2012, then decreased to approximately 25% in 2017 before increasing and stabilizing at around 30% in 2019. The decline in the proportion of catch below 25 cm in 2014 was due to the mandatory discarding of fish below 25 cm starting in 2014. As in the previous assessment, the larger portion of small fish was landed by commercial trawlers.

3.2. EXPERIMENTAL BAIT FISHERY

Length samples were taken on board vessels participating in the experimental bait fishery in the Magdalen Islands from 2006 to 2011. Figure 9 shows the resulting catch-at-length estimates in population numbers for 2008 to 2011. Earlier catch-at-length estimates for 2006 and 2007 are available in DFO (2010). This report showed that for 2006 to 2008, the length distributions of the experimental bait fishery samples were similar to those of commercial trawlers and seiners. These distributions show that more than 50% of fish caught are smaller than 25 cm.

We note that the large proportion of fish between 15 cm and 20 cm observed in the 2010 and 2011 commercial catch-at-lengths are absent from the experimental bait fishery for the corresponding years. The proportion of fish smaller than 20 cm decreased from 2008 to 2011.

Given the discrepancy between the at-sea observer data for the commercial fishery and that of the experimental bait-fishery, the fishery catch-at-age shown in Figure 9 for 2009 to 2012 may be somewhat inflated. As to why these two sample sets are different is not clear. The mesh sizes for the experimental bait fishery are smaller than those of the commercial bait fishery, so one would expect smaller fish to be more abundant in the former and not the latter, as was observed. This leaves some uncertainty as to the representativeness of the fishery catch-at-age for these years.

4. FISHERY-INDEPENDENT DATA

4.1. SEPTEMBER MULTI-SPECIES SURVEY

The September multi-species survey has been conducted annually since 1971. Sampling stations are distributed according to a stratified random design (Fig. 10) with strata defined by depth ranges and geographic regions. Comparative fishing experiments were undertaken for each change in survey vessel and fishing gear. The same stratification scheme has been used since 1971, with the exception of the addition of three inshore strata (401 to 403) in 1984. However, in order to maintain comparability between years, these strata were not considered when calculating abundance and biomass indices. While Yellowtail Flounder are found in strata 401 and 403, these areas represent a small proportion of the total distribution of the species. Each Yellowtail Flounder catch was weighed and a subsample of the catch (up to 200 fish) was measured for length and individual weight. Length-stratified otolith samples were collected for fish ageing.

Since 1985, the trawl gear used has been a Western IIA type with a liner in the cod-end with a mesh size of 19 mm. Further details on this survey may be found in Hurlbut and Clay (1990). Catches were standardized by tow length and scaled to daytime catches for the current trawl gear and survey vessel, the CCGS Teleost, as described in Benoît and Swain (2003a), Benoît and Swain (2003b) and Benoît (2006).

4.1.1. Abundance Indices

The overall abundance index for Yellowtail Flounder shows an increasing trend in the early years of the survey (1971 to 1981) to a maximum of 30 fish per tow, followed by a decrease through 1984, then a long-term stable level at around 18 fish per tow from 1985 to 2015 followed by a rapid decrease down to a level of 11 fish per tow from 2015 to 2020 (Fig. 11). In contrast, catch weights show a long term decreasing trend since 1986, from 4.3 kg per tow to 0.8 kg per tow in recent years. Length-frequencies show that this is due to decreasing trends in mean sizes of Yellowtail Flounder catches.

Temporal trends in abundance and biomass differed sharply between small (<25 cm) and large (\geq 25 cm) Yellowtail Flounder (Fig. 11, panels b, c, e, f). The abundance and biomass of small Yellowtail Flounder were at the lowest levels observed in the survey in 1971 (estimated trawlable

abundance of 810,000 fish) and then increased more or less steadily to the highest level observed in 2013, a trawlable abundance of 35 million fish. This represents a 10-fold increase over the 1985 level. Small flounder then decreased rapidly to an intermediate level of 11 million in 2016 and remained near this level since then (about 16 million fish). Large flounder (≥ 25 cm) were also at a low level in 1971 (about 5.4 million fish) and then increased to the highest level observed, 44 million, in 1981. Since then, their biomass and abundance have steadily declined. Their survey abundance reached a trawlable abundance of 2.8 million fish in 2011 and has remained near this level (a mean of 3.4 million) since then. These opposing trends in abundance for young and older Yellowtail Flounder suggest that mortality for older flounder has increased to high levels.

Considering that the local Magdalen Islands fishery is mostly the sole source of Yellowtail Flounder landings in NAFO 4T, a separate index was produced for the September survey strata (428, 434, 435 and 436, see Fig. B.1) associated with that fishery. The abundance indices for the Magdalen Islands show some similarities with those for the whole sGSL. After a peak in 1977 at 80 fish per tow, a pronounced decline down to 5 fish per tow was observed in 1984. For the next 7 years the values fluctuated around 10 fish per tow, followed by an increase from 1995 to 2006 at a mean value of 57 fish per tow. A sharp decrease was then observed down to 43 fish per tow in 2008. This short lived event was then followed by values around 55 fish per tow from 2010 to 2014 before declining in 2016 down to 25 fish per tow and finally stabilizing at around 43 fish per tow since 2017 (Fig. B.1). Catch weights also show a sharper decreasing trend than the abundance indices, with the more recent period from 2008 to 2020 situated at a lower level than the period from 1994 to 2006.

4.1.2. Length Frequencies

Stratified mean length-frequencies show a marked shift in the sizes of Yellowtail Flounder caught in the September survey (Fig. 12). Modal lengths were at 29 cm during the early portion of the survey (1971 to 1990), and then began shifting during the mid-1990s to 24 cm in the early 2000s and since down to 21-22 cm (Fig. 12 and Fig. 13). Annual length-frequency distributions for the past ten years show few changes, with the modal length and standard deviation remaining fairly stable. No indications of cohorts are discernible. The percentage of Yellowtail Flounder greater than or equal to 25 cm averages 20.5% since 2011, a major shift compared to the values of over 80% observed throughout the 70s and 80s (Fig. 14). A similar trend is observed when focusing only on the strata surrounding the Magdalen Islands, with the modal size shift occurring mainly during the 1990 to 2005 period and recent modal lengths at 21-22 cm (Fig. B.2). The annual length-frequency distributions for the Magdalen Islands for the past five years show no indication of consistent trends, except in 2018 when a shift toward even smaller specimens is observed with a mode at around 18 cm (Fig. B.3).

4.1.3. Spatial Distribution

The spatial distribution of standardized Yellowtail Flounder catches (in kg per tow) from the September survey is shown in Figure 15. Throughout the sGSL, Yellowtail Flounder are distributed along coastal to mid-shore ecosystems. They are distributed in and around the west, northern and sometimes eastern part of PEI, around the Shediac Valley, on the eastern part of the Acadian Peninsula, in St. George's Bay and around the Magdalen Islands.

Smaller catches (≤ 1 kg per tow) have become more prevalent at intermediate depths (50 to 65 m) in the sGSL in recent years (1996 to 2020), between the Magdalen Islands and PEI, where there were few catches before 1996.

This shift in habitat association is presented in Figure 16, which plots the cumulated catch against water depth. While the depth-profile of the sampling stations has changed little, the cumulative catch curves show a shift of catches to deeper waters with more fish caught in 50 to 65 m depths whereas none were caught at those depths prior to 2000. Despite this expansion of Yellowtail Flounder into

deeper waters, the scale of catches has decreased in all areas, though there are still some mid-sized catches in northern PEI and to the east of the Magdalen Islands.

4.1.4. Size-at-Maturity

Annual trends of size-at-maturity were calculated over the RV survey time series. Sampled fish were classified into various maturity stages, i.e. whether the fish is immature, ripe, running ripe or spent (post-spawning). Comparison of the relative proportions of these maturity assessments indicated that they were not consistently used throughout the time series. As previously discussed in Surette and Swain (2016), a portion of those maturity stages were classified as unsure in the previous assessment, which arises from the misdiagnosis of the spent maturity stage, ostensibly a post-spawning (i.e. mature) stage, characterized by small and emptied gonads which may be confused with the immature stage in smaller sized fish. However the analysis in Surette and Swain (2016) also revealed that this unsure component had a similar trend as the mature components for most of the time series. Therefore for the purpose of this study, the unsure and mature components were merged and the results of the proportions by year group of both maturity states (mature and immature) are presented in Figure 17 (males) and Figure 18 (females). Both sexes experienced a strong shift of their mature proportions towards smaller sizes through time, reflecting a decreasing trend in size-at-maturity. In 50 years the length at which 50% of the fish were classified as mature shifted considerably as indicated by logistic regressions over length curves fitted to the maturity data by survey year and sex (Fig. 19). The size-at-maturity for each year and sex decreased from approximately 21 cm for males and 27 cm for females in 1971 to the lowest estimated levels of the time series at about 10 and 14 cm in 2020, respectively. A declining trend in the age at maturation is often a symptom of high mortality. When mortality is high, early maturation is favored because it increases the probability of surviving to reproduction (Swain 2011; Forestier et al. 2020).

4.1.5. Ageing and Growth

The number of valid aged otoliths by year is shown in Table 10, however due to some uncertainties in the ageing protocol throughout the years, the growth data used for the population model, which covers the period from 1985-2020, was chosen to be from 2000, 2007, 2013, 2015 and 2017 pooled together (see Appendix C for more details).

4.2. MOBILE SENTINEL SURVEY

4.2.1. Abundance Index

The mobile sentinel (MS) survey, conducted each August since 2003, is a stratified-random bottom-trawl survey using the same stratification scheme as the RV survey. Each year the survey is conducted by three to four commercial fishing vessels, each using the same standardized otter trawl (the 300 Star Balloon) and standardized fishing protocols (see Savoie (2012) for details). Each year, the vessels fish in overlapping areas, with each vessel assigned random fishing locations in most survey strata. Over the time series (2003-2019), a total of 13 different vessels have participated in the survey (Table 9). No sentinel surveys were conducted in 2020.

The mobile Sentinel survey employs no structured comparative fishing to estimate the relative fishing performance among participating vessels. As these vessels do not fish at the same locations, their relative performance must be inferred relative to local area criterion, such as survey stratum, which may span over quite large areas. To estimate these vessel effects, we followed the same method as presented in Surette and Swain (2016) and used the following negative binomial model:

$$n_{ijk} \sim \text{NegBin}_{\mu_{ijk}, \sigma} \quad (1)$$

$$\mu_{ijkl} = \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_k + s(x_{ijkl}, y_{ijkl}) + s(d_{ijkl}) \quad (2)$$

where $i \in (1, \dots, 17)$ indexes survey year, $j \in (1, \dots, 29)$ indexes survey stratum $k \in (1, \dots, 13)$ indexes fishing vessel and l indexes individual observations within groups. The fixed effects coefficients for year, stratum and their interaction term are represented by α_i , β_j , and $(\alpha\beta)_{ij}$, respectively. The fixed vessel effect coefficient is represented by γ_k . A global spatial smoothing term is represented by $s(x_{ijkl}, y_{ijkl})$, with x_{ijkl} and y_{ijkl} being mean-centered UTM coordinates and $s(d_{ijkl})$ is a smoothing term over log-transformed water depth d_{ijkl} . The model was fit using the GAM function from the mgcv package in R (Wood 2011). The Miss Lamèque was used as the reference vessel as it has the longest history in the program (from 2003 to 2013). Vessel effects coefficients are provided in Table 9.

Catches were adjusted to a standard tow length of 1.25 nm and the estimated vessel effects. Stratified mean abundance and catch indices were calculated by year and are shown in Figure 20 for the sGSL and Figure B.4 for the Magdalen Islands strata. Contrary to the indices from the September survey, the trend from 2003 to 2019 for the Sentinel survey shows a higher magnitude of decrease of abundance and biomass, for both the sGSL and Magdalen Islands indices. This may be partially explained by the larger mesh size of 40 mm used in the cod-end of the trawl, which retains fewer small fish in the net. If the mean size of fish decreased, as was observed in the September survey catches, Yellowtail Flounder would effectively be selected out from the Sentinel catches.

4.2.2. Length Frequencies

Figure 21 and Figure B.5 show the stratified mean length-frequencies for the mobile Sentinel survey catches from 2003 to 2019 for the sGSL and the Magdalen Islands, respectively. For the sGSL, a slight decrease in mean size is observable from 2003 to 2012, and afterwards the trend breaks down, although catches are so small from 2013 to 2019 that sampling variability becomes an issue (Fig. 21). For the Magdalen Islands strata, there is no clear change in length-distribution owing to the smaller sample sizes (Fig. B.5).

4.2.3. Spatial Distribution

Figure 22 shows the spatial distribution of Mobile Sentinel survey catches from 2003 to 2019. Yellowtail Flounder catches in 2003 to 2005 were the highest of the time series south of the Shediac Valley, north and eastern coasts of PEI and around the Magdalen Island. Since 2006, the spatial distribution and abundance have drastically declined and specimens of Yellowtail Flounder were almost absent in the most recent 2019 Mobile Sentinel survey. Although the fishing intensity (number of tows per year) has declined over the years, especially in 2018 and 2019, those results provide a similar trend as the one observed during the September Multi-Species surveys.

5. POPULATION MODELLING

5.1. METHODS

The information available to develop a population model for this stock is limited. The fishery catch is relatively low over the entire period modelled except 1997. This makes it difficult to estimate the population scale. Ageing data are limited. The main information driving the model is the strong increase in the abundance and biomass of Yellowtail Flounder <25 cm in length coincident with the collapse in the abundance and biomass of Yellowtail Flounder ≥ 25 cm in length (Fig. 11). Consequently we developed a length-based age-structured model to examine the dynamics and status of this stock. This model is essentially the same as the model used in the last assessment of this stock (Surette and Swain 2016).

The population dynamics assumed in this model are described by the following equations:

$$N_{i+1,y+1} = N_{i,y} \exp\left(-\left(F_{i,y} + M_{i,y}\right)\right) \quad (3)$$

$$C_{i,y} = \left(\frac{F_{i,y}}{F_{i,y} + M_{i,y}}\right) N_{i,y} \left(1 - \exp\left(-\left(F_{i,y} + M_{i,y}\right)\right)\right) \quad (4)$$

$$r_y = \exp(R_a + rdev_y) \quad (5)$$

where $N_{i,y}$ represents population abundance at age i in year y , $F_{i,y}$ and $M_{i,y}$ are the instantaneous rates of fishing and natural mortality, respectively, at age i in year y , and $C_{i,y}$ is the fishery removal in numbers at age i in year y . Years spanned 1985 to 2020. Earlier years were omitted due to a lack of reliable fishery catch data. M was estimated separately for six time blocks (6-year blocks between 1985 and 2020, i.e. 1985-1990, 1991-1996, 1997-2002, 2003-2008, 2009-2014 and 2015-2020) and two age groups (1-3 and 5-8+). M of 4-year olds was assumed to be the average of M for ages 1-3 and 5-8+ in the same year. Model ages were 1 to 8+ years (the 8+ group represents fish 8 years and older). Abundance at age 1 (i.e., recruits r_y) was set equal to average recruitment (R_a) plus an annual deviate ($rdev_y$) on the logarithmic scale. The recruitment deviates were assumed to be normally distributed on the log scale with a mean of 0 and a standard deviation (SD) of 0.2 ($rdev_y \sim N(0,0.2)$). Age and year effects on F were assumed to be separable:

$$F_{i,y} = s_i F_y \quad (6)$$

where F_y is fully recruited F in year y and s_i is fishery selectivity for age i . Fishery selectivity-at-age was allowed to vary between three time periods: 1985 to 2008, 2009 to 2012 and 2013 to 2020. This was based on large changes in the size composition of the catch between these periods. Fishery selectivity-at-age was assumed to conform to a logistic curve.

Data inputs included:

1. total annual landings in tonnes,
2. annual abundance indices from the September research vessel (RV) survey for two length groups (<25 cm, >=25 cm),
3. the proportion of the annual landings (in numbers of fish) in each of the length groups,
4. the average weight of individuals in each of the length groups for the annual fishery catch and the annual survey indices,
5. the annual mean weight-at-age, and
6. the annual vector of proportion mature at age.

Catchability-at-age to the RV survey ($q_{i,y}$) was also modelled using a logistic curve for selectivity at age (s'_i) multiplied by fully-recruited catchability (q):

$$q_{i,y} = s'_i q \quad (7)$$

Abundance at age in the model was mapped into the two length groups used for the survey indices and catch proportions based on length-at-age data for 2000, 2007, 2013, 2015 and 2017, see Section 4.1.5 and Figure 23. Based on these data, fish aged 1-3 years were assigned to the < 25 cm length group, those aged 5 years and older were assigned to the >=25 cm length group, and half the 4 year olds were assigned to each length group.

Parameters estimated in the model included average log recruitment (R_a), annual recruitment deviations from 1986 to 2020 ($rdev_y$), initial recruitment deviations (eight in total) to obtain abundance at age in 1985, $\log(F_{init})$ (also used to obtain abundance at age in 1985), $\log(M)$ for the two age groups in each of six time periods, fishery and survey logistic selectivity parameters (two

each), fully recruited survey catchability (q), and log observation error variances for the two abundance indices.

In initial trials, survey catchability q was estimated to be 1.4, with the survey indices at the scale of trawlable abundance. A small flatfish like Yellowtail Flounder is not expected to be herded into the net by the doors. Thus, such a high value of q would only be possible if sampling locations in the survey were strongly biased towards areas where Yellowtail Flounder occurred at high densities, with these high catch rates extrapolated to areas where Yellowtail Flounder densities are actually low. Given the distributions of Yellowtail Flounder and of sampling sites in the survey area, this is not a plausible hypothesis. Thus, an informative prior for q was used in the model, with a mean of -0.3566 on the log scale ($q = 0.7$) and $SD = 0.15$. The scale of the population is affected by the prior for q but not the population trend. A lower prior was used in the 2016 model but estimated time trends and model conclusions were similar to those obtained in this model.

A prior for M was also used for the first time block (1985 to 1990). Prior means were 0.8 and 0.3 for initial M 's for ages 1-3 and 5+, respectively (with $SD = 0.05$ or 0.025 , respectively). The prior for the recruitment deviations was set at 0.2. Higher values for this prior (e.g., 0.35) resulted in unstable retrospective patterns.

Models were implemented using AD Model Builder (Fournier et al. 2012) and fit using penalized maximum likelihood. Likelihood weights were set at 1.5, 1.65 and 0.85 for the components related to the fits to the small fish index, large fish index and fishery catch proportions, respectively. These weightings were required to obtain reasonable fits to the indices. Uncertainty was incorporated based on 501,000 MCMC samples, with the first 1,000 samples discarded and every 100th subsequent sample retained to reduce autocorrelation, yielding a sample of 5,000 iterations from the joint posterior distribution of the parameters and derived variables.

5.2. RESULTS

The model fit the abundance indices fairly well (Fig. 24), though the small fish index tended to be underestimated in the 2005-2015 period and the large fish index tended to be overestimated in the 2010-2018 period. Fit to the length-group proportions in the fishery catch was good, except for a tendency to slightly overestimate the contribution of large fish to the fishery catches in the early to mid-2000s (Fig. 25).

Estimated catchability to the RV survey was very low for age 1 fish (0.018), increasing to 0.46 by age 8+ (Fig. 26). Estimated fishery selectivity in 1985 to 2008 was less than 0.01 for ages 1 to 3 years and then increased rapidly with age, particularly after age 5. Fishery selectivity for young ages was much higher in the 2009-2012 period. Fishery selectivity returned to a very low level for ages 1 to 3 years in 2013-2020.

Uncertainty in abundance estimates was high, especially for the youngest age group (Fig. 27). The median estimate of abundance of 1-3 year olds increased steadily from about 325 million in 1985 to a peak of 677 million in 2012 (i.e., about double the initial abundance). Age 1-3 abundance then declined to 520 million in 2020. The median estimate of abundance for four and five year olds was about 41 million in the 1980s, increasing to an average value of 201 million from 2000 to 2009 before declining by over 50% to about 95 million in 2019 and 2020. The median estimate of 6+ abundance was about 59 million in the mid-1980s, decreasing to 3 million in 2020, a 95% decline.

The median estimate of spawning stock biomass (SSB) averaged 31 kilotonnes (kt) in the 1980s, increasing to an average of 54 kt in 2000 to 2005 (Fig. 28). SSB then gradually declined to 40 kt in 2015. Since then, estimated SSB has declined to an average of 26 kt in 2017 to 2020.

The estimated age composition of the SSB has changed dramatically since the mid-1980s (Fig. 28). Fish 7 years and older are estimated to have contributed 30% of the SSB in 1985-1990, declining to

less than 0.1% of the SSB since 2015. In contrast, the estimated contribution of 3 and 4 year old fish to the SSB increased from 27% in the 1980 to 1990 to 54% since 2000.

The median estimates of recruitment fluctuated without trend between 180 and 283 million individuals (Fig. 29). The median estimate of recruitment rate (the abundance of recruits divided by the SSB producing them) averaged 6.3 fish/kg of spawners. Recruitment rate was above average in the late 1980s and early 1990s (averaging 8.3), in 2010 to 2012 (6.8) and since 2017 (9.5).

Large changes in estimated natural mortality occurred between time periods, with the changes in opposite directions for large and small individuals (Fig. 30). For young fish (ages 1-3), the median estimate of M in 1985-1990 was 0.76 (53% annual mortality), declining to 0.16 (15% annually) in 2003-2008 and then increasing to 0.41 (34%) in 2015 to 2020. For older fish (aged 5 years and older), the median estimate of M in 1985-1990 was 0.24 (21% annually), increasing to 1.99 (86% annually) in 2009-2020. Note that the estimates in 2009-2020 was near 2.0, the upper bound permitted for this parameter.

Any unreported fishery catch would be attributed to natural mortality by the model and thus may contribute to these extremely high estimates of M for large individuals. However, the larger individuals in most large-bodied groundfish species in the sGSL are also experiencing unusually high natural mortality (Swain and Benoît 2015). Predation by grey seals appears to be an important cause of this elevated mortality (Swain and Benoît 2015; Neuenhoff et al. 2019).

Fishing mortality is estimated to be very low on the young ages (Fig. 31). For age 2, F was below 0.00035 in all years except 2009 to 2012, when it increased to an average of 0.002. For age 4, F was also lowest early in the time series (1985-1996, mean F 0.0005), increasing to a maximum of 0.009 in 2020, the highest value observed in the time series but still a very low value. Age 6 F averaged 0.004 in 1985 to 1994 and then rapidly increased to an average of 0.03 in 1997 to 2008. Age 6 F declined to 0.007 in 2009 to 2012 before increasing to 0.063 in 2020, again the highest value observed. The estimated F for age 8 resembled the trend for age 6. F was low early in the time series (0.02, 1985-1996), increasing to an average of 0.13 in 1997 to 2008, the highest values observed for age 8. Like for age 6, age 8 F declined to a very low value in 2009-2012 (0.007) and then increased to 0.13 in 2020.

In summary, estimated F of Yellowtail Flounder was low for all ages over the entire time series. For all ages, F tended to be lowest in early years (1985 to about 1995) and increased to relatively high values in 2020. For older ages (6+) F was also relatively high in 1997-2008. For 6 year olds, F averaged 0.004 early in the time series, increasing to an average value of 0.03 in 1997 to 2008, and 0.058 in 2020. For 8 year olds F increased from 0.02 early in the time series to 0.13 in 1997 to 2008 and in 2020. Periods of relatively high F coincided with relatively high landings (1995-2012, Fig. 2) or low 4+ abundance (Fig. 27).

A retrospective analysis was conducted to determine the consistency of model estimates as data were added or removed (Fig. 32). The analysis started with the full 36 years of data and examined how estimates change as one to five years of data were removed. Estimates of abundance and spawner biomass were remarkably constant as the first four years of data were removed. Estimates also varied little for F and M as these years were removed. However, there was a substantial change in the estimates when the fifth year (2016) was removed. This change may reflect a change in estimated M . M was estimated in six 6-year blocks. When the fifth year was removed, this left only one year in the last M block, which may be insufficient to provide an accurate estimate. This problem might be resolved by modelling M as a random walk instead of six independent time blocks. However, a random walk would require subjective choices about constraints on changes in M . Nonetheless, there is no indication of bias in estimates over the last five years.

6. REFERENCE POINTS

Reference points for Yellowtail Flounder were developed during the previous assessment of this stock (Surette and Swain 2016). These were based on the biomass indices for large (≥ 25 cm) Yellowtail Flounder obtained by the September RV survey. The proxy value for B_{msy} was defined as the average value of the index during a productive period identified as 1977 to 1997. The B_{msy} proxy was estimated to be 2.64 kg per tow. The upper stock reference (B_{usr}) was set at 80% of this value (2.12 kg per tow) and the limit reference point (B_{lim} or the LRP) was set at 40% of the B_{msy} proxy (1.06 kg per tow).

In this assessment we have estimated reference points at the population scale (Fig. 33). Yield-based methods of calculating B_{msy} are not appropriate when natural mortality is time-varying and has risen to unusually high levels. Thus, we have used a method analogous to that used in the previous assessment to calculate reference points at the survey scale. The population biomass in the large length class was estimated and projected ahead to the timing of the RV survey in September to be consistent with the survey-based estimates. The average biomass in the 1985-1997 period (14.28 kt, 95% CI: 10.04 – 20.18) was used as the B_{msy} proxy. The productive period used here was shorter than the period used to calculate the index-based proxy (1977-1997) because the population model starts in 1985. However, the index-based estimates were about the same in the two periods (differing by a factor of 1.06). The population scale estimates of the reference points were 11.42 kt (95% CI: 8.03 – 16.14) for B_{usr} and 5.71 kt (95% CI: 4.02 – 8.07) for B_{lim} . The median estimate of large Yellowtail Flounder biomass was 39% of the LRP in 2020, and has been below the LRP since 2009. The estimated probability that this population was below the LRP exceeded 20% in 2006 and 70% in 2009. This probability exceeded 90% in 2010 to 2013 and 99% in 2016 to 2020 (Fig. 34).

7. PROJECTIONS

The population was projected forward 10 years assuming current productivity conditions would persist over this period. Projections were executed within the population model during the MCMC sampling phase. This took into account uncertainties in the model estimates. Projections were based on 501,000 MCMC samples, with the first 1,000 samples discarded and every 100th subsequent sample saved. Natural mortality was set at the levels estimated for the 2015 to 2020 time block. For each year and MCMC iteration, population weights at age, average individual weights in the fishery catch by length group, and recruitment rates were randomly sampled from the estimated values in the last ten years. Projections were conducted at three levels of annual fishery catch: 0, 100 and 300 t.

Estimated SSB declined slowly but steadily over the projection period even with no fishery catch (Fig. 35). The median estimate of SSB at the start of the projection period was 28.6 kt. With no fishery catch, estimated SSB declined to 16.1 kt over the 10-year projection, a 56% decline. Annual catches of 100 or 300 t had negligible impacts on declines, with SSB at 16.0 or 15.7 kt respectively at the end of the projection. Probabilities of decline in SSB over the projection period were 24% for a 15,000 t decline, 55% for a 10,000 t decline and 80% for a 5,000 t decline with no fishing. With annual catches of 300 t, these probabilities were 24%, 56% and 81%. The median estimate of decline was 10,686 t or 10,827 t with no fishery catch or an annual catch of 300 t, respectively.

We also projected estimated biomass of the large length class (≥ 25 cm) of Yellowtail Flounder forward to 2030. Biomass was adjusted to mid-September to be comparable with the population-level Limit Reference Point (LRP). This biomass declined progressively over the 10-year projection. The biomass trajectory again varied very little between the three catch levels (Fig. 36). The median estimate of this biomass was 2,230 t in 2020, declining to 1,270 t, 1,240 t and 1,160 t in 2030 with catches of 0 t, 100 t and 300 t, respectively. Projected biomass differed very little between fishery

catches of 0 and 300 t. At these levels of catch, natural mortality appears to currently be the dominant factor affecting stock status at the scale of the sGSL.

The stock is estimated to remain well below the LRP over the projection period. The probability that the stock was below the LRP was 100% in all projection years. The median estimate of biomass relative to the LRP was 37% in the first projection year declining to 22% or 20% in the last projection year with catches of 0-100 t or 300 t, respectively.

8. DISCUSSION

Estimated abundance of large Yellowtail Flounder (approximately 6 years and older) has declined by 95% since 1985 and appears to be continuing to decline. This strong and ongoing decline in the abundance of large individuals represents a severe risk to this population. The cause of this decline appears to be the extreme increase in natural mortality estimated to have occurred among the larger individuals in this population. This increase in natural mortality resembles those observed throughout the marine fish community of the southern Gulf of St. Lawrence (Benoît and Swain 2008; Swain and Benoît 2015). Predation by grey seals appears to be an important cause of these increases in natural mortality (Hammill et al. 2014; Neuenhoff et al. 2019; Swain et al. 2019a, 2019b).

Less severe declines in abundance have recently occurred for younger Yellowtail Flounder, a 50% decline for intermediate ages (4-5) from 2009 to 2019-2020 and a slight decline (8%) for the youngest ages. This may reflect the recent increases in natural mortality for younger ages.

Estimated SSB increased by about 75% from the 1980s to the early 2000s. It then declined gradually until 2015 followed by a rapid decline to an average value of 26 kt in 2017 to 2020, about 50% of the peak value in the early 2000s. Furthermore there has been a large change in the composition of the SSB between the 1980s and now. Fish 7 years and older made up 30% of the SSB in the late 1980s declining to less than 0.1% now. The SSB now consists almost entirely of fish 4 years and younger.

This change in the age composition of the SSB reflects a severe decline in the abundance of Yellowtail Flounder six years and older and a decrease in the size at maturity from about 22-27 cm in 1971 to about 10-14 cm in 2020. Early maturation is an expected consequence of increased mortality of older individuals (e.g. Law 1979; Reznick and Ghalambor 2006). A decline in the age and size at maturity is, in turn, expected to result in increased survival costs to reproduction (Hutchings 1994; Roff 2002). Earlier maturation may also influence maternal effects on offspring and thus recruitment success. Maternal effects are non-genetic effects on offspring fitness (Green 2008). Of particular importance here is the role of the demographic structure of the adult component of fish populations with respect to recruitment success. Many studies have reported a positive correlation between maternal size, egg size and offspring size early in life, and that larger offspring have a survival advantage early in life (e.g., Hutchings 1991; Reznick et al. 1996; Heath et al. 1999). In addition to maternal size, maternal age has been reported to be a determinant of larval growth and survival in a marine fish (Berkeley et al. 2004). Thus, the decline in the age and size composition of the Yellowtail Flounder spawning stock may result in a decline in recruitment success. However, this is not evident in the model estimates of recruitment rate (Fig. 29). The increased survival costs to reproduction that are expected to occur when maturation is at an early age or small size may also contribute to the elevated mortality estimated to occur in this population.

For all sizes of Yellowtail Flounder and in all time periods, estimated fishing mortality is very low compared to natural mortality, suggesting that fishing mortality has little impact on the population trajectory. This is evident in the projection trajectories, which differ very little between catch levels of 0, 100 and 300 t. Fishing impacts could be greater if there is substantial unreported catch. Mortality due to unreported catch would be interpreted as natural mortality by the model. However, unreported catch would need to be many times greater than reported catch in order to comprise an important component of the mortality attributed to natural causes. On the other hand, the population model is at

the scale of the entire southern Gulf whereas fishing activity is now largely restricted to the waters around the Magdalen Islands. It is possible that fishing has had an important impact on Yellowtail Flounder in the vicinity of the Magdalen Islands that is not evident at the level of the entire southern Gulf stock.

The estimated scale or level of the population depends on the value of catchability (q) to the survey. The freely estimated value of 1.4 is clearly too large. The informative prior for q was $\log(0.7)$ and the estimated value for q was equal to the prior. It might be argued that a q of 0.7 is still too large for a small flatfish like Yellowtail Flounder in the sGSL. However, the effective value of q estimated by the model was considerably lower at 0.46 (95% CI: 0.34-0.62). This lower value was produced by a low estimate for maximum selectivity to the survey (0.66). The current estimate of 0.46 is closer to the prior used in the previous assessment based on estimates of catchability of flatfish (American Plaice) to survey trawls obtained by Harley and Myers (2001).

