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# The status of NAFO Division 4T winter flounder (*Pseudopleuronectes americanus*), February 2012

# État de la plie rouge (*Pseudopleuronectes americanus*) de la division 4T de l'OPANO, février 2012

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## ABSTRACT

Annual winter flounder landings in NAFO 4T reached over 3,000 tonnes in the 1960s, but varied widely due to unreliable catch statistics up to the 1990s. Landings have declined through the 1990s to less than 200 tonnes in 2007 and 2008. Approximately 300 tonnes were landed in the 2010 and 2011 fisheries. Landings have been consistently below 500 tonnes for the past 10 years, well below the average of 1,481 tonnes since 1960 and the annual TAC of 1,000 tonnes that was introduced in 1996. The fishery is increasingly concentrated around the Magdalen Islands where there is a high demand for winter flounder as bait for lobster fishing. Otter trawls and gillnets are the dominant gear used to capture 4T winter flounder. Despite low harvest levels in recent years, there is no evidence that the resource is rebounding anywhere in the southern Gulf. Survey catch rates were highest before the mid-1980s and then underwent a decline. For the past two decades, winter flounder abundance has fluctuated near the 41-year average of survey catches, but stock biomass has continued to decline to its lowest point in 2011. Data from the mobile gear sentinel program indicate a declining trend since 2003. The size distribution of 4T winter flounder in surveys has shifted to smaller sizes, with fewer large-bodied fish in the population. The size and weight at age have declined over time. The dynamics of 4T winter flounder since 1973 are described using an age structured population model for the first time. The spawning stock biomass (SSB) has peaked at intervals, but exhibits a downward trend over the past 20 years. The age composition of the SSB has shifted from older spawners (age 6+ years) to 3 to 5-year-old fish. Recruitment at age-3 increased sharply in the 1980s to a peak in the 1990s and early 2000s, but has declined since then. Natural mortality (M), estimated for two age groups, is high and appears to drive the dynamics of the 4T winter flounder stock. High M, declining SSB and recruitment, combined with a loss of productivity due to changes in the size composition and declining growth rate, make the prognosis for stock recovery low in the short term.

## RÉSUMÉ

Les débarquements annuels de plie rouge de la division 4T de l'OPANO ont atteint plus de 3 000 tonnes dans les années 1960, mais ce chiffre a connu de grandes variations en raison de statistiques de prises peu fiables jusqu'aux années 1990. Les débarquements ont décliné au cours des années 1990 pour atteindre moins de 200 tonnes en 2007 et en 2008. Environ 300 tonnes ont été débarquées durant les pêches de 2010 et de 2011. Les débarquements se sont continuellement situés sous les 500 tonnes au cours des 10 dernières années, ce qui est bien inférieur à la moyenne de 1 481 tonnes depuis 1960 et au TAC annuel de 1 000 tonnes qui a été mis en œuvre en 1996. La pêche se concentre de plus en plus autour des îles de la Madeleine, où l'on observe une grande demande de plie rouge pour servir d'appâts à homard. Les chaluts à panneaux et les filets maillants sont les principaux engins utilisés pour capturer la plie rouge dans la division 4T. Malgré les faibles niveaux de prises des dernières années, rien n'indique que la ressource se redresserait ailleurs dans le sud du golfe. Les taux de prises des relevés étaient plus élevés avant le milieu des années 1980, après quoi ils ont commencé à décliner. Au cours des deux dernières décennies, l'abondance de la plie rouge a fluctué près de la moyenne de 41 ans des prises des relevés, mais la biomasse du stock a continué à diminuer, pour atteindre son niveau le plus faible en 2011. Les données dérivées du programme sentinelle avec engins mobiles indiquent une tendance à la baisse depuis 2003. La répartition de la taille des plies rouges de la division 4T est désormais axée sur les plus petites tailles, la population comptant moins de poissons de grande taille. La taille et le poids selon l'âge ont décliné au fil du temps. La dynamique de la plie rouge de la division 4T depuis 1973 est, pour la première fois, décrite à l'aide d'un modèle de la population structuré selon l'âge. La biomasse du stock reproducteur (BSR) a atteint des sommets périodiquement, mais affiche une tendance à la baisse pour les 20 dernières années. La composition selon l'âge de la BSR met dorénavant l'accent sur les poissons de 3 à 5 ans plutôt que sur les reproducteurs plus âgés (âge 6 et plus). Le recrutement à l'âge 3 a connu un accroissement marqué dans les années 1980 pour atteindre un pic dans les années 1990 et au début des années 2000, mais il a décliné depuis. La mortalité naturelle (M), estimée pour deux groupes d'âge, est élevée et semble dicter la dynamique du stock de plie rouge de la division 4T. Une mortalité naturelle élevée ainsi qu'un recrutement et une BSR en déclin, combinés à une perte de productivité attribuable aux changements dans la composition selon la taille et au taux de croissance à la baisse, permettent d'émettre un pronostic de faible rétablissement du stock à court terme.

