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The Status of Yellowtail Flounder in NAFO Division 4T to 2015

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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*) landings in NAFO 4T peaked in 1986-1987 (400 t) and in 1997 (819 t) and declined from 305 t in 1999 to 102 t in 2015. A TAC of 300 t has been in place since 2000. Yellowtail are mainly exploited in a bait fishery located in the Magdalen Islands since 1995 and almost exclusively so since 2004. Abundance indices from a research survey have been stable since the mid-eighties. However, corresponding biomass indices have decreased due to a shift in modal size from 29 cm in the early 1970s to 22 cm in recent years. Size-at-maturity in both males and females has declined from 23-24 cm in the in the early 1970s to 12-13 cm in recent years. Annual mortality of small fish has decreased from 53% to 16-22% while that of larger fish has increased from 22% to 86% from the middle to late eighties to the present. While spawning stock biomass has increased, the proportion of older (7+ years) fish has declined from 40% in 1985-1990 to less that 0.5% since 2013. Fishing mortality is estimated to be very low and there were no perceived differences in stock projections over the next five years at catch levels of 0 t, 100 t, and 300 t annually. A limit reference point (B_{lim} = 1.06 kg/tow) was derived from the commercial sized (≥ 25 cm) biomass index from the research vessel survey. The abundance index in 2015 was at 61% of B_{lim}.

État de la limande à queue jaune dans la division 4T de l'OPANO jusqu'en 2015

RÉSUMÉ

Les débarquements de limande à queue jaune (*Limanda ferruginea*) dans la division 4T de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO) ont atteint un sommet en 1986-1987 (400 t) et en 1997 (819 t) avant de diminuer, passant de 305 t en 1999 à 102 t en 2015. Un total autorisé des captures (TAC) de 300 t est en place depuis 2000. La limande à queue jaune est principalement exploitée dans le cadre d'une pêche à l'appât pratiquée aux îles de la Madeleine depuis 1995, et presque exclusivement de cette façon depuis 2004. Les indices d'abondance tirés du relevé de recherche sont stables depuis le milieu des années 1980. Cependant, les indices correspondants de la biomasse ont diminué en raison d'une réduction de la taille modale, qui a passé de 29 cm au début des années 1970 à 22 cm ces dernières années. La taille à la maturité chez les mâles et les femelles a diminué de 23-24 cm au début des années 1970 à 12-13 cm au cours des dernières années. Le taux de mortalité annuel des petits poissons a décliné, passant de 53 % à 16-22 %, tandis que la mortalité des plus gros poissons a augmenté de 22 % à 86 % de la seconde moitié des années 1980 à aujourd'hui. Si la biomasse du stock reproducteur a augmenté, la proportion de poissons plus âgés (plus de 7 ans) a chuté de 40 % en 1985-1990 à moins de 0,5 % depuis 2013. La contribution de la mortalité par pêche à la mortalité totale estimée de la limande à queue jaune est tellement faible qu'aucune différence n'est perçue dans les projections du stock au cours des cinq prochaines années pour des niveaux des prises de 0 t, de 100 t et de 300 t par an. Un point de référence limite (B_{lim} = 1,06 kg/trait) a été calculé à partir de l'indice de la biomasse des individus de taille commerciale (≥ 25 cm) tiré du relevé par navire de recherche. En 2015, l'indice d'abondance correspondait à 61 % de la B_{lim}.

INTRODUCTION

Yellowtail flounder (*Limanda ferruginea*) is a righteye flounder occurring in the northwest Atlantic Ocean between Chesapeake Bay and 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 report for this stock was produced in 1997 and the most recent one was produced in 2002 (Poirier and Morin 2002). A quota of 300 t for Yellowtail flounder in NAFO Div. 4T has been in effect since 2000.

This report 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.

FISHERY DESCRIPTION

MANAGEMENT MEASURES

Historically, gear mesh size and fishing season were the key management measures on southern Gulf 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 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. By 1995, the mesh size for Winter flounder fishing in Northumberland Strait remained at 130 mm, but increased to 135 mm in Chaleur Bay, Miscou and the Shediac Valley. The Conservation Harvest Plan for 1998 set the minimum cod-end mesh size for Yellowtail flounder at 140 mm throughout 4T. At present, minimum cod-end mesh size is 145 mm square; however, on the Magdalen Islands, 140 mm is permitted when directing for Yellowtail flounder. From 2001 to 2012, trawlers in the Magdalen Islands bait fishery were permitted cod-end meshes of 120 and 130 mm.

The following table summarizes other management measures that have been in effect for 4T Yellowtail fisheries:

Management measure	Specifics
Test fishery prior to opening	Yes, where there is a high probability of cod by-catch
By-catch limits	Cod: 5% daily, fixed gear; 10% per trip, mobile gear Hake & other: 10% daily
Departure hail-out required	Yes
Observer coverage	10% Magdalen Islands; 25% elsewhere in 4T
Dockside monitoring	100%, but not bait fishery on Magdalen Islands
Small fish protocol, all species	Yes
Gear, minimum mesh size	145 mm gillnets & mobile gear (140 mm Yellowtail directed)

LANDINGS

Preliminary landings of Yellowtail flounder for NAFO Div. 4T in 2015 were 102 t, near the lowest recorded levels of 82 and 86 t of the available time series, which were observed in 2013 and 2014 (Table 1; Fig. 2). Yellowtail catches have fluctuated widely over the available time series, though 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 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 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 2). The fishery has been increasingly dominated by boats originating from the Magdalen Islands in NAFO unit area 4Tf (Table 2, Fig. 1 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 4Tl; Table 2 and Fig. 4). The Magdalen Islands Yellowtail flounder fishery is mainly destined for lobster bait in a near-shore fishery that also targets Winter flounder and Windowpane flounder; 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. Catch distribution maps by time period are shown in Figure 4.

In the 1980s and 1990s, Yellowtail landings were reported mainly from August to November. Since then, most catches have tended to occur earlier, in May to June, although in 2014 and 2015 a third of landings were made in July (Table 3, Fig. 3). The shift to early fishing coincided with the concentration of the Yellowtail 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. 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 landings in most years; since then, trawlers have been dominant, contributing roughly 70-80% of landings since 2011 (Table 4; Fig. 3).

The importance of bait fishing cannot be over-emphasized in the development of the 4T Yellowtail 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 from 2000 onward, a 300 t quota has remained in effect. This level of harvest was insufficient to supply the Japanese market and the Yellowtail resource on the Magdalen Islands reverted to bait fishing.

From 2001 to 2012, the DFO Quebec 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 2009). 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.

COMMERCIAL CPUE ANALYSIS

Annual Catch-per Unit Effort (CPUE) of Yellowtail flounder was calculated from logbook data for the period 1985 to 2015 for NAFO Div. 4T. Net immersion time was either not recorded or was 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. The vast majority of catches are from day trips (~95%) or trips where fishing occurred over a single day (~99%).

There were 14,806 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. As there were very few (22 records) null catches in the data set, these were removed from the CPUE analysis and log-transformed catches were analyzed. The number of observations used in the analysis was 14,284. A linear mixed effects model was applied to the data.

$$\ln \mu_{ijkl} = \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_k + \upsilon_l + \varepsilon_{ijkl}$$

$$\upsilon_l \sim N\left(0, \sigma_\upsilon^2\right) \text{ and } \varepsilon_{ijkl} \sim N\left(0, \sigma_j^2\right)$$

where I = 1,…,31 indexes fishing year, j = 1,2 indexes fishing gear, k = 1,…,7 indexes fishing month and l = 1,…,425 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. 2016; R Core Team, 2014).

The interaction term between year and gear was found to be significant ($F_{1,13792}$ = 19.14, p < 0.0001), as was the additive month term ($F_{6,13792}$ = 23.2, p < 0.0001). Model predictions for the month of June were performed over the time series by gear type (Fig. 5). Model residuals for a number of covariates are shown in Figure 6. Intra-class correlation for the vessel effects was 0.65 for trawlers and 0.53 for seiners.

Figure 6 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.

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. 240 kg and peaking in 1996 to 1997 for seiners at approx. 440kg. Since then, catches have decreased to low levels, below 50 kg for the period 2010 to 2015. The decreasing trend reflects not only the performance of the fishery, but also wider changes in practice of the fishery towards a larger number of small vessels operating in near shore areas.

Immersion Time

As background information, the mean immersion time of available data by year and type of fishing gear is shown in Figure 7. 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.

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. We reiterate that the accuracy and validity of these data should be kept in mind when interpreting the results.

FISHERY-DEPENDENT DATA

CATCH-AT-LENGTH

Annual catch-at-length estimates for Yellowtail flounder in NAFO Div. 4T were generated from pooled commercial and observer-at-sea samples, gathered from 1985 to 2015. Table 5 and Table 6 show the number of commercial and observer-at-sea length-frequency samples by year, gear and season, as well as the total number of fish measured by group.

Prior to calculating the catch-at-length, individual commercial length-frequency samples 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 2015 period (Fig. 3). 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 8 shows the commercial catch-at-length, standardized to proportions-at-length, for NAFO Div. 4T estimated from commercial and observer samples for years 1986 to 2015. The proportions represented by trawlers and seiners are show by blue and red lines, respectively.

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 9 shows that the proportion of catches below 25 cm reached levels of approx. 80% in 2010, 2011 and 2012, then decreased to 35 to 40% in 2013 to 2015. The larger portion of small fish was landed by commercial trawlers. 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.

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 10 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-length shown in Figure 8 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-length for these years.

FISHERY INDEPENDENT DATA

SEPTEMBER MULTI-SPECIES SURVEYS

The September multi-species survey has been conducted annually since 1971. Sampling stations are distributed according to a stratified random design (Fig. 11) with strata defining areas of similar habitat and depth. Comparative fishing experiments were undertaken for each change in survey vessel and fishing gear. Inshore strata 401, 402 and 403 were added in 1984. 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 catch was weighed and a subsample of the catch (up to 200 fish) was measured for length. Length-stratified otolith samples were collected for fish ageing. Since 1985, the trawl gear used is 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, 2003b).

Abundance Indices

The overall abundance index for Yellowtail flounder shows an increasing trend in the early years of the survey (1971 to 1980) to a maximum of 40 fish per tow, followed by a decrease through 1984, then a long-term stable level at approx. 20 fish per tow from 1985 to 2015, punctuated by small annual fluctuations (Fig. 12). In contrast, catch weights show a long term decreasing trend throughout the latter two thirds of the survey series, from about 4 kg per tow to 1.5 kg per tow in recent years. Length-frequencies show that this is due to decreasing trends in mean sizes of Yellowtail catches (see below).

Due to the importance of the local Magdalen Islands fishery, a separate index was produced for the September survey strata (428, 434, 435 and 436, see Figure 11) associated with that fishery. The abundance indices for the Magdalen Islands are broadly similar to those for the whole sGSL, but with a more pronounced decrease to 1984, followed by an increase to 1995, a decrease in 2008, a peak in 2012 and a decreasing trend from 2013 to 2015 (Fig. 13). Catch weights also show a sharper decreasing trend than the abundance indices, with the more recent period from 2008 to 2015 situated at a lower level than the period from 1994 to 2006.

The relative fishing mortality-at-length (Sinclair 1998) was calculated by dividing the fishery catches at length by the September survey trawlable population abundance at length (Fig. 36). The analysis was performed by year groups 1985-1988, 1995-2000, 2001-2005, 2006-2010 and 2011-2015.

Length Frequencies

Stratified mean length-frequencies show a marked reduction in the sizes of Yellowtail caught in the September survey (Fig. 14). Modal lengths were at 29 cm during the early portion of the survey (1971 to 1995), and then began shifting during the mid-1990s to 24 cm in the early 2000s to 21-22 cm in the past ten years (Fig. 15). Annual length-frequency distributions for the past six years show no obvious changes, with the modal length and standard deviation remaining fairly stable. No indications of cohorts are discernible. Figure 16 shows that the proportion (in numbers) of fish smaller than 25 cm has gradually increased from 10% to the present level of 80-90%. The picture for the Magdalen Islands is very similar, with the modal size shift occurring mainly during the 1990 to 2005 period and recent modal lengths at 20 cm (Fig. 17).

The annual length-frequency distributions for the Magdalen Islands for the past six years show no indication of consistent trends and are more variable from year to year owing to the smaller data set being used for the analysis (Fig. 18).

Spatial Distribution

The spatial distribution of standardized Yellowtail catches (in kg per tow) from the September survey is shown in Figure 19. Yellowtail flounder are distributed along the mid-shore area throughout the sGSL. 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 (Fig. 19). Smaller catches have become more prevalent in the deeper (50 to 65 meter) part of the sGSL in recent years (1996 to 2015), between the Magdalen Islands and PEI, where there were no catches before (1971-1995). One can see this shift in habitat association curves (Fig. 20), 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.

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. Figure 21 (males) and Figure 22 (females) show the empirical proportions by year groups of three maturity states; those which are surely immature, those which are surely mature and those for which we are unsure, i.e. there is some doubt as to whether they are mature. The presence of latter unsure component 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.

Supposing that the unsure component is composed primarily of mature fish through to smaller sizes, it is expected that the trends between it and the mature components would be running in parallel as a function of fish length. This seems to be the case for the 1971-1982, 1998-2008 and 2009-2015 periods, while there seem to be marked departures between the two trends for the 1983-1989 and 1990-1997 periods. Thus we have some confidence that the maturity diagnoses at the periods which bookend the time series are correct. We note that there has been a clear shift in the mature proportions towards smaller sizes through time, reflecting a decreasing trend in size-at-maturity.

To show this, logistic regressions over length curves were fitted to the maturity data by survey year and sex. The unsure category above was treated as mature for this analysis. The size-at-maturity, the fish length at which 50% of fish are mature, was estimated for each year and sex (Fig. 23). Keeping in mind that there is some potential for bias between 1983 and 1997, there is a clear decrease from a size-at-maturity of 23-24 cm for both sexes to the present levels of about 12-13 cm. The trends associated with the intervening and potentially biased data are consistent with the broader trend, and there are few indications of strong year effects, with the possible exception of females in 1986.

A previous study estimated size-at-maturity from local near-shore experimental bait fishery samples for 2006, 2007 and 2008 (Surette and Morin 2009). The size-at-maturity estimates varied widely from 16 to 23 cm for males and from 16 to 24 cm for females. The variability of the estimates over the short study period and the highly localized provenance of the samples lead us to conclude that these were not consistent with biological norms. These are of limited value when compared to the estimates derived from the September survey, which cover most of the stock distribution in the sGSL.

Ageing and Growth

Historical ageing data were available from the September survey samples of 1972 to 1982 and aged by staff from the St. Andrews Biological Station at that time. 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. To assess possible changes in growth, a portion of the otoliths sampled from survey years 1982, 1986, 2000, 2007 and 2015 were aged by an experienced technician. Due to time restrictions, only sub-samples of collected otoliths were aged for 1986, 2000, 2007 and 2015. These were randomly selected in such a way that for each length and sex combination, a target of three otoliths were aged per year. All the samples from 1982 was re-aged as a way of comparing the new age interpretations with the previous ones. The number of valid aged otoliths by year and age is shown in Table 9.

Otoliths collected up to and including 1986 were stored in vials containing a mixture of glycerin-thymol, while those from 2000 onward were stored in dry labelled envelopes. Otoliths were aged by direct observation of annuli using a dissection microscope. A reference otolith collection for Yellowtail flounder was unavailable for this exercise and so the ager used a collection for American plaice. We felt that this was a reasonable step owing to the similarity of otolith sizes and shapes between the two species.

Previously aged versus re-aged samples for 1982 are shown in Figure 24. The plot shows that the newer values are systematically under-aged relative to the older ones. On average, they are biased by one year across all age groups.

We pose the following hypotheses:

- The glycerin/thymol solution used as a stabilizer in 1982 (as well as those 1986) seems to have resulted in otoliths which were in a somewhat fragile state in a portion of the samples observed. While the nature of the chemical process is not known, one may conjecture that the quality of the edge of the otolith may have been compromised, leading to under-estimates of age.
- An alternative, but not necessarily disjoint hypothesis, is that the agers between the two periods have differing interpretations of certain aspects of the otolith, namely how the nucleus or the edge of the otolith is tabulated in the final age assessment.

We note that the first hypothesis would lead to an ageing bias which would lie somewhere between 0 and 1, but not exactly at 1, as was observed. The observed bias under this hypothesis would imply that the chemical process was uniform across samples and otolith sizes. While the observed bias may be more consistent with the second hypothesis, even if we subtract one year from the previous ages, the ages only matched about 45% of the time, so there is some doubt as to the degree of consistency between the two agers and methods.

Mean lengths-at-age by year are shown in Figure 25. The top panel shows the curves for the raw data while the bottom panel shows the historical data curves (1972-1982), offset by one year. The raw data shows that previously aged samples have the lowest mean sizes with respect to re-aged values. However, including a one year offset for these data led to curves which are similar between the 1970s and those from the 2000s. The curve corresponding to 1986 lies well above those of other years, including that of the re-aged data for 1982. To a lesser degree, the curve for 2000 also lies above those of other years, but only for younger ages.

Summarizing these results is difficult because of the uncertainty in the ageing methods between the historical and present exercise. There does not seem to be a systematic change in growth throughout the time series, as was observed in the size-at-maturity series. The series for 1986 lies at a much higher level than either the 1970s or the 2000s, which under the assumption of a one-year offset, are very similar. Possession of a reference collection for Yellowtail flounder would eliminate some doubts as to the quality of the readings of the dry-stored otoliths. Further readings from the 2000-2015 series would also shed light on the interannual variation that is to be expected from the survey data. More information on the physical condition of earlier otoliths would allow us to make more informed interpretations of the earlier data.

Dwyer et al. (2003) showed that direct ageing of otoliths was significantly biased when compared to more reliable methods, such as thin sectioning, tag-recapture and bomb radiocarbon assays in Yellowtail flounder from the Grand Banks of Newfoundland. However, such biases were only found in fish older than seven years. In the sGSL, Yellowtail flounder are much smaller than those found in the Grand Banks and older fish represent but a small fraction of fish caught in the September survey.

Faced with these uncertainties, the growth data used for the population model, which covers the period from 1985-2015, was chosen to be from 2000, 2007 and 2015 pooled together, with 1986 not being considered as reliable. Based on a von Bertalanffy model fit to these data, asymptotic length is estimated to be 36 cm (Fig. 26).

MOBILE SENTINEL SURVEYS

Annual Mobile Sentinel surveys have been conducted by active commercial groundfish fishermen to provide complimentary data on fish abundance using gear and timing which mimic some aspects of the modern fishing fleet. The mobile Sentinel survey in its current form has been conducted annually since 2003 during the month of August by four otter trawlers, following the same stratified-random experimental design as the September multi-species survey (Fig. 11). Over the time series (2003-2015), a total of 11 different vessels have participated in the survey (Table 8). The protocol calls for tows to be performed during daylight hours with a target tow distance of 1.25 nm and speed of 2.5 knots. The trawl is an otter trawl, but not of the same type as that of the September survey and the cod-end liner has a mesh size of 40 cm compared to 19 mm in the September survey. Further information on the mobile Sentinel survey can be found in Savoie (2014).

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 used the following negative binomial model:

$$n_{ijk} \sim NegBin\left(\mu_{ijk}, \theta\right)$$

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

where i = 1,…,13 indexes survey year, j = 1,…,29 indexes survey stratum, and k = 1,…,11 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 (R Core Team 2014).

Catches were adjusted to that of the Miss Lamèque vessel. The estimated catch coefficients were as follows: the Line Guy x 5.4, the Cap Adèle x 0.37, the Atlantic Quest I x 2.6, the Tamara Louise x 4.3 and the J.L.S.R. x 0.21. Prior to analysis, catches were adjusted to a standard tow length of 1.25 nm and adjustments for vessel effects were applied. Stratified mean abundance and biomass indices were calculated by year and are shown in Figure 27 for the sGSL and Figure 28 for the Magdalen Islands strata. Contrary to the indices from the September survey, the trend from 2003 to 2015 for the Sentinel survey shows a ten-fold gradual decrease in both abundance and biomass, for both the sGSL and Magdalen Islands indices. This decrease 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. Supposing the mean size of fish goes down, as was observed in the September survey catches, Yellowtail flounder would effectively be selected out from the Sentinel catches.

Figure 29 and Figure 30 show the stratified mean length-frequencies for the mobile Sentinel survey catches from 2003 to 2015 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 2015 that sampling variability becomes an issue (Fig. 29). For the Magdalen Islands strata, there is no clear change in length-distribution owing to the smaller sample sizes (Fig. 30).

Spatial Distribution

Figure 31 shows the spatial distribution of Sentinel survey catches from 2003 to 2015. Mobile Sentinel Yellowtail catches off the North and western coasts of PEI in 2003 and 2004 were absent in subsequent years, as were catches to the north of the Magdalen Islands. There were Yellowtail catches to the west of the Magdalen Islands throughout most of the time series but catches declined to low levels in recent years. There were no large catches of Yellowtail flounder in the survey from 2013 to 2015. As for the abundance index, this is most probably due to the survey trawl being unable to retain smaller fish as efficiently as that of the September multi-species survey.

SNOW CRAB SURVEY - GROUNDFISH DATA

Description

An annual snow crab trawl survey has been conducted in the sGSL since 1988 (Moriyasu et al. 2008, 2016). 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 32 shows the survey area, the underlying grid stratification and the locations of the stations sampled for groundfish, in particular Yellowtail flounder, from 2010 to 2015. We note that 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, results are not expected to be adversely affected. Further information on this survey may be found in Moriyasu et al. (2008, 2016).

This survey is designed to have a spatially homogeneous distribution, so abundance indices (Fig. 33) and mean length-frequencies (Fig. 34) were simply calculated as averages of the observations, scaled to the level of the catch when sub-sampling occurred and standardized to abundance per km^2 using the calculated swept area of the trawl tow.

Abundance Index

Mean catches of Yellowtail flounder in the snow crab surveys 2010 to 2015 are shown in Figure 33. There is an apparent 4 to 5 fold decrease in the mean density from approx. 6000 fish per km^2 in 2010 to approx. 1000 fish per km^2 in 2015. Confidence intervals for these estimates are rather large, owing to the low number of sampling stations with Yellowtail catches (approx. 32% overall). However, the observed decline is consistent with that observed in the latter part of the mobile Sentinel survey index.

Length Frequencies

Length-frequency distributions of Yellowtail by year are shown in Figure 34. While the snow crab survey and the mobile Sentinel surveys have identical mesh sizes in the cod-end (40mm), 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 length-frequency distributions for the snow crab survey data resemble those of the September survey (codend mesh size of 19mm, Fig. 15). As was the case for the September survey and the Sentinel survey, there is no apparent shift in fish size between 2010 and 2015. 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.

Spatial Distribution

Figure 35 shows the spatial distribution of snow crab survey Yellowtail catches from 2010 to 2015. The number of stations which caught Yellowtail flounder in the snow crab survey was too low to make strong inferences regarding changes in spatial distribution over the short time series. We do note the absence of strong catches around the Magdalen Islands in 2015, though this may be due to the absence of sampling stations in previously abundant areas.

FISHING MORTALITY

Figure 36 shows the relative fishing mortality as a function of fish size for five time periods spanning 1985 to 2015. Relative fishing morality is defined as the ratio of commercial catch in numbers-at-length, to the trawlable population-at-length from the September survey. This index is meant to provide a relative measure of fishing pressure through time, relative to the survey abundance. The figure shows that during the period from 1995 to 2015 there was much higher fishing mortality for smaller fish from 20-27 cm than during the 1985 to 1988 period. The period from 2001 to 2010 has a peak fishing mortality at 27 cm and a decrease at larger sizes. The period from 2011 to 2015 does not show this decrease, but the number of fish beyond 27 cm size in commercial and survey catches may be too small for proper estimation. This phenomenon may be a result of the local Magdalen Islands fishery catching smaller fish than is observed in the survey over the entire sGSL.

REFERENCE POINTS

Figure 37 shows the catch indices for large (>= 25 cm) Yellowtail flounder from the September survey (see Table 7 for data). This index was used to derive a proxy value for B_{msy}, defined as the average index over a productive period from 1977 to 1997. The value corresponding to this B_{msy} proxy was 2.64 kg per tow. The upper stock reference (B_{USR}) was set at 80% of this value equal to 2.12 kg per tow and the limit reference point (B_{lim}) was set at 40% of B_{msy} proxy, a value of 1.06 kg per tow. The index for 2015 was 61% of B_{lim} and the index has been below B_{lim}, i.e. in the critical zone, since 2006.

POPULATION MODELLING

METHODS

A length-based age-structured model was developed to examine the dynamics and status of the Yellowtail flounder stock from the sGSL The population dynamics assumed in this model are described by the following equations:

$$N_{a+1,y+1} = N_{a,y} e^{-(F_{a,y}+M_{a,y})} \tag{1}$$

$$C_{a,y} = \left(\frac{F_{a,y}}{F_{a,y}+M_{a,y}}\right) N_{a,y} \left(1 - e^{-(F_{a,y}+M_{a,y})}\right) \tag{2}$$

$$r_y = e^{R_0 + rdev_y} \quad (3)$$

where $N_{a,y}$ represents population abundance at age a in year y, $F_{a,y}$ and $M_{a,y}$ are the instantaneous rates of fishing and natural mortality, respectively, at age a in year y, and $C_{a,y}$ is the fishery removal in numbers at age a in year y. Years spanned 1985 to 2015. Earlier years were omitted due to a lack of reliable fishery catch data. M was estimated separately for five time blocks (6-year blocks between 1985 and 2008 and a final 7-year block) 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+ groups represents fish 8 years and older). Abundance at age 1 (i.e., recruits r_y) was set equal to average recruitment (R_0) 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. Age and year effects on F were assumed to be separable:

$$F_{a,y} = s_a F_y \quad (4)$$

where F_y is fully recruited F in year y and s_a is fishery selectivity for age a. Fishery selectivity-at-age was allowed to vary between three time periods: 1985 to 2008, 2009 to 2012 and 2013 to 2015. 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:

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

Catchability-at-age to the RV survey ($q_{a,y}$) was also modelled as a logistic function of selectivity at age (s'_a) times the fully-recruited catchability (q):

$$q_{a,y} = s'_a q \quad (5)$$

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 and 2015 (Fig. 38). 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_0), annual recruitment deviations from 1986 to 2015 ($rdev_y$), 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), M for the two age groups in each of five 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 was estimated to be q = 1.4, with the survey indices at the scale of trawlable abundance. For a small flatfish like Yellowtail flounder, 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, based on estimates of catchability of flatfish (plaice) to survey trawls obtained by Harley and Myers (2001). For a flatfish 30-35 cm in length, their estimate for q was about 0.3. A prior for log(q) with a mean of -1.14 (q = 0.32) and SD = 0.1 was used in the 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).

