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Assessment of the Winter Flounder (*Pseudopleuronectes americanus*) stock of the southern Gulf of St. Lawrence (NAFO Div. 4T) to 2016 and advice for the May 2017 to May 2022 fisheries

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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

Winter Flounder (*Pseudopleuronectes americanus*) ranges from southern Labrador to Chesapeake Bay. In the southern Gulf of St. Lawrence (NAFO Div. 4T; sGSL), Winter Flounder tends to be distributed in shallow, near shore areas where it is fished primarily for bait. A total allowable catch was first instituted in 1996 at 1,000 t. Following the most recent assessment in 2011, the TAC was reduced to 300 t and has been in effect for the period 2012 to 2016. Winter Flounder is currently caught in a relatively small directed fishery concentrated mainly around the Magdalen Islands with landings ranging from 190 to 320 tonnes over the past 10 years. Abundance indices from a research survey show that there has been a decrease in the size distribution of the Winter Flounder stock with percentages of fish >= 25 cm (minimum size limit for the fishery) decreasing from an average of 85% during 1971 to 1975 to 30% during 2011 to 2015. Estimates of spawning stock biomass (SSB) were highest in the period from 1975 to 1994 at an average of 356,100 t (median). Over the recent period, the SSB estimate has declined to 235,700 t in 2003 and 76,270 t in 2016. The proportion of the SSB represented by older fish (5+) has also decreased over time. Based on a population model, the estimates of natural mortality have recently increased for young fish (ages 2 to 4) and continually increased for older fish (aged 5+). The instantaneous fishing mortality rate is estimated to be low to very low for all ages. The stock is considered to have been below the LRP since 2006. In 2016, the estimated SSB was 54% of the LRP. Projections at catch levels of 0 t, 100 t, and 300 t show no perceivable difference in stock trends over the next five years. Fishing mortality is a very small proportion of the total mortality of Winter Flounder in the southern Gulf of St. Lawrence and natural mortality is estimated to be the dominant factor affecting abundance. The contraction in size structure of Winter Flounder, the decline in the estimated size at 50% maturity, and the decline in abundance indices of the previously abundant commercial sized group are consistent with a stock experiencing very high levels of mortality.

INTRODUCTION

Winter Flounder (*Pseudopleuronectes americanus*) is common to shallow areas of the southern Gulf of St. Lawrence (NAFO Division 4T, Fig. 1) where it has been exploited commercially for several decades in a mixed fishery. The Winter Flounder fishery in the southern Gulf of St. Lawrence (sGSL) is managed using a five-year management plan (May 15, 2012 to May 14, 2017) with an annual total allowable catch set at 300 t, by fishing year (mid-May year t to mid-May year t+1). The last stock assessment was completed in February 2012 to provide advice for fishery years May 2012 to May 2017 (DFO 2012; Morin et al. 2012). Updates of RV survey indices were provided in 2013, 2014, and 2015 (DFO 2014, 2015, 2016a).

The RV and sentinel biomass indices for commercial sizes of Winter Flounder in the sGSL in recent years show that there has been no improvement in biomass since the last assessment with commercial biomass remaining at record low level (DFO 2016a). Based on catches in annual surveys, the average size of Winter Flounder has declined in most years since the surveys began in 1971. Previous assessments of sGSL Winter Flounder have underlined uncertainties in landing statistics up to the 1990s and in the nature of stock structure for sGSL Winter Flounder. The distribution of Winter Flounder extends beyond the inshore margin of the monitoring survey.

In this assessment, we update all available sources of survey data, including data on the age and growth of Winter Flounder. We describe trends in the fishery, including landing statistics and estimates of annual removals by length and age. We further develop a population model to explain the dynamics of sGSL Winter Flounder, with associated estimates of stock abundance and mortalities.

SPECIES BIOLOGY

Winter Flounder is widely distributed in the Northwest Atlantic from Labrador southward to Georgia (Scott and Scott 1988). It inhabits mainly shallow coastal waters, although offshore populations are found in locations such as Sable Island and George's Bank (Scott 1976). In the Gulf of St. Lawrence, it is found mainly along the southern coastline from Chaleur Bay, throughout the Northumberland Strait and into St. Georges Bay, with concentrations found around the Magdalen Islands and in the lower St. Lawrence River estuary. Some commercial catches are reported from the northern Gulf of St. Lawrence (NAFO Div. 4S) and off western Newfoundland (NAFO Div. 4R), indicating their wide distribution throughout the Gulf.

Winter Flounder are hardy, capable of inhabiting a wide range of environmental conditions. In southern populations, Winter Flounder have been found in habitats with a salinity range of 4-30 ‰ and temperatures ranging between 0 and 25°C (Pearcy 1962). In their northern limits of distribution, including Newfoundland waters, Winter Flounder possess serum antifreeze that lowers the freezing point of the blood to about -1.4°C (Fletcher 1977). Winter Flounder do not leave the Gulf in winter or migrate to deep water like Atlantic Cod and American Plaice (Swain et al. 1998). Instead, they overwinter in estuaries or coastal areas (Hanson and Courtenay 1996; Darbyson and Benoît 2003). In winter trawl surveys of the northern Gulf of St. Lawrence between 1983 and 1994, Winter Flounder were caught six times out of over 1,800 tows, but never in deep channels (R. Morin, unpublished data).

Spawning occurs in spring, from March to June, in Newfoundland waters (Kennedy and Steele 1971). There are no direct observations of spawning time in the sGSL. Females have been described as single-event spawners, depositing their eggs in a short period of time (Burton 1998), but also listed as batch spawners (Murua and Saborido-Rey 2003). Oocyte development may take more than one year between spawning (Dunn 1970) and female Winter Flounder may

reverse gonad development when feeding is restricted (Burton 1991). Fertilized Winter Flounder eggs are demersal, adhesive and tend to clump together. These traits are thought to have adaptive significance in maintaining the eggs and larvae in inshore nursery grounds where conditions are favourable for development (Klein-MacPhee 1978). Hatching occurs within 15 to 18 days at 3°C and the larvae drift in surface waters, changing to the benthic flatfish form within 2.5 to 3.5 months (Scott and Scott 1988). Winter Flounder larvae have been collected in June in Chaleur Bay (de Lafontaine et al. 1991) and were most abundant from mid-May to mid-July in the Gulf estuary (de Lafontaine et al. 1984). Winter Flounder larvae were collected at the surface in late June to early July in the northern part of Northumberland Strait (Faber 1976).

Throughout their range, Winter Flounder are typically sedentary, moving seasonally between the inshore and the offshore (reviews by Klein-MacPhee 1978; Phelan 1992). McCracken (1963) found Winter Flounder in Northumberland Strait concentrated in shallow water in spring and early summer, but by mid-summer catches declined in the shallows and increased at depths of 15-24 m. Tagging in the southern Gulf from 1999 to 2004 (R. Morin, unpublished) yielded 125 recaptured fish with the distance travelled ranging from <1 km to 75 km and the recovery time ranging from several weeks to four years. Thirty-eight percent of recoveries were made within five km of the release location (data unadjusted for fishing effort). FishBase lists a variety of organisms that comprise the diet of Winter Flounder (Froese and Pauly 2012), including various benthic invertebrates (amphipods, isopods, shrimps), mollusks and polychaete worms. Winter Flounder also concentrate on spawning areas of Atlantic Herring and Capelin, consuming their eggs in large quantities (Frank and Leggett 1984; Tibbo et al. 1963). The seasonal nearshore movements and the lack of evidence that Winter Flounder make extensive migrations have led to speculation that the sGSL may have several local stocks of Winter Flounder, partly linked through larval drift.

Beacham (1982) found that sGSL Winter Flounder were smaller at age than Scotian Shelf Winter Flounder, but with higher median length and age at maturity. Vaillancourt et al. (1985) reported that Winter Flounder in the Gulf estuary grew slower than more southerly populations, but that condition was higher, suggesting a requirement to accumulate more food energy as reserve in an environment with a relatively brief growing season. We provide further information on growth and maturity in the section on survey data.

DESCRIPTION OF THE FISHERY

Winter Flounder landings in NAFO Div. 4T have been recorded yearly since 1960 (Table 1). Reported landings have varied widely, reaching over 3,000 t in the mid-1960s, but declining through the 1990s, to less than 200 t in 2007 and 2008 (Table 1, Fig. 2). They then rose to more than 300 t in 2010 to 2012 but then declined in 2013 to 211 t. Preliminary landings for the 2016 fishery are 191.9 t, far below the long-term average of 1,481 t. In previous assessments, the variable pattern of Winter Flounder landings has been attributed partly to unreliable catch statistics.

Also shown in Figure 2 are the annual Total Allowable Catch (TAC) values. The TAC was 1,000 t during 1996 to 2011 and has been set at 300 t since 2012. Landings from the Magdalen Island bait fishery (description below), began in 2001 at a level of tens of tonnes per year and peaked in 2009 to 2011, with 64, 122 and 114 t, respectively, representing a sizeable portion of total landings for those years. Bait fishery landings have declined in recent years to 10 t or less (Fig. 2).

The Magdalen Islands lobster fishery considers the local stocks of flatfish, mainly Winter Flounder, Yellowtail Flounder and Windowpane, as a necessary and high quality source of bait. Flatfish also provide an important alternative to herring and mackerel which are not available in that sector during the lobster fishing season. In 2001, fishery managers in the DFO Quebec Region authorized an experimental bait fishery for flatfish. The main gear used in this fishery was the

otter trawl, scaled to operate from small lobster vessels and equipped with smaller codend mesh sizes (120 and 130 mm) than were authorized in the commercial Winter Flounder fishery. In 2001, roughly 20 vessels were active in this fishery, catching about 11 t of Winter Flounder, or 6 % of the local fishery (DFO 2010). This activity increased over time and, by 2008, 36 trawlers with bait licenses reported 34 t of Winter Flounder; in 2009, 47 trawlers with bait licenses caught 56 t of Winter Flounder. The activity peaked in 2010 with 96 lobster boats with bait permits reporting 117 t. Landings of Winter Flounder by commercially licensed boats on the Magdalen Islands matched landings by bait-licensed boats in 2009 and 2010. In December 2010, a decision was made by DFO to gradually reduce the number of bait permits and the days of fishing. Landings in 2011 indicate that the commercial boats provided a larger share of the total catch. After 2012, flatfish bait on the Magdalen Islands was provided by the commercial fishery alone. Landings for this bait fishery are presented in Table 1 and in Figure 2.

The NAFO Div. 4T Winter Flounder fishery came under quota regulation in 1996, following concern that the closure of the NAFO Div. 4T Atlantic cod fishery in 1993 would increase fishing effort on secondary resources, such as Winter Flounder. Winter Flounder fishing was closely related to fisheries for cod and White Hake, so the moratorium on NAFO Div. 4T hake fishing in 1995 added to this concern. The 1,000 t TAC was established as a precautionary measure, based on the average of previous recent landings. Prior to the 1993 cod closure, there were relatively few restrictions on Winter Flounder fishing, other than mesh size. Clay et al. (1984) reported that up to 1976, the minimum codend 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 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 codend mesh size for Winter Flounder at 140 mm throughout NAFO Div. 4T. Presently, the minimum codend mesh size is 145 mm square; however, on the Magdalen Islands, 140 mm is permitted when directing for Yellowtail Flounder.

The collapse of East Coast cod stocks triggered a number of alternative management measures for groundfish stocks and a tightening of existing measures. The 1993 report of the Fisheries Research Conservation Council (FRCC 1993), in their recommendations to the Minister of Fisheries and Oceans Canada, outlined the rationale for enhanced management measures. The FRCC stressed the need for alternative conservation options to the approach of defining harvest levels based on F0.1. In addition to TAC recommendations, they promoted “(1) using selective gears which allow escapement of fish below spawning age, (2) closing areas where spawning takes place for the period when fish aggregate to spawn, and (3) restricting the areas available to different gear types based on their respective impacts on the resource”. Gear restrictions (mainly mesh size), area closures and protected zones, and increased surveillance (mainly through at-sea observers and dockside monitors) became key management measures adopted in the 1990s.

Alternative management measures to mesh size came into effect in the 1990s that continue to form the basis for how Winter Flounder is managed in the southern Gulf. Bait permits were abolished in 1994 and there were limits set on the amount of cod caught incidentally. Small fish protocols were established for all groundfish species and limits were set on the capture of fish less than a minimum size (25 cm for Winter Flounder). Areas were closed when more than 15 % of catches were composed of Winter Flounder less than 25 cm. It became mandatory to land all fish caught, although this condition was relaxed for Winter Flounder in 1995, permitting fish harvesters to release live Winter Flounder when the survival of released fish was possible. A minimum level of observer coverage was established for each fleet and licence conditions required fish harvesters to accept observers to board their vessels, as required in the management plan. All vessels were required to notify dockside monitors of their movements to

and from port. All catches became subject to verification by dockside monitors who also sampled catches to test that limits on the capture of small fish were not exceeded.

The management measures that were in effect in the 2015 and 2016 fishing seasons for Winter Flounder are summarized in Table 2.

Since 1991, logbooks have become a license condition for commercial fishing of groundfish. In addition, mobile gear logbooks and purchase slips began in 1995 to indicate Winter Flounder as a landed species. Logbooks in previous years included a column indicating “flounder” which was frequently used to indicate the weight of mixed flatfish catches. Improved logbooks and the expansion of the dockside monitoring program resulted in more detailed accounting of landed species (Morin and Forest-Gallant 1997). A number of other management measures, discussed in this section, may have contributed to improving records on Winter Flounder landings.

Table 3 shows the landings and Figure 3 shows the proportion of landings by NAFO sub-areas, showing the transition of the fishery to the 4Tf region, i.e. the Magdalen Islands. This local fishery accounted for the 168.4 t landed in 4Tf in 2015, out of the 215.9 t landed in NAFO Div. 4T. Divisions 4Tg and 4Tm make up the bulk of the remaining landings at 28.1 and 17.1 t, respectively. Maps in Figure 4 shows this geographic shift in terms of local mean catches averaged by 5-year periods and aggregated by latitude and longitude of capture in 10-minute blocks, from 1991 to 2016. Landings have largely disappeared from around the Acadian Peninsula (4Th), western PEI (4Tl) and St. George’s Bay (4Tg). Some fishery activity remains in the northern part of the Chaleur Bay (4Tm and 4Th) and eastern PEI (4Tg), but at a much reduced scale. Landings from the Magdalen Islands now dominate the fishery.

Figure 3 shows that the timing of the fishery shifted toward earlier dates from 1960 to 2015. The majority of the landings were made in October and November in the 1960s, shifting to May and June in 2006 to 2015. The early timing since 2000 reflects the bait requirements of the Magdalen Islands lobster fishery. The Winter Flounder fishery is now conducted mainly from May to October, though it may begin in April, if weather conditions permit.

Otter trawls have been the dominant gear used to capture Winter Flounder in the commercial fishery (Table 5, Fig. 3). Since the mid-1980s, gillnets have increased in importance, peaking in the mid-1990s due to the expansion of “tangle net” fisheries. Tangle nets, gillnets with flotation removed, are set on herring spawning beds in spring and fall where Winter Flounder concentrate to feed on herring roe. From 1993 to 1999, gillnets contributed 30-46 % of annual landings, but the contribution has since declined to roughly 20-30% of Winter Flounder landings. Seines have varied in importance in this fishery, rarely contributing more than a quarter of annual landings. Seining is presently an important gear sourcing Winter Flounder for the Magdalen Islands lobster fishery.

Figure 3 shows that Winter Flounder as by-catch occurs mainly in the Yellowtail Flounder fishery, whereas Winter Flounder by-catch in Atlantic Cod and American Plaice fisheries largely disappeared during the 1990s.

INDICES AND BIOLOGICAL CHARACTERISTICS

MATERIALS AND METHODS

Fishery-Dependent Data

Size composition

In this section, data on the size and age composition of Winter Flounder in the NAFO Div. 4T commercial fishery are presented. As in previous assessments, these data originate principally from sampling of commercial catches in landing ports by DFO staff (Daigle and Benoît 2007). Since 1994, at-sea observers have sampled catches and measured Winter Flounder based on similar sampling requirements to port samplers. In general, the minimum sample of Winter Flounder for length frequencies is 200 to 250 fish. The landed number of Winter Flounder in the year's commercial fishery is obtained by scaling the sampled length frequencies to vessel catches and total landings. Aggregated annual estimates are produced, rather than estimated by season or area. Since the last assessment, the size and age composition of Winter Flounder catches for the entire time series has been re-estimated by main gear type (trawls, seines and fixed gear), where possible. Table 6 summarizes the number of samples and fish measured by gear type since 1973.

Commercial sampling of the catches began in 1973. From 1973 to 1981, there were fewer than five samples taken yearly from the commercial fishery (with the exception of 1976 when 12 samples were taken). There were no samples collected in two years, 1979 and 1981. Annual length composition in the 1970s and 1980 was obtained by combining samples from adjacent years.

Fishery-Independent Data

September multi-species surveys

The September multi-species bottom trawl (RV) survey has been conducted annually since 1971. Sampling stations are distributed according to a stratified random design (Fig. 5) with strata defining areas of similar habitat and depth. Comparative fishing experiments were undertaken for each change in gear (1985) and / or survey vessel (1985, 1992, 2004). In-shore strata 401, 402 and 403 were added in 1984. These were not considered when calculating abundance and biomass indices, to maintain comparability between years. Given that Winter Flounder do occur in these strata, a comparison of indices including and excluding these inshore strata was made (see below). Each Winter Flounder 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. The trawl was a Yankee 36 before 1985 and Western IIA type with a liner in the cod-end with a mesh size of 19 mm since 1985. Further details on this survey may be found in Hurlbut and Clay (1990). Catches were standardized by tow length and scaled to daytime catches on the current survey vessel, the CCGS Teleost, as described in Benoît and Swain (2003) and Benoît (2006).

Mobile sentinel surveys

Annual mobile sentinel surveys provide complimentary data on fish abundance using commercial vessels and gear. 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. 5). Over the time series (2003 to 2016) a total of 11 different vessels have participated in the survey (Table 7). The sampling protocol requires that tows be performed during daylight hours with a target tow distance of 1.25 nm and speed of 2.5 knots. The fishing gear is an otter trawl, but not of the same type as that of

the September survey and unlike the former, lacks a liner at the cod-end, which has a mesh size of 40 mm rather than 19 mm in the RV survey gear. Further information on the mobile sentinel survey can be found in Savoie (2014). Since stratum 402 was sampled for only a portion of the time series, only strata 401, 403 and 415-439 were used in the analyses.

The mobile sentinel survey does not have a structured comparative fishing component to estimate the relative fishing performance of participating vessels. As these vessels do not fish at the same locations, their relative performance would need to be inferred relative to some local area criterion, such as survey stratum. However, due to the limited spatial distribution of Winter Flounder, vessel effects were not estimated due confounding spatial effects which would need to be considered. Thus catches were only standardized to a standard distance of 1.25 nm.

Northumberland Strait survey

There are few sustained surveys of inshore areas in the southern Gulf of St. Lawrence, in habitat that is used extensively by Winter Flounder and that is not fully covered in the annual RV survey. The Northumberland Strait (NS) survey extends to depths less than 10 m (Morin et al. 2002). It was initiated in 2000 to monitor abundance and distribution of lobster in Lobster Fishing Area (LFA) 25 but was expanded over the years to cover most of LFA 26A as well. The survey used a random-block experimental design with an overlaying grid of 2 X 2 nautical miles. The blocks were partitioned into nine survey strata which cover the Northumberland Strait (Fig. 6). Primary and alternate stations were randomly selected within each block. A number 286 bottom trawl equipped with rubber “rock-hopper” footgear has been used since 1990 (Hanson 1996; Hanson and Lanteigne 2000; Voutier and Hanson 2008). The tow duration was 15 minutes with a target vessel speed of 2.5 knots, for a tow distance of 0.625 nm. After each tow, the catch was sorted to species, each taxon weighed and numbers recorded. A complete description of the survey design can be find in Comeau et al. (2008) and Voutier and Hanson (2008).

In 2010 and 2011, the survey design was modified. For those two years, a Bigouden Nephrops trawl with a smaller footgear was used along with a different fishing protocol to sample rock crab (*Cancer irroratus*) and sand shrimp (*Crangon septemspinosa*) more efficiently (Conan et al. 1994). Tow duration was 5 minutes with a target tow distance of 0.125 nm. The survey area was standardized and the number of sampling stations was set at 100 to 110 stations. In 2012, the sampling gear reverted to the “rock-hopper” trawl while the spatial survey design was left unchanged. No comparative fishing experiments were performed to estimate differences in catchability between the different gears.

Size-at-Maturity

Sampled fish were classified into maturity stages as immature, ripe, running ripe, or spent (post-spawning). Comparison of the relative proportions of maturity stages assigned indicated that they were not consistently used through the time series. Figure 7 (males) and figure 8 (females) show the empirical proportions of three groups of fish; 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, by year groups. The 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.

Maturity-at-age by year, a requirement to the population model, was calculated as the ratio of mature to total abundance-at-age. Annual length-based maturity curves were estimated and applied to the corresponding RV length-frequencies to derive the mature component.

Age and Growth

Individual ages for Winter Flounder were determined by reading whole sagittal otoliths under a dissecting microscope using reflected light. All age determinations since 1990 were performed by the same reader (I. Forest, DFO Gulf Region) who trained with the previous reader (M. Strong, DFO Maritimes Region, St. Andrew's Biological Station). Age reading was suspended in 1995 (Morin et al. 1995) following an exchange of otoliths with the Northeast Fisheries Science Center (Woods Hole, MA) which showed large differences in age interpretations between otolith readers, casting doubt on the validity of previous southern Gulf otolith readings. The differences in interpretation between readers were subsequently resolved and age reading resumed during 2004 to 2007, but was subsequently halted in the following years. Although Winter Flounder otoliths are collected annually from the September RV survey, they are not read regularly. To obtain more recent age samples and to fill in some gaps in intervening years, a random sub-sample of approximately 150 otoliths per year was chosen so as to have up to a maximum six otoliths per centimeter of fish length, with three per sex. A reference otolith collection for Winter Flounder was unavailable for this exercise and so the ager used a collection for American Plaice. This is considered reasonable owing to the similarity of otolith sizes and shapes between the two species. This procedure was applied to samples from 1998, 1999, 2012, 2013 and 2014.

The number of valid aged otoliths by year and age is presented in Table 8. In total, ageing data is available for 21 of the 46 RV survey years. For 10 of these 21 years, empirical age-length keys, i.e. estimates of proportions-at-age per fish size, are potentially unreliable in that they contain fewer than 300 valid otolith readings and empirical estimates of age-proportions at-length would be unreliable for most length values. Thus the ageing data is deficient over the time series in that there are 25 years with no data and 10 years with deficient data.

Smoothed Age-Length Key Model

Age data are either missing or deficient and empirical age-length keys cannot be generated for about three quarters of the survey time series. If the temporal growth pattern is deemed to be relatively constant, pooling of data over multi-year periods may be justified, but in this case, there are observed changes in growth.

Thus we applied a parametric model which makes use of temporal and length-based correlations in the data to help infer age-proportions for those years and length categories with missing or deficient data. We adopted the model described in Stari et al. (2010). The method, a type of multi-logistic model, estimates the proportions at age from a set of logistic regressions, with each age regressed over length with respect to a chosen reference. We refer to this model as a smoothed age-length key (ALK) model, as the resulting age-length key is "smoothed" over length with respect to an empirical model. This reduces the number of estimated parameters from $n_l(n_a - 1)$ in the empirical case, where n_l and n_a are the numbers of length and age categories in the key, to $2(n_a - 1)$ parameters for the smoothed-ALK model, which correspond to the logit-linear intercept and slope parameters for $n_a - 1$ logsitic regression curves. This approach is often justified, as the pairwise age proportions are often nicely modeled by a logisitic curve over length (Stari et al. 2010). We extended this model to include a random term incorporating temporal variability.

Let α_a and β_a, indexed by age a, be logit-scale intercept and slope parameters, respectively. Also let φ_{at} be a two-dimensional first-order autoregressive random field over age a and year t. Using the last age category as the reference, we define:

$$\eta_{lat} = \exp(\alpha_a + \beta_a \lambda_l + \varphi_{at}), \qquad \text{for } a = 1, \dots, n_a - 1$$

$$\eta_{lat} = 1, \qquad \text{for } a = n_a$$

$$\varphi_{at} \sim \rho_A \rho_T \varphi_{a-1,t-1} + \varepsilon_\varphi, \qquad \varepsilon_\varphi \sim N(0, \sigma_\varphi)$$

where n_a is the number of age categories, ρ_A and ρ_T are age and year correlation parameters, σ_φ is an error parameter, λ_l is fish length indexed by l, t is an index of year. Now let the probability of having an observation at age a for a fish of length λ_l at year t be defined as

$$P_{lat} = \frac{\eta_{lat}}{\sum_{a=1}^{n_a} \eta_{lat}}$$

The distribution of the vector of observed counts for each age is assumed to be multinomial with probability vector P_{lat} with total number of observations N_{lt}.

$$y_{lat} \sim Mult(P_{lat}, N_{lt})$$

This model was formulated in TMB (Kristensen et al. 2016), which then generated the corresponding log-likelihood function and was optimized using optim from R's stats package (R Core Team, 2016).

RESULTS

Age and Growth

Empirical mean lengths-at-age by year groups are shown in Figure 9. The mean length-at-age has generally decreased through time on the order of 2 to 3 cm across all ages from 1975 to 2014. This downward trend is consistent across periods, however, the most recent period from 2012 to 2014 slightly reverses the trend, though the sample size is small over this period. The age at commercial size (25 cm) changes from 5 to 6 years over the range of sample years.

Model to Generate Age-Length Keys

The maximum likelihood values of the logit-scale intercept α_a and slope β_a parameters values are shown in Figure 10. Figure 11 shows a bubble plot of logit-scale random intercept term φ_{at}, showing the deviations from the fixed intercept terms α_a over age and time. Maximum likelihood estimates (and 95 % confidence intervals in square brackets) for the parameters of the random intercept term were $\sigma_\varphi = 2.86\ [1.47, 5.77]$ for the error parameter, $\rho_A = 0.987\ [0.947, 0.997]$ for the age correlation parameter and $\rho_T = 0.685\ [\ 0.538, 0.793]$ for the year correlation parameter. The autoregressive term for φ_{at} was found to be significant over a null model without the term (Likelihood-ratio test, χ^2(2448, df = 3), $p \ll 10^{-5}$). Similarly, the smooth ALK-model with autoregressive structure for φ_{at} was found to be highly significant with respect to an alternative model with independent random effects for φ_{at} (Likelihood-ratio test, χ^2(358.2, df = 2), $p \ll 10^{-5}$). As the random term φ_{at} acts as a modifier of the logit intercept parameters α_a, a more complex model incorporating a similar random effect for modifying the logit-slope parameters β_a was also considered. However, the addition of the term was not found to be significant, as estimates of its scale error parameter converged towards very small values, showing that the overall effect was negligible.

Some strong year effects are visible for φ_{at}, notably for 1977 and 1991 (Fig. 11). This may indicate possible reading biases for those years, as such strong changes over all age classes in a given year would not generally be expected. Given the large number of data observations for 2004 to 2007, the large negative deviations observed in the lower right portion of the plot may indicate a decrease in size-at-age for younger fish. The trend did not extend to the 2012 to 2014 period, although the number of observations in this period was not large.

The smoothed-ALK model fits were compared to empirical proportions for a data-rich year in 2006 and a data-poor year in 2014 (Figs. 12 and 13). For 2006, the multi-logistic component fit the empirical proportions well for lengths with abundant data, while fish lengths with fewer data have empirical proportions which are noisier and for which the model smooths the predictions. For 2014, the smoothing was more severe as the number of observations was much smaller. As the random effect term is temporally correlated, the resulting model is not only a function of the data in 2014, but also of adjacent years, in accordance to the degree of correlation estimated by the model. Given the autoregressive structure used for random intercept term, it is stationary with respect to time. Thus when interpolating or extrapolating in years with no data, the model will naturally tend towards the global mean when the temporal correlation is weak. For instance, the estimated random effect for the period from 1984 to 1988 tends towards zero, owing to the absence of data from 1983 to 1989.

The actual age-length key used for all catch-at-age calculation is an amalgam of both the empirical and smoothed-ALK model estimates. Where the number of observations for a given length category was less than 10, the smoothed estimate was used rather than the empirical estimate. This means that for 2006 for instance(Fig. 12), the empirical values between fish lengths of 11 and 35 cm were used rather than the model-based estimates, as these length categories all had more than 10 observations. For 2014, where all length categories had less than 10 observations, only model-based estimates were used (Fig. 13).

The output of the model was a set of age-length keys for each year in the RV time series. This key was used for all catch-at-age conversions, including survey abundances-at-age and fishery catch-at-age.

Size and Age Composition of Commercial Catches

The commercial catch-at-length of NAFO Div. 4T Winter Flounder is presented in Figure 14. Though length distributions are generally unimodal, they do show some variability in their size range and to a lesser extent in their means (Fig. 15). There is no obvious decrease in mean size over the period. In 2010 and 2011, mean size was approximately 25 cm and mean sizes increased to the overall mean of 27 to 28 cm in 2012 to 2016. In particular, the periods from 1975 to 1978 and from 2010 to 2014 show fairly high proportions (15% to 40%) of fish smaller than 25 cm (Fig. 15). The mid- to late-1980s and during 2000 to 2009 are periods with moderate proportions of small fish (approx. 10%) (Figs 14 to 16).

Despite the small mesh sizes that were in effect throughout the 1970s and 1980s, Winter Flounder less than 25 cm were not regularly abundant in landed catches (Figs. 14 to 16). Winter Flounder < 25 cm comprised less than 10% in most years up to 1990 (Fig. 16). Mesh sizes and regulations imposed in 1994 may have contributed to maintaining a low percentage of small fish, but their proportion of the total catch was already at a low level since 1989. Despite the use of larger mesh sizes, the proportion of Winter Flounder < 25 cm in the total catch appears to have increased since the late 1990s (Fig. 16). Maximum sizes of Winter Flounder were greater early in the time series of commercial sampling. Until 1990, maximum size was mostly between 45 and 55 cm, with fish of 60 and 68 cm recorded in 1985 and 1986 catches. For the last five years, maximum sizes have ranged between 43 and 47 cm fish. This decline is visible in the 97.5th percentile of measured fish lengths (Fig. 15).

Figure 17 and Table 9 show the estimated commercial catch-at-age from 1973 to 2016. These were calculated by applying the smoothed age-length key derived from the September survey to the commercial catch-at-length estimates described in the previous section. Though the levels of catches have changed a lot through time, the proportions-at-age have not. Except for the 2010 to 2012 years, which reflect the smaller sizes caught during those years, the modal age has not

varied much through time. This is not surprising given that catches at length show little change through time. The fishery harvests mainly ages 5 through 9, with a maximum age of 12 years.

Abundance Indices

RV Survey

The overall abundance index for Winter Flounder was fairly stable throughout most of the history of the survey, with a slightly higher level of about 61 fish per tow in the early part of the series during 1974 to 1983, followed by an extended period of relative stability up to 2009 at 35 fish per tow, a decrease in 2010 to present levels of about 15 fish per tow and a value of 10.5 fish per tow in 2016 (Fig. 18). The long-term mean is 37.2 fish per tow. For comparison, the index including the inshore strata 401, 402 and 403 is also shown for the period 1984 to 2016. These strata do include a significant amount of the catches of Winter Flounder, their inclusion in the index produces very similar trends overall (Fig. 18). In contrast, catch weight indices show a long term decreasing trend during the survey series, from a mean of 17.4 kg per tow during 1974 to 1983, decreasing to less than 2 kg per tow in recent years, and a value of 1.1 kg per tow in 2016. Again, the inclusion of inshore strata yields a very comparable index (Fig. 18).

Figure 19 shows the catch index, for commercial and non-commercial sizes. Catches of small fish (< 25 cm) increased in the early 1970s and remained fairly stable through most of the times series, though in 2010, there was a decline of about half and it has remained at this level since then. In contrast, catches of commercial sized (>= 25 cm) fish have seen a significant and consistent decline through time. This decline is largely due to the decline in the abundance of larger fish (see RV length-frequency results below).

Figure 20 shows the spatial variability of abundance indices for four sub regions in the sGSL. The abundance for strata 418 and 419 in the region of Chaleur Bay shows a highly variable series with little indication of temporal trends. The index for strata 420 and 421, near the Miramichi region, shows some year effects though a trend is visible with slight decreases in recent years. Strata 428 and 435 around the Magdalen Islands show a period of higher abundance from 1973 to 1984, lower levels from 1985 to 1999, followed by an increase to new levels in 2000 and decrease in 2015 and 2016, though the trend is punctuated by what seemed to be year effects. Strata 432 and 433 in Eastern PEI show a pattern which is very similar to that of the global trend, but with a visible decrease from 1995 onward to relatively low levels in recent years.

Length-Frequencies

Stratified mean length-frequencies show a marked reduction in the sizes of Winter Flounder caught in the September RV survey (Fig. 21). Modal lengths were at around 26 to 30 cm during the early portion of the survey (1971 to 1985), and then decreased to 23 cm from the mid-1980s to 20 cm in the early 2000s and 18 to 20 cm in the past 16 years (Fig. 21). The proportion of fish larger than 25 cm has gradually decreased from 81.7% to the present levels of 24.6% for 2011 to 2016. These decreases in size explain much of the decrease in observed catch indices from the RV survey. Annual length-frequency distributions for the past six years show no obvious changes, with the mean length at approximately 20 cm and the standard deviation remaining fairly stable (Fig. 22).

Figure 23 shows annual fish length statistics from the RV survey. There is a consistent decrease from an initial mean size of 30 cm in 1971 to present levels of approximately 20 cm in 2016, with little deviation from the trend. This decrease is also noted in the 2.5th and 97.5th percentiles as well as the quartiles. This represents a substantial decrease in sizes caught in the RV survey.

Figure 24 shows the trend in mean individual weight for a 25 cm Winter Flounder, as estimated from the RV length-weight data. This series is somewhat difficult to interpret in that the precision

of on-board balances has changed much over the history of the survey. Where spring balances with precisions of 25 g were initially used, subsequent balances with 10 g, 5 g, and then 1 g precisions were used as time progressed. Now balances with 0.1g precision are used. Thus the variability in the earlier part of the series is partly due to variations in precision and some estimates, such as those for 1989 and 1993, appear unrealistic. Assuming that balances were generally unbiased, there is a visible decreasing trend in the data from levels of about 200 g in the earlier part of the series to weights of 180 to 190 g in the present period. While these changes may point to a decrease in condition in the animals, other observed physiological changes, as decreases in size-at-maturity or growth, may explain the decrease in mean weight.

Age Specific Abundance Indices

RV survey trawlable abundances-at-age over strata 415-439 are shown in Table 10 and a bubble plot of this data is shown in Figure 25. There is a general decrease in the mean and modal age of Winter Flounder through time and there is weak evidence of cohorts passing through the population at any time. Pairwise scatterplots and the correlation between ages are shown in Figure 26. Linear correlation values are generally very weak and the strongest one, between age 8 and age 9 fish, is 0.312.

Figure 27 shows the mean length-at-age for RV survey catches. There is a general decline of 2 to 3 cm across all ages, down to a low in the 2005 to 2008 period, followed by a slight increase in recent years. This decrease is a reflection of the decrease in growth as shown in Figure 9.

Sentinel

Figure 28 shows the abundance and biomass indices for the sentinel surveys from 2003 to 2016. There is a large overall decline from a mean 10 fish per tow in 2003 to about 1 fish per tow in 2016. Catches were slightly higher in intervening years from 2009 to 2011 but there was a large decrease in 2012 and slight increases since then to a level about 90% lower than in 2003. The trend in the biomass index is very similar.

Length-frequencies

Figure 29 shows the stratified mean length-frequencies for mobile sentinel survey catches from 2003 to 2016 for the sGSL. While there is an overall decrease in abundance, there is no clear trend in the mean size over the series. The proportion of fish smaller than 25 cm tended to be higher in recent years at 69% and 76% in 2015 and 2016, respectively.

Northumberland Strait

Figure 30 shows the stratified mean abundance indices of Winter Flounder for both subsets of blocks. Catches were standardized to 0.625 nm when the “rock-hopper” trawl was used and to 0.125 nm when the Bigouden Nephrops trawl was used. Estimates excluding and including stratum 6 were very similar and show identical trends and scales. Catches throughout the survey area increased (Fig. 27) and the percentage of non-zero catches increased to 97.5 %. The series from 2000 to 2009 is highly variable. The annual indices are highly variable with minima of 15 fish per tow during 2000, 2004 and 2005, local highs of 30 fish per tow in 2001 and 2002 and an abrupt global increase in 2006 to 56 fish per tow. Catches remained high in 2007 and 2008, but abruptly decreased in 2009 to 17 fish per tow. Given that the survey protocol was fairly constant from 2000 to 2009, these fluctuations in mean catches are most likely due to an influx of Winter Flounder from outside the survey area. Catches doubled from 2010 to 2011, though the scale of these catches cannot be compared with other years because of the use of the Bigouden Nephrops trawl. Catches from 2012 to 2016 show a slight upward trend, from approximately 20 fish per tow to 40 fish per tow, though the uncertainty for these values is large owing to the reduced number of sampling stations.