# INTRODUCTION

Winter flounder is common to shallow areas of the southern Gulf of St. Lawrence (NAFO Division 4T, Figure 1) where it has been exploited commercially for several decades in a mixed fishery. The last full peer-reviewed assessment of this resource was conducted in 2002 (Morin et al. 2002), followed two years later by an update of fishery and survey data (DFO 2005). The 2002 assessment noted that recent estimates of stock abundance and biomass were approximately at the level of the long-term average. The average size of winter flounder in surveys which began in 1971 had declined through most of the time period, but by 1995 they appeared to level (DFO 2005).

Previous assessments of 4T winter flounder have underlined uncertainties in landing statistics up to the 1990s and in the nature of stock structure for 4T winter flounder. The main source of survey data required to track stock changes does not cover inshore habitat where winter flounder occur. 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. Lastly, we introduce a population model for 4T 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 to 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 4S) and off western Newfoundland, indicating their wide distribution throughout the Gulf.

Winter flounder are hardy, capable of inhabiting a wide range of environmental conditions. Southern populations may inhabit salinities 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 antifreezes that lower the freezing point of their 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 southern Gulf. 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 2.5-3.5 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 their catches declined in the shallows and increased at depths of 15-24 m. Tagging in the southern Gulf from 1999-2004 (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 within 4 years. Thirty-eight percent of recoveries were made within 5 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).

Their seasonal nearshore movements and the lack of evidence that winter flounder make extensive migrations have led to speculation that the southern Gulf may comprise several local stocks of winter flounder, partly linked through larval drift.

Beacham (1982) found that southern Gulf 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 4T have been recorded yearly since 1960. Reported landings have varied widely, reaching over 3,000 tonnes in the mid-1960s, but declining through the 1990s, to less than 200 tonnes in 2007 and 2008 (Table 1, Fig. 2). Preliminary landings for the 2011 fishery indicate 302 tonnes, far below the long-term average of 1,481 tonnes. In previous assessments, the variable pattern of 4T winter flounder landings has been attributed partly to unreliable catch statistics.

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, resulting 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.

Otter trawls have been the dominant gear used to capture winter flounder in the commercial fishery (Table 1). Despite some decline in the importance of trawling relative to other gears, trawls have accounted for more than half of the landed catches in 18 of the past 20 years. Gillnets have grown in importance over the years, peaking in the mid-1990s due to the growth 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 roe. From 1993 to 1999, gillnets contributed from 30-46% of annual landings, but have since declined to roughly 20% 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 source of winter flounder in the Magdalen Islands fishery.

The 4T fishery is conducted mainly from May to October, but in areas such as the Magdalen Islands where a spring lobster fishery occurs, winter flounder fishing may begin in April, when conditions permit. The fishery has declined in almost all unit areas of 4T, except 4Tf where there is a strong demand for lobster bait (Figure 3). This local fishery accounted for the 246 tonnes landed in 4Tf in 2011, out of the 302 tonnes landed in 4T.