Models were implemented using AD Model Builder (Fournier at 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 200,200 MCMC samples, with the first 200 samples discarded and every 40th subsequent sample retained to reduce autocorrelation, yielding a sample of 5,000 iterations from the joint posterior distribution of the parameters and derived variables.

RESULTS

The model fit the abundance indices fairly well (Fig. 39), though the small fish index tended to be underestimated in recent years. 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. 40).

Estimated catchability to the RV survey was near zero for age 1 fish (0.008), increasing to 0.25 by age 8+ (Fig. 41). Estimated fishery selectivity in 1985 to 2008 was less than 0.01 for ages 1-3 years and then increased rapidly with age, particularly after age 5 (Fig. 41). Fishery selectivity for young ages was much higher in the 2009 to 2012 period. Fishery selectivity returned to a very low level for ages 1-3 years in 2013 to 2015.

Uncertainty in abundance estimates was high, especially for the youngest age group (Fig. 42). The median estimate of abundance of 1-3 year olds increased steadily from about 600 million in 1985 to a peak of 1.3 billion in 2012 (i.e., about double the initial abundance). The median estimate of abundance for four and five year olds was about 70 million in the 1980s, increasing to an average value of 350 million since 2000. The median estimate of 6+ abundance was about 100 million in the mid-1980s, decreasing to 11 million in 2014, a 90% decline.

The median estimate of spawning stock biomass (SSB) was 55 to 60 kt in the 1980s, increasing to 110 kt in the early 2000s and then declining slightly to 75 to 90 kt (Fig. 43). Uncertainty in the estimates of SSB was also high. The age composition of the SSB is estimated to have changed dramatically since the mid-1980s. Fish 7 year and older are estimated to have contributed 40% of the SSB in 1985 to 1990, declining to less that 0.5% of the SSB since 2013. In contrast, the estimated contribution of 3 and 4 year old fish to the SSB increased from 27% in the 1980s to 59% since 2000.

The median estimate of recruitment fluctuated without trend between 350 and 550 million individuals (Fig. 44). The estimated recruitment rate (the abundance of recruits divided by the SSB producing them) was above average in the late 1980s and early 1990s and since about 2010.

Large changes in estimated natural mortality occurred between time periods, with the changes in opposite directions for large and small individuals (Fig. 45). For young fish (ages 1-3), the median estimate of M in 1985 to 1990 was 0.76 (53% annual mortality), declining to 0.17 to 0.23 (16 to 21% annually) since 1997. In contrast, for older fish (aged 5 years and older), the median estimate of M in 1985 to 1990 was 0.25 (22% annually), increasing to 1.99 (86% annually) in 2009 to 2015. Note that the estimate in 2009 to 2015 was at the upper bound permitted for this parameter.

Fishing mortality is estimated to be very low on the younger ages (Fig. 46). For age 2, F was below 0.0002 in all years except 2009 to 2012, when it increased to an average of 0.001. For age 4, F was also lowest early in the time series (1985 to 1996, mean F = 0.0003), increasing to a mean of 0.002 in 1997 to 2008, 0.003 in 2009 to 2012 and 0.002 in 2013 to 2015, all very low values. For 6 year olds, F averaged 0.0027 early in the time series, increasing to an average value of 0.017 in 1997 to 2008, and then declining to an average of 0.005. The pattern in F was similar for fish aged 8 years and older, averaging 0.012 prior to 1997, 0.076 from 1997 to 2008 and 0.0055 since 2009.

A retrospective analysis was conducted to determine the consistency of model estimates as years of data were added or removed (Fig. 47). Adding or removing years of data had little impact on the time trends in the estimates but did affect the overall level of the estimates. Estimates were nearly superimposed for analyses ending in 2013 and 2014, and were generally very close to the estimates produced with data up to 2015. The largest change in level occurred when three years of data were removed (data ending in 2012). This change in level is likely mostly due to changes in the estimates for M in the last time block as the amount of data available to make these estimates decreases from 7 years to 4 years. This is illustrated by an analysis in which the size of the last time block was increased to 11 years (Fig. 48). In this analysis, estimates vary little between models with 0, 1 or 2 years of data removed. Furthermore, the direction of change as data are removed is not consistent. For example, estimated SSB in 2013 decreases slightly when one year of data is removed and increases slightly when two years of data are removed (Fig. 48). This suggests that there is no consistent bias in the estimates.

DISCUSSION

The population model indicates that there have been large changes in natural mortality in this population. For small fish, natural mortality was relatively high in the 1980s, declining to lower levels in the 1990s. In contrast, the natural mortality of large fish was relatively low in the 1980s, increasing steadily to very high levels since then. These changes in natural mortality provide an explanation for the increasing abundance of small fish and the decreasing abundance of large fish. These are also consistent with the changes in productivity observed throughout the marine fish community of the southern Gulf of St. Lawrence (Benoît and Swain 2008; Swain and Benoît 2015). For all sizes of Yellowtail 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. However, the population model is at the scale of the entire southern Gulf whereas fishing activity is 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.

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 200,000 MCMC samples, with every 40th sample saved. Natural mortality was set at the levels estimated for the 2009 to 2015 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 vales in the last ten years. Projections were conducted at three levels of annual fishery catch: 0, 100 and 300 tonnes.

Estimated SSB declined slowly but steadily over the projection period even with no fishery catch (Fig. 49). The decline was negligibly greater with catches of 100 t and slightly greater with catches of 300 t. As in the historical period, uncertainty in the level of SSB was great during the projection period.

Estimated abundance of fish 6 years and older declined slightly (with fluctuations) during the first half of the projection and then leveled off (Fig. 50). Final abundance was highest with no catch and slightly lower with catches set at 300 t. In all cases median abundance was above the 2014 level, with uncertainty again very high. Abundance of fish aged 4 – 5 years declined to about the 2014 level early in the projection with negligible further declines later in the projection. Estimated abundance differed very little for catch levels of 0 to 300 t. At the scale of the sGSL, natural mortality appears to be the dominant factor affecting stock status.

CONCLUSIONS

Yellowtail flounder is currently caught in a relatively small directed fishery with landings less than about 200 t over the past 14 years. It is primarily concentrated around the Magdalen Islands and supplies the market for bait. Despite a minimum size limit of 25 cm, the proportion of the sampled catch that is less than 25 cm has increased rapidly from less than 20% before 2000 to a peak of 75% in 2010. This has declined slightly, to less than 40% in the past three years.

There has been a decrease in the modal length of Yellowtail in the sGSL. Abundance indices from the September survey show that small (< 25 cm) Yellowtail abundance has increased whereas large (>= 25 cm) Yellowtail abundance has declined. The proportion of survey catches (in numbers) which are less than 25 cm has increased from less than 20% before 1990 to almost 80% by 2011, but decreased slightly to 60% in 2015. This identical pattern of abundance and size distribution was also observed for the survey strata around the Magdalen Islands.

Natural mortality on larger and older Yellowtail flounder is estimated to have increased from 22% annual mortality during 1985 to 1990 to 86% in 2009 to 2015. In contrast, natural mortality on small and young Yellowtail is estimated to have declined from 53% annually in 1985 to 1990 to 16-21% annually since 1997.

Although SSB is estimated to be higher in the past decade than in the mid to late 1980s, the proportion of the SSB composed of larger and older (7+ years) fish has declined from 40% in 1985 to 1990 to less that 0.5% since 2013. The estimated contribution of 3 and 4 year old fish to the SSB increased from 27% in the 1980s to 59% since 2000.

Fishing mortality is estimated to generally be very low, for both size groups and for most ages and years. Fishing mortality is such a small proportion of the estimated total mortality of Yellowtail that there is no perceived difference in stock trends over the next five years at catch projections of 0 t, 100 t, and 300 t annually.

A limit reference point for this stock (B_{lim} = 1.06 kg pr tow) was derived from the commercial sized (>= 25 cm) biomass index from the RV survey. Based on this index, the stock decline began in 1998 and the index reached the lowest value of the time series in 2012. The stock has been in the critical zone since 2006. The abundance index in 2015 was 61% of B_{lim}. The estimated SSB from the model has not changed in contrast to the large size Yellowtail index used to define the reference point. However, the SSB is now composed primarily of fish less than 25 cm, 72% of total SSB during 2011 to 2015 compared to 36% during 1985 to 1989. This is an important consideration as there is an assumed greater value to reproductive potential of larger animals in the population.

The contraction in size structure of Yellowtail flounder, the decline in the estimated size at 50% maturity from 23 to 24 cm in the 1970s to 12 to 13 cm in recent years, and the decline in abundance indices of the previously abundant commercial sized group are consistent with a stock experiencing very high mortality levels. At the scale of the sGSL, natural mortality appears to be the dominant factor affecting stock status. The causes of the high natural mortality are not fully known but available evidence supports the hypothesis that predation by grey seals is a major component of this increased natural mortality (Swain and Benoît, 2015).

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TABLES

Table 1. Annual recorded landings (t) of Yellowtail flounder and unspecified flatfish in NAFO Div. 4T, 1960 to 2015. Data from 1960 to 1995 are taken from NAFO files. Data from 1996 to 2015 are from fishery logbooks from the DFO Statistics Branch (ZIFF files). In parentheses are the landings (t) attributed to the Magdalen Islands experimental bait fishery, 2001 to 2012.

Year	Yellowtail	Unsp. flatfish	Year	Yellowtail	Unsp. flatfish
1960	2.0	2,405.0	1988	198.0	0.0
1961	7.0	2,493.0	1989	43.0	36.0
1962	2.0	1,304.0	1990	15.0	37.0
1963	51.0	0.0	1991	54.0	37.0
1964	39.0	0.0	1992	117.0	91.0
1965	51.0	0.0	1993	87.0	12.0
1966	125.0	0.0	1994	61.0	15.0
1967	55.0	0.0	1995	204.0	5.0
1968	6.0	0.0	1996	216.0	0.0
1969	243.0	0.0	1997	819.0	0.0
1970	44.0	0.0	1998	213.0	30.0
1971	5.0	0.0	1999	305.0	0.0
1972	3.0	1,201.0	2000	291.0	0.0
1973	1.0	1,388.0	2001	318.0 (5)	0.0
1974	21.0	602.0	2002	215.3 (4)	0.0
1975	0.0	2,464.0	2003	157.7 (3)	0.0
1976	29.0	668.0	2004	192.0 (8)	0.7
1977	25.0	1,163.0	2005	175.5 (8)	0.6
1978	3.0	764.0	2006	182.2 (11)	0.1
1979	52.0	841.0	2007	141.9 (18)	2.8
1980	41.0	759.0	2008	91.6 (16)	0.0
1981	10.0	118.0	2009	101.4 (34)	0.0
1982	6.0	344.0	2010	185.8 (72)	0.0
1983	26.0	792.0	2011	180.8 (62)	0.0
1984	82.0	46.0	2012	110.9 (25)	0.0
1985	215.0	3.0	2013	82.4	0.0
1986	396.0	0.0	2014	85.8	0.0
1987	404.0	0.0	2015	101.5	0.0

Table 2. Annual landings (kg) of Yellowtail flounder by subdivision in NAFO Div. 4T, 1985 to 2015. 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	1587	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
Mean 1985 to 2015	149,028	3,781	62	1,109	115	10,299	5,800	575	123	211	45	16,253	187,356

Table 3. 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	June	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	28,395	46,407	10,874	0	75	8	0	0
2015	0	0	0	95	24,193	43,091	31,141	0	0	0	0	0
Mean 1985 to 2015	0	0	0	3,391	49,754	54,285	19,590	21,855	19,191	13,615	5,640	36

Table 4. Annual landings (kg) of Yellowtail flounder in NAFO Div. 4T by gear type, 1985 to 2015. 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	1056	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	69,866	0
2015	61	0	0	0	29,291	72,168	0
Mean 1985 to 2015	750	29	31	110	124,334	61,700	322

Table 5. Summary of commercial Yellowtail flounder length frequency samples by NAFO subdivision, season and fishing gear, 1985 to 2015. In addition, there were two samples obtained from gillnets, one in 1986 and one in 2007. Shown in parentheses are the total number of fish in the samples.

		Seine		Trawl	
Year	NAFO subdivision	April-June	July-October	April-June	July-October
1985	4Tg	1 (7)	na	na	1 (55)
1985	4Tl	na	7 (815)	na	na
1986	4T	na	na	na	3 (112)
1986	4Tg	1 (112)	7 (187)	2 (16)	5 (24)
1986	4Tl	4 (230)	5 (397)	1 (72)	1 (55)
1987	4Tf	na	1 (250)	na	na
1987	4Tg	8 (219)	5 (368)	1 (7)	na
1987	4Tj	na	na	na	2 (249)
1987	4Tl	1 (156)	2 (72)	1 (8)	na
1987	4Tn	na	na	na	1 (202)
1988	4T	na	3 (464)	na	na
1988	4Tg	2 (218)	na	na	na
1988	4Tl	na	1 (10)	na	na
1992	4Tf	3 (716)	na	3 (813)	1 (259)
1995	4Tf	1 (263)	1 (250)	3 (755)	na
1996	4Tf	1 (271)	na	na	na
1997	4Tf	3 (749)	9 (2377)	na	na
1998	4Tf	6 (1438)	4 (1018)	1 (66)	na
1999	4Tf	6 (1543)	1 (254)	na	na
2000	4Tf	6 (1429)	1 (251)	na	na
2001	4Tf	4 (1012)	na	na	na
2002	4Tf	6 (1469)	na	na	na
2002	4Tg	na	na	na	2 (332)
2003	4Tf	5 (1172)	1 (239)	na	na
2004	4Tf	3 (546)	na	na	na
2005	4Tf	4 (956)	na	na	na
2006	4Tf	3 (711)	na	1 (259)	na
2007	4Tf	3 (636)	1 (191)	1 (87)	na
2008	4Tf	3 (1032)	na	2 (317)	na
2009	4Tf	3 (730)	na	1 (120)	na
2010	4Tf	4 (738)	na	na	na
2011	4Tf	3 (605)	na	na	na
2012	4Tf	2 (258)	na	2 (206)	na
2013	4Tf	1 (200)	na	2 (262)	na
2014	4Tf	na	na	na	1 (71)
2015	4Tf	1 (250)	1 (196)	1 (209)	na

Table 6. Summary of number of length-frequency samples of Yellowtail flounder obtained by observers, by NAFO subdivision, season and fishing gear. In addition, there were five samples obtained from gillnets, two in 1996, one in 2013 and two in 2014. The total number of fish sampled are shown in parentheses.

	NAFO	Seine		Trawl	
Year	subdivision	April-June	July-October	April-June	July-October
1992	4Tf	na	na	8 (853)	na
1992	4Tl	na	na	na	1 (85)
1995	4Tf	1 (110)	na	1 (108)	na
1996	4Tf	9 (2,420)	na	na	na
1996	4Tj	na	na	na	na
1996	4Tn	na	na	na	2 (40)
1997	4Tf	2 (517)	5 (1,345)	na	na
1998	4Tf	4 (1,113)	na	2 (138)	na
2000	4Tf	4 (1,028)	na	na	na
2001	4Tf	9 (2,031)	2 (309)	na	na
2002	4Tf	1 (320)	1 (339)	na	na
2003	4Tf	10 (2,099)	2 (276)	1 (124)	na
2004	4Tf	10 (2,647)	3 (616)	na	na
2005	4Tf	10 (2,608)	1 (157)	3 (215)	na
2006	4Tf	13 (3,115)	3 (655)	7 (1,118)	na
2007	4Tf	9 (2,229)	2 (570)	23 (2,038)	2 (175)
2008	4Tf	3 (705)	1 (262)	12 (1,002)	na
2009	4Tf	5 (791)	na	23 (1,244)	na
2010	4Tf	16 (2,748)	1 (99)	20 (3,177)	na
2011	4Tf	15 (2,352)	na	34 (4,931)	na
2012	4Tf	10 (1,981)	na	38 (4,087)	6 (87)
2013	4Tf	10 (919)	na	51 (5,094)	na
2014	4Tf	3 (285)	na	29 (3,387)	2 (59)
2015	4Tf	4 (648)	6 (906)	13 (1,642)	11 (1,775)

Table 7. 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 (>= 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 >= 25 cm (kg / tow)
1971	5.4	12.9	0.051	0.864
1972	4.5	16.3	0.066	0.893
1973	8.6	9.4	0.097	1.375
1974	14.2	47.5	0.212	1.691
1975	8.7	40.4	0.229	0.756
1976	8.0	14.3	0.136	0.882
1977	23.2	66.7	0.748	2.713
1978	16.7	23	0.240	2.043
1979	28.1	32.5	0.174	3.348
1980	27.8	45.5	0.314	3.377
1981	45.1	72.2	0.553	4.907
1982	17.5	12.7	0.203	2.688
1983	27.4	25.7	0.259	3.133
1984	6.4	7.4	0.058	0.802
1985	15.4	4.4	0.174	2.690
1986	20.1	9.1	0.255	4.022
1987	15.4	11.2	0.253	2.328
1988	17.4	25.3	0.310	3.850
1989	12.6	7.3	0.351	1.567
1990	19.9	9.8	0.612	2.054
1991	20.3	22.4	0.489	3.077
1992	14.3	25.3	0.524	1.606
1993	29.8	66.0	1.158	3.003
1994	18.5	34.7	0.715	1.711
1995	21.6	55.1	0.658	3.258
1996	18.0	45.5	0.446	2.284
1997	13.8	38.6	0.620	1.071
1998	15.7	41.7	0.724	1.180
1999	19.0	55.3	1.107	1.912
2000	18.8	72.3	0.931	2.008
2001	20.7	56.6	0.940	2.160
2002	18.3	57.5	0.780	1.222
2003	15.3	40.0	0.531	0.968
2004	23.3	83.5	1.242	1.568
2005	16.0	58.1	0.962	1.015
2006	27.4	101.7	1.414	1.046
2007	21.5	50.0	0.998	0.731
2008	23.3	32.2	1.148	0.649
2009	18.8	49.5	0.913	0.407
2010	24.2	60.9	1.154	0.420
2011	16.3	64.6	0.841	0.250
2012	21.2	91.3	1.031	0.236
2013	26.6	62.3	1.397	0.475
2014	18.9	55.0	0.908	0.431
2015	18.7	34.4	0.927	0.648

Table 8. Mobile sentinel survey tows performed by each vessel in the southern Gulf of St. Lawrence, 2003 to 2015.

Year	Riding it out	Line Guy	Cape Ryan	Cap Adele	Alberto	Manon Yvon	Viking II	Atlantic Quest	Tamara Louise	Miss Lameque	J.L.S.R.
2003	50	0	0	0	52	54	0	0	0	65	0
2004	50	0	0	0	0	56	64	0	0	67	0
2005	51	0	0	0	0	56	70	0	0	68	0
2006	51	0	0	51	0	0	63	0	0	61	0
2007	0	0	0	52	0	0	65	51	0	62	0
2008	0	0	0	51	0	0	64	50	0	59	0
2009	0	0	0	42	0	0	54	44	0	48	0
2010	0	0	0	42	0	0	54	0	44	48	0
2011	0	0	0	38	0	0	53	0	41	44	0
2012	0	0	0	40	0	0	53	0	41	43	0
2013	0	0	0	37	0	0	59	0	39	35	0
2014	0	0	57	33	0	0	0	0	35	0	31
2015	0	27	56	32	0	0	0	0	0	0	27

Table 9. 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
1972	St. Andrews	0	0	2	6	32	25	56	39	4	3	0
1973	St. Andrews	0	1	6	22	17	26	35	44	19	9	2
1974	St. Andrews	0	1	26	46	53	55	44	36	21	3	1
1975	St. Andrews	0	7	29	62	38	37	25	11	6	0	0
1976	St. Andrews	0	1	8	41	46	42	29	10	6	2	0
1977	St. Andrews	0	0	15	48	71	57	51	24	5	0	0
1978	St. Andrews	0	4	15	28	59	67	72	61	26	19	6
1980	St. Andrews	0	3	22	35	69	72	50	37	18	4	2
1981	St. Andrews	0	0	10	56	48	70	34	15	2	0	0
1982	St. Andrews	0	0	3	20	58	56	74	34	4	1	1
1982 rev.	Gulf	0	3	36	61	63	71	35	11	3	0	1
1986	Gulf	17	39	30	14	18	17	4	3	1	0	0
2000	Gulf	30	36	27	33	19	12	1	0	0	0	0
2007	Gulf	36	30	24	21	21	11	3	1	0	0	0
2015	Gulf	28	20	23	26	21	7	3	3	0	0	0

Table 10. 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

FIGURES

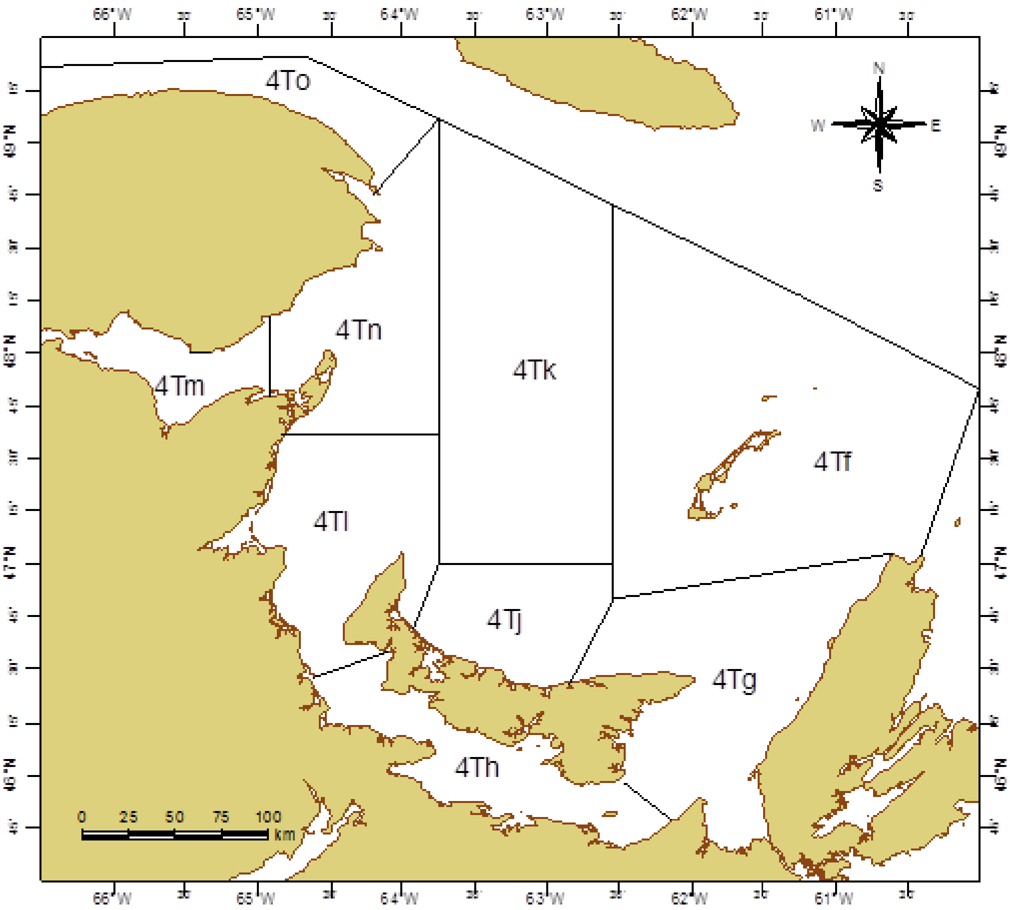

Figure 1. Map of the southern Gulf of St. Lawrence (sGSL) showing NAFO Div. 4T subdivisions.

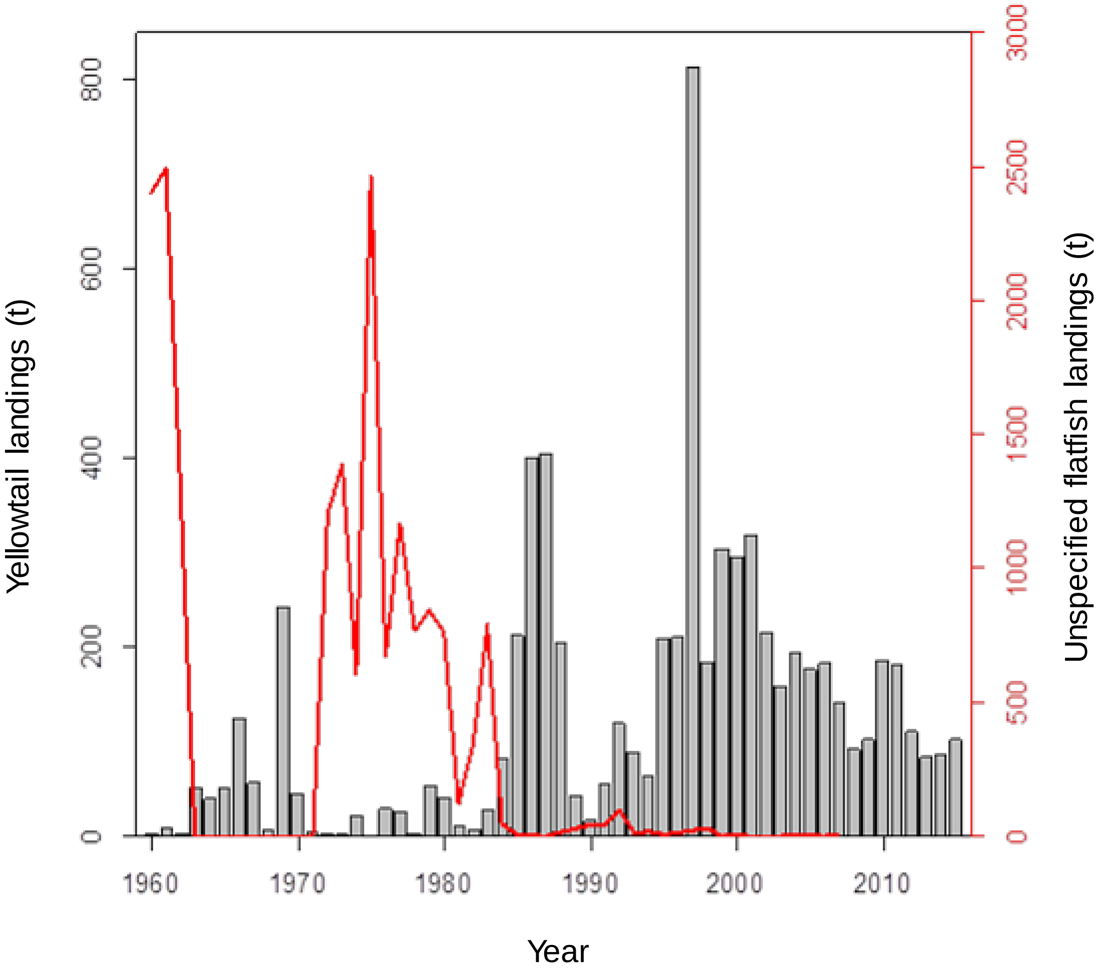

Figure 2. Yellowtail flounder landings (t) in NAFO Div. 4T from 1960 to 2014. The solid red line corresponds to landings of unspecified flatfish.