Length-frequencies

The length frequency distributions are shown in Figure 31 for the two subsets of strata considered. Estimates excluding and including stratum 6 were similar. Contrary to other surveys, the length distributions show variations with some evidence of cohorts possibly moving through the sampled area. Distributions are multi-modal for some years, such as in 2012 and 2013 and 2014 to 2016. The mean size decreased across the series from 2000 to 2011, but has been stable since then at about 15 cm. Fish larger than 25 cm seem to be largely absent from catches since 2012.

Spatial Distribution

RV Survey

The spatial distribution of standardized Winter Flounder catches over time from the September survey is shown in Figure 32. An inverse weighting method with a range parameter of 10 km was applied to 5-year groups of data. Winter Flounder are distributed along near-shore areas throughout the sGSL. They are distributed in and around the eastern and western parts of PEI, around the Shediac Valley and the Acadian Peninsula and around the Magdalen Islands. Though catches have decreased through time, presence of Winter Flounder in the various areas has generally remained the same, though at much lower levels, with the exception of the Shediac Valley and eastern PEI areas, as well as the northern Magdalen area, which now have very few Winter Flounder in the RV catches.

Cumulative RV Winter Flounder catches versus depth by time period are shown in Figures 33 and 34. From 805 to 90% of Winter Flounder catches from the RV survey were recorded in the 25 to 40 meter depth range of stations. While the depth distribution of catches has varied little over time, there has been a slight shift towards deeper waters. This can be seen in the recent period (2011 to 2016) where 40% of catches occurred in waters shallower than 30 meters whereas it was 60% in the remainder of the series. The proportion of non-zero catches has remained fairly constant over time with about around 20% of tows having Winter Flounder catches over each period.

Sentinel

Figure 35 shows the spatial distribution of sentinel survey catches from 2003 to 2016. The overall distribution is very similar to that from the RV survey over the same period (Fig. 33). Catches were originally coastally-distributed from the Chaleur Bay, around the Acadian Peninsula, down to Shediac Valley, along the north coast of PEI, in western PEI and around the Magdalen Islands. With the precipitous decline in catches, there are now low levels all around PEI and the Shediac Valley, as well as in Chaleur Bay. The proportion of survey stations with Winter Flounder catches has also declined from 25% during 2003 to 2006 to 14% in 2015 and 2016.

Northumberland Strait

The spatial distribution of Winter Flounder in the Northumberland Strait (NS) survey is shown in Figure 36 for the period 2000 to 2016. We note that the spatial distribution of stations was not constant from 2000 to 2009. Survey strata 1, 2, 3 and 5 were sampled relatively consistently through time, whereas stratum 6 was sampled from 2003 onward. For practical reasons, we selected survey stations from strata 1, 2, 3 and 5 to estimate indices and length frequencies. We compared these values with indices which also included stratum 6.

We note that the current survey area does not cover some northern portions of strata 1 and 2. The absence of comparative fishing experiments and heterogeneity in the spatial sampling makes comparison of annual survey indices difficult. Winter Flounder were widely distributed across the NS survey area. With the exception of 2004 and 2005, the percentage of stations with Winter

Flounder catches all exceeded 80%. High concentrations of Winter Flounder are found in the areas near Richibuctou and Western PEI, in the area near Cape Tormentine, and the area near Pictou in the southeastern part of PEI.

Size- and Age-at-Maturity

Size-at-Maturity

Annual trends of size-at-maturity were calculated over the RV survey time series. Sampled fish were classified into maturity stages of immature, ripe, running ripe, or spent (post-spawning). Comparison of the relative proportions of these maturity stages indicated that they were not consistently used throughout the time series. Figure 7 (males) and Figure 8 (females) show the empirical proportions of three groups of maturity stages by year groups; those which are surely immature, those which are surely mature, and those which are unsure, i.e. there is some doubt as to whether they are mature. The unsure component arises from the misdiagnosis of the spent maturity stage, ostensibly a post-spawning (i.e. mature) stage, characterized by small and empty gonads which may be confused with the immature stage in smaller sized fish.

Assuming that the unsure component is comprised primarily of mature fish through to smaller sizes, it is expected that the trends between it and the mature components would run in parallel as a function of fish length. This seems to be the case for the 1971 to 1982, 1998 to 2008 and 2009 to 2015 time periods, whereas departures between the two trends are noted for the 1983 to 1989 period for males and the 1990 to 1997 period for both sexes. There is some confidence that the maturity observations for the periods which bookend the time series are correct. There has been a clear shift in the mature proportions towards smaller sizes through time, reflecting a decreasing trend in size-at-maturity.

Logistic regressions over length were fitted to the maturity data by survey year and sex. The unsure category described 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. 37). Although there is a potential bias during the years 1983 to 1997, there is a clear decreasing trend in the size-at-maturity, from 22 to 24 cm for both sexes at the start of the time series to the present sizes of approximately 17 cm. While the trend is punctuated with some strong year effects, such as in the mid-1980s and in 1992, which may not be realistic, the trend is clearly visible and is consistent with those observed in other species in the southern Gulf.

POPULATION MODELLING

Population modelling of Winter Flounder is difficult as there is no clear evidence of relative cohort abundances in the length-frequencies; the latter are generally unimodal (Figs. 14 and 21). The survey catches-at-age show weak cohort dynamics which makes it difficult to estimate the scale of the population model parameters.

METHODS

Winter Flounder in the sGSL was modelled as a single population because the data were not available to support finer spatial resolution. A Virtual Population Analysis (VPA) was used in the previous assessment (Morin et al. 2002). In this assessment, a Statistical Catch-at-Age (SCA) model is applied, implemented in Template Model Builder (TMB) (Kristensen 2014; Kristensen et al. 2016). The data are assumed to have a multinomial structure with aggregated catches from the survey and the fishery, and their respective proportions at age, fitted by the model. This is a combined sex model.

Data Inputs

The data inputs to the population model are as follows:

- the total landings from 1973 to 2016 (tonnes; Table 1),
- the estimated RV survey trawlable abundance from 1973 to 2016 (tonnes; Figure 18),
- the commercial catch-at-age proportions (in numbers) for ages 2 to 12+ years from 1973 to 2016 (Table 9),
- the RV survey abundance at-age proportions for ages 2 to 12+ years from 1973 to 2016 (Table 10; Fig. 25),
- the proportions of mature fish at age from the RV survey 1973 to 2016 (used in calculating the spawning stock biomass) (Table 12), and
- the estimated mean weights-at-age by year for the RV survey and the fishery (kg per fish) (Table 13).

There are 44 years and 11 age classes of data in the time series inputs.

Model Parameters

Natural mortality

Natural mortality (*M*) was considered to be constant within blocks of five years starting from 1973, with the last period from 2013 to 2016 consisting of four years. Natural mortality was also allowed to vary by age group. Two scenarios were considered. The first considered the natural mortality to be similar within two age blocks for ages 2 to 4 years in one block and ages 5 years and older in the second block. The second scenario consisted of three age blocks of 2 to 4 years old, 5 to 7 years old, and 8 years and older fish. Age 5 fish roughly corresponds to the commercial size of 25 cm, though there has been a decrease in mean size of age 5 fish from 26 cm in the 1970s to 22 cm in recent years.

Selectivity model

Selectivity curves for the survey indices and the fishery were assumed to be logistic curves over fish age. The selectivity for the RV survey was scaled with respect to an overall catchability parameter q_{rv} and the fishery selectivity was scaled with respect to the overall estimated fishing mortality F_t for each fishing year. These logistic curves are parameterized by their age at the 50% and 95% selectivity levels, and are defined as:

$$\pi(a) = \left[1 + \exp\left(-\frac{\ln(19)}{\Delta_{95\%}}(a - a_{50\%})\right)\right]^{-1}$$

where $a_{50\%}$ is the age at which the relative selectivity is 0.5 and $a_{50\%} + \Delta_{95\%}$ is the age at which the relative selectivity is 0.95.

Temporal variation in selectivity was tested by allowing some model variants to have different curves for different time blocks.

For the RV survey, the time series was partitioned into two blocks, one from 1973 to 1984 (i.e. the period during which the vessel E. E. Prince was active), and the other from 1985 to 2016. This was considered to account for the two trawls used in these periods. The RV length-frequency plots (Fig. 21) and catch-at-age (Fig. 25) show some tendency for the trawl in the later time period to catch smaller and younger individuals, evident from 1990 onward and possibly earlier for age 3 fish, hence to have different trawl selectivities.

Fishery selectivity was also allowed to vary by time blocks. Based on changes in gear, fishing locations and seasonality as seen in Figures 3 and 4, the time series was divided into periods of 1973 to 1985, 1986 to 2005, and 2006 to 2016. The blocks were chosen to account for changes in gear composition in the fleet, with the expansion in use of gillnets in the mid-1980s. The change over 2005 to 2006 makes reference to the fishery becoming concentrated on the Magdalen Islands.

Population dynamics

Let $t = 1, \dots, T$ be a year index for 1973 to 2016, where $T = 44$, and $a = 1, \dots, A$ be an index for the $A = 11$ age categories for ages 2 to 12+. The population dynamics equations are as follows:

The first-year (i.e. 1973) population abundances are defined as:

$$N_{1,1} = \mu_R \times \exp(\varepsilon_1^{(R)})$$

$$N_{1,a} = \mu_R \times \exp\left[\varepsilon_{-a+2}^{(R)} - \sum_{j=2}^{a}\left(F_{init}S_{1,j}^{(f)} + M_{1,j}\right)\right], a = 2, \dots, A-1$$

$$N_{1,A} = \frac{\mu_R \times \exp\left[\varepsilon_{-A+2}^{(R)} - \sum_{j=2}^{A}\left(F_{init}S_{1,j}^{(f)} + M_{1,j}\right)\right]}{1 - \exp\left[-S_{1,A}^{(f)} \times F_{init} - M_{1,A}\right]}$$

Where $N_{t,a}$ is the population abundance in year t at age a, μ_R is the median recruitment rate, $\varepsilon_t^{(R)} \sim N(0, \sigma_R)$ are log-scale recruitment deviations for $t = -A+2, \dots, T$, (i.e. from 1963 to 2016), F_{init} is the initial fishery exploitation rate prior to 1973, $S_{1,j}^{(f)}$ is the fishery selectivity for the first year at age j and $M_{1,j}$ is the natural mortality rate for the first year at age j. The recruitment for the first age class (i.e. age 2) for $t = 2, \dots, T$ was given a first order auto-regressive (AR(1)) form:

$$N_{t,1} = \exp\left(\phi_R \ln\left(N_{t-1,1}\right) + (1 - \phi_R)\ln\mu_R + \varepsilon_{t-1}^{(R)}\right),$$

where $\varepsilon_{t-1}^{(R)} \sim N(0, \sigma_R)$, and ϕ_R is a correlation parameter, which was given low fixed value ($\text{logit}(\phi_R) = -4$), which approximately reduces the recruitment model to a random walk. The dynamic equations for the remaining years were defined as:

$$N_{t,a} = N_{t-1,a-1} \times \exp\left(-Z_{t-1,a-1}\right), a = 2, \dots, A-1,$$

$$N_{t,A} = N_{t-1,A-1} \times \exp\left(-Z_{t-1,A-1}\right) + N_{t-1,A} \times \exp(-Z_{t-1,A})$$

where $Z_{t-1,a-1}$ is the total mortality rate for year $t-1$ and age class $a-1$, defined as $M_{t-1,a-1} + S_{t-1,a-1}^{(f)}F_t$. The Baranov catch equations were solved iteratively for F_t using Newton's method.

Gaussian priors are stated in the form $N(\mu_M, \sigma_M)$, where μ_M is the mean and σ_M is the standard deviation. Natural mortality parameters for the first year block (1973 to 1977) were assigned priors of $\ln(M_{1,a}) \sim N(0.6, 0.1)$, for $a = 1, \dots 3$ (ages 2 to 4) and $\ln(M_{1,a}) \sim N(0.44, 0.1)$, for $a = 4, \dots, A$ (ages 5+) in the two age blocks models. For models with three age blocks for natural mortality, the priors were $\ln(M_{1,a)} \sim N(0.6, 0.1)$, for $a = 1, \dots 3$ (ages 2 to 4), $\ln(M_{1,a)} \sim N(0.52, 0.1)$, for $a = 4, \dots, 6$ (ages 5 to 7) and $\ln(M_{1,a}) \sim N(0.44, 0.1)$, for $a = 7, \dots, A$ (ages 8 and older).

A prior of $\ln(q_{rv}) \sim N(-1.7, 0.7)$ was assigned to the RV catchability parameter, which has a median of 0.20, and percentiles at 2.5% and 97.5% of 0.046 and 0.720, a range which we assumed to be reasonable for the RV survey (Fig. 38). Given the incomplete survey coverage of

the stock area and the fishing efficiency of the gear, it was considered very improbable that q_{rv} would exceed 0.720.

Uncertainty was also assumed for catches, with a fairly low level of error, except for 1984 which was assumed to have a large associated error. Formally, we let $\ln C_t \sim N(\ln C_t^{(obs)}, 0.1)$, for $t = 1, \dots 11, 13, \dots, T$ while the prior $\ln C_{12} \sim N(\ln C_{12}^{(obs)}, 2)$ was assumed for 1984.

The predicted trawlable abundance from the model was calculated as:

$$\hat{B}_t^{(rv)} = q_{rv} \cdot \sum_{a=1}^{A} S_{t,a}^{(rv)} \cdot N_{t,a} \cdot \exp(-f^{(rv)} \cdot Z_{t,a}) \cdot w_{t,a}$$

Where $f^{(rv)} = 0.71$ is the fraction of the year at which the survey occurs, $S_{t,a}^{(rv)}$ is the selectivity-at-age for the RV survey, $w_{t,a}$ is the individual weight-at-age as estimated from the RV surveys, based on year-specific length-weight regressions, stratified annual length-frequencies and the age length key described above.

The log-likelihood contribution from the observed RV survey trawlable biomass $B_t^{(rv)}$ is given by:

$$-\mathrm{T}\ln \sigma_{(rv)} - \frac{1}{2\sigma_{(rv)}^2} \sum_{t=1}^{T} \left(\ln B_t^{(rv)} - \ln \hat{B}_t^{(rv)} \right)^2$$

where $B_t^{(rv)}$ is the stratified trawlable abundance estimate from the RV survey data, and $\sigma_{(rv)}$ is the survey observation error, estimated from the population model. Model-based proportions-at-age were calculated from predicted trawlable abundance $\hat{N}_{t,a}^{(rv)}$,

$$\hat{P}_{t,a} = \frac{\hat{N}_{t,a}^{(rv)}}{\sum_{a=1}^{A} \hat{N}_{t,a}^{(rv)}}$$

where $\hat{N}_{t,a}^{(rv)} = q_{rv} \cdot S_{t,a}^{(rv)} \cdot N_{t,a} \cdot \exp(-f^{(rv)} \cdot Z_{t,a})$.

Similarly, model-based proportions-at-age for fishery catches were calculated from predicted fishable abundance $\hat{N}_{t,a}^{(f)}$:

$$\hat{N}_{t,a}^{(f)} = S_{t,a}^{(f)} \cdot N_{t,a}$$

The likelihood contribution from the proportions-at-age data for the survey and fishery catches were treated as follows. Let the log-scale residuals for the observed proportions be defined as $r_{t,a}^{(P)} = \ln P_{t,a} - \ln \hat{P}_{t,a}$. We then calculate the annual mean of these residuals over age $\mu_t^{(P)} = \frac{1}{A} \sum_{a=1}^{A} r_{t,a}^{(P)}$. The resulting log-likelihood contribution is calculated as a sum of squares term:

$$-\frac{1}{T} \sum_{t=1}^{T} \sum_{a=1}^{A} (r_{t,a}^{(P)} - \mu_t^{(P)})^2$$

with one term for the RV survey proportions-at-age and another for those of the fishery.

Models considered

There were seven major model variants which were considered, depending on the selectivity curve blocking and the natural mortality age-blocking used. Each model had either 1 or 2 selectivity curves for the RV survey, 1 or 3 selectivity curves for the fishery, and 2 or 3 age-blocks

for the natural mortality. Table 11 shows a summary for each model, including log-likelihoods, the number of parameters, AIC values, and issues with each model.

A total of 123 to 138 parameters were estimated, depending on the model, including the mean recruitment rate μ_R, the recruitment deviations $\varepsilon_{t-1}^{(R)}$, survey catchability q_{rv}, the natural mortality parameters for each year and age block, the selectivity curve parameters, the RV survey error parameter $\sigma_{(rv)}$ and the estimated catches.

RESULTS

Figure 39 shows the fitted selectivity-at-age curves for the RV survey and fishery from inference Model 2. The selectivity curves for the RV survey have age-at-50% values of 5.9 and 6.4 years for the 1973 to 1984 and the 1985 to 2016 periods, respectively. The age selectivity curve for the later period seems to favour younger fish from age 2 to 4 while the selectivity for ages 6+ seems to be lower than in the early period. This may be a response to the increase in abundance of younger fish in the later period. The age-at-50% value of the fishery is 6.2 years. In Model 5, which has three mortality age-blocks, the estimates of the age-at-50% selectivity were lower, at 4.5 years for the early period and 5.1 years for the later period. The selectivity curves are sensitive to other model components. The catchability-at-age for a given year is the product of the RV survey coefficient and the selectivity curve for that year.

The survey catchability coefficient q_{rv} was estimated at 0.232. However, the parameter estimate is weakly inferred from the data. Setting a flat prior over a reasonable range of values from 0.04 to 0.7 resulted in q_{rv} estimates at the upper limit of the range. The prior distribution represents our knowledge about the range and probability of q_{rv} from other studies and there is little information in the data to update the value. The estimates of q_{rv} from other population models yielded similar values.

In the population model for Yellowtail Flounder, the catchability coefficient was assumed to be about 0.3 (Surette and Swain 2016). However, the area of the sGSL occupied by Yellowtail Flounder is broader than for Winter Flounder and well covered by the RV survey, whereas the survey coverage of Winter Flounder habitat is more limited. Figure 40 shows the surface areas by 1-meter depth intervals of the sGSL and of the RV survey sampling area. Given that Winter Flounder inhabit depths ranging from tidal waters to 45 meters, we see that the RV survey covers only half of habitat occupied by Winter Flounder. This unsampled area has implications for the assumed catchability coefficient for the survey.

Natural morality (*M*) estimates for Models 1, 2, 5, and 7 are shown in Figure 41. Different models with two age-blocks show little difference in mortality estimates. For Model 2 (top-right) *M* for ages 2 to 4 is initially estimated at 0.48, decreases to 0.25, and rises to 0.72 and 0.90 in the last two age blocks. *M* is high for ages 5+ and increases through time, increasing from 0.68 to 1.25 and 1.02 in the last age blocks. Models with three age-blocks for *M* (3-M block model) have similar mortality values and trends. For Model 5, ages 5-7 have substantially lower *M* estimates than those of fish aged 2-4 and ages 8+ with the youngest and oldest age groups showing similar trends in *M*. *M* for ages 5 to 7 is initially estimated at 0.44, decreases to a low of 0.12, and then increases to 0.47. In contrast, for ages 2 to 4, *M* is initially estimated at 0.59 and gradually increases to 1.36 in the last block. Similarly for ages 8+, *M* is initially estimated at 0.60 and increases over time to 1.37 and declines to 0.84 in the last period. Except for the ages 5 to 7 block in the 3-M block model, there is an indication of a fairly consistent increase in mortality, especially for younger and older Winter Flounder. The reason for the lower estimates of *M* for fish aged 5 to 7 is unknown.

Figure 42 compares the observed and predicted total RV trawlable biomass based on Model 2. The model fit is generally good except for strong year effects in the 1970s, notably in 1974, 1976 and 1977. The number of survey stations for these earlier years was lower than in later years with the result that the indices of biomass for the earlier years are more uncertain. We expect the model to perform more smoothing in the 1970s compared to later periods. In the last 10 years, the model and observations are in good accordance, except for a positive year effect in 2009.

There are a number of strong year effects notably in the 1970s, as shown in the total biomass estimates (Fig. 43). In recent years, there are positive year effects for 2009 and 2010, and a negative one for 2012. The overall residual pattern is fairly good in that there is a low prevalance of contiguous years with consistent biases. The exception to this is for ages 2 and 3 in the early part of the time series. This pattern is particularly strong for Model 1 with opposite patterns for the 1973 to 1994 period (over-estimates) compared to the 1995 to 2016 period (under-estimates). While this pattern is somewhat as well for Model 2, the incorporation of an additional selectivity curve for the RV survey improves the pattern. The catchability of age 2 fish is fairly weak and not well estimated by the survey. The addition of an additional M age-block only weakly improves the pattern.

Figure 44 shows the log-scale residual plots of fitted proportions to the RV survey catch-at-age proportions and the fishery catch-at-age proportions. The pattern for proportions shows more issues than seen in the RV abundance residuals. For survey proportions, there are periods of blocks of biased proportions, such as age 8+ fish from 1982 to 1988. Overall however, the pattern for the RV proportions is similar to the residual pattern for the predicted RV abundances, as one would expect given that they are related. For catch proportions, one can visually distinguish periods having similar biases. For the period from 1975 to 1982 there are negative biases for fish aged 6+ and positive biases for younger fish. A switch then occurs in 1985 which lasts until about 2009 with positive biases for fish aged 8+. The inclusion of time varying fishery selectivity only partially remedied the problem. While the fit of the proportions is of some relevance, we note that these proportions represent two components of the model likelihood and the greater emphasis is placed on fits to the abundance RV survey index.

The fits for Models 2, 5 and 7 are very similar overall. Model 1 is included for comparison and shows the lack of fit for early ages across the series. Abundances of ages 2-3 in the early part of the series are estimated to be somewhat lower in Model 2 than for Models 5 and 7.

Figure 45 shows the estimated population abundances by age-group for Model 2. Abundances of ages 2 to 4 are fairly stable through time although there is a decrease of about 20% in the past 10 years. For ages 5 to 7, there are occasional peaks of abundance around 1980, 1990 and 2003 followed by a marked decline from approximately 744 million fish in 2008 to 203 million fish in 2016. Similarly for ages 8 to 10, abundance peaks are noted in 1983, 1993, and 2003 but abundance declines to present levels of 12 to 13.5 million fish. This represents a decline of 89% from peak abundance. The picture is similar for fish aged 11 and 12, with peak abundance of approximately 10 million in the 1970s and early 1980s, followed by a decrease to 1.4 million in 1998, followed by an increase to 4.4 million in 2004 and a decrease to present levels of 0.46 million fish.

Figure 46 shows the total abundance in numbers for ages 2 to 12+ predicted by Model 2. There is a slight decrease in the period from 1973 to 2009, with intermediate peaks of 7.2 billion fish in 1976, 5.1 billion in 1993, 4.9 billion in 2001, and 5.3 billion in 2008. The overall stock then declines to 3.05 billion in 2016, a 42% decrease in less than 10 years.

Figure 47 shows the estimated annual fishing mortality rate (*F*) for fully recruited ages for Model 2. Fishing mortality by age for a given year is the product of the annual fully-recruited F and the annual selectivity-at-age curve. *F* is estimated to be very low for ages 2, 3, and 4, with all values

over the time series being inferior to 0.000008, 0.00006, and 0.0005, respectively. Maximum *F* values over the series were 0.003 for age 4, 0.015 for age 5, 0.039 for age 6, 0.049 for age 7, and 0.051 for ages 8+. Overall the level of fishing mortality is very low compared to that of natural mortality. Natural mortality is on the order of 5 to 25 times the maximal fishing mortality rate in 1991, and 15 to 65 times the fishing mortality rate in recent years.

Figure 48 shows estimates of spawning stock biomass (SSB). The overall mean SSB is estimated to be 257,000 tonnes. The period from 1975 to 1994 had higher levels with a mean of 356,100 t while the following period from 1995 to 2016 had a mean of 165,400 t. Moreover, there has been a decline in this last period from 235,700 t in 2003 down to 76,270 t in 2016, a 67% reduction. The proportion represented by older fish has also decreased over the period from 30% to 40% in the 1970s and early 1980s down to 20% since 2010.

The recruitment of age 2 and 3 to the population is shown in Figure 49. Age 3 is included as age 2 is not well represented in the RV survey index and there is concern that reconstructed numbers may be too smoothed by the model to be an adequate reflection of the true underlying recruitment. Recruitment for age 2 fish is estimated to be relatively constant through the time series. Though there is an initial peak in abundance of 3.0 billion fish in 1974, the series shows a slight increase in the remainder of the series, from 1.7 billion in 1979 to 1.8 billion in 2015 and 1.8 billion in 2016. Recruitment of age-3 fish is also generally stable and shows the same peak abundance in the mid-1970s at 1.8 billion fish, followed by a fairly stable extended period from 1980 to 2009. The levels have declined from 1.2 billion fish in 2009 to 0.7 billion fish in 2016, a decline of 36%.

Estimates of the recruitment deviates are shown in Figure 50. Some autocorrelation is present in the results and the deviates show a peak in recruitment in the mid-1970s, followed by a slight increase in recruitment rate from 1979 onward. These deviations determine the values and trends observed for age-2 fish (Fig. 49).

A retrospective analysis was conducted to determine the consistency of model estimates as data from the five previous years were added or removed (Fig. 51). Additional years of data had little impact on time trends in the estimates but did affect the overall level of abundance of younger fish aged 2 to 4, whereas the abundance trend for older fish showed some, but not a large effect on the overall level. Additional years of data for young fish resulted in decreases in inferred abundance, with the highest deviation resulting from addition of data from 2015 onward. For older fish, there does not seem to be a consistent bias. The addition of data for 2015 and 2016 resulted in the largest deviation in estimates, whereas prior years back to 2011 produced the lowest deviations. The trends are nearly identical, except for the addition of data from 2015 and 2016 which led to reductions in abundance of young and old fish. The retrospective pattern for SSB shows slight overall change, but the trends are very similar. The decline in SSB in the past few years is stronger with additional years of data. There were few retrospective patterns for *F*. The retrospective pattern for estimates of *M* was good overall. For younger ages 2 to 4, there were shifts in overall levels of abundance, though the variation was not very large. As years were removed, estimates for *M* increased. Removal of data to 2014 resulted in a large decrease, by more than half, in inferred natural mortality for the last year block which consisted of years 2013 and 2014. For older ages, the pattern was good and there was little change in overall level. Variability is noted mainly in the last two year blocks, though there is no consistent bias in the estimates.

DISCUSSION

The results of the population model indicate that there have been increases in natural mortality in this population and that levels are generally high. Estimates from population models with three mortality age-blocks show that *M* for young (age 2 to 4) and older fish (age 8+) are at overall

levels that were very high and showed an increase over time. In contrast, natural mortality estimates for intermediate ages 5 to 7, were much lower, though an increase was still observed in the later periods. These increases in natural mortality provide an explanation for the decreasing abundance of fish. They 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 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 now largely restricted to the waters around the Magdalen Islands. Furthermore, it is suspected that an important portion of the stock lies in shallow waters unsampled by the RV survey. It is possible that fishing has had an important impact on Winter Flounder in the vicinity of the Magdalen Islands that is not evident at the level of the entire southern Gulf stock.

REFERENCE POINTS

In the absence of an acceptable surplus production model or stock and recruitment model to derive B_{msy}-based reference points, a proxy for B_{msy} was defined as the spawning stock biomass of Winter Flounder during a productive period, 1973 to 1994 (DFO 2009; Fig. 48). This period was chosen because the SSB was high and the SSB comprised an important number of older and larger fish. The average biomass over the productive period is 369.6 thousand tonnes. The upper stock reference point, defined as 80%B_{msy}, corresponds to 295.7 thousand tonnes. The limit reference point (LRP; 40% B_{msy}) value from the model is 147.8 thousand tonnes.

The modelled SSB has been below the LRP since 2006, except for 2008. In 2016, the modelled SSB was estimated at 52% of the LRP, with a 76% chance of being below the LRP.

PROJECTIONS

The population was projected forward five years assuming current productivity conditions would persist over the period from 2017 to 2021 (Fig. 52). Recruitment over this period was assumed to be the mean recruitment level of the past five years. Four levels (0 t, 100 t, 200 t and 300 t) of annual fishery catches were considered.

Projections at catch levels examined show no perceivable difference in stock trends over the next five years relative to no fishing. Projected SSB in the absence of fishing declined slightly over the period from 74.7 thousand tonnes in 2017 to 73.8 thousand tonnes in 2021. Under the 300 t catch scenario, the decline was only 0.1 t greater. Estimated uncertainty is very large over the projection period. For all catch scenarios including no catch, the SSB is expected to be below the LRP in all projection years. Fishing mortality is a very small proportion of the total mortality of Winter Flounder in the sGSL and at the scale of the southern Gulf, natural mortality is estimated to be the dominant factor affecting abundance.

INDICATOR ANALYSIS FOR INTERVENING YEARS

The NAFO Div. 4T Winter Flounder is currently assessed and managed on a five-year cycle. Indicators are needed to characterize stock status in the intervening years between assessments (DFO 2016b). The chosen indicator is the RV survey biomass index of commercial-sized Winter Flounder, defined as fish measuring 25 cm and longer. Since this index can have large observation error and changes in stock status should not be inferred from annual variations in the index, a three-year moving average is recommended.

In order to implement this approach it is necessary to relate the limit reference point (LRP) from its modelled population scale to the scale of the September RV biomass index of commercial-sized Winter Flounder. Over the productive period used to define the proxy value for B_{msy}, 1973 to 1994, the trawlable biomass index for Winter Flounder >= 25 cm averaged 16,523 t (Fig. 53). The re-scaled (to the trawlable biomass) limit reference point, 40% B_{msy}, is 6,609 t (40% of 16,523 t).

In 2016, the trawlable biomass index of commercial-sized Winter Flounder was estimated at 744 t, 11.3% of the re-scaled LRP (Fig. 53). The three-year average of the index to 2016 was estimated at 20.2% of the re-scaled LRP. As the stock is currently below the LRP and expected to remain there even in the absence of fishing, a re-assessment would be recommended if the stock status indicator signaled an increase in abundance to a level above the LRP.

An interim year update will be provided mid-way in the five-year assessment cycle, i.e. in early December 2019, to allow sufficient time to complete a full assessment and plan the peer review if the indicator signals that a re-assessment is warranted in the winter of 2020.

CONCLUSIONS

Winter Flounder is currently caught in relatively small directed fishery with landings that have varied between 190 and 320 tons over the past 10 years. The fishery is now primarily concentrated around the Magdalen Islands and supplies the market for bait. There has been a decline in fish length, with proportions of fish larger than 25 cm now accounting for about 20% of RV survey catches, in contrast to 85% of the catches in the early 1970s. Mean length in the survey has declined from 30 cm to 20 cm over the period 1971 to 2016.

Indices from the RV survey show that small (< 25 cm) Winter Flounder abundance has been generally stable through time, though there has been a decrease in the past eight years, whereas large (>= 25 cm) Winter Flounder abundance has declined over much of the entire series, after a period of relatively high abundance in the early to mid-1970s.

Natural mortality estimates for Winter Flounder are generally high and are estimated to have increased from 49% annual mortality during 1973 to 1977 to 64% in 2013 to 2016 in older Winter Flounder (age 5+) and from 38% to 60% for younger Winter Flounder (age 2 to 4).

Spawning stock biomass (SSB) has declined over much of the series, down 78% in recent years from the average value during 1975 to 1994. In addition, the proportion represented by older fish (age 5+) has decreased from 30-40% to 20%. This has negative implications for stock productivity since younger, smaller fish produce fewer eggs and possibly of lesser quality than older, larger fish.

Fishing mortality is estimated to generally be very low over all ages and years. Fishing mortality is such a small proportion of the estimated total mortality of Winter Flounder that there is no perceived difference in stock (forthcoming) trends over the next five years at catch projections of 0 t, 100 t, 200 t and 300 t annually.

A limit reference point for this stock (LRP = 147.8 thousand t) was calculated based on modelled estimates of SSB during a productive period. The modelled SSB (median) has been below the LRP since 2006, with exception of 2008. In 2016 the SSB was estimated at 52% of the LRP with a 76% chance of being below the LRP.

The contraction in size structure of Winter Flounder, the decline in the estimated size at 50% maturity from 23 to 24 cm in the 1970s to 17 to 18 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 southern Gulf, 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.

UNCERTAINTIES

The annual surveys of the sGSL do not sample the full distribution of Winter Flounder. Small, young Winter Flounder are found inshore of the area sampled by the survey (Fig. 54). This implies that smaller fish are underrepresented in the survey data.

The population model assumes that the proportion of Winter Flounder occurring outside of the survey area is constant from year to year. If the range occupied by Winter Flounder contracts and expands in relation to Winter Flounder density, the assumption of constant availability to the survey would not be appropriate. While the RV catchability coefficient from the population model in principle corrects for this unsampled inshore proportion of the stock, its value is poorly informed with the available data and reflects the prior assumption of its value. Thus there is uncertainty as to the overall scale of the population.

Stock structure is a source of uncertainty for this resource. Winter Flounder have a discontinuous, near shore distribution and some known traits, such as their adhesive eggs and the limited movement of tagged animals, suggest that there may be local breeding populations within the sGSL. Some degree of mixing may be expected due to the pelagic larval stage and straying of adult Winter Flounder.

While the densities of Winter Flounder over shallow depths are unknown, those depths which have been sampled by the RV survey tend to indicate that they may be important and that they are primarily composed of smaller Winter Flounder. Furthermore there is uncertainty in the ageing data in that these are generally uncalibrated against a reference set and a recent ageing exercise was not compared for consistency with earlier interpretations. The absence or sparseness of data required that a complex model be used to smooth out the age-length key estimates and the appropriateness of the interpolated and smoothed values is not fully known.

There are also some observational uncertainties as to the maturity curves of Winter Flounder over time, in that maturity criteria were not consistently applied from year to year. These issues are mainly found in intermediate survey years whereas data from the early and recent years suggest significant changes in size-at-maturity with the intermediate year values reflecting the transition between the two states. Uncertainty in annual maturity curves carry over to uncertainties in the estimates of Spawning Stock Biomass (SSB).

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TABLES

Table 1. Annual recorded landings (tonnes) of Winter Flounder in NAFO Div. 4T, southern Gulf of St. Lawrence, 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, from 2001 to 2015.

Year	Landings (t)	Year	Landings (t)
1960	900	1989	2089
1961	1596	1990	2077
1962	2312	1991	2536.2
1963	3148	1992	1892.7
1964	3002	1993	1664.8
1965	4412	1994	1237.1
1966	3056	1995	668.0
1967	2444	1996	836.1
1968	550	1997	1128.9
1969	1694	1998	620.7
1970	2684	1999	647.5
1971	2821	2000	576.7
1972	1822	2001	573.3 (11.4)
1973	2300	2002	440.3 (7.6)
1974	1920	2003	468.3 (13.8)
1975	2010	2004	381.4 (29.7)
1976	2407	2005	383.3 (20.7)
1977	1235	2006	246.7 (19.9)
1978	1121	2007	192.8 (29.3)
1979	1585	2008	197.3 (38.9)
1980	1976	2009	209.7 (64.6)
1981	1941	2010	301.3 (122.2)
1982	2305	2011	317.8 (113.9)
1983	1799	2012	305.9 (62)
1984	149	2013	211.1 (6.5)
1985	1180	2014	191.9 (10.5)
1986	2044	2015	215.9 (10.9)
1987	1811	2016	191.9
1988	1414	2017	na

Table 2. Fishery management measures for the Winter Flounder fishery in the southern Gulf of St. Lawrence.

Management measure	Specifics
Test fishery prior to opening	Yes, where there is a high probability of cod by-catch
Hake & other species:	10 % daily
By-catch limits Cod:	5 % daily, fixed gear; 10 % per trip, mobile gear
Departure hail-out required	Yes
Observer coverage Fixed gear:	5 %; mobile gear: 25 % in SE Gulf (4T8), 10 % elsewhere
Dockside monitoring	100 %, but not bait fishery on Magdalen Isl.
Small fish protocol, all species	Yes
Gear, minimum mesh size	145 mm gillnets & mobile gear

Table 3. Annual landings (kg) of Winter Flounder overall and by subdivision in NAFO Div. 4T, 1991 to 2015. Data are from DFO Statistics Branch, estimates of unreported catches and fishery logbooks. Unknown NAFO subdivisions are grouped under the heading 4T.