Figure 4 shows the distribution of average winter flounder catches derived from logbook data for four five-year period, aggregated by latitude and longitude of capture in 10-minute blocks. The colour scale of Figure 4 is based on the 10, 25, 50, 75 and 90$^{th}$ percentiles of mean catches over all years. Catches have weakened over time in areas where the fishery was once concentrated, particularly in the area east of PEI and in St. Georges Bay (4Tg) and in Chaleur Bay (4Tm). Catches of winter flounder have become increasingly concentrated in the waters surrounding the Magdalen Islands.

Commercial catches rise and fall with stock abundance, but also in response to market conditions and other factors that influence the time and effort expended at sea. To detect changes in fishing effort over time, we monitor the nominal effort recorded in logbooks as the number of days spent fishing. Figure 5 shows nominal effort for otter trawls, the main gear landing 4T winter flounder. In 1991, when fishing effort was at its maximum in 4T for the effort time series, trawlers directing for winter flounder totalled over 1,800 sea days to land nearly 1,500 tonnes of winter flounder. Effort declined continuously, reaching its lowest level in 2006 when only 121 days were spent directing for 38 tonnes. Fishing effort increased again in the 2000s, reaching nearly 1,600 days for a landed catch of less than 120 tonnes. Most of the recent increase in fishing effort by trawlers may be attributed to the local Magdalen Islands flatfish fishery.

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 Québec 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 tonnes of winter flounder, or 6% of the local fishery (DFO 2009). This activity increased over time and, by 2008, 36 trawlers with bait licenses reported 34 tonnes of winter flounder; in 2009, 47 trawlers with bait licenses caught 56 tonnes of winter flounder. The activity peaked in 2010 with 96 lobster boats with bait permits reporting 117 tonnes. Landings of winter flounder by commercially licensed boats on the Magdalen Islands matched landings by bait-licensed boats in 2009 and 2010 (Figure 5). In December 2010, a decision was made by DFO resource managers to gradually reduce the number of bait permits and the days of fishing. Landings in 2011 indicate that the commercial boats are providing a larger share of the total catch (Figure 5). After 2012, flatfish bait on the Magdalen Islands will be provided by the commercial fishery alone.

The 4T winter flounder fishery came under quota regulation only in 1996, following concern that the closure of the 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 4T hake fishing in 1995 added to this concern. The 1000-tonne limit 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 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 provoked 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 the $F_{0.1}$. 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 their survival 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 following table summarizes management measures that were in effect in the 2010-2011 fishing season for winter flounder:

| | |
|---|---|
| Test fishery prior to opening | Yes, where there is a high probability of cod by-catch |
| By-catch limits | Cod: 5% daily, fixed gear; 10% per trip, mobile gear<br>Hake & other species: 10% daily |
| 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 |

Telephone opinion surveys were conducted annually from 1995 to 2008 to obtain the views of active fish harvesters on the state of groundfish in the southern Gulf. The opinion survey was dropped in 2003 and after 2009 due to the closure of the 4T Atlantic cod fishery. Respondents were chosen based on early purchase slip data to ensure that only active fish harvesters were contacted; participants were also chosen by statistical district to ensure, if possible, that opinions were received from throughout the southern Gulf. The number of respondents who identified winter flounder as their first or second fishing priority declined over time from 46 to 78 before 1999 to as few as 17 in 2001 and 2008.

Among the various questions, fish harvesters were asked to judge the relative abundance of winter flounder (less, same or more) in the present year relative to abundance the previous year, the previous 5 years, and compared to all years in their fishing experience. Table 2 shows the numbers and percent of responses. In assessments before 2000, responses to this question tended slightly to favour a perception that there were more winter flounder in the year of the opinion survey compared to the previous year, but this opinion was less strongly held when compared to the last 5 years or to all previous years. The opinions since 2000 have tended to reflect a less positive view of abundance. The proportion of respondents who perceive abundance as being greater than last year has tended to decline over time, with the exception of the 2008 survey (Table 2). The opinion that abundance was less in the year of the opinion survey continued to dominate as the period of recall is increased.