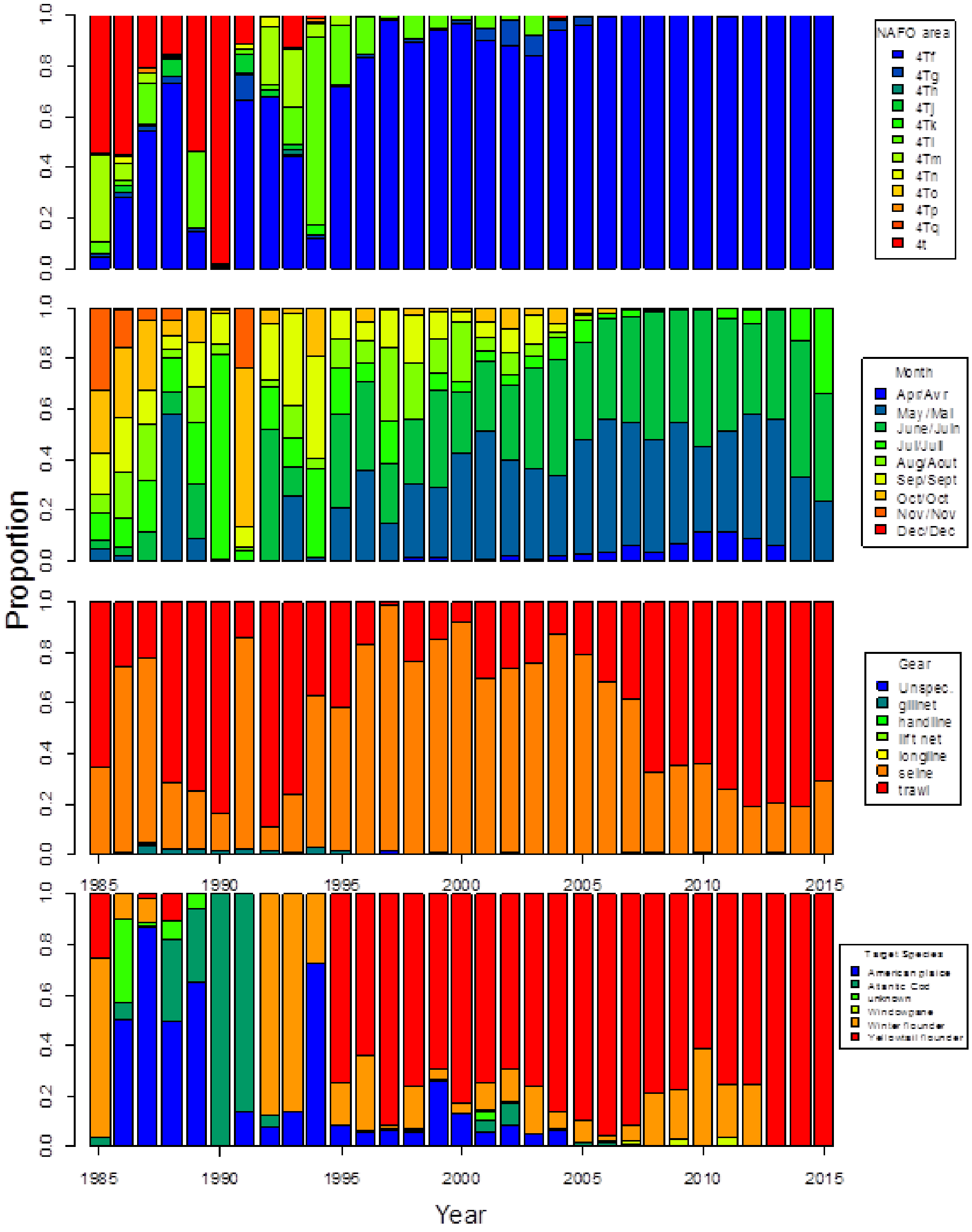

Figure 3. Proportions of Yellowtail flounder landings by year (1985 to 2015) by NAFO 4T subdivision (top panel), fishing month (second row panel), type of fishing gear (third row panel), and target fishing species (bottom panel).

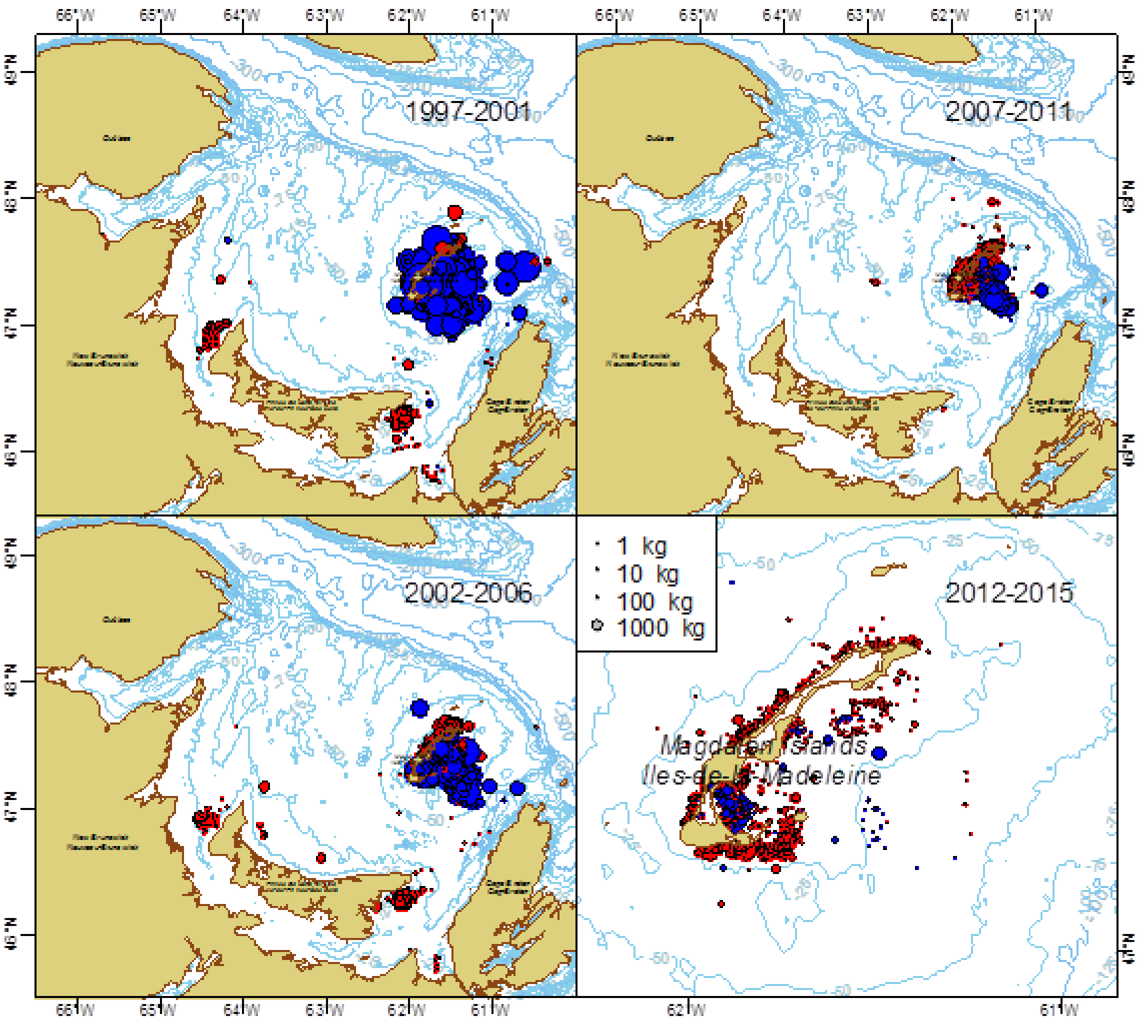

Figure 4. Spatial distribution of logbook catches of Yellowtail flounder by year and fishing gear type (trawl = red and seine = blue). The surface area of the plotted circle is proportional to the recorded catch.

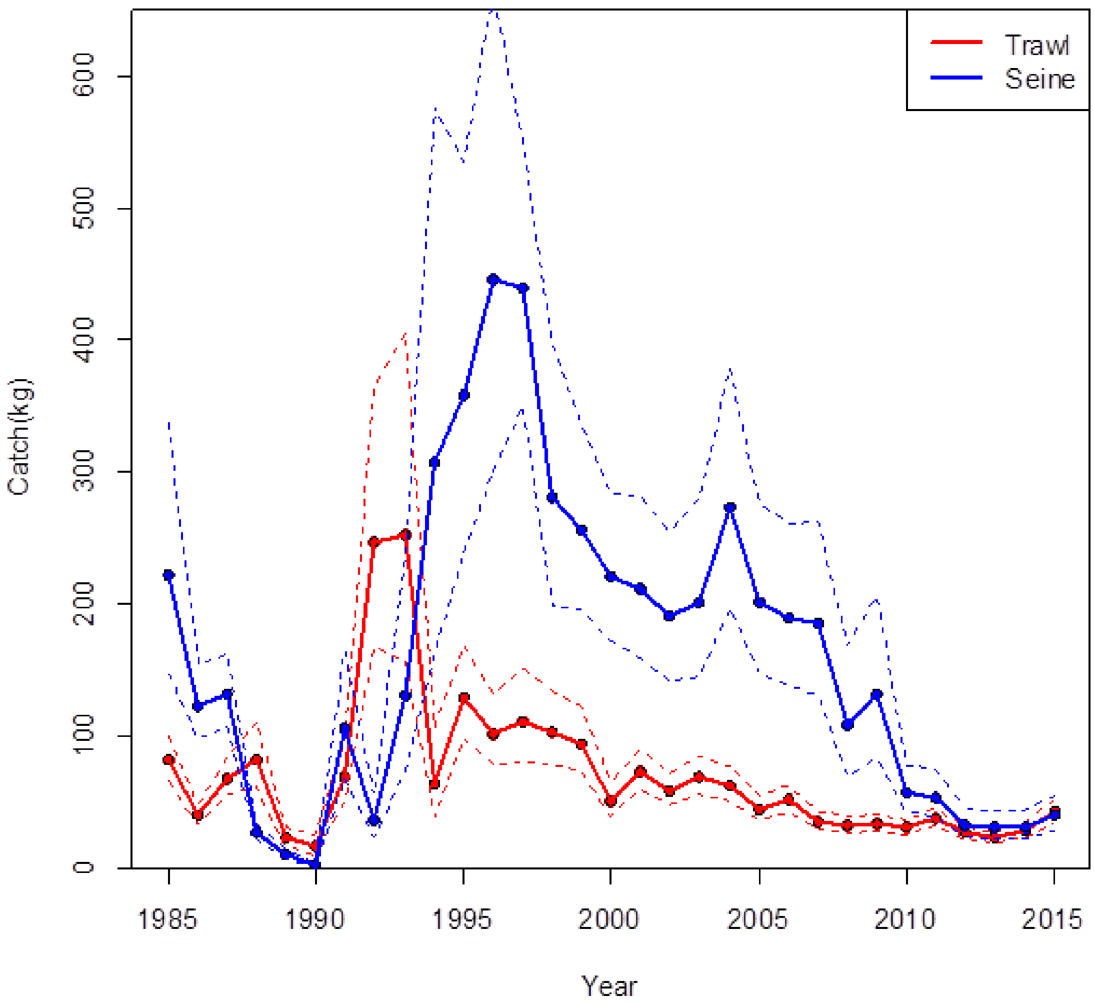

Figure 5. Time series predictions from the commercial Yellowtail flounder CPUE model by fishing gear for the month of June. Confidence intervals (p = 0.05 level) are shown as dashed lines.

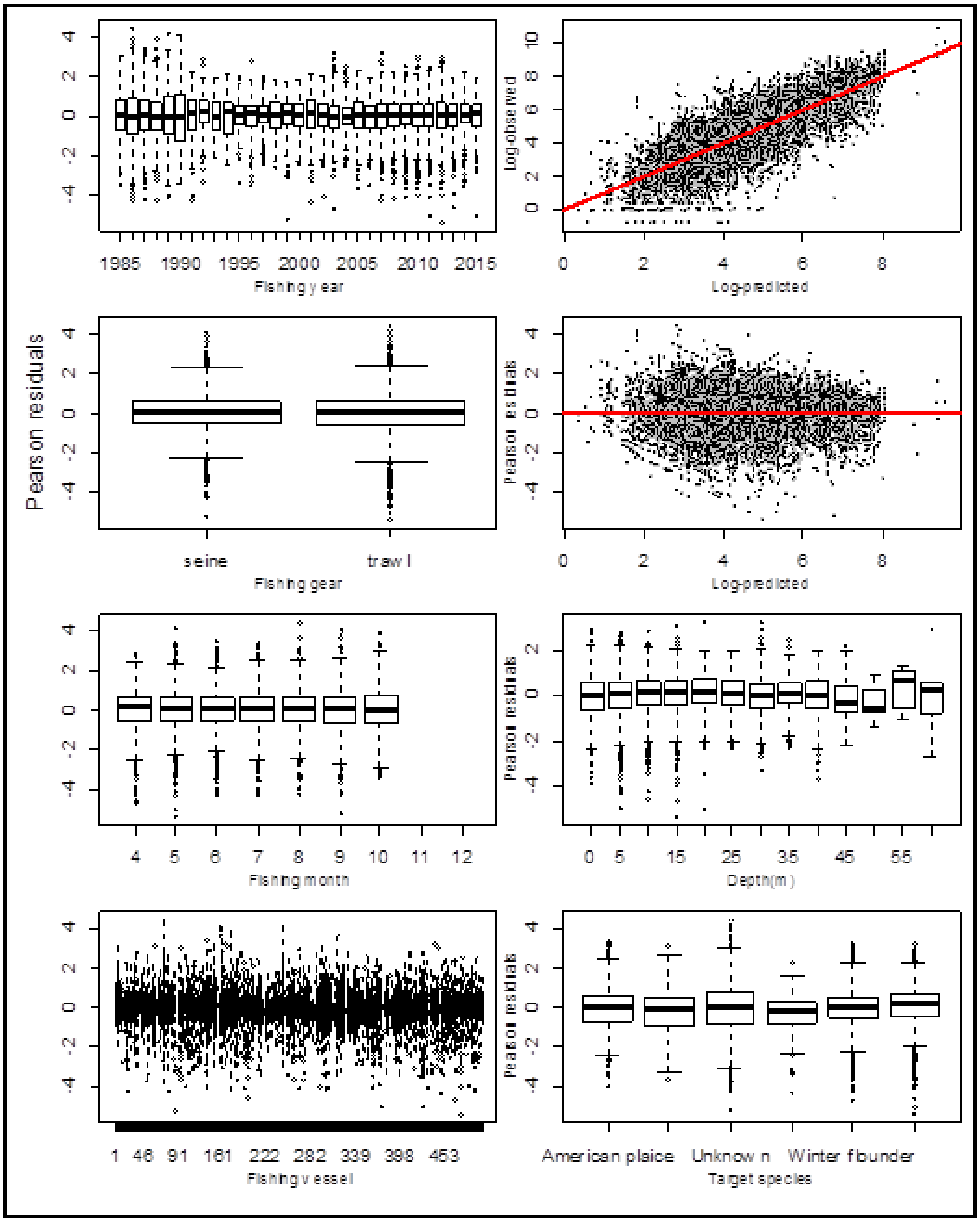

Figure 6. Residual plots of the commercial Yellowtail flounder CPUE model for various covariates and auxiliary variables, in the southern Gulf of St. Lawrence. The top-right panel shows the plot of observed versus predicted values for the model.

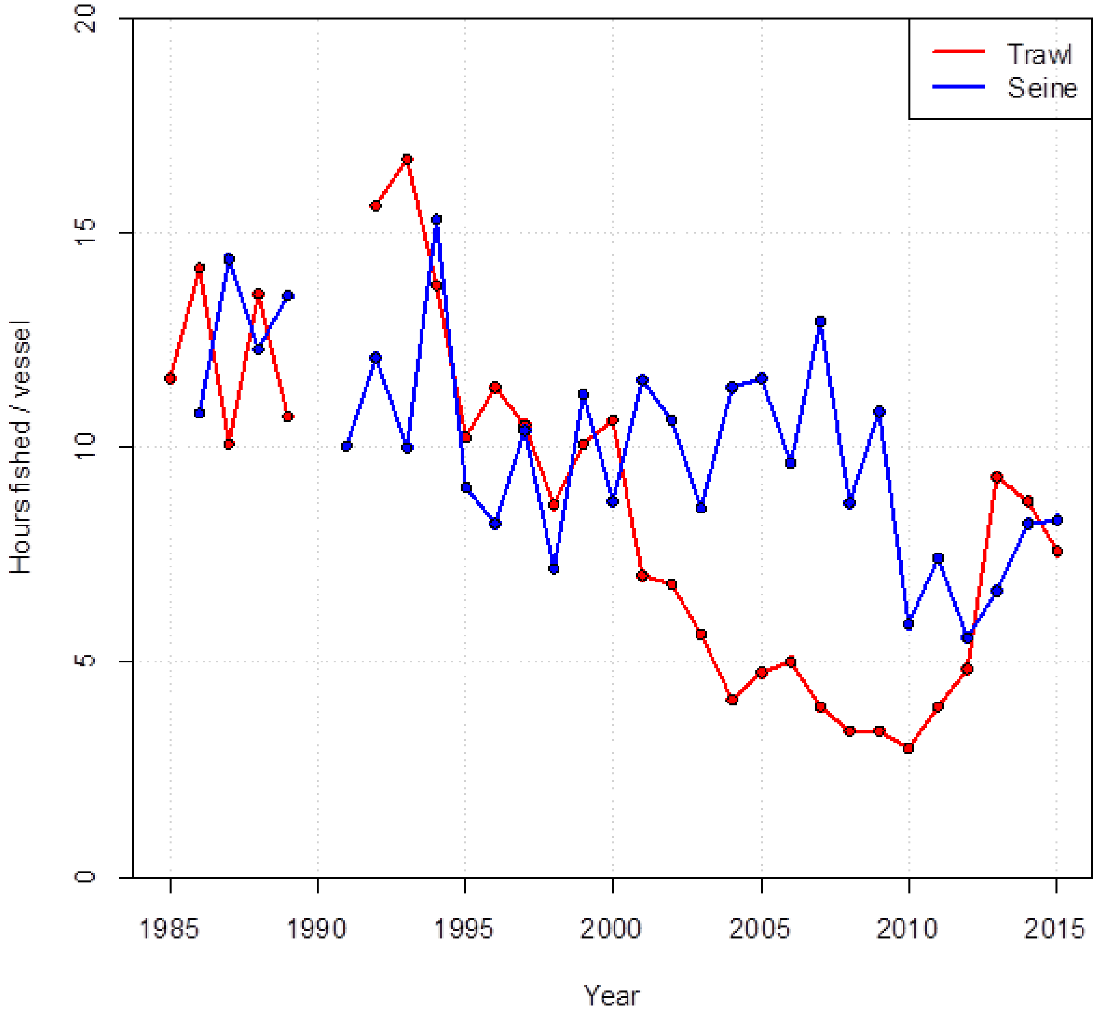

Figure 7. Mean number of hours fished by year and fishing gear type directing for Yellowtail flounder in the southern Gulf of St. Lawrence. Soak times were averaged by fishing vessel and the resulting values were then averaged over the year. Missing values were removed.

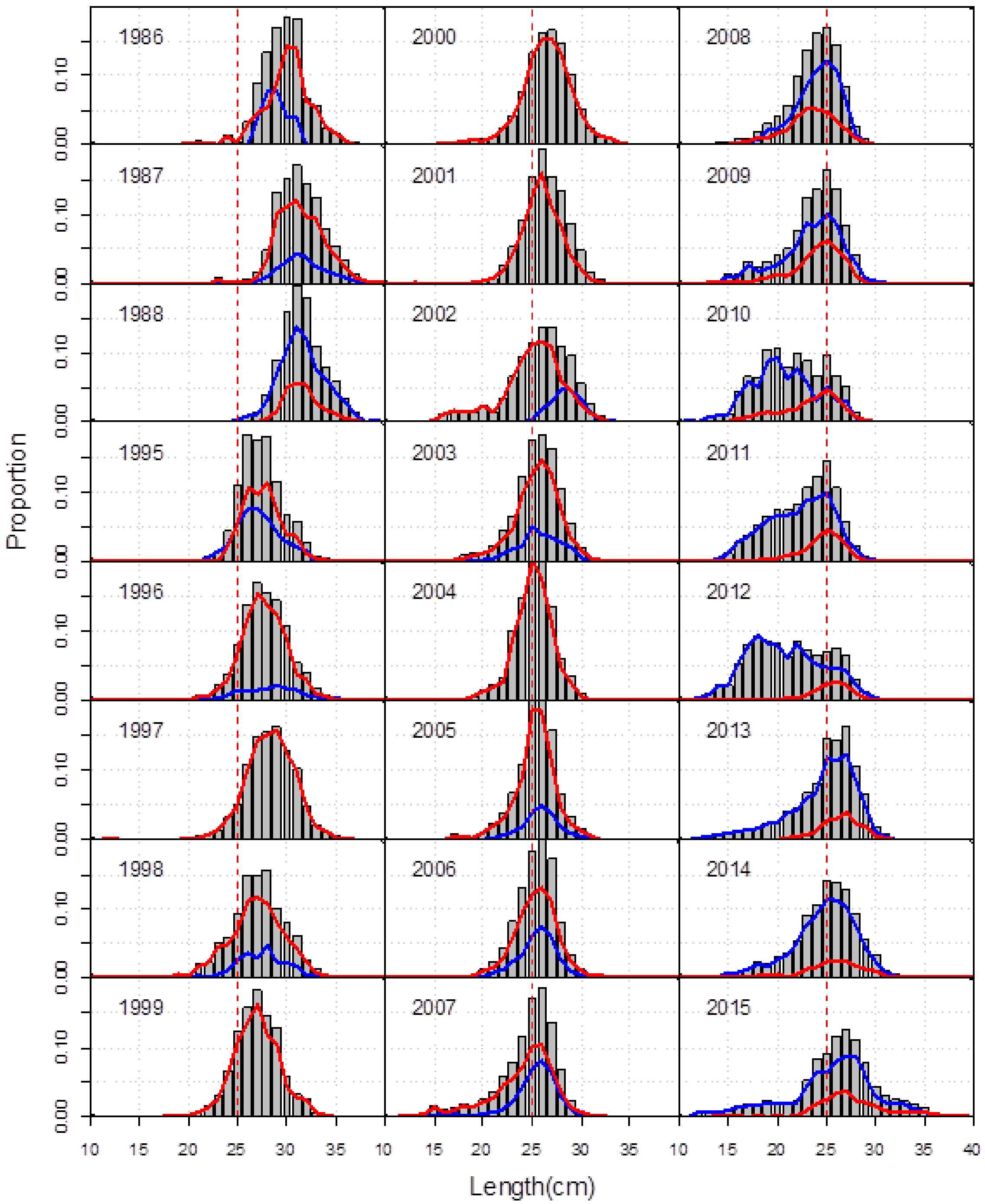

Figure 8. Proportions-at-length of Yellowtail flounder catches based on commercial and observer samples. The vertical red dashed lines correspond to the 25 cm legal size limit. Overlaid solid lines indicate portions of the total proportions represented by trawler (blue) and seiner (red) catches. Note that for certain years, no trawl samples were available (e.g. 1999 to 2001).

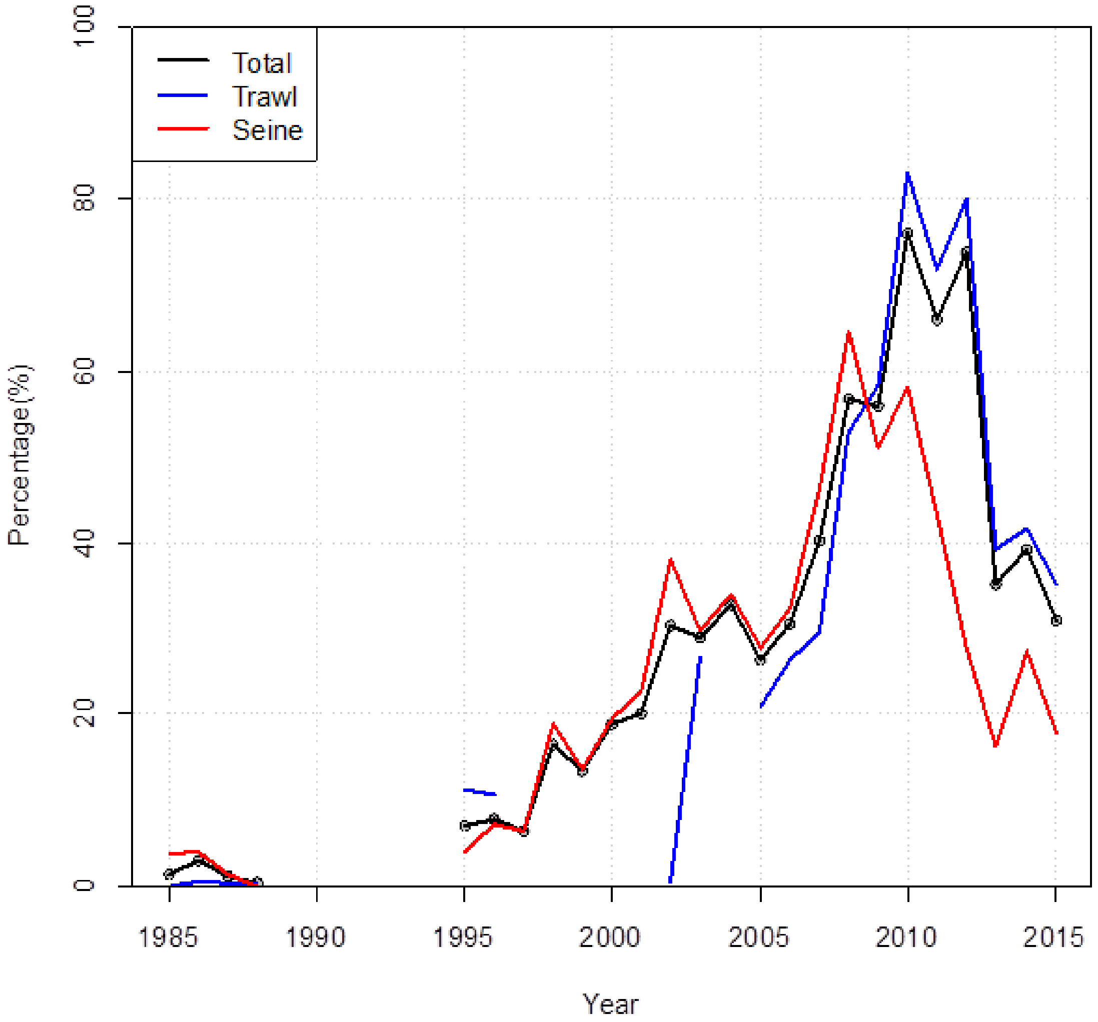

Figure 9. Annual percentages of Yellowtail flounder catches comprised of fish < 25 cm, based on catch-at-length estimates from trawl catches, seine catches, and for gears combined.