Year	4T	4Tf	4Tg	4Th	4Tj	4Tk	4Tl	4Tm	4Tn	4To	4Tp	4Tq
1991	577,434	228,621	740,072	390,713	12,423	1,250	187,383	226,294	152,304	678	0	19,065
1992	16,844	150,777	771,422	185,356	11,204	314	338,251	297,514	116,049	148	49	4,817
1993	70,155	192,100	293,136	120,051	7,686	541	525,479	318,414	135,493	888	482	418
1994	87,180	403	457,071	129,286	6,383	1,406	240,856	121,731	190,726	2,084	0	0
1995	197	5,185	247,660	179,225	158	2,325	72,796	113,032	38,309	8,288	200	578
1996	14,986	79	370,652	135,283	21	127	111,893	147,311	21,252	23,501	15	10,934
1997	90,524	72,461	444,293	102,617	134	843	266,240	78,992	61,574	10,982	0	220
1998	259	34,536	308,793	45,895	185	5	195,654	29,351	5,296	697	0	39
1999	0	83,492	364,885	53,835	715	0	82,258	24,524	37,472	336	0	0
2000	0	217,163	252,199	14,264	29	0	56,091	25,861	11,043	0	0	0
2001	0	178,274	270,207	34,628	67	499	75,338	10,073	4,176	85	0	0
2002	0	100,079	277,662	14,062	1,349	36	39,808	6,377	898	0	0	0
2003	0	133,761	220,928	15,415	0	633	67,897	17,239	12,206	0	0	240
2004	18	155,328	163,949	25	1,695	0	29,301	16,021	15,070	0	0	0
2005	4,150	174,069	149,669	1,845	328	31	43,364	8,249	1,631	0	0	0
2006	5,998	160,954	31,507	0	0	272	35,208	11,975	745	0	0	0
2007	760	121,696	45,582	0	0	0	10,789	13,806	133	0	0	0
2008	272	111,921	64,793	0	0	45	9,633	10,665	0	0	0	0
2009	15	155,417	27,020	2,341	0	0	8,820	14,759	1,343	0	0	0
2010	666	242,779	36,213	0	0	0	8,246	13,369	0	0	0	0
2011	2,467	243,948	58,068	235	0	498	2,582	9,962	0	0	0	0
2012	248	235,006	53,223	617	0	75	611	15,220	919	0	0	0
2013	116	163,453	35,196	0	0	180	0	10,751	1,372	0	0	0
2014	0	173,099	5,549	0	0	30	0	11,562	1,627	0	0	0
2015	0	168,388	28,112	0	0	126	0	17,133	2,168	0	0	0

Table 4. Annual landings (kg) by month of Winter Flounder in NAFO Div. 4T from 1960 to 2015. Data are from DFO Statistics Branch, estimates of unreported catches and fishery logbooks.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1960	4,000	9,000	0	0	0	13,000	93,000	147,000	144,000	246,000	241,000	3,000
1961	4,000	0	0	0	17,000	127,000	60,000	52,000	288,000	468,000	537,000	43,000
1962	3,000	11,000	0	0	33,000	99,000	194,000	153,000	502,000	945,000	297,000	75,000
1963	23,000	0	0	0	86,000	172,000	224,000	327,000	527,000	1,528,000	243,000	18,000
1964	0	0	0	3,000	88,000	148,000	240,000	258,000	503,000	1,412,000	341,000	9,000
1965	4,000	0	0	63,000	224,000	144,000	200,000	495,000	528,000	2,263,000	461,000	30,000
1966	5,000	0	0	133,000	115,000	225,000	241,000	290,000	560,000	1,151,000	267,000	69,000
1967	0	0	0	7,000	197,000	104,000	118,000	239,000	551,000	829,000	364,000	35,000
1968	0	1,000	0	33,000	82,000	93,000	126,000	16,000	10,000	69,000	119,000	1,000
1969	7,000	0	0	0	23,000	3,000	103,000	116,000	159,000	709,000	562,000	12,000
1970	3,000	0	2,000	111,000	128,000	153,000	239,000	229,000	474,000	661,000	637,000	47,000
1971	21,000	0	0	112,000	243,000	172,000	280,000	152,000	324,000	1,023,000	452,000	42,000
1972	0	1,000	0	0	4,000	33,000	81,000	212,000	277,000	782,000	418,000	14,000
1973	1,000	1,000	0	1,000	2,000	222,000	202,000	291,000	606,000	894,000	80,000	0
1974	1,000	1,000	0	0	10,000	59,000	405,000	389,000	433,000	472,000	150,000	0
1975	1,000	0	0	0	0	49,000	217,000	463,000	721,000	534,000	23,000	2,000
1976	1,000	0	0	0	14,000	543,000	595,000	442,000	475,000	334,000	3,000	0
1977	1,000	0	0	0	4,000	18,000	309,000	336,000	328,000	233,000	6,000	0
1978	0	1,000	0	0	25,000	43,000	165,000	211,000	281,000	372,000	23,000	0
1979	0	0	0	1,000	6,000	59,000	275,000	404,000	429,000	392,000	19,000	0
1980	0	3,000	0	0	38,000	229,000	322,000	372,000	487,000	511,000	14,000	0
1981	0	0	2,000	42,000	74,000	119,000	424,000	531,000	385,000	361,000	3,000	0
1982	2,000	2,000	3,000	1,000	155,000	158,000	372,000	438,000	762,000	388,000	23,000	1,000
1983	2,000	2,000	0	0	33,000	207,000	156,000	556,000	505,000	327,000	11,000	0
1984	1,000	0	0	4,000	54,000	13,000	6,000	8,000	36,000	26,000	0	1,000
1985	0	0	0	0	47,000	84,000	208,000	271,000	319,000	230,000	21,000	0
1986	0	0	0	7,000	180,000	160,000	460,000	479,000	434,000	306,000	18,000	0
1987	0	0	0	6,000	185,000	191,000	333,000	378,000	329,000	367,000	22,000	0
1988	0	0	0	2,000	182,000	155,000	271,000	257,000	286,000	238,000	23,000	0
1989	0	0	0	2,000	281,000	286,000	368,000	421,000	509,000	220,000	2,000	0
1990	0	0	0	1,000	207,000	439,000	459,000	397,000	346,000	223,000	5,000	0
1991	0	0	0	0	110,668	379,813	571,979	484,200	693,930	291,138	4,509	0
1992	0	0	0	91	93,470	205,211	366,448	412,235	522,549	283,940	8,801	0
1993	92	0	0	563	196,342	224,450	178,980	188,161	406,096	470,144	15	0
1994	0	0	0	0	19,231	209,803	165,319	206,078	498,741	137,747	0	207
1995	579	99	0	0	6,824	78,931	173,983	133,667	162,328	111,455	87	0
1996	0	0	0	0	57,293	114,889	119,039	166,196	234,695	143,883	59	0
1997	0	0	0	0	140,353	277,840	73,621	185,968	239,217	209,776	2,105	0
1998	0	0	0	1,013	154,925	70,912	29,868	84,848	173,496	103,108	2,528	12
1999	148	280	0	11,291	122,362	60,832	59,499	116,135	193,308	83,631	31	0
2000	0	0	0	3,709	126,068	154,205	55,245	78,442	76,921	82,050	10	0

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	0	0	0	5,499	142,321	100,959	27,566	108,693	117,623	70,132	554	0
2002	0	0	0	5,275	84,532	47,855	13,360	111,426	126,616	51,120	87	0
2003	0	0	0	2,851	125,140	69,520	31,878	61,630	132,467	44,833	0	0
2004	0	0	0	4,429	101,460	85,824	13,742	67,348	79,582	29,022	0	0
2005	0	0	0	6,612	129,204	84,582	15,922	56,548	65,815	24,653	0	0
2006	0	0	0	7,047	135,460	56,992	3,723	6,767	21,820	14,850	0	0
2007	0	0	0	17,204	63,533	59,376	4,552	9,463	24,487	14,151	0	0
2008	0	0	0	4,143	70,127	57,307	1,793	30,548	27,976	5,435	0	0
2009	0	0	0	14,570	85,627	77,392	4,132	5,200	18,337	4,457	0	0
2010	0	0	0	37,051	102,492	126,900	1,067	2,852	9,088	21,823	0	0
2011	0	0	0	33,481	125,816	94,885	10,648	295	41,544	11,091	0	0
2012	0	0	0	29,969	115,620	87,919	19,062	0	23,621	29,521	207	0
2013	0	0	0	14,431	84,035	76,741	80	116	25,968	9,697	0	0
2014	0	0	0	504	85,406	83,463	16,842	0	2,476	3,176	0	0
2015	0	0	0	711	64,495	80,138	38,927	2,083	3,036	25,711	826	0

Table 5. Annual landings (kg) of Winter Flounder in NAFO Div. 4T by gear type, from 1960 to 2016. Data are from DFO Statistics Branch, estimates of unreported catches and fishery logbooks. Data for 2016 are preliminary.

Year	Trawl	Seine	Gillnet	Paired	Longline	Other
1960	730,000	137,000	0	0	17,000	16,000
1961	1,043,000	452,000	1,000	0	2,000	98,000
1962	1,407,000	642,000	115,000	0	8,000	140,000
1963	2,324,000	697,000	66,000	0	15,000	46,000
1964	2,247,000	546,000	0	0	0	209,000
1965	4,026,000	217,000	12,000	0	89,000	68,000
1966	2,640,000	300,000	53,000	0	0	63,000
1967	1,870,000	464,000	58,000	0	33,000	19,000
1968	424,000	107,000	16,000	0	2,000	1,000
1969	1,263,000	51,000	25,000	0	12,000	343,000
1970	1,809,000	576,000	142,000	0	21,000	136,000
1971	1,769,000	572,000	79,000	0	23,000	378,000
1972	1,193,000	533,000	36,000	0	44,000	16,000
1973	1,807,000	399,000	29,000	0	42,000	23,000
1974	1,330,000	388,000	23,000	0	4,000	175,000
1975	1,577,000	254,000	35,000	0	3,000	141,000
1976	2,142,000	96,000	24,000	0	3,000	142,000
1977	903,000	48,000	24,000	0	6,000	254,000
1978	744,000	104,000	77,000	0	13,000	183,000
1979	1,280,000	52,000	64,000	0	10,000	179,000
1980	1,264,000	80,000	274,000	0	147,000	211,000
1981	1,605,000	30,000	215,000	0	16,000	75,000
1982	1,652,000	32,000	579,000	0	1,000	41,000
1983	1,413,000	131,000	231,000	0	7,000	17,000
1984	43,000	32,000	13,000	0	4,000	57,000
1985	935,000	56,000	97,000	51,000	38,000	3,000
1986	1,167,000	243,000	538,000	80,000	6,000	10,000
1987	824,000	307,000	526,000	62,000	85,000	7,000
1988	783,000	280,000	321,000	4,000	20,000	6,000
1989	1,191,000	392,000	469,000	0	37,000	0
1990	1,171,000	274,000	588,000	0	32,000	12,000
1991	1,864,196	187,927	347,385	118,306	13,813	4,610
1992	1,233,267	225,760	323,659	102,474	3,726	3,859
1993	774,985	64,327	763,620	29,363	2,489	30,059
1994	731,888	31,829	458,883	349	1,947	12,230
1995	386,990	10,000	267,185	2,417	0	1,361
1996	487,404	10,666	336,627	1,192	165	0
1997	524,875	64,953	528,365	10,629	58	0
1998	314,876	10,974	259,507	14,326	20,844	183
1999	362,441	11,878	199,980	72,596	194	428

Year	Trawl	Seine	Gillnet	Paired	Longline	Other
2000	299,151	113,882	141,968	21,587	39	23
2001	331,432	76,992	163,419	1,485	19	0
2002	306,971	55,831	67,188	10,246	12	23
2003	274,389	70,994	119,001	3,934	1	0
2004	176,976	85,068	104,510	14,853	0	0
2005	210,886	76,785	95,254	382	29	0
2006	85,336	89,363	69,104	290	0	2,566
2007	96,014	48,934	39,186	4,583	13	4,036
2008	128,300	28,869	36,191	0	0	3,969
2009	116,603	32,997	54,860	696	143	4,416
2010	170,292	56,884	67,886	0	1	6,210
2011	202,758	29,134	74,033	0	5,909	5,926
2012	197,784	16,136	90,096	0	0	1,903
2013	131,842	15,196	62,842	0	371	701
2014	124,984	12,253	53,928	0	0	702
2015	94,461	27,920	93,544	0	2	0
2016	125,000	37,700	29,400	0	0	0

Table 6. Summary of annual sampling effort by gear type used to determine commercial catch-at-length. Gear codes are: OTB = otter trawls; SNU = seines; FIX = gillnets and longlines, MOB = trawls and seines combined, SEN = sentinel program (either trawl (O), seine (S), combined mobile (M), or fixed gear (F)). The number of port samples and observer trips (n) as well as the number of fish measured are also shown. [1] Commercial and sentinel samples (unlined codends) combined.

Year	Gear	n	Measured	Year	Gear	n	Measured	Year	Gear	n	Measured	Year	Gear	n	Measured
1973	MOB	5	1000	1989	SNU	4	587	1999	FIX[1]	15	2126	2008	FIX	6	1304
1974	MOB	8	1550	1989	FIX	3	358	1999	MSEN	4	121	2008	OSEN	9	628
1975	MOB	12	3550	1990	OTB	4	550	2000	OTB[1]	20	3426	2009	OTB	12	1956
1976	MOB	16	3599	1990	SNU	5	757	2000	SNU[1]	5	1015	2009	SNU	5	686
1977	MOB	11	3249	1990	FIX	2	206	2000	FIX[1]	24	4316	2009	FIX	12	2075
1978	MOB	5	849	1991	OTB	1	225	2001	OTB[1]	15	2767	2009	OSEN	9	941
1979	MOB	2	328	1991	SNU	4	701	2001	SNU[1]	4	620	2010	OTB	10	1590
1980	MOB	7	974	1991	FIX	4	179	2001	FIX[1]	25	4131	2010	SNU	2	360
1980	FIX	2	400	1992	OTB	12	1562	2002	MOB[1]	18	3154	2010	FIX	9	1500
1981	MOB	6	774	1992	SNU	4	373	2002	FIX	11	2497	2010	OSEN	9	741
1981	FIX	2	400	1992	FIX	4	434	2002	SSEN	6	521	2011	OTB	14	2849
1982	OTB	4	510	1993	OTB	4	790	2003	OTB	19	6379	2011	SNU	4	584
1982	SNU	1	136	1993	SNU	2	394	2003	SNU	6	803	2011	FIX	15	2209
1982	FIX	2	400	1993	FIX	7	661	2003	FIX	8	1871	2011	OSEN	7	466
1983	OTB	17	2722	1994	OTB	11	9965	2003	OSEN	11	3382	2012	GNS	24	6436
1983	SNU	1	234	1994	SNU	3	969	2004	OTB	22	6223	2012	SNU	6	816
1983	FIX	4	362	1994	FIX	3	363	2004	SNU	4	605	2012	OTB	41	7611
1984	OTB	9	1430	1995	OTB	15	9039	2004	FIX[1]	13	2749	2013	GNS	17	3709
1984	SNU	2	163	1995	SNU	1	162	2004	OSEN	10	2271	2013	SNU	7	791
1984	FIX	3	289	1995	FIX	10	1634	2005	OTB	15	4957	2013	OTB	39	7946
1985	OTB	6	1280	1996	MOB	23	8024	2005	SNU	3	672	2014	GNS	18	2545
1985	SNU	1	258	1996	FIX	13	3220	2005	FIX[1]	12	2821	2014	LLS	1	1
1985	FIX	1	227	1996	MSEN	10	1378	2005	OSEN	10	1459	2014	SNU	4	370
1986	OTB	7	1684	1996	FSEN	49	1213	2006	OTB	4	1034	2014	OTB	34	4574
1986	SNU	2	300	1997	OTB	25	3793	2006	SNU	5	648	2015	GNS	25	5795
1986	FIX	12	847	1997	SNU[1]	6	1304	2006	FIX	2	429	2015	SNU	5	1091
1987	OTB	24	3051	1997	FIX[1]	37	4023	2006	OSEN	11	851	2015	OTB	16	3040
1987	SNU	54	7063	1997	MSEN	4	413	2007	OTB	17	2460	2016	GNS	13	1319
1987	FIX	2	233	1998	OTB[1]	21	3347	2007	SNU	8	902	2016	LLS	1	1
1988	OTB	1	183	1998	SNU[1]	3	554	2007	FIX	5	1160	2016	SNU	8	1503
1988	SNU	2	280	1998	FIX[1]	29	4638	2007	OSEN	11	925	2016	OTB	231	4132
1988	FIX	2	143	1998	MSEN	3	117	2008	OTB	7	747	2017	na	na	na
1989	OTB	10	1645	1999	MOB[1]	12	2417	2008	SNU	4	224	2017	na	na	na

Table 7. Number of mobile Sentinel survey tows performed by each vessel, 2003 to 2016.

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
2016	0	33	55	28	0	0	0	0	0	0	30

Table 8. Number of valid otoliths aged per year from the September RV survey by year and age.

Year	2	3	4	5	6	7	8	9	10	11	12+	Total
1975	0	8	26	18	22	35	21	11	6	4	5	156
1977	4	16	26	45	19	17	10	10	5	4	6	162
1978	6	11	21	38	64	35	22	2	7	2	0	208
1979	7	21	29	53	65	53	44	16	7	2	2	299
1980	4	28	49	49	53	53	49	13	10	2	2	312
1981	11	22	42	54	49	63	31	26	9	5	0	317
1982	0	3	5	13	24	20	11	5	0	0	0	81
1990	25	67	133	141	79	60	32	16	9	4	3	569
1991	17	50	102	111	102	81	51	25	5	3	3	551
1992	39	106	116	124	121	88	60	29	17	6	4	720
1993	60	118	124	127	125	80	69	45	25	5	7	790
1997	29	110	135	144	130	109	76	36	10	5	3	792
1998	16	29	21	24	24	23	21	12	4	0	1	176
1999	13	22	15	19	15	15	29	14	4	4	2	181
2004	54	106	114	124	115	68	61	31	15	8	3	702
2005	33	101	125	125	126	81	68	32	19	7	4	723
2006	40	135	195	183	141	113	103	72	29	16	13	1046
2007	54	129	147	195	164	108	67	58	26	10	6	972
2012	21	16	19	13	15	14	25	12	5	0	2	145
2013	19	19	18	19	17	11	18	5	6	4	1	158
2014	22	21	15	18	15	8	19	15	4	3	2	161

Table 9. Commercial catch-at-age (number, in thousands) of Winter Flounder from the southern Gulf of St. Lawrence, 1973 to 2016. Estimates for 2016 are preliminary.

Year	2	3	4	5	6	7	8	9	10	11	12
1973	0	1	72	378	898	1260	1060	610	344	170	165
1974	3	44	239	519	857	1088	771	399	220	111	111
1975	3	60	765	988	1347	1218	800	362	157	63	47
1976	31	323	1199	1874	1646	1399	808	357	178	90	71
1977	11	127	430	1058	905	782	480	277	87	37	24
1978	47	407	749	921	1397	583	352	106	98	48	26
1979	0	0	310	1373	1725	1440	853	251	66	27	14
1980	0	1	164	752	1818	1988	1464	226	85	46	19
1981	0	16	228	1053	1576	1841	960	447	95	69	23
1982	0	6	226	1397	1860	1650	1083	499	243	122	98
1983	5	25	152	581	1291	1544	1118	576	210	76	43
1984	0	6	50	120	155	124	73	29	9	3	2
1985	0	4	33	143	405	627	614	385	171	68	42
1986	1	33	264	805	1260	1245	932	474	199	81	58
1987	1	38	393	1054	1373	1270	919	448	174	68	36
1988	1	45	476	1220	1300	1007	612	259	94	37	20
1989	0	7	225	952	1351	1334	929	482	212	88	58
1990	0	1	209	1184	1624	1555	856	299	79	50	28
1991	0	137	571	1464	2623	1921	1094	410	91	15	23
1992	24	79	430	993	1460	1176	760	358	167	41	20
1993	0	22	269	671	1158	965	819	437	245	43	29
1994	5	22	199	674	1102	860	637	289	96	29	16
1995	0	3	51	214	433	436	368	187	66	23	12
1996	0	4	70	292	570	601	497	244	80	29	16
1997	1	20	152	472	922	959	738	289	71	45	16
1998	0	4	70	275	523	517	319	139	44	15	7
1999	0	3	62	277	542	541	354	150	46	16	7
2000	1	9	60	221	391	417	457	188	57	23	11
2001	2	9	57	227	418	417	422	184	61	25	12
2002	5	18	68	212	361	328	311	137	47	19	8
2003	0	7	77	274	463	368	320	137	48	19	7
2004	0	2	25	150	348	258	272	134	44	28	17
2005	1	5	61	172	389	297	285	146	68	12	16
2006	0	1	27	67	174	172	223	147	41	30	13
2007	3	4	22	112	162	169	108	93	36	9	2
2008	5	6	16	73	165	171	142	87	30	11	4
2009	3	7	29	104	191	178	152	76	25	9	4
2010	35	113	197	263	287	226	205	93	32	12	6
2011	32	122	220	288	324	254	255	98	31	11	5
2012	13	74	236	363	291	210	117	46	15	6	3
2013	5	23	100	211	184	144	78	33	12	5	2
2014	2	11	66	148	185	152	88	33	9	3	2
2015	5	13	33	86	134	122	165	92	35	16	8
2016	3	10	36	99	154	135	146	69	24	10	4

Table 10. Trawlable abundance (number, thousands) at age of Winter Flounder from the annual September RV survey in NAFO Div. 4T, 1973 to 2016.

Year	2	3	4	5	6	7	8	9	10	11	12
1973	387	2028	5306	6371	6742	6678	4726	2322	1110	514	399
1974	11381	11428	10564	14498	20262	26622	20330	11095	5852	2848	2240
1975	111	1210	8089	9507	12503	11714	7950	3796	1915	797	792
1976	1529	15401	48329	59452	46577	40860	25153	11944	6293	3258	3128
1977	439	4051	8450	12297	6694	4223	2284	1559	371	158	99
1978	100	2489	11841	23764	33984	13603	8256	2591	2279	1140	677
1979	226	5086	8825	14166	13041	10986	6434	2288	1039	456	407
1980	164	4057	14594	19283	23245	23579	17933	3117	1419	746	448
1981	2347	7587	12994	17859	17659	19800	10742	5743	2553	1652	948
1982	127	1247	6208	17271	15576	12106	7749	3709	1965	1022	927
1983	808	5976	13897	21775	26244	23348	15026	7484	2779	1016	555
1984	1203	3280	5121	5949	5486	4721	3649	2266	1092	445	308
1985	1414	4283	6776	9398	9034	6696	4148	1813	664	255	153
1986	1603	7385	13050	14997	12675	9501	6244	2908	1148	455	274
1987	824	4443	8330	8486	5632	3644	2229	1009	399	159	90
1988	694	3856	9762	12568	9515	6831	4260	1924	735	289	158
1989	710	6289	19575	23339	13435	7699	3853	1555	612	251	166
1990	1947	9512	28774	30570	12341	6319	2734	676	93	93	43
1991	2644	7932	17666	15921	8824	5137	2886	926	205	24	51
1992	2408	12818	18495	18326	13276	7465	3008	1272	454	121	57
1993	1795	7490	10730	11331	10829	5989	4501	2409	1300	232	230
1994	3606	5453	6433	7439	6437	3751	2460	1066	356	108	56
1995	19438	29683	18923	12956	8562	5036	3218	1331	427	145	88
1996	4225	10571	11028	10541	7969	5104	3246	1350	434	162	105
1997	4785	12933	13084	11581	7669	4650	2445	847	236	137	48
1998	2878	10094	11337	9506	6080	3390	1583	581	169	58	27
1999	4776	13079	16666	17061	12567	7377	3606	1236	340	116	47
2000	6845	17178	16860	17359	11828	7106	5471	1650	401	156	66
2001	3085	9519	10835	11254	8321	5024	3730	1216	329	129	57
2002	6667	15030	13886	13351	11319	8068	7257	3337	1291	553	279
2003	5784	12779	11568	10118	7508	4284	3296	1363	498	208	91
2004	3055	9041	13780	14124	11317	5455	4658	1555	563	256	137
2005	13065	25583	16093	12158	10901	5767	3770	1575	647	105	163
2006	1697	7288	10936	9953	7218	5022	4184	2419	692	402	199
2007	1487	7502	8845	10463	8146	4707	2795	2401	984	393	151
2008	2539	6475	7327	8386	6347	3595	2188	1094	358	136	62
2009	9494	19192	14730	11779	8132	4804	3318	1456	443	160	60
2010	3167	9080	10599	9053	5955	3354	2537	1032	340	128	60
2011	1977	3699	4416	4062	3288	2145	1964	712	211	75	30
2012	1129	3098	4539	3844	1831	955	441	154	48	18	8
2013	2126	4824	6339	5432	2923	1848	879	325	101	37	15
2014	5844	8947	8150	5354	2792	1423	634	200	51	18	12
2015	3260	5498	4086	3472	2440	1452	1553	720	250	109	53
2016	2794	4819	4132	3034	1605	783	636	255	81	33	14

Table 11. Summary of characteristics of candidate population models considered for analysis of Winter Flounder in the southern Gulf of St. Lawrence, including the number of RV and fishery selectivity curve year-blocks, the number of natural morality age-blocks, the number of parameters (k), log-likelihood values (lnL), the RV catchability coefficient q_{rv}, AIC values and a summary of issues with the model.

Model	Number of RV Selectivity curves	Number of fishery selectivity curves	Number of M age-blocks	k	lnL	q_rv	AIC	Issues
1	1	1	2	123	41.6	0.214	162.9	RV residual pattern for fish age 2-3.
2	2	1	2	125	54.9	0.233	140.2	Slight RV residual pattern, but good overall.
3	1	3	2	127	52.0	0.178	150.0	RV residual pattern for fish age 2-3.
4	2	3	2	129	63.4	0.212	131.3	Slight RV residual pattern Strong differences in RV selectivity curves.
5	2	1	3	134	72.5	0.211	123.1	Good residual pattern RV selectivities are reverse of model 4.
6	1	3	3	136	62.1	0.195	147.8	RV residual pattern for fish age 2-3.
7	2	3	3	138	77.3	0.209	121.5	Good residual pattern RV selectivities are reverse of model 4.

Table 12. Proportions of mature Winter Flounder at age from the RV survey of the southern Gulf of St. Lawrence.

Year	2	3	4	5	6	7	8	9	10	11	12
1973	0.054	0.212	0.472	0.689	0.847	0.920	0.954	0.976	0.987	0.990	0.995
1974	0.082	0.192	0.693	0.887	0.949	0.974	0.985	0.991	0.994	0.995	0.997
1975	0.276	0.448	0.795	0.869	0.945	0.969	0.980	0.988	0.994	0.996	0.999
1976	0.269	0.494	0.712	0.835	0.921	0.961	0.978	0.989	0.994	0.995	0.998
1977	0.205	0.382	0.562	0.740	0.850	0.940	0.967	0.936	0.989	0.991	0.996
1978	0.223	0.671	0.670	0.818	0.880	0.937	0.950	0.997	0.994	0.988	0.998
1979	0.079	0.257	0.466	0.722	0.857	0.869	0.921	0.951	0.989	0.993	0.998
1980	0.078	0.304	0.529	0.698	0.842	0.899	0.944	0.977	0.985	0.993	0.998
1981	0.114	0.219	0.501	0.752	0.894	0.925	0.947	0.965	0.938	0.991	0.998
1982	0.267	0.498	0.713	0.821	0.884	0.918	0.937	0.954	0.967	0.971	0.980
1983	0.475	0.614	0.762	0.857	0.918	0.950	0.967	0.980	0.987	0.989	0.993
1984	0.429	0.714	0.856	0.923	0.962	0.982	0.991	0.996	0.998	0.998	0.999
1985	0.382	0.562	0.803	0.906	0.951	0.970	0.981	0.988	0.993	0.995	0.997
1986	0.430	0.618	0.789	0.887	0.946	0.970	0.982	0.989	0.994	0.995	0.997
1987	0.408	0.584	0.738	0.838	0.909	0.946	0.966	0.981	0.989	0.991	0.995
1988	0.345	0.555	0.749	0.854	0.919	0.952	0.968	0.980	0.987	0.989	0.994
1989	0.405	0.589	0.760	0.854	0.912	0.943	0.961	0.977	0.988	0.990	0.996
1990	0.396	0.703	0.826	0.899	0.949	0.955	0.971	0.981	0.997	0.993	0.998
1991	0.601	0.720	0.816	0.886	0.956	0.968	0.964	0.983	0.994	0.998	0.996
1992	0.704	0.811	0.905	0.939	0.969	0.971	0.989	0.990	0.998	0.998	1.000
1993	0.416	0.712	0.855	0.906	0.959	0.977	0.984	0.988	0.993	0.999	0.999
1994	0.255	0.532	0.802	0.905	0.950	0.970	0.980	0.987	0.992	0.993	0.996
1995	0.180	0.372	0.617	0.798	0.911	0.955	0.973	0.984	0.991	0.993	0.997
1996	0.174	0.394	0.669	0.829	0.918	0.955	0.973	0.985	0.992	0.994	0.997
1997	0.267	0.437	0.707	0.824	0.910	0.958	0.981	0.991	0.989	0.990	0.990
1998	0.392	0.561	0.727	0.831	0.905	0.946	0.968	0.983	0.991	0.993	0.996
1999	0.337	0.546	0.761	0.869	0.929	0.956	0.971	0.982	0.989	0.991	0.995
2000	0.322	0.522	0.737	0.861	0.929	0.959	0.973	0.984	0.991	0.992	0.996
2001	0.323	0.520	0.731	0.859	0.933	0.963	0.976	0.985	0.991	0.993	0.996
2002	0.252	0.458	0.695	0.855	0.945	0.976	0.987	0.993	0.996	0.997	0.998
2003	0.218	0.427	0.686	0.849	0.943	0.975	0.987	0.993	0.996	0.997	0.999
2004	0.254	0.494	0.730	0.880	0.955	0.968	0.981	0.992	0.967	0.999	0.998
2005	0.201	0.371	0.642	0.880	0.951	0.971	0.985	0.992	0.996	0.999	0.996
2006	0.217	0.398	0.656	0.840	0.927	0.959	0.984	0.987	0.995	0.998	0.998
2007	0.193	0.395	0.606	0.816	0.893	0.943	0.969	0.981	0.998	0.989	1.000
2008	0.282	0.463	0.709	0.852	0.930	0.961	0.976	0.986	0.992	0.993	0.997
2009	0.312	0.463	0.668	0.833	0.930	0.965	0.979	0.987	0.992	0.993	0.996
2010	0.378	0.564	0.754	0.868	0.937	0.968	0.982	0.991	0.995	0.996	0.998
2011	0.332	0.592	0.791	0.899	0.956	0.977	0.986	0.992	0.995	0.996	0.998
2012	0.391	0.647	0.853	0.936	0.972	0.986	0.991	0.995	0.997	0.998	0.999
2013	0.285	0.546	0.781	0.916	0.971	0.986	0.991	0.994	0.996	0.996	0.997
2014	0.229	0.430	0.703	0.856	0.935	0.967	0.981	0.989	0.994	0.995	0.998
2015	0.301	0.458	0.689	0.847	0.932	0.965	0.979	0.988	0.993	0.994	0.997
2016	0.251	0.468	0.677	0.804	0.893	0.940	0.964	0.980	0.989	0.991	0.995

Table 13. Mean weights-at-age (kg) of Winter Flounder from the RV survey of the southern Gulf of St. Lawrence.

Year	2	3	4	5	6	7	8	9	10	11	12
1973	0.046	0.094	0.152	0.215	0.291	0.360	0.422	0.499	0.584	0.616	0.741
1974	0.036	0.060	0.187	0.278	0.365	0.443	0.503	0.566	0.624	0.644	0.708
1975	0.067	0.097	0.181	0.230	0.316	0.404	0.467	0.570	0.717	0.806	1.041
1976	0.078	0.118	0.169	0.223	0.299	0.369	0.426	0.493	0.577	0.619	0.853
1977	0.064	0.093	0.129	0.179	0.240	0.316	0.382	0.357	0.548	0.585	0.706
1978	0.062	0.162	0.142	0.193	0.234	0.338	0.398	0.599	0.563	0.550	0.712
1979	0.042	0.077	0.114	0.182	0.250	0.276	0.340	0.446	0.582	0.625	0.777
1980	0.051	0.097	0.141	0.184	0.258	0.310	0.354	0.470	0.547	0.591	0.767
1981	0.053	0.079	0.138	0.210	0.295	0.336	0.379	0.432	0.542	0.576	0.760
1982	0.066	0.114	0.176	0.225	0.272	0.313	0.350	0.398	0.458	0.484	0.574
1983	0.052	0.076	0.118	0.165	0.225	0.286	0.341	0.408	0.473	0.495	0.559
1984	0.037	0.076	0.121	0.169	0.242	0.334	0.418	0.502	0.570	0.592	0.664
1985	0.046	0.074	0.139	0.196	0.254	0.310	0.365	0.442	0.535	0.573	0.721
1986	0.052	0.083	0.132	0.191	0.266	0.334	0.396	0.479	0.572	0.607	0.729
1987	0.048	0.076	0.115	0.161	0.222	0.288	0.352	0.433	0.512	0.539	0.619
1988	0.048	0.082	0.133	0.184	0.247	0.308	0.361	0.424	0.491	0.518	0.614
1989	0.059	0.091	0.138	0.181	0.231	0.283	0.341	0.435	0.550	0.592	0.718
1990	0.037	0.090	0.132	0.180	0.241	0.277	0.315	0.384	0.717	0.564	0.887
1991	0.052	0.081	0.113	0.151	0.240	0.298	0.310	0.408	0.508	0.688	0.558
1992	0.081	0.101	0.148	0.182	0.235	0.266	0.366	0.409	0.546	0.563	0.778
1993	0.043	0.090	0.146	0.188	0.256	0.322	0.384	0.442	0.514	0.705	0.774
1994	0.030	0.067	0.132	0.186	0.242	0.293	0.340	0.401	0.465	0.488	0.557
1995	0.029	0.055	0.099	0.158	0.233	0.295	0.347	0.417	0.509	0.550	0.720
1996	0.031	0.061	0.111	0.163	0.222	0.279	0.335	0.415	0.513	0.551	0.678
1997	0.035	0.055	0.104	0.143	0.198	0.261	0.318	0.416	0.438	0.400	0.418
1998	0.048	0.072	0.108	0.146	0.200	0.262	0.322	0.398	0.477	0.507	0.610
1999	0.040	0.068	0.115	0.160	0.210	0.258	0.303	0.365	0.434	0.460	0.547
2000	0.034	0.057	0.097	0.140	0.189	0.234	0.276	0.334	0.405	0.433	0.530
2001	0.038	0.061	0.100	0.146	0.199	0.242	0.278	0.329	0.402	0.436	0.575
2002	0.033	0.056	0.096	0.151	0.223	0.286	0.336	0.396	0.459	0.482	0.558
2003	0.032	0.053	0.090	0.138	0.200	0.252	0.294	0.345	0.403	0.426	0.504
2004	0.032	0.057	0.090	0.137	0.194	0.227	0.254	0.317	0.317	0.404	0.396
2005	0.022	0.037	0.075	0.129	0.179	0.214	0.259	0.295	0.336	0.437	0.374
2006	0.025	0.043	0.078	0.118	0.170	0.207	0.256	0.302	0.374	0.394	0.458
2007	0.029	0.046	0.074	0.125	0.158	0.235	0.270	0.331	0.430	0.429	0.578
2008	0.031	0.049	0.087	0.128	0.175	0.216	0.254	0.305	0.366	0.391	0.483
2009	0.033	0.048	0.080	0.127	0.184	0.230	0.267	0.310	0.351	0.365	0.407
2010	0.039	0.058	0.089	0.124	0.170	0.217	0.262	0.322	0.387	0.410	0.478
2011	0.035	0.060	0.095	0.134	0.179	0.216	0.248	0.288	0.330	0.346	0.394
2012	0.035	0.063	0.108	0.152	0.201	0.245	0.285	0.339	0.403	0.428	0.507
2013	0.030	0.059	0.108	0.176	0.241	0.283	0.313	0.346	0.380	0.394	0.439
2014	0.031	0.053	0.097	0.144	0.199	0.250	0.295	0.353	0.426	0.460	0.591
2015	0.040	0.058	0.098	0.148	0.205	0.255	0.296	0.347	0.406	0.430	0.519
2016	0.035	0.060	0.094	0.129	0.176	0.226	0.272	0.325	0.376	0.394	0.446

FIGURES

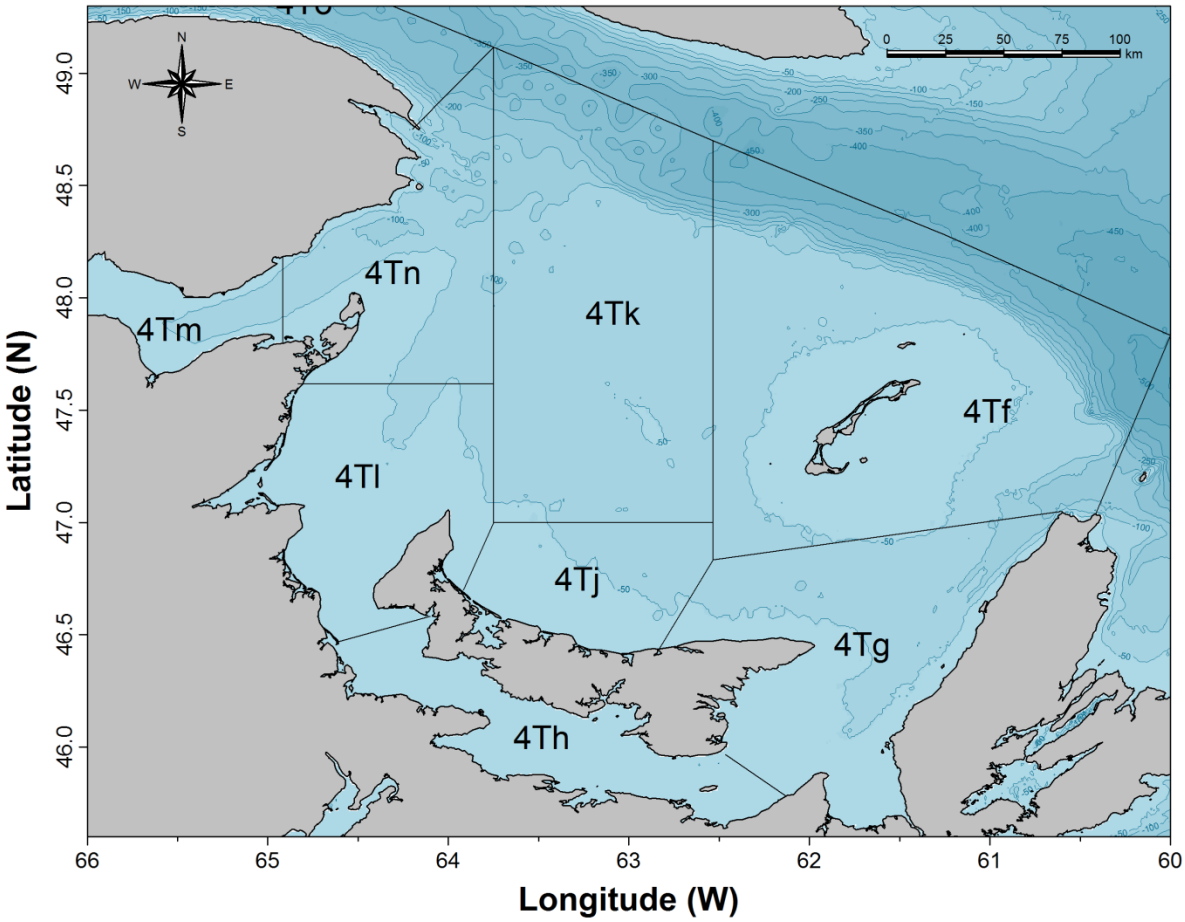

Figure 1. Southern Gulf of Saint Lawrence (sGSL) and NAFO 4T subdivisions.