Of course, factors other than abundance of the resource influence the fishery. Area officers in Antigonish and the Magdalen Islands reported that the decline in fishing effort in their area is due to rising cost of fuel and operating costs (including costs of at-sea observers and dockside monitoring), low demand for the resource and lack of buyers in areas where there previously was a food market. Fish harvesters on the Magdalen Islands noted the high abundance of small winter flounder in their area. They have expressed the view that the current minimum mesh size prevents the capture of some legal sized winter flounder. Some mobile gear harvesters feel that a smaller diamond mesh may improve their catches of winter flounder.

## FISHERIES DATA

In this section, we present data on the size and age composition of winter flounder in the 4T commercial fishery. 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 with similar sampling requirements. In general, the minimum sample of winter flounder for length frequencies is 200-250 individuals. We determine the landed number of winter flounder in the year’s commercial fishery 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 3 summarizes the number of samples, fish measured and the landings associated with each gear type since 1982.

As our analyses progressed, we wanted to extend population modeling to the 1970s. However, commercial sampling in that decade was limited and 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). Two years (1979 & 1981) had no samples. We estimated the length composition in each year of the 1970s, including 1980, by combining samples in neighbouring years.

The commercial catch-at-length of 4T winter flounder is presented in Figure 6. 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 (Figure 7). Winter flounder <25 cm comprised less than 10% in most years up to 1990. 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, Figure 7 (upper graph) indicates that the proportion of <25 cm winter flounder in the total catch appears to be increasing since the late 1990s. 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. In the 2000s, maximum size has varied between 36 and 42 cm. This decline is visible in the 95$^{th}$ percentile of fish lengths (Figure 7). Modal length has not changed notably over time, ranging between 25 and 30 cm.

The commercial catch-at-length was converted to catch-at-age using age-length keys established from an annual ecosystem trawl survey (details in following section), as no age determinations were available from the sampling of commercial catches. Age determinations were available from surveys in three time periods: (A) 1975 and 1977-1982; (B) 1990-1993 and 1997; (C) 2004-2007. We combined age-length keys for years within each time block and estimated the catch-at-age in the following way: 1973-1982 catch-at-age was estimated from age-length keys in block A; 1990-1997 catch-at-age was estimated from block B; 2004-2011 catch-at-age was estimated from block C. To estimate the catch-at-age between periods (i.e. 1983-1989 and 1998-2003) we merged age-length keys from blocks A and B and blocks B and C.

The commercial catch-at-age for 4T winter flounder (Table 4, Figure 8) ranges mainly between 3 and 12 years of age. Catches of winter flounder aged 15 years or more were very small in all years during the 1970s-1990s, and absent during the 2000s. Six-year-olds have formed the modal age throughout the time series.

# SURVEY DATA

## ECOSYSTEM TRAWL SURVEY

Abundance indices and the population structure of 4T winter flounder have been estimated through an annual trawl survey conducted every September since 1971. The survey is conducted using a stratified random design with the 4T survey area divided into depth-related strata. The survey area was extended inshore in 1984 by the addition of three strata (401-403, Figure 9). As a result, we use two standardized series of indices: one that includes the initial 24 strata (years 1971-2011) and the other that includes the three added inshore strata (1984-2011).

The survey has been conducted with standardized gear, fishing methods and sampling procedures (Hurlbut and Clay 1990). Whenever it has been necessary to change the research vessel, experimental fishing has been conducted with the two vessels fishing side-by-side (Benoît 2006; Benoît and Swain 2003). These experiments have established the relative efficiency of gear/vessels and have made it possible to adjust catch rates when required. Four research vessels and two survey trawls have been used since 1971. The *E.E. Prince* fishing the Yankee 36 trawl was used from 1971-1984, replaced by the *Lady Hammond* fishing the Western IIa trawl. The Western IIa trawl has been used since 1984. In 1992, the Canadian Coast Guard vessel *Alfred Needler* was used for the first time in this survey, subsequently replaced over two years in 2004 and 2005 by the CCG *Teleost*. In comparative fishing experiments, no significant differences in winter flounder catch rates were found between vessels used since the *Lady Hammond*; however, catches of the *E.E. Prince* required an adjustment to match the fishing efficiency of *Lady Hammond* (Benoît and Swain 2003). In 2003, mechanical failure of the *Alfred Needler* resulted in an uncalibrated vessel being used for that survey. The length-frequency distribution of winter flounder in 2003 was irregular compared to surveys before and after (DFO 2005) and, for this reason, the 2003 survey has been removed from the data series.