Estimates of reference points at the population scale were developed in this assessment based on the approach used in the previous assessment for reference points at the survey scale. The main advantages of using the model-based approach is that it smooths through the observation error inherent in the survey data and allows for the calculation of probabilities of the status of the stock relative to reference points. In order to be comparable to the survey-based reference points model estimates were projected to mid-September to be consistent with the survey data. Because of the high mortality experienced by this stock, biomass estimates in September are considerably lower than those at the beginning of the year. The biomass of the large size class of Yellowtail Flounder was estimated to be 39% of the LRP in 2020. Taking the uncertainty in model estimates into account, the probability that the stock was below the LRP in 2020 was 99%. The probability that the stock remained below the LRP was 100% in all projection years and at all three catch levels. The estimated biomass at the end of the projection was about 20% of the LRP.

9. CONCLUSIONS

Although the abundance of pre-commercial sizes (< 25 cm) of Yellowtail Flounder in the sGSL increased for most of the period since 1985, commercial abundance has been in decline since about 1980. Based on the model estimates, the abundance of fish 6 years and older has declined by 95% since the mid-1980s. This decline appears to be on-going. Based on the model, this decline in the abundance of older, larger fish is due to extreme increases in the natural mortality of these fish from 21% annually early in the time series to 86% annually in the last 12 years. Similar elevated natural mortality is widespread among large individuals of many fish species in the sGSL. There is evidence that predation by grey seals is an important cause of this elevated mortality.

SSB was relatively high in the mid-2000s but has declined by 50% since then. Furthermore the age composition of the spawning stock has changed from one with a high proportion of older, larger fish to one dominated by younger smaller fish.

Fishing mortality is estimated to be low on all ages of Yellowtail Flounder. It is at negligible levels for young ages and reaches a maximum of 0.13 for the oldest age (8+). At the current level of natural mortality, projections indicate that catches of 100 or 300 t have a negligible impact on the population trajectory.

The population in 2020 is estimated to be 39% of the LRP with a 99% probability that it is below the LRP. The probability that the stock remained below the LRP during the projection to 2030 was 100% in all years at all catch levels from 0 t to 300 t. The estimated population level in 2030 was about 20% of the LRP.

At the scale of the sGSL, natural mortality appears to be the dominant factor affecting Yellowtail Flounder stock status.

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TABLES

Table 2. Annual recorded landings (t) of Yellowtail Flounder and unspecified flatfish in NAFO Div. 4T, 1960 to 2020. Data from 1960 to 1995 are taken from NAFO files. Data from 1996 to 2020 are from fishery logbooks from the DFO Statistics Branch (ZIFF files).

Year	Yellowtail Flounder	Unspecified Flatfish	Year	Yellowtail Flounder	Unspecified Flatfish
1960	2	2,405	1991	53.6	39.4
1961	7	2,493	1992	119.4	92.6
1962	2	1,304	1993	87.5	11.5
1963	51	0	1994	62.4	15.7
1964	39	0	1995	208.1	4.9
1965	51	0	1996	209.3	0
1966	125	0	1997	813.4	0
1967	55	0	1998	182.2	26.4
1968	6	0	1999	304.8	0.2
1969	243	0	2000	294.5	2.9
1970	44	0	2001	317.4	0.3
1971	5	0	2002	215.3	0
1972	3	1,201	2003	157.7	0
1973	1	1,388	2004	192	0.7
1974	21	602	2005	175.5	0.6
1975	0	2,464	2006	182.2	0.1
1976	29	668	2007	141.9	2.8
1977	25	1,163	2008	91.6	0
1978	3	764	2009	101.4	0
1979	52	841	2010	185.8	0
1980	41	759	2011	180.8	0
1981	10	118	2012	110.9	0
1982	6	344	2013	82.4	0
1983	26	792	2014	85.9	0
1984	82	46	2015	101.5	0
1985	215	3	2016	80.7	0.4
1986	396	0	2017	135.1	0
1987	404	0	2018	100.2	0
1988	198	0	2019	120.5	0.1
1989	43	36	2020	136.2	0
1990	15	37			

Table 3. Annual landings (kg) of Yellowtail Flounder by subdivision in NAFO Div. 4T, 1985 to 2020. Data are from DFO Statistics Branch, estimates of unreported catches (1998) and fishery logbooks.

Year	4Tf	4Tg	4Th	4Tj	4Tk	4Tl	4Tm	4Tn	4To	4Tp	4Tq	4Tu	Total
1985	9,324	2,965	91	0	0	9,999	72,891	431	51	0	7	115,567	211,326
1986	113,337	7,883	0	10,306	0	9,131	28,000	9,599	2,752	15	7	219,316	400,346
1987	218,604	8,572	0	3,932	0	64,530	17,282	726	325	6,468	0	84,059	404,498
1988	148,984	6,613	0	13,084	0	2,153	0	674	837	100	1,412	30,075	203,932
1989	6,160	402	0	0	0	12,922	0	0	0	0	0	22,526	42,010
1990	14	3	0	0	0	116	45	116	0	0	0	15,297	15,591
1991	35,999	5,260	228	3,909	0	1,311	0	703	0	0	0	6,210	53,620
1992	81,589	29	0	2,463	0	2,398	27,909	4,062	0	413	0	499	119,362
1993	38,965	266	1,587	1,582	0	13,342	20,446	53	0	324	0	10,946	87,511
1994	7,266	998	0	0	2,512	46,554	3,193	253	0	759	0	907	62,442
1995	148,915	2,021	0	0	0	49,876	6,724	224	0	288	0	38	208,086
1996	173,711	3,630	0	51	25	29,904	1,904	0	28	0	0	0	209,253
1997	799,641	5,340	0	0	0	6,936	1,448	0	4	0	0	0	813,369
1998	162,333	2,230	0	0	95	17,140	0	362	0	0	0	0	182,160
1999	287,917	2,472	11	0	0	13,843	0	604	0	0	0	0	304,847
2000	284,445	3,585	0	0	0	6,444	0	0	0	0	0	0	294,474
2001	285,157	16,871	0	0	0	15,366	0	0	0	0	0	0	317,394
2002	189,663	21,032	0	0	5	4,587	0	0	0	0	0	0	215,287
2003	132,677	12,899	0	0	392	11,723	0	0	0	0	0	0	157,691
2004	180,591	7,293	0	1,029	0	1,047	0	0	0	0	0	1,995	191,955
2005	168,450	6,323	0	225	25	310	0	134	0	0	0	0	175,467
2006	181,368	413	0	0	0	311	0	0	5	0	0	127	182,224
2007	141,823	0	0	0	0	117	0	0	0	0	0	0	141,940
2008	91,348	225	0	0	23	0	0	0	0	0	0	0	91,596
2009	101,361	0	0	0	0	0	0	0	0	0	0	0	101,361
2010	185,847	0	0	0	0	0	0	0	0	0	0	0	185,847
2011	179,796	4	0	0	497	396	0	0	0	0	0	69	180,762
2012	110,912	0	0	0	0	0	0	0	0	0	0	0	110,912
2013	82,390	0	0	0	0	0	0	0	0	0	0	0	82,390
2014	85,788	0	0	0	0	0	0	0	0	0	0	0	85,788
2015	101,520	0	0	0	0	0	0	0	0	0	0	0	101,520
2016	80,742	0	0	0	0	0	0	0	0	0	0	0	80,742

Year	4Tf	4Tg	4Th	4Tj	4Tk	4Tl	4Tm	4Tn	4To	4Tp	4Tq	4Tu	Total
2017	134,245	0	0	0	858	0	0	0	0	0	0	0	135,103
2018	100,173	0	0	0	0	0	0	0	0	0	0	0	100,173
2019	120,498	0	0	0	0	0	0	0	0	0	0	0	120,498
2020	136,191	0	0	0	0	0	0	0	0	0	0	0	136,191
Mean 1985 to 2020	147,437	3,259	53	1,016	123	8,902	4,996	498	111	232	40	14,101	180,769

Table 4. Annual landings (kg) by month of Yellowtail Flounder in NAFO Div. 4Th. Data are from DFO Statistics Branch, estimates of unreported catches (1998) and fishery logbooks.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985	0	0	0	0	9,185	8,878	21,370	15,836	34,707	52,982	68,368	0
1986	0	0	0	0	9,452	14,984	42,917	74,524	86,679	108,885	62,144	761
1987	0	0	0	600	1,265	44,342	83,786	87,858	56,775	109,403	20,141	328
1988	0	0	0	0	119,421	17,650	26,006	7,841	10,440	12,383	10,169	22
1989	0	0	0	0	3,818	9,064	10,031	6,144	7,203	5,447	303	0
1990	0	0	0	0	0	150	12,661	582	1,889	261	48	0
1991	0	0	0	0	0	0	1,977	1,019	4,594	33,446	12,584	0
1992	0	0	0	0	136	62,218	19,950	2,756	26,963	6,485	854	0
1993	0	0	0	0	22,680	9,758	10,468	11,049	31,974	1,582	0	0
1994	0	0	0	0	759	253	21,599	2,719	25,206	11,906	0	0
1995	0	0	0	288	43,456	76,985	38,517	23,027	24,548	1,265	0	0
1996	0	0	0	0	75,255	72,400	16,157	18,258	15,311	11,872	0	0
1997	0	0	0	0	121,723	194,042	139,800	229,807	124,783	2,972	242	0
1998	0	0	0	2,870	53,504	46,581	0	39,536	34,519	5,142	8	0
1999	0	0	0	3,792	85,029	117,450	21,412	40,031	33,304	3,829	0	0
2000	0	0	0	0	125,070	72,056	12,272	70,001	11,341	3,734	0	0
2001	0	0	0	1,701	162,236	86,964	12,835	17,483	18,638	17,537	0	0
2002	0	0	0	3,927	82,883	63,625	9,356	17,599	20,427	17,442	28	0
2003	0	0	0	1,586	56,190	62,556	7,797	6,903	18,158	4,501	0	0
2004	0	0	0	3,746	61,316	87,854	16,291	4,630	6,913	11,205	0	0
2005	0	0	0	4,676	79,849	67,615	15,163	3,273	2,390	2,501	0	0
2006	0	0	0	5,960	96,660	71,968	4,123	388	600	2,525	0	0
2007	0	0	0	8,749	68,659	59,078	4,558	5	891	0	0	0
2008	0	0	0	3,083	41,404	46,374	510	179	46	0	0	0
2009	0	0	0	7,065	48,125	45,763	408	0	0	0	0	0
2010	0	0	0	21,345	62,636	101,149	717	0	0	0	0	0
2011	0	0	0	20,541	72,451	80,089	7,669	12	0	0	0	0
2012	0	0	0	10,119	54,630	39,716	6,167	0	91	189	0	0
2013	0	0	0	5,360	41,153	35,623	0	0	171	83	0	0
2014	0	0	0	29	28,394	46,463	10,884	0	75	8	0	0
2015	0	0	0	95	24,193	43,091	34,141	0	0	0	0	0
2016	0	0	0	4,668	36,974	39,091	9	0	0	0	0	0
2017	0	0	0	11,727	36,573	69,120	17,683	0	0	0	0	0

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2018	0	0	0	5,734	52,063	36,590	5,786	0	0	0	0	0
2019	0	0	0	5,107	49,144	58,899	7,348	0	0	0	0	0
2020	0	0	0	3,739	48,547	64,765	19,140	0	0	0	0	0
Mean 1985 to 2020	0	0	0	3,792	52,079	54,256	18,320	18,929	16,629	11,877	4,858	31

Table 5. Annual landings (kg) of Yellowtail Flounder in NAFO Div. 4T by gear type, 1985 to 2020. Data are from DFO Statistics Branch, estimates of unreported catches (1998) and fishery logbooks.

Year	Gillnet	Handline	Lift Net	Longline	Seine	Trawl	Unspecified
1985	15	0	0	55	70,904	137,872	0
1986	466	748	0	5	296,073	103,054	0
1987	14,921	1,056	0	2,703	292,846	92,972	0
1988	3,421	0	0	362	53,052	147,097	0
1989	587	0	0	28	9,811	31,584	0
1990	153	45	0	0	2,281	13,112	0
1991	906	21	0	105	44,680	7,908	0
1992	937	0	0	0	11,751	106,674	0
1993	377	0	0	0	20,323	66,811	0
1994	1,298	0	0	0	37,843	23,301	0
1995	2,345	0	0	38	118,570	87,133	0
1996	114	0	0	0	173,958	35,181	0
1997	11	0	0	355	793,296	9,728	9,979
1998	34	0	0	38	138,667	43,421	0
1999	398	0	0	0	257,957	46,492	0
2000	9	0	0	0	270,075	24,390	0
2001	13	0	0	0	218,582	98,799	0
2002	412	0	0	0	157,617	57,258	0
2003	0	0	0	0	119,307	38,384	0
2004	196	0	0	0	165,878	25,881	0
2005	61	0	0	0	137,520	37,886	0
2006	191	0	0	0	123,629	58,404	0
2007	180	0	0	0	86,345	55,415	0
2008	0	0	544	0	28,901	62,151	0
2009	60	0	3	0	35,095	66,201	0
2010	149	0	150	0	65,076	120,472	0
2011	0	0	15	0	45,522	135,225	0
2012	7	0	0	1	20,732	90,172	0
2013	4	0	250	0	16,454	65,682	0
2014	48	0	0	0	15,874	69,931	0
2015	61	0	0	0	29,291	72,168	0
2016	5	0	0	0	31,088	49,649	0
2017	2	0	0	0	47,313	87,770	0
2018	24	0	0	0	21,528	78,621	0
2019	5	0	0	0	35,265	85,228	0
2020	0	0	0	0	35,354	100,837	0
Mean 1985 to 2020	761	52	27	103	111,902	67,580	277

Table 6. Summary of Yellowtail Flounder length frequency samples obtained by port samplers and presented by NAFO subdivision, season and fishing gear, 1985 to 2020. Shown in parentheses are the total number of fish in the samples.

Year	NAFO subdivision	Seine		Trawl		Gillnet	
		April-June	July-October	April-June	July-October	April-June	July-October
1985	4Tg	1 (7)	na	na	1 (55)	na	na
1985	4TI	na	7 (815)	na	na	na	1 (100)
1986	4T	na	na	na	3 (112)	na	na
1986	4Tg	1 (112)	7 (187)	2 (16)	5 (24)	na	na
1986	4TI	4 (230)	5 (397)	1 (72)	1 (55)	na	na
1987	4Tf	na	1 (250)	na	na	na	na
1987	4Tg	8 (219)	5 (368)	1 (7)	na	na	na
1987	4Tj	na	na	na	2 (249)	na	na
1987	4TI	1 (156)	2 (72)	1 (8)	na	na	na
1987	4Tn	na	na	na	1 (202)	na	na
1988	4T	na	3 (464)	na	na	na	na
1988	4Tg	2 (218)	na	na	na	na	na
1988	4TI	na	1 (10)	na	na	na	na
1992	4Tf	3 (716)	na	3 (813)	1 (259)	na	na
1995	4Tf	1 (263)	1 (250)	3 (755)	na	na	na
1996	4Tf	1 (271)	na	na	na	na	na
1997	4Tf	3 (749)	9 (2,377)	na	na	na	na
1998	4Tf	6 (1,438)	4 (1,018)	1 (66)	na	na	na
1999	4Tf	6 (1,543)	1 (254)	na	na	na	na
2000	4Tf	6 (1,429)	1 (251)	na	na	na	na
2001	4Tf	4 (1,012)	na	na	na	na	na
2002	4Tf	6 (1,469)	na	na	na	na	na
2002	4Tg	na	na	na	2 (332)	na	na
2003	4Tf	5 (1,172)	1 (239)	na	na	na	na
2004	4Tf	3 (546)	na	na	na	na	na
2005	4Tf	4 (956)	na	na	na	na	na

Year	NAFO subdivision	Seine		Trawl		Gillnet	
		April-June	July-October	April-June	July-October	April-June	July-October
2006	4Tf	3 (711)	na	1 (259)	na	na	na
2007	4Tf	3 (636)	1 (191)	1 (87)	na	1 (7)	na
2008	4Tf	3 (1,032)	na	2 (317)	na	na	na
2009	4Tf	3 (730)	na	1 (120)	na	na	na
2010	4Tf	4 (738)	na	na	na	na	na
2011	4Tf	3 (605)	na	na	na	na	na
2012	4Tf	2 (258)	na	2 (206)	na	na	na
2013	4Tf	1 (200)	na	2 (262)	na	na	na
2014	4Tf	na	na	na	1 (71)	na	na
2015	4Tf	1 (250)	1 (196)	1 (209)	na	na	na
2016	4Tf	2 (504)	na	2 (87)	na	1 (95)	na
2016	4To	na	na	na	na	2 (291)	na
2017	4Tf	1 (209)	na	7 (666)	3 (128)	na	na
2017	4Tg	1 (181)	na	na	na	na	na
2017	4To	na	na	na	na	1 (150)	1 (113)
2017	4Tp	na	na	na	na	2 (272)	na
2018	4Tf	4 (370)	1 (31)	na	na	na	na
2019	4Tf	5 (991)	na	1 (135)	na	na	na
2020	4Tf	1 (150)	na	na	na	na	na

Table 7. Summary of number of length-frequency samples of Yellowtail Flounder obtained by observers, by NAFO subdivision, season and fishing gear. The total number of fish sampled are shown in parentheses.

Year	NAFO subdivision	April-June	July-October	April-June	July-October	April-June	July-October
1992	4Tf	na	na	8 (853)	na	na	na
1992	4Tl	na	na	na	1 (85)	na	na
1995	4Tf	1 (110)	na	1 (108)	na	na	na
1996	4Tf	9 (2,420)	na	na	na	na	na
1996	4Tj	na	na	na	na	na	2 (2)
1996	4Tn	na	na	na	2 (40)	na	na
1997	4Tf	2 (517)	5 (1,345)	na	na	na	na
1998	4Tf	4 (1,113)	na	2 (138)	na	na	na
2000	4Tf	4 (1,028)	na	na	na	na	na
2001	4Tf	9 (2,031)	2 (309)	na	na	na	na
2002	4Tf	1 (320)	1 (339)	na	na	na	na
2003	4Tf	10 (2,099)	2 (276)	1 (124)	na	na	na
2004	4Tf	10 (2,647)	3 (616)	na	na	na	na
2005	4Tf	10 (2,608)	1 (157)	3 (215)	na	na	na
2006	4Tf	13 (3,115)	3 (655)	7 (1,118)	na	na	na
2007	4Tf	9 (2,229)	2 (570)	23 (2,038)	2 (175)	na	na
2008	4Tf	3 (705)	1 (262)	12 (1,002)	na	na	na
2009	4Tf	5 (791)	na	23 (1,244)	na	na	na
2010	4Tf	16 (2,748)	1 (99)	20 (3,177)	na	na	na
2011	4Tf	15 (2,352)	na	34 (4,931)	na	na	na
2012	4Tf	10 (1,981)	na	38 (4,087)	6 (87)	na	na
2013	4Tf	10 (919)	na	51 (5,094)	na	1 (3)	na
2014	4Tf	3 (285)	na	29 (3,387)	2 (59)	2 (2)	na
2015	4Tf	4 (525)	6 (603)	13 (1,499)	11 (1,699)	na	na
2016	4Tf	11 (1,373)	na	33 (3,345)	na	1 (2)	na
2017	4Tf	8 (1,342)	1 (120)	32 (2,654)	8 (2,124)	7 (31)	na
2018	4Tf	12 (1,843)	2 (87)	36 (4,804)	1 (47)	4 (8)	na
2018	4Tm	na	na	na	na	na	1 (1)
2019	4Tf	10 (1,286)	na	28 (3,489)	na	6 (21)	na

Year	NAFO subdivision	April-June	July-October	April-June	July-October	April-June	July-October
2020	4Tf	na	na	na	na	na	na

Table 8. Abundance indices (numbers per tow) of Yellowtail Flounder in NAFO Div. 4T (2nd column) research surveys of the southern Gulf of St. Lawrence (strata 415-439), and from the strata around the Magdalen Islands (3rd column; strata 428, 434, 435 and 436). Also shown are biomass indices (kg per tow) for small (<25 cm; 4th column) and large \geq 25 cm; 5th column) Yellowtail Flounder for the entire southern Gulf of St. Lawrence.

Year	4T (n/tow)	Magdalen Isl. (n/tow)	4T < 25 cm (kg/tow)	4T \geq 25 cm (kg/tow)
1971	3.620	8.660	0.051	0.864
1972	4.209	18.071	0.066	0.893
1973	5.836	6.330	0.097	1.375
1974	9.798	31.957	0.212	1.691
1975	6.046	27.183	0.229	0.756
1976	5.449	9.621	0.136	0.882
1977	20.827	79.576	0.748	2.713
1978	12.559	24.309	0.240	2.043
1979	19.307	21.861	0.174	3.348
1980	19.089	30.590	0.314	3.377
1981	30.440	48.569	0.553	4.907
1982	14.374	14.678	0.203	2.688
1983	18.472	17.321	0.259	3.133
1984	4.140	4.955	0.058	0.802
1985	13.064	4.861	0.174	2.690
1986	18.510	7.596	0.255	4.022
1987	14.389	10.703	0.253	2.328
1988	18.520	27.238	0.310	3.850
1989	11.163	7.142	0.351	1.567
1990	16.174	7.885	0.612	2.054
1991	19.924	22.686	0.489	3.077
1992	15.226	28.412	0.602	1.786
1993	25.217	65.254	1.050	2.565
1994	16.212	38.343	0.715	1.711
1995	23.604	78.818	0.658	3.258
1996	17.535	52.755	0.446	2.284
1997	14.285	39.285	0.620	1.071
1998	15.139	41.955	0.724	1.180
1999	22.840	68.011	1.107	1.912
2000	21.720	79.740	0.931	2.008
2001	21.700	58.775	0.940	2.160
2002	16.526	55.639	0.780	1.222
2003	11.620	42.146	0.531	0.968
2004	22.415	86.176	1.201	1.499
2005	17.481	67.253	0.962	1.015
2006	24.281	83.097	1.414	1.046
2007	18.127	46.884	0.998	0.731
2008	20.058	26.885	1.148	0.649
2009	15.688	42.675	0.913	0.407
2010	20.031	56.595	1.154	0.420
2011	13.905	55.476	0.841	0.250
2012	16.421	54.786	1.031	0.236

Year	4T (n/tow)	Magdalen Isl. (n/tow)	4T < 25 cm (kg/tow)	4T ≥ 25 cm (kg/tow)
2013	23.035	59.997	1.397	0.475
2014	15.597	50.427	0.908	0.431
2015	16.754	32.206	0.927	0.648
2016	7.613	24.544	0.456	0.195
2017	10.433	49.920	0.609	0.282
2018	9.235	34.356	0.481	0.146
2019	13.371	47.607	0.680	0.276
2020	10.070	41.377	0.515	0.320

Table 9. Mobile sentinel survey tows performed by each vessel in the southern Gulf of St. Lawrence, 2003 to 2019.

Year	Riding it out	Line Guy	J.L.S.R.	Cap Adele	L. Alberto	Manon Yvon	Viking II	Atlantic Quest I	Tamara Louise	Harbour Leta	Miss Lameque	Cape Ryan	Boreas VII	Total
2003	50	0	0	0	52	54	0	0	0	0	65	0	0	221
2004	50	0	0	0	0	56	64	0	0	0	67	0	0	237
2005	51	0	0	0	0	56	70	0	0	0	68	0	0	245
2006	51	0	0	51	0	0	63	0	0	0	61	0	0	226
2007	0	0	0	52	0	0	65	51	0	0	62	0	0	230
2008	0	0	0	51	0	0	64	50	0	0	59	0	0	224
2009	0	0	0	42	0	0	54	44	0	0	48	0	0	188
2010	0	0	0	42	0	0	54	0	44	0	48	0	0	188
2011	0	0	0	38	0	0	53	0	41	0	44	0	0	176
2012	0	0	0	40	0	0	53	0	41	0	43	0	0	177
2013	0	0	0	37	0	0	59	0	39	0	35	0	0	170
2014	0	0	57	33	0	0	0	0	35	0	0	31	0	156
2015	0	27	56	32	0	0	0	0	0	0	0	27	0	142
2016	0	33	55	28	0	0	0	0	0	0	0	30	0	146
2017	0	33	54	28	0	0	0	0	0	0	0	0	0	115
2018	0	32	50	30	0	0	0	0	0	0	0	0	30	142
2019	0	0	39	38	0	0	0	0	0	20	0	0	0	97
Coef n/tow	0.825	0.094	1.428	2.707	0.613	1.094	1.238	0.387	0.234	na	1.000	5.097	1.499	na
Coef kg/tow	1.032	0.165	1.023	2.630	0.626	1.158	1.112	0.517	0.262	na	1.000	3.568	1.401	na

Table 10. Number of valid otoliths of Yellowtail Flounder aged per year from the September bottom trawl survey of the southern Gulf of St. Lawrence, by year and age (1 to 11).

Year	Ager location	1	2	3	4	5	6	7	8	9	10	11	Total
1972	St. Andrews	0	0	2	6	32	25	56	39	4	3	0	167
1973	St. Andrews	0	1	6	22	17	26	35	44	19	9	2	181
1974	St. Andrews	0	1	26	46	53	55	44	36	21	3	1	286
1975	St. Andrews	0	7	29	62	38	37	25	11	6	0	0	215
1976	St. Andrews	0	1	8	41	46	42	29	10	6	2	0	185
1977	St. Andrews	0	0	15	48	71	57	51	24	5	0	0	271
1978	St. Andrews	0	4	15	28	59	67	72	61	26	19	6	357
1980	St. Andrews	0	3	22	35	69	72	50	37	18	4	2	312
1981	St. Andrews	0	0	10	56	48	70	34	15	2	0	0	235
1982	St. Andrews	0	0	3	20	58	56	74	34	4	1	1	251
1982 rev.	Gulf 1	0	3	36	61	60	71	33	11	3	0	1	279
1986	Gulf 1	17	39	30	14	18	17	4	3	1	0	0	143
2000	Gulf 1	30	36	27	33	19	12	1	0	0	0	0	158
2001	Gulf 2	2	14	38	25	25	22	16	5	0	1	0	148
2003	Gulf 2	0	10	29	31	27	20	12	3	2	0	0	134
2005	Gulf 2	1	12	35	32	26	20	16	3	0	1	0	146
2007	Gulf 1	36	30	24	21	21	11	3	1	0	0	0	147
2009	Gulf 2	0	18	26	29	29	26	5	0	0	0	0	133
2011	Gulf 2	0	11	19	40	31	15	5	1	0	0	0	122
2013	Gulf 1	10	22	19	26	21	21	7	2	2	0	0	130
2013	Gulf 2	1	13	26	28	29	23	5	5	2	0	0	132
2015	Gulf 1	28	20	23	26	21	7	3	3	0	0	0	131
2017	Gulf 1	19	24	11	16	28	19	5	4	2	0	0	128
2017	Gulf 2	3	32	15	24	29	23	3	2	0	0	0	131
2019	Gulf 2	15	67	285	135	98	42	17	0	1	0	0	660

Table 11. Number of vessels landing Yellowtail Flounder by year, based on logbook data, from NAFO Div. 4T.

Year	Trawlers	Seiners
1985	45	18
1986	47	59
1987	61	47
1988	20	39
1989	17	23
1990	12	6
1991	19	16
1992	15	13
1993	9	4
1994	5	4
1995	16	5
1996	25	9
1997	10	18
1998	14	11
1999	15	11
2000	11	14
2001	19	9
2002	27	9
2003	23	6
2004	25	6
2005	27	5
2006	30	5
2007	41	3
2008	37	3
2009	48	2
2010	96	5
2011	99	5
2012	86	6
2013	13	5
2014	14	3
2015	12	4
2016	13	4
2017	14	5
2018	14	4
2019	13	4
2020	13	3

FIGURES

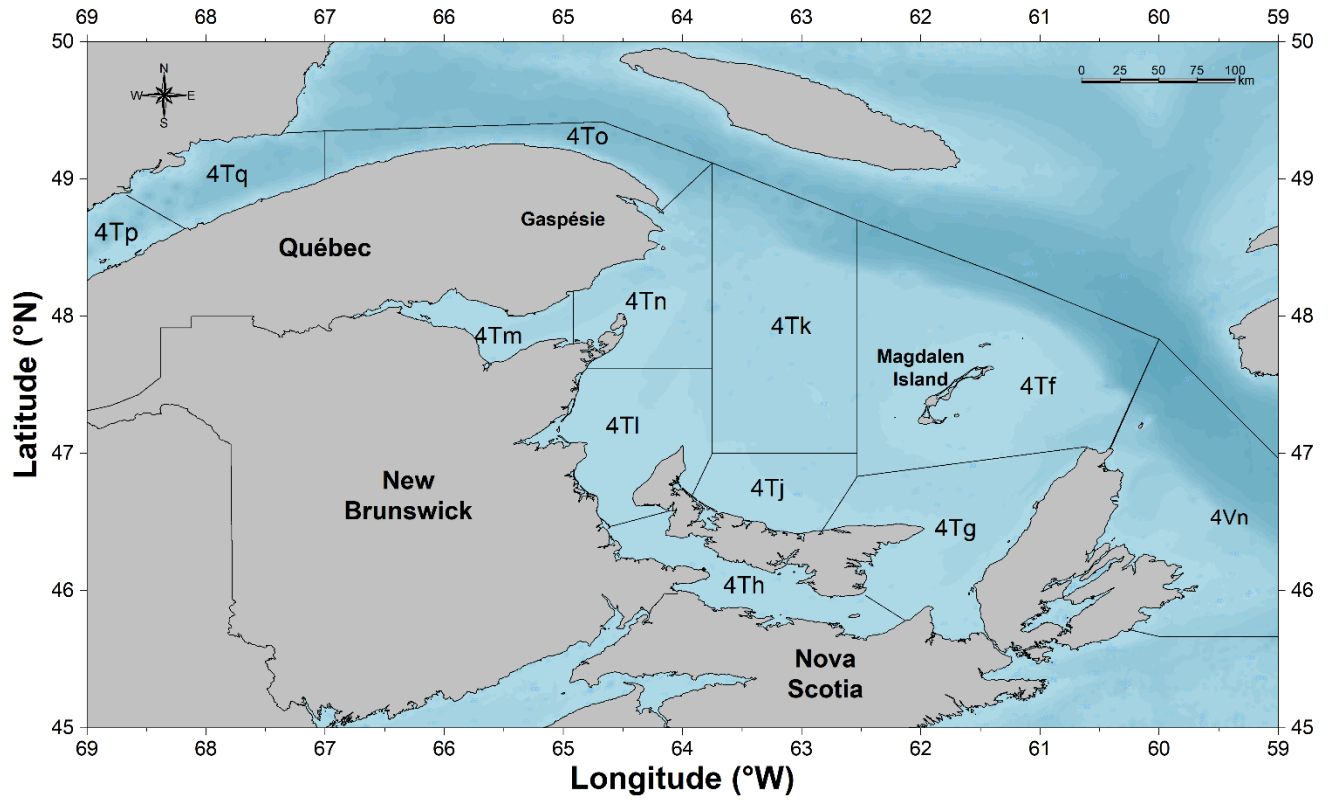


Figure 1. Map of the southern Gulf of St. Lawrence (sGSL) showing NAFO Div. 4T subdivisions.