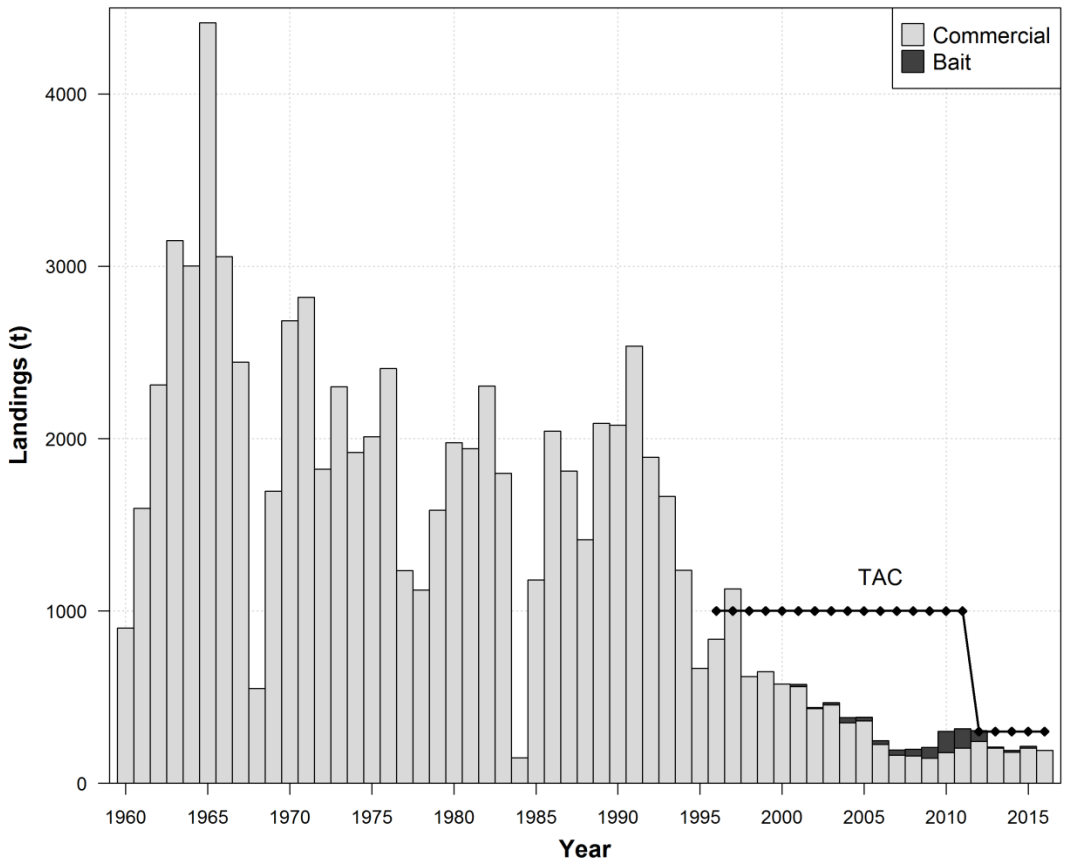

Figure 2. Winter Flounder landings (tonnes) from the southern Gulf of St. Lawrence, 1960 to 2016. Diamond-dotted line shows the annual TACs and darker shade shows the Magdalen Island bait fishery component.

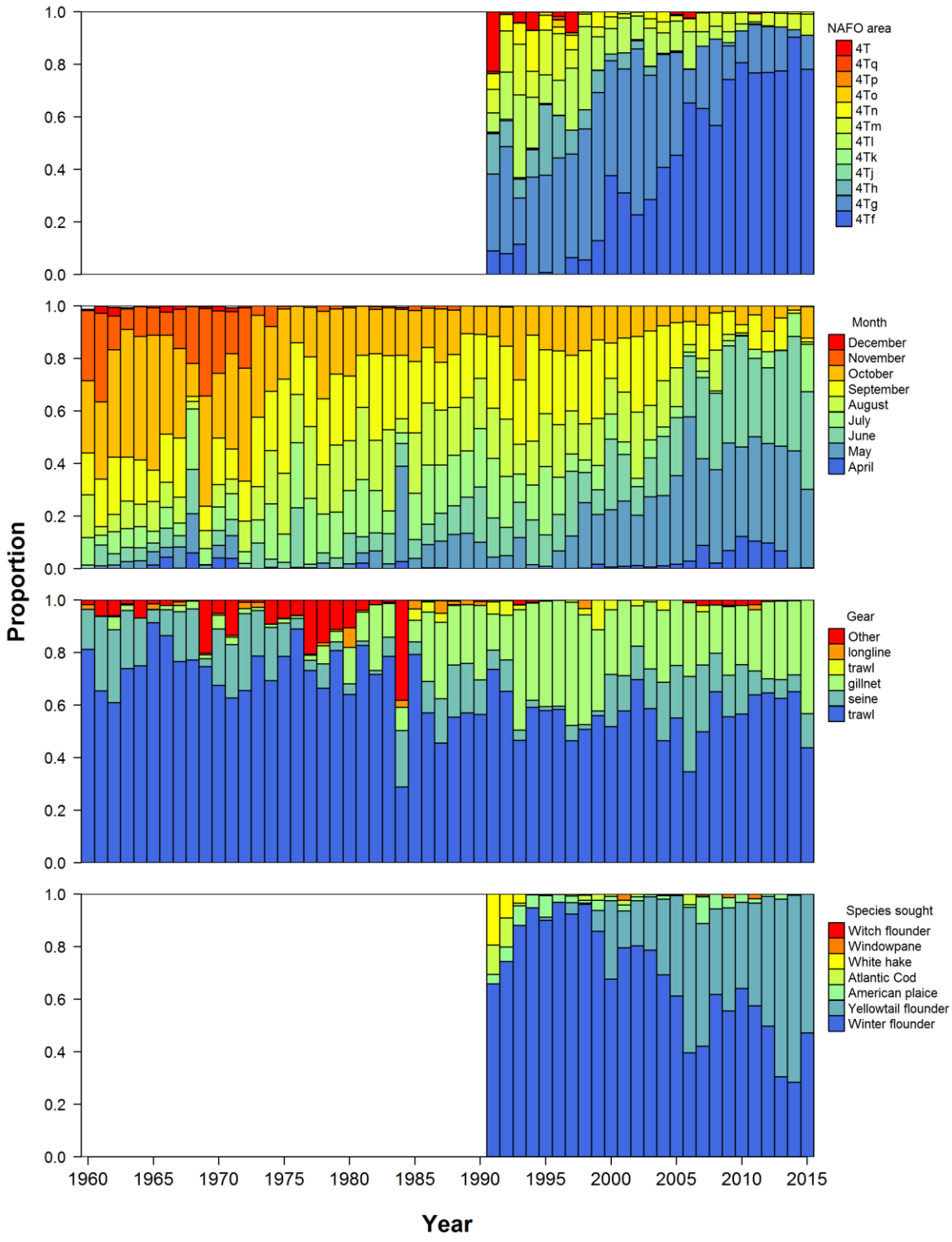

Figure 3. Proportion of Winter Flounder landings by year by NAFO 4T subdivision (first panel, top), fishing month (second panel), type of fishing gear (third panel), and target fishing species (fourth panel, bottom).

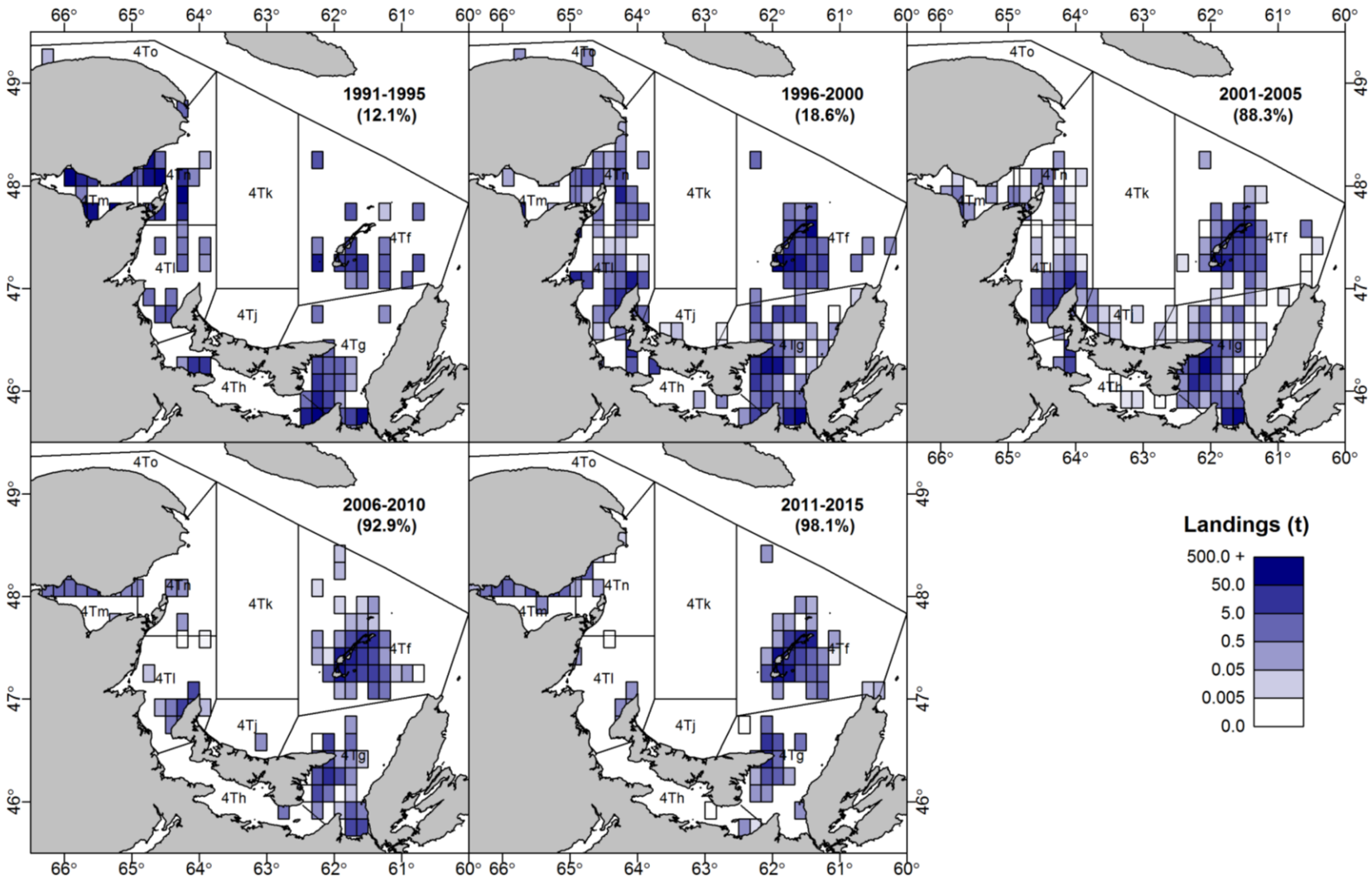

Figure 4. Log-scale spatial distribution of Winter Flounder logbook catches by five-year periods in the southern Gulf of St. Lawrence. Shown in each map is the percentage of reported landings with geographic coordinates for each period. Geographically referenced landings were scaled to total landings for display purposes.

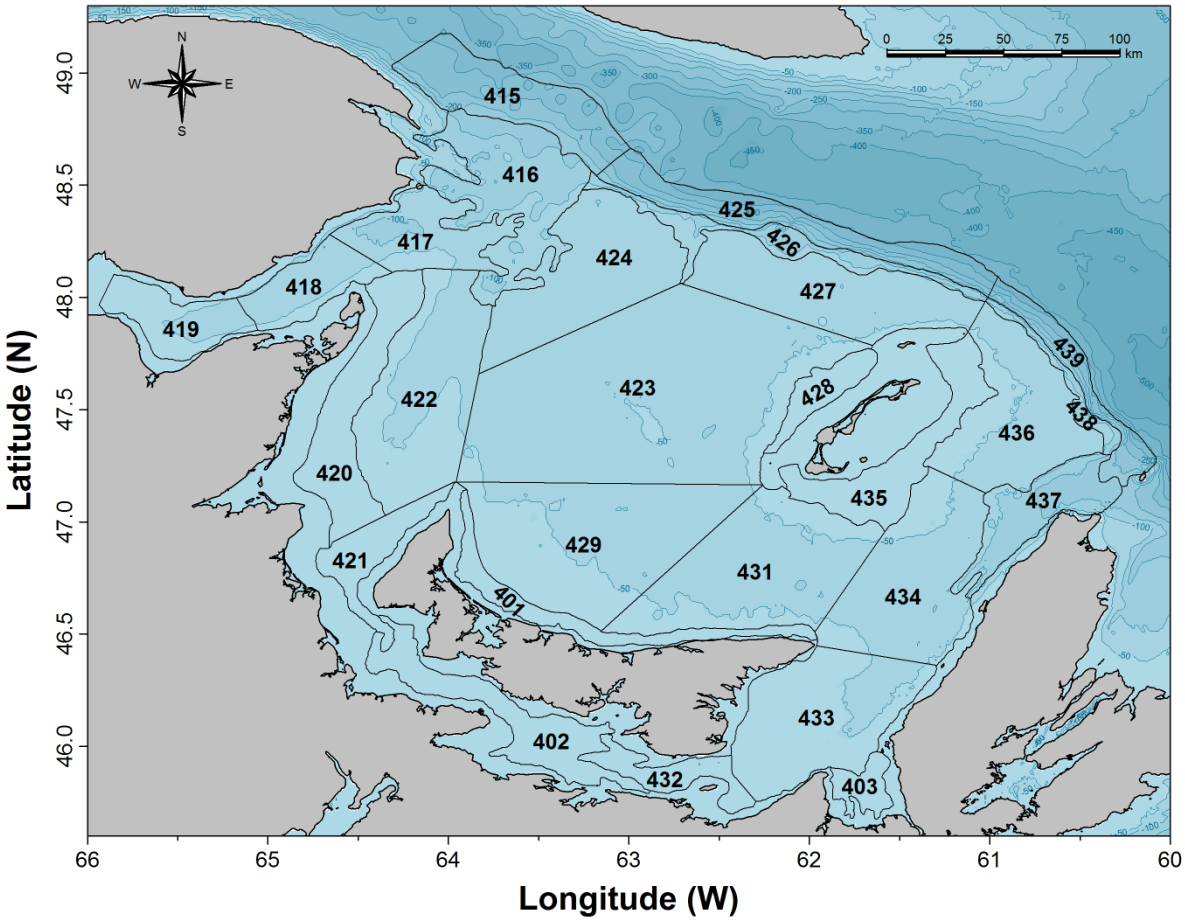

Figure 5. Stratification scheme of the annual research vessel multi-species bottom trawl survey in the southern Gulf of Saint Lawrence (sGSL).

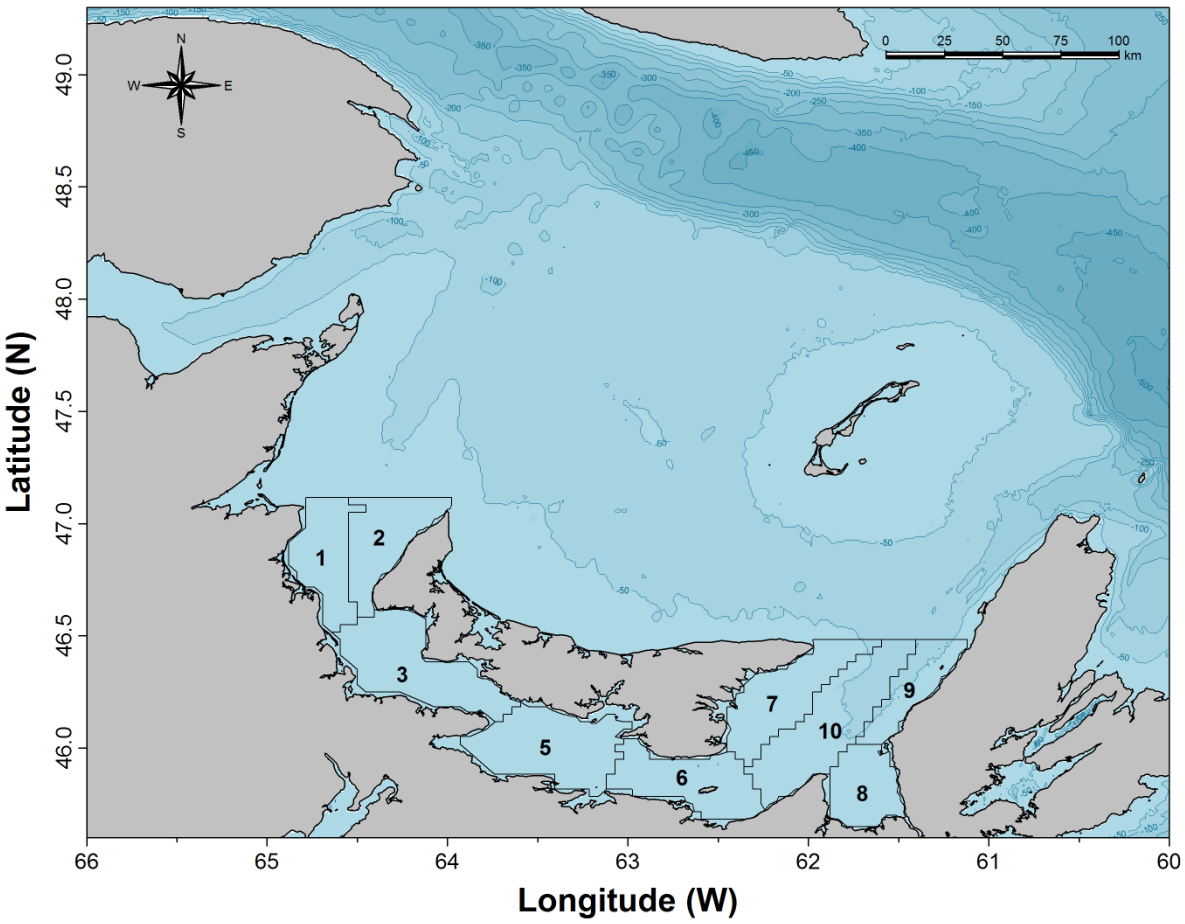

Figure 6. Stratification scheme of the annual bottom trawl survey in the Northumberland Strait, southern Gulf of St. Lawrence.

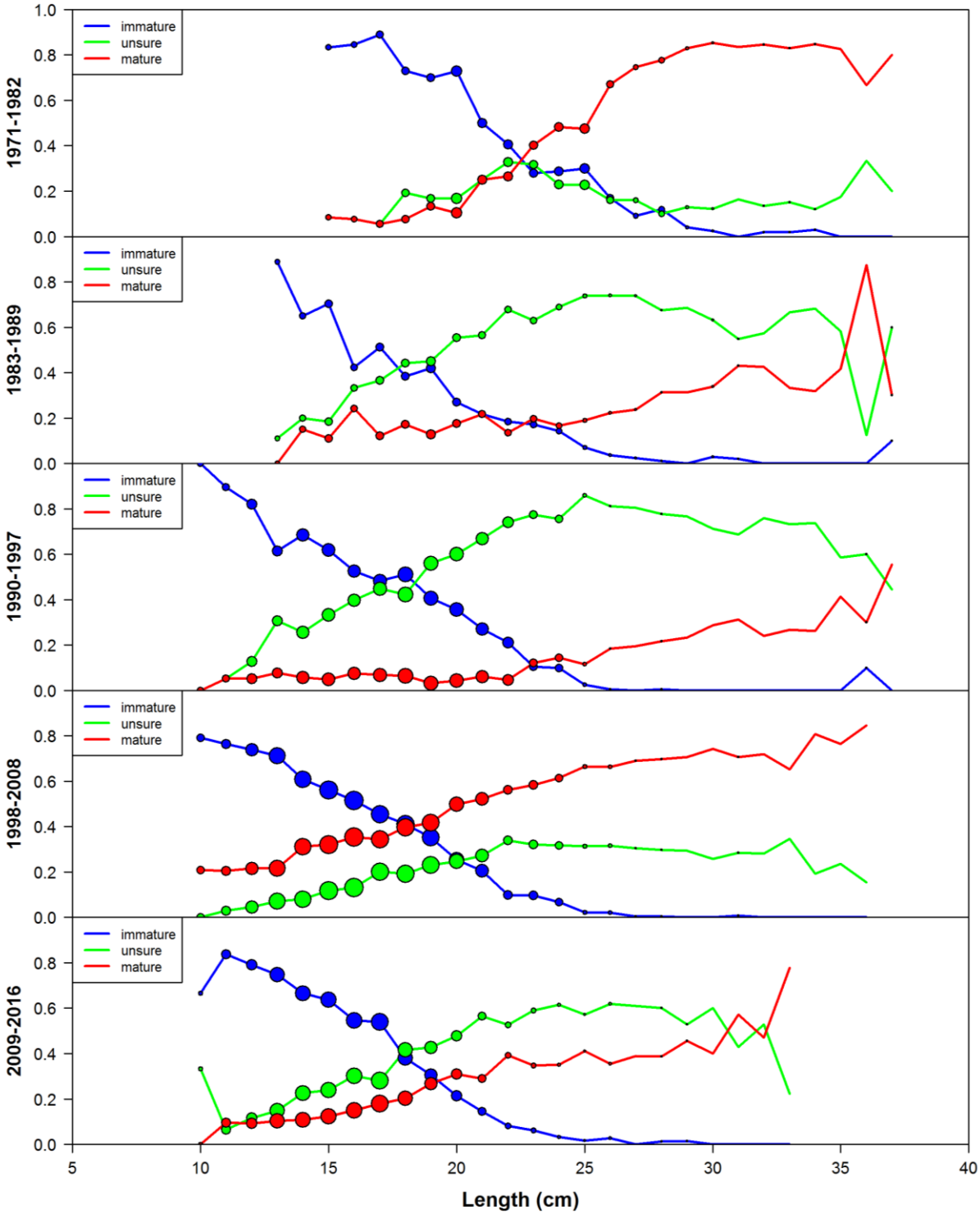

Figure 7. Observed maturity stage proportions by fish length for male Winter Flounder using data from the September RV survey, by blocks of years. The "unsure" category reflects a coding which is meant to be mature, but for which there is some level of misclassification by on-board Science staff. Time periods which are problematic are 1983-1989 and 1990-1997.

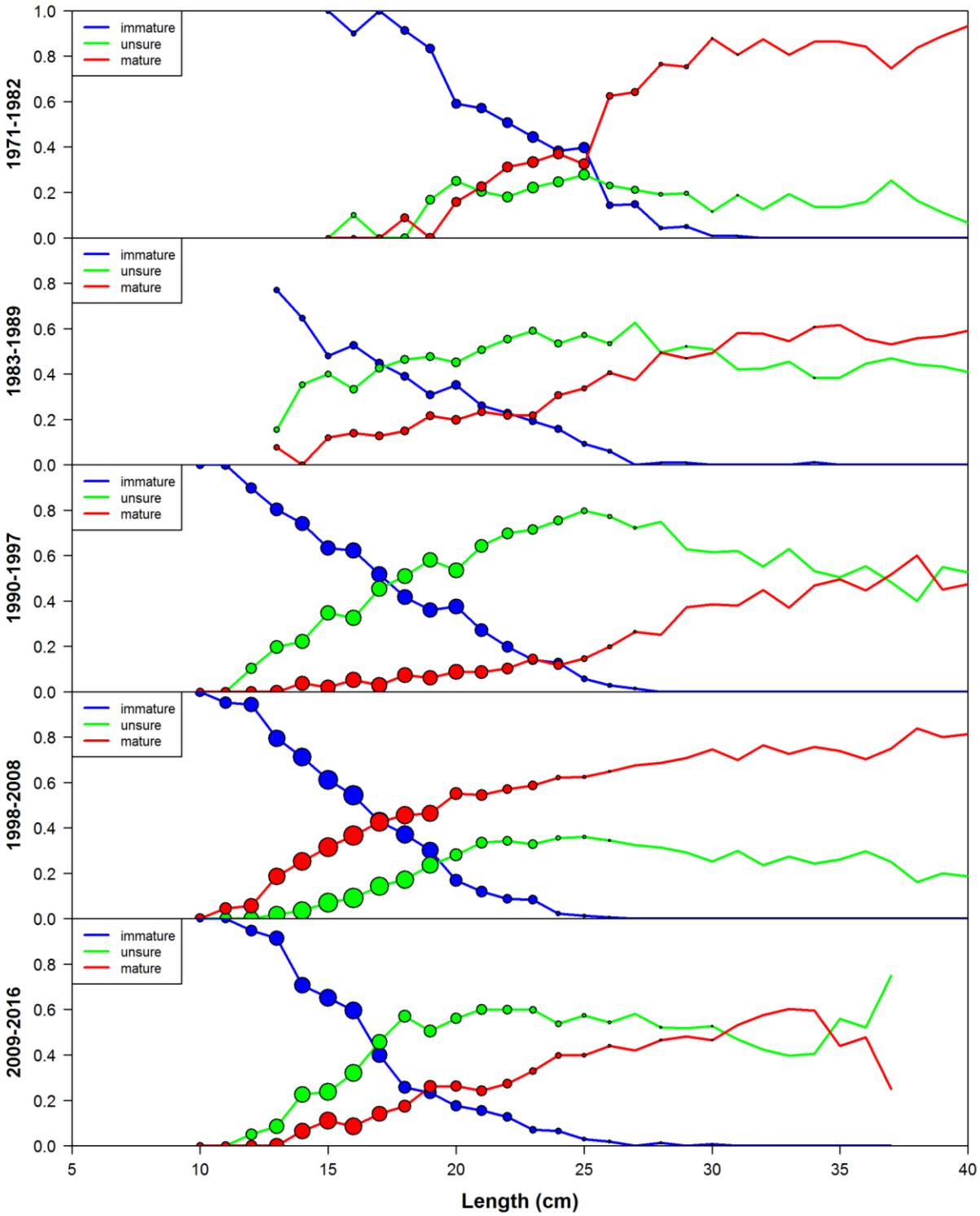

Figure 8. Observed maturity stage proportions by fish length for male Winter Flounder using data from the September RV survey, by blocks of years. The "unsure" category reflects a coding which is meant to be mature, but for which there is some level of misclassification by on-board Science staff. Time periods which are problematic are 1983-1989 and 1990-1997.

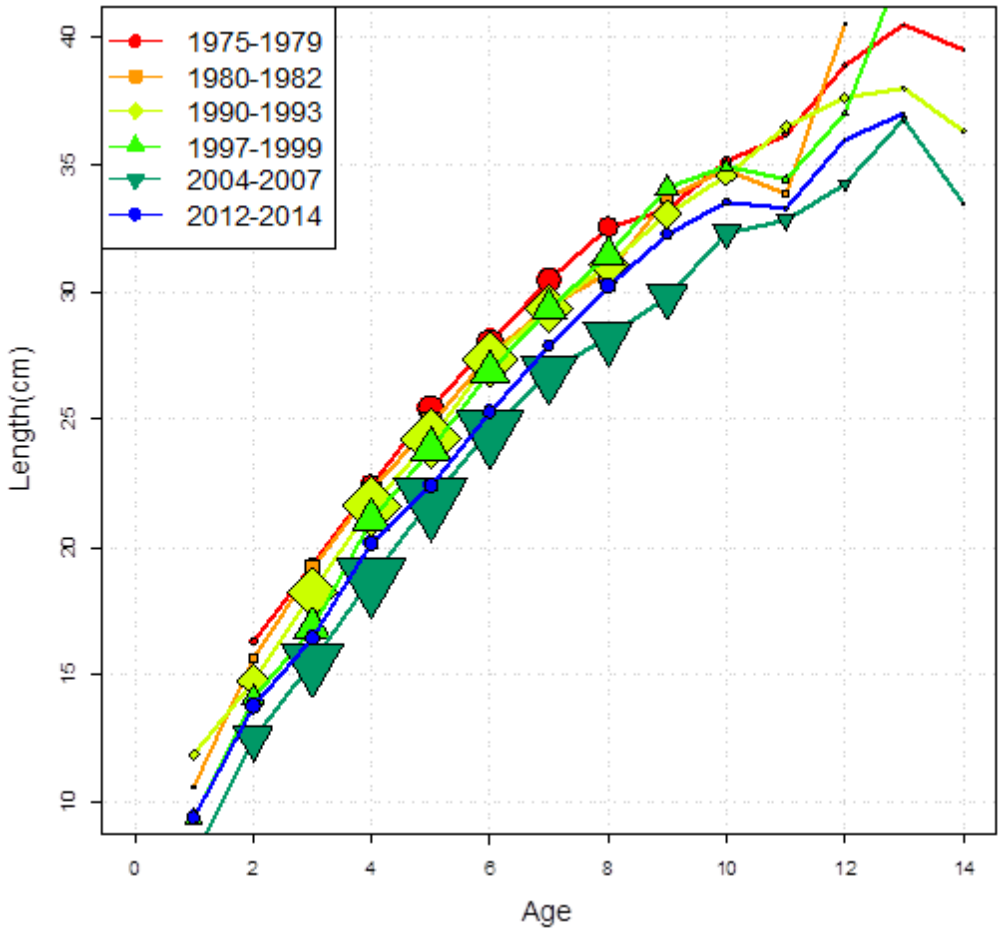

Figure 9. Empirical mean length (cm) at age plots, by year groups, of Winter Flounder based on ageing of samples collected during the September RV survey. The area of each symbol is proportional to the number of samples analysed.

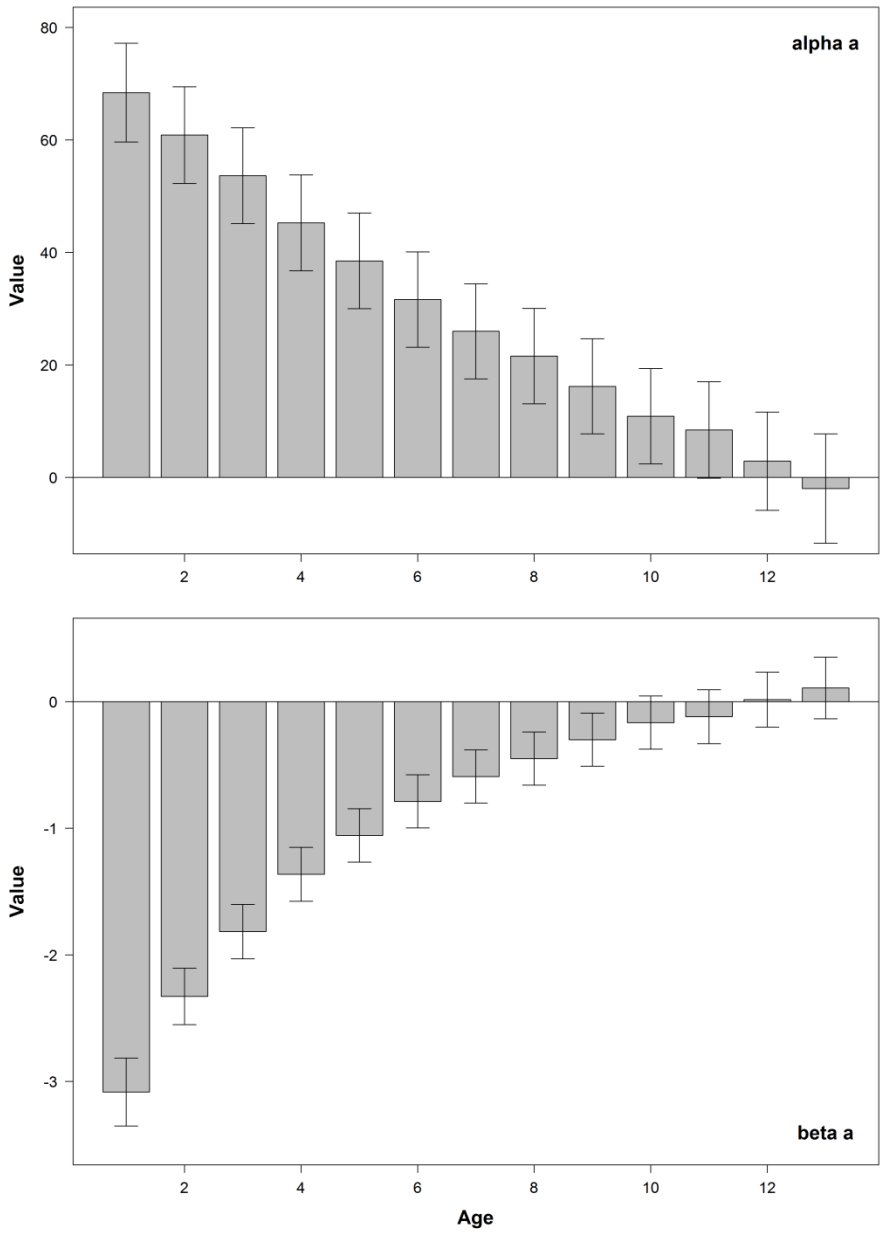

Figure 10. Maximum likelihood estimates and 95 % confidence intervals of the logit-scale intercept α_a (top panel) and slope β_a (bottom panel) parameters from the smoothed age-length key model for Winter Flounder from the southern Gulf of St. Lawrence.

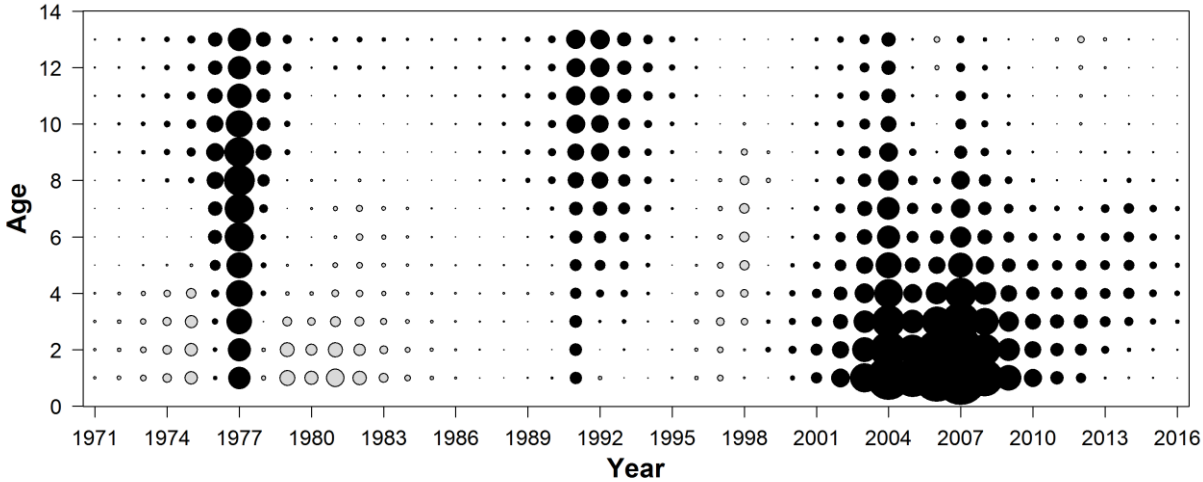

Figure 11. Bubble plot of logit-scale random intercept term φ_{at} from the smoothed age-length key model for Winter Flounder from the southern Gulf of St. Lawrence, showing the deviations from the fixed intercept terms α_a through time. Negative deviations are shown in black and positive deviations are shown in grey.