The catch rates of winter flounder in this survey were highest before the mid-1980s for both numbers and weight of winter flounder caught (Figure 10). The mean number of winter flounder has tended to fluctuate near the long-term mean catch without a clear trend since the late 1980s. However, the mean weight of catches has declined since the late 1980s. The lowest weight per tow (1.9 kg) was recorded in the 2011 survey. The long-term mean catch has been 9.1 kg per tow; catch levels have been below that level in most of the past 20 years. The lack of a clear trend in the stock abundance index over the past two decades, while biomass declined, is indicative of important changes in the size composition of the stock.

Annual winter flounder length frequencies from the survey (Figure 11) typically fail to show distinct length modes that would signal the presence of strong or weak cohorts. More typically, the size distribution may be unimodal or dome shaped. This may be a result of the type of gear used in this survey which may under-represent small fish or it may be due to a lack of inshore survey coverage. Figure 11 shows, however, that winter flounder at lengths <20 cm were uncommon in the surveys of the 1970s, but increasingly dominated catches in the 1990s and 2000s. The decadal shift of winter flounder to smaller size is illustrated in Figure 12; it shows that mean length and the upper and lower quantiles of winter flounder length have declined progressively over time.

We converted the estimated survey population-at-length to a population-at-age using the same procedure outlined in the section on commercial fishery data. Table 5 shows in shaded blocks the years when age determination was conducted on winter flounder. For each of these years, the population-at-age was determined from the age-length key from the same survey. For all other years, age-length keys were combined and applied in the same way as used for commercial data. Modal age in the estimated survey population has decreased over time, as the population shifted to smaller size (Figure 13). Until 1983, modal age tended to centre around 6 years-of-age, then age-5 until 1994, followed by age-4.

This survey index was tested for its ability to track year-classes over time. We correlated the abundance of ages 2 to 14 with their abundance in the same cohort one to five years later. Only one age group (age-12) correlated with its abundance one year later (R=0.34; n=38, P=0.04); six cohorts correlated significantly with abundance two years later (R=0.34-0.61; n=37; $P<0.05$). No other correlations were detected at lags of three years or more.

We estimated total mortality (*Z*) of age 7+ winter flounder, considered to be fully recruited to the survey gear, using the survey population-at-age data and the method described by Sinclair (2001). The method calculates *Z* as the slope of log-transformed catch in relatively short time periods, accounting for variation in year-class abundance. The analytical model was the following:

$$\ln\left(A_{ij}\right) = \beta_0 + \beta_1 \mathrm{I} + \beta_2 J + \varepsilon$$

where $A_{ij}$ is the survey index for age *i* and year-class *j*; $I$ is a continuous variable indicating the age; *J* is a design matrix year-class, which is treated as a categorical variable. The parameter $\beta_1$ is the slope of the catch curve representing *Z*, standardized for year-class abundance. We calculated *Z* for winter flounder beginning at an age that was dominant in survey catches over most years. *Z* was calculated over ages 5-15 in a moving window of 5-year time blocks (beginning with 1971-1975; ending with 2007-2011). Zero catches, occurring at ages 14 and 15, were converted to half of the long term average catch of each age class before transforming to the natural logarithm.