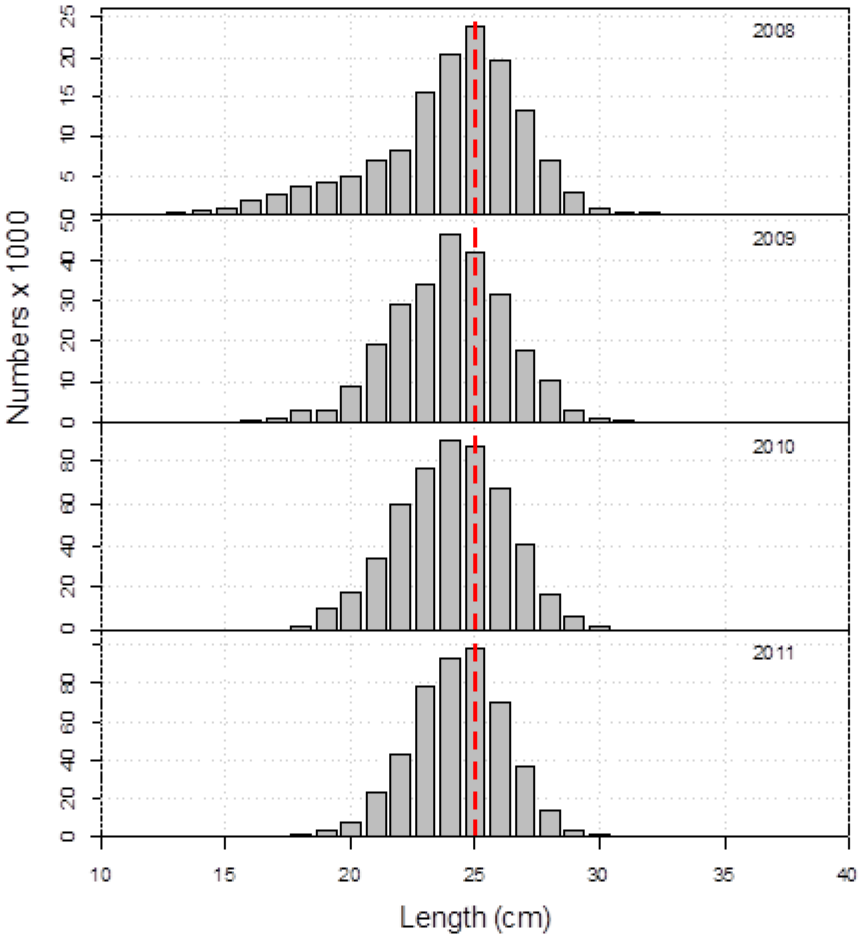

Figure 10. Length frequency distributions from port samples of Yellowtail flounder in the Magdalen Islands experimental bait fishery, 2008 to 2011.

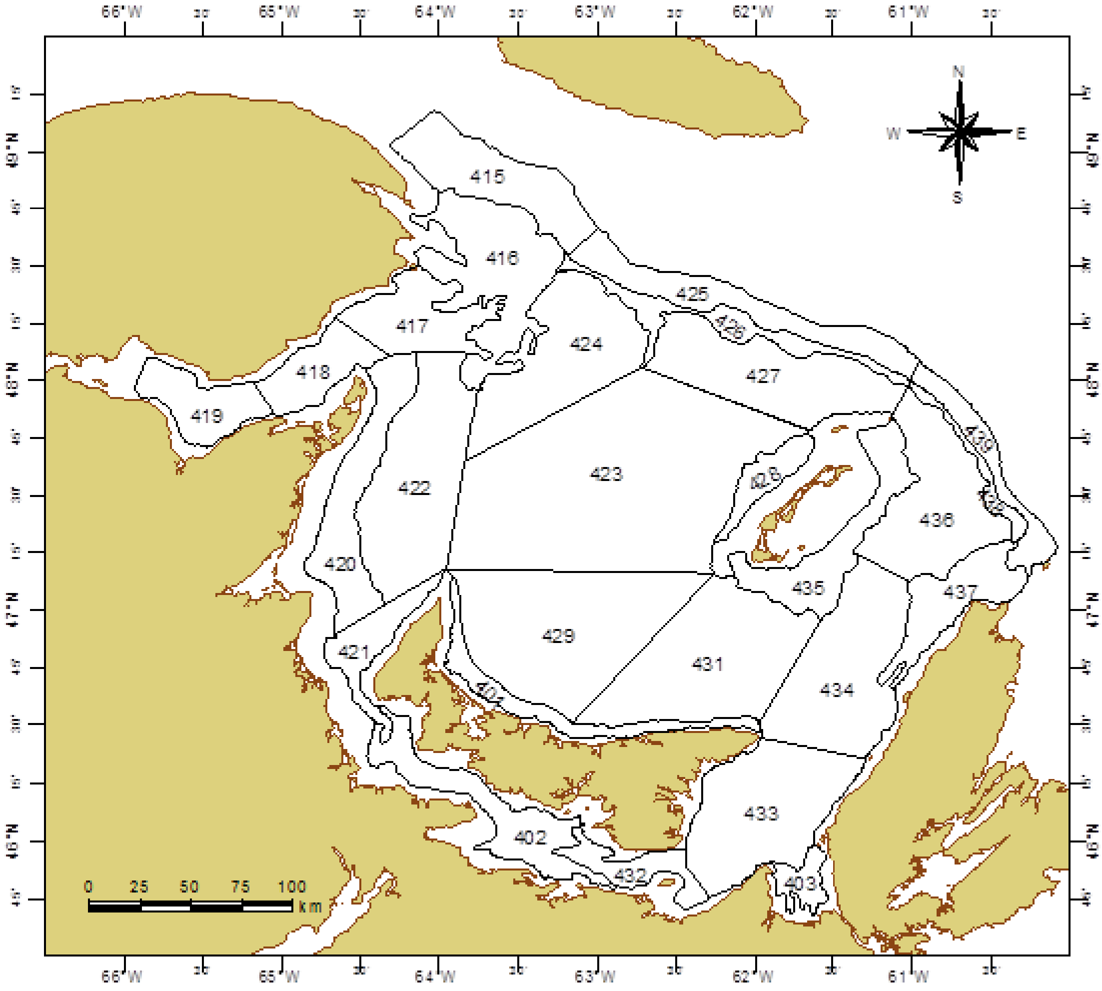

Figure 11. Spatial stratification scheme used in the southern Gulf of St. Lawrence September bottom trawl research vessel and mobile Sentinel surveys.

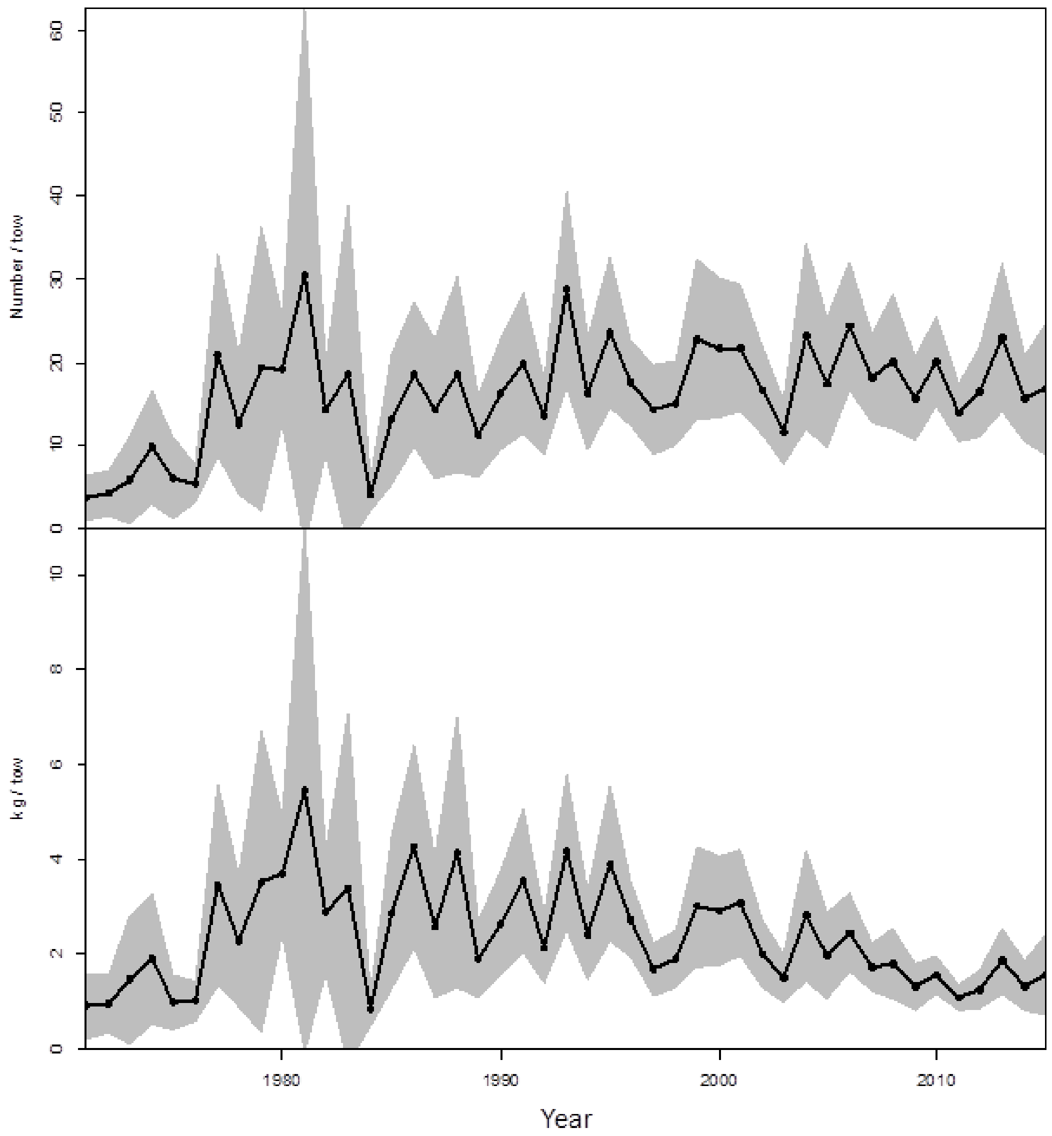

Figure 12. Estimated abundance (number per tow, upper panel) and biomass (kg per tow, lower panel) of Yellowtail flounder from the southern Gulf of St. Lawrence September bottom trawl survey (strata 415 to 439). Shaded area represents the 95% confidence intervals about the mean values.

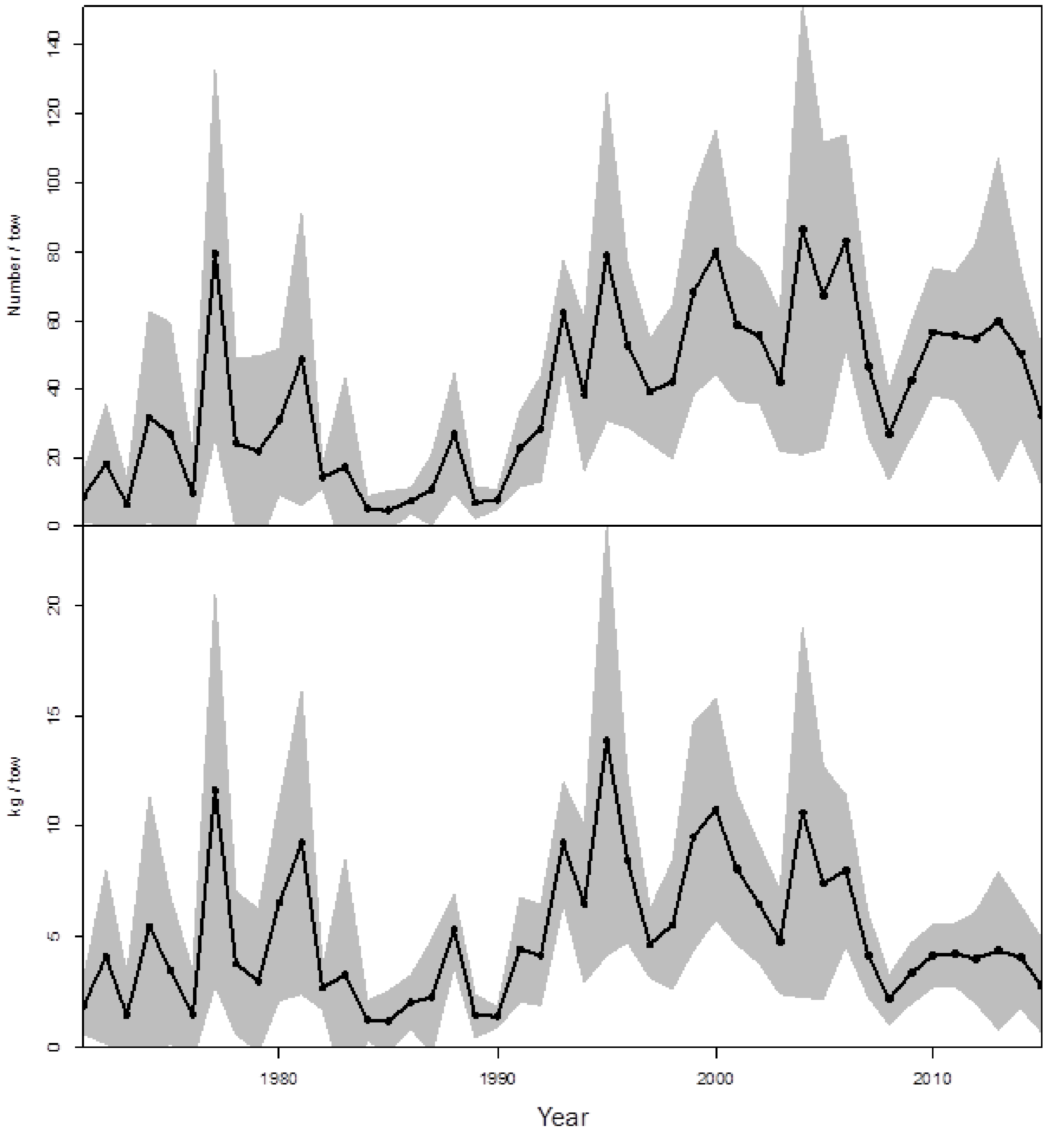

Figure 13. Estimated abundance (number per tow, upper panel) and biomass (kg per tow, lower panel) of Yellowtail flounder from the southern Gulf of St. Lawrence September bottom trawl survey of strata (428, 434, 435 and 436) around the Magdalen Islands. Shaded area represents the 95% confidence intervals about the mean values.

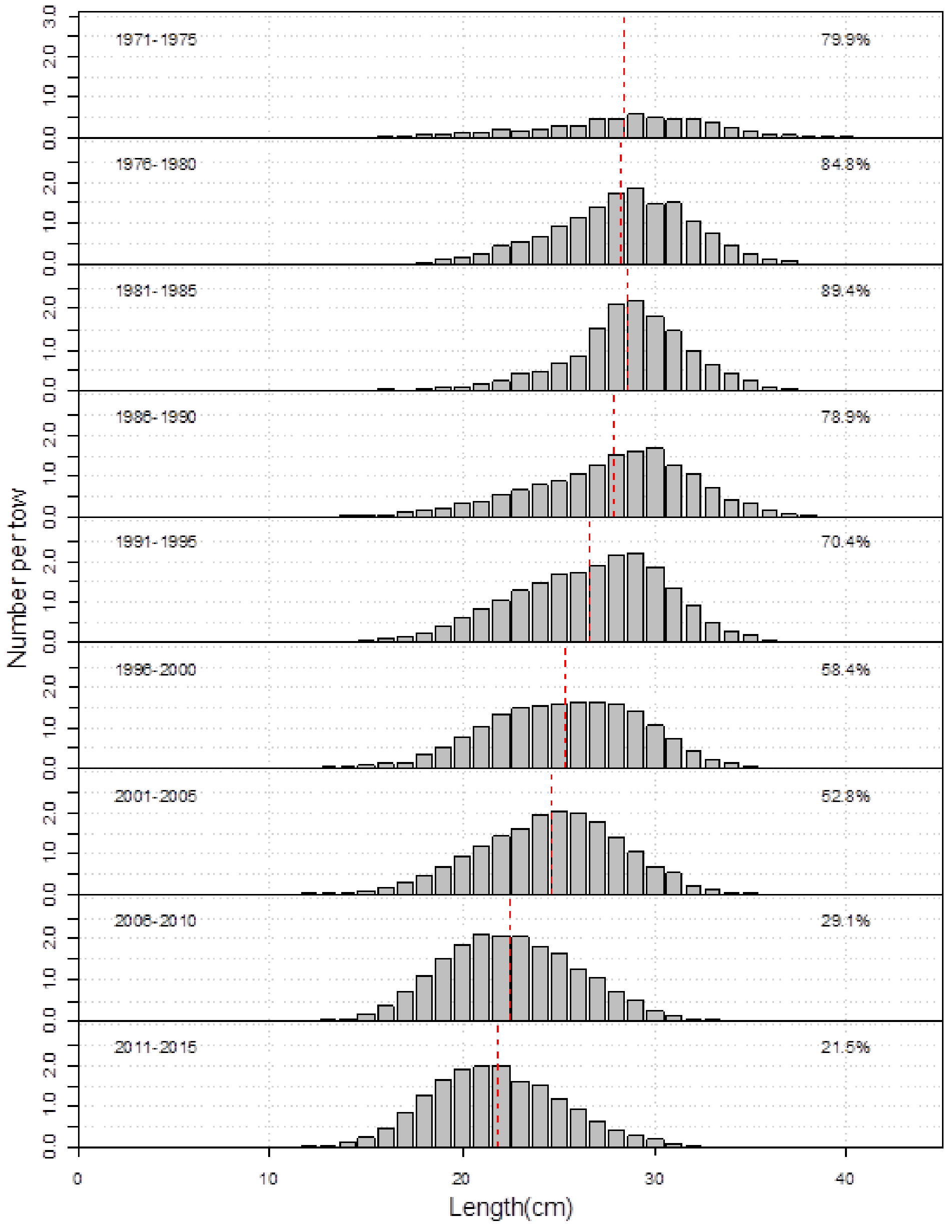

Figure 14. Length frequency distributions of Yellowtail flounder, expressed in number per tow, from the September bottom trawl survey of the southern Gulf of St. Lawrence, in five year blocks, 1971 to 2015. The dashed vertical line shows the mean length for each period. The percentage of yellowtail greater than or equal to 25 cm in length is also shown.

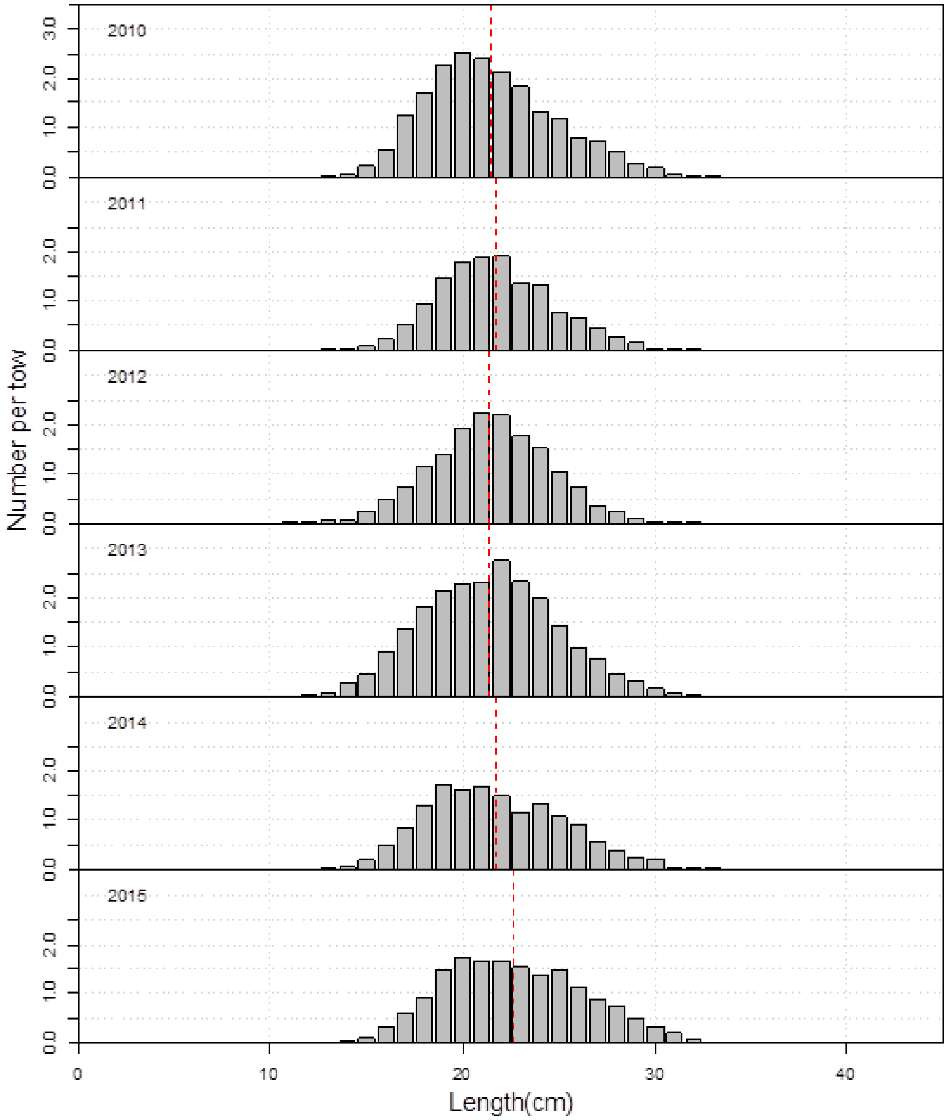

Figure 15. Length frequency distributions of Yellowtail flounder, expressed in number per tow, from the September bottom trawl survey of the southern Gulf of St. Lawrence, 2010 to 2015.

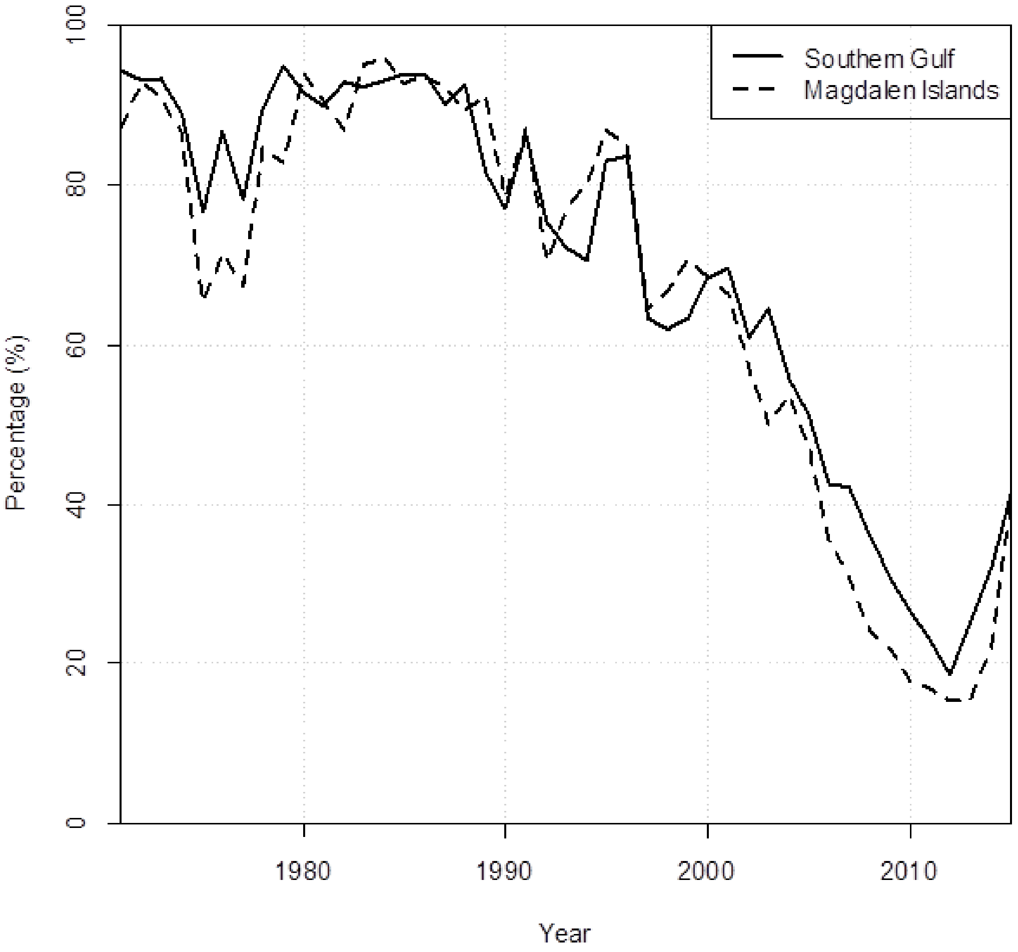

Figure 16. Percentages of Yellowtail flounder ≥ 25 cm in total length, based on standardized length-frequencies, in the September bottom trawl survey catches.