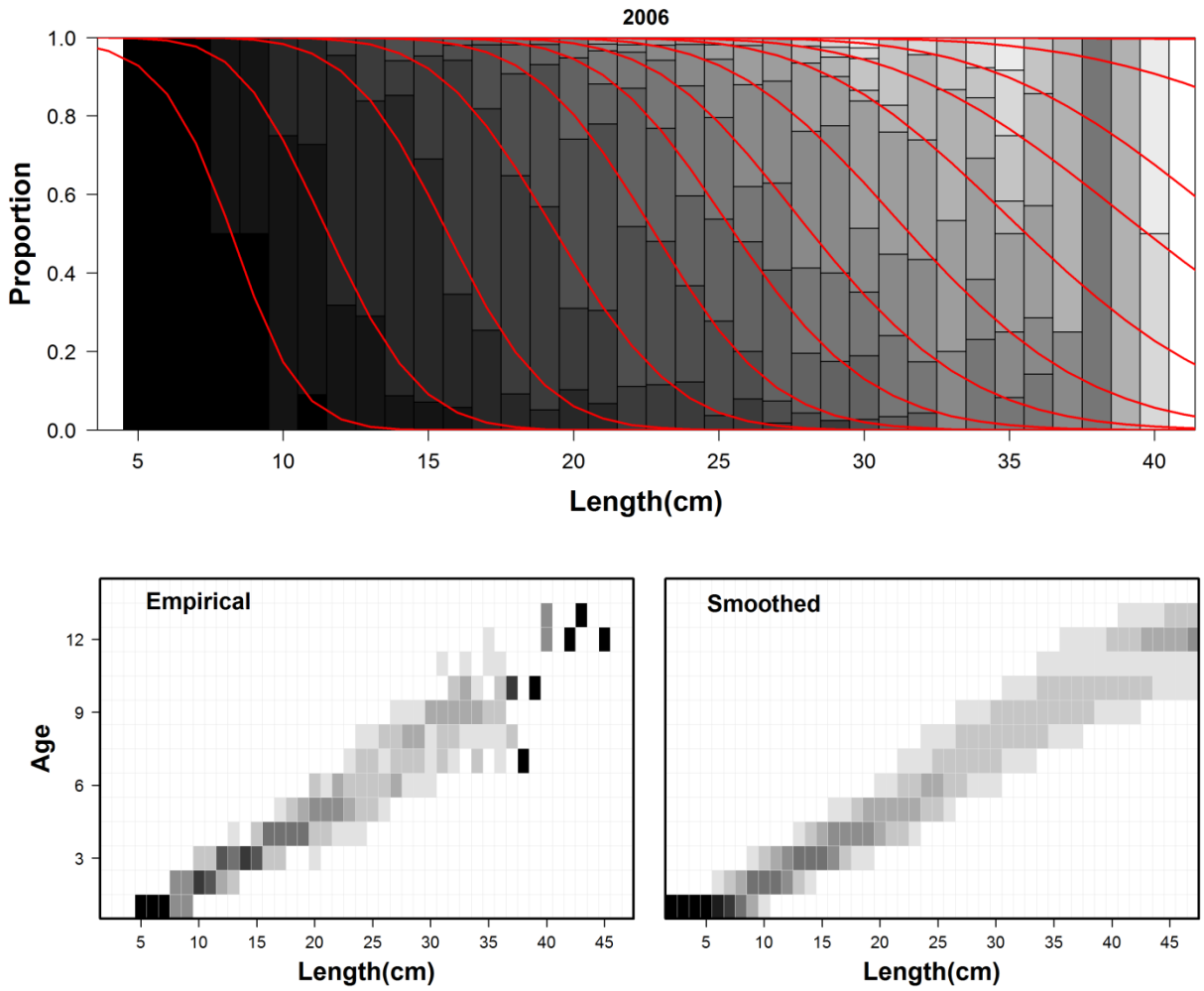

Figure 12. Fit of the smoothed age-length key model for Winter Flounder from the southern Gulf of St. Lawrence for a data-rich year in 2006 (n = 1,046). The top graph shows the model estimates (solid red lines) versus empirical values (greyscale bars). Similarly, the two bottom plots show the empirical age-length (bottom left) and the model fit (bottom right) as proportions-at-age, where darker shades indicate higher proportions.

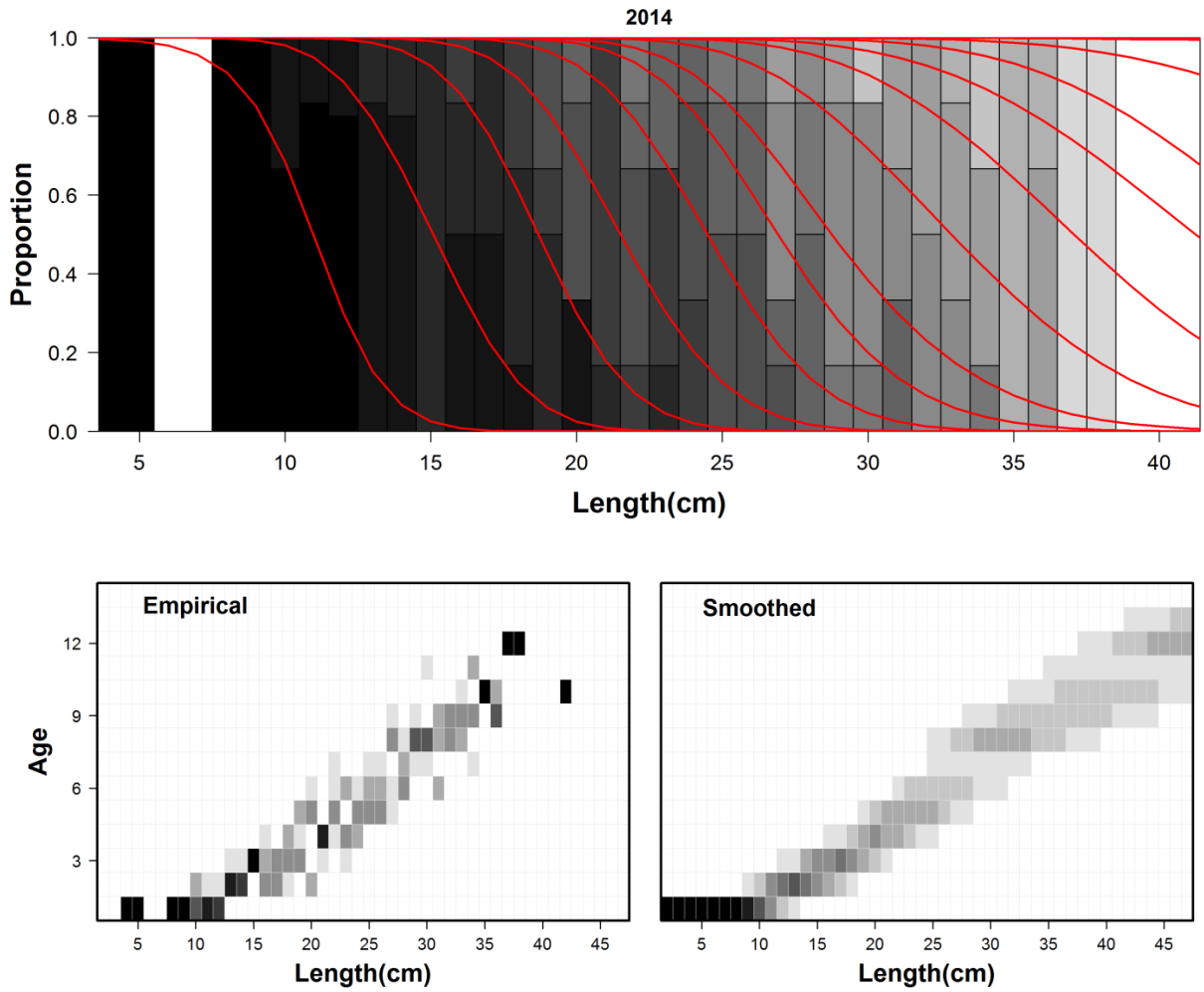

Figure 13. Fit of the smoothed age-length key model for Winter Flounder from the southern Gulf of St. Lawrence for a data-poor year in 2014 (n = 161). The top graph shows the model estimates (solid red lines) versus empirical values (greyscale bars). Similarly, the two bottom plots show the empirical age-length (bottom left) and the model fit (bottom right) as proportions-at-age, where darker shades indicate higher proportions.

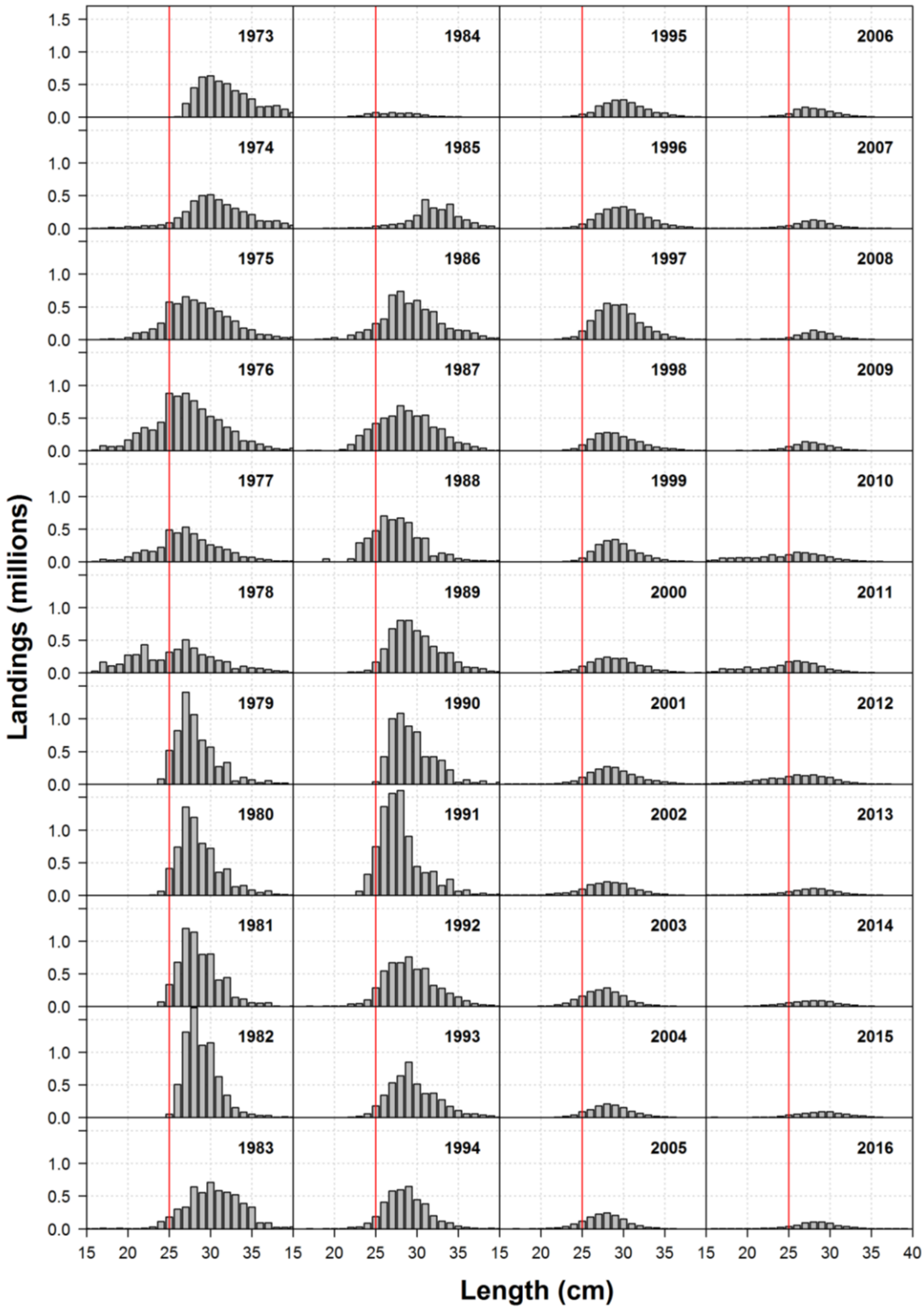

Figure 14. Catch-at-length (number of fish) by cm length bin of Winter Flounder in the southern Gulf of St. Lawrence commercial fisheries, 1973 to 2016, estimated from commercial catch sampling. The solid red line indicates the minimum commercial size of 25 cm.

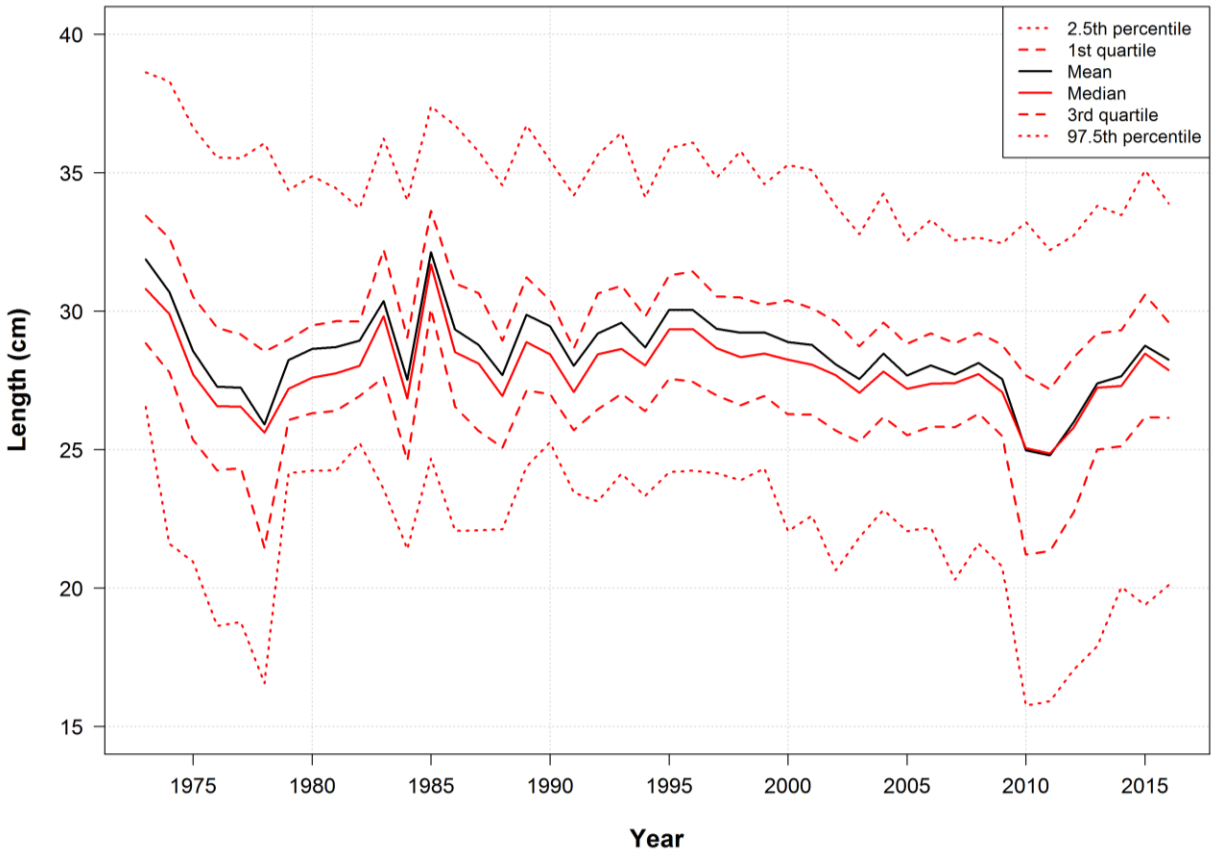

Figure 15. Annual change in total length (cm) statistics of Winter Flounder in the southern Gulf of St. Lawrence commercial catches, 1973 to 2016.

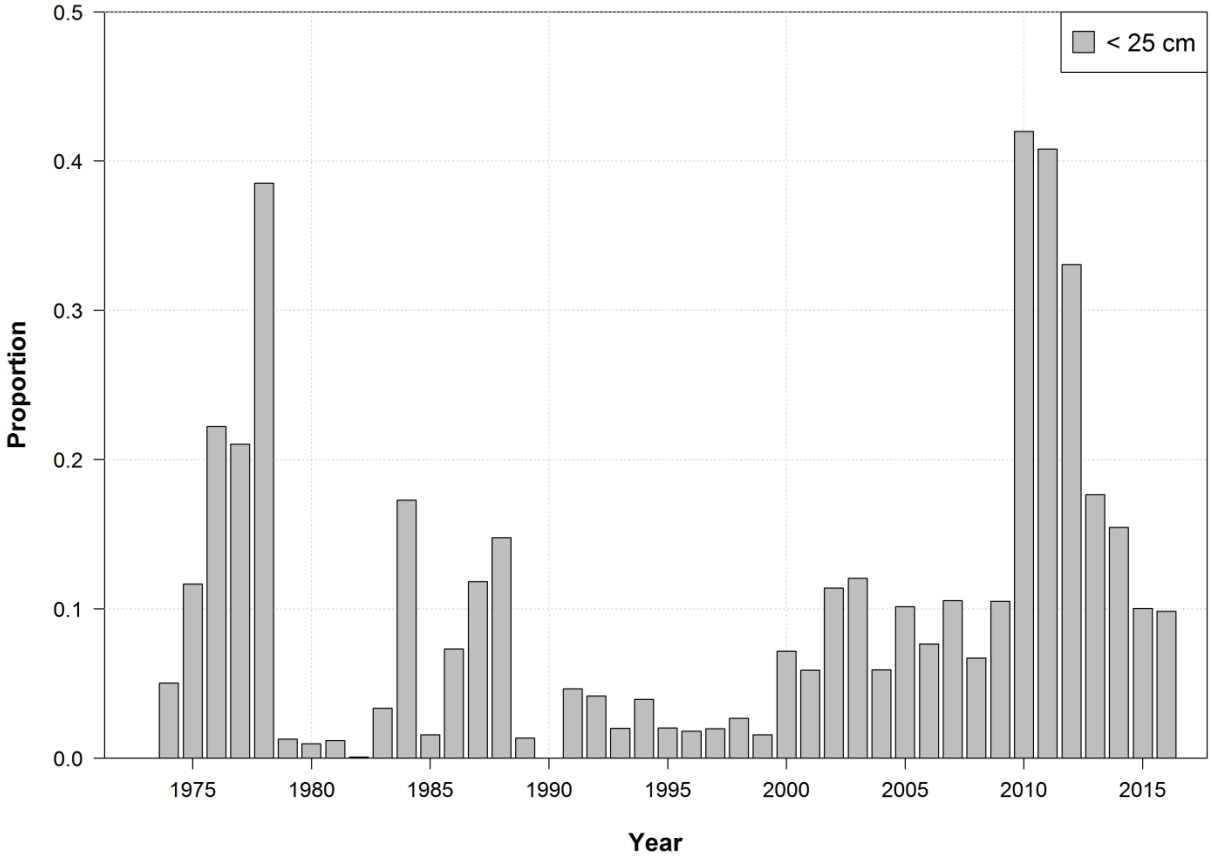

Figure 16. Proportions of Winter Flounder measuring less than 25 cm total length in the commercial catches of the southern Gulf of St. Lawrence, 1973 to 2016.

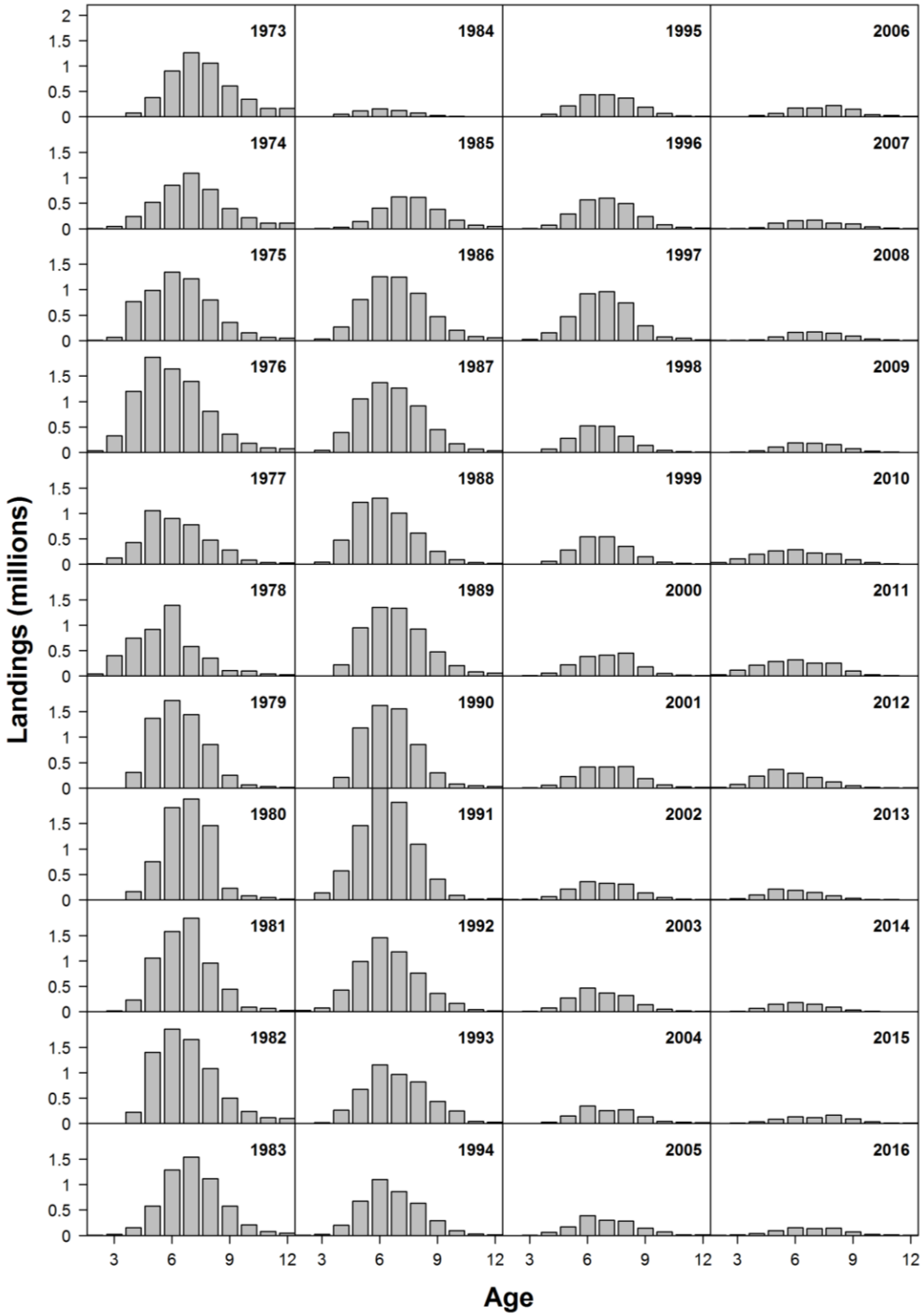

Figure 17. Commercial catch-at-age (number of fish) of Winter Flounder in the southern Gulf of St. Lawrence commercial fisheries, 1973 to 2016.

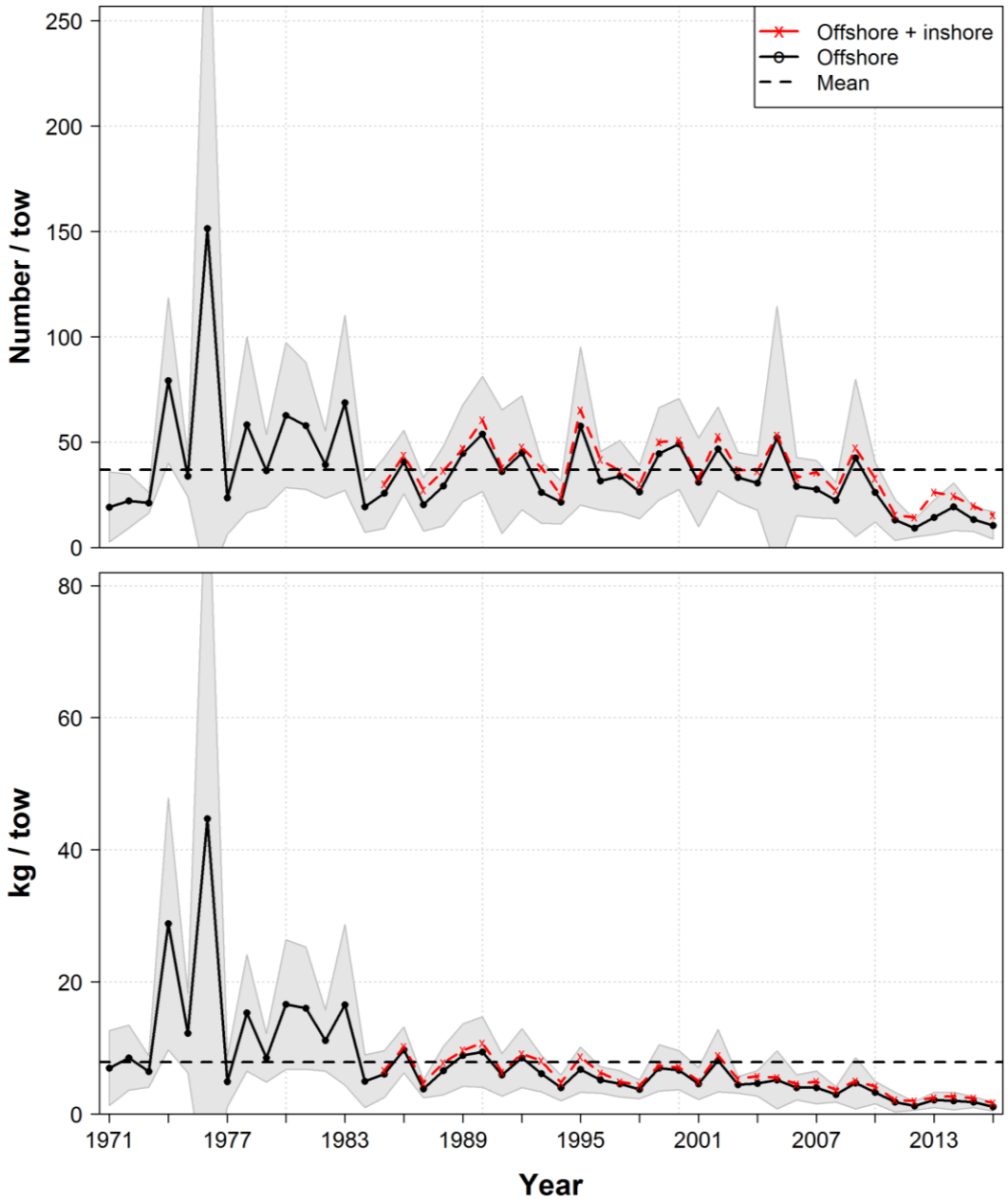

Figure 18. Indices of abundance, by number per tow (upper panel) and by weight per tow (kg; lower panel), of Winter Flounder in the annual September research vessel (RV) survey of the southern Gulf of St. Lawrence, 1971 to 2016. Solid line are indices for strata 415-439, with 95 % confidence interval in grey. Dashed red lines shows indices with inshore strata (401-403) included from 1984 onward. The horizontal dashed line indicates the series mean.

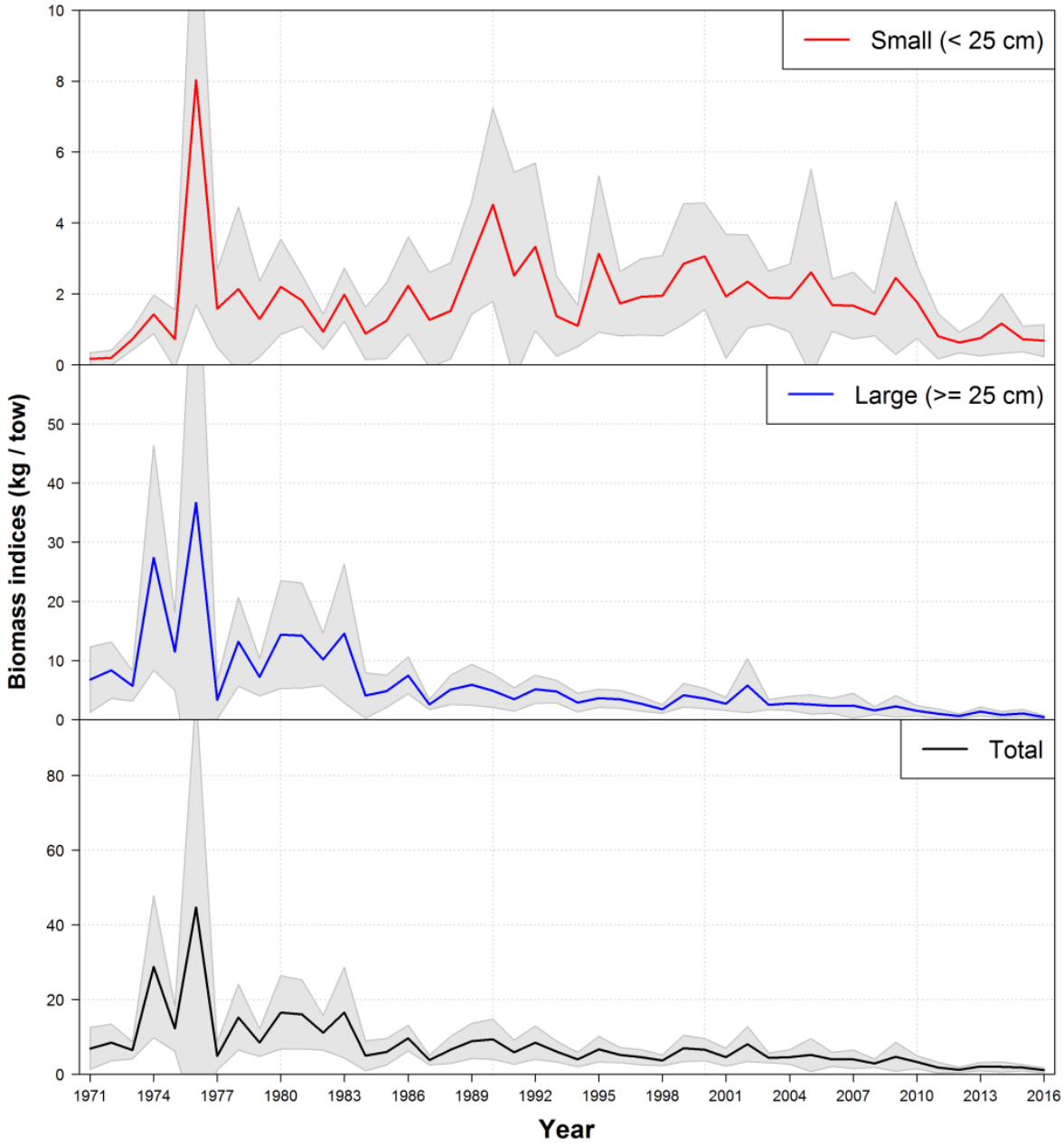

Figure 19. Indices of abundance, by weight per tow (kg), for non-commercial (< 25 cm; top panel), commercial sizes (>= 25 cm; middle panel), and sizes combined (lower panel) of Winter Flounder in the annual September research vessel (RV) survey of the southern Gulf of St. Lawrence, 1971 to 2016.

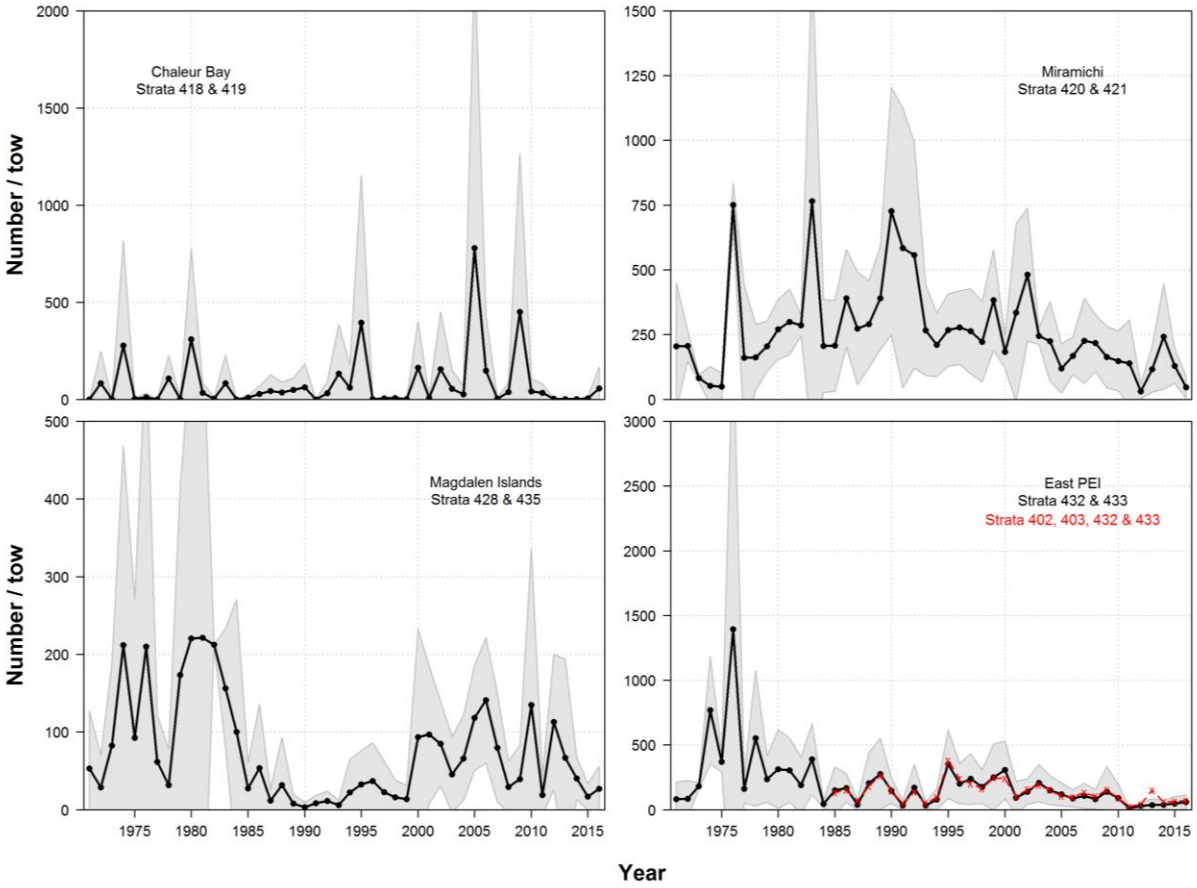

Figure 20. Abundance indices, in number per tow, of Winter Flounder by sub regions (Chaleur Bay, top-left; Miramichi, top-right; Magdalen Islands, bottom-left; East PEI, bottom-right) in the southern Gulf of St. Lawrence, 1971 to 2016. Solid line indicates indices based on strata 415-439, with 95 % confidence interval in grey. The dashed red line in the lower right panel shows the index with inshore strata (402 and 403) included, from 1984 onward.

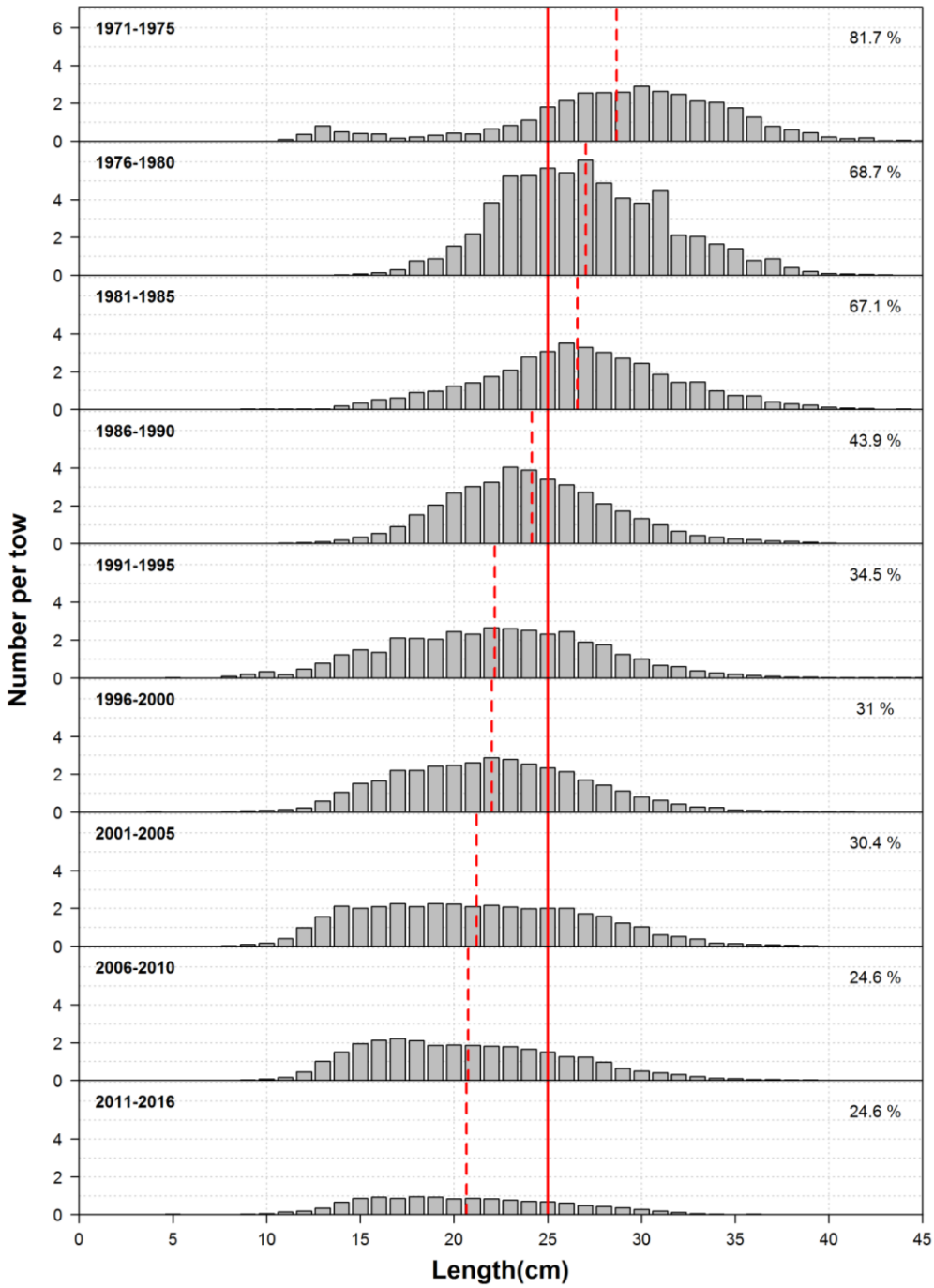

Figure 21. Length-frequency distributions, expressed as number per tow, of Winter Flounder from the research vessel survey of the southern Gulf of St. Lawrence (offshore strata only 415-439) in five year groups from 1971 to 2016. The dashed vertical red line shows the mean length over the period, the solid vertical red line is the commercial size (25 cm). The percentages of the catches which are >= 25 cm are shown in the top right of each panel.