The analyses provided significant estimates of total mortality for all time periods, except the 1972-1976 period. $Z$ for winter flounder (ages 7+) was at its lowest level in the first time period (1971-1975 at 0.41), but increased rapidly to values greater than 1.0 throughout the 1970s and 1980s, with the exception of the 1977-1981 period when it was estimated at 0.66. $Z$ has been below 1.0 through most of the 1990s and was estimated at 0.61 in the 1998-2002 period (Figure 14). In the 2000s, $Z$ appears to follow an increasing trend, with the most recent estimate for the period 2007-2011 at 1.1. 95% confidence limits varied between ±0.20 and 0.36 in the 1970s and 1980s and between ±0.14 and 0.26 since then.

We evaluated trends in relative fishing mortality ($F_{rel}$) by computing the ratio of landings and estimated survey population size. Assuming that the size composition of commercial removals and the winter flounder population are sampled are sampled adequately by port sampling and by the annual survey, Sinclair (1998) proposed that their ratio (Relative $F$) is proportional to fishing mortality obtained through population modeling. Relative $F$ was calculated for two winter flounder size groupings, <25 cm and 25 cm+. The 25 cm+ size range was chosen because it is the current legal minimum size. Fishing mortality appears to have been concentrated on winter flounder 25 cm+ since the late 1970s. $F_{rel}$ on 25 cm+ winter flounder increased over time to its highest levels from the late 1980s to the end of the 1990s, then declined (Figure 15). The 2011 catch level, combined with a low abundance index in the survey, resulted in an upturn in $F_{rel}$ for the last year.

## LOCAL CHANGES IN WINTER FLOUNDER ABUNDANCE

Winter flounder catches in the annual ecosystem survey of 4T reflect their coastal distribution (Figure 16). In these surveys, winter flounder are commonly found at 30 m depth and less, at the edge of the survey coverage. The distribution of winter flounder may not be continuous over its coastal range, giving further support to the notion that southern Gulf winter flounder comprise several stock units. For example, survey catches suggest that winter flounder on the Magdalen Islands are separate from concentrations found on Prince Edward Island and Cape Breton. However, some apparent discontinuities can be caused by low sampling due to depth, bottom type or other factors. There is no clear evidence to separate winter flounder off northern New Brunswick from concentrations in Chaleur Bay from catch data. As a result, it may be misleading to infer stock units on the basis of the observed distribution alone.

As in previous assessments, we presented survey indices for stratum groupings to illustrate abundance trends in different 4T sectors. These indices are not necessarily indicative of local stock trends for the reasons stated above. Chaleur Bay is an area where abundance indices fluctuate widely and without a clear trend, although the two largest mean catches since 2005 were made there (Figure 17). The two strata that compose this area include both shallow and deep areas, so the random selection of fishing locations may contribute to this variability. The Magdalen Islands are represented by two strata, and in this area, winter flounder catches were most abundant in the 1970s and early 1980s. Abundance appears to have been weak throughout the 1990s, but higher in the 2000-2006 period. Catches since 2006 have tended to decline, with the exception of the 2010 survey (Figure 17). Catches in the Miramichi area (strata 420 and 421) were low in the 1970s, reaching highs in 1983 and 1990-1993. Catches in this area appear to be in a gradual decline, despite low harvests in the local fishery. A similar lack of recovery, despite low harvests in recent years, is evident in survey indices for eastern PEI. In this area, the survey catches were highest in the mid-1970s to early 1980s. Due to the scale of the graph in Figure 17, it may be difficult to discern, but winter flounder abundance off eastern PEI has been in decline since 1995, reaching its lowest level in the 2011 survey.

## BIOLOGICAL CHARACTERISTICS OF 4T WINTER FLOUNDER

Swain et al. (2011b) examined the interannual variation in body condition for 29 fish species in the southern Gulf ecosystem survey. There was no evidence of an effect of stock biomass on winter flounder condition, but a significant negative effect of temperature. Winter flounder and a majority of other marine fishes in the southern Gulf experienced lower condition factors in the mid-1990s. Model estimates of an index of condition suggest that the interannual variation in winter flounder condition has varied 6% between periods of high and low condition, a moderate level of variation compared to other fish species in their analysis.