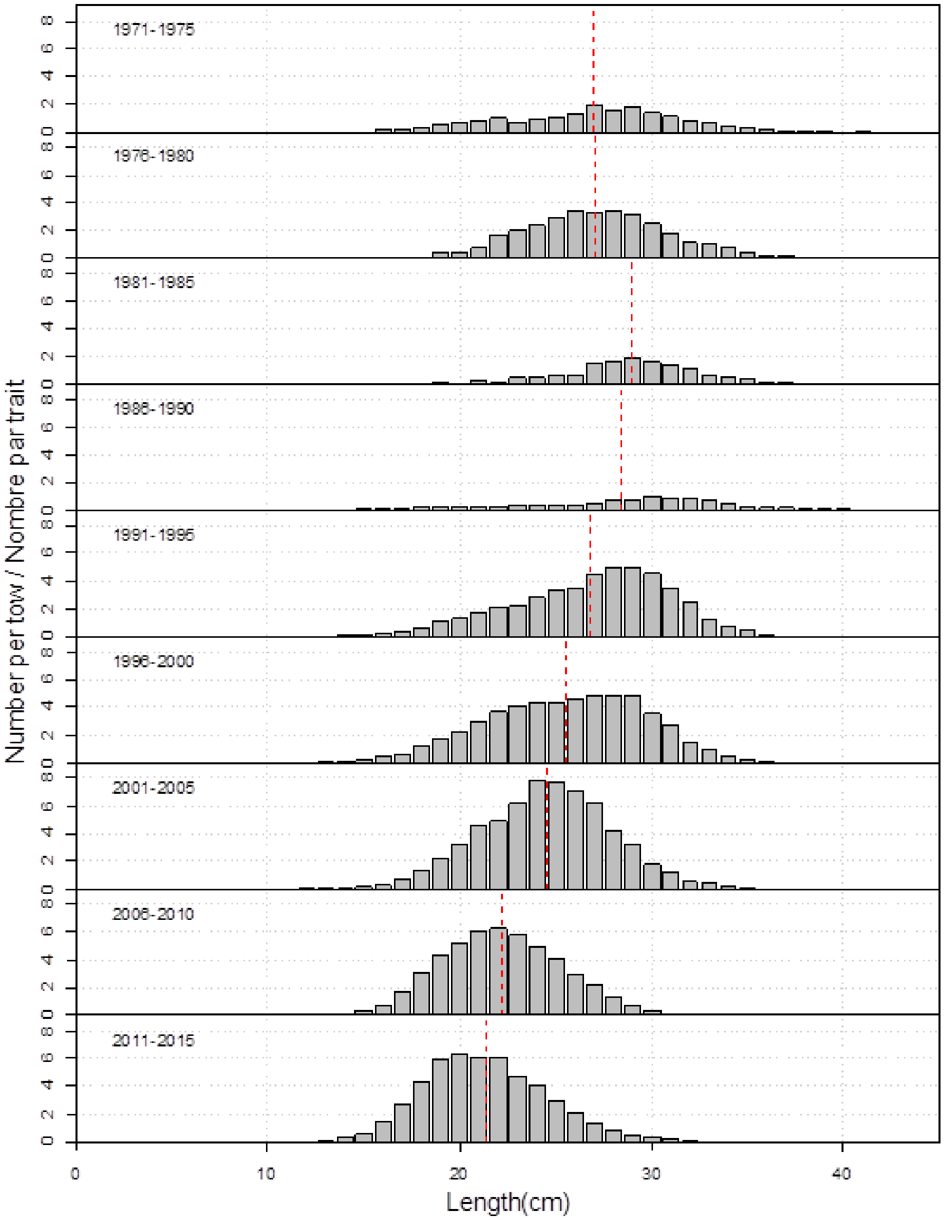

Figure 17. Length-frequency distributions (expressed in number per tow) of Yellowtail flounder based on catches from the September bottom trawl survey of strata around the Magdalen Islands (strata 428, 434, 435 and 436) by five year blocks, 1971 to 2015.

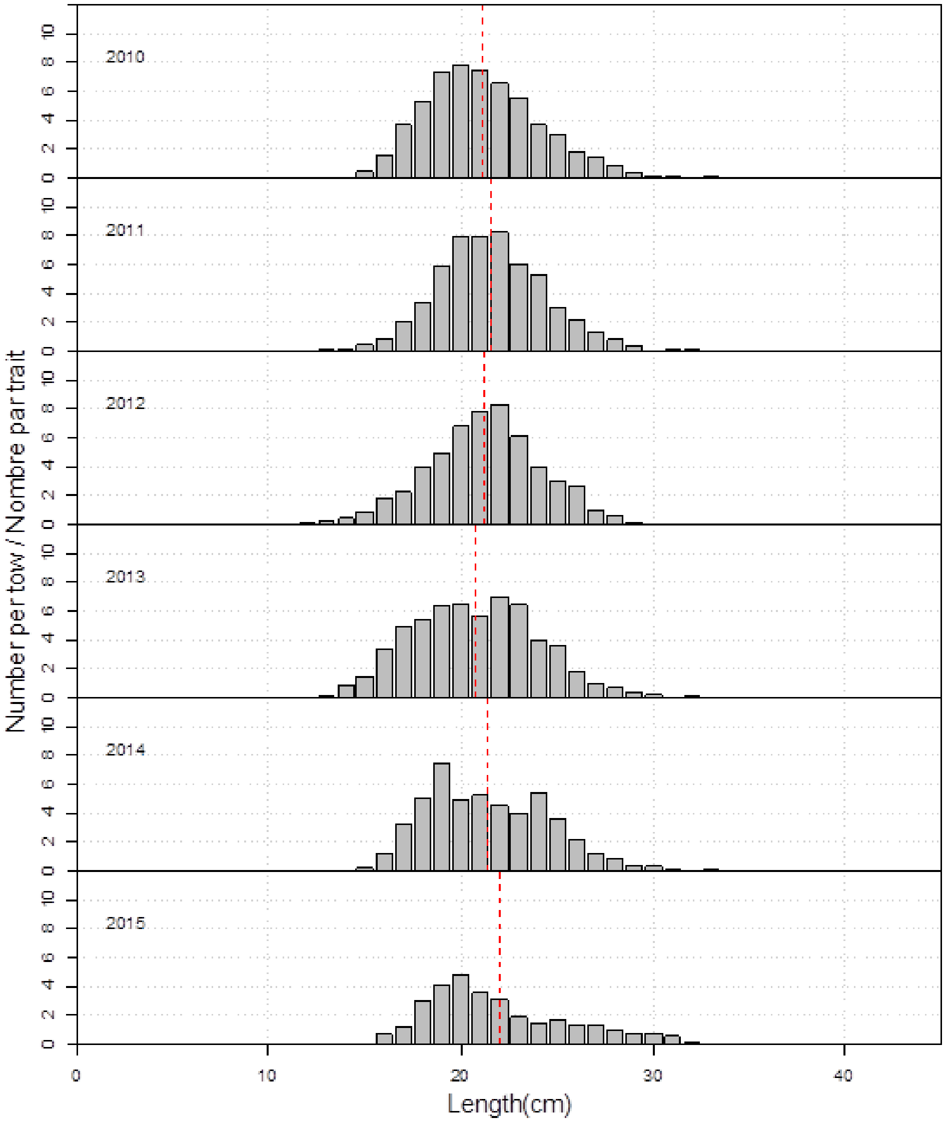

Figure 18. Length-frequency distributions (expressed in number per tow) of Yellowtail flounder based on catches from the September bottom trawl survey of strata around the Magdalen Islands (strata 428, 434, 435 and 436), 2010 to 2015.

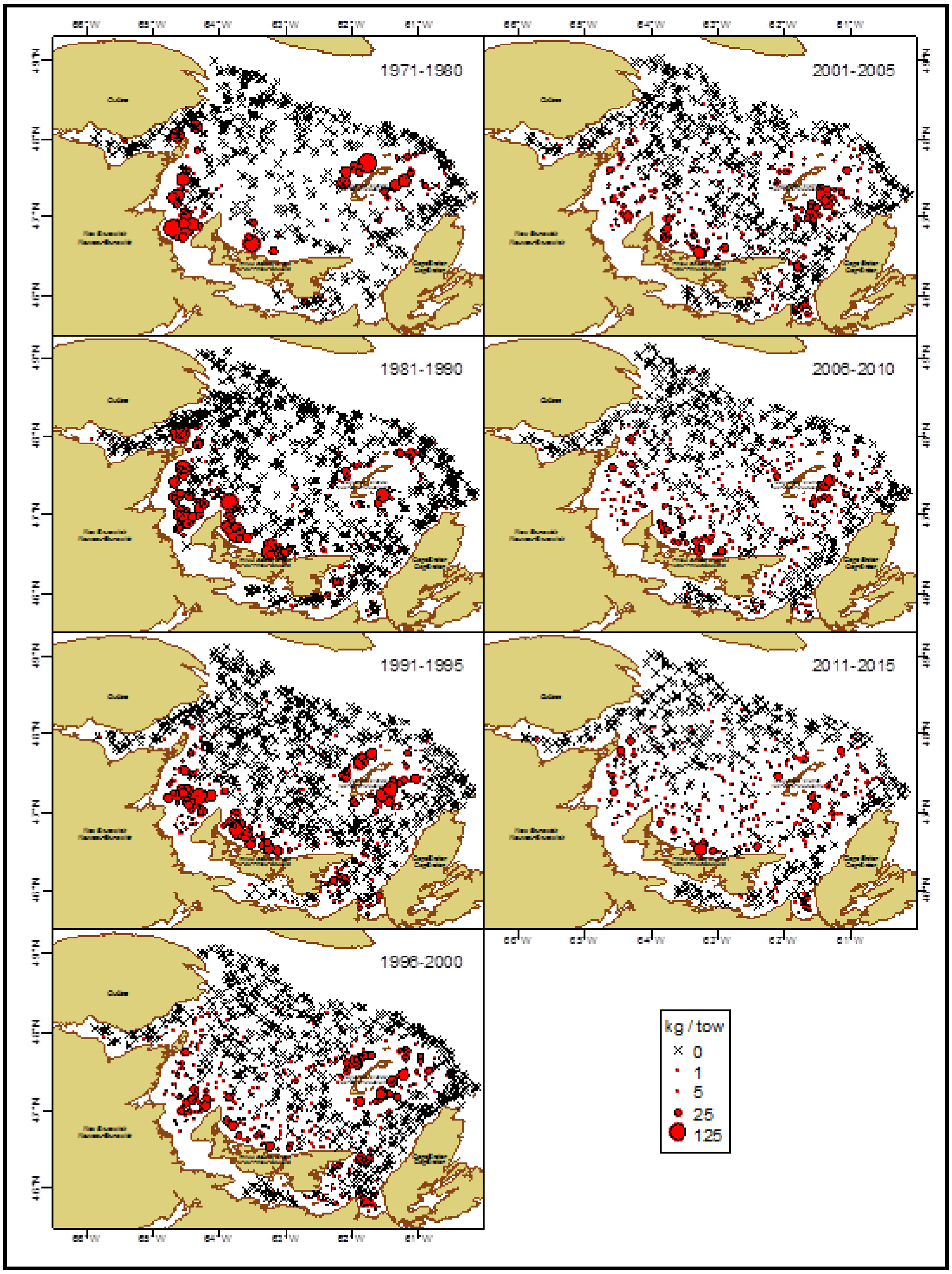

Figure 19. Spatial distribution of September bottom trawl survey catches (in kg per standard tow) of Yellowtail flounder, 1971 to 2015.

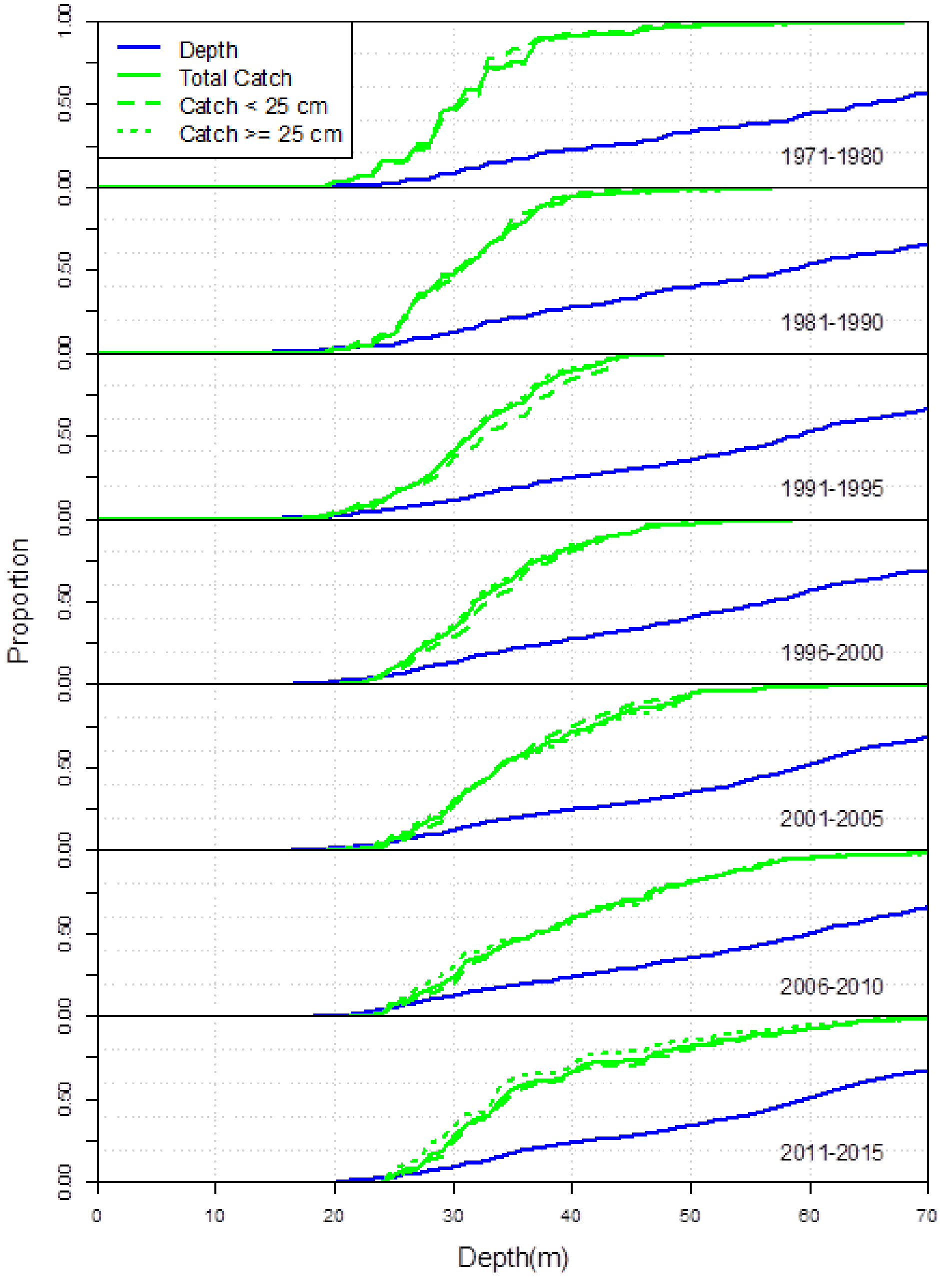

Figure 20. Habitat association curves of Yellowtail flounder with respect to water depth based on catches from the September bottom trawl survey, 1971 to 2015. Blue lines correspond to the cumulative frequency curves of the survey sampling stations while green lines correspond to the cumulative catch curves for the total catch (solid), small fish (long dashes) and larger fish (short dashes).

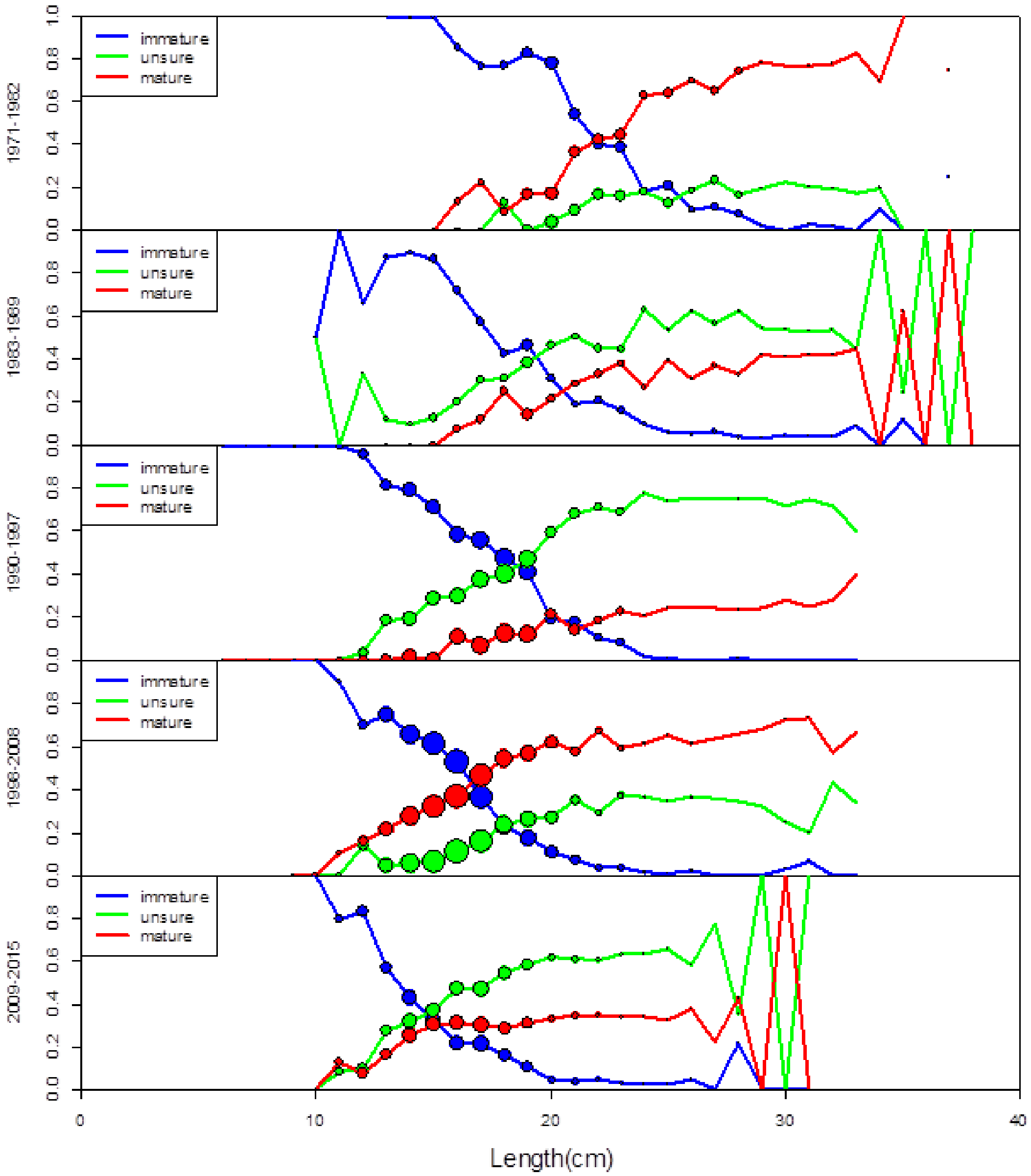

Figure 21. Observed male maturity proportions by length for Yellowtail flounder based on data from the September RV survey of the southern Gulf of St. Lawrence. The "unsure" category reflects a coding which is meant to be mature, but for which there is some level of misclassification expected by on-board Science samplers. Time periods which are problematic are 1983-1989 and 1990-1997.

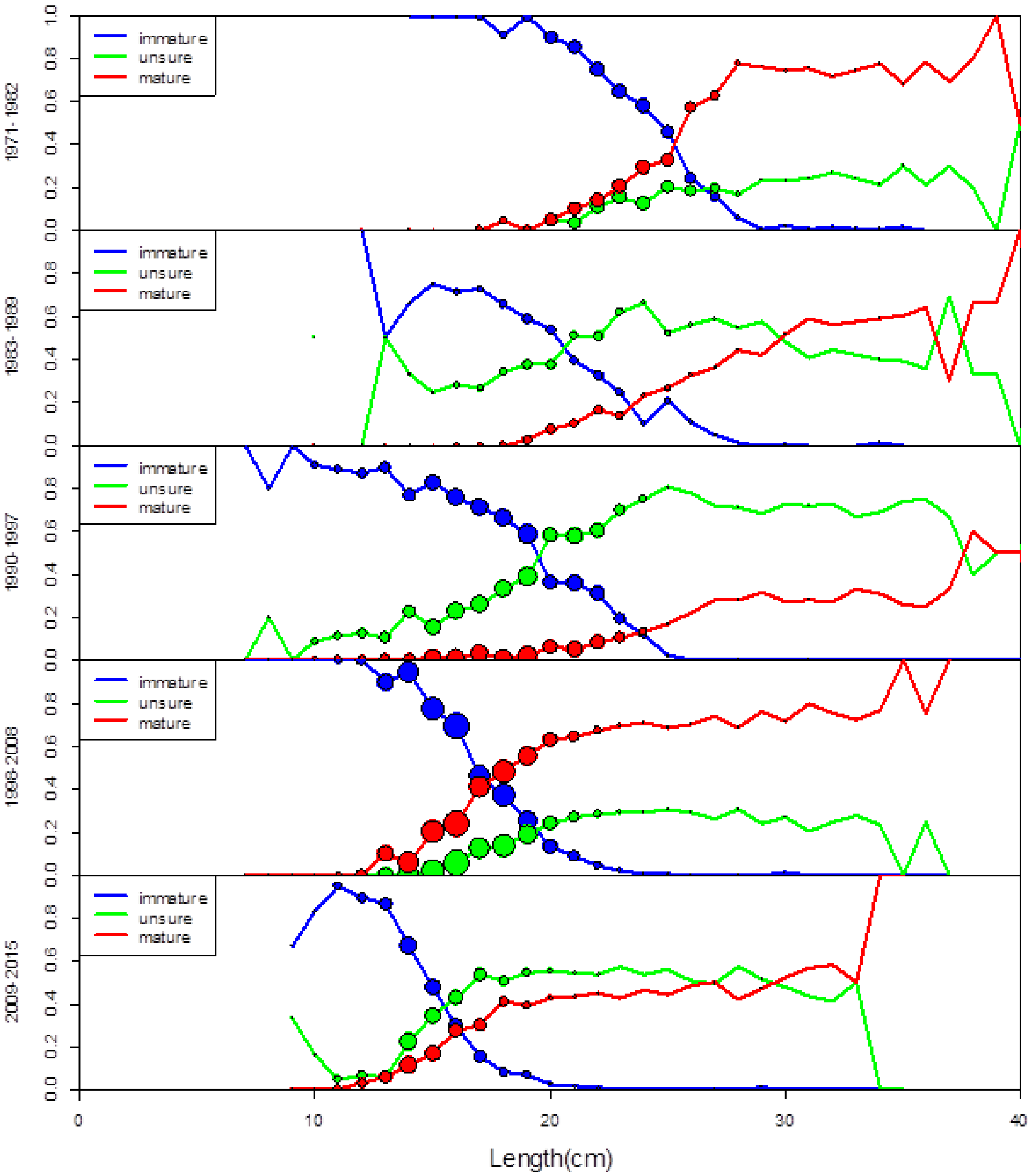

Figure 22. Observed female maturity proportions by length for Yellowtail flounder based on data from the September RV survey of the southern Gulf of St. Lawrence. The "unsure" category reflects a coding which is meant to be mature, but for which there is some level of misclassification expected by on-board Science samplers. Time periods which are problematic are 1983-1989 and 1990-1997.

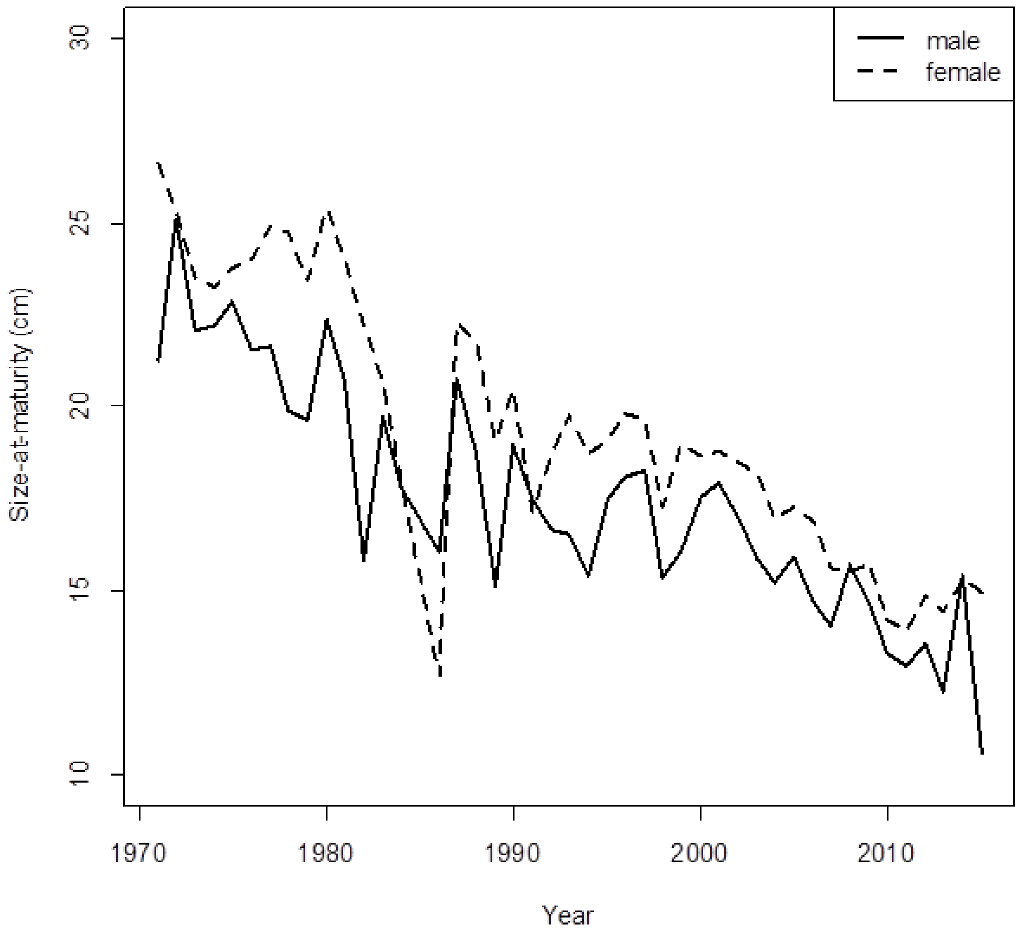

Figure 23. Length (cm) at 50% maturity of Yellowtail flounder estimated from September bottom trawl survey biological data by year and sex, 1971 to 2015.