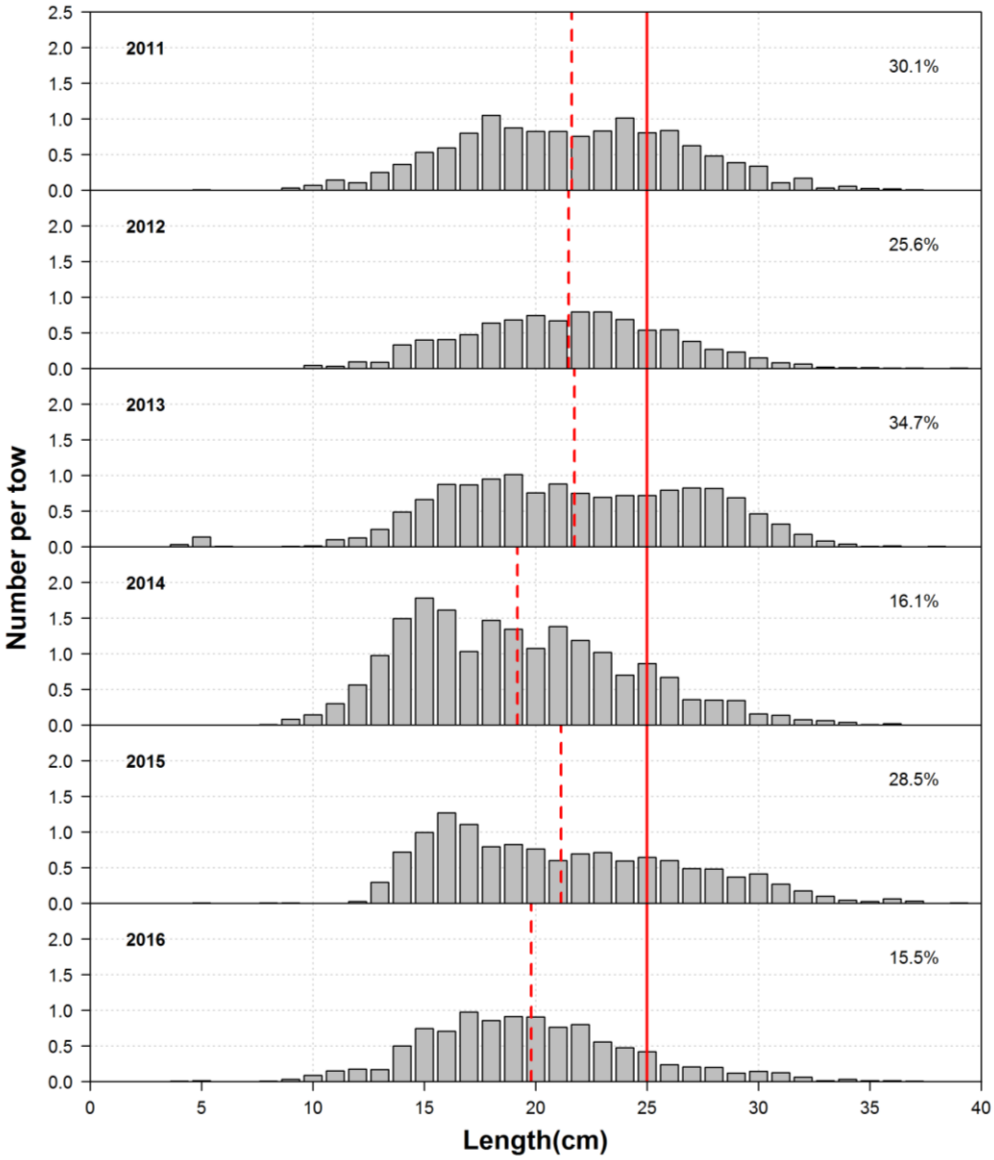

Figure 22. Length-frequency distributions, expressed as number per tow, of Winter Flounder from the research vessel survey of the southern Gulf of St. Lawrence (offshore strata only 415-439) for 2011 to 2016. The dashed vertical red line shows the mean length for the year and the solid vertical red line is the commercial size (25 cm). The percentages of the catches which are >= 25 cm are shown in the top right of each panel.

Figure 23. Annual change in total length (cm) statistics of Winter Flounder in the southern Gulf of St. Lawrence September RV survey catches, 1971 to 2016.

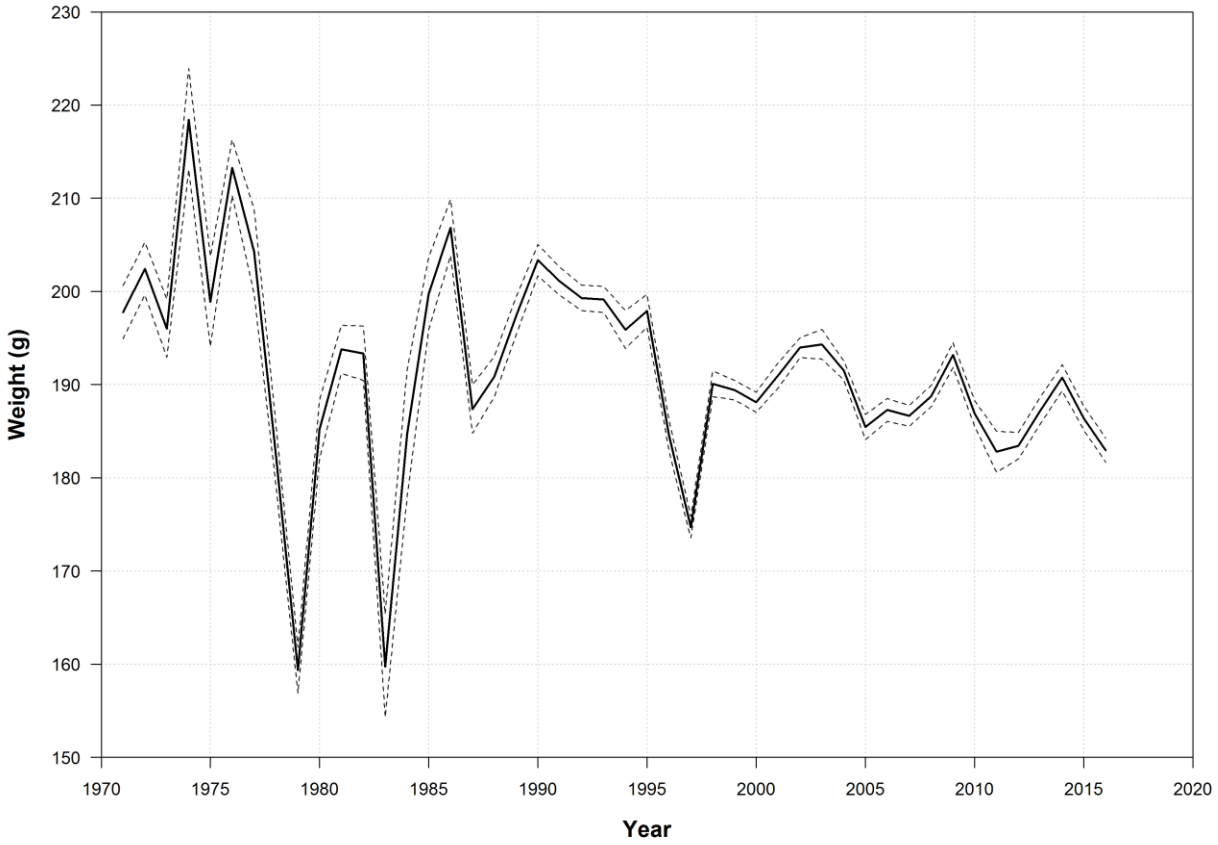

Figure 24. Predicted weight (g; mean and 95% confidence interval) of a 25 cm Winter Flounder based on RV survey length-weight regressions.

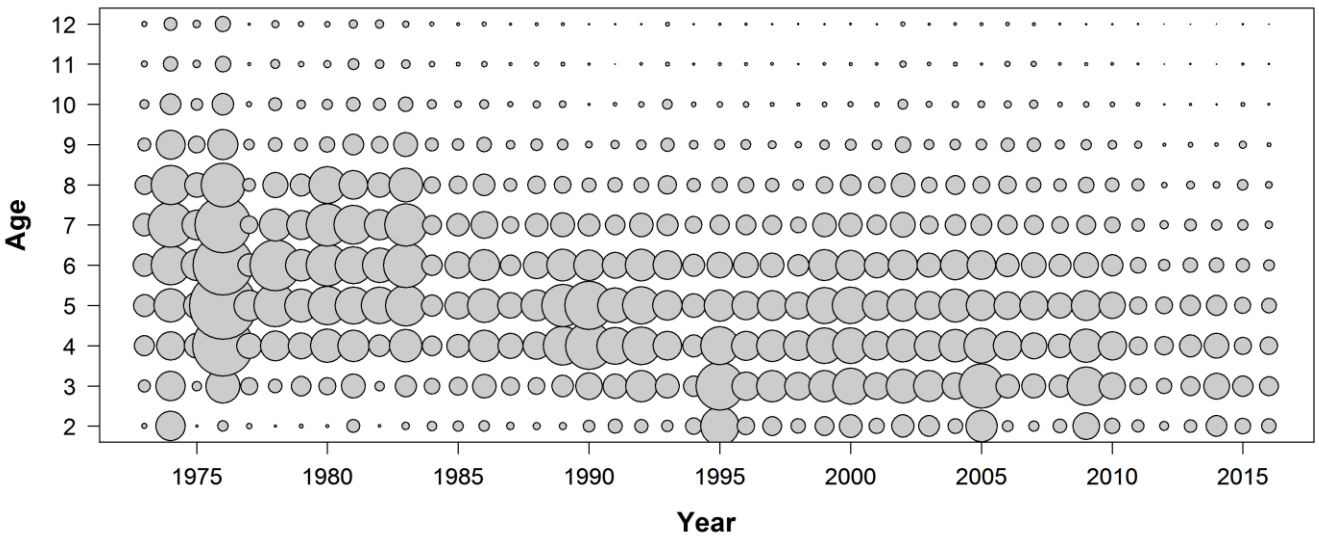

Figure 25. Catch at age (number of fish) of Winter Flounder from the offshore strata (415-439) in the September RV survey of the southern Gulf of St. Lawrence, 1973 to 2016. Circle area is proportional to estimated trawlable biomass.

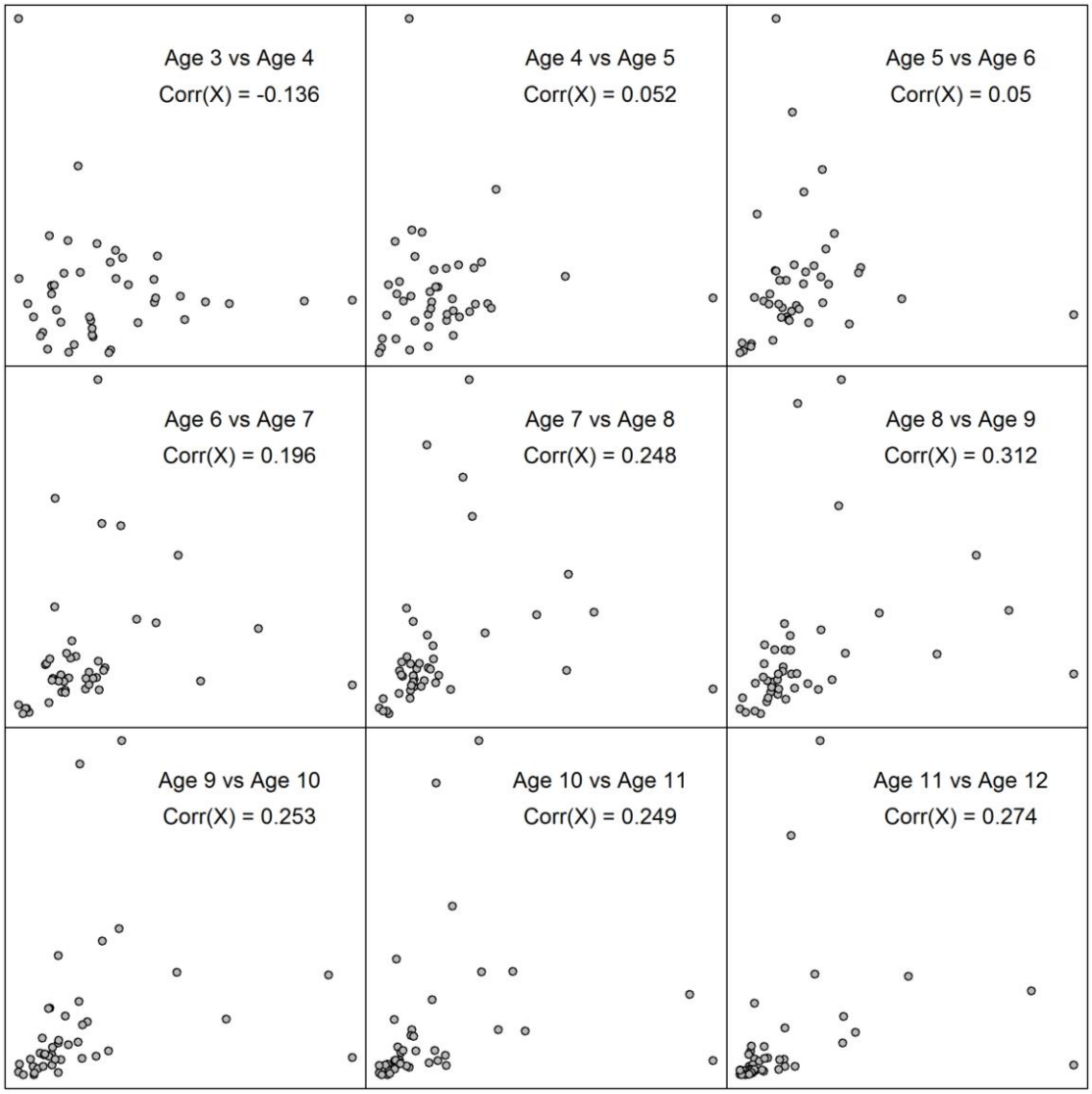

Figure 26. Research vessel survey age-cohort correlations for ages 3 to 12+ years Winter Flounder from the southern Gulf of St. Lawrence.

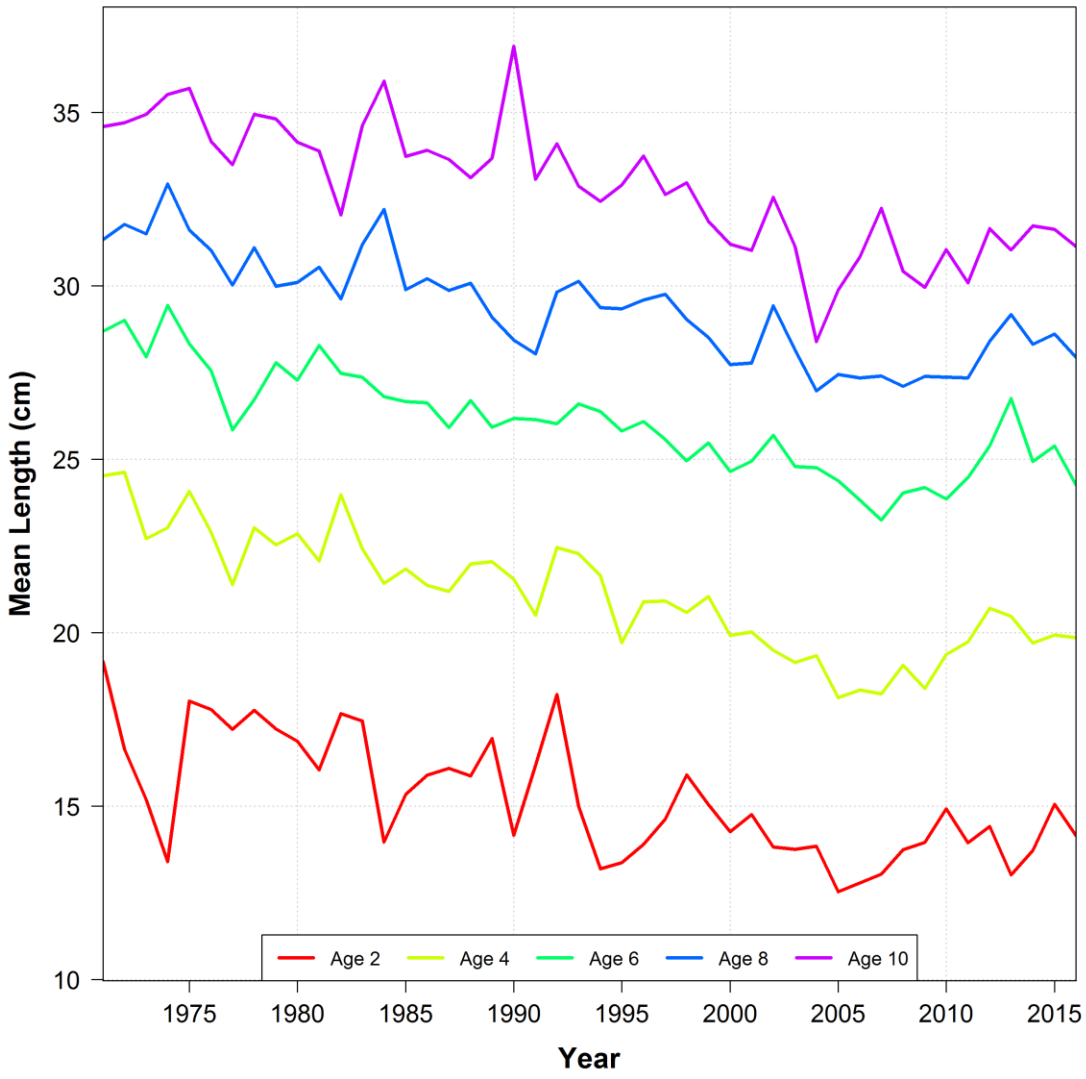

Figure 27. Estimated mean length-at-age of Winter Flounder, 1971 to 2016, based on September RV survey length-frequencies and the smoothed age-length key model.

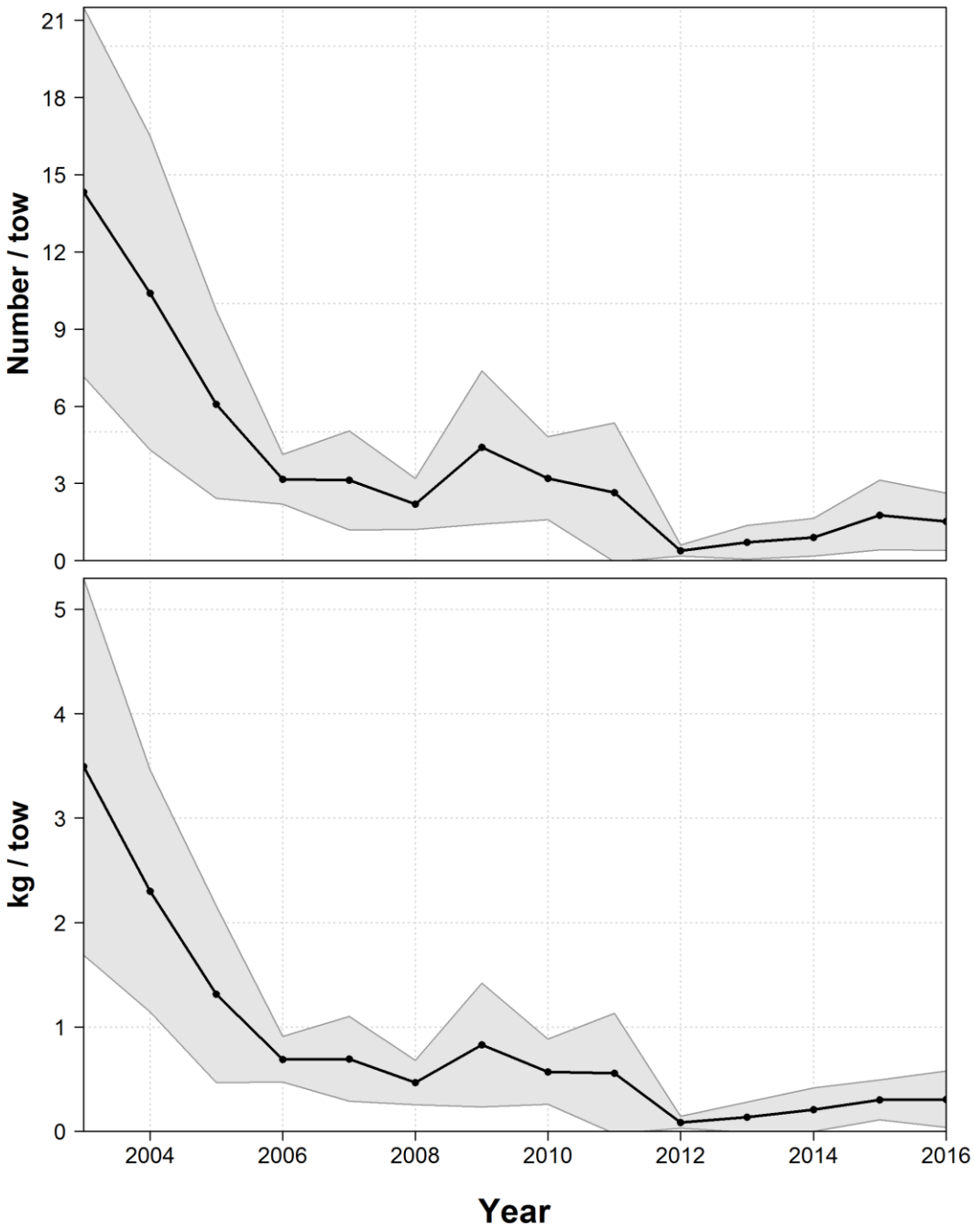

Figure 28. Mobile sentinel survey indices (number per tow in upper panel, kg per tow in lower panel) of Winter Flounder for strata 401, 403 and 415-439 of the southern Gulf of St. Lawrence, 2003 to 2016. Black lines indicate the means and the shaded areas indicate the 95 % confidence intervals.

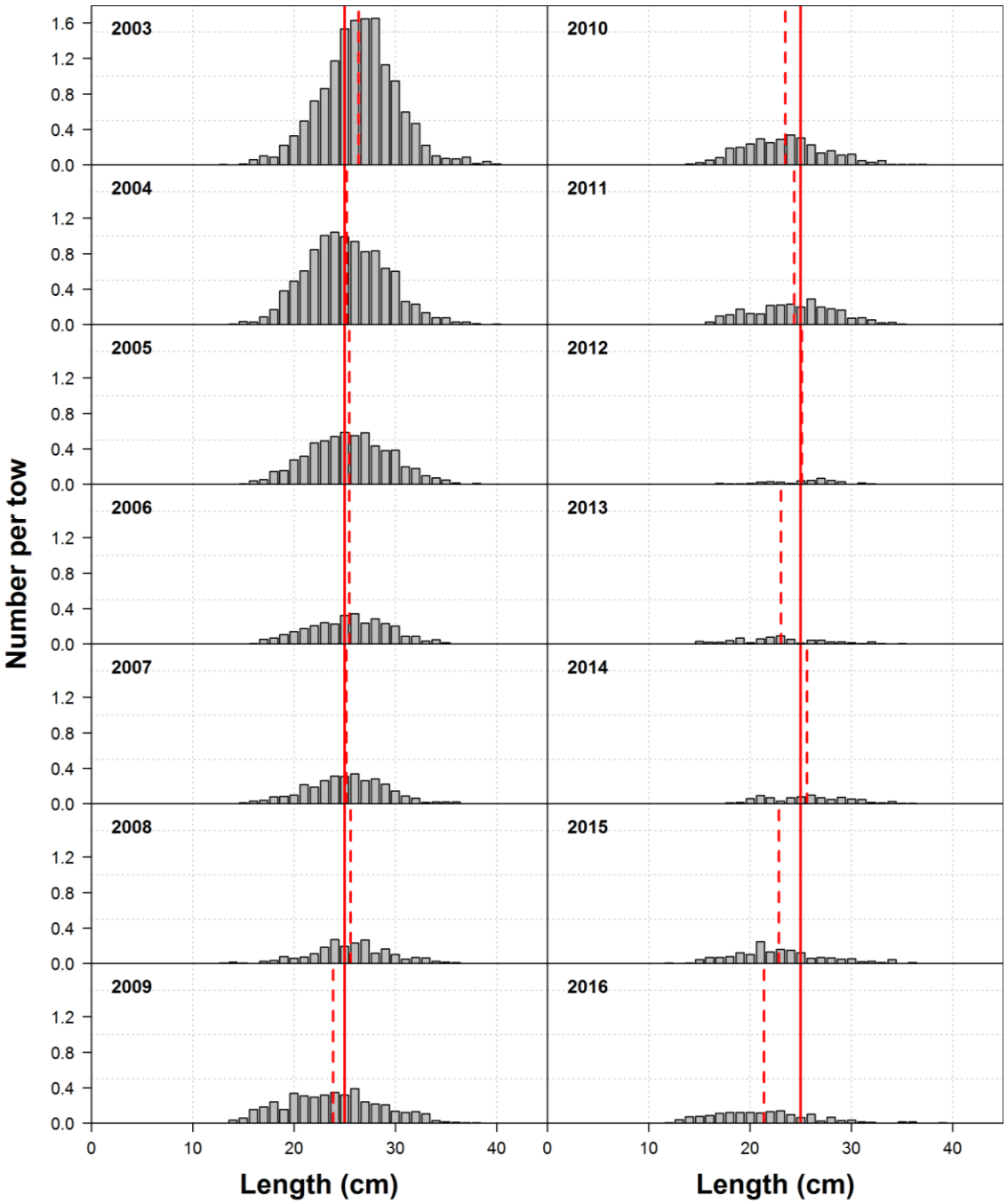

Figure 29. Length frequencies of Winter Flounder from the mobile sentinel survey for strata 401, 403 and 415-439 of the southern Gul of St. Lawrence, 2003 to 2016. The solid red line indicates the commercial size (25 cm) of Winter Flounder and the dashed red line indicates the mean size per year.

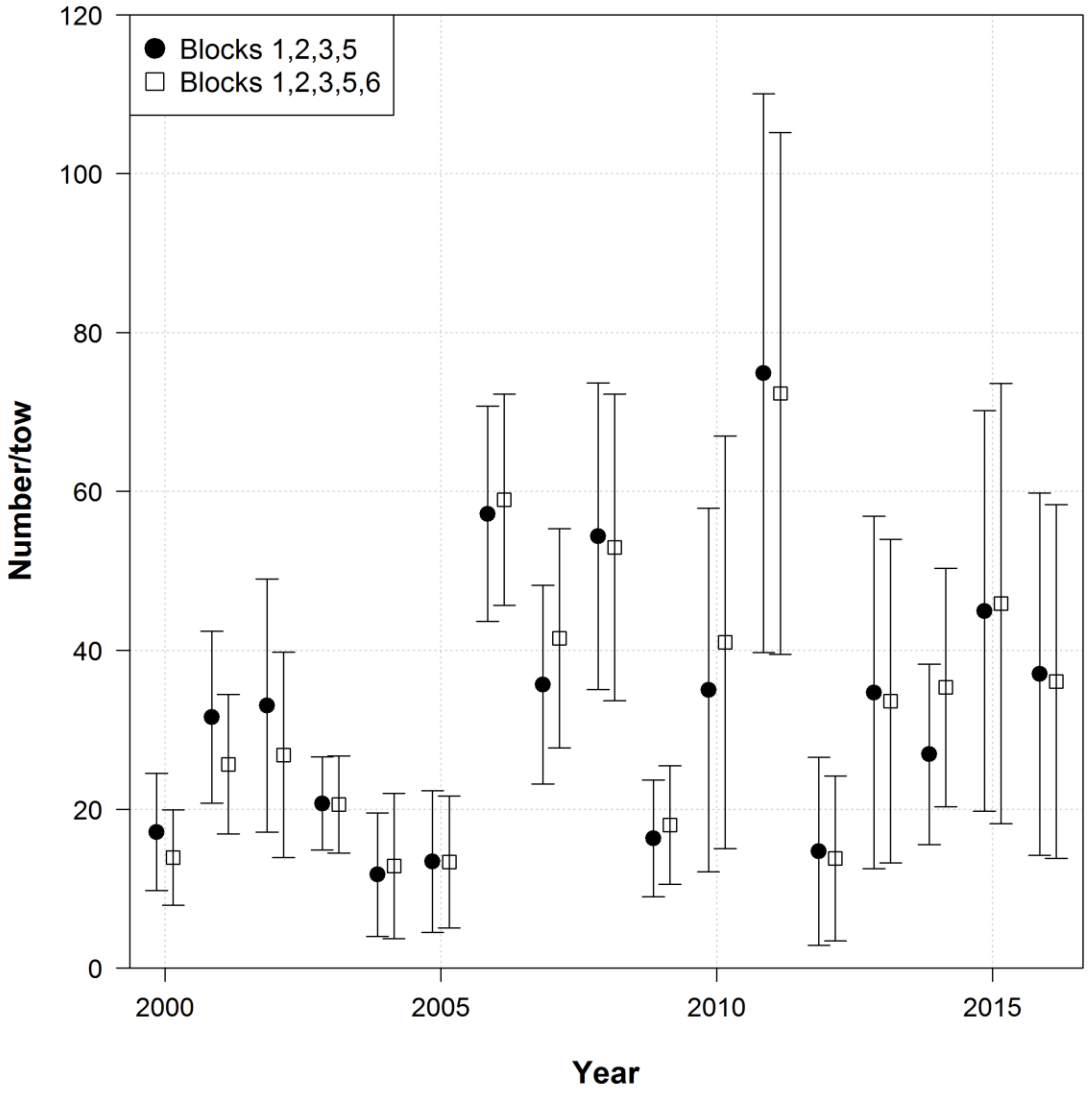

Figure 30. Indices (number per tow; mean and 95% confidence intervals) of Winter Flounder in the Northumberland Strait survey of the southern Gulf of St. Lawrence, 2000 to 2016. The black circles indicate that stratum 6 data are excluded and the white squares are when stratum 6 data are included. In 2010 and 2011, the catches were obtained using a different trawl and are standardized to a tow distance of 0.125 nm instead of 0.625 nm for the remainder of the time series.

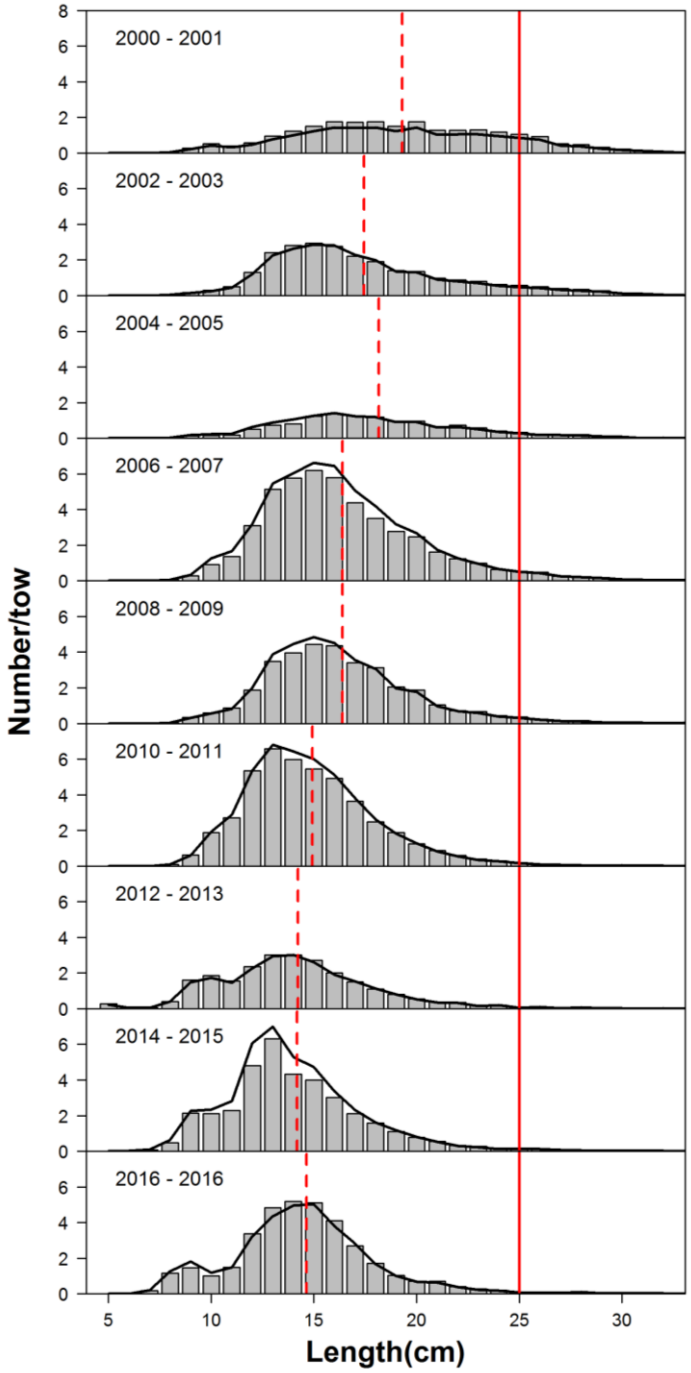

Figure 31. Length frequencies of Winter Flounder from the catches of the Northumberland Strait survey, southern Gulf of St. Lawrence, 2000 to 2016, excluding (grey bars) and including (black line) stratum 6 data. In 2010 and 2011, the catches were obtained using a different trawl and are standardized to a tow distance of 0.125 nm instead of 0.625 nm for the remainder of the time series. The solid red line shows the commercial size (25 cm) of Winter Flounder and the dashed red line shows the mean size in the catch for each panel.

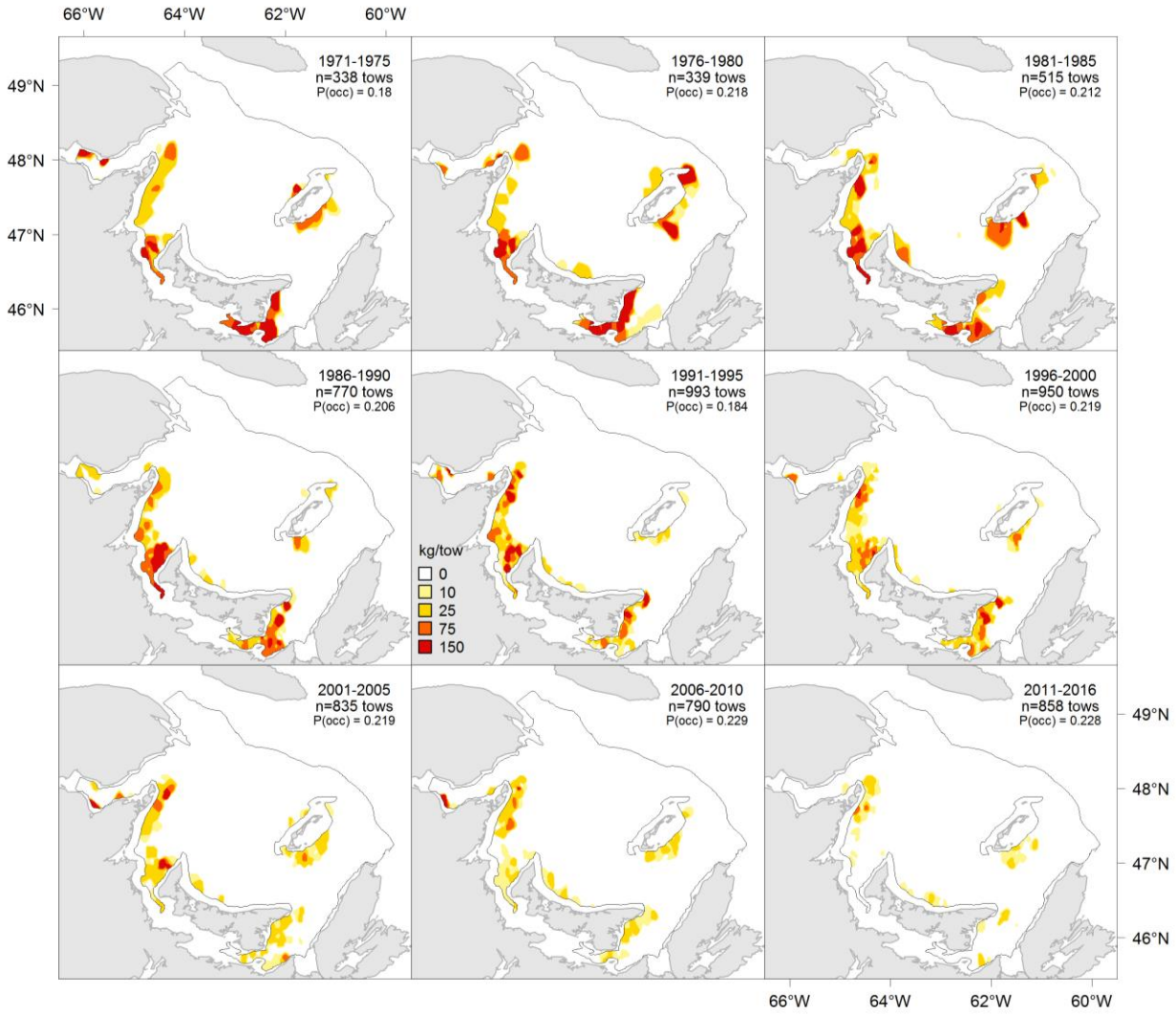

Figure 32. Spatial distribution of standardized Winter Flounder catches (kg per standard tow) from the September RV survey, by five year blocks, 1971 to 2016. Contours were drawn using an inverse-distance weighting method with a range parameter of 10 km. Shown in each map are the total number of tows used in the analyses for each panel and the proportion of tows having non-zero catches of Winter Flounder.