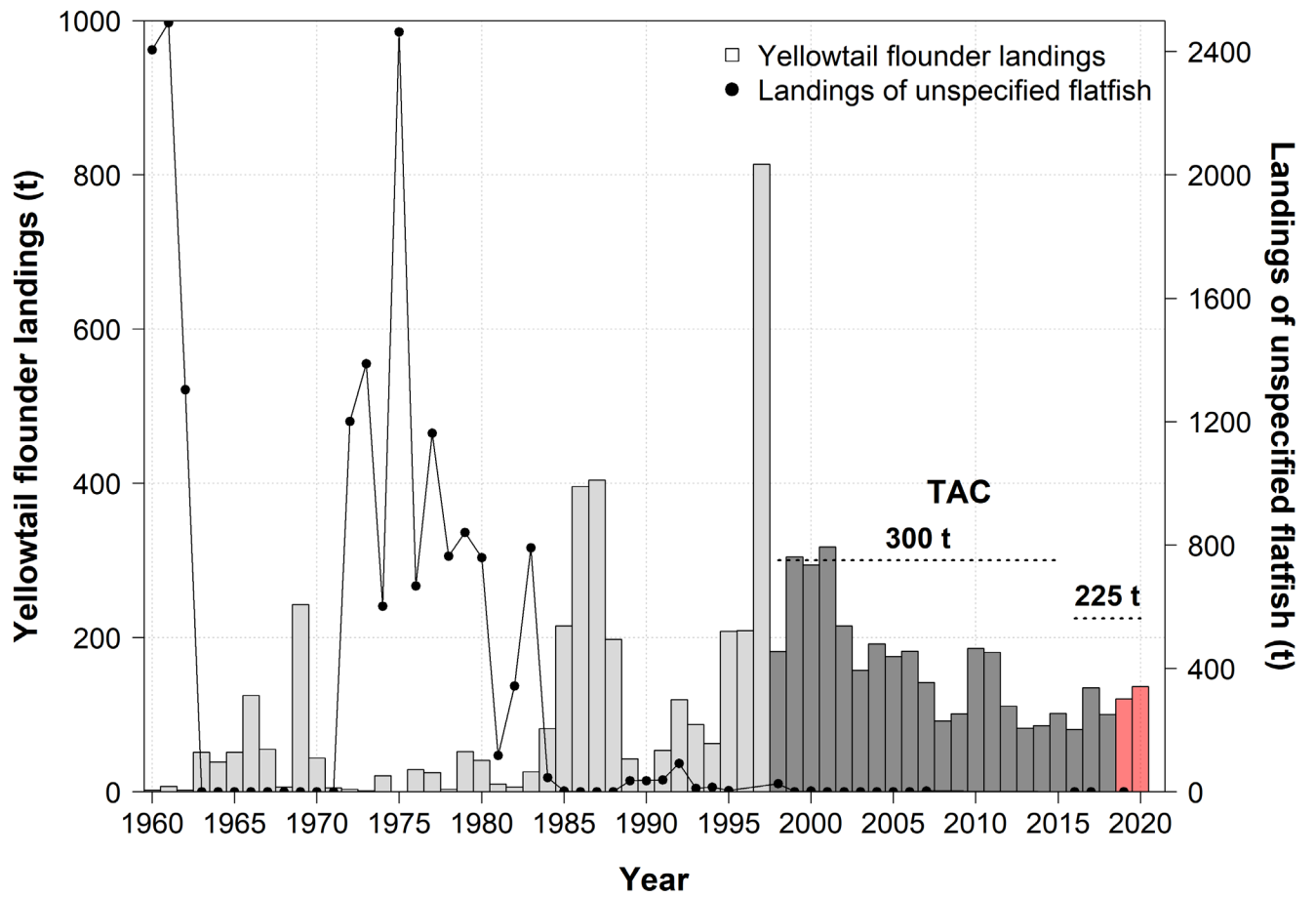


Figure 2. Yellowtail Flounder landings (t) in NAFO Div. 4T from 1960 to 2020. The solid black line corresponds to landings of unspecified flatfish. Landings for 2019 and 2020 are preliminary. The current total allowable catch (TAC) is 225 tonnes.

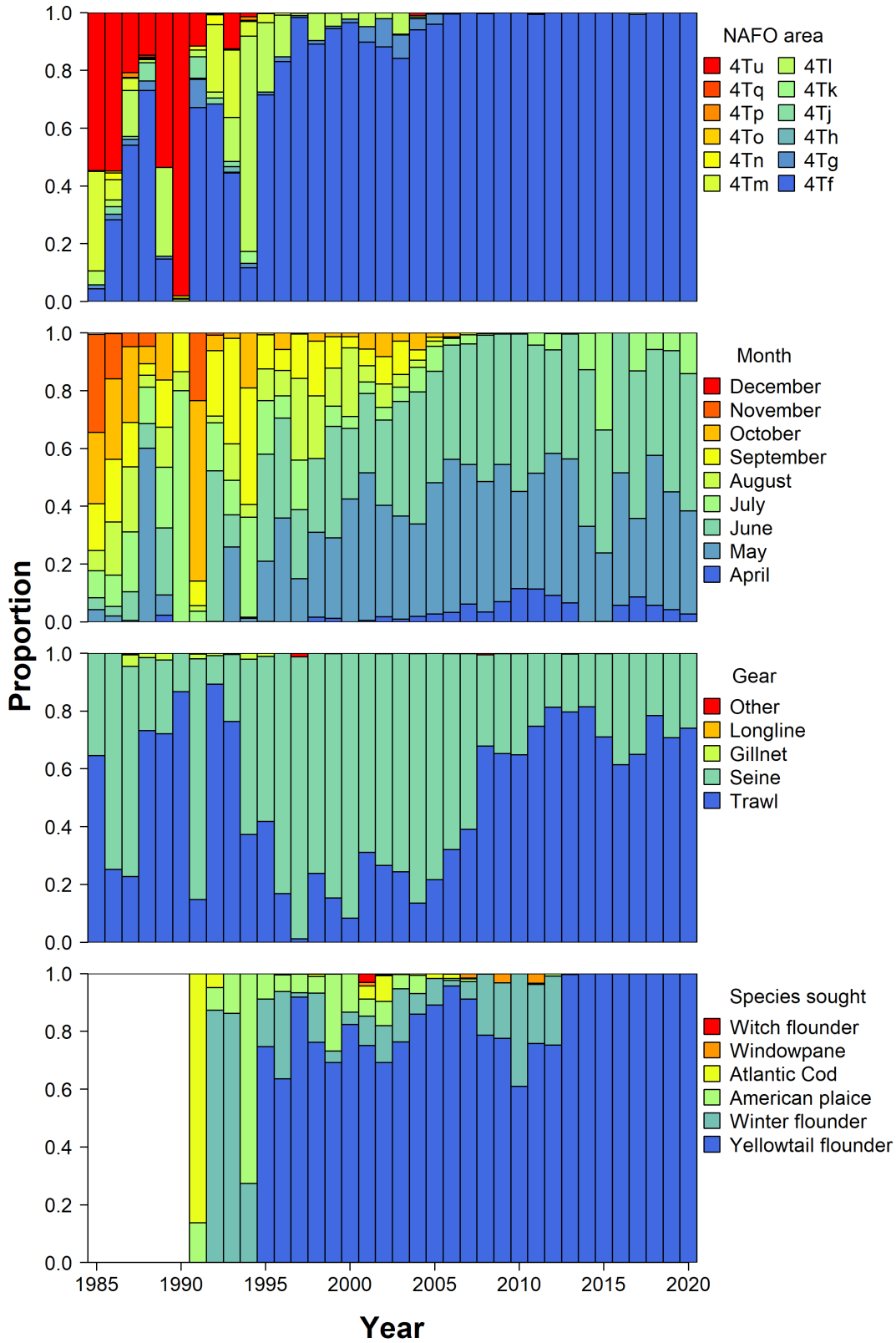


Figure 3. Proportions of Yellowtail Flounder landings by year for NAFO 4T subdivision (first panel, top), fishing month (second panel), type of fishing gear (third panel) and target fishing species (fourth panel, bottom).

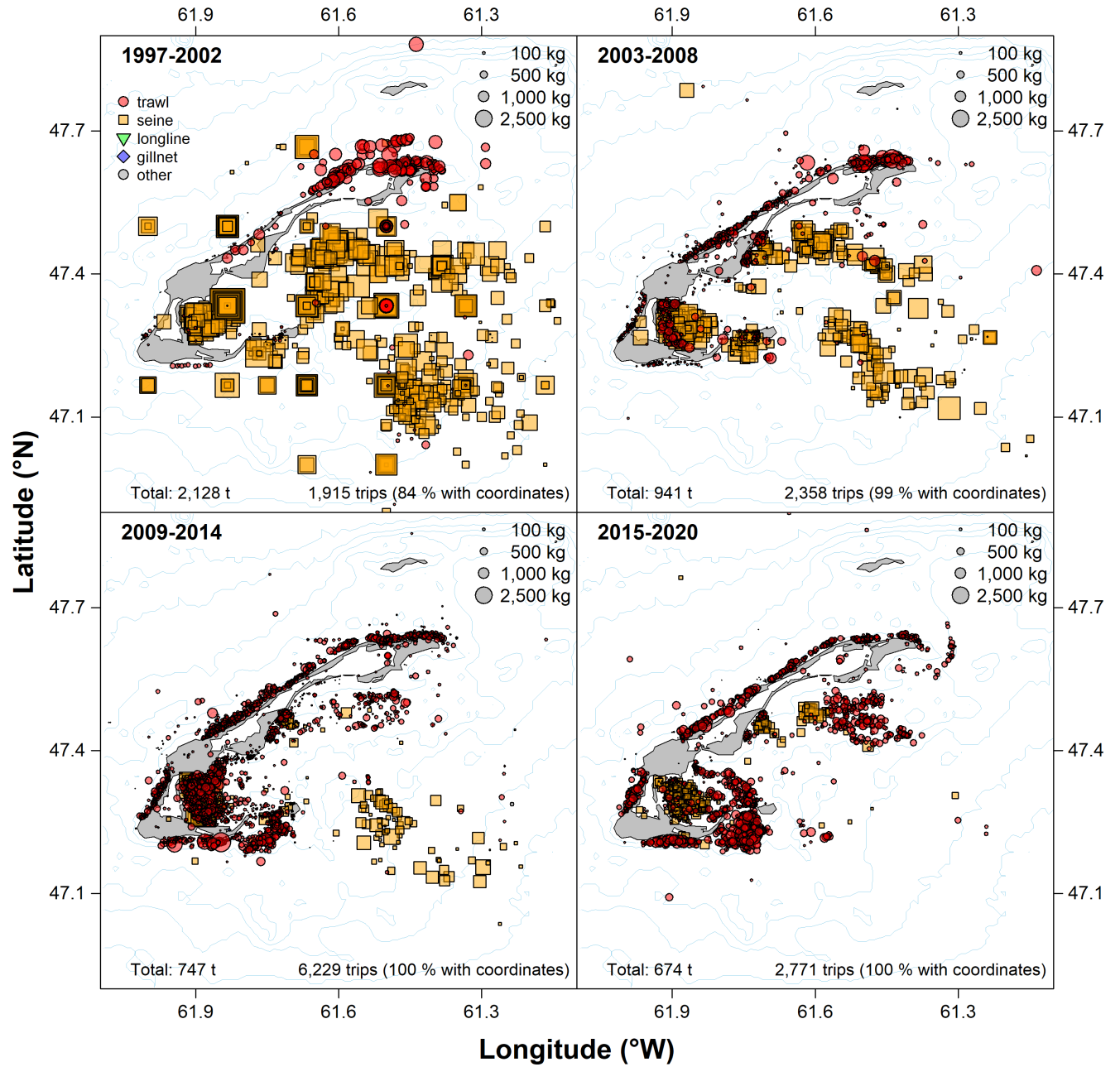


Figure 4. Spatial distribution of logbook catches of Yellowtail Flounder by year and fishing gear type. The surface area of the plotted circle is proportional to the recorded catch.

Vessel speed

- ≤ 0.1 kn
- $0.1 > \text{kn} \leq 2.0$
- $2.0 > \text{kn} \leq 4.0$
- > 4.0 kn

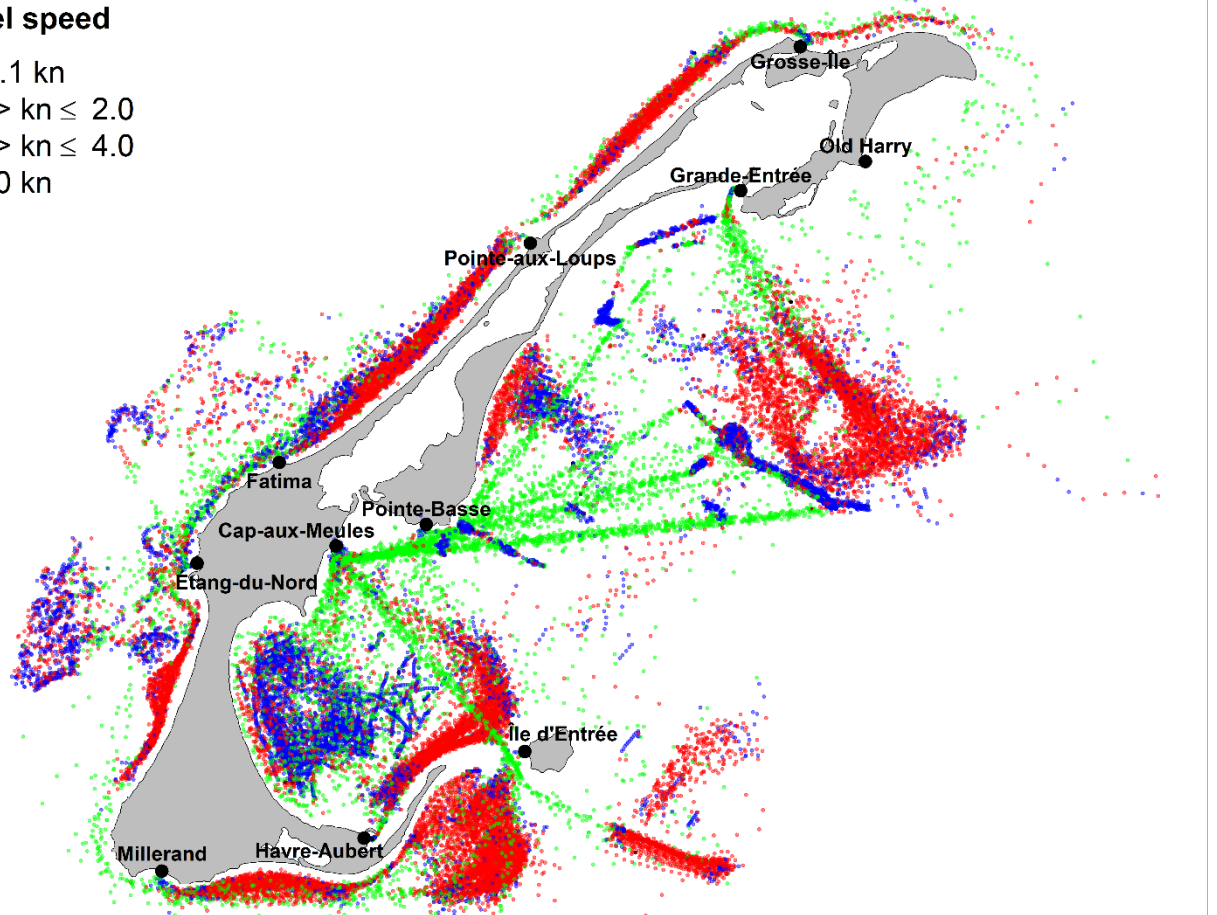


Figure 5. Spatial distribution of the 2019 fishing activities of the Yellowtail Flounder fleet using its onboard mandatory Vessel Monitoring System (VMS) set at a minimum frequency of 15 minutes. Vessel speed categories (in knots) were estimated based on the time difference and distance between each continuous recordings.

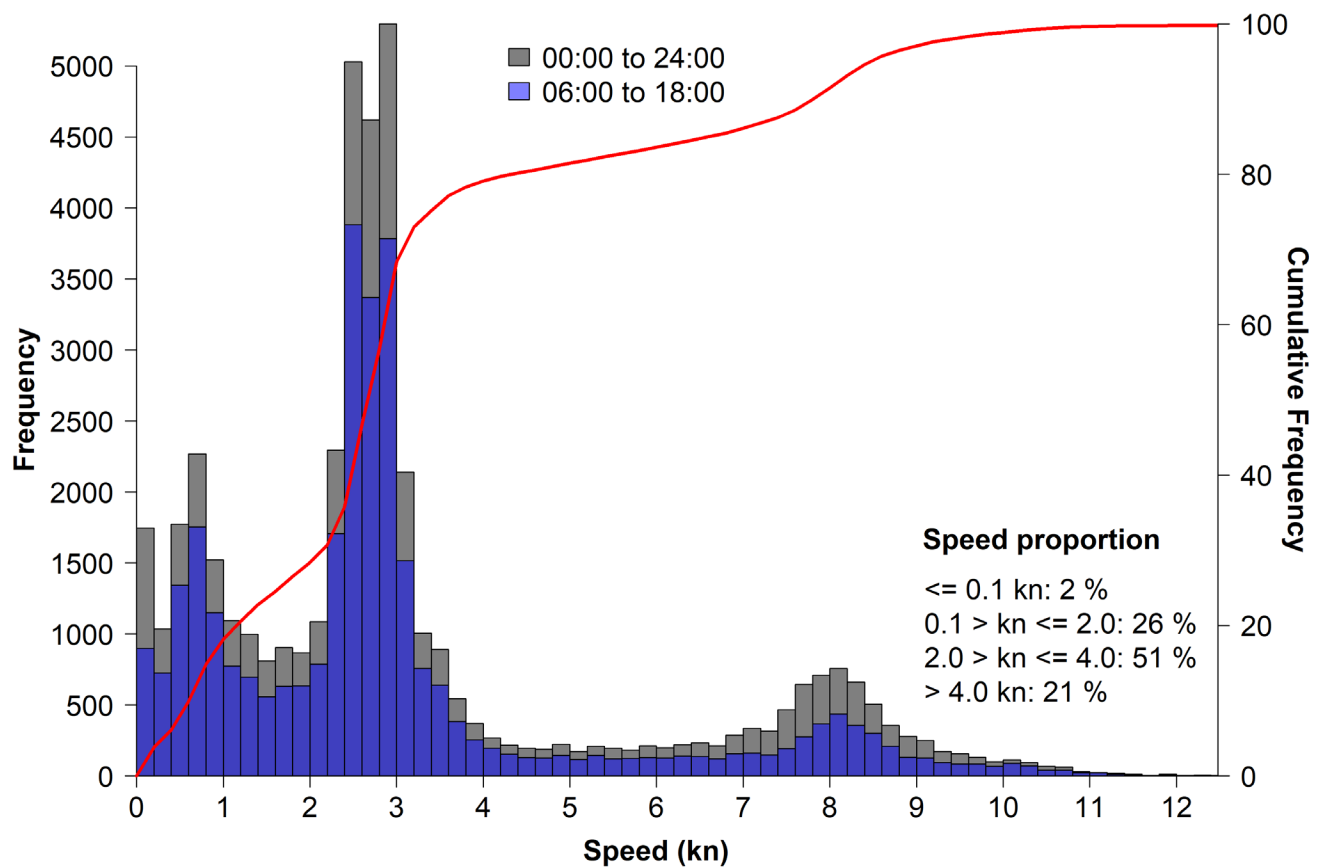


Figure 6. Vessel speed (in knots) frequency distribution and proportion from the 2019 fishing activities of the Yellowtail Flounder fleet using its onboard mandatory Vessel Monitoring System (VMS) set at a minimum frequency of 15 minutes. Vessel speed categories were estimated based on the time and distance of each continuous recordings. For each category the day (06h00 to 18h00) frequency is presented alongside its total.

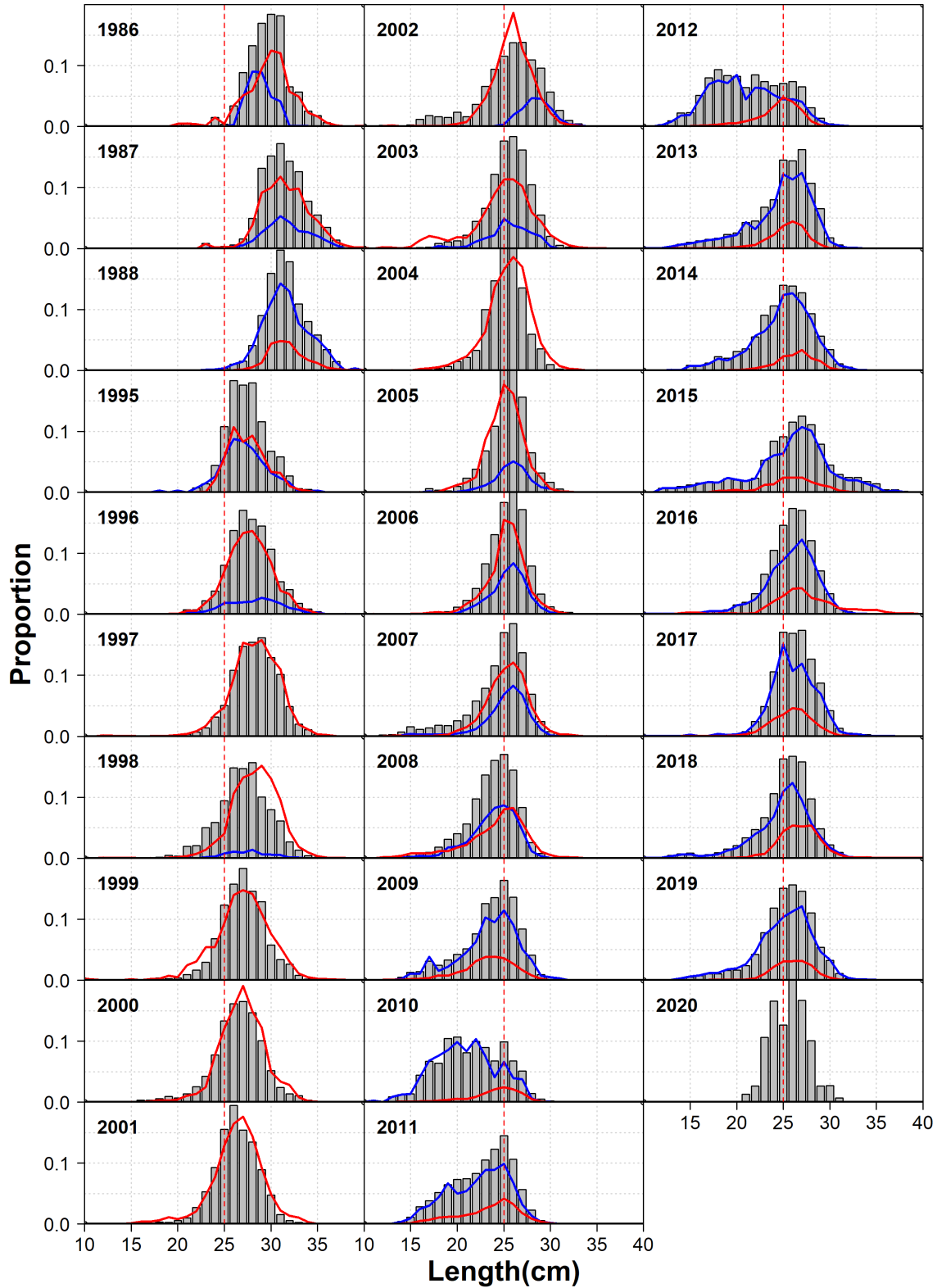


Figure 7. Proportions-at-length of Yellowtail Flounder catches based on commercial and observer samples. The vertical red dashed lines correspond to the 25 cm legal size limit. Overlaid solid lines indicate portions of the total proportions represented by trawler (blue) and seiner (red) catches. Note that for certain years, no trawl samples were available (e.g. 1999 to 2001).

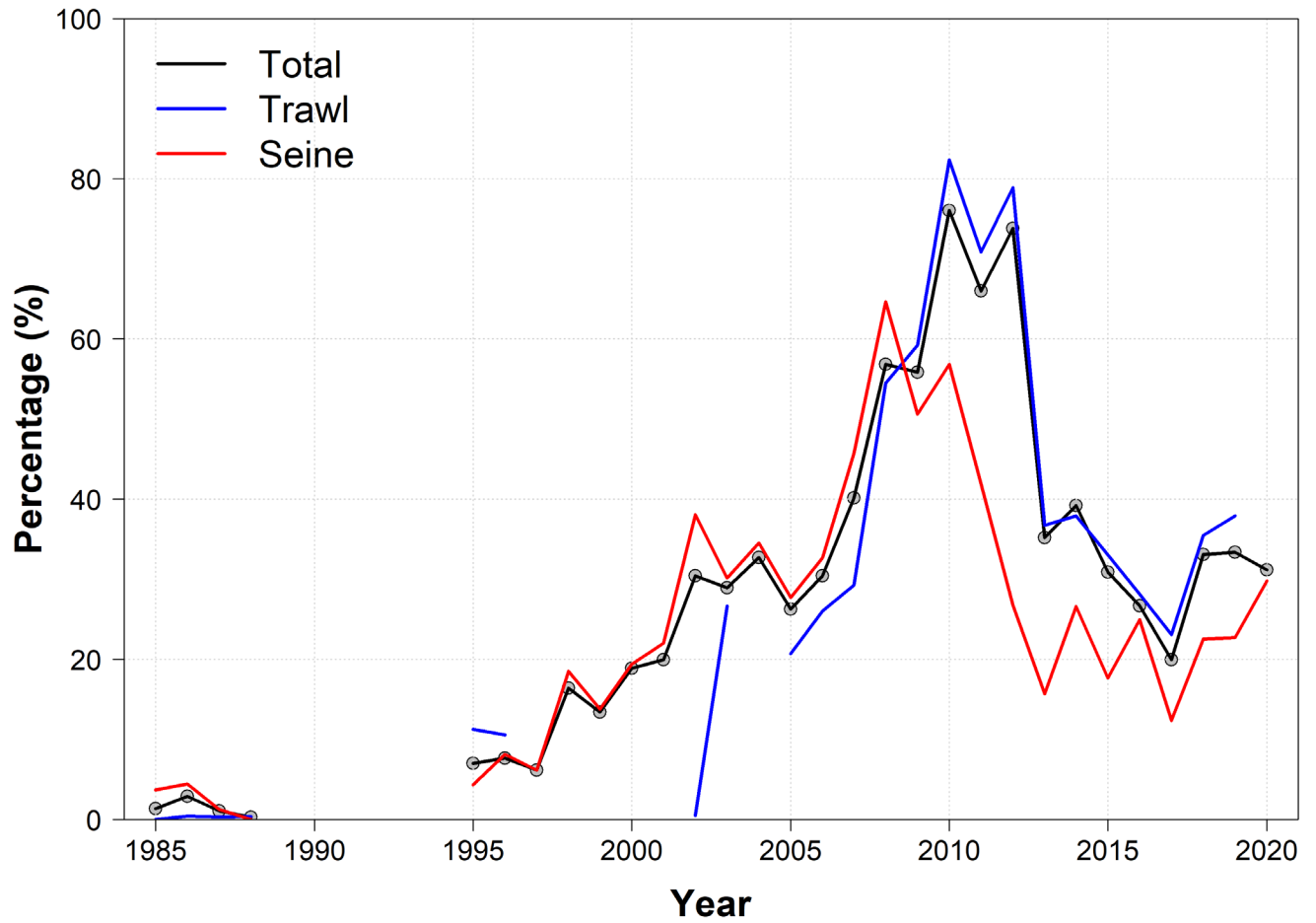


Figure 8. Annual percentages of Yellowtail Flounder catches composed of fish < 25 cm, based on catch-at-length estimates from trawl catches, seine catches, and for gears combined.

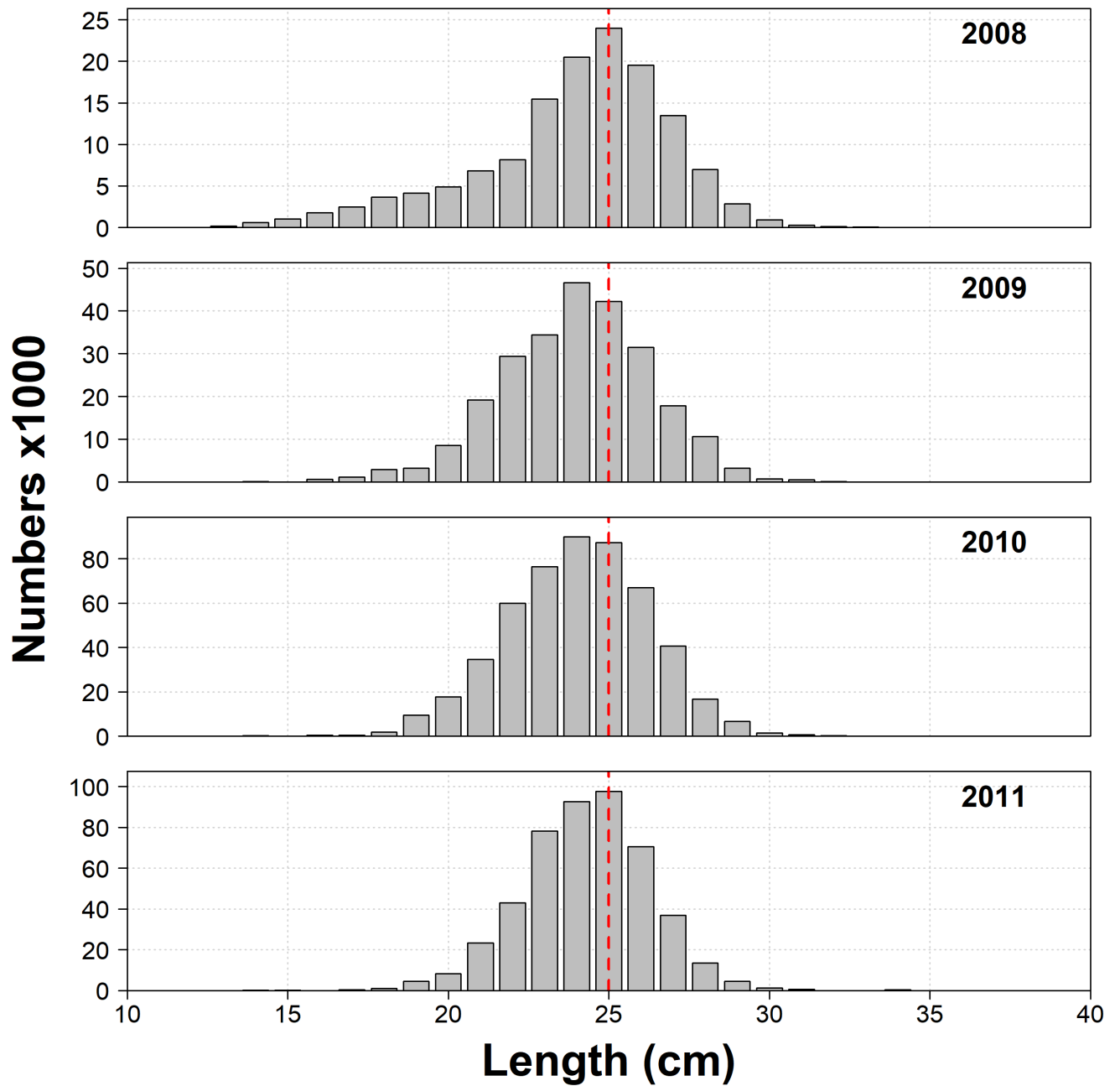


Figure 9. Length frequency distributions from port samples of Yellowtail Flounder in the Magdalen Islands experimental bait fishery, 2008 to 2011.

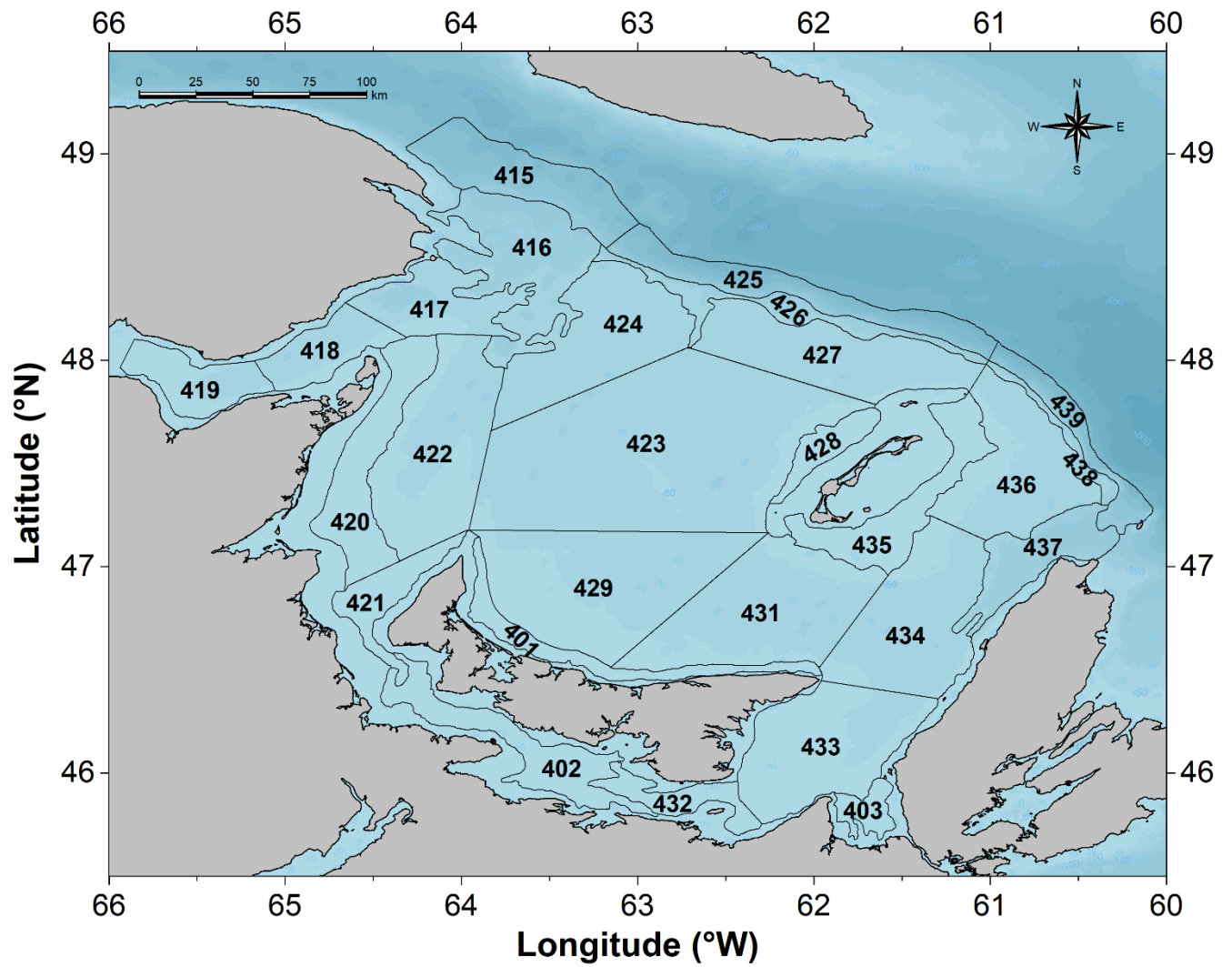


Figure 10. Spatial stratification scheme used in the southern Gulf of St. Lawrence September bottom trawl research vessel and mobile Sentinel surveys.