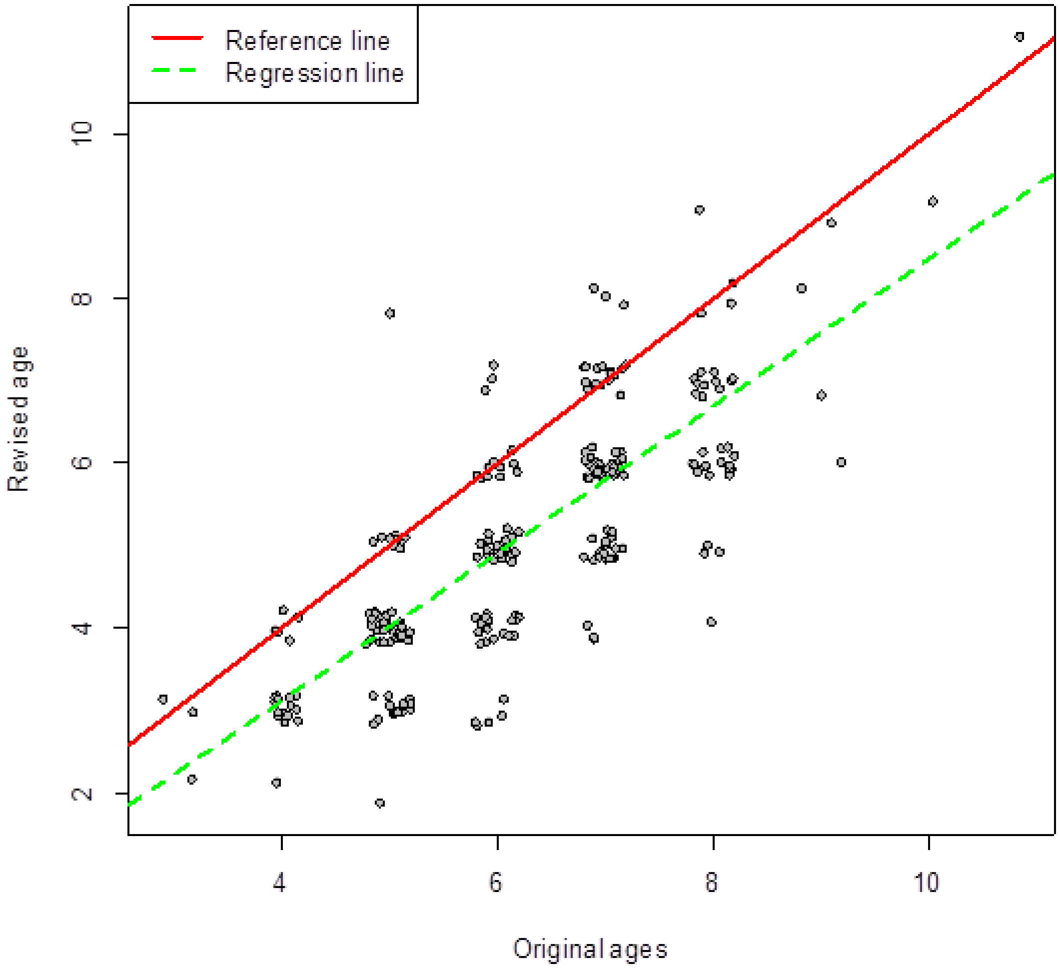

Figure 24. Comparison of interpreted otolith ages of Yellowtail flounder from the 1982 September survey. The horizontal axis shows the ages interpreted from the original ageing and the vertical axis the corresponding age for the same otoliths from the recent age interpretations. The solid red diagonal line is the one:one line representing correspondence between the two age interpretations. Points are jittered slightly to improve clarity.

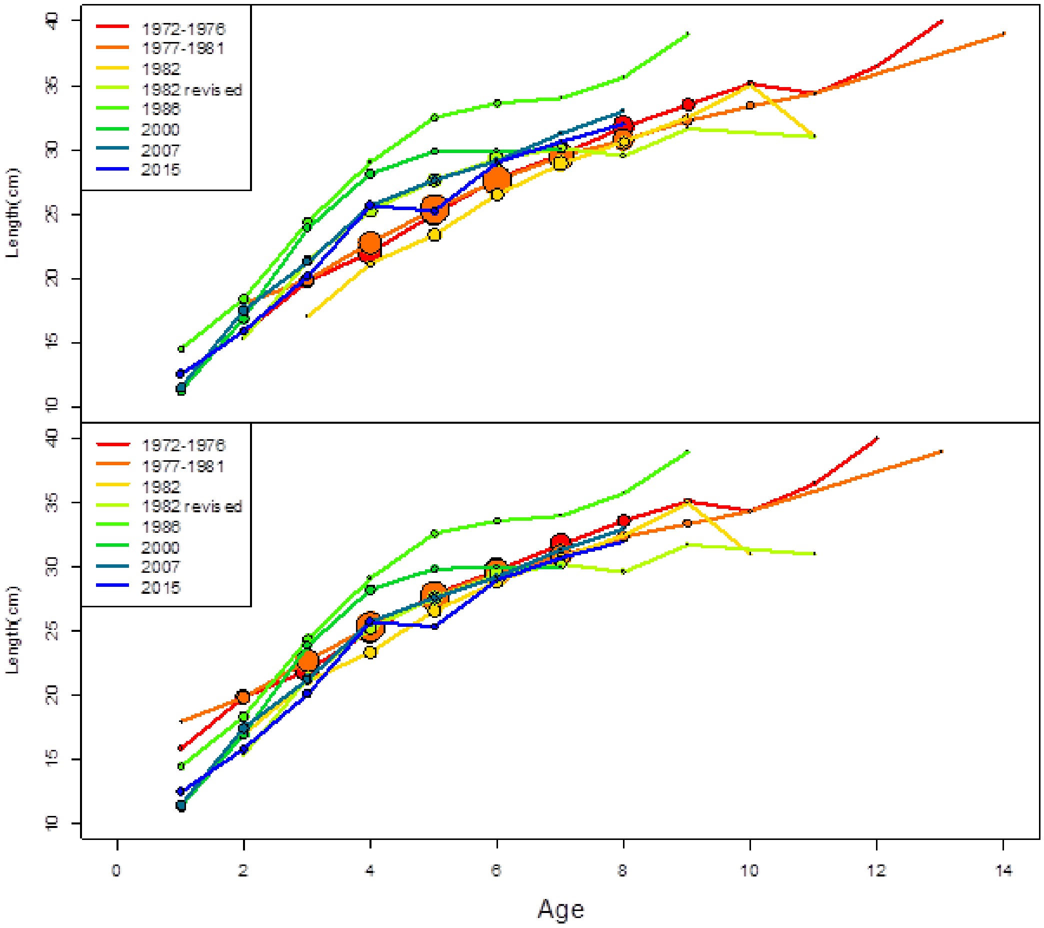

Figure 25. Empirical mean length-at-age based on length and age data from the September survey of the southern Gulf of St. Lawrence. Top graph presents the original data while the bottom graph show the historical data (1972-1982) scaled down by one year.

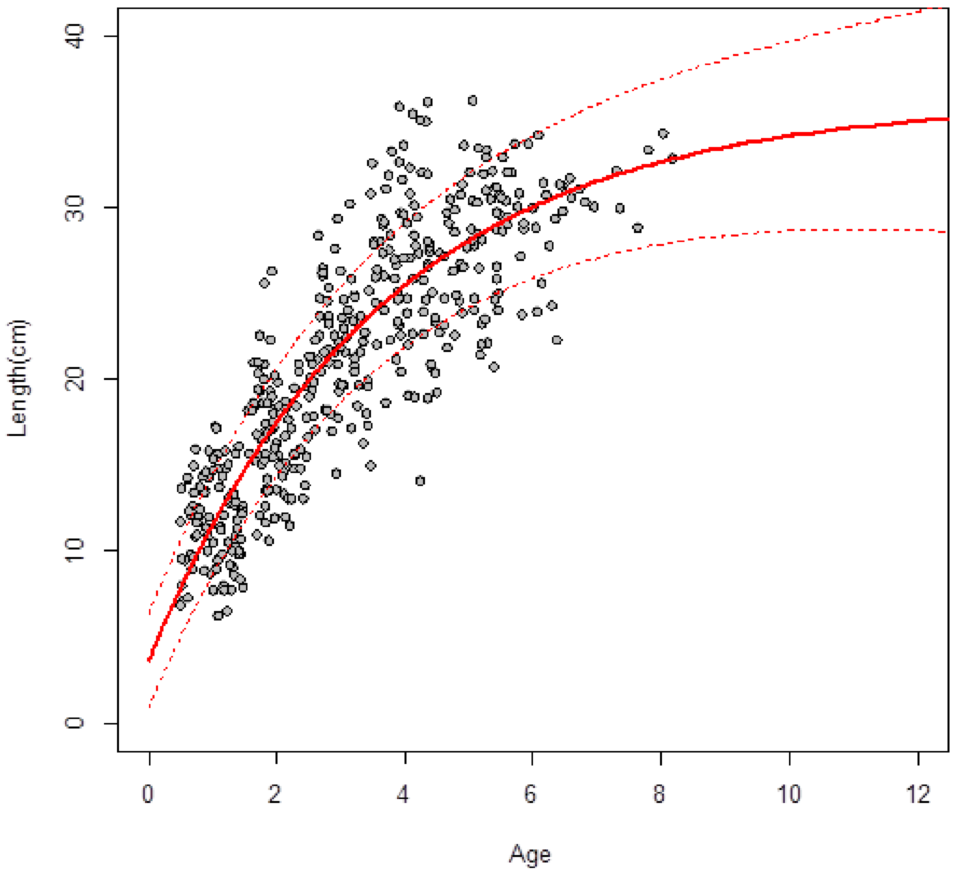

Figure 26. Fitted Von Bertalanffy growth model to the pooled age data from 2000, 2007 and 2015. Estimated parameter values are L_∞ = 36.2 cm, k = 0.278 and t_0 = -0.380 per year. Data points were jittered for clarity.

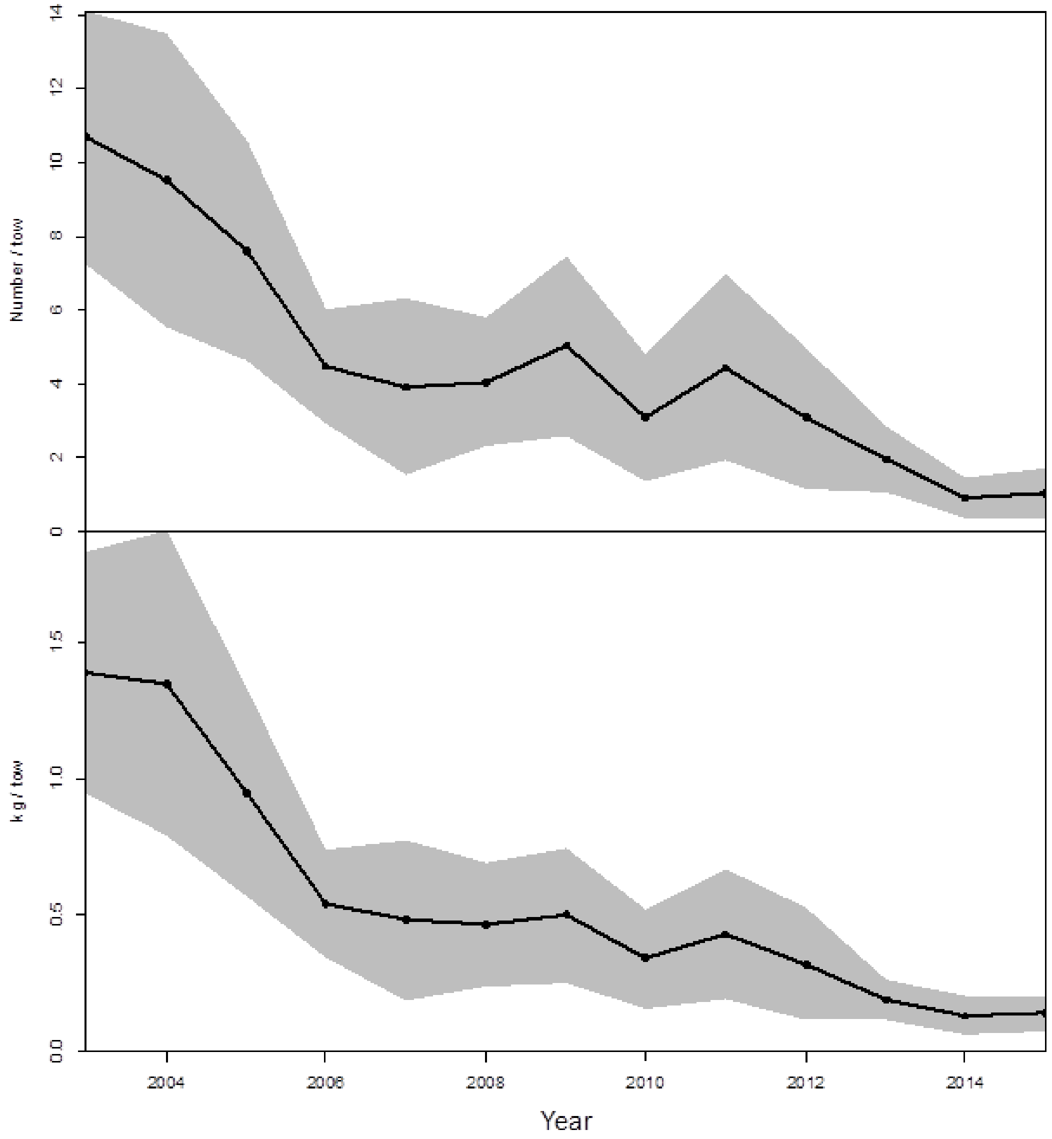

Figure 27. Yellowtail flounder abundance (number per tow; top panel) and biomass (kg per tow; bottom panel) indices from the southern Gulf of St. Lawrence mobile Sentinel survey (strata 401-439). Shaded area represents the 95% confidence intervals about the mean values.

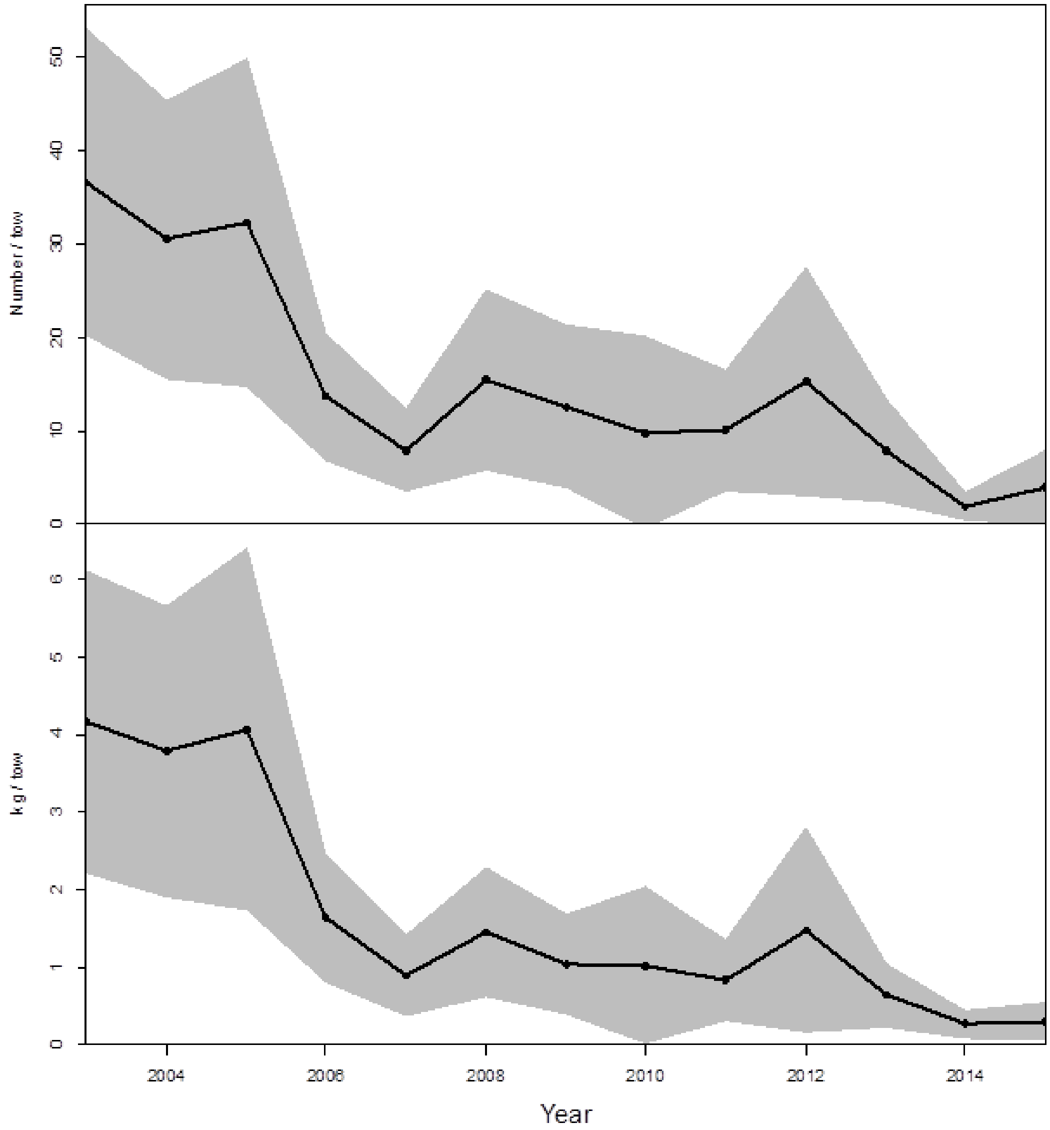

Figure 28. Magdalen Islands Yellowtail flounder abundance (number per tow; top panel) and biomass (kg per tow; bottom panel) indices for the southern Gulf of St. Lawrence Sentinel survey (strata 428, 434, 435 and 436). Shaded area represents the 95% confidence intervals about the mean values.

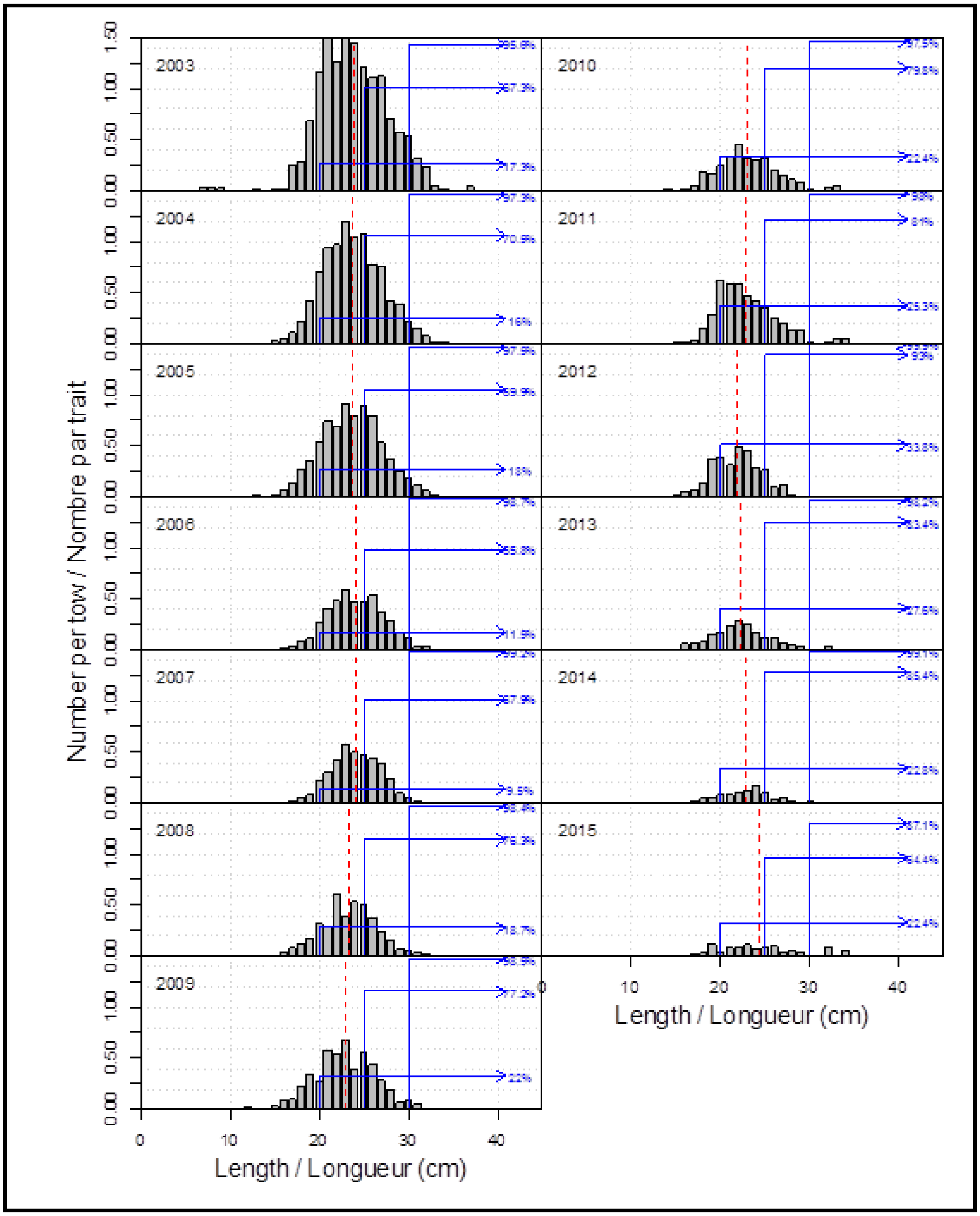

Figure 29. Mobile Sentinel survey length-frequency distributions (number per tow) of Yellowtail flounder, 2003 to 2015. Blue lines show the cumulative percentile values at 20 cm, 25 cm and 30 cm while the red dashed line shows the location of mean value.

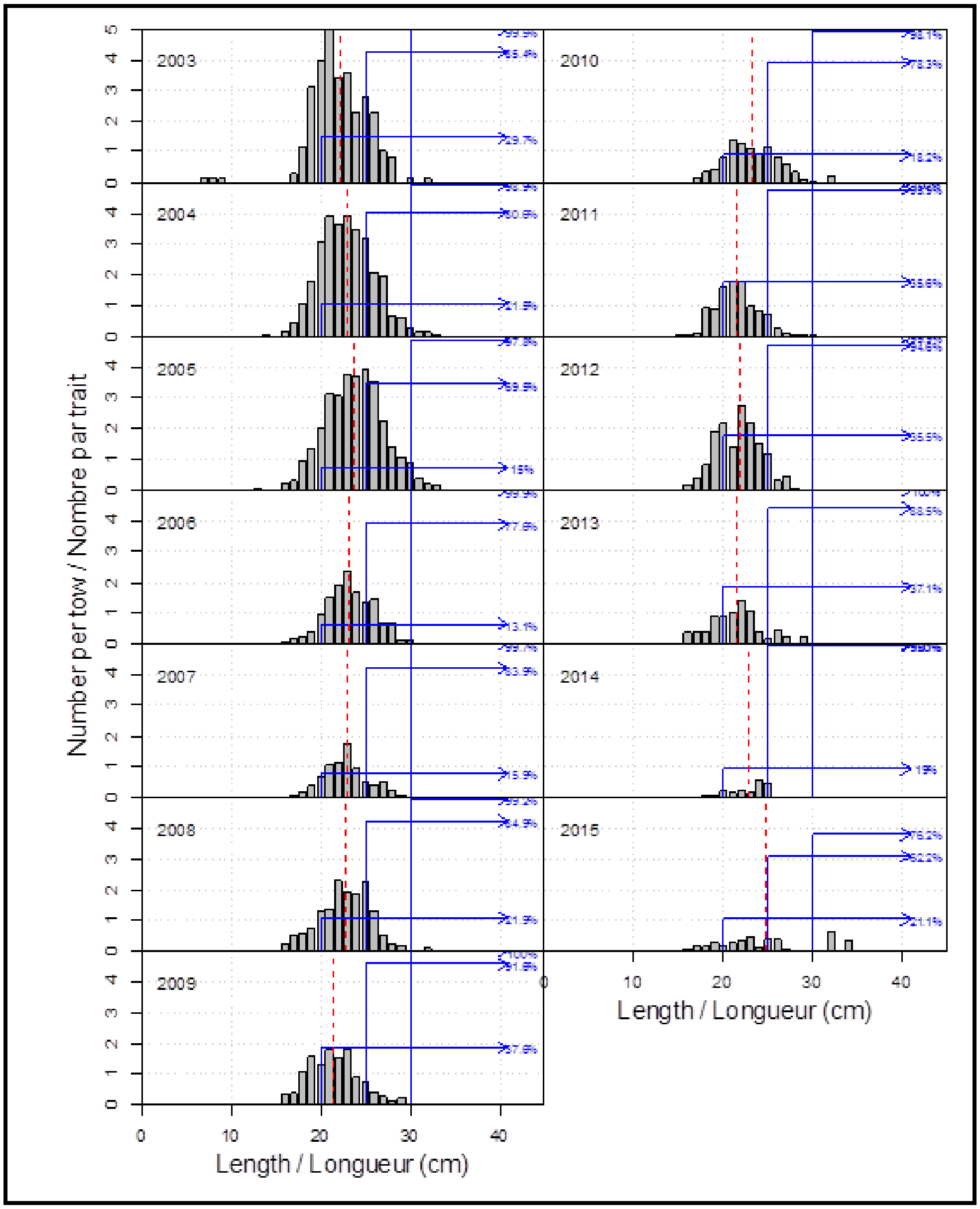

Figure 30. Mobile Sentinel survey length-frequency distributions (number per tow) of Yellowtail flounder for Magdalen Islands strata (428, 434, 435 and 436). Blue lines show the cumulative percentile values at 20 cm, 25 cm and 30 cm while the red dashed line shows the location of mean value.