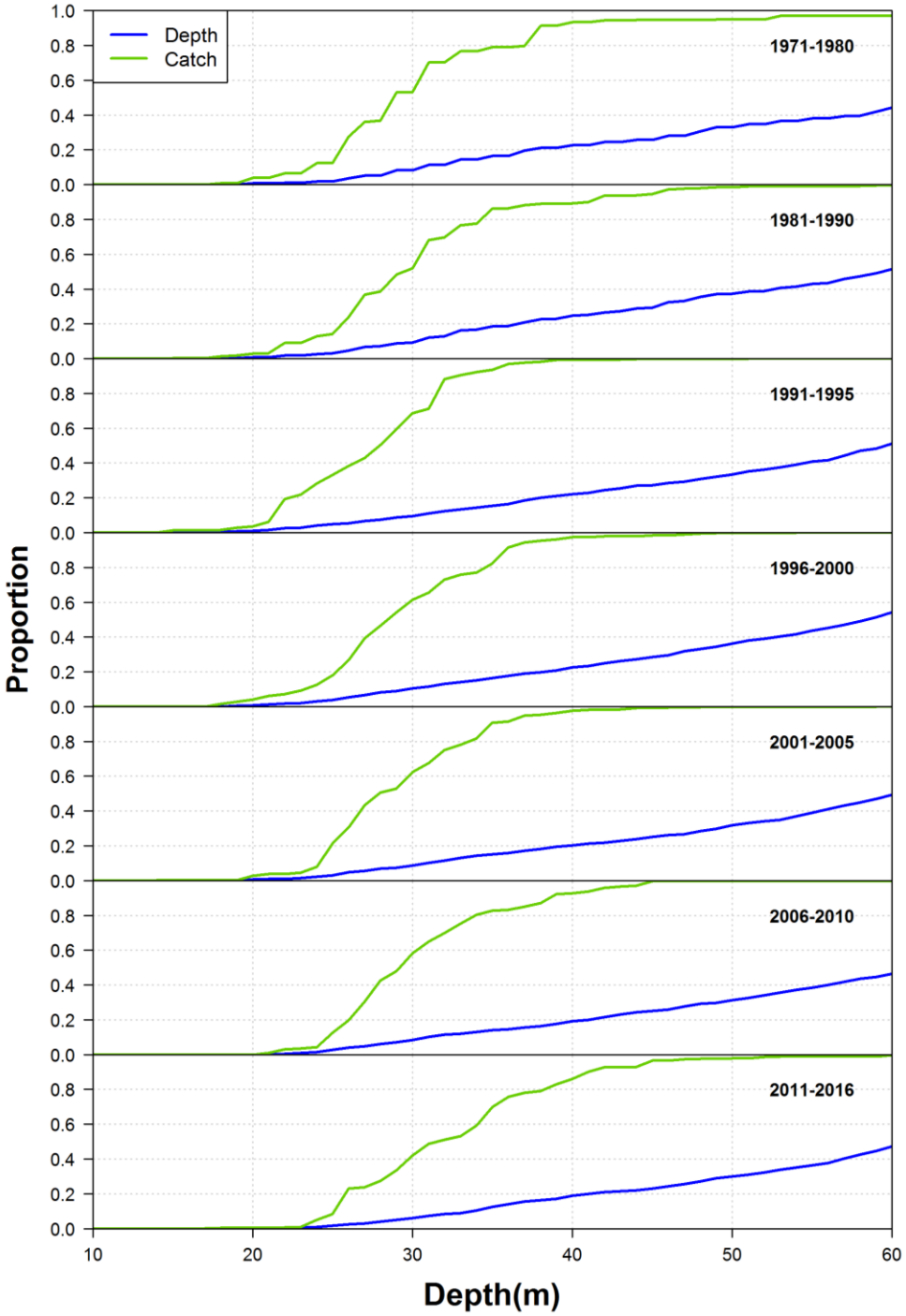

Figure 33. Cumulative proportion by depth (m) of stations sampled and Winter Flounder catches from the RV survey of the southern Gulf of St. Lawrence for strata 415-439, in five year blocks, 1971 to 2016.

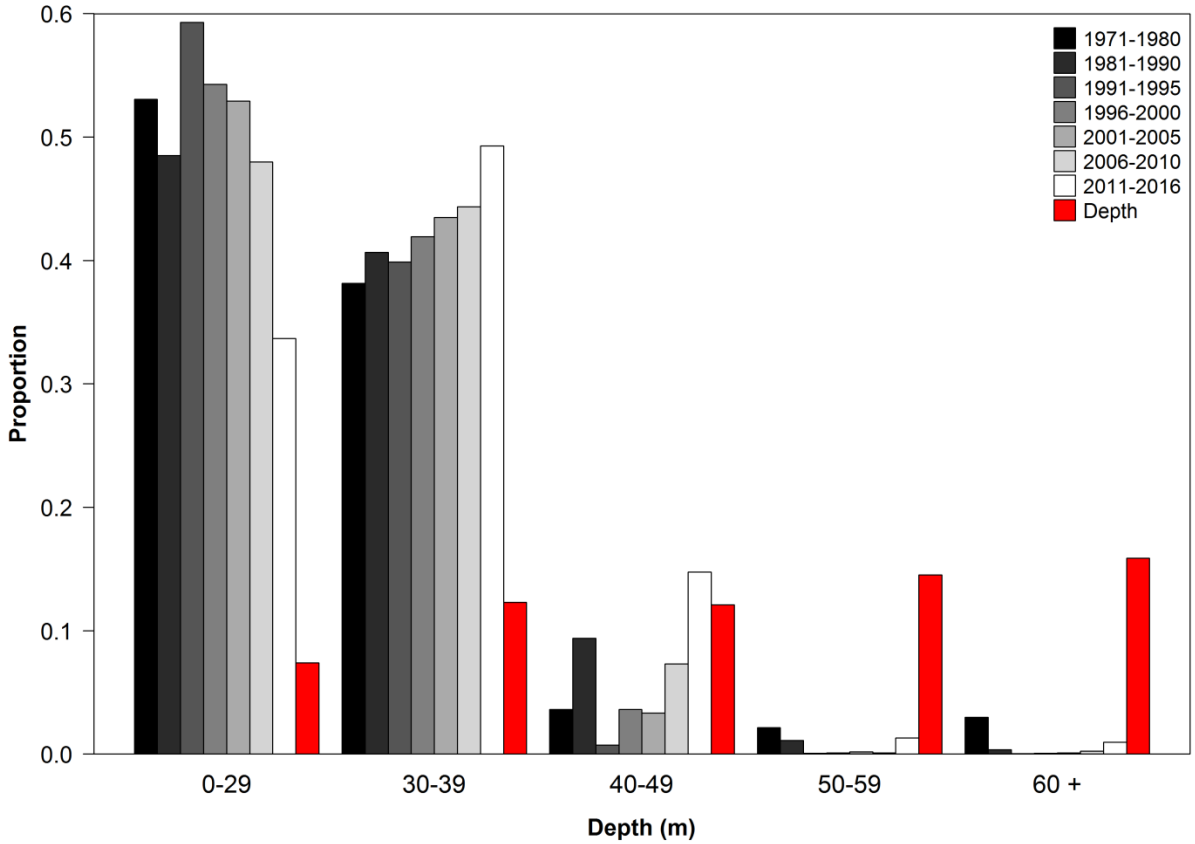

Figure 34. Decadal variation in the proportions of catches of Winter Flounder by depth bins from the southern Gulf of St. Lawrence RV survey, strata 415-439, 1971 to 2016. Grey graduated shaded bars show Winter Flounder catches by decadal period. Red bars show the proportions of the sampling stations in each depth bin for the period 1971-2016.

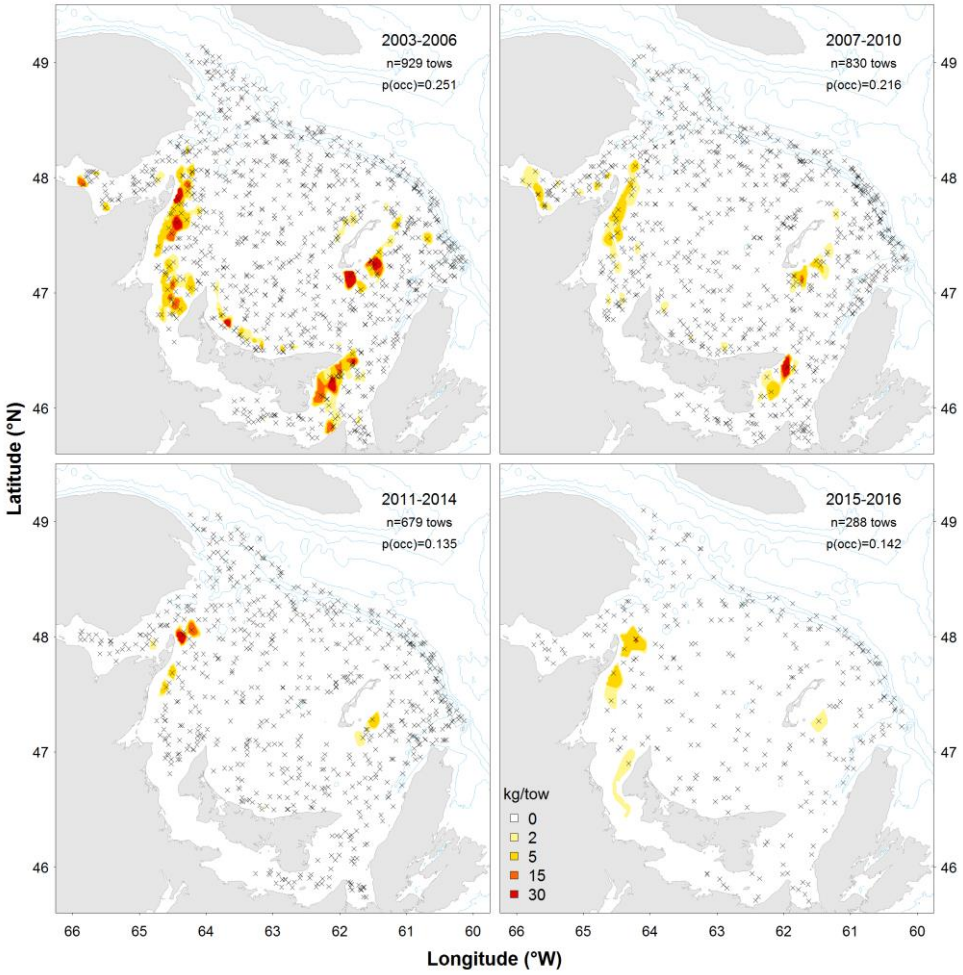

Figure 35. Spatial distribution of standardized Winter Flounder catches (kg per tow) from the mobile sentinel survey, 2003 to 2016. Contours were drawn using an inverse-distance weighting method with a range parameter of 10 km. Shown in each map are the total number of tows used in the analyses and the proportion of tows having non-zero catches of Winter Flounder.

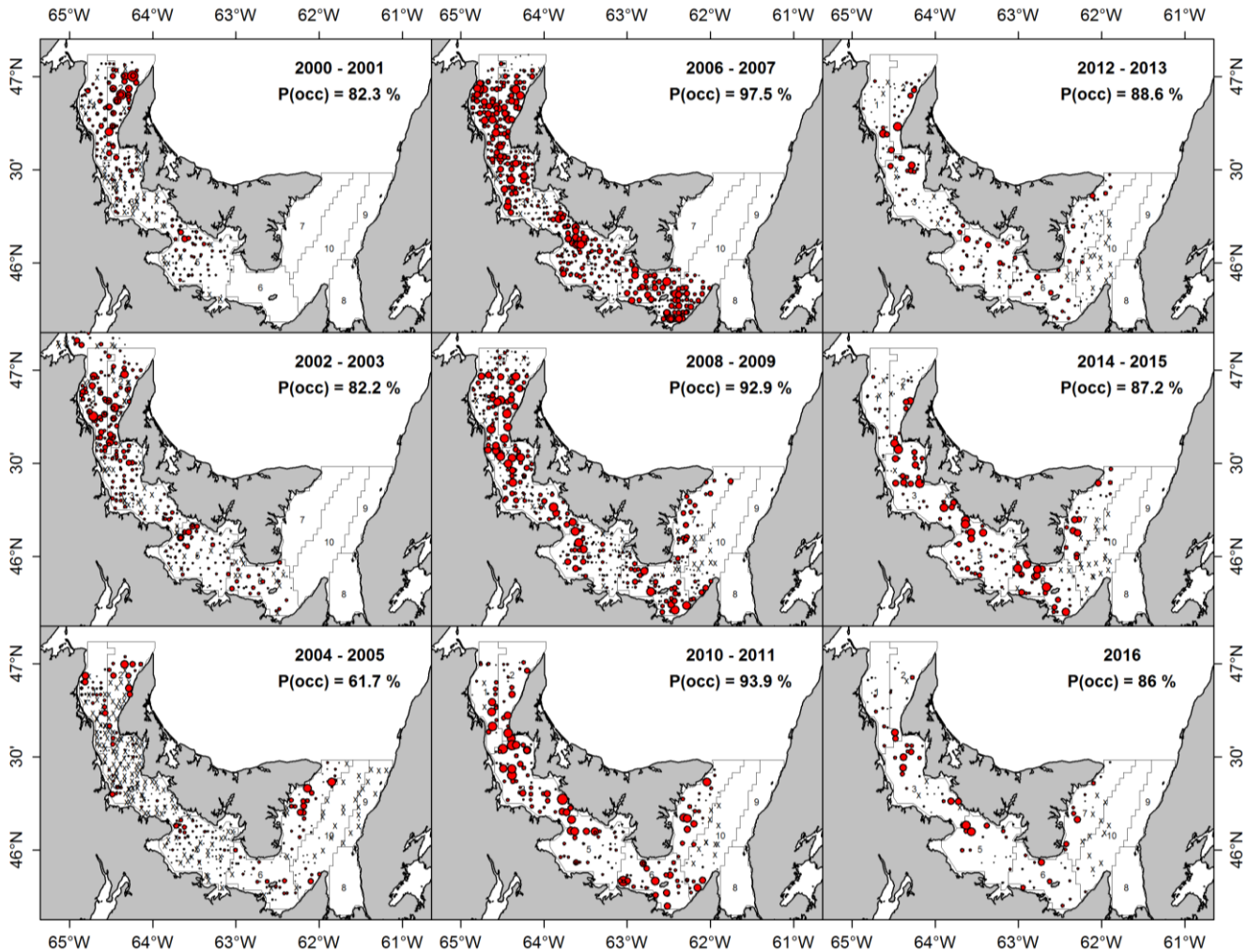

Figure 36. Spatial distribution Winter Flounder catches in the Northumberland Strait survey, southern Gulf of St. Lawrence, 2000 to 2016. Small "x"s indicate a tow with no Winter Flounder catch. Circle area is proportional to number per tow. Note that the catches in 2010 and 2011 were obtained with a Nephrops trawl rather than the modified Yankee trawl used for other years. Also shown is the percentage of tows with non-zero Winter Flounder catches.

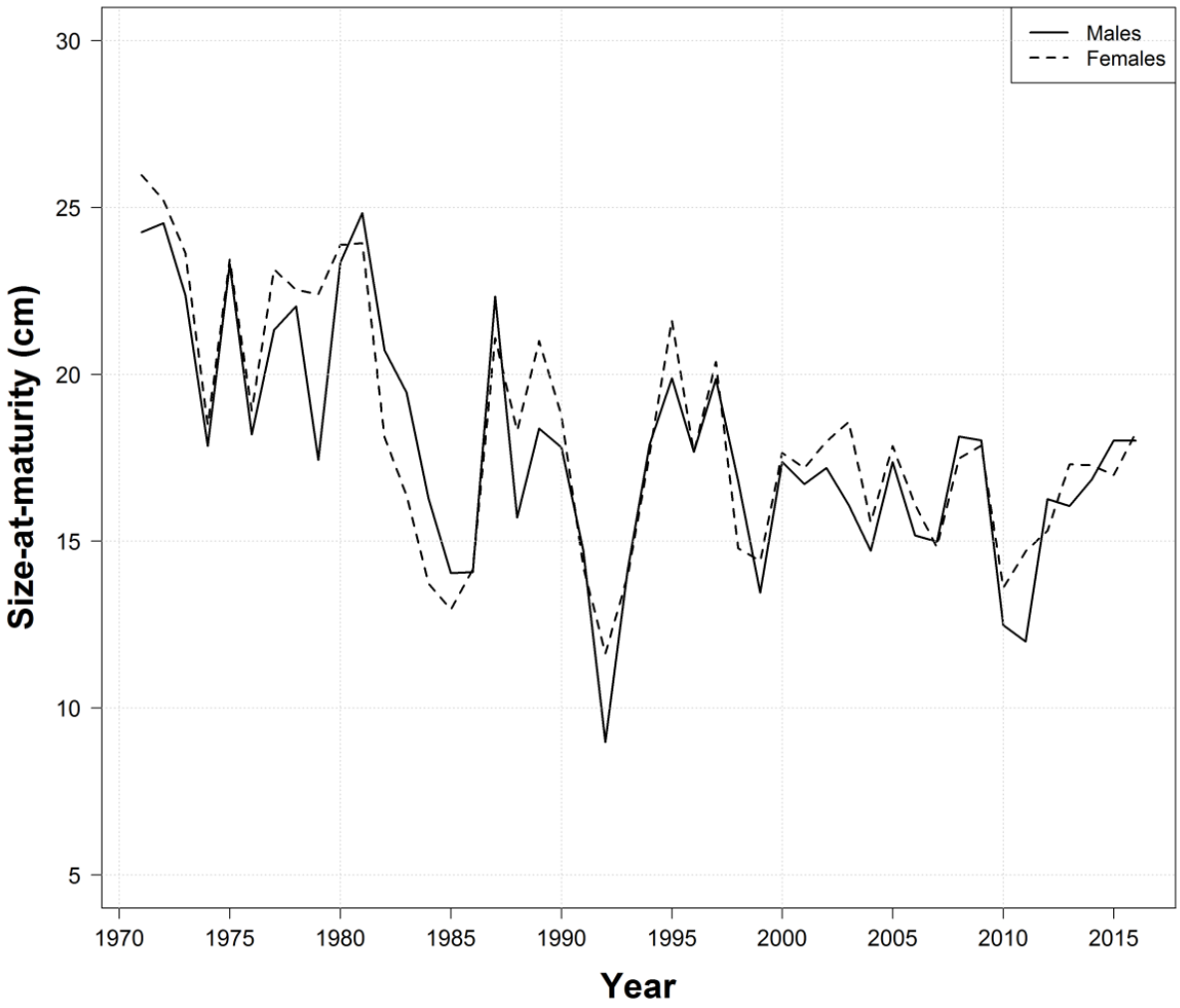

Figure 37. Mean size-at-50% maturity (length, cm) of Winter Flounder by sex and year estimated from sampling of catches in the research vessel September survey, 1971 to 2016.

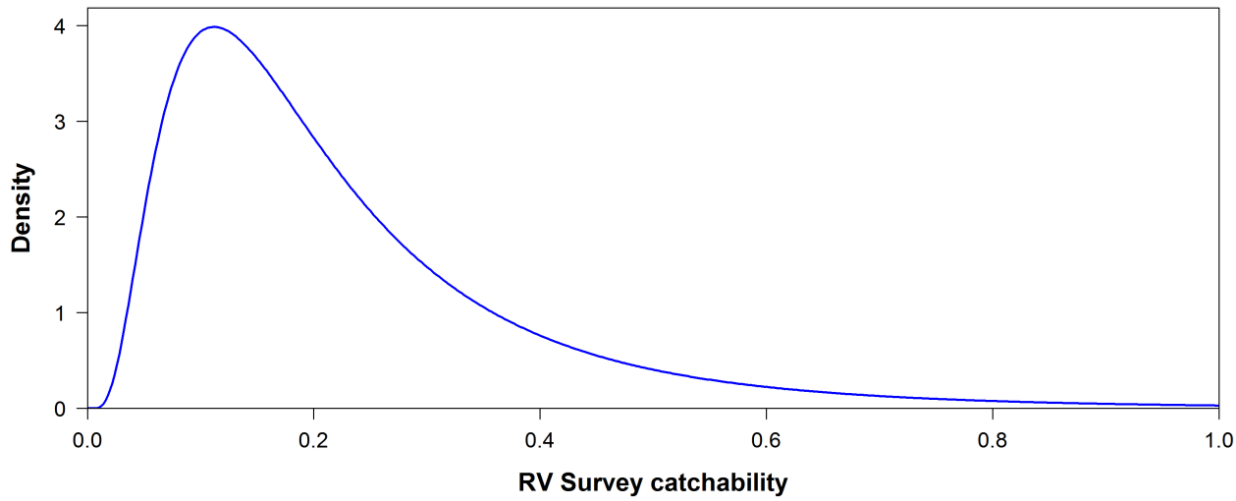

Figure 38. Prior density for the September research vessel survey catchability coefficient $q_{rv} \sim LN(-1.7, 0.7)$*. The mode of this prior is at* $q_{rv} = 0.112$*.*

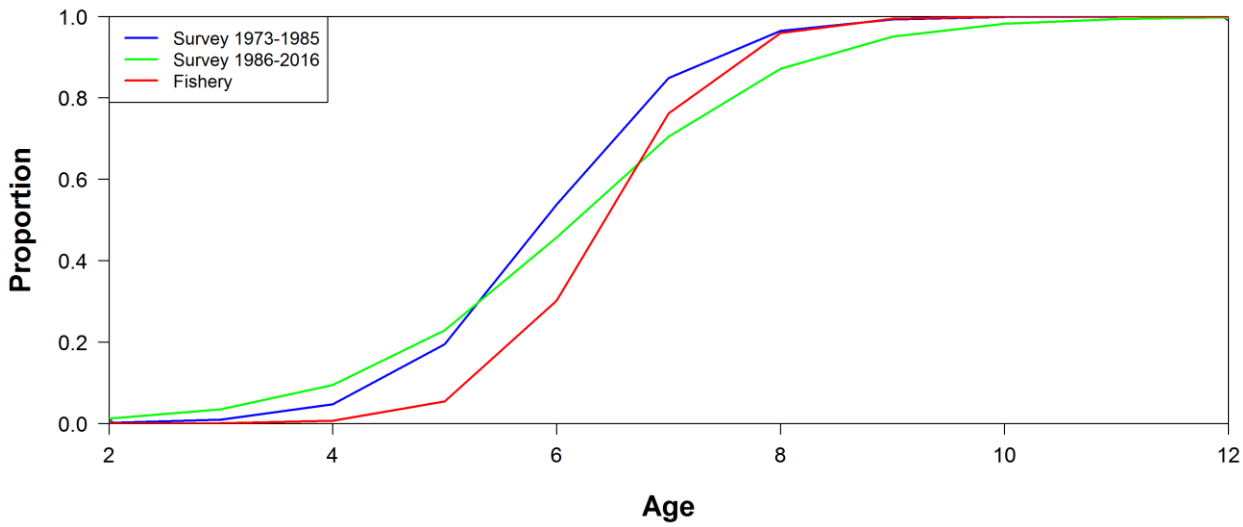

Figure 39. Selectivity-at-age curves for Winter Flounder estimated for the research survey and for the fishery based on Model 2.

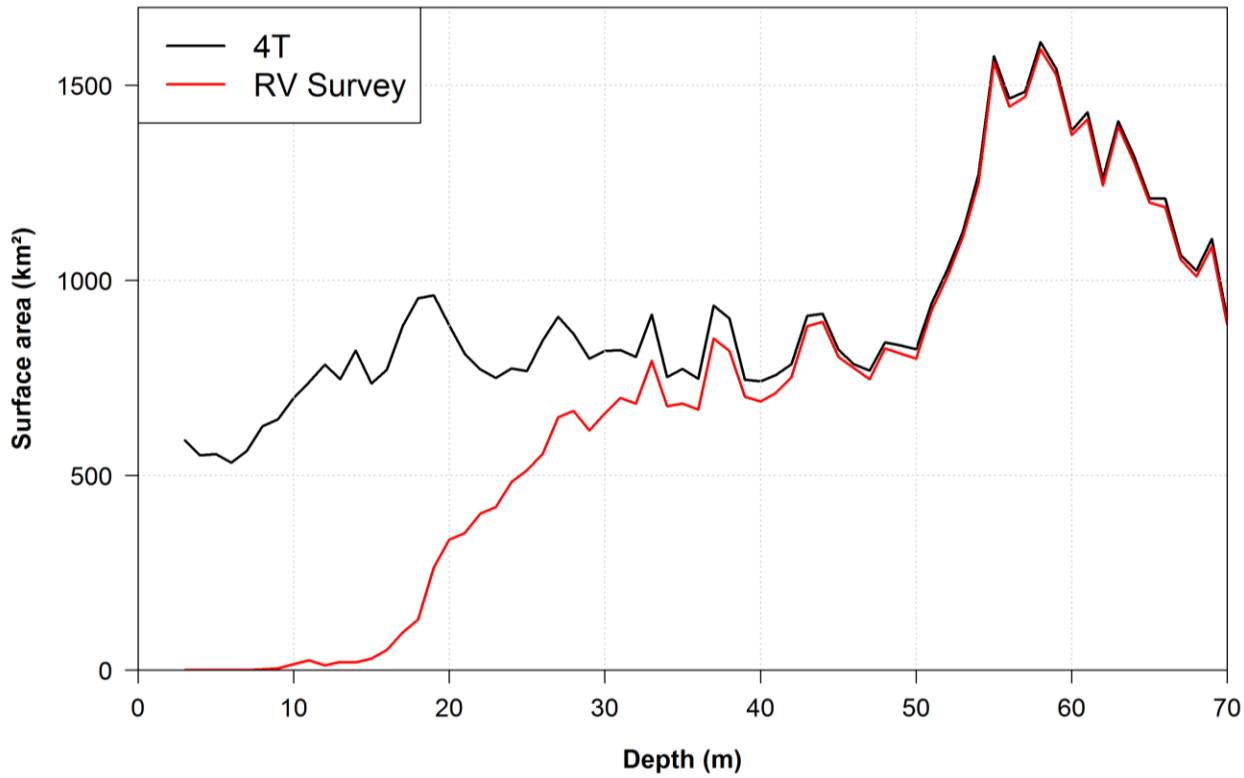

Figure 40. Surface area (km²) of the southern Gulf of St. Lawrence by 1-meter depth intervals (black line) and the area by depth included in the research vessel survey strata 415-439. There are approximately 17,500 km² of the southern Gulf of St. Lawrence between the 1 and 70-meter isobaths which are not included in the RV survey sampling domain.

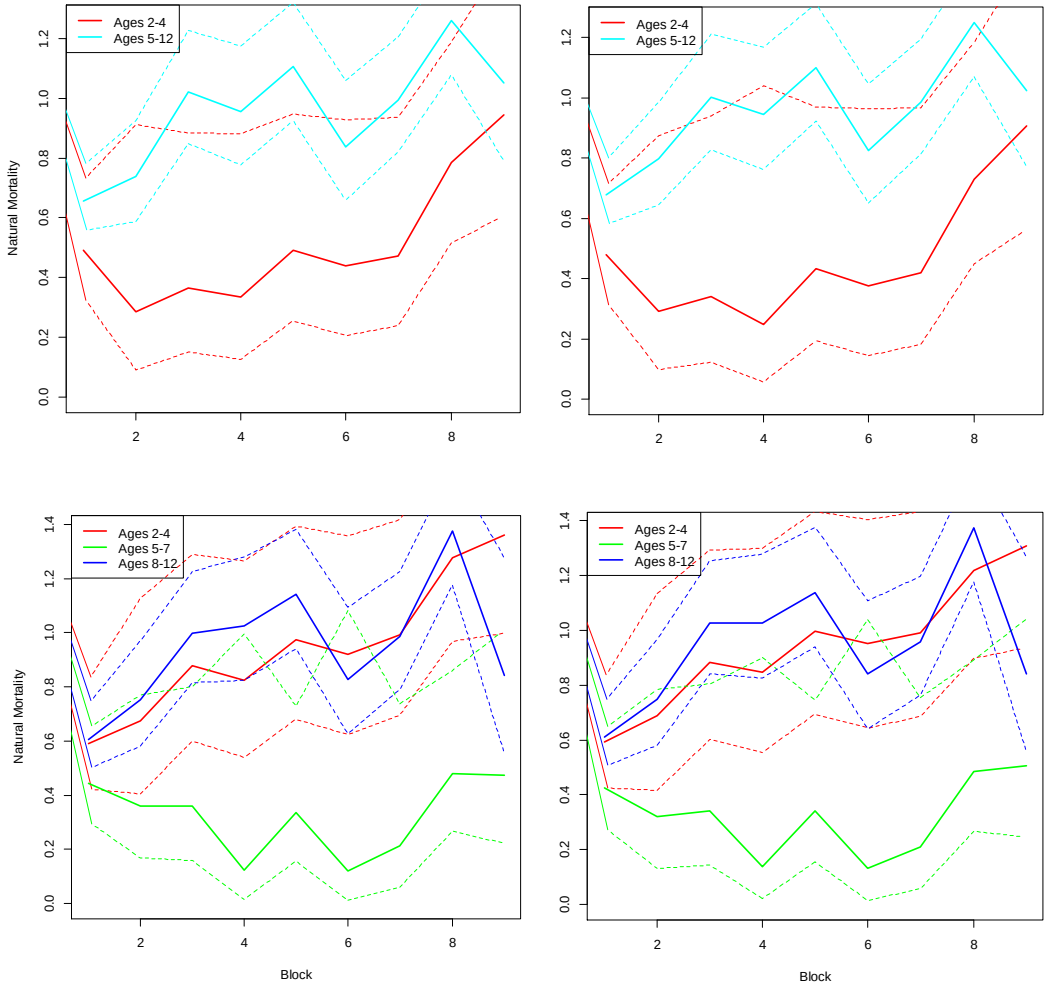

Figure 41. Natural mortality estimates by age blocks of Winter Flounder in the southern Gulf of St. Lawrence for Model 1 (top-left), Model 2 (top-right), Model 5 (bottom-left) and Model 7 (bottom-right). Dashed lines are the confidence interval ranges for each block estimate.

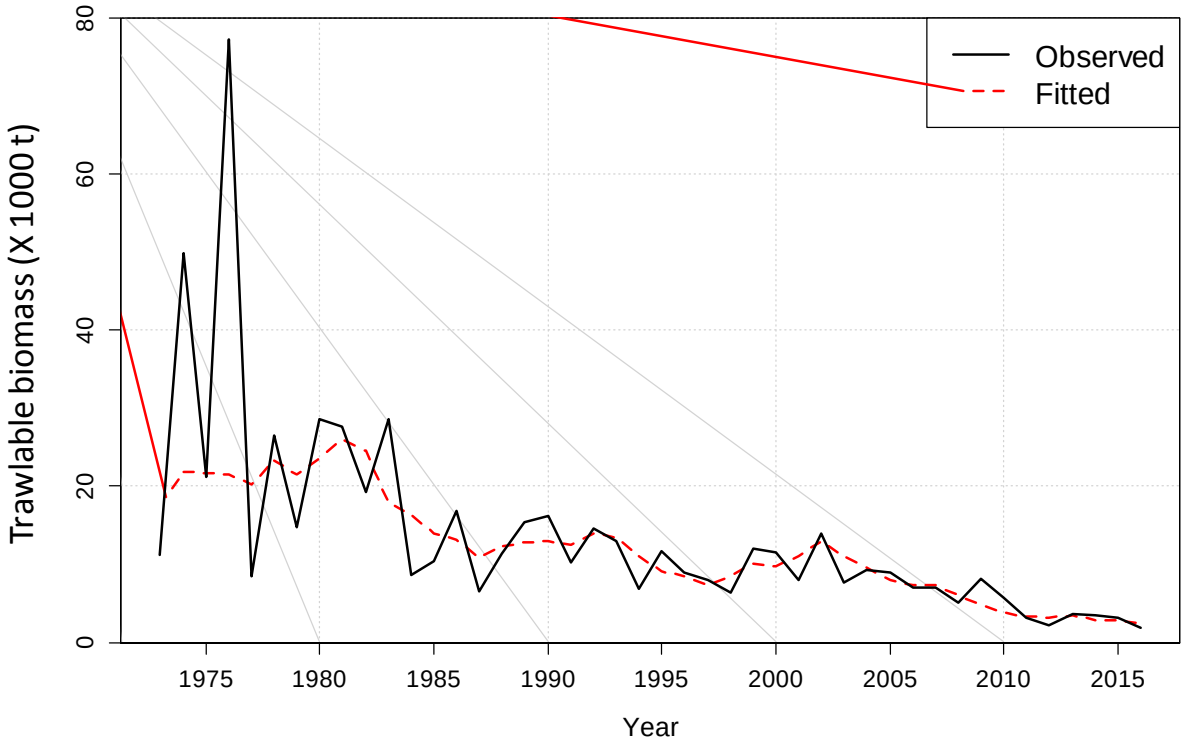

Figure 42. Comparison between observed (solid black line) and predicted (dashed red line) RV trawlable biomass of Winter Flounder from the southern Gulf of St. Lawrence, 1971 to 2016.

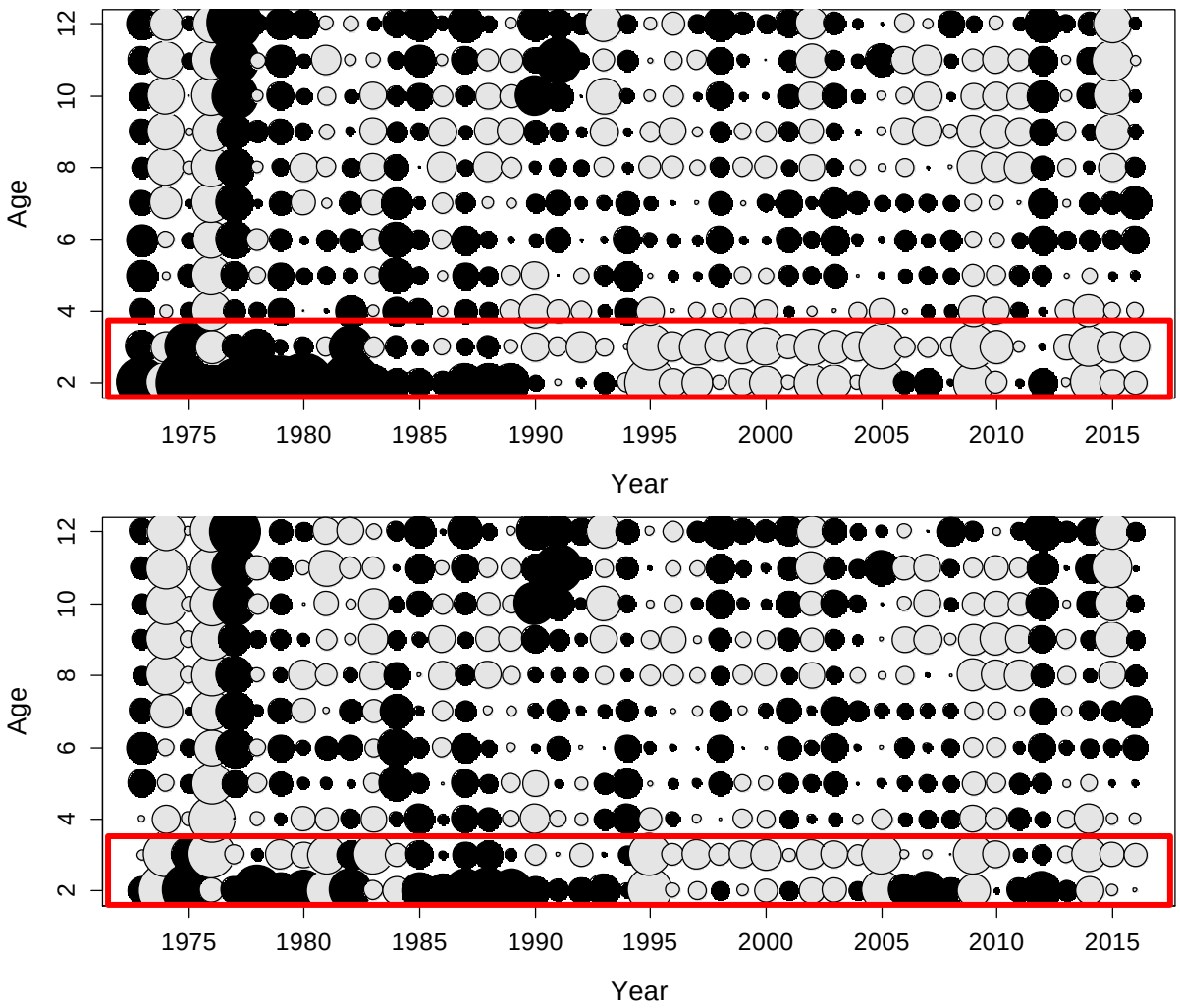

Figure 43. Log-scale residual patterns of research vessel survey catches at age of Winter Flounder from the southern Gulf of St. Lawrence, for Model 1 (top panel) and Model 2 (bottom panel). Highlighted in each panel is the problematic pattern for ages 2-3 for models with a single selectivity curves for the RV survey (Model 1). The residual pattern for Model 2 is an improvement.