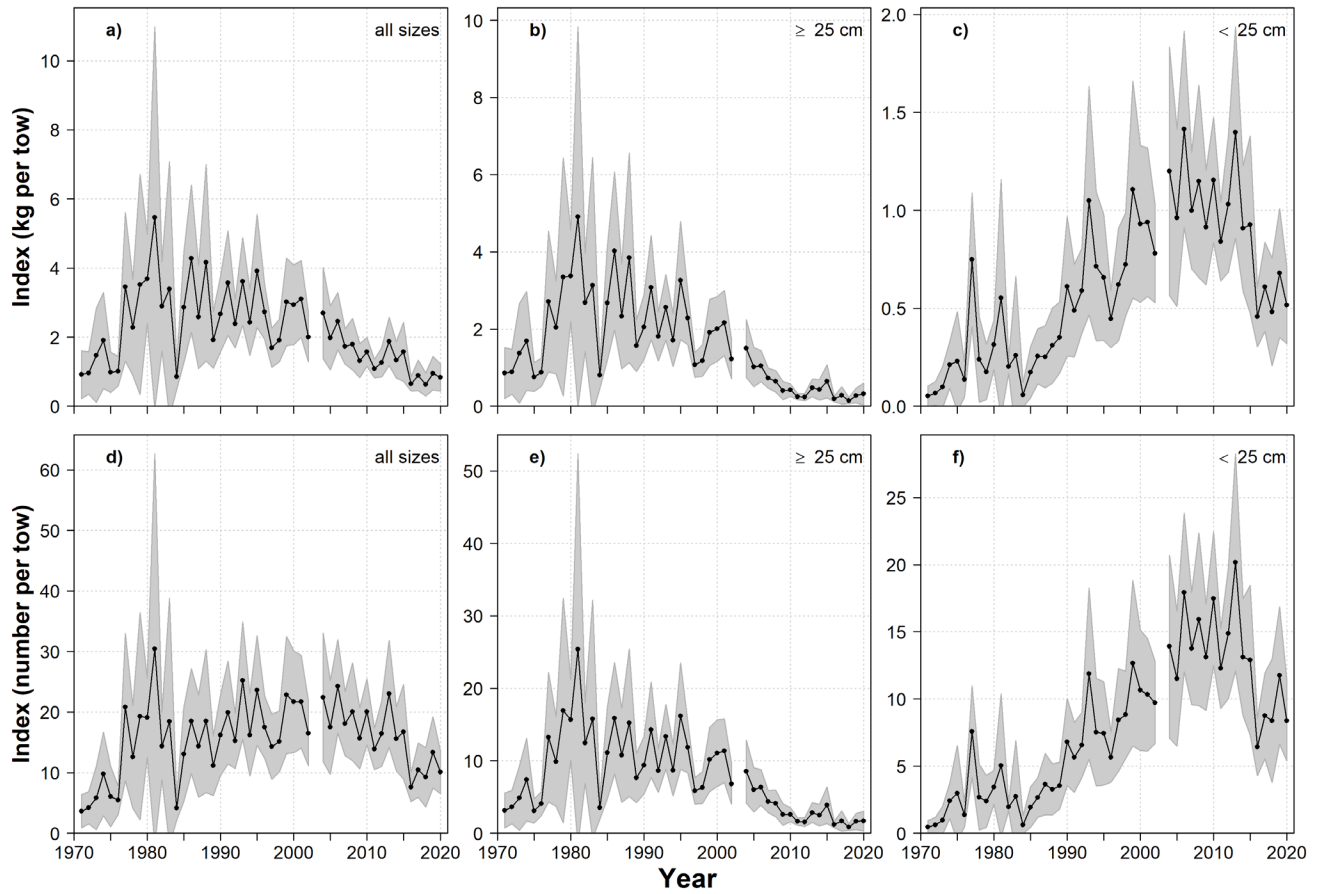


Figure 11. Estimated abundance (kg per tow, upper panel) and biomass (number per tow, lower panel) of Yellowtail Flounder from the southern Gulf of St. Lawrence September bottom trawl survey (strata 415 to 439). Shaded area represents the 95% confidence intervals about the mean values.

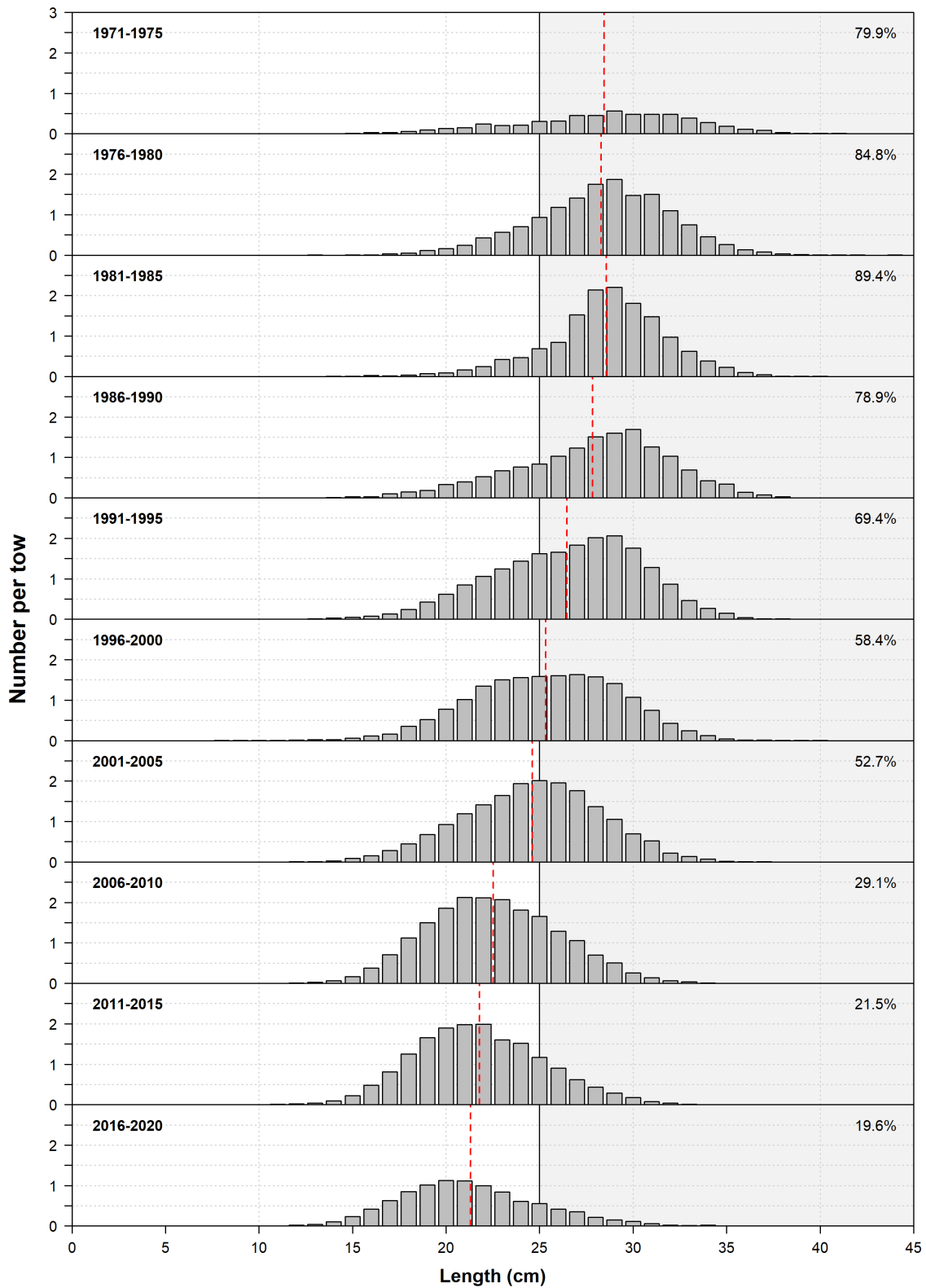


Figure 12. Length frequency distributions of Yellowtail Flounder, expressed in number per tow, from the September bottom trawl survey of the southern Gulf of St. Lawrence, in five year blocks, 1971 to 2020. The dashed vertical line shows the mean length for each period. The percentage of yellowtail greater than or equal to 25 cm in length is also shown.

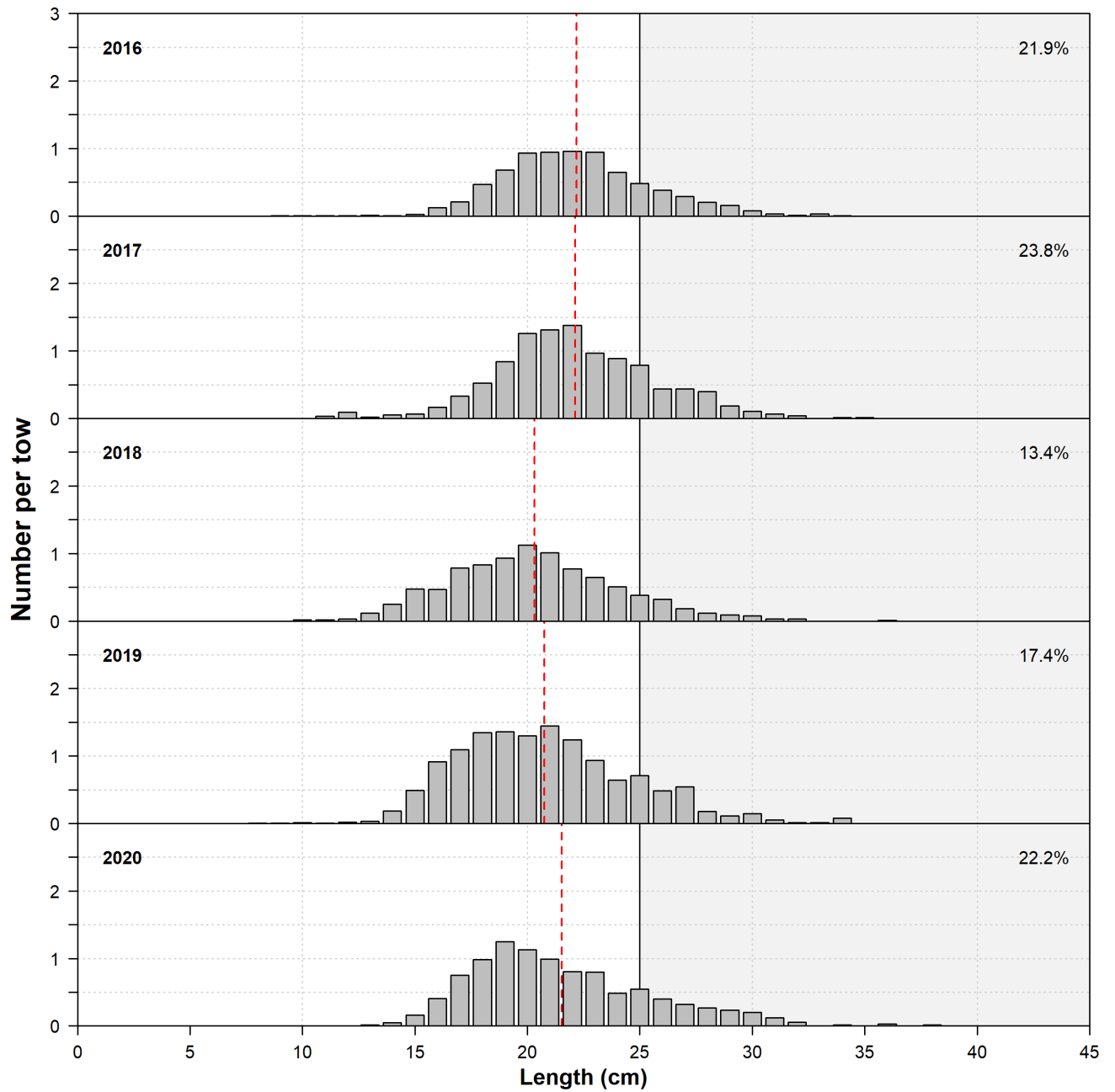


Figure 13. Length frequency distributions of Yellowtail Flounder, expressed in number per tow, from the September bottom trawl survey of the southern Gulf of St. Lawrence, 2016 to 2020.

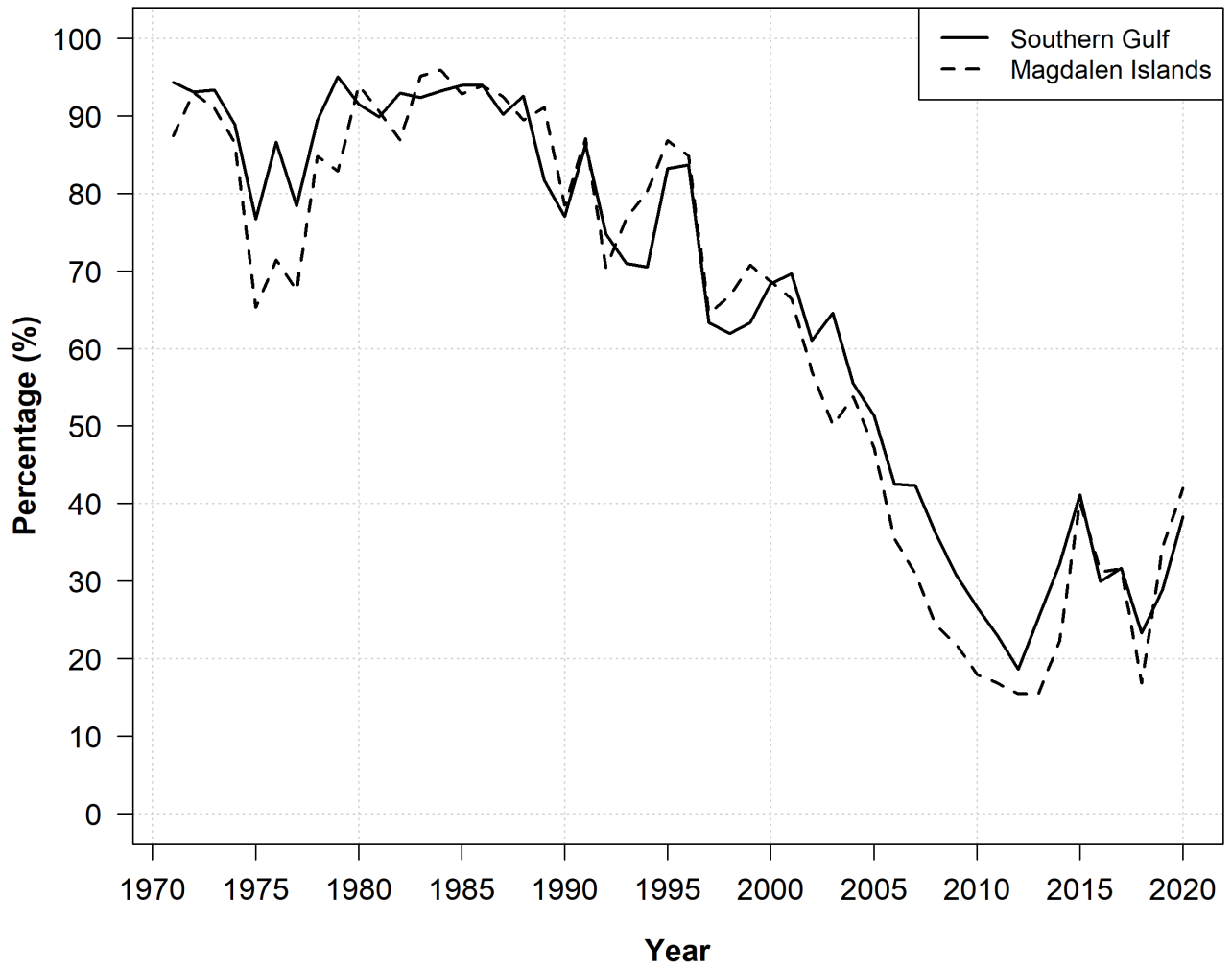


Figure 14. Percentages of Yellowtail Flounder ≥ 25 cm in total length, based on standardized length frequencies, in the September bottom trawl survey catches.

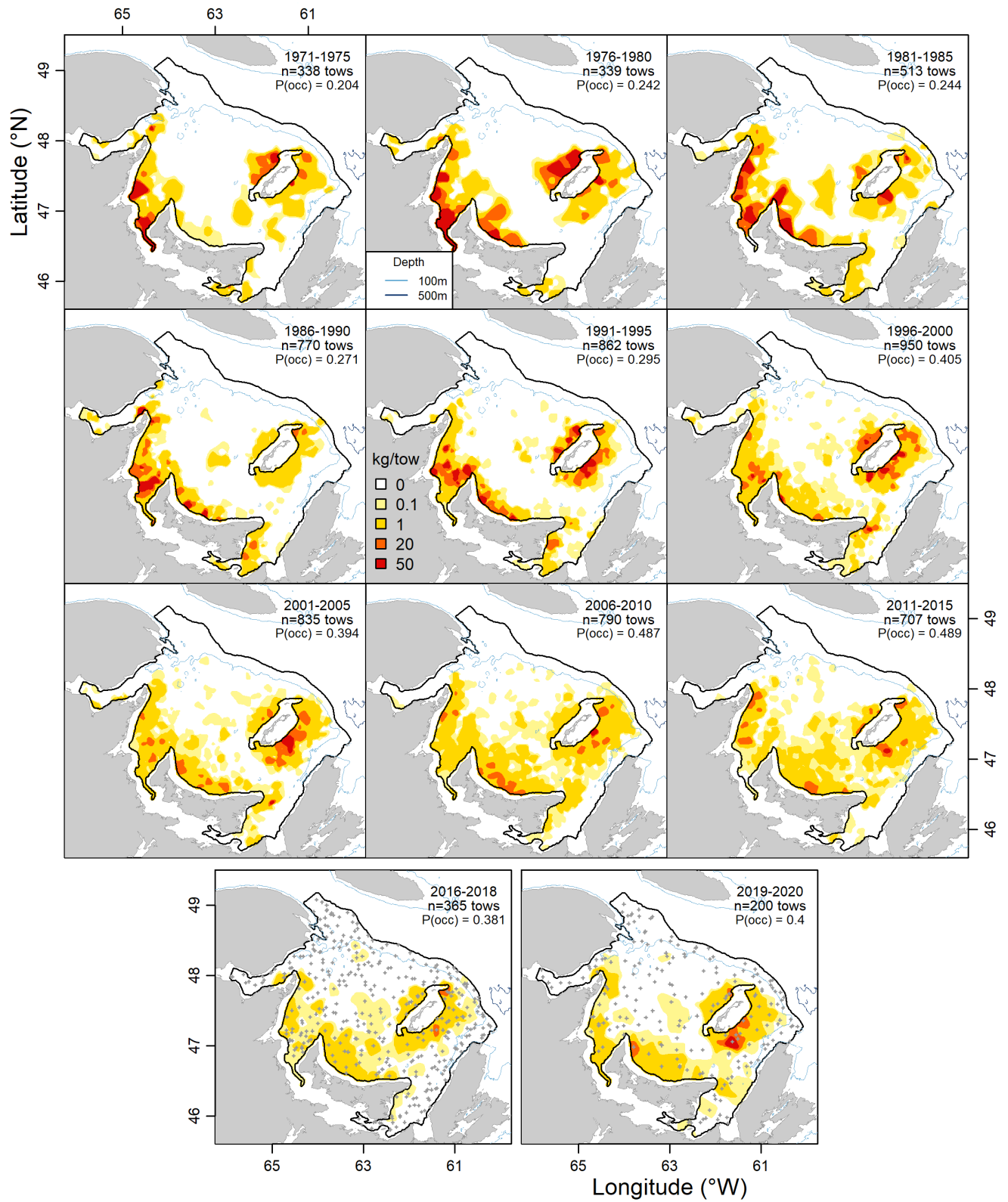


Figure 15. Spatial distribution of September bottom trawl survey catches (in kg per standard tow) of Yellowtail Flounder, 1971 to 2020.

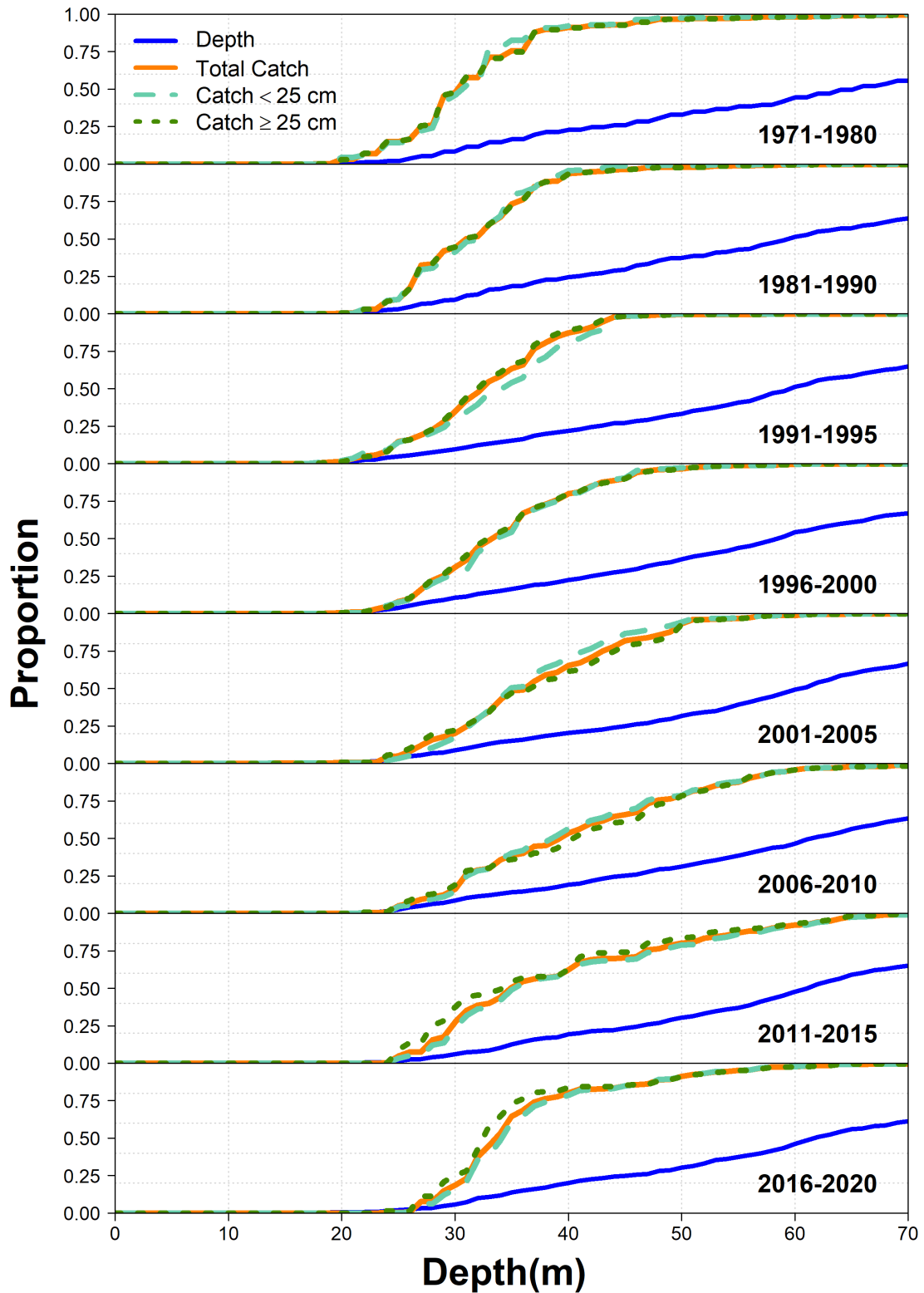


Figure 16. Habitat association curves of Yellowtail Flounder with respect to water depth based on catches from the September bottom trawl survey, 1971 to 2020. Blue lines correspond to the cumulative frequency curves of the survey sampling stations while the other lines correspond to the cumulative catch curves for the total catch (solid dark orange), small fish (long chartreuse dashes) and larger fish (short dark green dashes).

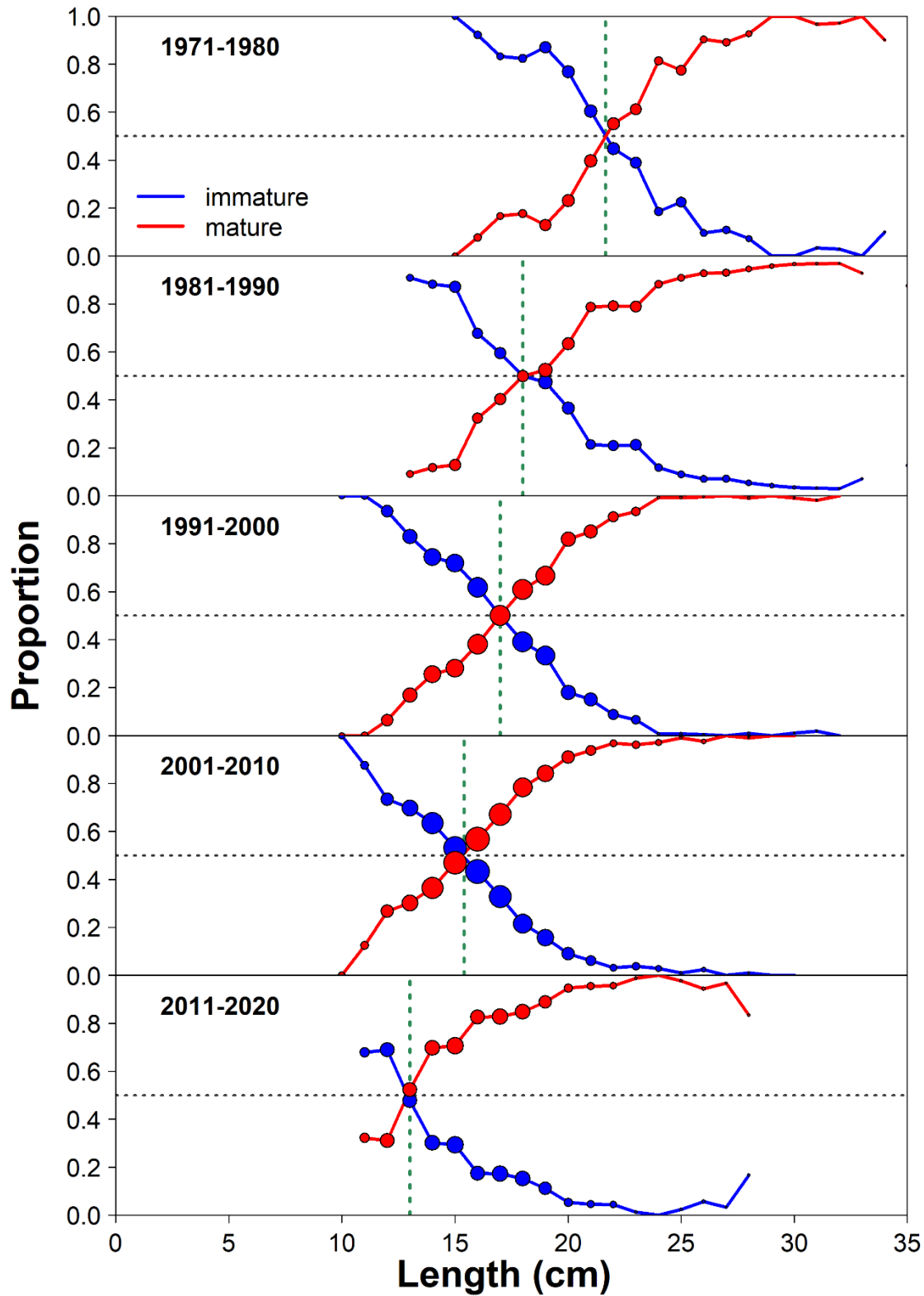


Figure 17. Observed male maturity proportions by length for Yellowtail Flounder based on data from the September RV survey of the southern Gulf of St. Lawrence. The “unsure” category reflects a coding which is meant to be mature, but for which there is some level of misclassification expected by on-board Science samplers. Time periods which are problematic are 1983-1989 and 1990-1997.

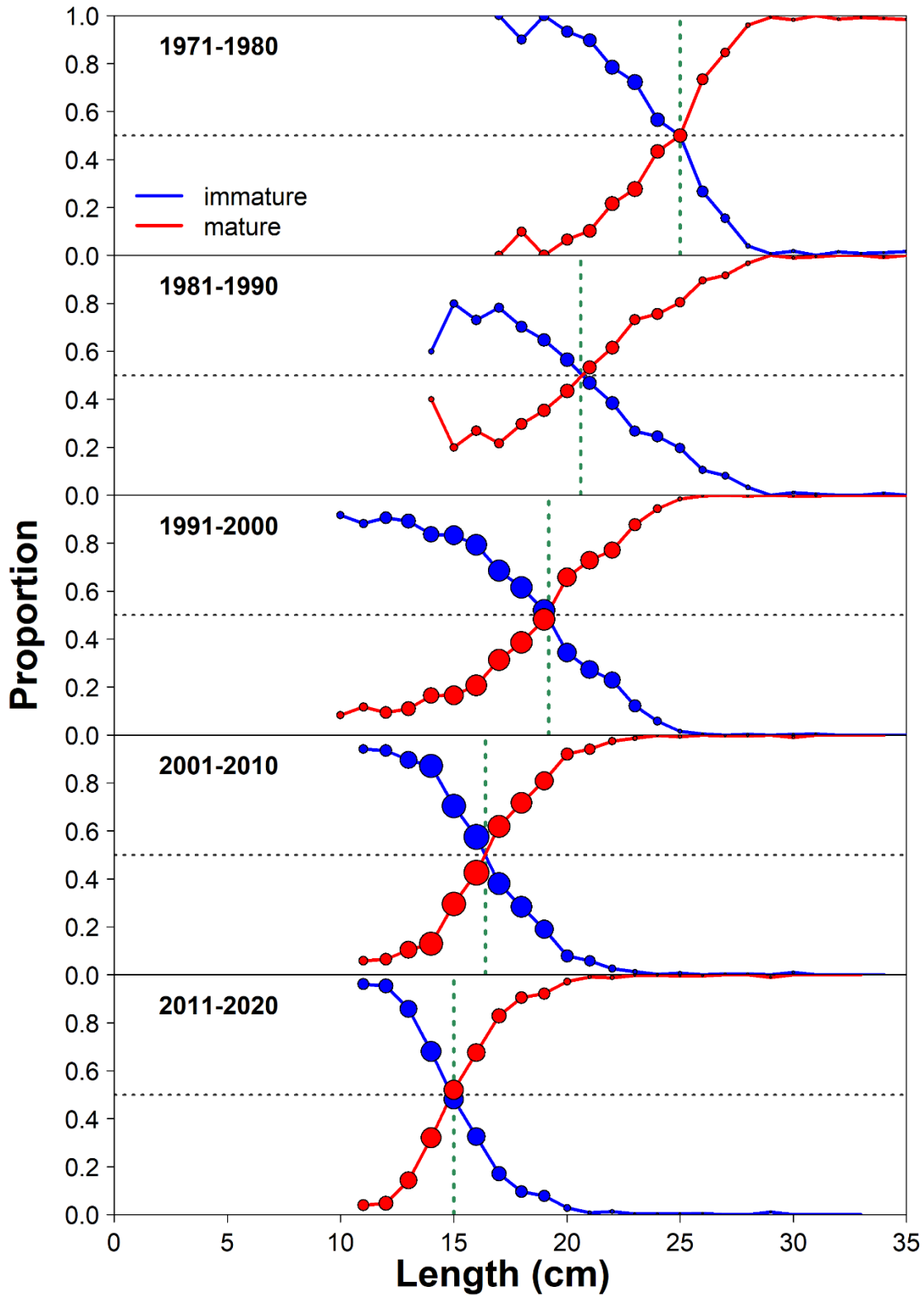


Figure 18. Observed female maturity proportions by length for Yellowtail Flounder based on data from the September RV survey of the southern Gulf of St. Lawrence. The “unsure” category reflects a coding which is meant to be mature, but for which there is some level of misclassification expected by on-board Science samplers. Time periods which are problematic are 1983-1989 and 1990-1997.