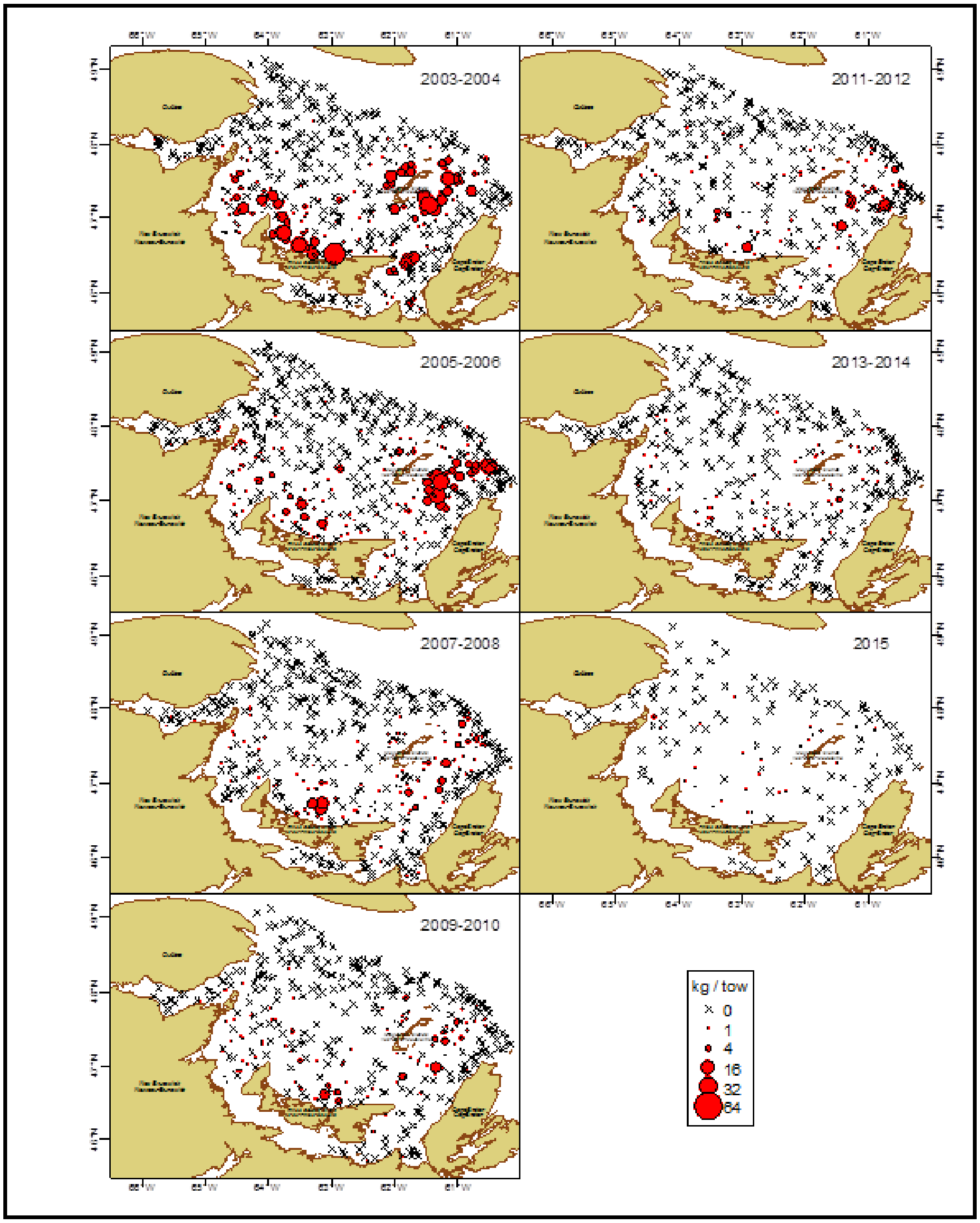

Figure 31. Spatial distribution of standardized mobile Sentinel survey catches (kg per standard tow) of Yellowtail flounder, 2003 to 2015.

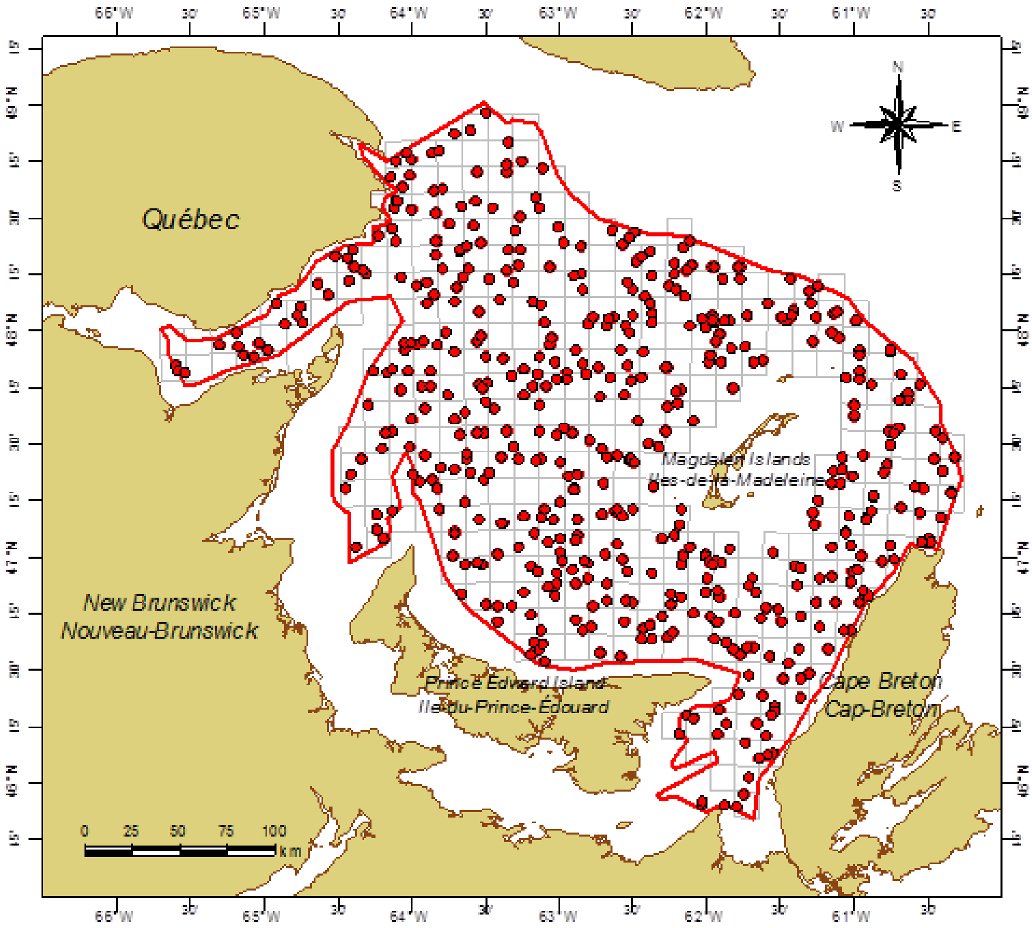

Figure 32. Snow crab survey area (red line), sampling grids (grey squares) and the location of stations (red dots) sampled for groundfish in 2010 to 2015.

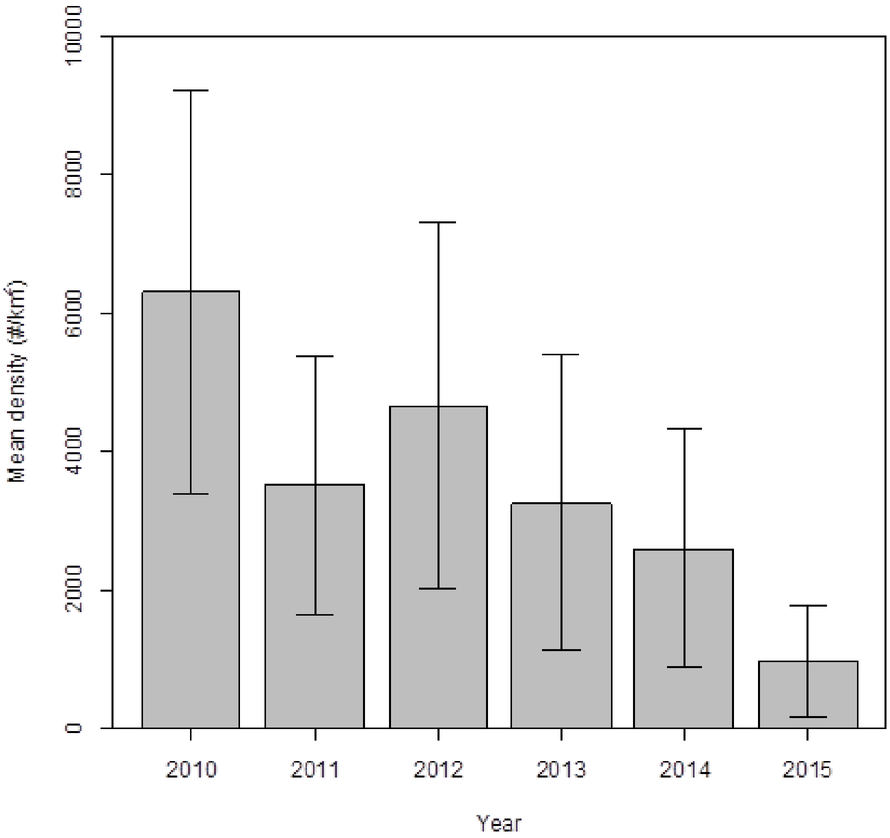

Figure 33. Mean number per km^2 and confidence intervals (95%) of total Yellowtail flounder from the snow crab survey.

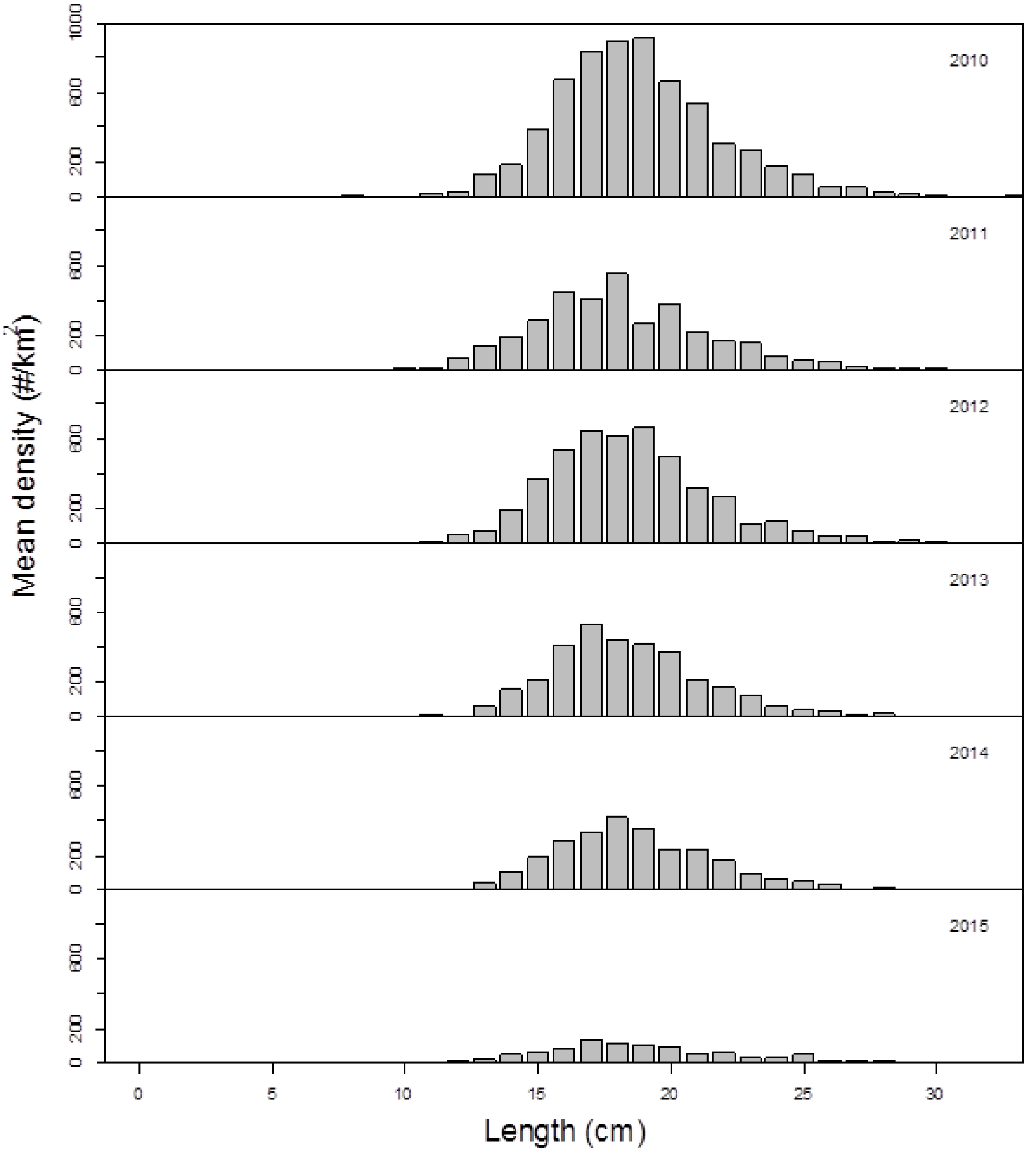

Figure 34. Mean length-frequency distributions (numbers per km^2) of Yellowtail flounder from the snow crab survey, 2010 to 2015.

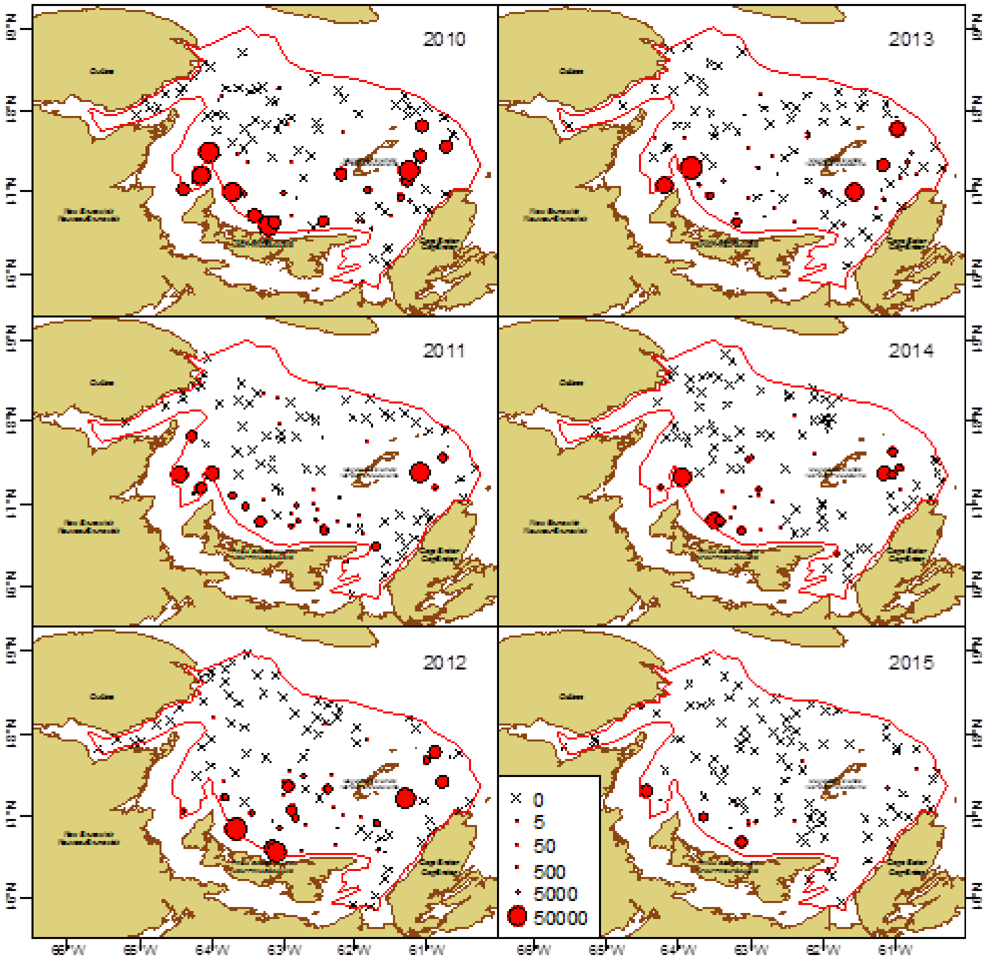

Figure 35. Spatial distribution of Yellowtail flounder catches in the snow crab surveys, 2010 to 2015. Units are in number per km^2.

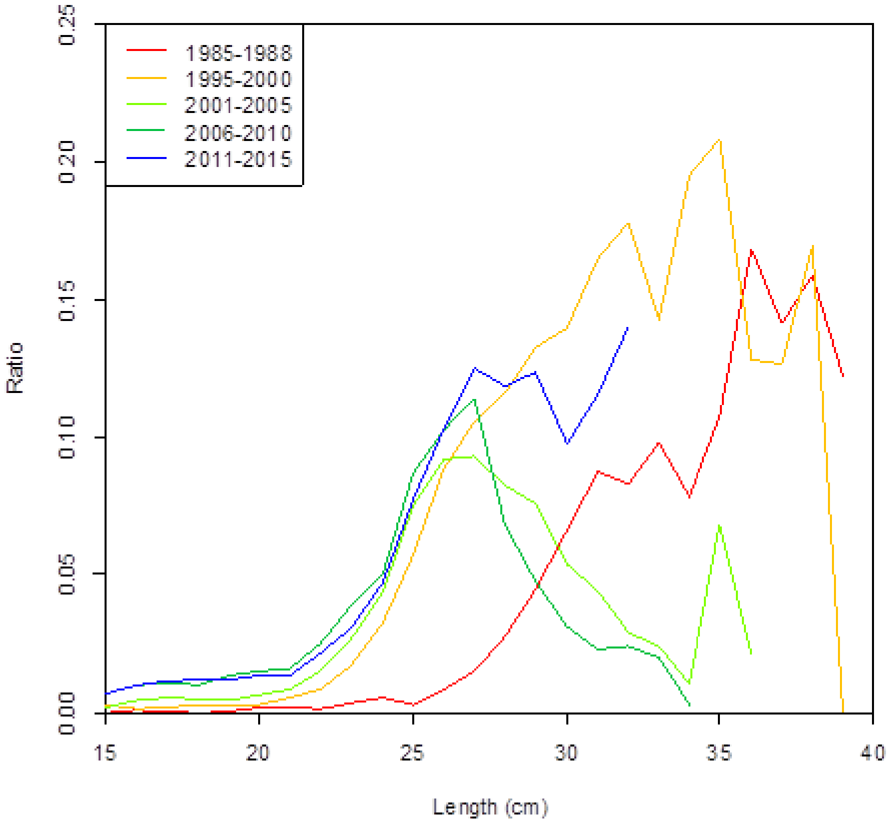

Figure 36. Estimates of relative fishing mortality for Yellowtail flounder from the southern Gulf of St. Lawrence, calculated as the ratio of commercial catch at length to estimated trawlable abundance at length from the September bottom trawl survey.

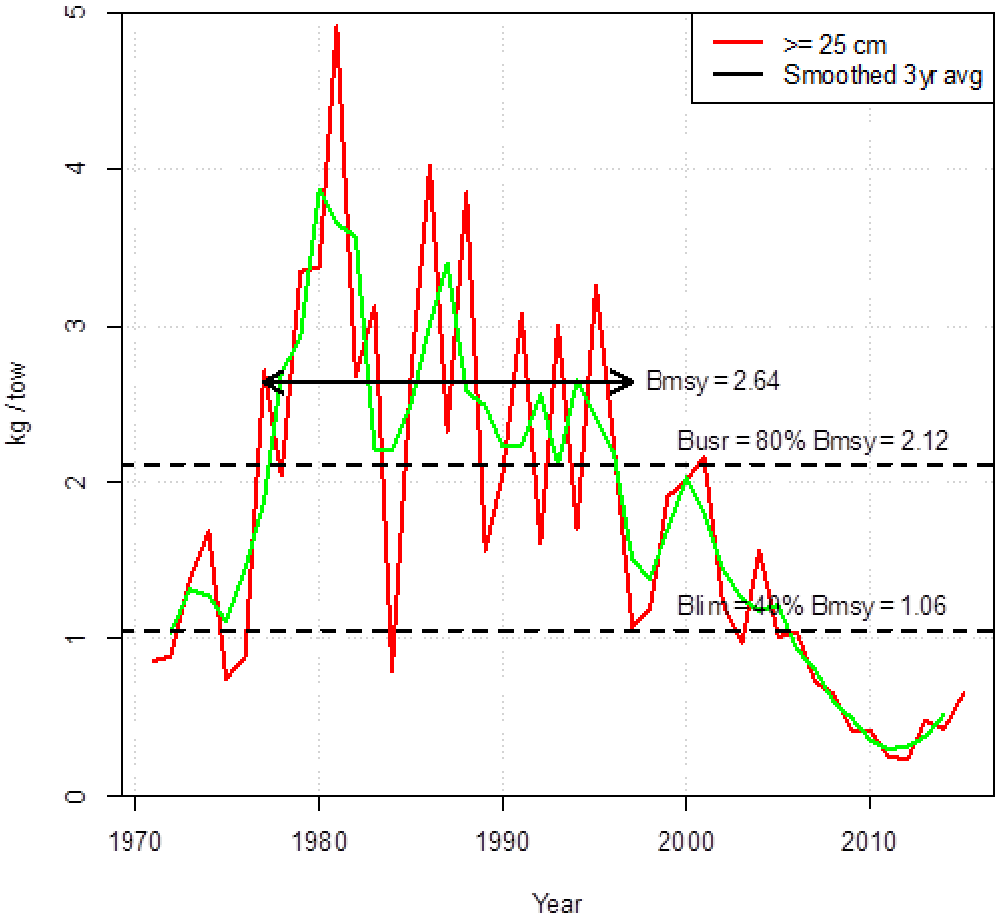

Figure 37. Trends in status of Yellowtail flounder relative to the B_{msy} proxy values, 1971 to 2015. The B_{msy} proxy value is calculated as the average September survey weight index (kg per tow) of fish ≥ 25 cm from 1977 to 1997.

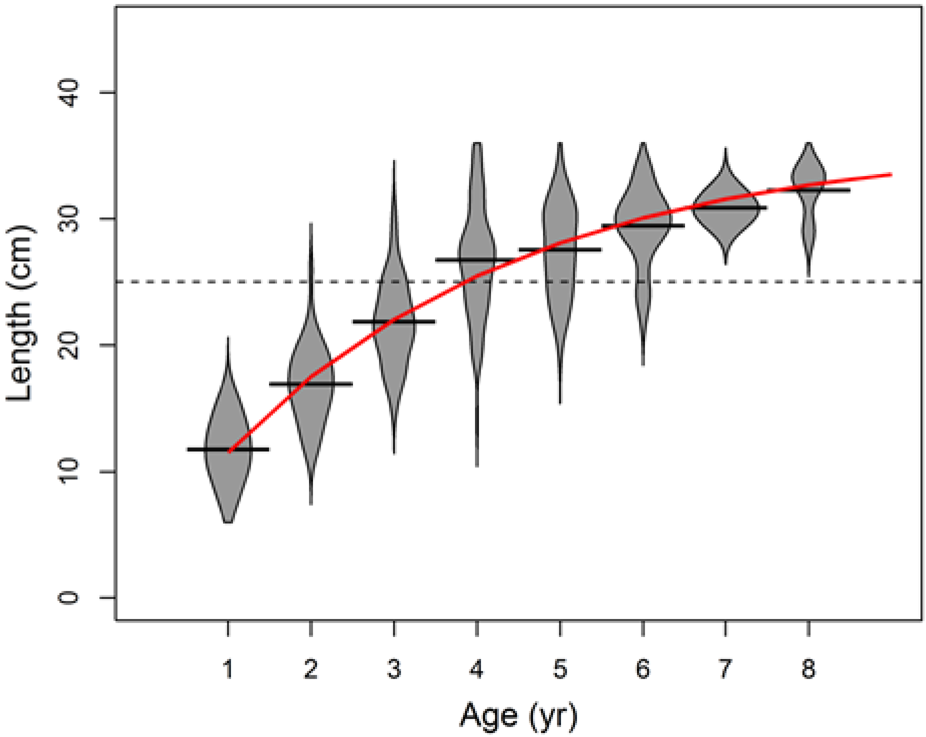

Figure 38. Length at age of Yellowtail flounder sampled from the southern Gulf of St. Lawrence in September 2000, 2007 and 2015. The shaded area describes the distribution of length at age and the horizontal lines indicate the mean length at age. The red line is the fit of a von Bertalanffy model to these data. The dashed horizontal line shows the division (25 cm) between the two length groups used in the population modelling.

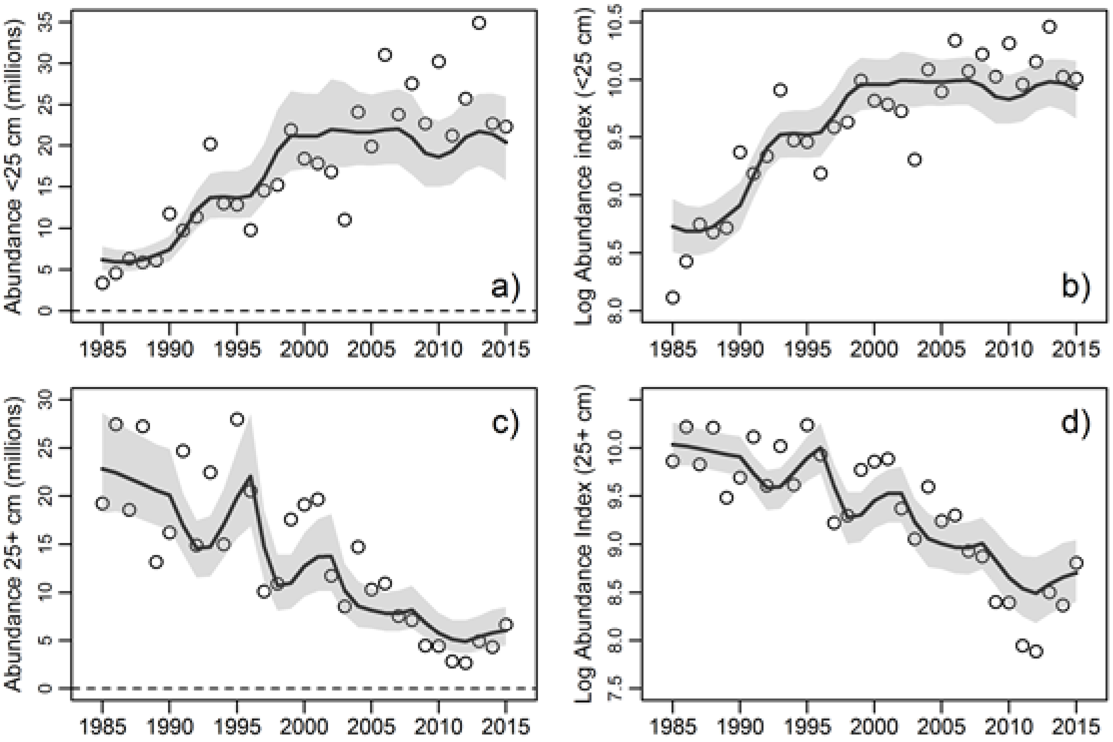

Figure 39. Fit of the population model to the RV abundance indices for small (panels a and b) and large (panels c and d) Yellowtail flounder at the natural log scale (panels b and d; the scale used in the fitting) and the natural scale (panels a and c).Circles show the observed indices. Lines and shading show the median predicted value and the corresponding 95% confidence interval.