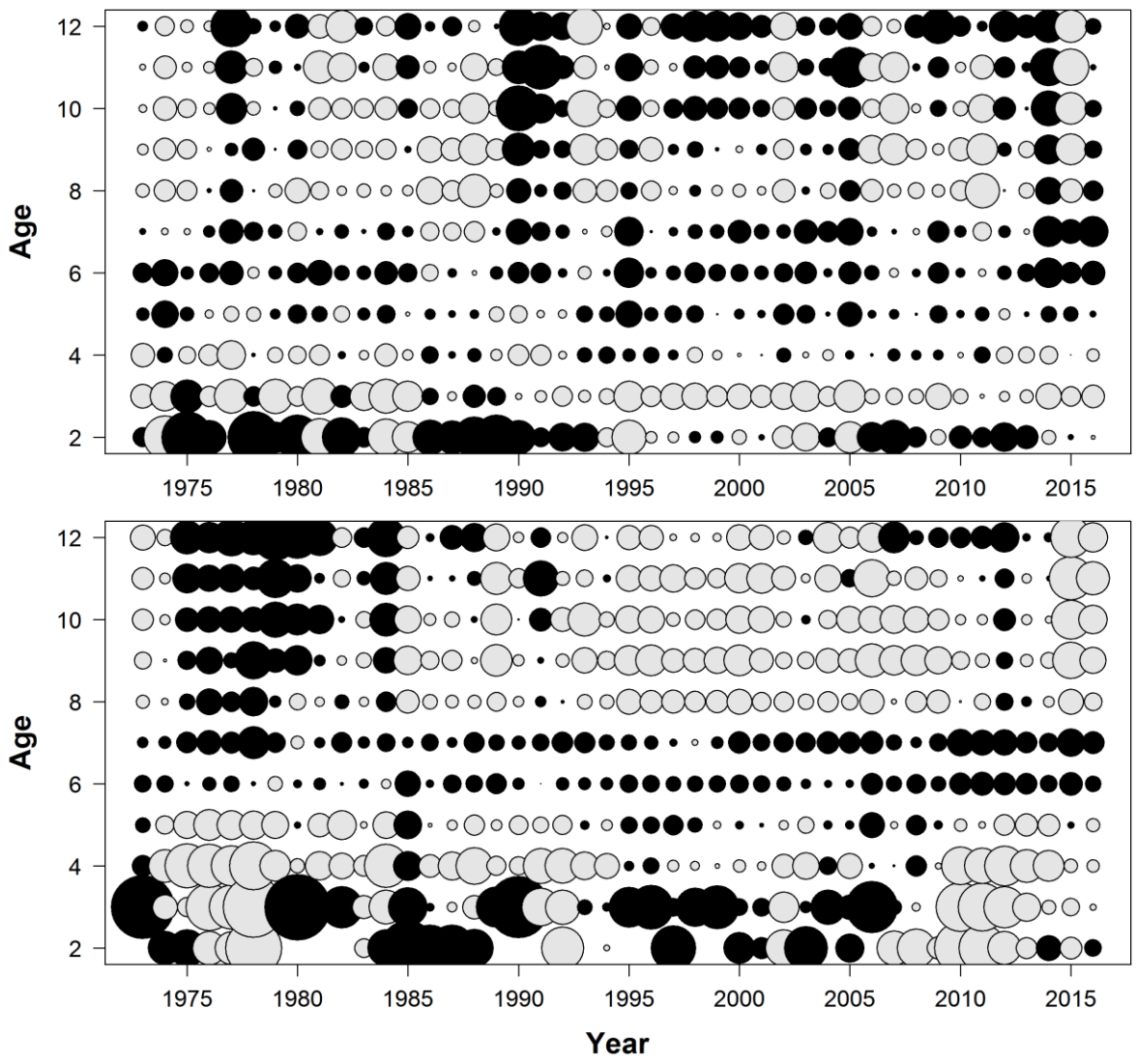

Figure 44. Log-scale residual plots of proportions at age for the RV survey catch-at-age proportions (top panel) and the fishery catch-at-age proportions (bottom panel) of Winter Flounder from the southern Gulf of St. Lawrence. Proportions are calculated from numbers. Black circles indicate underestimation and grey circles indicate overestimation from the model.

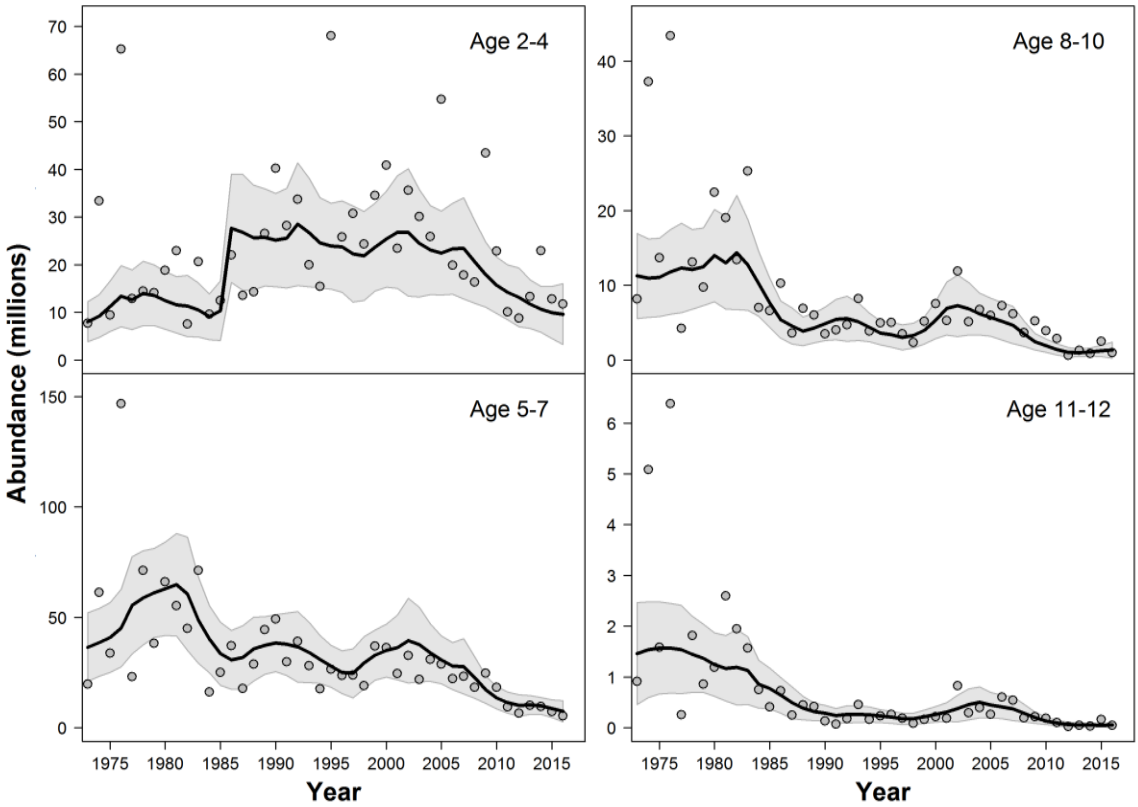

Figure 45. Observed (open circle symbols) versus predicted (black solid lines are the maximum likelihood estimates and the shaded area represent the 95% confidence interval range) trawlable abundance (in millions) of Winter Flounder by age groups from the research vessel catches in the southern Gulf of St. Lawrence, 1973 to 2016.

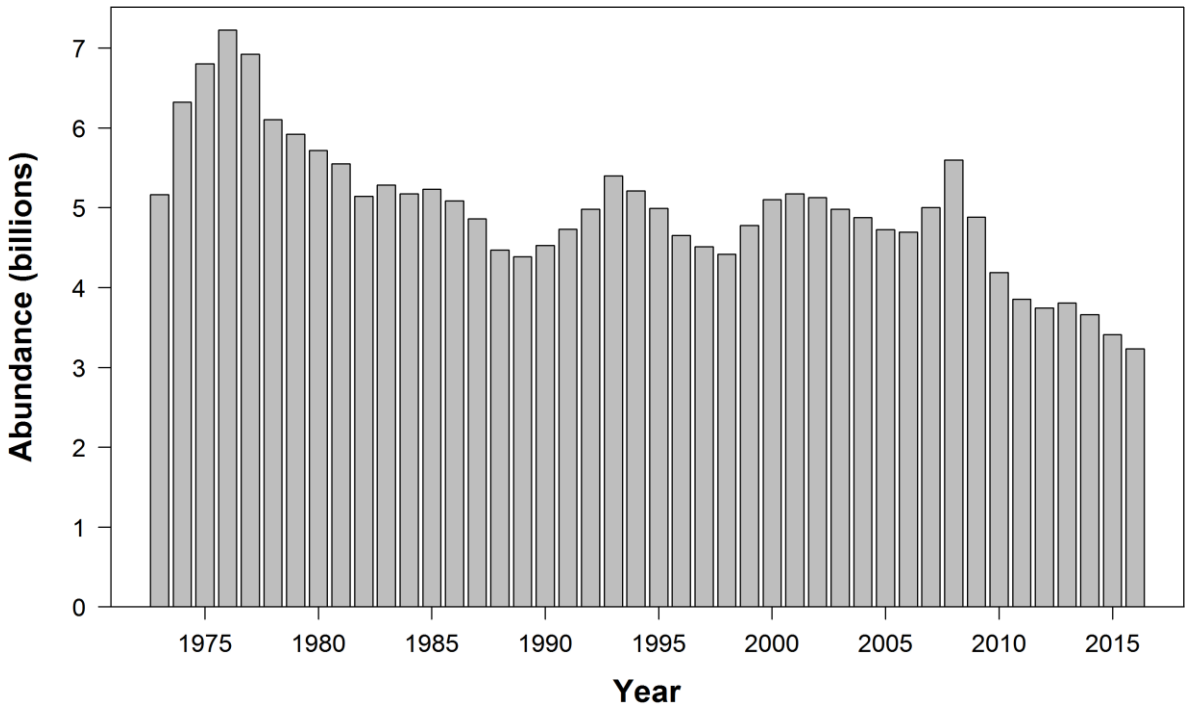

Figure 46. Total abundance (numbers) of Winter Flounder, ages 2-12+, from the southern Gulf of St. Lawrence, predicted by Model 2, 1973 to 2016.

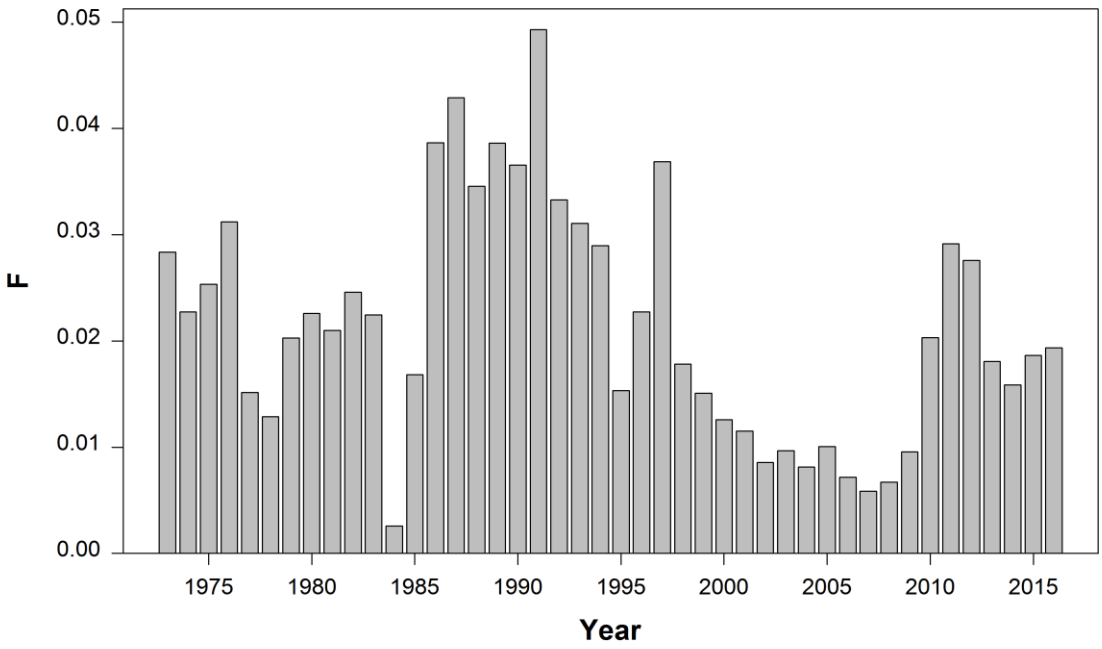

Figure 47. Estimated annual fishing mortality rate (F) on Winter Flounder from the southern Gulf of St. Lawrence, 1973 to 2016.

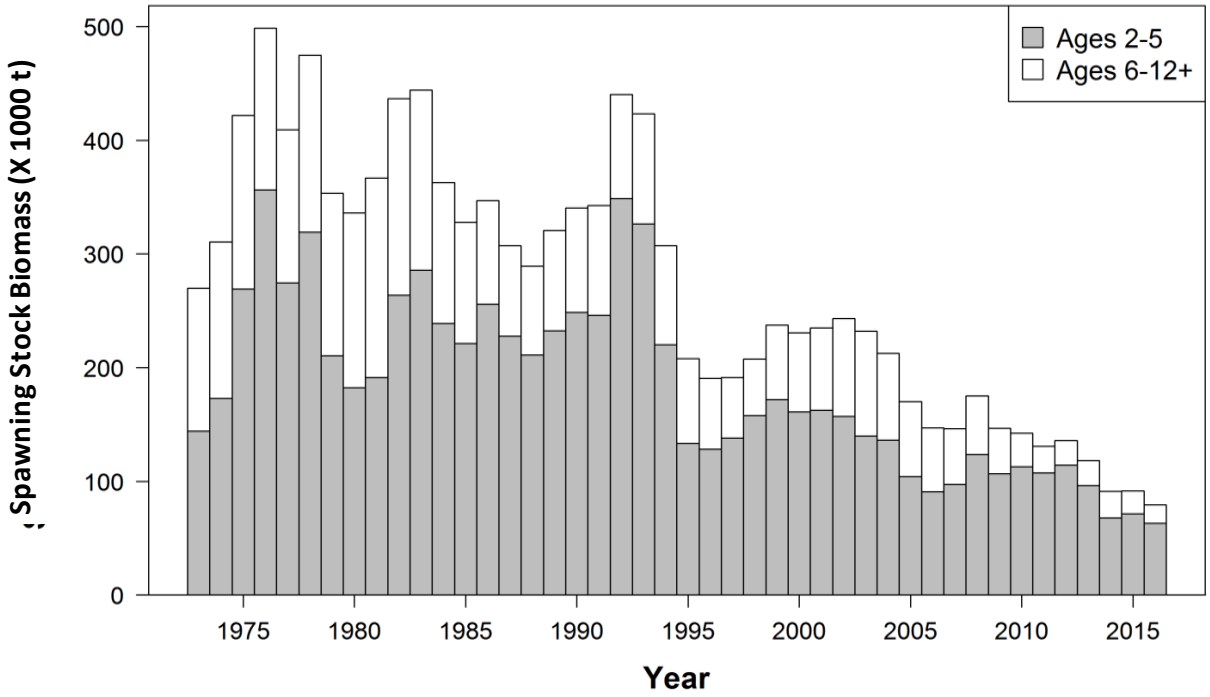

Figure 48. Estimated spawning stock biomass (SSB; t) by age groups of Winter Flounder in the southern Gulf of St. Lawrence, 1973 to 2016.

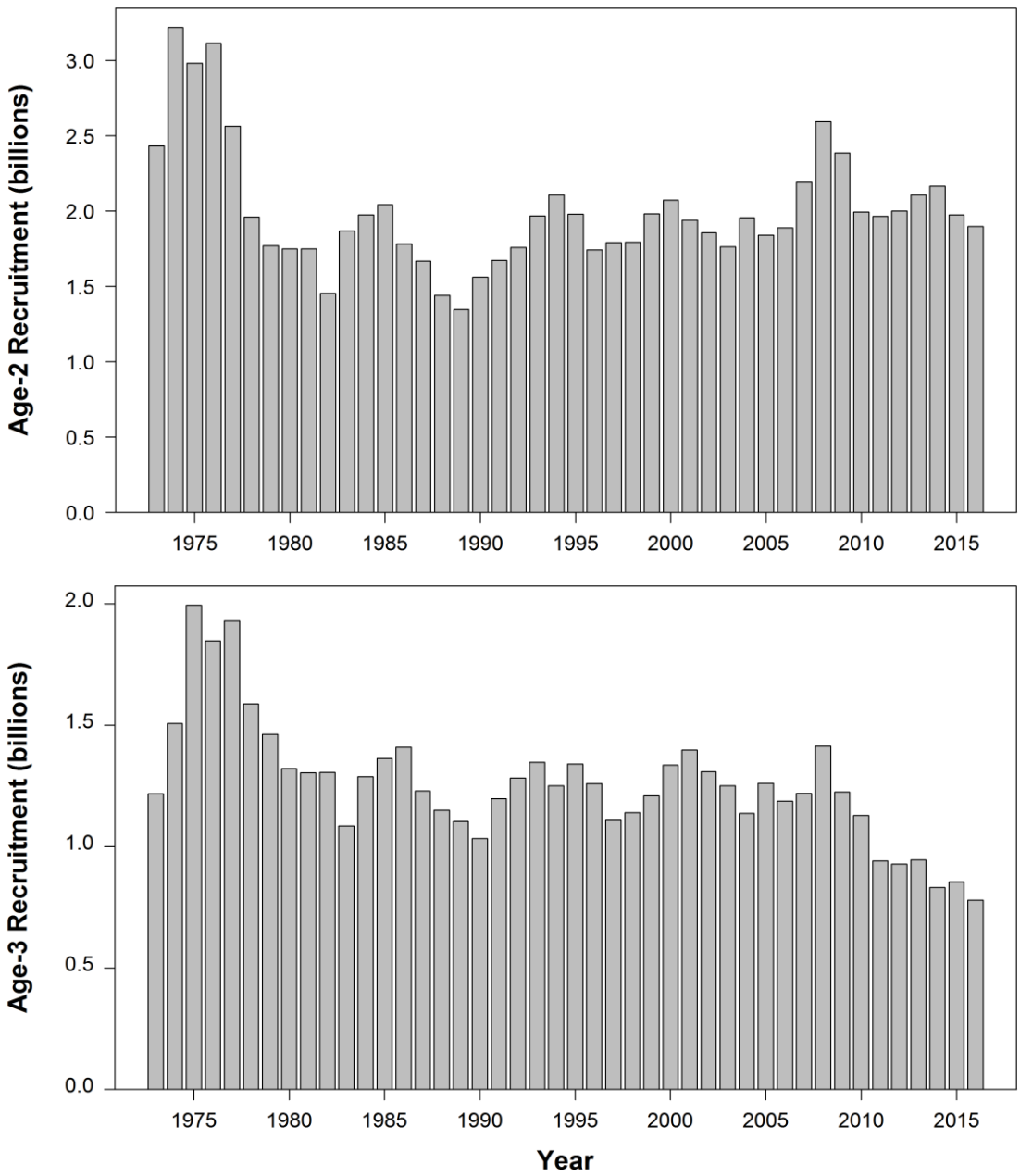

Figure 49. Predicted recruitment (number) at age-2 (top panel) and age-3 (bottom panel) of Winter Flounder from the southern Gulf of St. Lawrence, 1973 to 2016, based on Model 2.

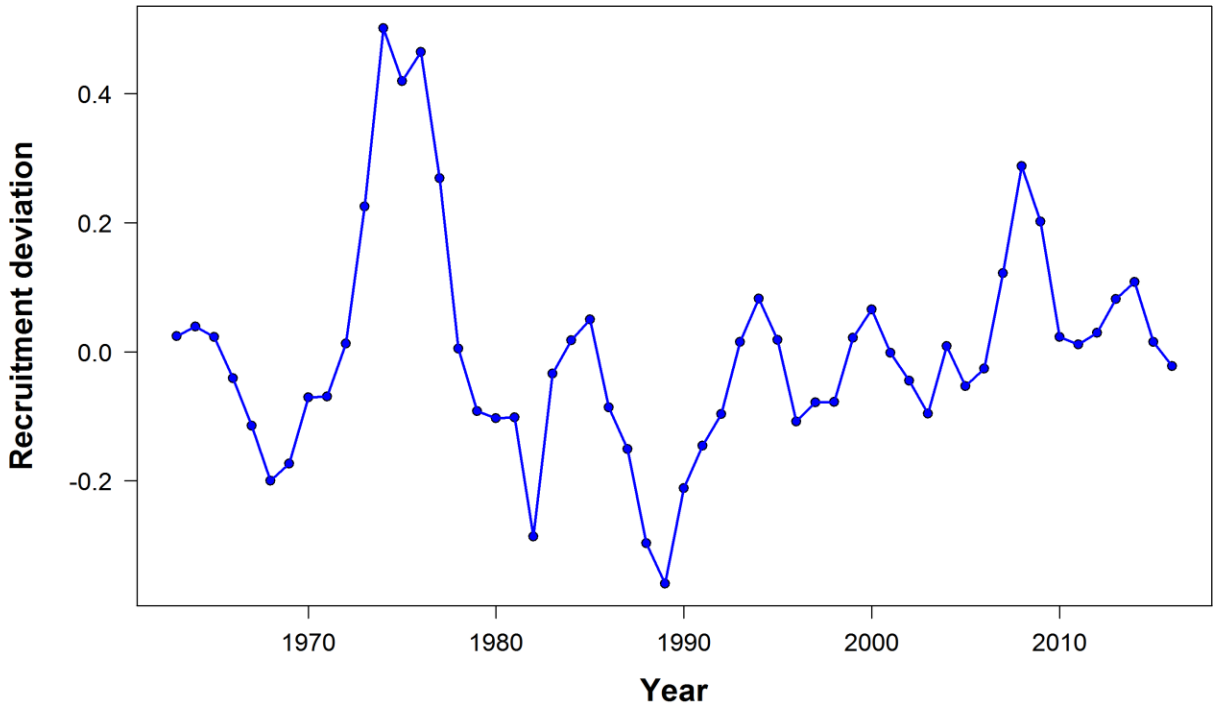

Figure 50. Recruitment deviations at age-2 by year of Winter Flounder from the southern Gulf of St. Lawrence, for the 1963 to 2014 cohorts.

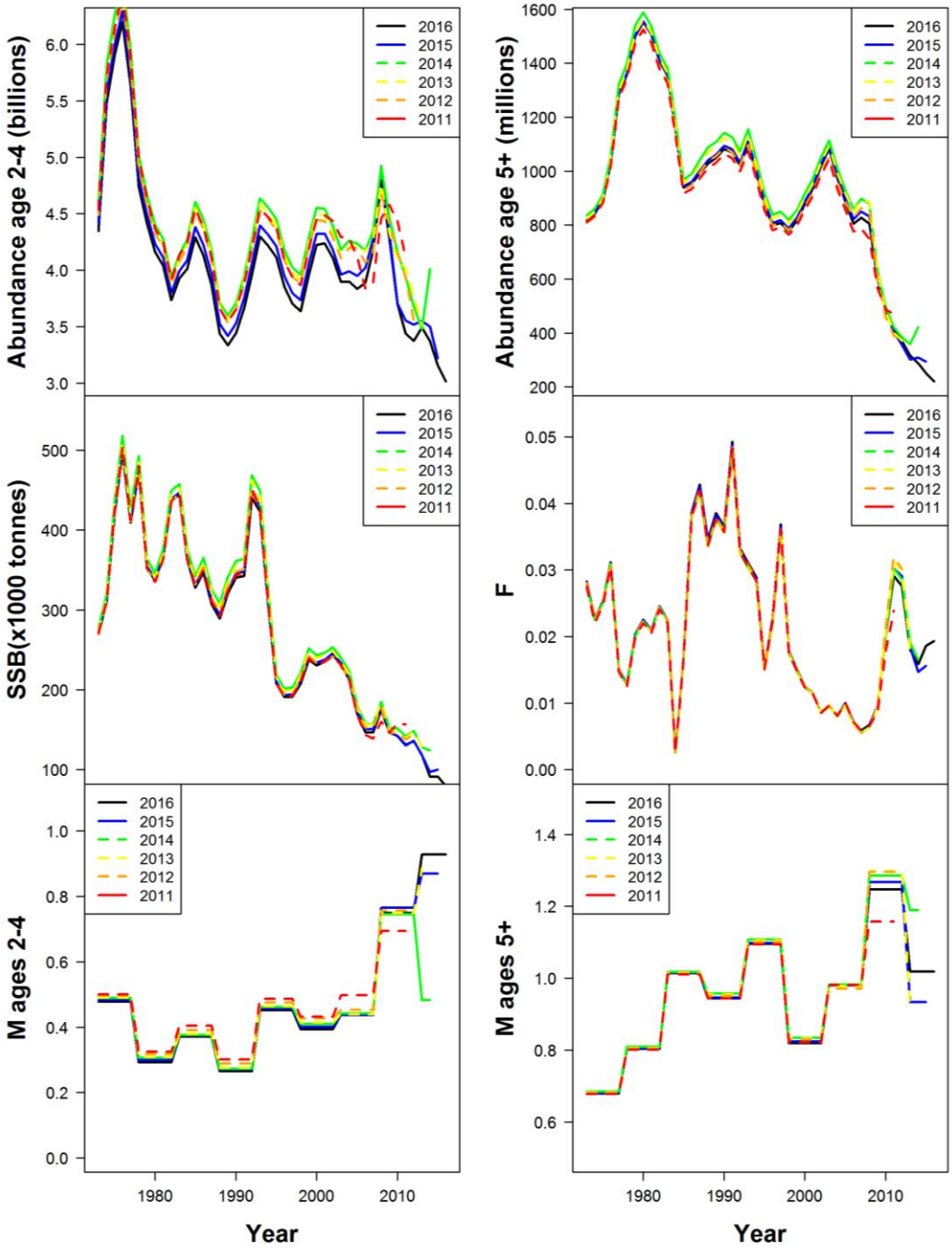

Figure 51. Summary of retrospective analyses of the Winter Flounder population model inferences for abundance at age 2-4 (number; top left panel), abundance at age 5+ (number; top right panel), SSB (t; middle left panel), fishing mortality rate (F; middle right panel), natural mortality at age 2 to 4 (M; bottom left panel) and natural mortality at ages 5+ (M; bottom right panel) for models using data ending in 2011 to 2016. Line colour indicates the last year of data included in the analysis.

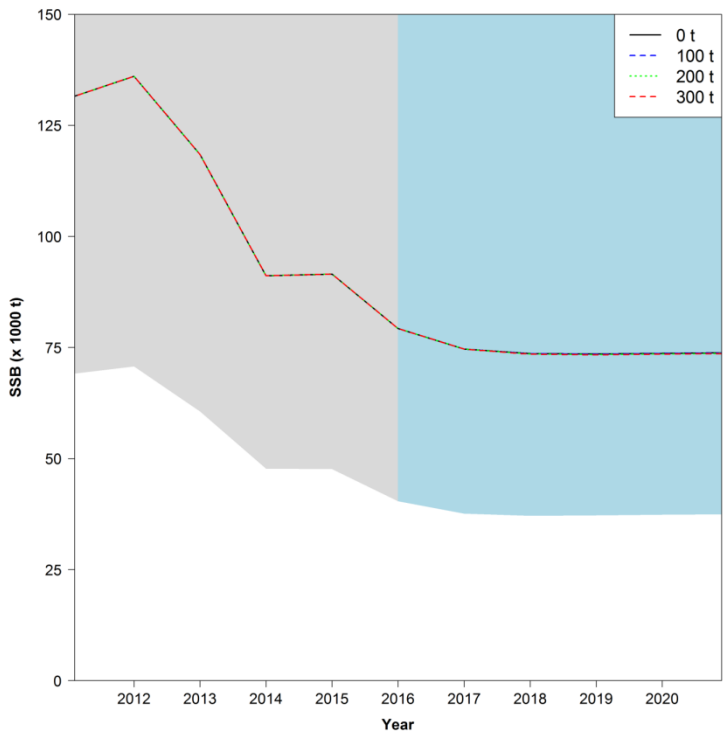

Figure 52. Projected spawning stock biomass (SSB; X 1000 t) of Winter Flounder of the southern Gulf of St. Lawrence for 2017 to 2021, for four levels of annual fishery catches (0 t, 100 t, 200 t, 300 t). Lines show historical and projected estimates (median). Shading shows the uncertainty bands (+/- 1 std. dev.) for the historical period (grey shading) and the projection period (blue shading) with no catch. There are no perceivable differences in stock abundance over the range of catch levels examined.

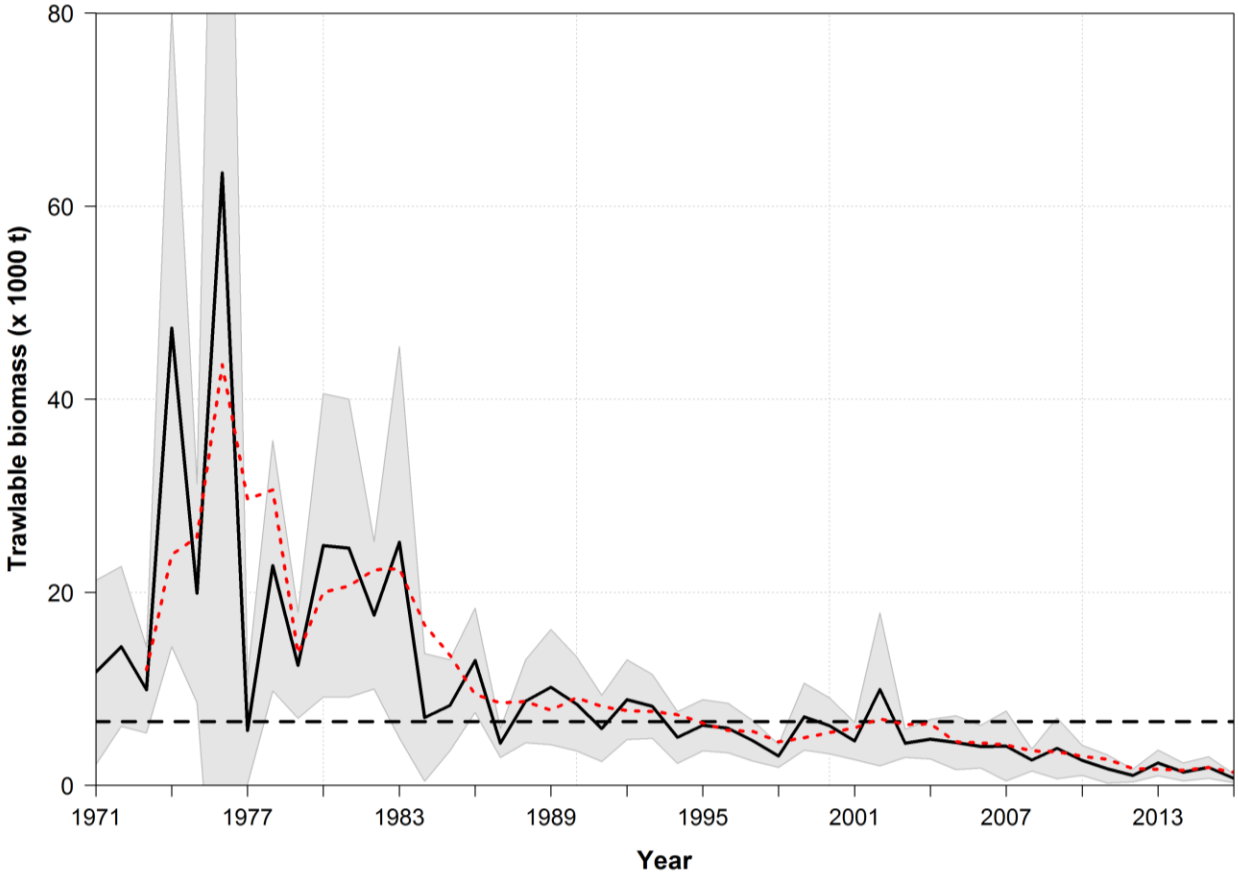

Figure 53. Trend in the stock status indicator (black solid line is the annual point estimates, grey shading is the 95 % confidence interval band of the annual estimate, red dotted line is the three-year moving average value of the point estimate) of commercial-sized (>= 25 cm) Winter Flounder in units of trawlable biomass (thousand t) in the southern Gulf of St. Lawrence, 1971 to 2016. Also shown, as the dashed horizontal black line, is the limit reference point re-scaled to units of trawlable biomass of commercial-sized Winter Flounder (6,609 tonnes).

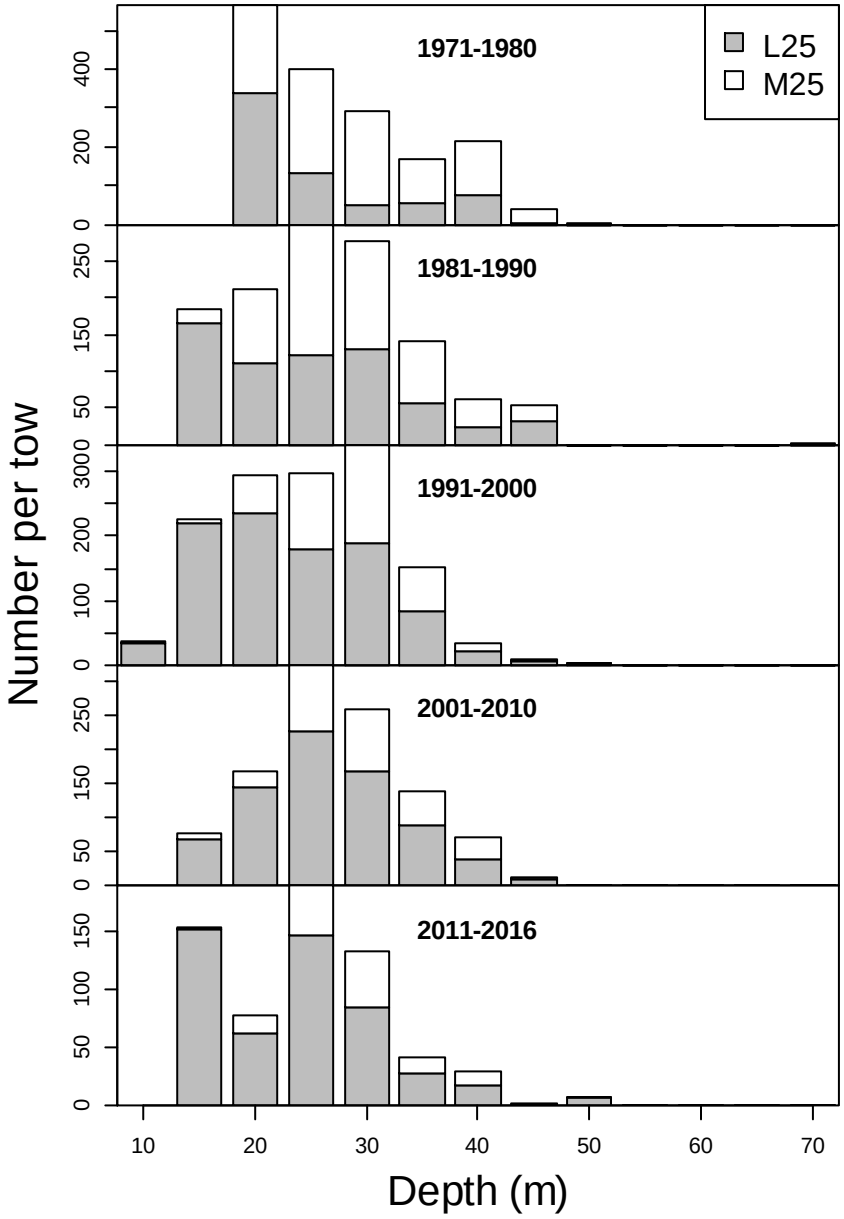

Figure 54. Mean densities (number per tow) by 5-meter depth intervals of standardized catches of Winter Flounder by size group (L25 = less than 25 cm total length; M25 = greater than or equal to 25 cm total length) from the September RV survey, by 10-year groups and a final 6-year group 2011-2016. Note that there are much fewer samples in shallower depths (i.e. 10-20 meters) than in deeper ones.