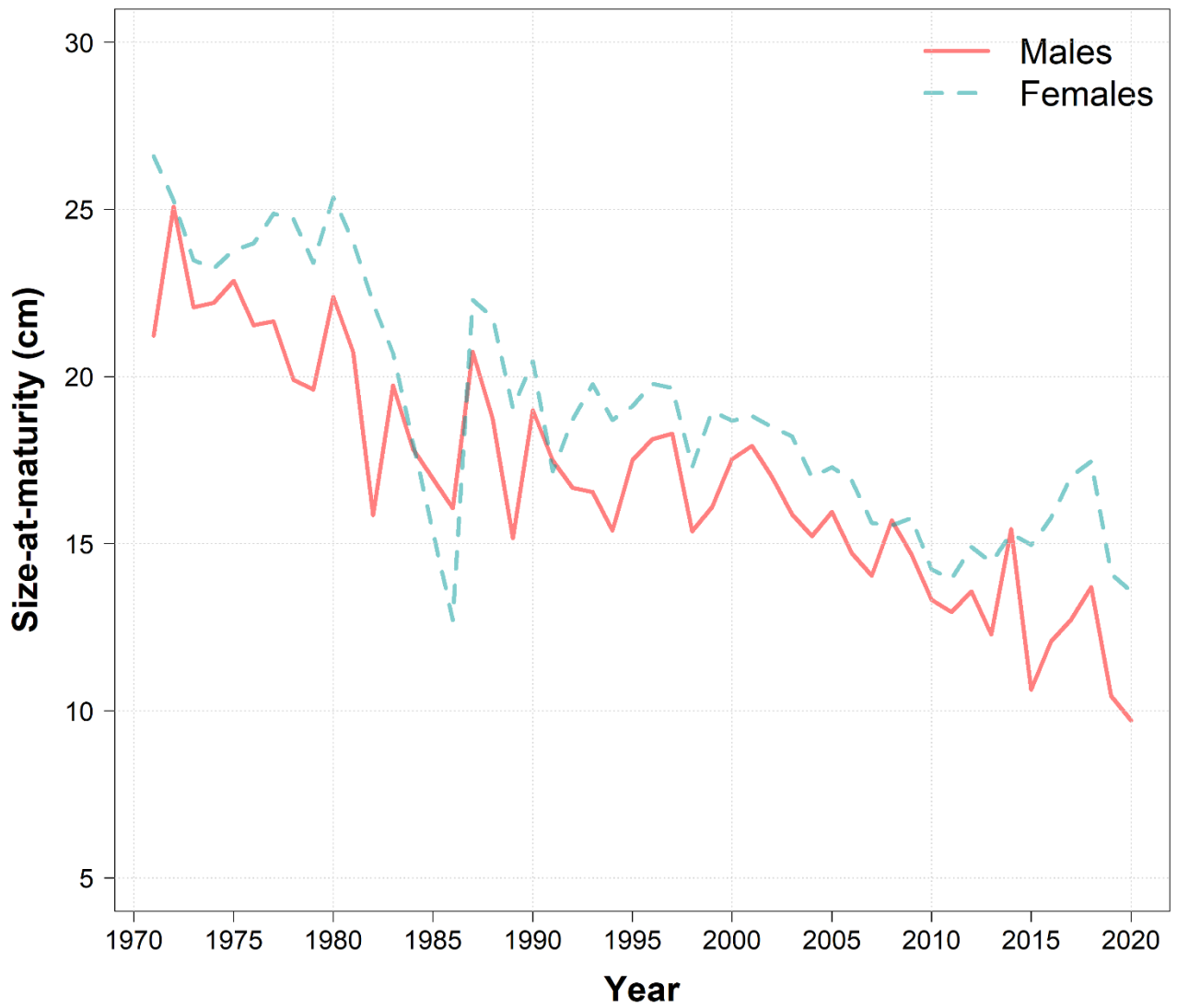


Figure 19. Length (cm) at 50% maturity of Yellowtail Flounder estimated from September bottom trawl survey biological data by year and sex, 1971 to 2020.

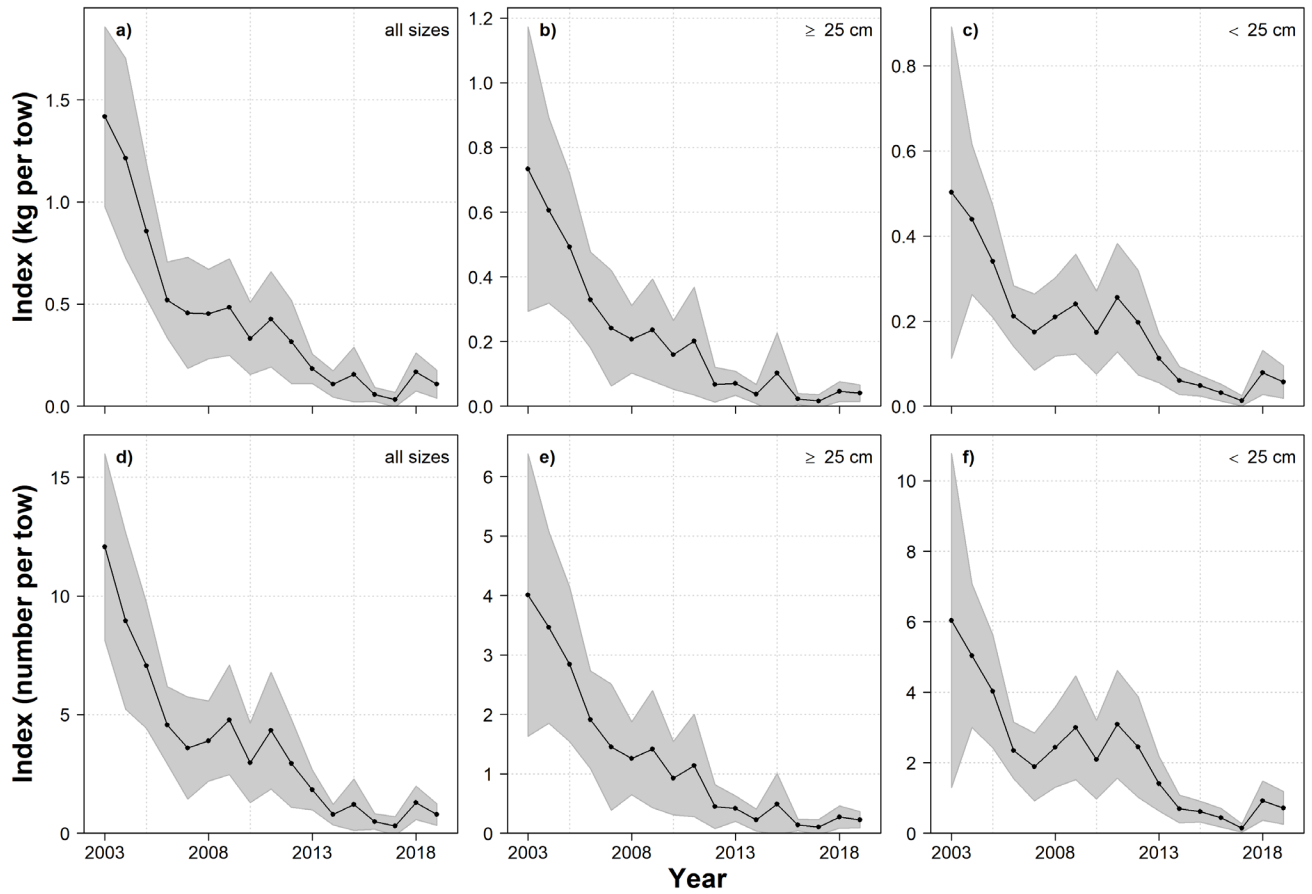


Figure 20. Yellowtail Flounder abundance (number per tow; top panel) and biomass (kg per tow; bottom panel) indices from the southern Gulf of St. Lawrence mobile Sentinel survey (strata 401-439). Shaded area represents the 95% confidence intervals about the mean values.

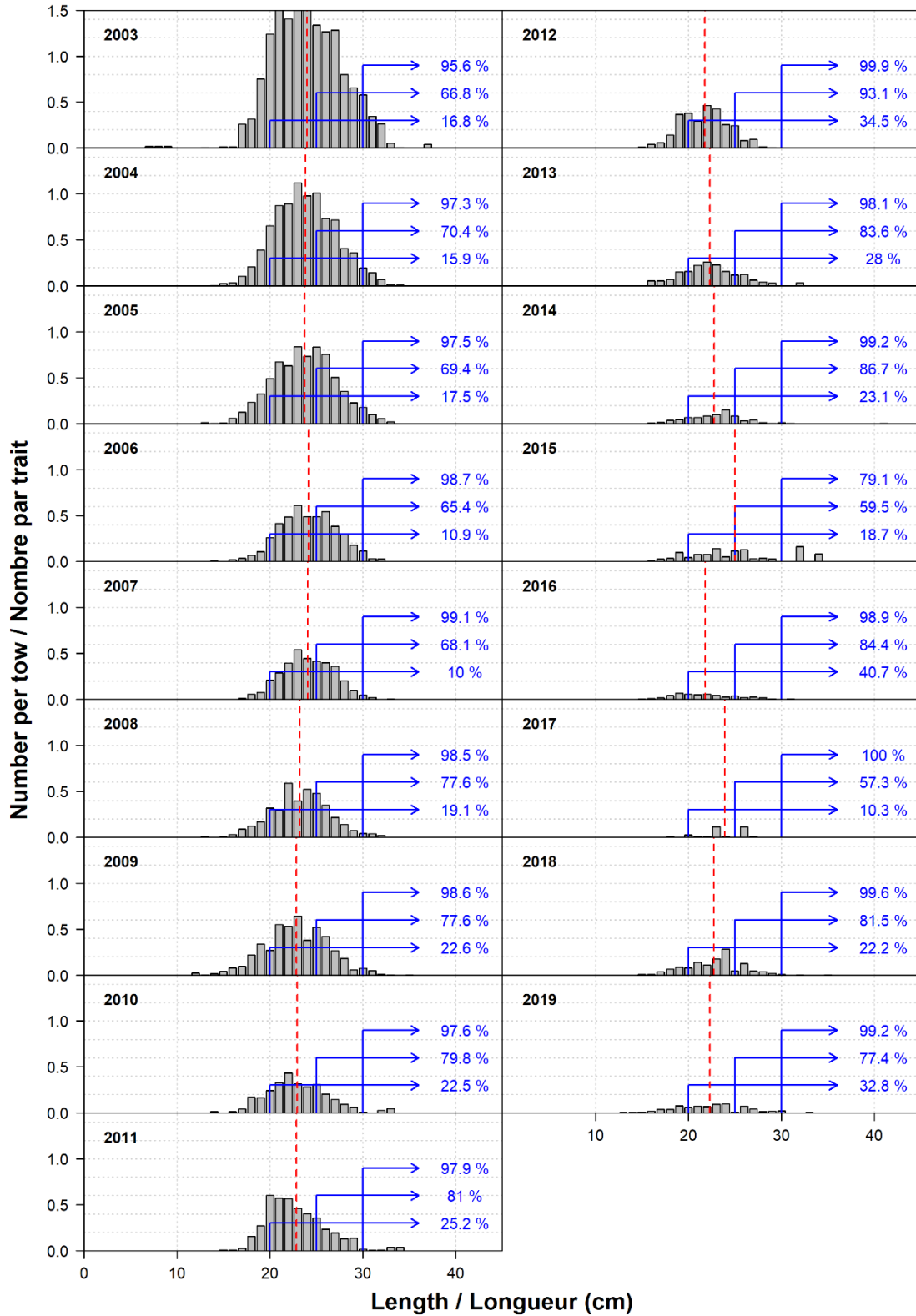


Figure 21. Mobile Sentinel survey length-frequency distributions (number per tow) of Yellowtail Flounder, 2003 to 2019. Blue lines show the cumulative percentile values at 20 cm, 25 cm and 30 cm while the red dashed line shows the location of mean value.

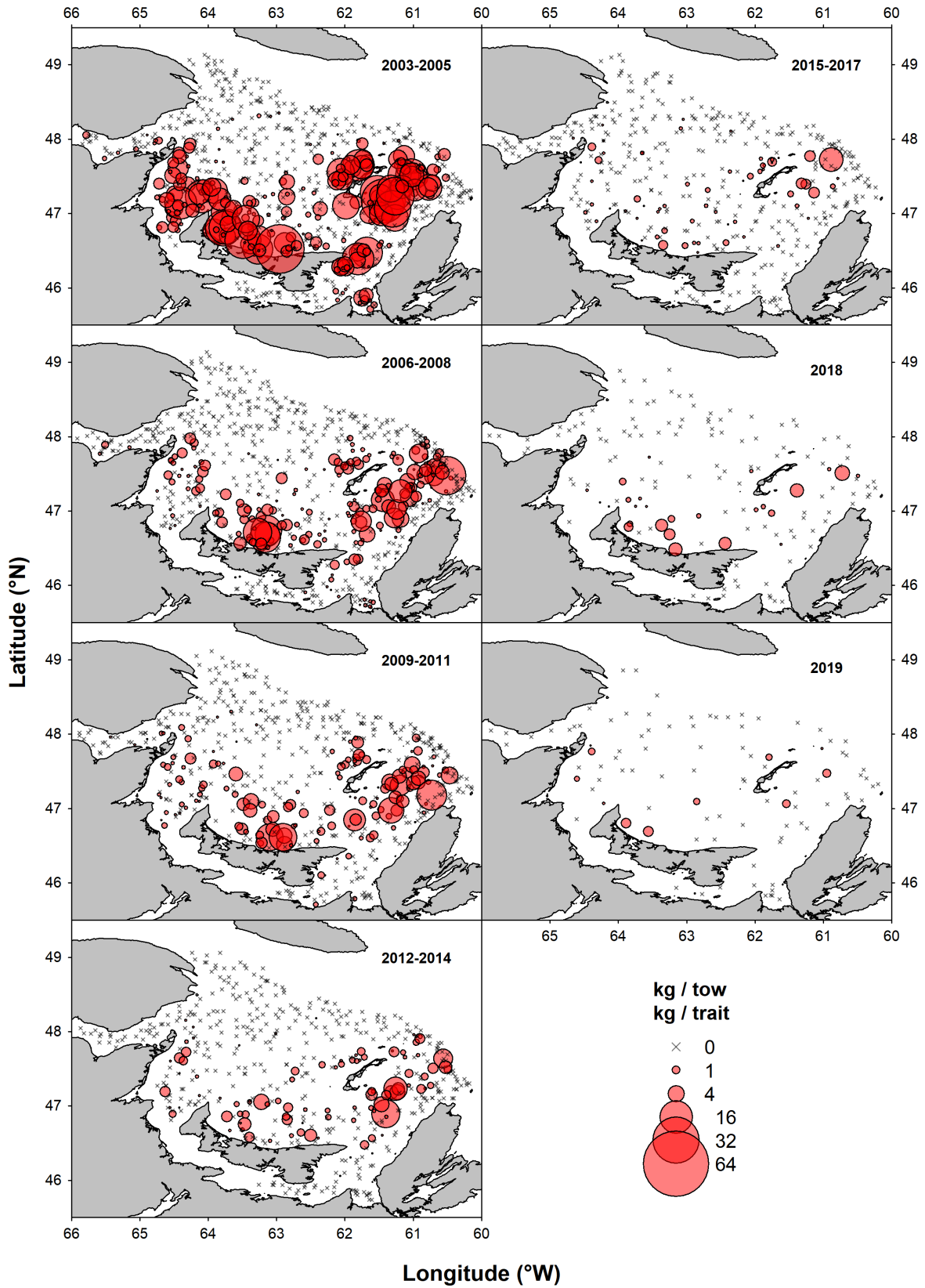


Figure 22. Spatial distribution of standardized mobile Sentinel survey catches (kg per standard tow) of Yellowtail Flounder, 2003 to 2019.

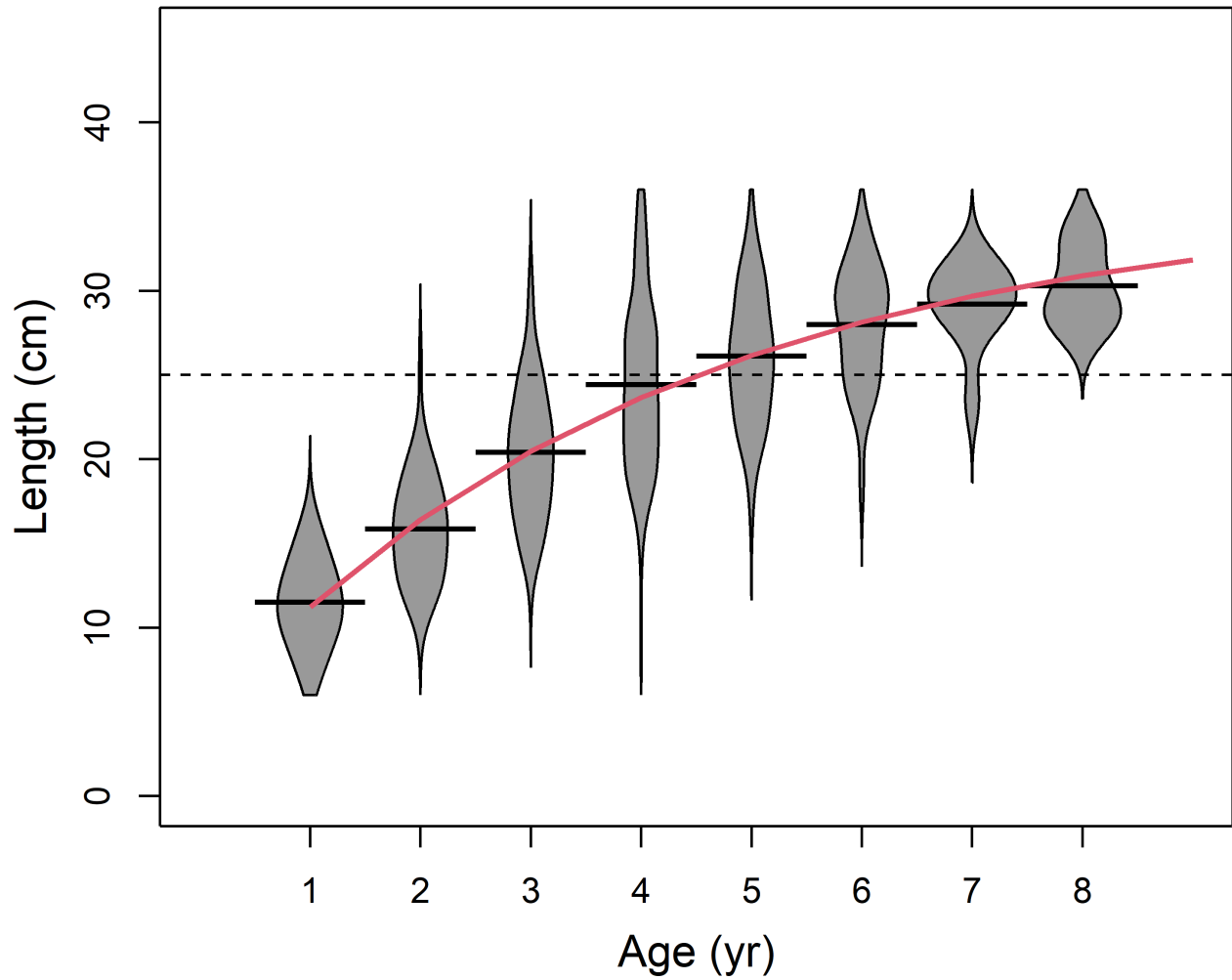


Figure 23. Length at age of Yellowtail Flounder sampled from the southern Gulf of St. Lawrence in September 2000, 2007, 2013, 2015 and 2017. The shaded area describes the distribution of length at age and the horizontal lines indicate the mean length at age. The red line is the fit of a von Bertalanffy model to these data. The dashed horizontal line shows the division (25 cm) between the two length groups used in the population modelling.

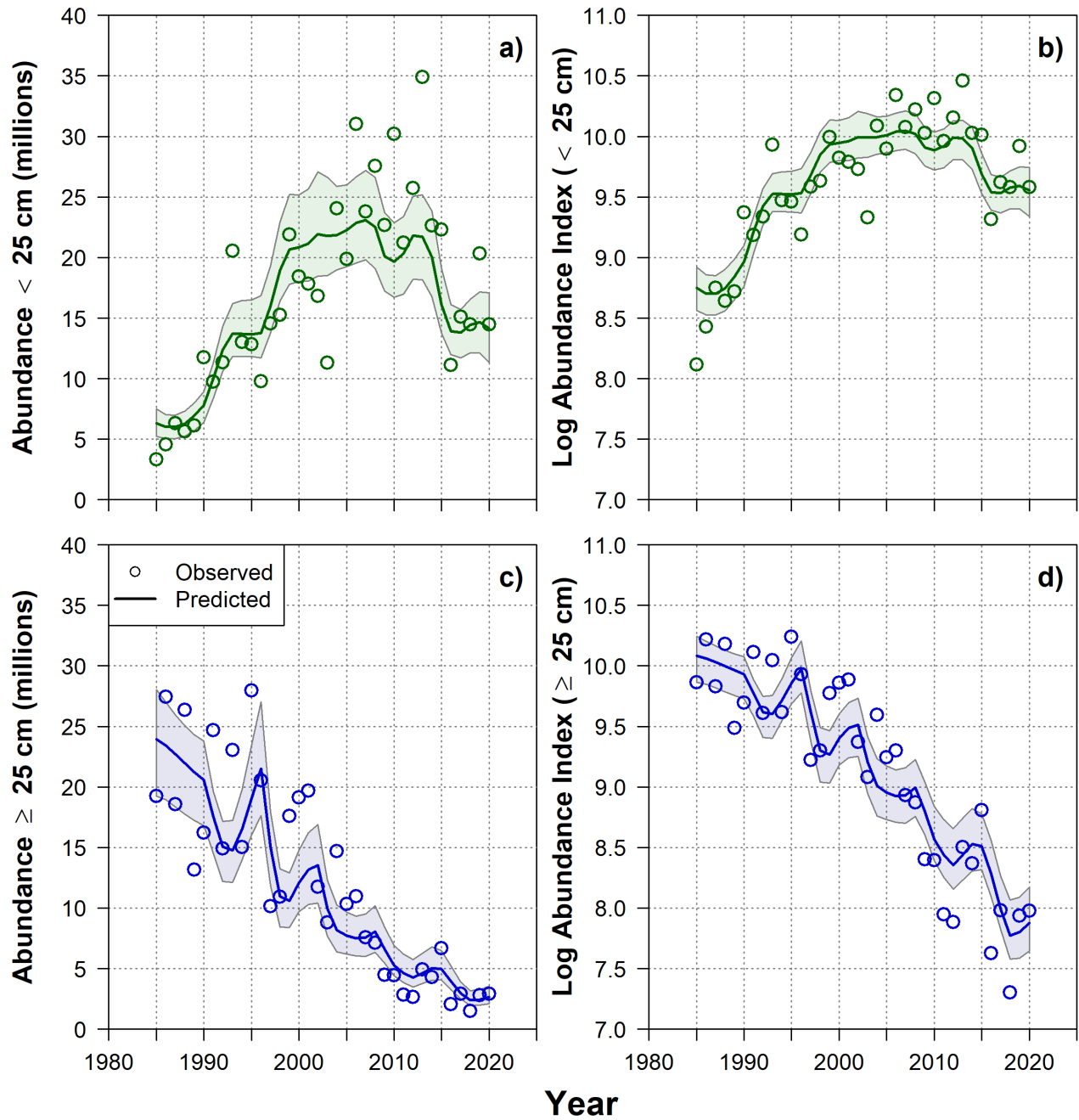


Figure 24. Fit of the population model to the RV abundance indices for small (panels a and b) and large (panels c and d) Yellowtail Flounder at the natural log scale (panels b and d; the scale used in the fitting) and the natural scale (panels a and c). Circles show the observed indices. Lines and shading show the median predicted value and the corresponding 95% confidence interval.

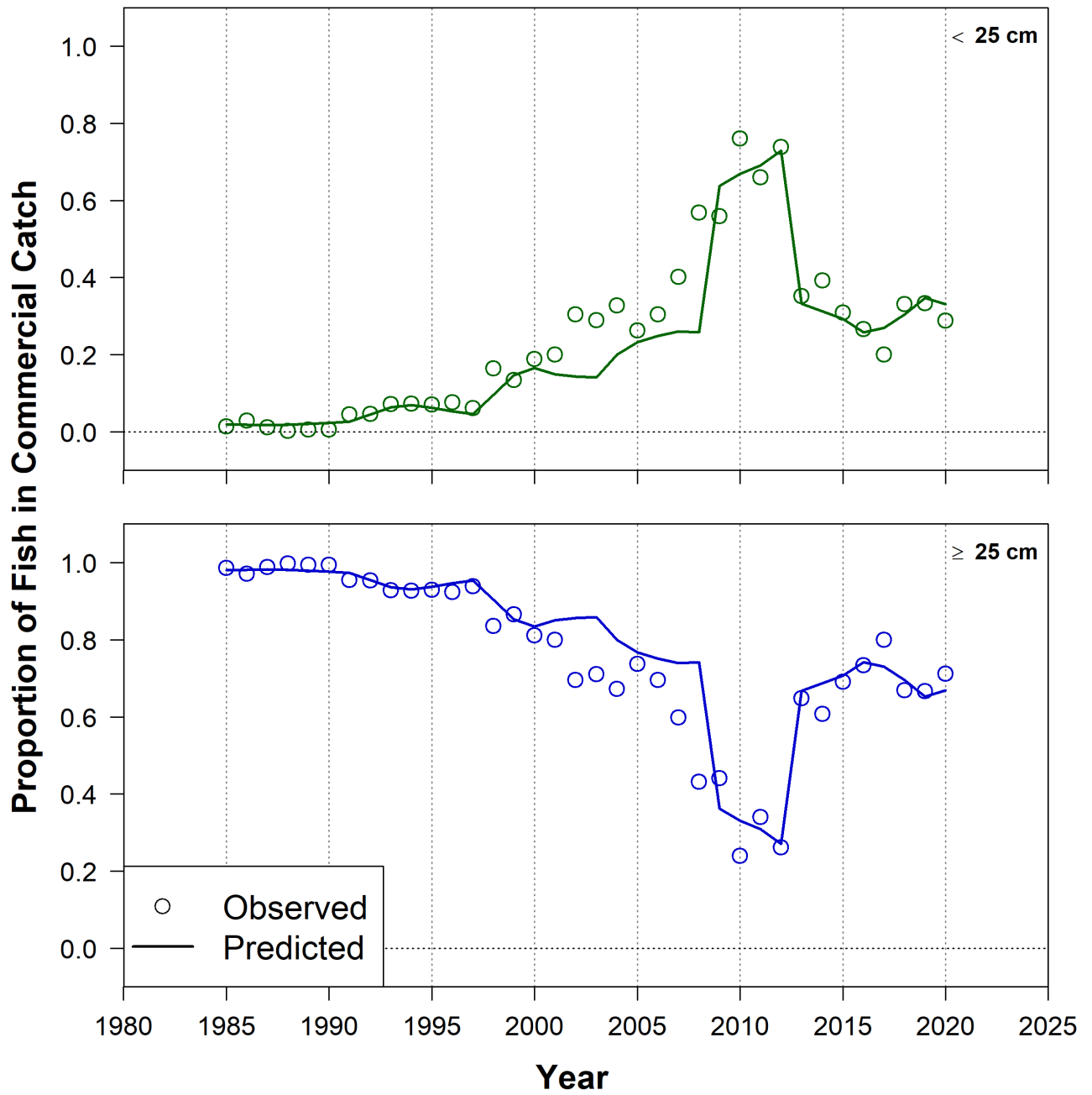


Figure 25. Observed (circles) and predicted (line) proportion of small (<25 cm) and large fish (≥25 cm) in the fishery catches of Yellowtail Flounder.

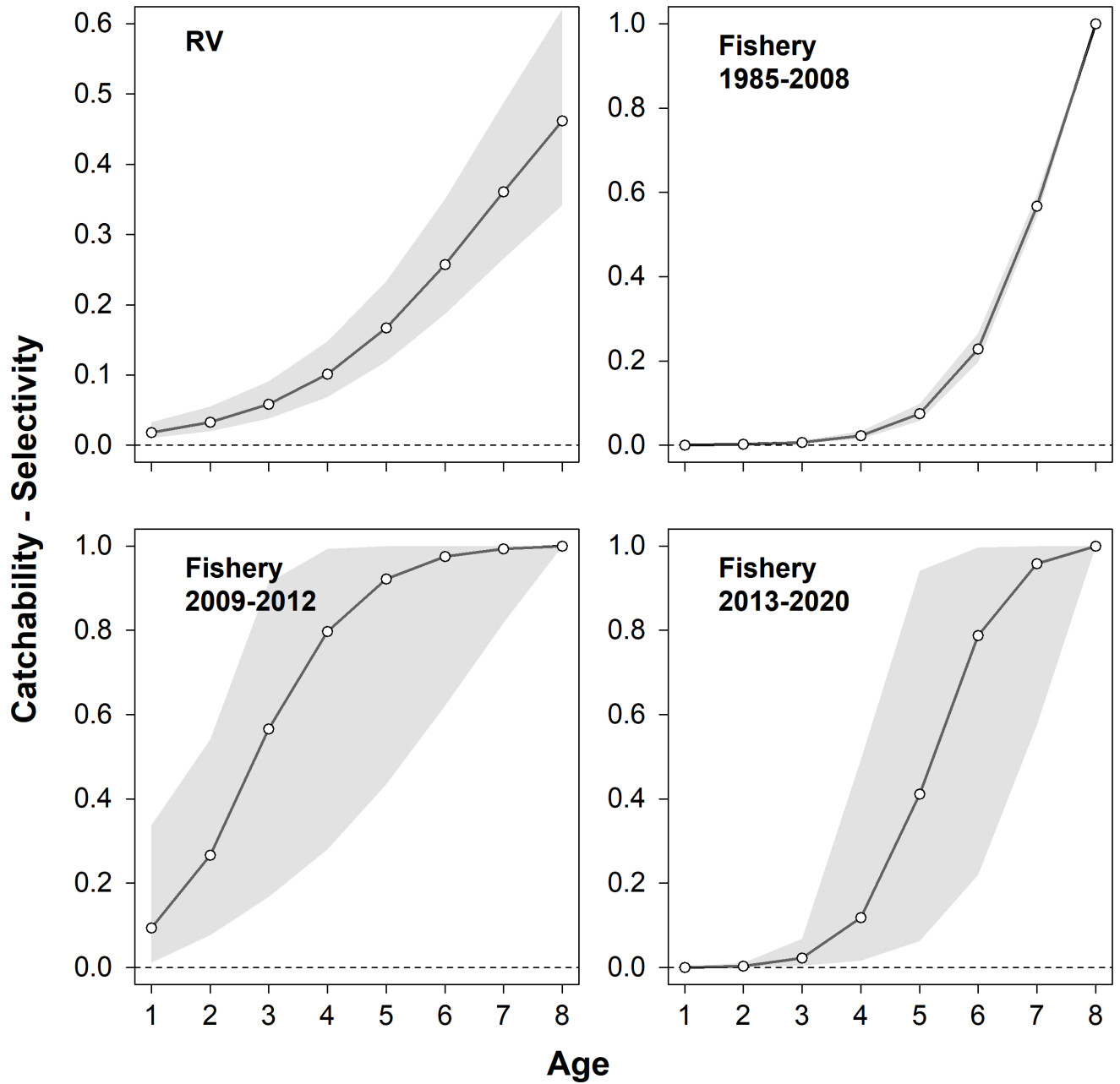


Figure 26. Estimated catchability at age to the RV survey and fishery selectivity in three time periods for Yellowtail Flounder in the southern Gulf of St. Lawrence. Lines show median estimate and shading the 95% confidence interval.