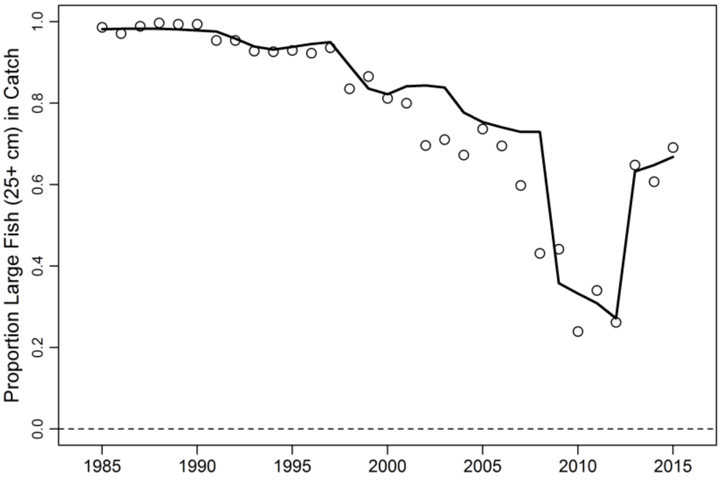

Figure 40. Observed (circles) and predicted (line) proportion of large fish (> 25 cm) in the fishery catches of Yellowtail flounder.

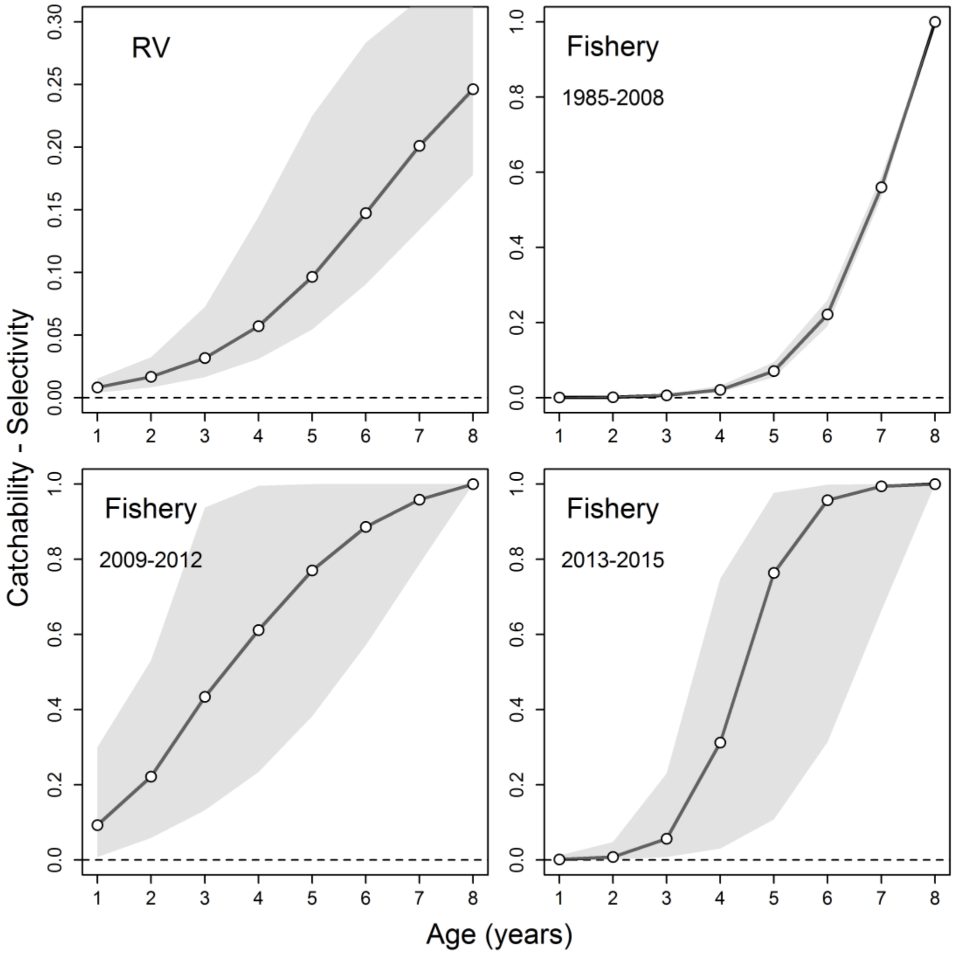

Figure 41. Estimated catchability at age to the RV survey and fishery selectivity in three time periods for Yellowtail flounder in the southern Gulf of St. Lawrence. Lines show median estimate and shading the 95% confidence interval.

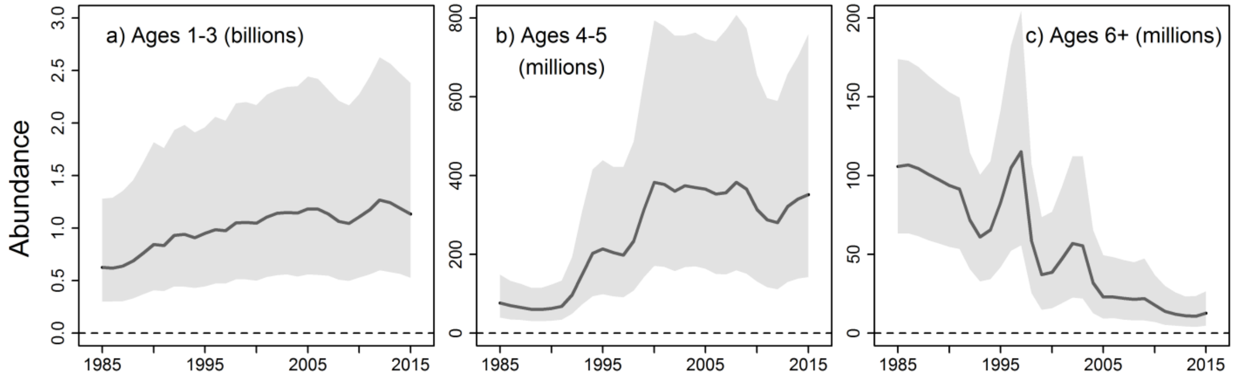

Figure 42. Estimated abundances of three age groups of Yellowtail flounder in the southern Gulf of St. Lawrence. Lines show the median values and shading their 95% confidence intervals.

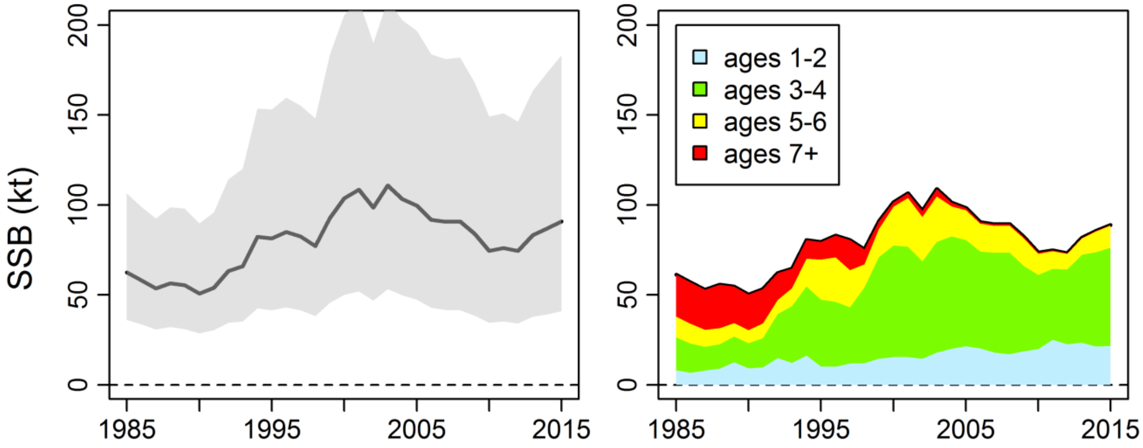

Figure 43. Estimated spawning stock biomass (SSB, kt) of Yellowtail flounder in the southern Gulf of St. Lawrence (left panel) and its estimated age composition (right panel). In the left panel, lines show the median estimate and shading its 95% confidence interval.

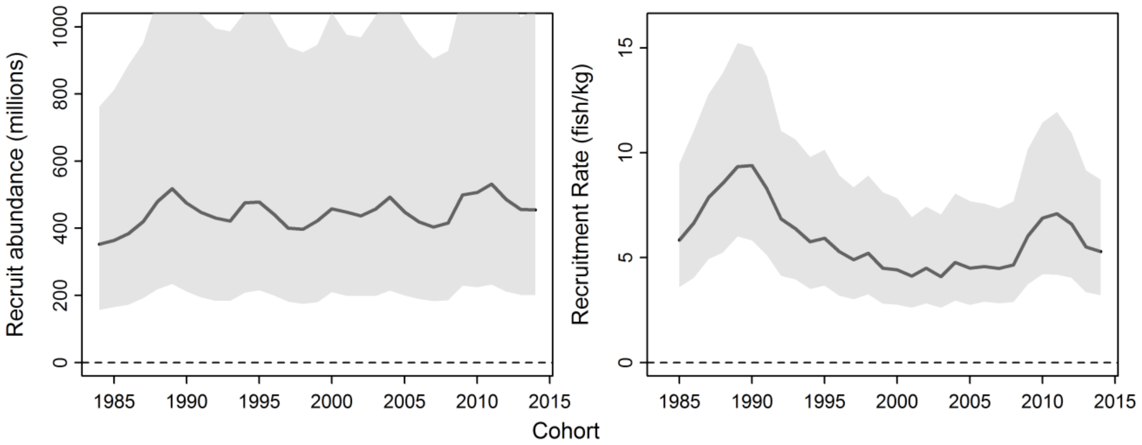

Figure 44. Estimated recruit abundance (millions) and recruitment rate (recruits/SSB) of Yellowtail flounder in the southern Gulf of St. Lawrence. Lines and shading show the median and its 95% confidence interval.

Figure 45. 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.

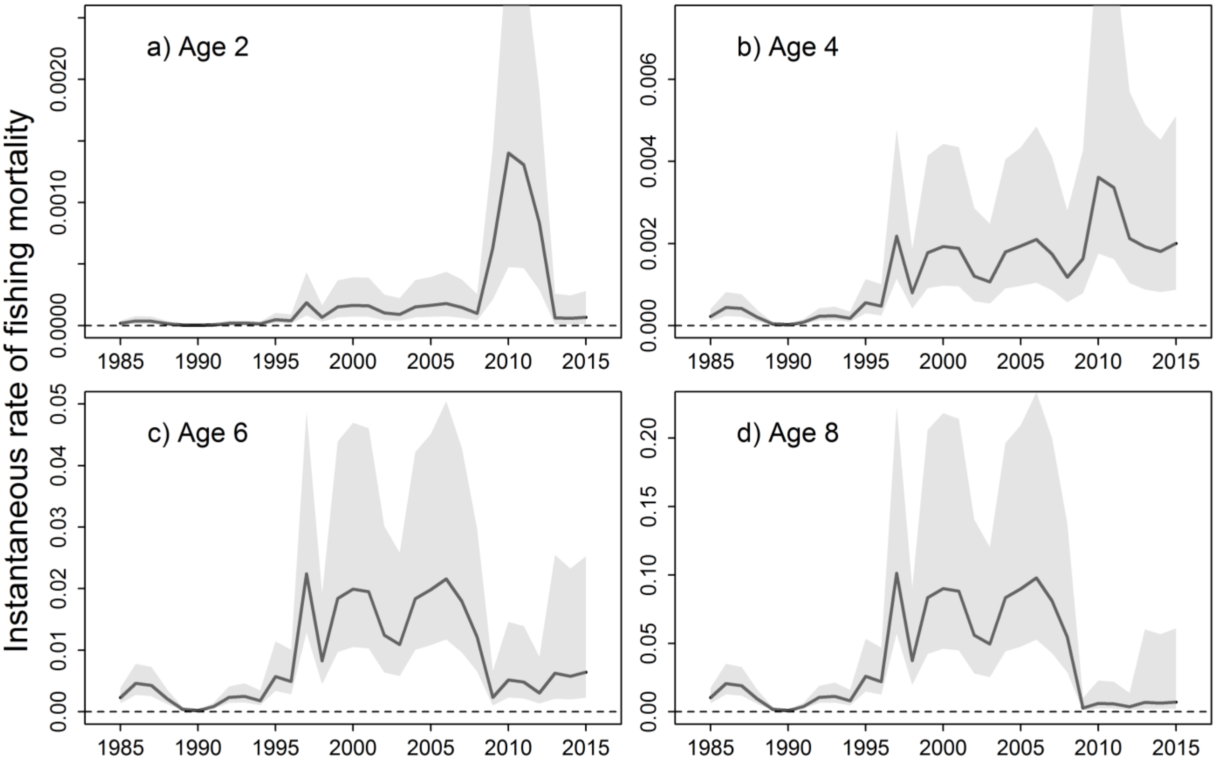

Figure 46. Estimated fishing mortality of four ages of Yellowtail flounder in the southern Gulf of St. Lawrence. Solid lines and shading indicate the median and 95% confidence interval based on MCMC sampling.

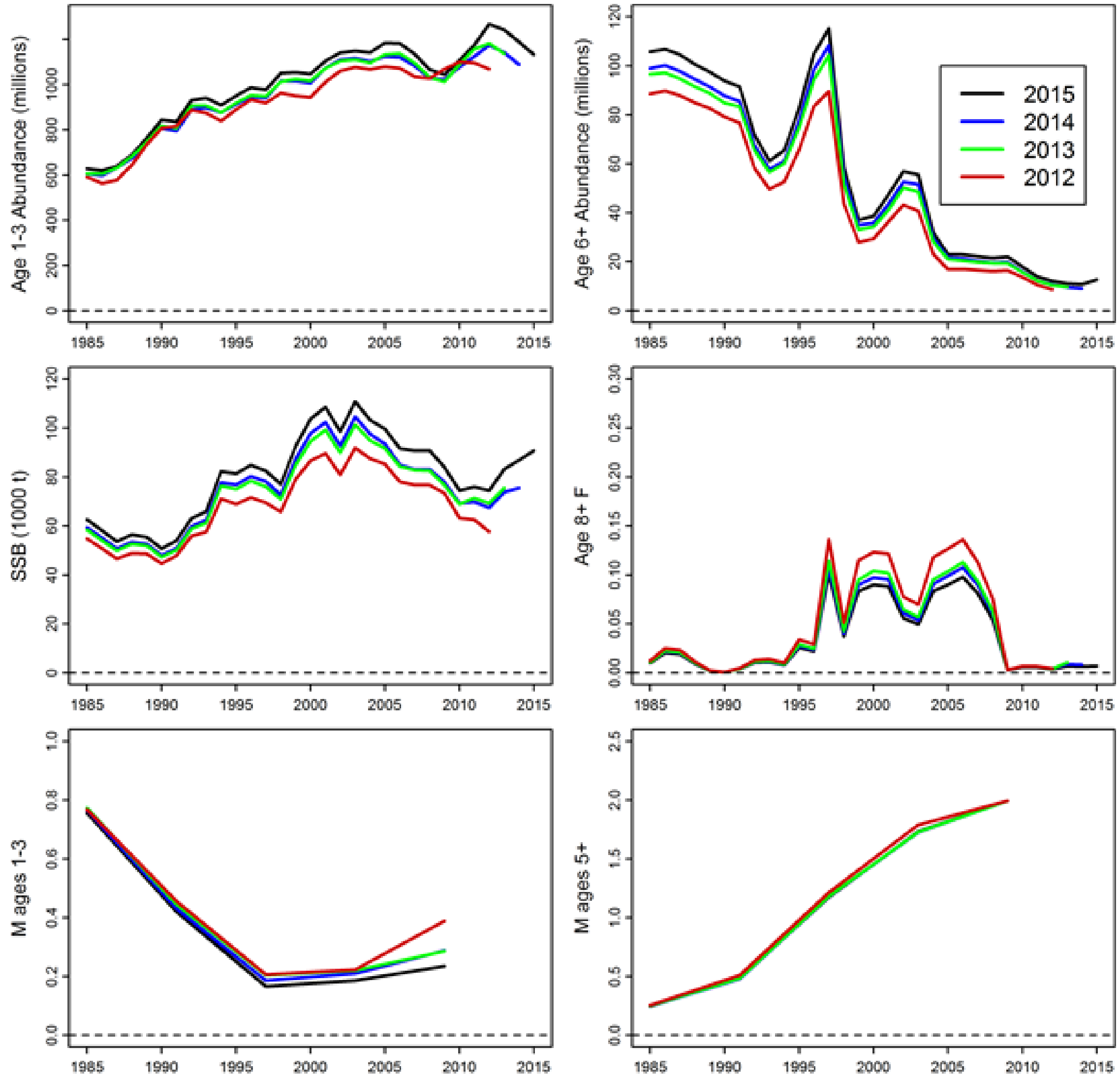

Figure 47. Retrospective analysis of a Yellowtail flounder population model estimates of abundance (upper row figures), biomass (middle left figure), fishing mortality at age 8+ years (middle right figure), and natural mortality (lower row figures). This analysis shows how estimates change as years of data are added or removed. Line colour indicates the last year of data included in the analysis.

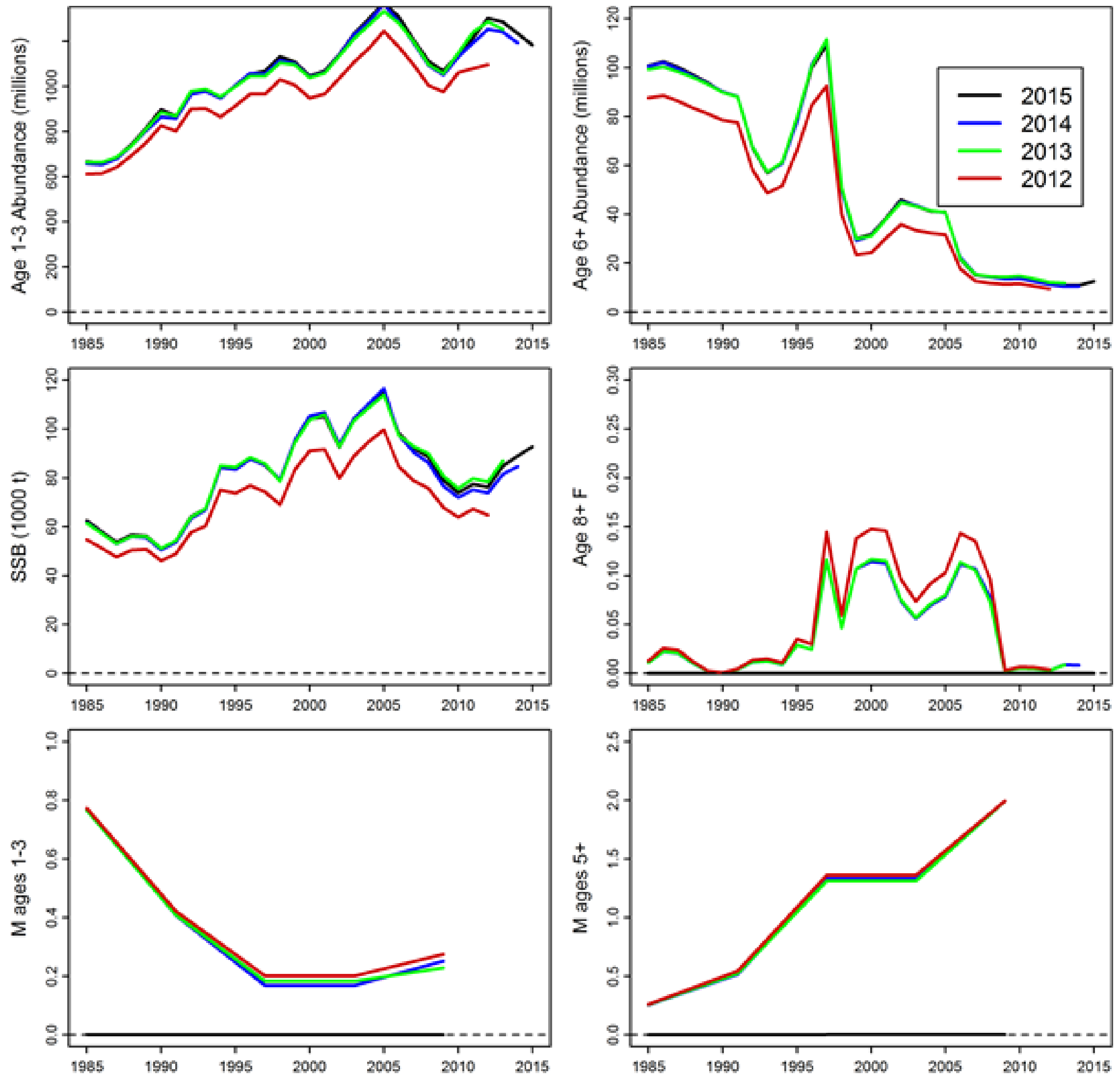

Figure 48. Retrospective analysis of a Yellowtail flounder population model estimates of abundance (upper row figures), biomass (middle left figure), fishing mortality at age 8+ years (middle right figure), and natural mortality (lower row figures) with the last time block for estimating M increased from 7 to 11 years. 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.

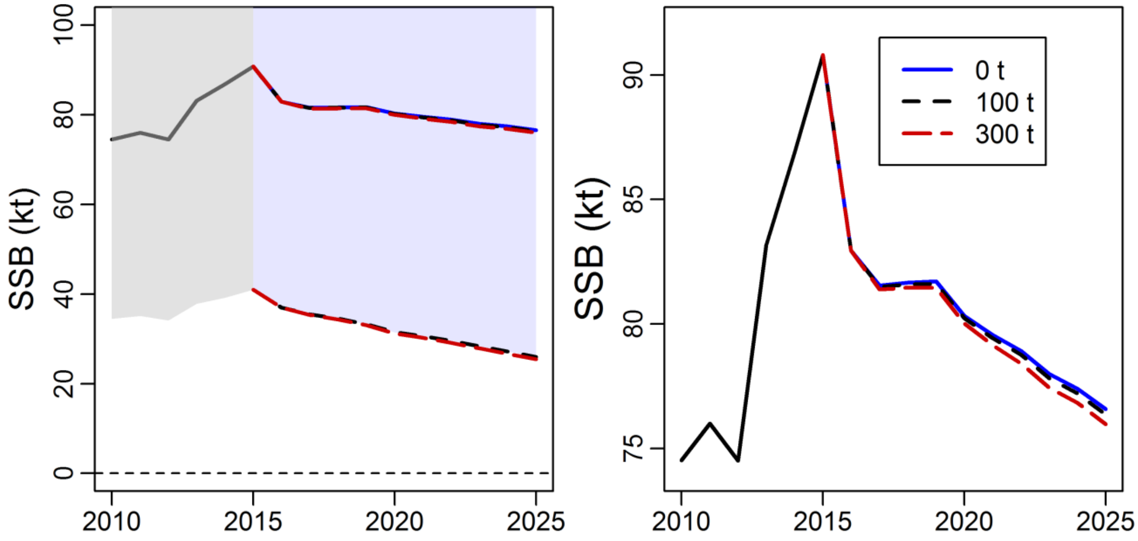

Figure 49. Projected spawning stock biomass (kt) of Yellowtail flounder aged 6 years and older (left panel) or aged 4-5 years (right panel) at three levels of fishery catch. Black lines show historical estimates and coloured lines show projected estimates (median). Grey and blue shading shows the 95% confidence intervals for the historical period and the projection with no catch. Dashed lines indicate the lower confidence limits and the medians for projections with fishery catches of 100 or 300 t.

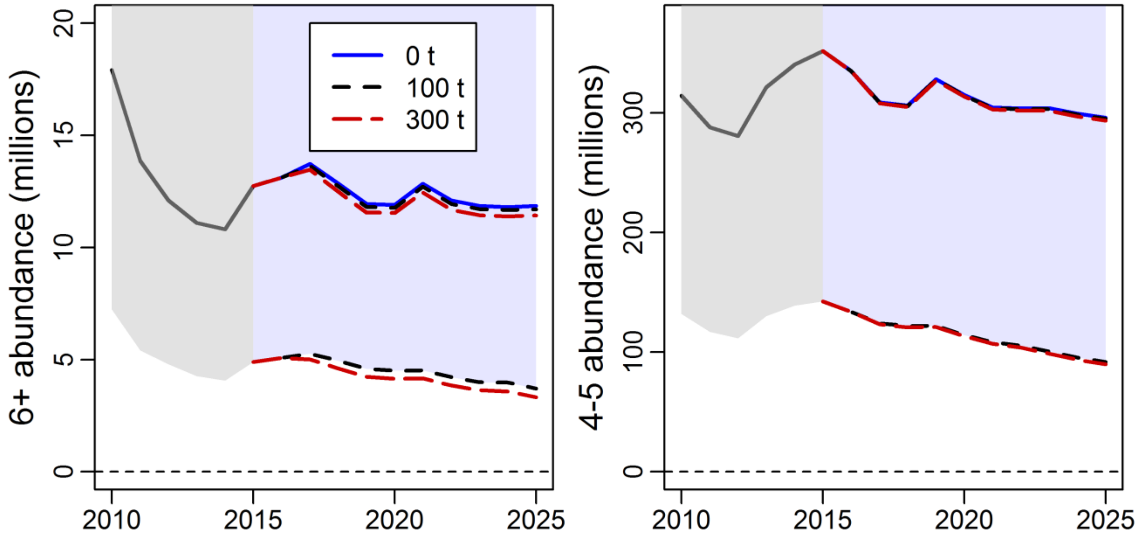

Figure 50. Projected abundance (millions of fish) of Yellowtail flounder aged 6 years and older (left panel) or aged 4-5 years (right panel) at three levels of fishery catch. Black lines show historical estimates and coloured lines show projected estimates (median). Grey and blue shading shows the 95% confidence intervals for the historical period and the projection with no catch. Dashed lines indicate the lower confidence limit and the median for projections with fishery catches of 100 or 300 t.