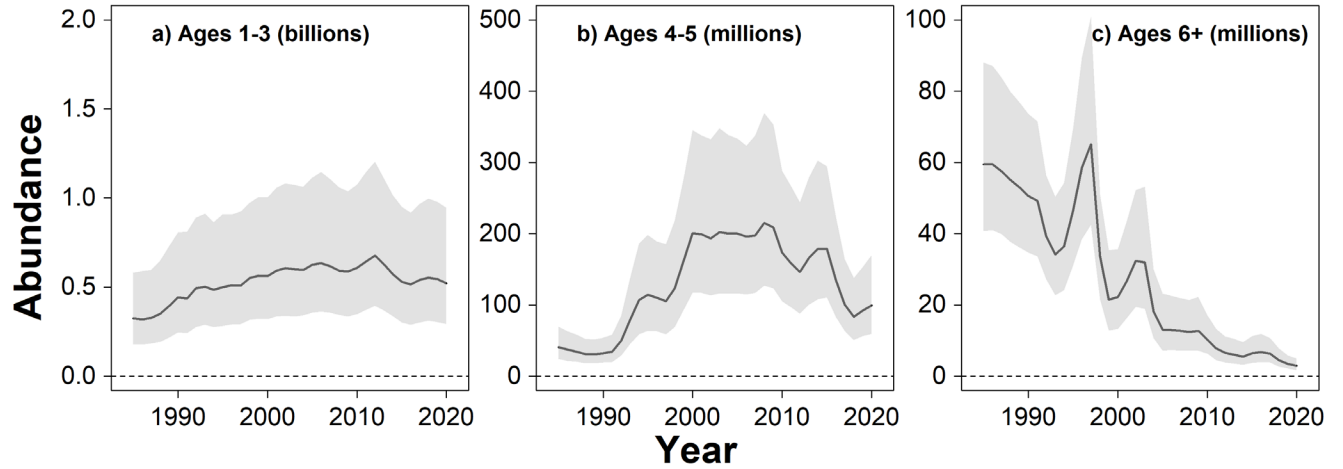


Figure 27. Estimated abundances of three age groups of Yellowtail Flounder in the Southern Gulf of St. Lawrence. Lines show the median values and shading their 95% confidence interval.

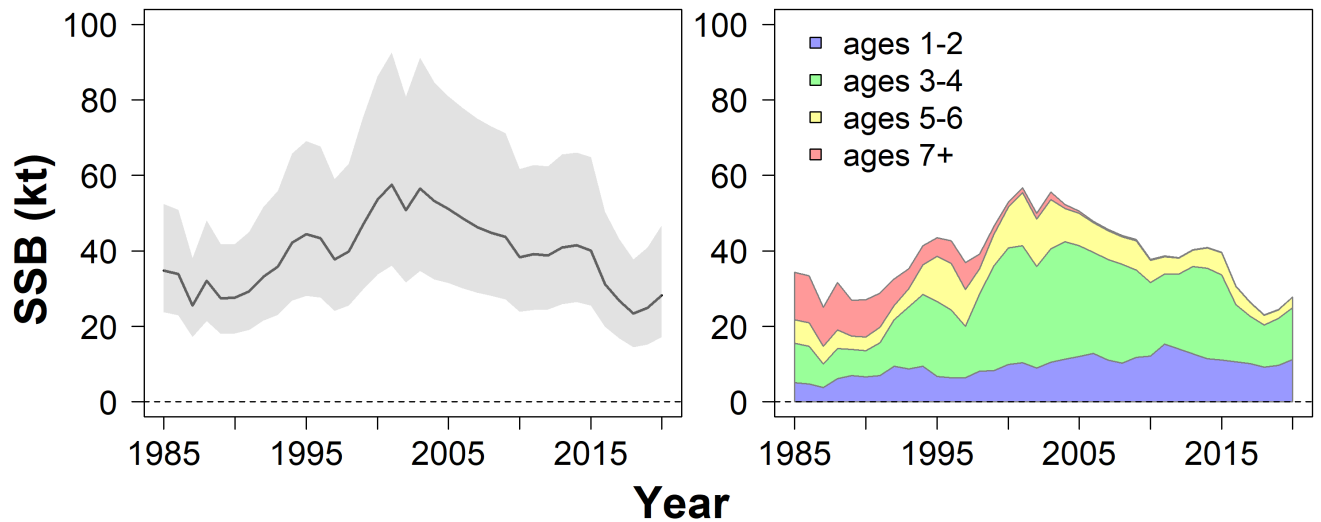


Figure 28. Estimated spawning stock biomass (SSB, kt) of Yellowtail Flounder in the southern Gulf of St. Lawrence (left panel) and its estimated age composition (right panel). In the left panel, lines show the median estimate and shading its 95% confidence interval.

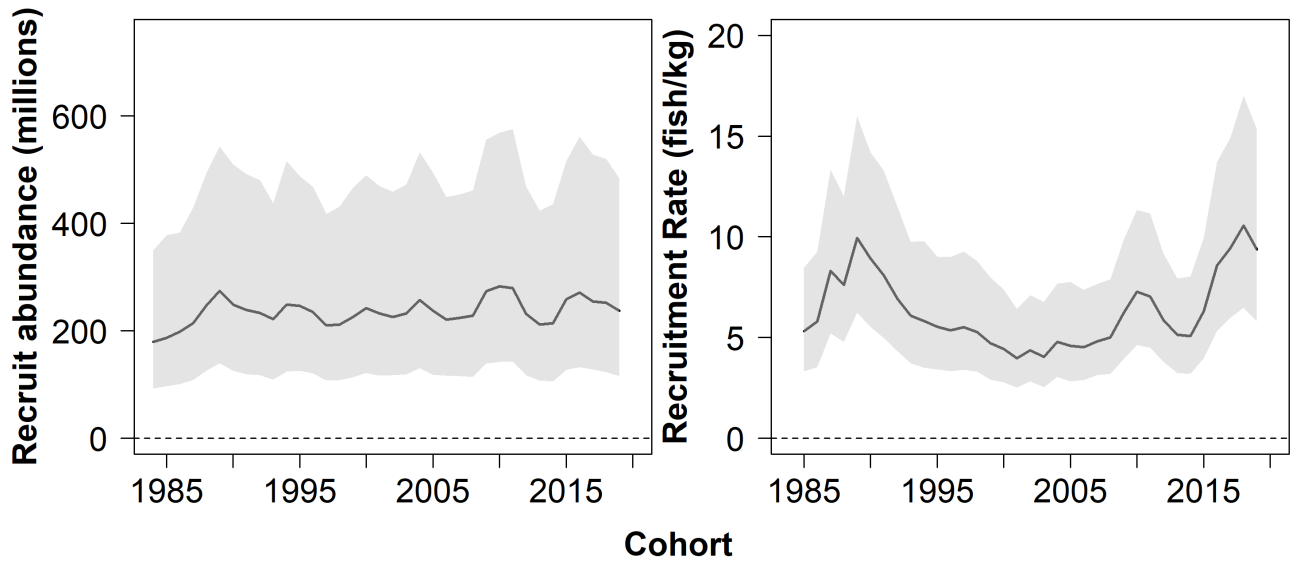


Figure 29. Estimated recruit abundance (millions) and recruitment rate (recruits/SSB) of Yellowtail Flounder in the southern Gulf of St. Lawrence. Lines and shading show the median and its 95% confidence interval.

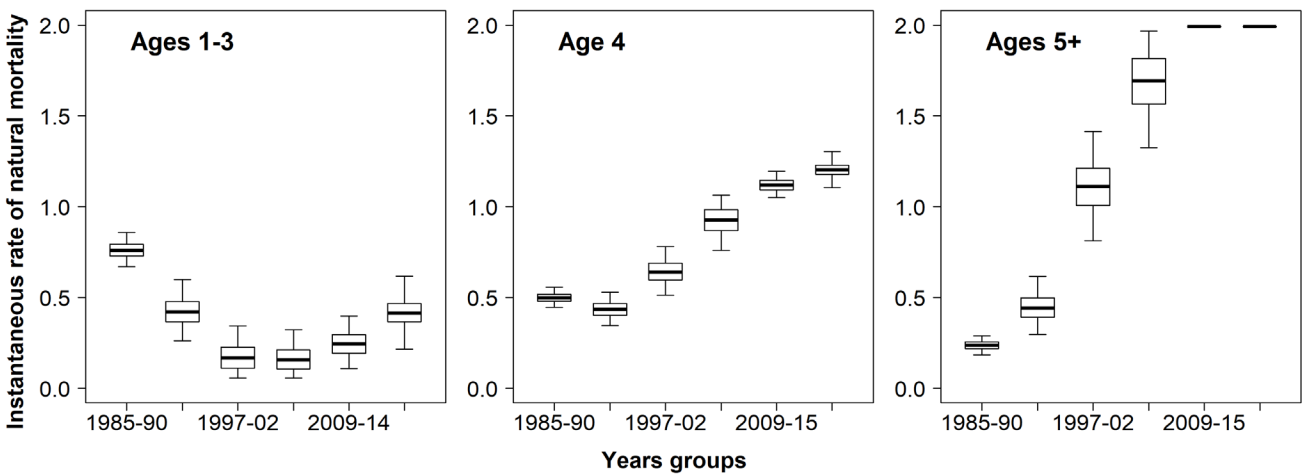


Figure 30. Estimated natural mortality of three age groups of Yellowtail Flounder during five time periods in the southern Gulf of St. Lawrence. Horizontal lines show the median, boxes the interquartile range (25 to 75 percentiles) and error bars the 95% confidence interval.

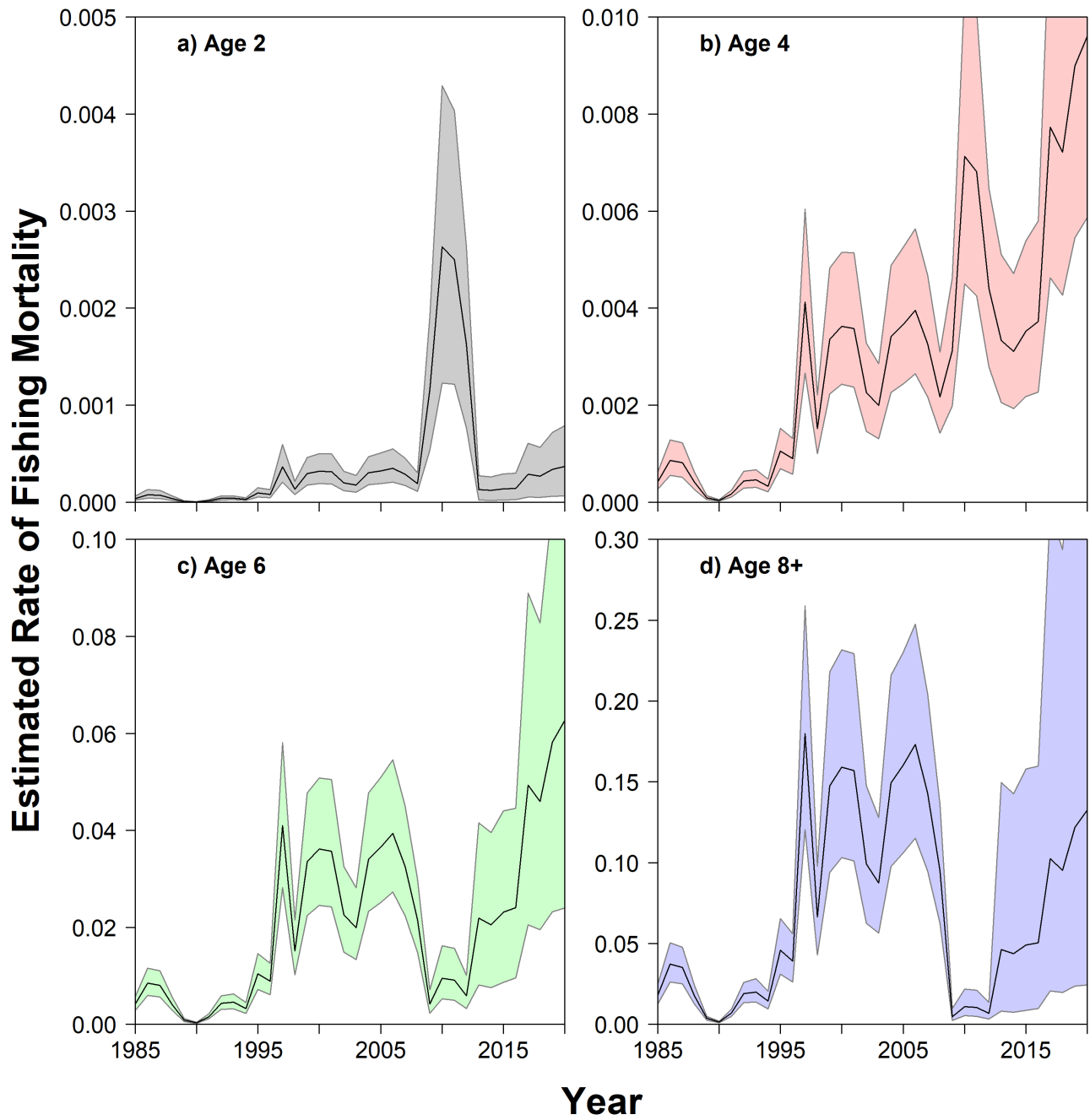


Figure 31. Estimated fishing mortality of four ages of Yellowtail Flounder in the southern Gulf of St. Lawrence. Solid lines and shading indicate the median and 95% confidence interval based on MCMC sampling.

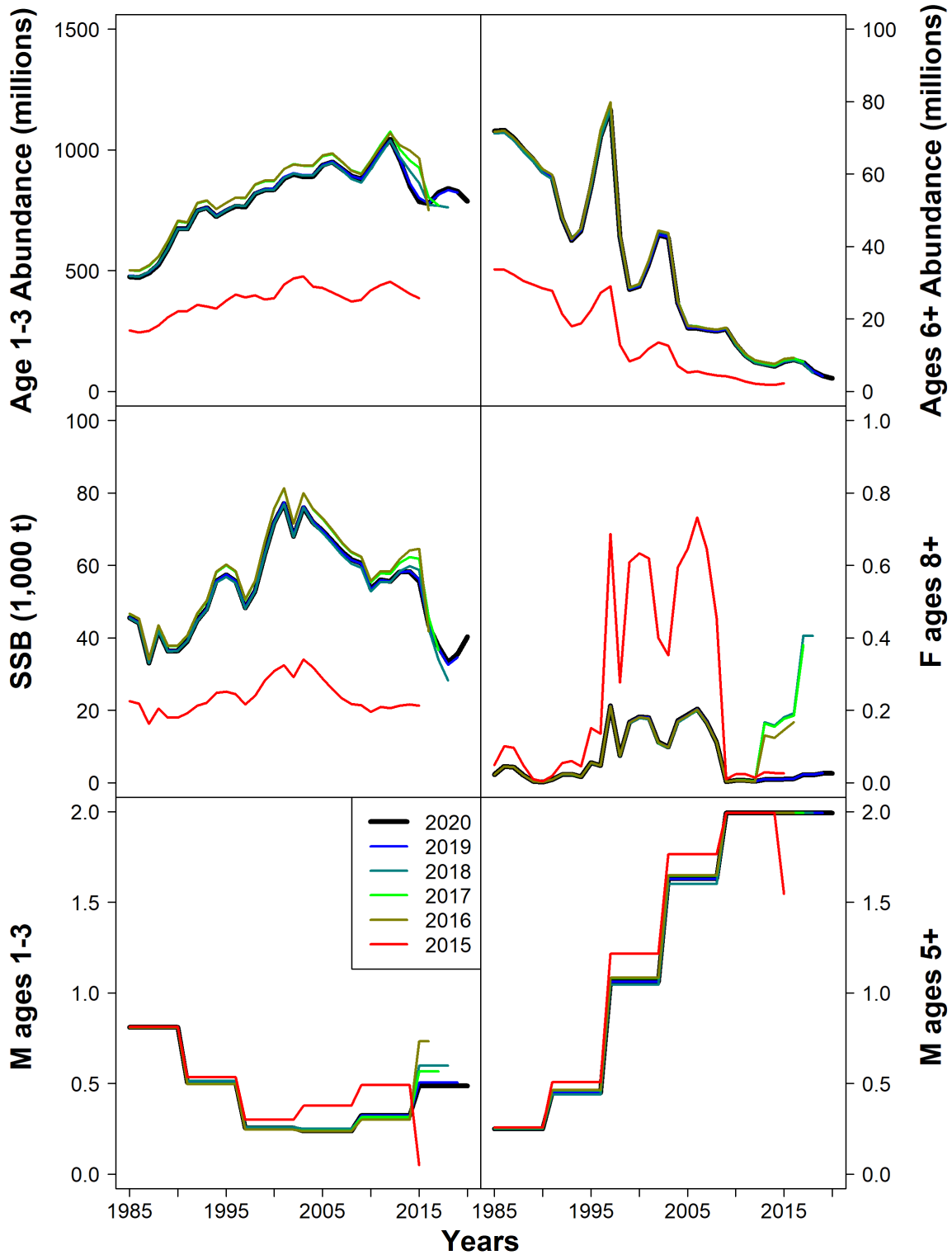


Figure 32. Retrospective analysis of a Yellowtail Flounder population model estimates of abundance (upper row figures), biomass (middle left figure), fishing mortality at age 8+ years (middle right figure), and natural mortality (lower row figures). This analysis shows how estimates change as years of data are added or removed. Line colour indicates the last year of data included in the analysis.

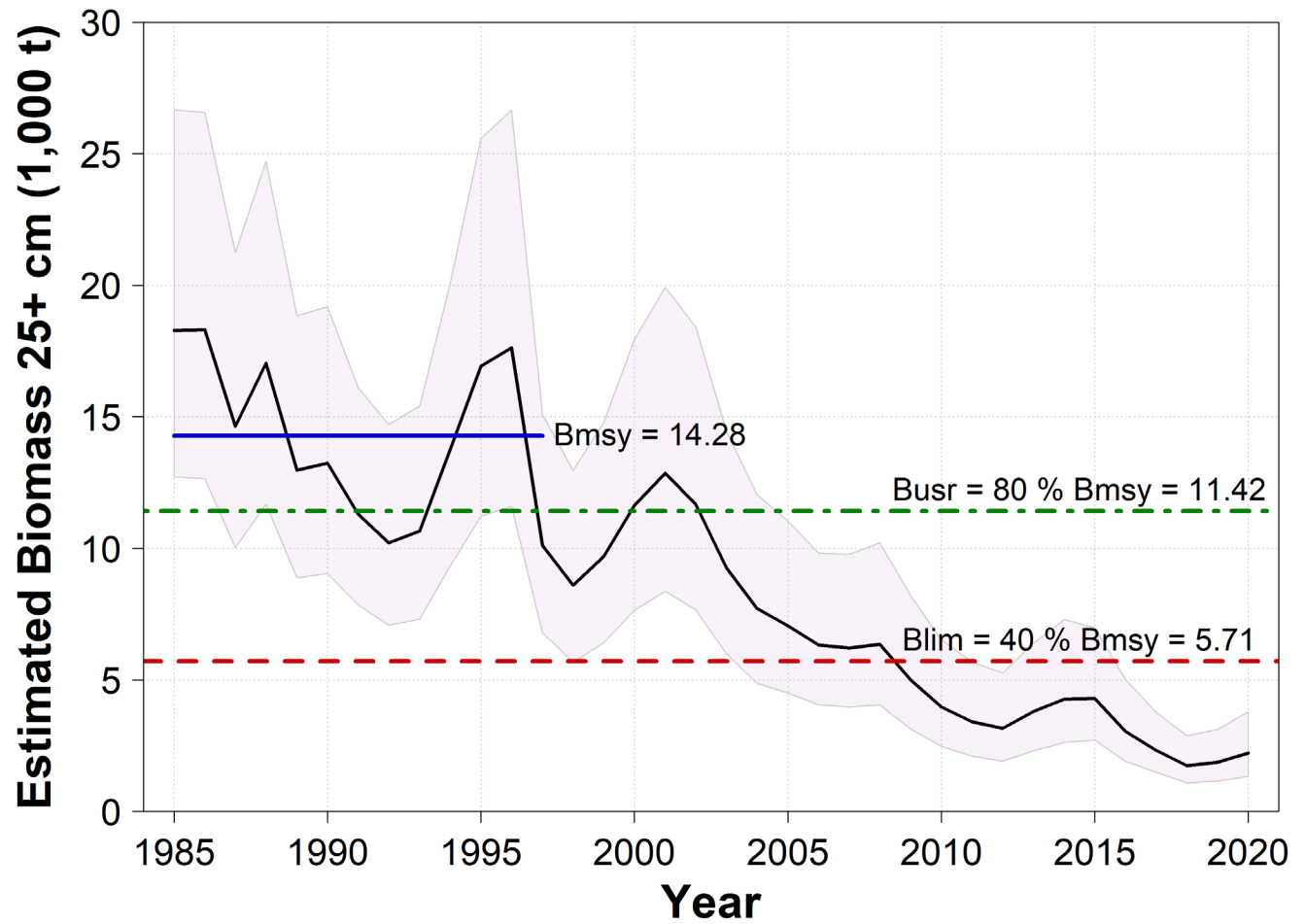


Figure 33. Estimated biomass of Yellowtail Flounder in the large length group (≥ 25 cm) in September. The black line is the median estimate and the shading is the 95% confidence interval. Horizontal lines show the median estimates of reference points: dark blue, $B_{msy} = 14.28$ kt; dark green, $B_{usr} = 11.42$ kt; dark red, $B_{lim} = 5.71$ kt.

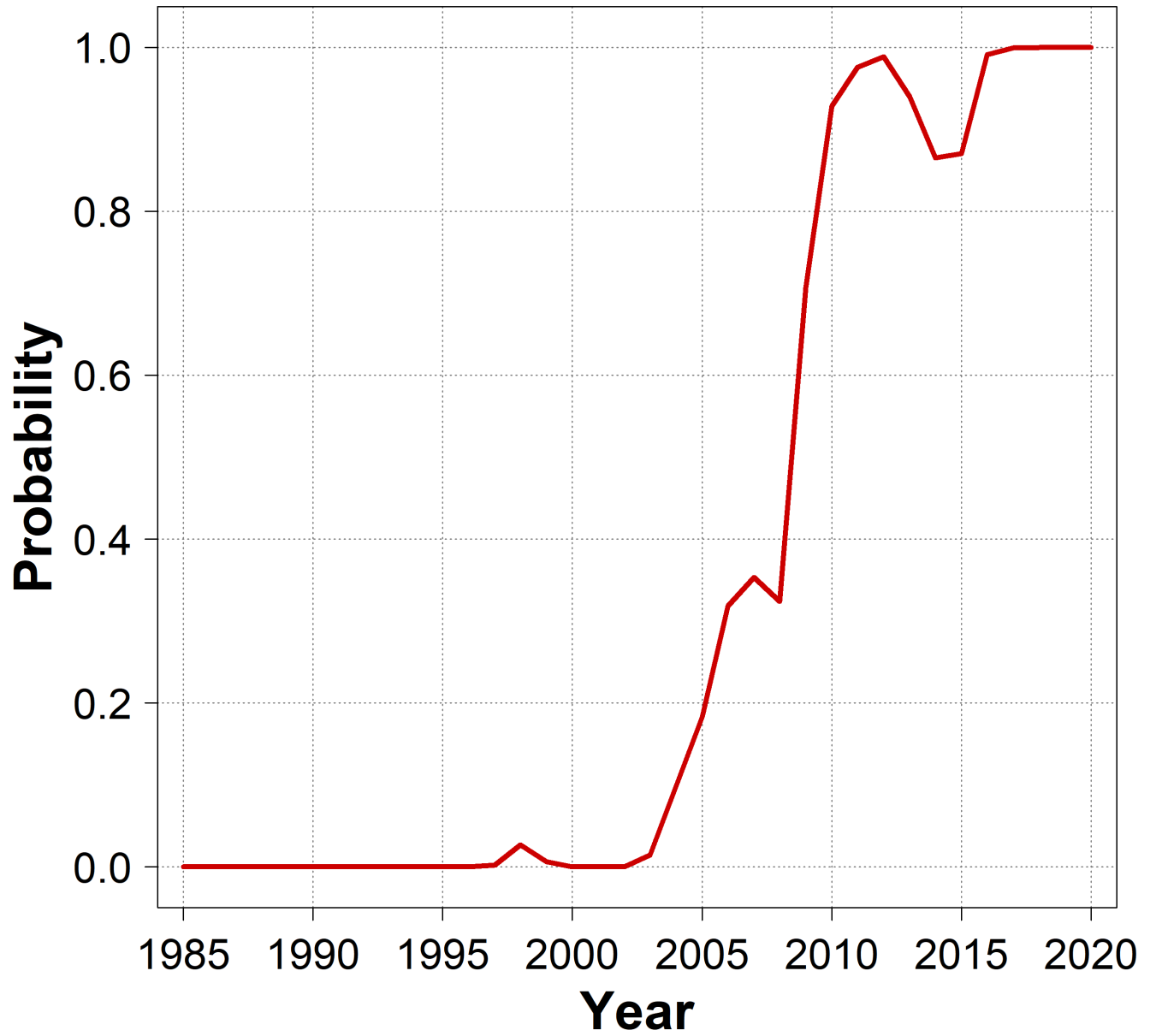


Figure 34. Estimated probability that biomass of Yellowtail Flounder in the large length group (≥ 25 cm) in September is below B_{lim} (the LRP).

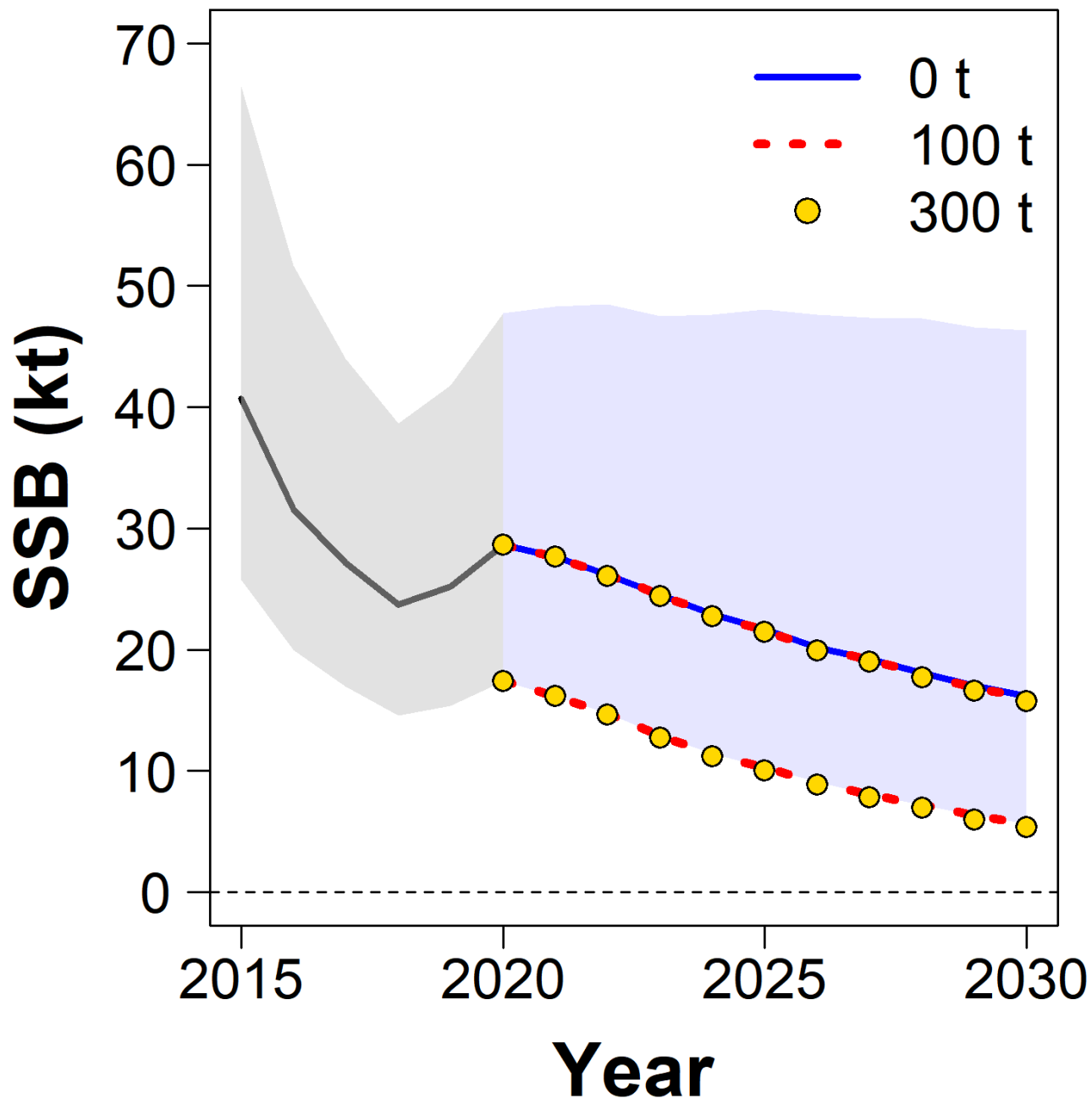


Figure 35. Projected spawning stock biomass (kt) of Yellowtail Flounder at three levels of fishery catch. Black lines show historical estimates and coloured lines show projected estimates (median). Grey and blue shading shows the 95% confidence intervals for the historical period and the projection with no catch. The red dashed lines and yellow circles indicate the lower confidence limits and the medians for projections with fishery catches of 100 or 300 t respectively.

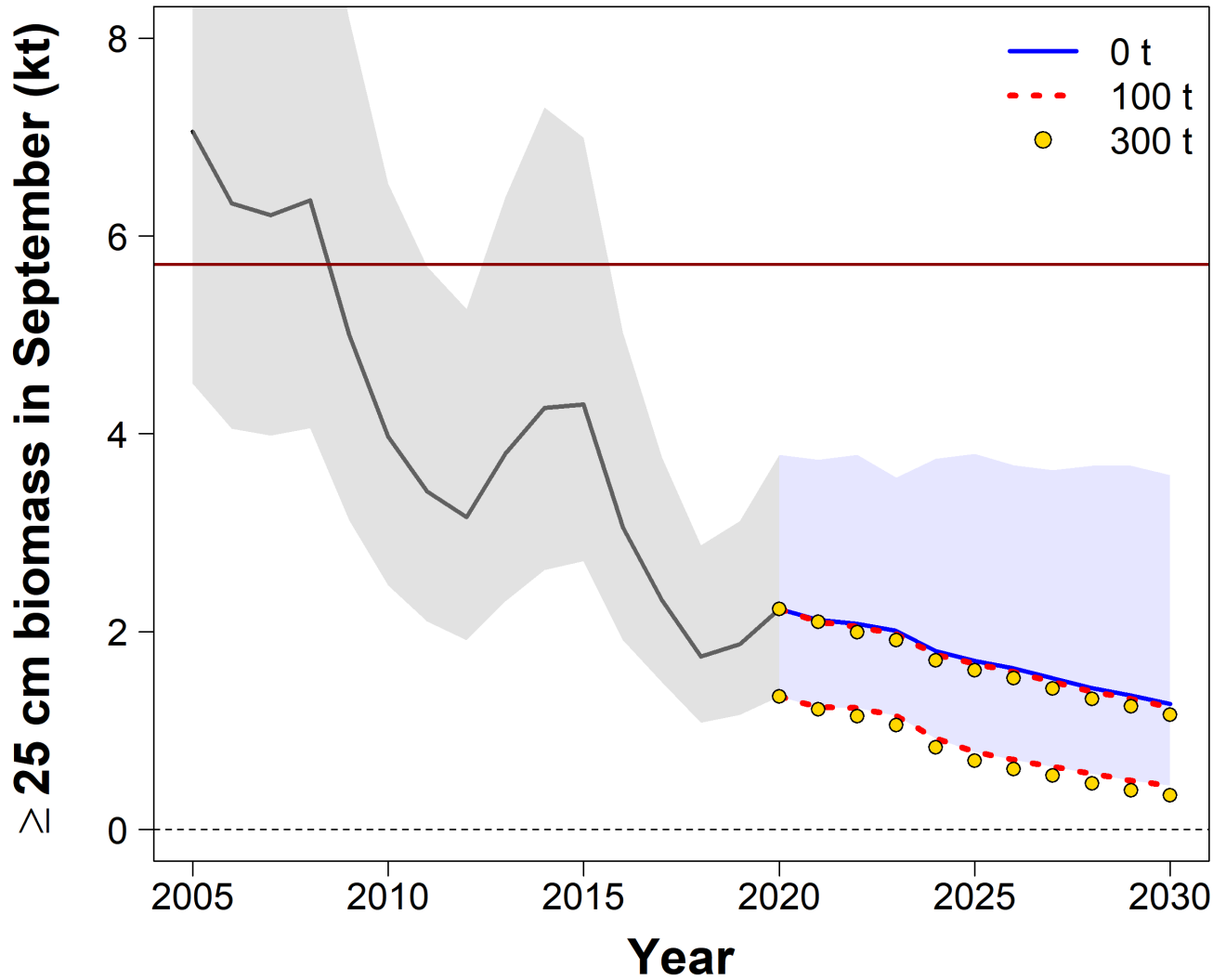


Figure 36. Projected September biomass of the large length class (≥ 25 cm) of Yellowtail Flounder. Black lines show historical estimates and coloured lines show projected estimates (medians). Grey and blue shading shows the 95% confidence intervals for the historical period and the projection with no catch. The red dashed lines and yellow circles indicate the lower confidence limits and the medians for projections with fishery catches of 100 or 300 t respectively. The red horizontal line is the Limit Reference Point (5,710 t).

APPENDIX A. COMMERCIAL CPUE ANALYSIS

Annual Catch-per Unit Effort (CPUE) of Yellowtail Flounder was calculated from logbook data for the period 1985 to 2020 for NAFO Div. 4T. Net immersion time was either not recorded or when recorded with insufficient consistency and clarity to be used as a standardizing variable throughout the time series. In particular, it was often not possible to tell whether a stated immersion time entry was limited to a portion of the catch or whether it represented the total effort for the trip. As a consequence, the CPUE values being modeled are catches by fishing trip.

There were 17,180 logbook entries with listed Yellowtail Flounder catches over this period. For the CPUE analysis, only trawler and seiner catches with identifiable CFV (Canadian Fishing Vessel) numbers and fishing between April and October inclusively were retained for the analysis. Catches stemming from the mobile Sentinel survey were removed from the analysis. Catches were log-transformed and the number of observations used in the CPUE analysis was 16,641. A linear mixed effects model was applied to the data.

$$\ln(\mu_{ijkl}) = \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_k + v_l + \epsilon_{ijkl} \quad (\text{A.1})$$

$$v_l \sim N(0, \sigma_v^2) \quad (\text{A.2})$$

$$\epsilon_{ijkl} \sim N(0, \sigma_j^2) \quad (\text{A.3})$$

where $i \in (1, \dots, 41)$ indexes fishing year, $j \in (1, \dots, 2)$ indexes fishing gear, $k \in (1, \dots, 7)$ indexes fishing month and $l \in (1, \dots, 428)$ indexes fishing vessel. The fixed effects coefficients for year, fishing gear and their interaction term are represented by α_i , β_j , and $(\alpha\beta)_{ij}$, respectively. The fixed effect coefficient for month is represented by γ_k . The random effects component of the model is given by the vessel effects v_l and residual error term ϵ_{ijkl} . The mean catch per trip is represented by μ_{ijkl} . The model was fit using the `lme` function from the `nlme` package in R (Pinheiro et al. 2020; R Core Team 2020).

The interaction term between year and gear was found to be significant ($F_{35,16136} = 21.4$, $p < 0.0001$), as was the additive month term ($F_{6,16136} = 23.1$, $p < 0.0001$). Model predictions for the month of June were performed over the time series by gear type (Fig. A.1). Model residuals for a number of covariates are shown in Figure 6. Intra-class correlation for the vessel effects was 0.66 for trawlers and 0.55 for seiners.

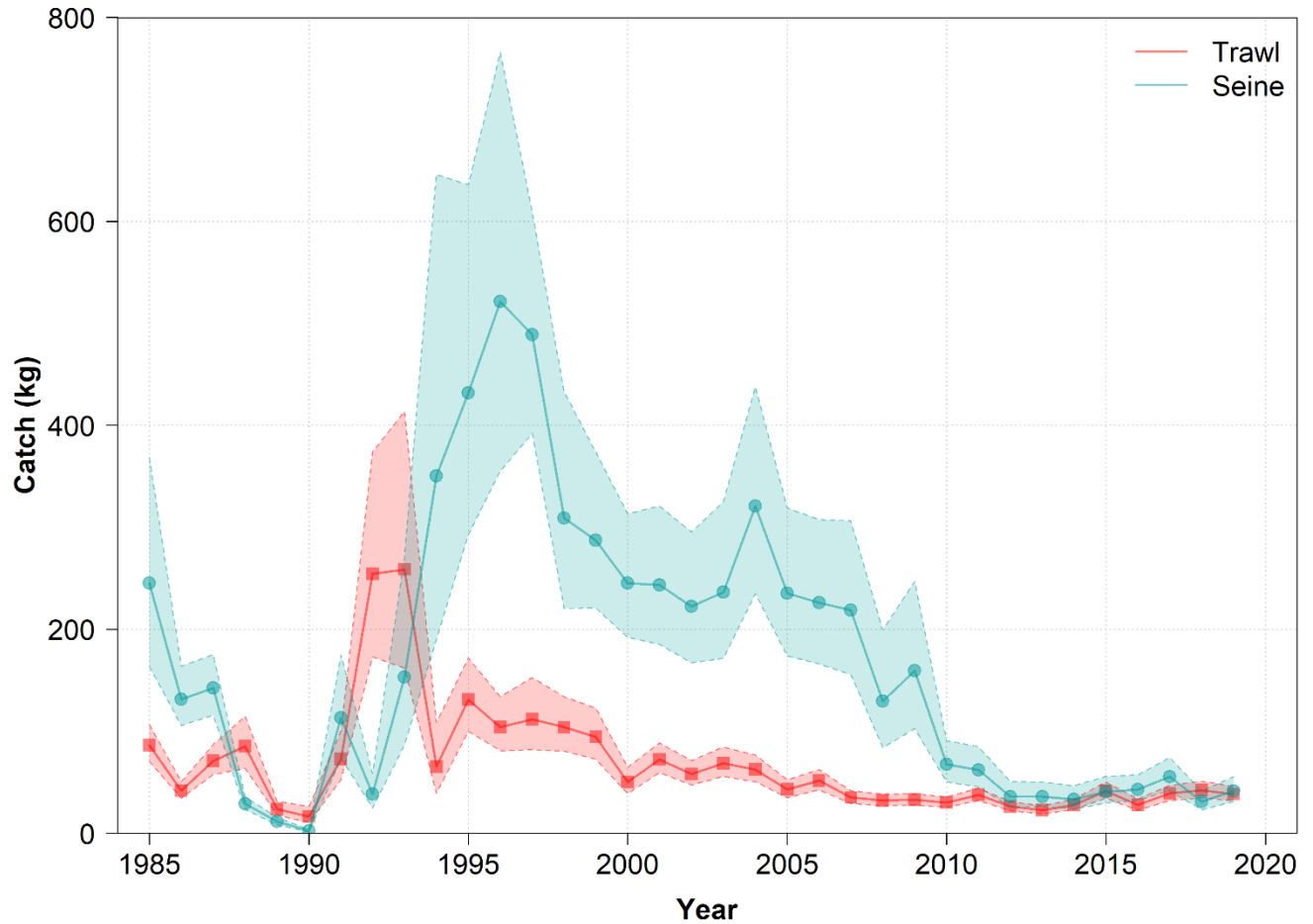


Figure A.1. Time series predictions from the commercial Yellowtail Flounder CPUE model by fishing gear for the month of June. Confidence intervals ($p = 0.05$ level) are shown as dashed lines and polygon shadows.

Figure A.2 shows log-scale residual plots for a number of covariates (i.e. fishing year, fishing gear, fishing month, fishing vessel) as well as auxiliary variables (water depth and target fishing species). There are no visible residual patterns in any residual plot.

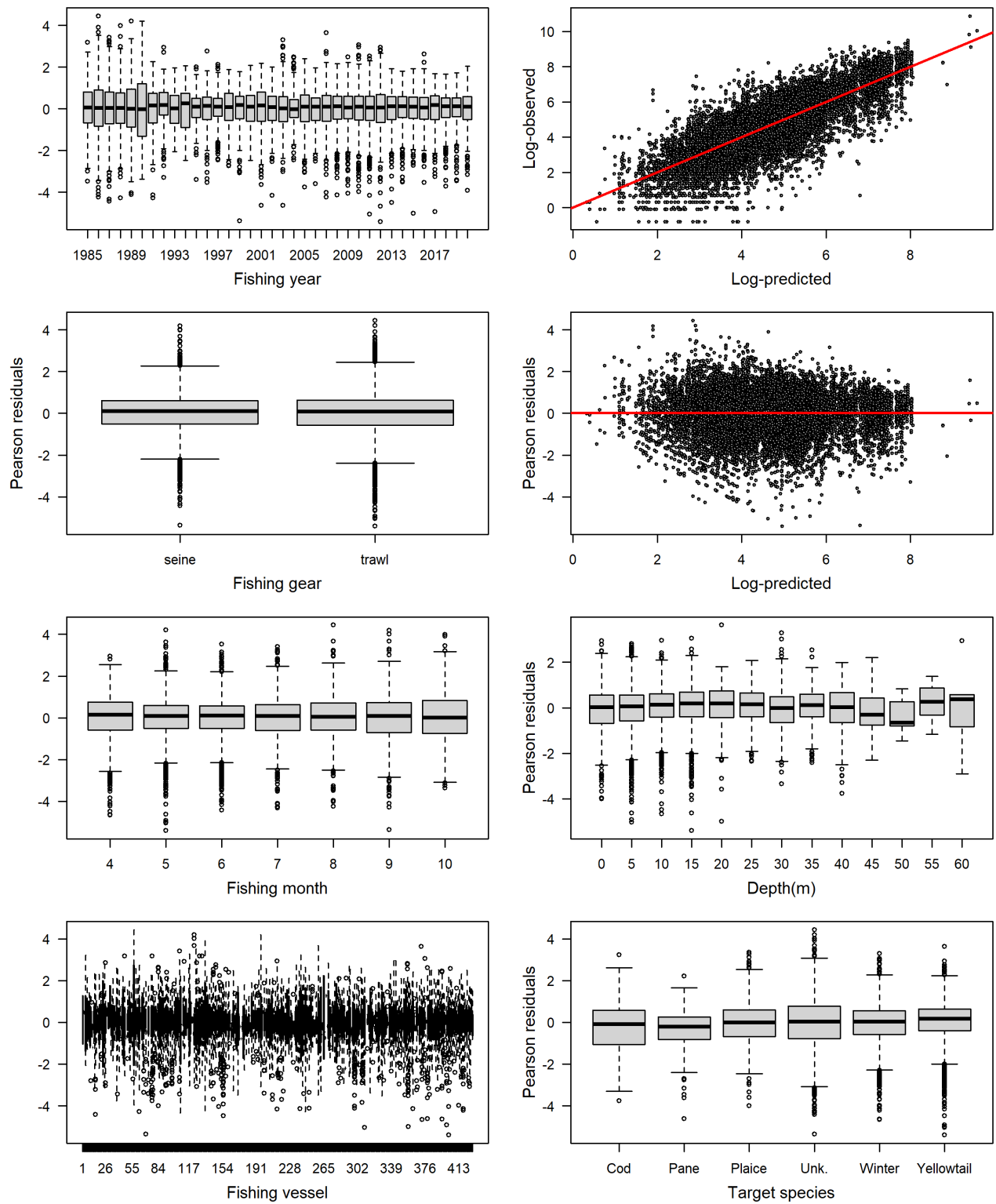


Figure A.2. Residual plots of the commercial Yellowtail Flounder CPUE model for various covariates and auxiliary variables, in the southern Gulf of St. Lawrence. The top-right panel shows the plot of observed versus predicted values for the model.

Model predictions show a large decrease in mean catches per trip in 1990, followed by increases in both types of gear, peaking in 1992 to 1993 for trawlers at approx. 255 kg and peaking in 1996 to 1997 for seiners at approximately 512 kg. Since then, catches have decreased to levels averaging less than 45 kg for the period 2015 to 2020.

IMMERSION TIME

As background information, the mean immersion time of available data by year and type of fishing gear is shown in Figure A.3. These values were calculated by first averaging recorded immersion time by fishing vessel and fishing day, then averaging over fishing vessels by year and gear type.

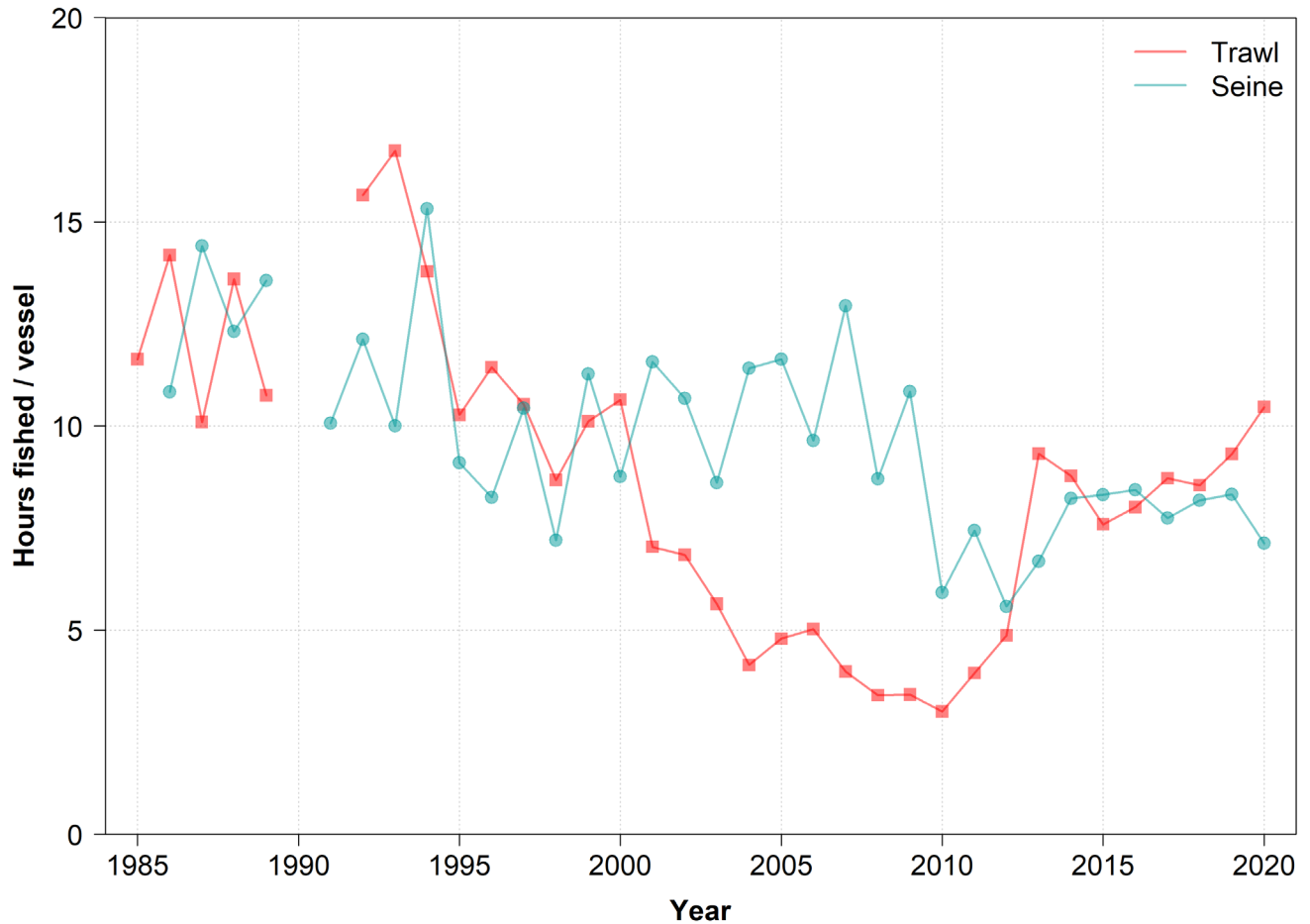


Figure A.3. Mean number of hours fished by year and fishing gear type directing for Yellowtail Flounder in the southern Gulf of St. Lawrence. Soak times were averaged by fishing vessel and the resulting values were then averaged over the year. Missing values were removed.

For the available data, the immersion time was about 10 hours from 1985 to 2000 with trawls and seines. Starting in 2001, there was a marked decrease in immersion time for trawlers, with the entry into the fishery of numerous small inshore vessels. Seiners also show a decline in recorded immersion time from 2010 onward at approx. 7 hours. Since 2015, both gear show a stable trend at around 8 hours. It is important to note that the accuracy and validity of these data should be kept in mind when interpreting the results.

APPENDIX B. MAGDALEN ISLANDS INDICES

SEPTEMBER MULTI-SPECIES SURVEY

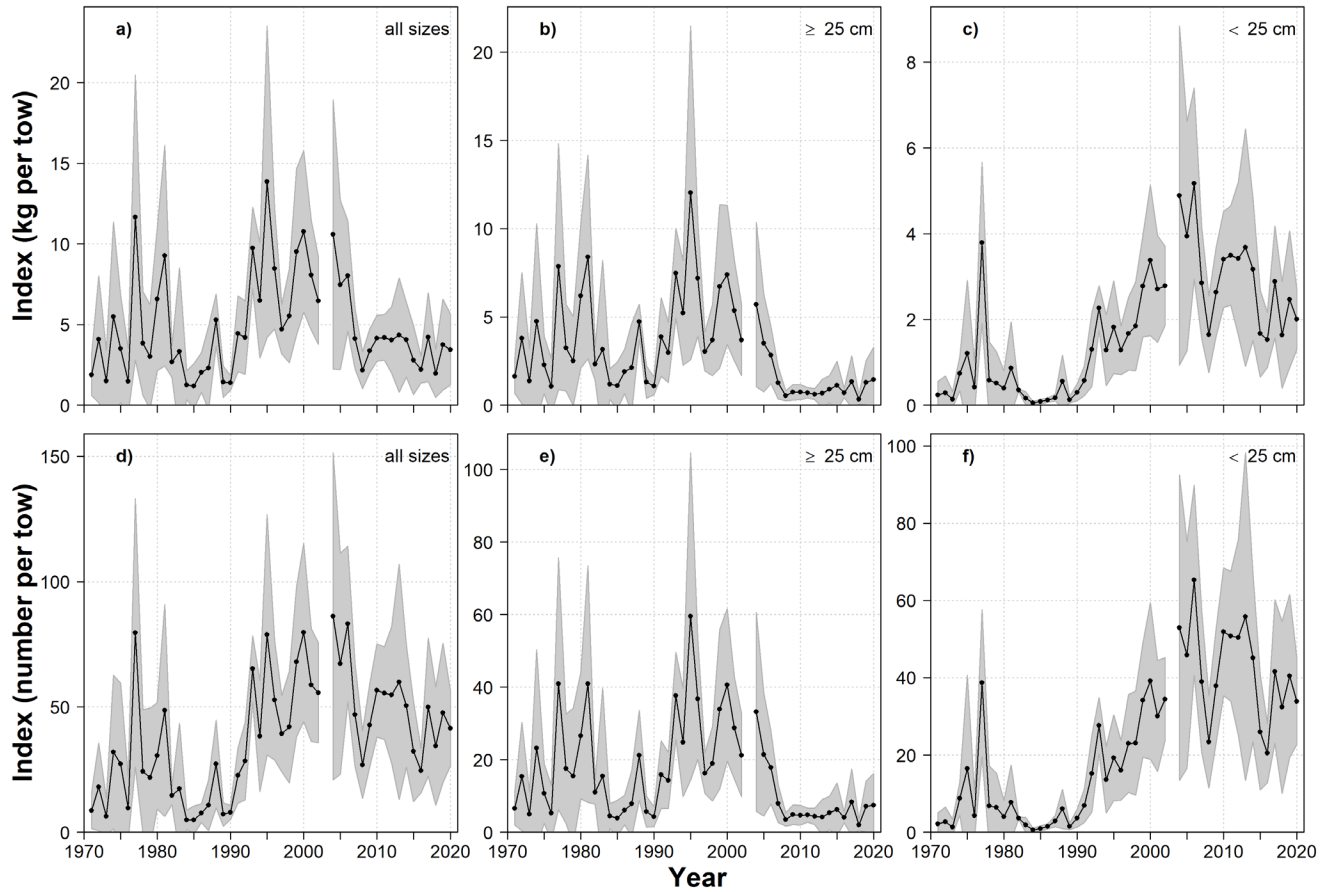


Figure B.1. Estimated abundance (number per tow, upper panel) and biomass (kg per tow, lower panel) of Yellowtail Flounder from the southern Gulf of St. Lawrence September bottom trawl survey of strata (428, 434, 435 and 436) around the Magdalen Islands. Shaded area represents the 95% confidence intervals about the mean values.

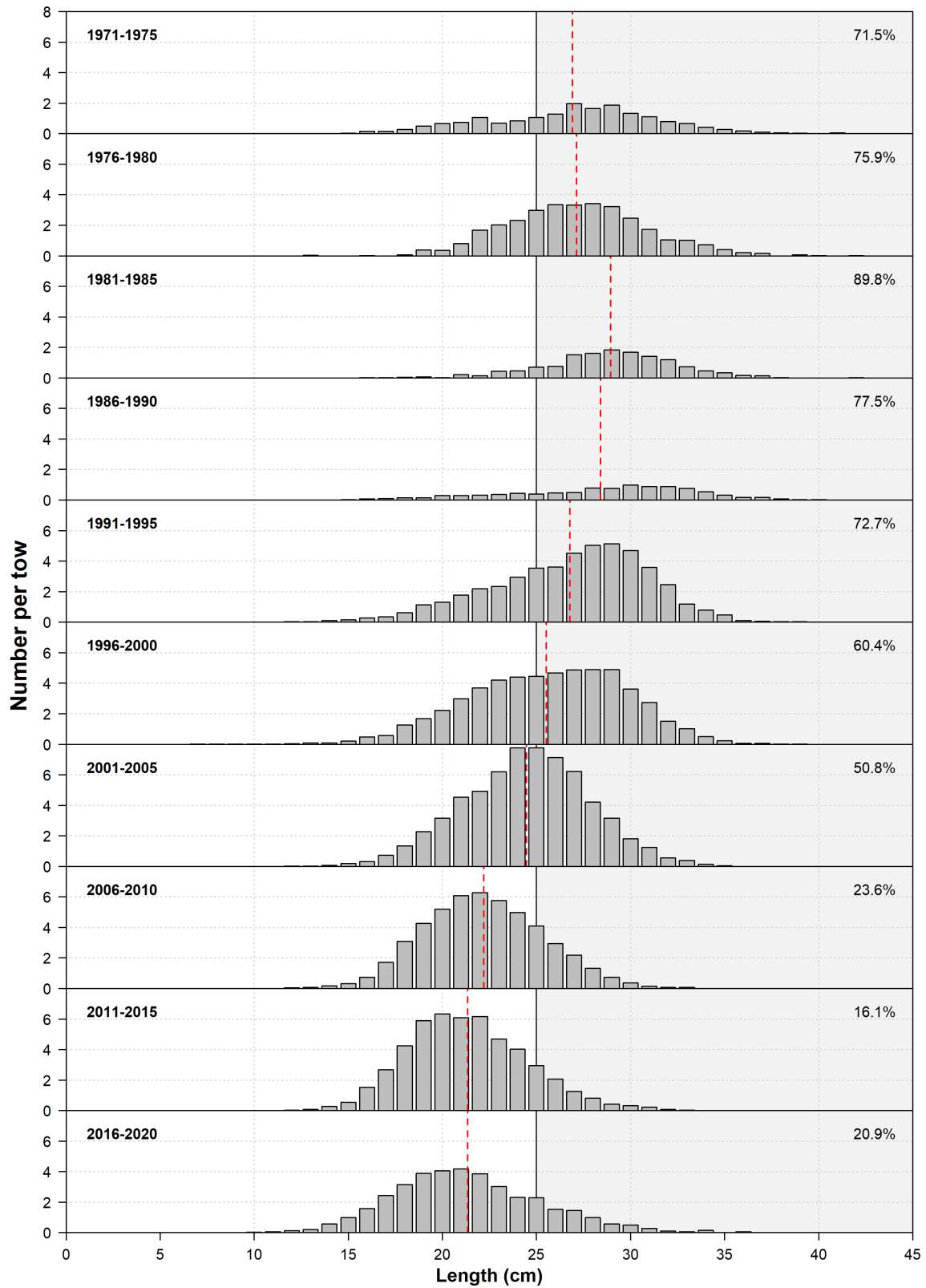


Figure B.2. Length-frequency distributions (expressed in number per tow) of Yellowtail Flounder based on catches from the September bottom trawl survey of strata around the Magdalen Islands (strata 428, 434, 435 and 436) by five year blocks, 1971 to 2020.

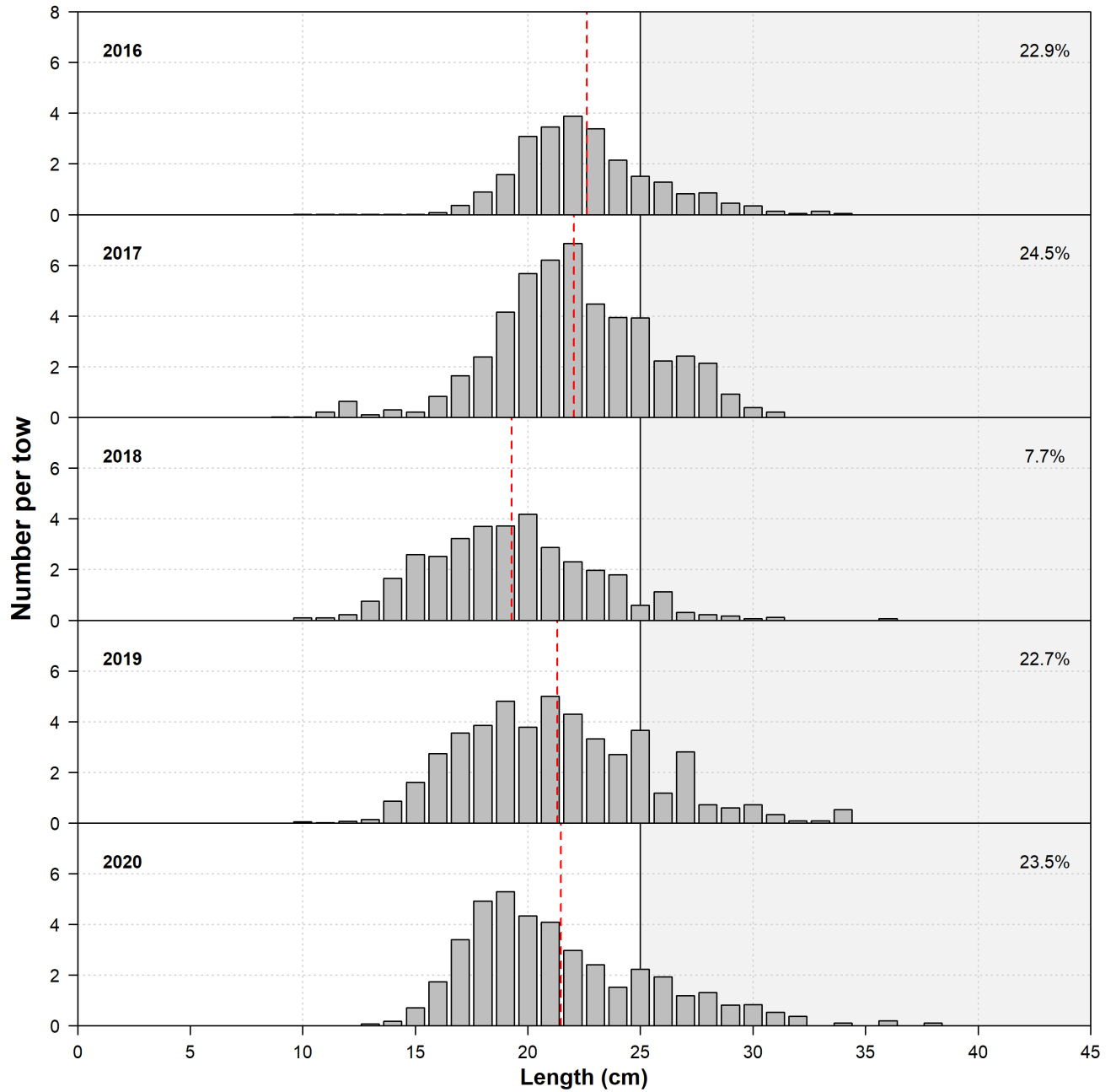


Figure B.3. Length-frequency distributions (expressed in number per tow) of Yellowtail Flounder based on catches from the September bottom trawl survey of strata around the Magdalen Islands (strata 428, 434, 435 and 436), 2016 to 2020.

MOBILE SENTINEL SURVEYS

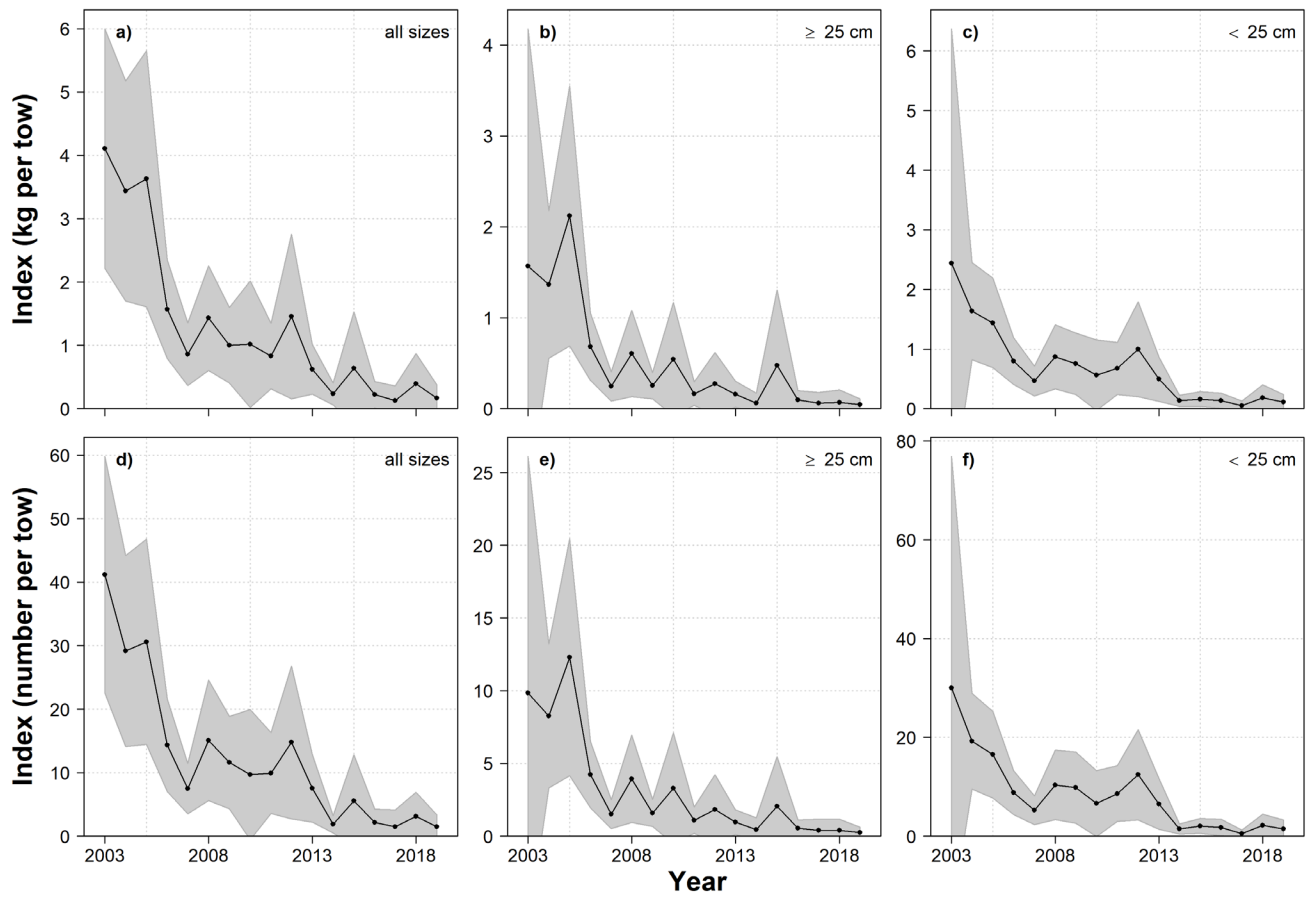


Figure B.4. Magdalen Islands Yellowtail Flounder abundance (number per tow; top panel) and biomass (kg per tow; bottom panel) indices from the southern Gulf of St. Lawrence mobile Sentinel survey (strata 428, 434, 435, and 436). Shaded area represents the 95% confidence intervals about the mean values.

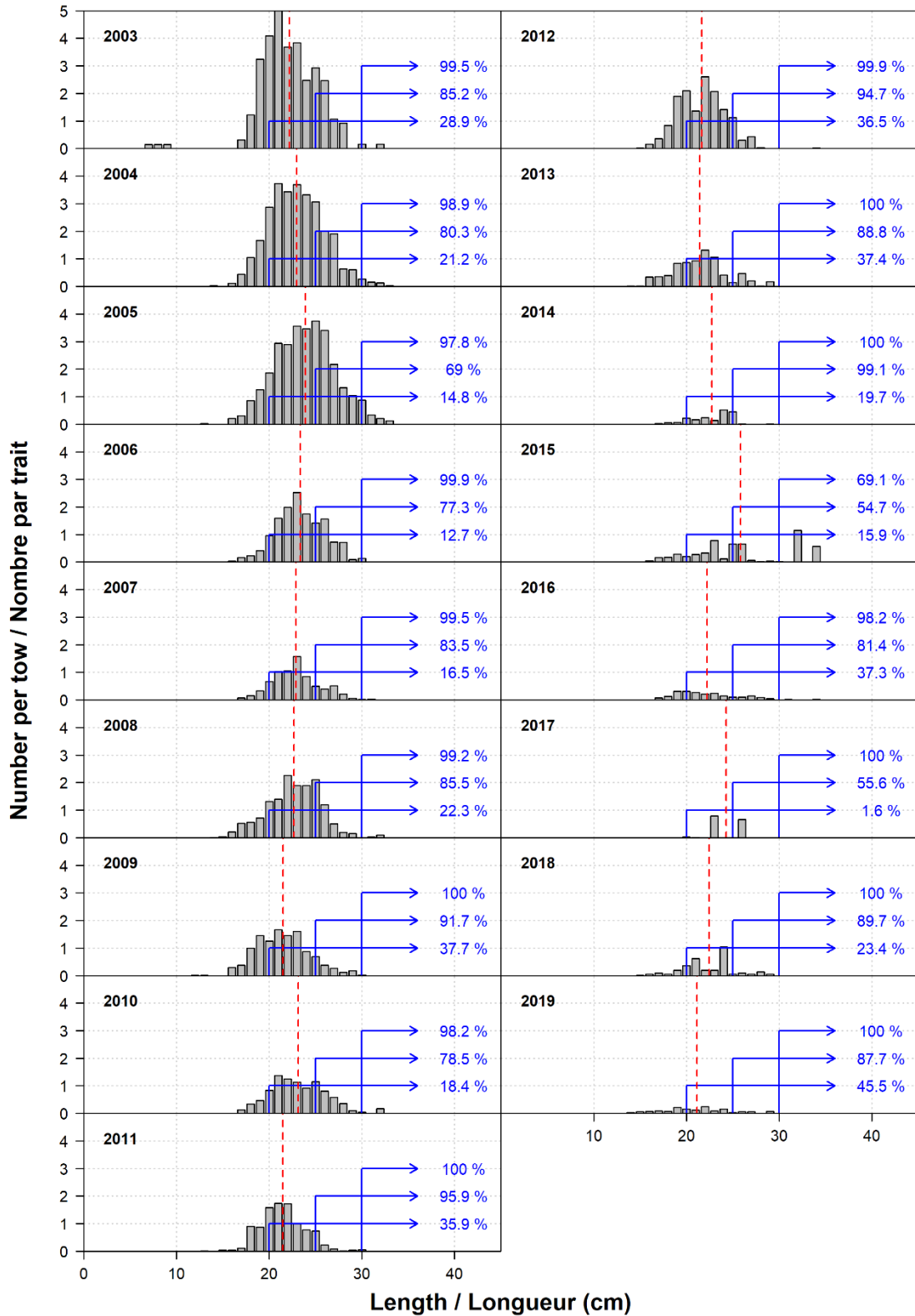


Figure B.5. Mobile Sentinel survey length-frequency distributions (number per tow) of Yellowtail Flounder, 2003 to 2019, for Magdalen Islands strata (428, 434, 435 and 436). Blue lines show the cumulative percentile values at 20 cm, 25 cm and 30 cm while the red dashed line shows the location of mean value.

APPENDIX C. AGEING METHODOLOGY

Yellowtail Flounder ageing data from the September survey dates back to 1972, but otolith collection was not systematically conducted on a yearly basis. Until 1982 otolith were collected and age reading was processed at DFO's St. Andrews Biological Station. From 1983 to 1986, length-stratified sampling for otoliths was conducted but the otoliths were not aged. There was no otolith sampling from 1987 to 1999 but sampling was re-initiated in 2000 onward. In the meantime, strong disparities between historical agers were revealed in Surette and Swain (2016) and the model used in the previous stock assessment relied only on three years (2000, 2007 and 2015) pooled together and aged by a now retired technician from DFO's Gulf Region, here referred as GLF 1.

Since 2019, a new experienced technician (GLF 2) was given the task to increase our ageing database for Yellowtail Flounder and 8 more years were processed (2001, 2003, 2005, 2009, 2011, 2013, 2017 and 2019). Except for 2019 where all the otoliths collected were aged, approximately 130 otoliths were randomly selected in such a way that for each length and sex combination, a minimum target of three otoliths were aged per year. The number of valid aged otoliths by year, age and ager is shown in Table 10.

Taking into consideration that ages before 2000 were removed from the previous assessment, the same methodology was applied for this assessment, thus limiting our number of samples to GLF 1 and 2 agers, the latter having been trained by GLF 1. However, the mean lengths-at-age by year revealed again some discrepancies between both GLF agers (Fig. C.1). This analysis also sheds light on the interannual variation that is to be expected from the survey data.

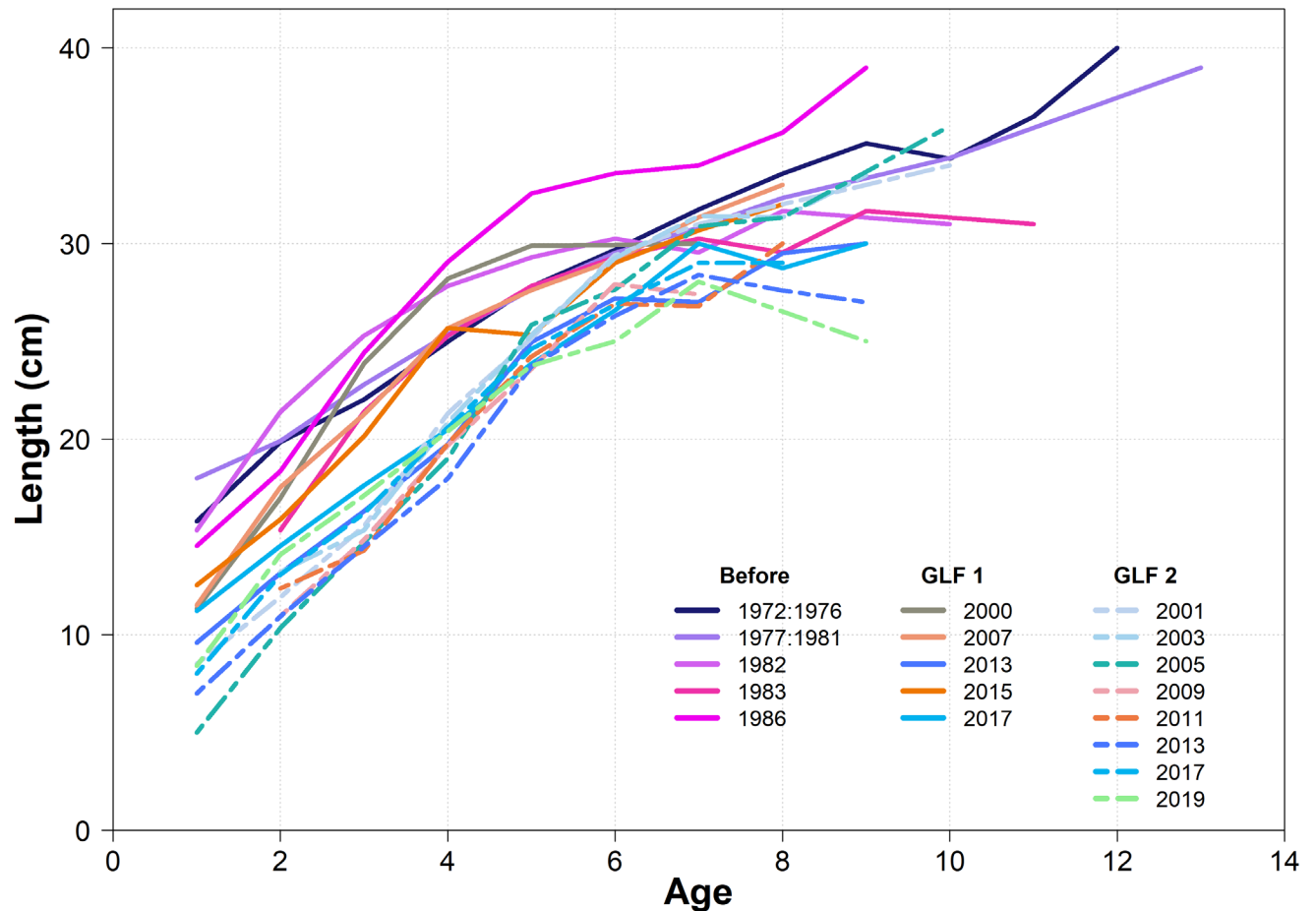


Figure C.1. Mean length-at-age based on length and age data from the September survey of the southern Gulf of St. Lawrence.

In order to better assess the situation, otoliths from 2013 and 2017 were evaluated by GLF 1. The results concluded that ages from GLF 2 were both over or under estimated compared to GLF 1 readings. Further discussion helped identified that both agers did not agreed on how they evaluate the nucleus and edges. Such inconsistent discrepancy limited our ability to apply a correction factor to either ager in order to use the full time series. A reference collection for Yellowtail Flounder was not yet fully completed at the time of this assessment. With the recent discussion between both agers, this reference collection and a more robust regional protocol for ageing otoliths that is under-development, such discrepancies should no longer be an issue in a near future.

Faced with these uncertainties, the growth data used for the population model, which covers the period from 1985-2020, was chosen to be from 2000, 2007, 2013, 2015 and 2017 pooled together, thus relying only on our GLF-1 ager (Fig. C.2).

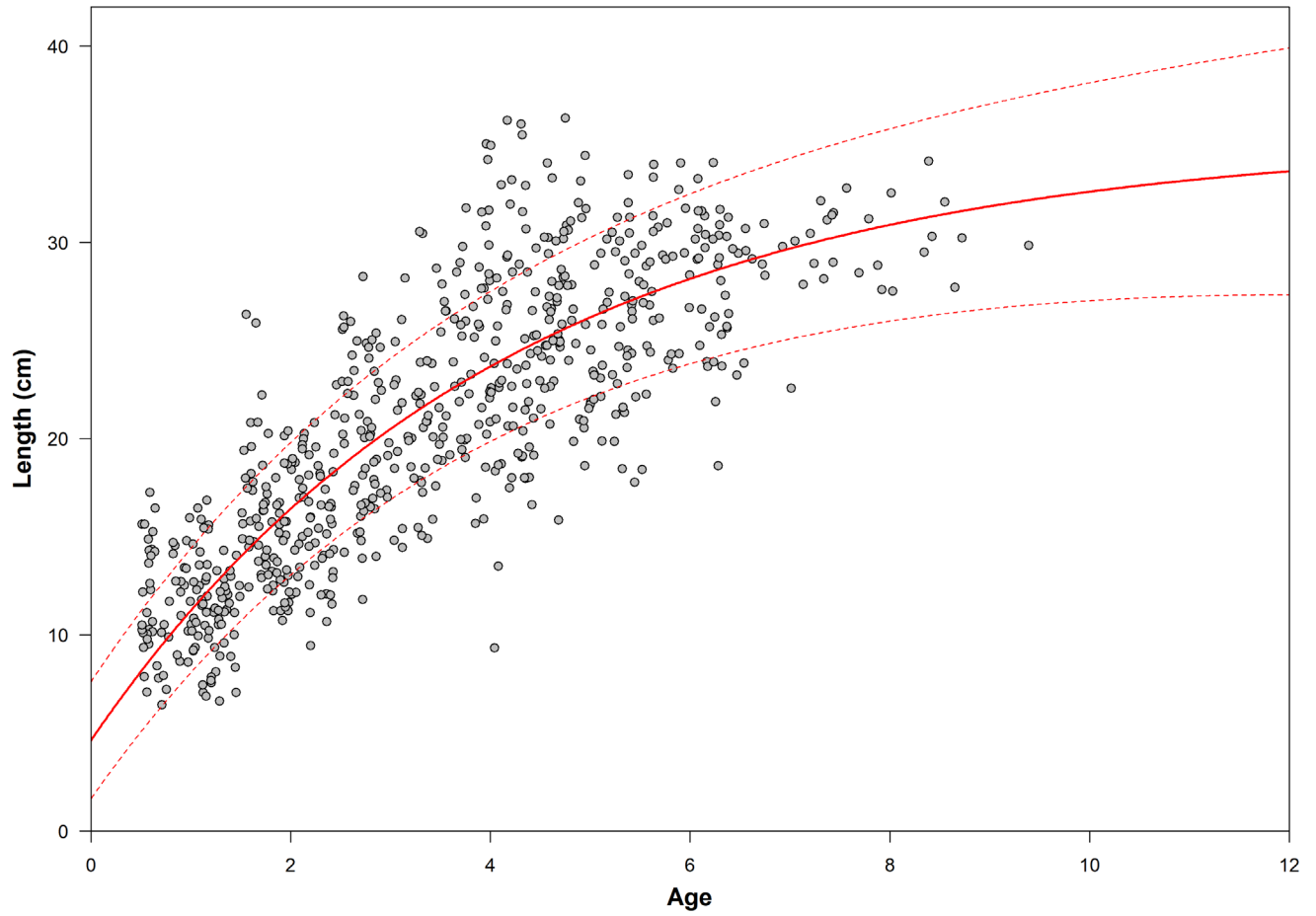


Figure C.2. Fitted Von Bertalanffy growth model to the pooled age data from 2000, 2007, 2013, 2015, and 2017. Parameter values are $L_{\infty} = 35.3$ cm, $k = 0.243$ and $t_0 = -0.577$ year. Data points were jittered for display purposes.

APPENDIX D. SNOW CRAB SURVEY - GROUND FISH DATA

DESCRIPTION

An annual snow crab trawl survey has been conducted in the sGSL since 1988 (Moriyasu et al. 2008; Allain et al. 2019). The survey uses a Bigouden Nephrops trawl designed to dig lightly in soft or sandy sediment. The liner in the cod-end has a mesh size of 40 mm. Since 2010, catch weight data from all fish species (between 325 and 355 stations annually) are recorded as well as length-frequency data from a randomly selected subset of 100 stations.

Figure D.1 shows the survey area, the underlying grid stratification and the locations of the stations sampled for groundfish, including Yellowtail Flounder, from 2010 to 2020. The survey areas were slightly smaller in 2010 and 2011 as a Northeastern region along the Laurentian Channel was not sampled. As this region represents but a small fraction of the larger survey area, the results presented here are not expected to be adversely affected by this change in survey coverage. Further information on this survey may be found in Moriyasu et al. (2008) and in Allain et al. (2019).

This survey is designed to have a spatially homogeneous distribution, so abundance indices (Fig. D.2) were calculated as the mean abundance per km² after standardizing catch by the calculated swept area of each trawl tow. Similarly, mean length-frequencies (Fig. D.3) are presented for the tows where length sampling was performed.

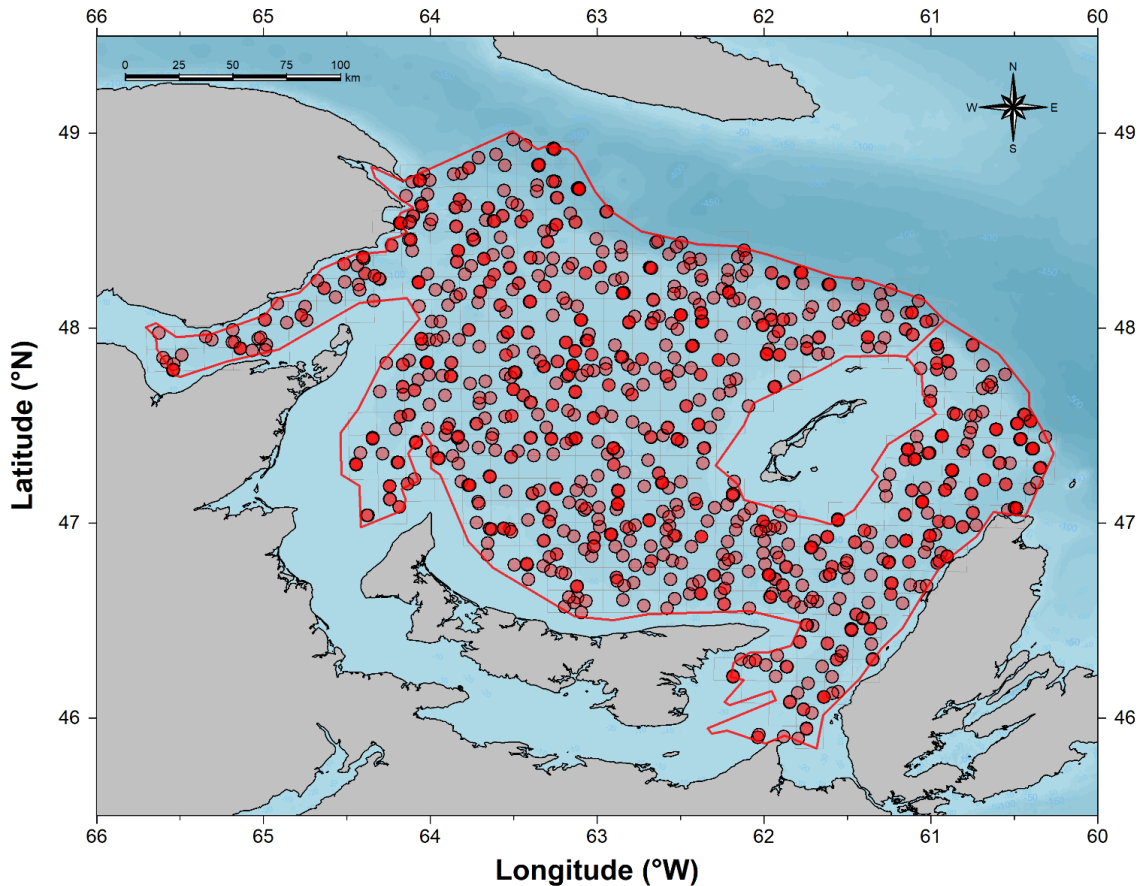


Figure D.1. Snow crab survey area (red line), sampling grids (grey squares) and the location of the 1088 stations (red dots) sampled for groundfish in 2010 to 2020.

ABUNDANCE INDEX

Mean catches of Yellowtail Flounder in the snow crab surveys 2012 to 2020 are shown in Figure D.2. There is a small decrease in the mean density over the time series from approximately 5,000 fish per km² in 2012 to approx. 3,500 fish per km² in 2020. Confidence intervals for these estimates are rather large, owing to the low number of sampling stations with Yellowtail Flounder catches. However, the observed decline is consistent with that observed in the latter part of the mobile Sentinel survey index.

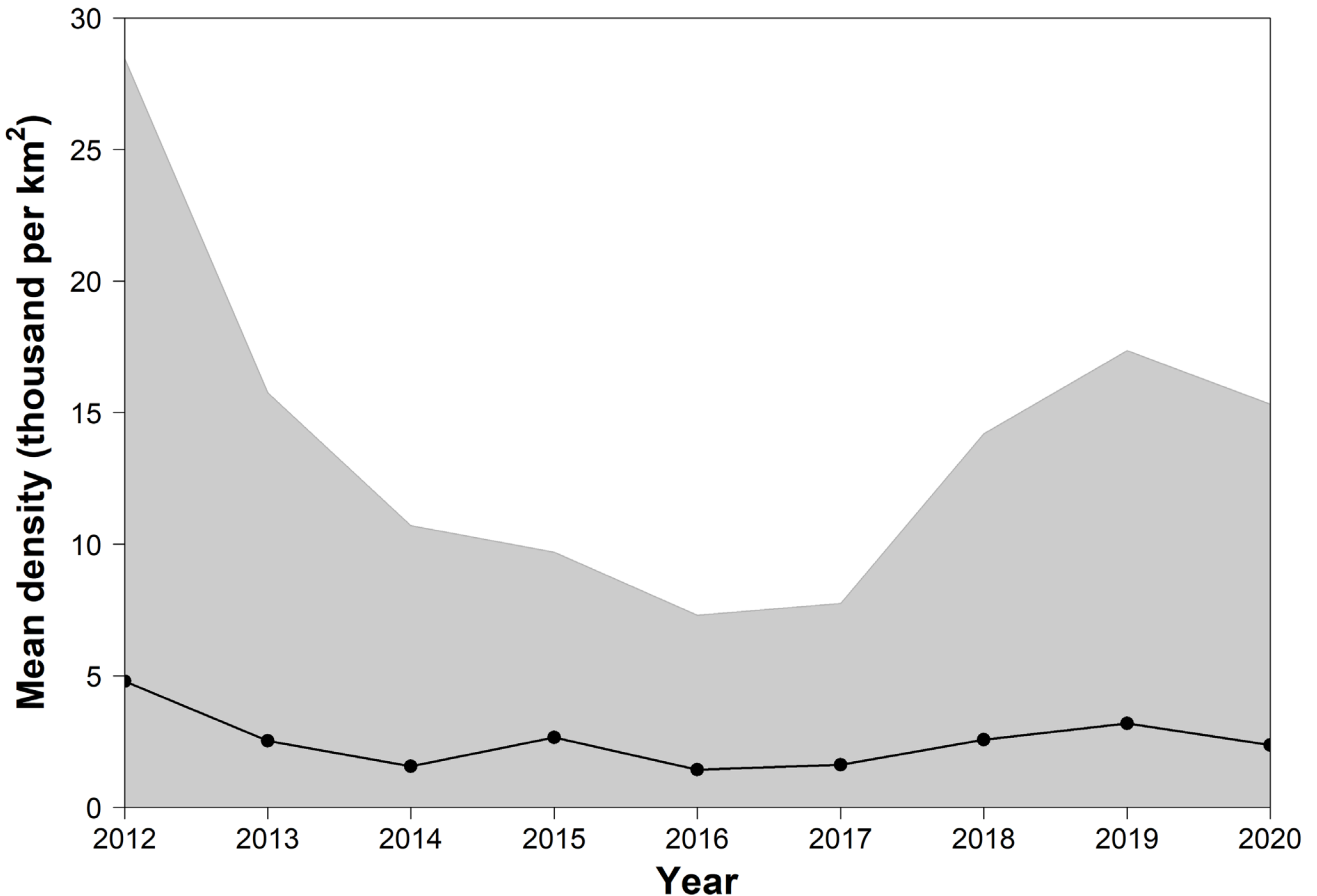


Figure D.2. Mean number per km² and confidence intervals (95%) of total Yellowtail Flounder from the snow crab survey.

LENGTH FREQUENCIES

Length-frequency distributions of Yellowtail Flounder by year are shown in Figure D.3. While the snow crab survey and the mobile Sentinel surveys have identical mesh sizes in the cod-end (40 mm), smaller fish are retained in the snow crab survey, most probably due to the accumulation of debris over the duration of the trawl.

Except for the overall decreasing trend, Yellowtail Flounder length-frequency distributions for the snow crab survey data resemble those of the September survey (codend mesh size of 19 mm, Fig. 12). As was the case for the September survey and the Sentinel survey, there is no apparent shift in fish size between 2010 and 2020. Though there seems to be a decrease in

abundance across the short time series, the large error associated with the estimates hinders formal inference of the change.

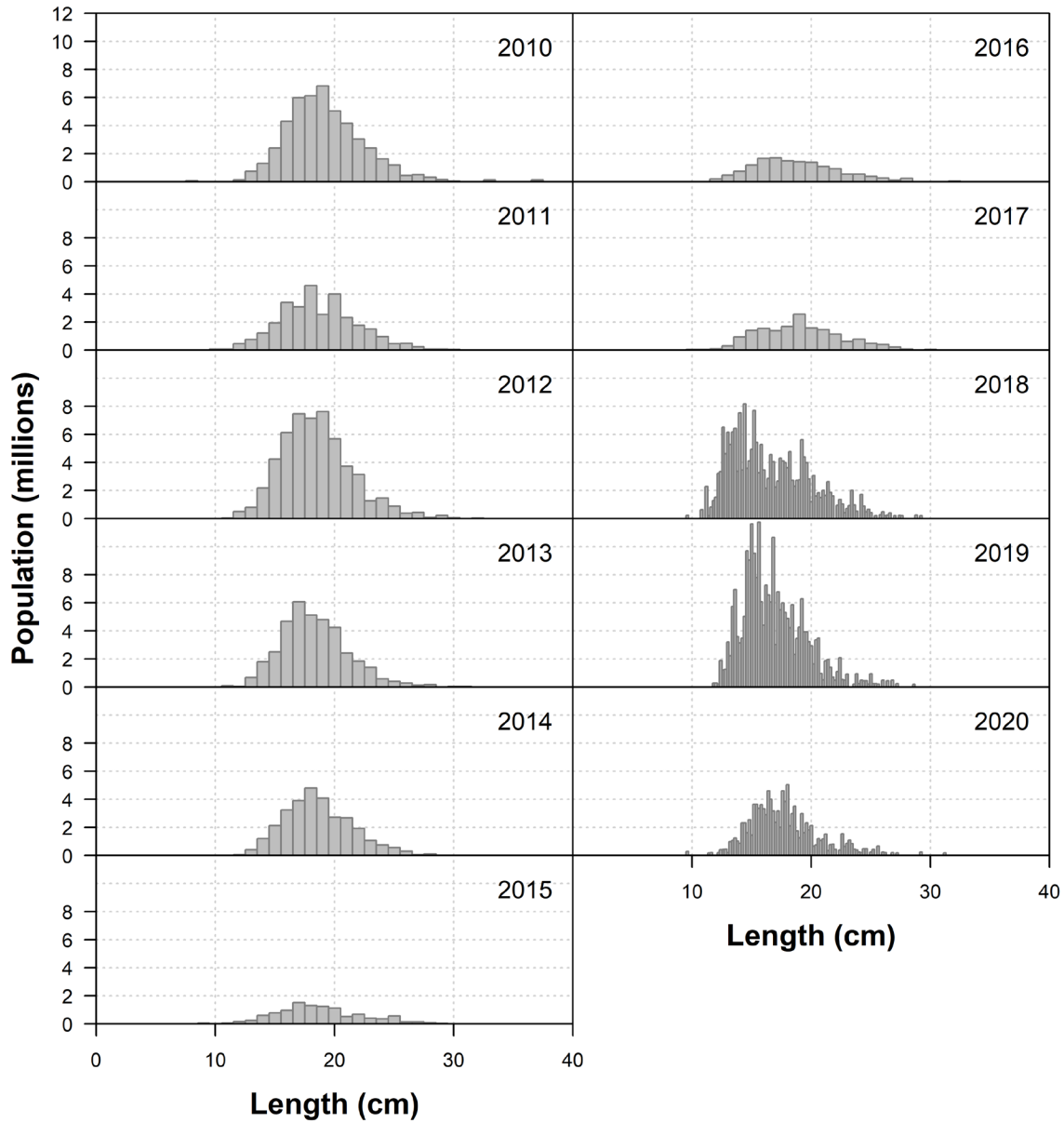


Figure D.3. Mean length-frequency distributions (numbers per km²) of Yellowtail Flounder from the snow crab survey, 2010 to 2020.

SPATIAL DISTRIBUTION

Figure D.4 shows the spatial distribution of snow crab survey Yellowtail Flounder catches from 2010 to 2020.

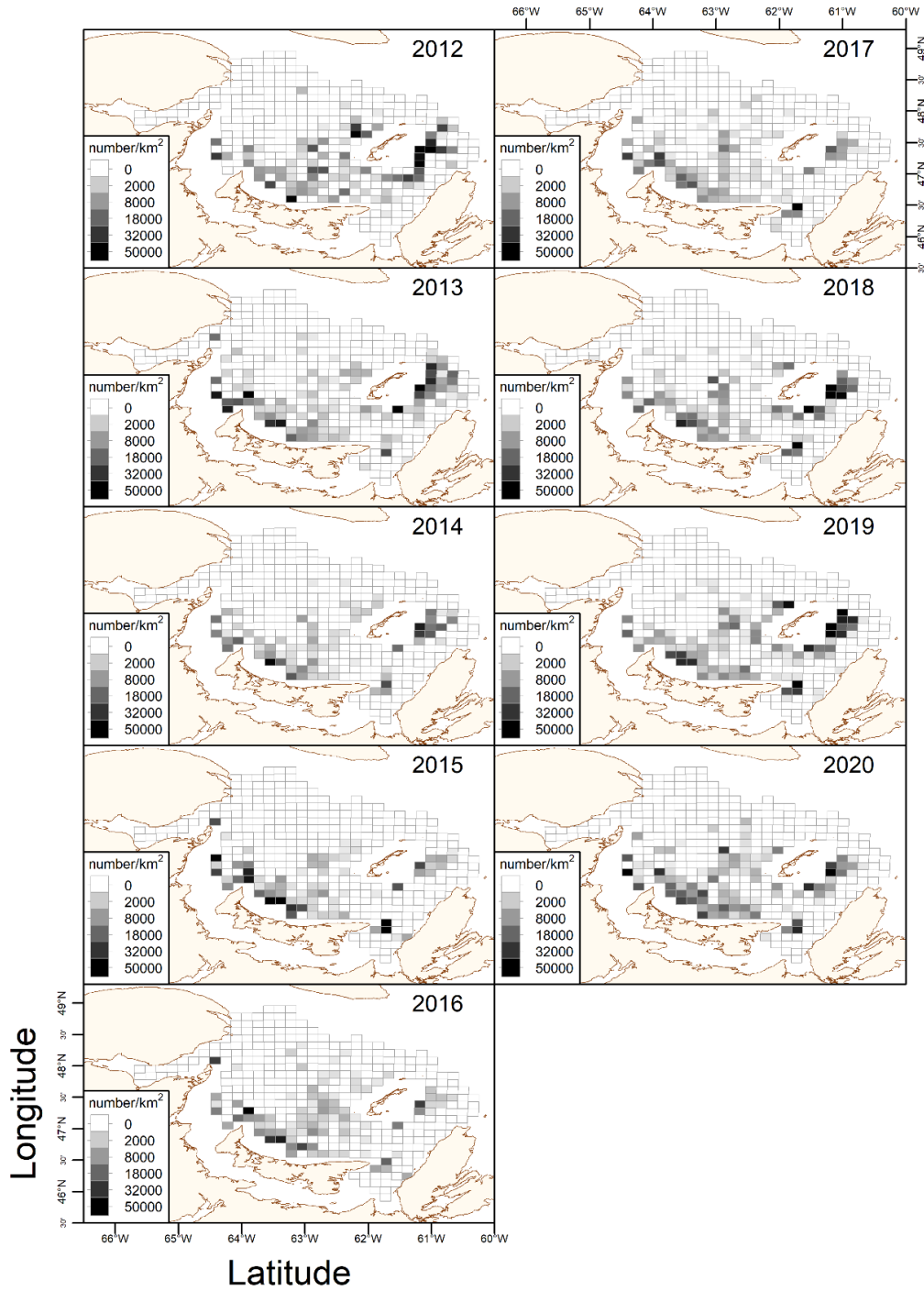


Figure D.4. Spatial distribution of Yellowtail Flounder catches in the snow crab surveys, 2012 to 2020. Units are in number per km².