The age of winter flounder has been determined by reading their sagittal otoliths. Readings are made on whole otoliths under a dissecting scope 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. Andrews 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) that resulted in large differences in age interpretations between otolith readers, casting doubt on the validity of 4T winter flounder age determinations. The differences in interpretation of readers were resolved subsequently and age reading was resumed in 2004. Winter flounder otoliths are collected yearly from the September ecosystem survey, but are not read regularly.

Winter flounder growth was approximated from observed annual length-at-age data, fitting a von Bertalanffy growth function to male and female age-length keys. Across all ages, the stratified mean length and the estimated lengths from the growth function indicate that the size at age has declined over time (Table 6, Figure 18). We used the observed length frequencies in surveys, combined with the aggregated age-length keys for years without age determination, to estimate the annual age-specific size composition. Using annual survey length-weight relationships, we then calculated the annual survey mean weight of winter flounder. Once again, we found a downward trend in the mean weights at age, shown in Figure 18 for 8-year-old winter flounder.

The maturity state of winter flounder is determined yearly in the September survey by visual examination of gonads. The coding systems for describing maturity stages, described in Hurlbut and Clay (1980), changed in 1982 along with a change in the administration of the survey. The classification system in effect after 1982 can be summarized in three groupings: immature fish (stage 1); ripening, spawning and spent fish (stages 2-6) and a non-ripe stage (8). Until 1982, stage-8 fish were described as “recovering or resting” and were interpreted differently. In previous winter flounder assessments, attention was drawn to the difficulty in interpreting stage-8 and the lack of correspondence between winter flounder sampled in spring and in September surveys (Morin and Forest-Gallant 1997). Swain (2011a) found that for the same survey, stage-8 Atlantic cod were misclassified as immature (stage-1) after 1982. Figure 19 shows that up to 1982, stage-8 winter flounder were distinct from stage-1 fish. There was apparent confusion between stage-1 and stage-8 winter flounder during the 1990s. In the 2000s, we feel that incorrect application of a classification system in effect for American plaice may have led to confounding some immature winter flounder with the previous classification of ripening fish (Figure 19). We have proceeded with the maturity ogives developed for the 1975-1982 period, assuming that stage-8 fish will recover and spawn the following spring.

# POPULATION MODEL

Population modelling was undertaken to improve understanding of the causes and implications of the changes in size structure observed in winter flounder in the southern Gulf in recent decades. Winter flounder throughout the 4T area were modelled as a single population because the data did not support any finer population structure.

## METHODS

The model was a Virtual Population Analysis (VPA) implemented in AD Model Builder (Fournier t al. 2011). The model included a plus group (14+ years) and was fit using the F-ratio method, as described by Gavaris (1999). The F-ratio (in this case, the ratio between F's of 14+ and 13-year-old fish in year t) was set to 1 in all years. Data inputs were the commercial catch at ages 3-14+ years in 1973 – 2011 and abundance indices for ages 3 – 11 years in 1976 – 2002 and 2004 – 2011 from the annual September Research Vessel (RV) survey. Abundance indices were not available for 2003 because the survey was incomplete and conducted by an uncalibrated vessel. Abundance indices were at the scale of "trawlable abundance".

Variation in the instantaneous rate of natural mortality (*M*) was modelled as a random walk, with separate trends estimated for ages 3-8 and 9+ years. These time trends in *M* were modelled as follows:

$M_{j,y} = M\text{init}_j$ if y=1973
$M_{j,y} = M_{j,y}\text{-1} * \exp(M\text{dev}_{j,y})$ if y>1973

where *y* indexes year and *j* indexes age class (3-8 or 9+), *M*dev is normally distributed with mean 0 and standard deviation *sdev*, and $M\text{init}_j$ is a parameter for *M* of age-class *j* in 1973. The value of *sdev* affects the degree to which the random walk is constrained. Based on previous experience (Swain 2012), values of 0.1 were used for both age classes. The groupings chosen for the separate trends in *M* were those which provided the best fit to the RV indices in terms of residual patterns. The other two-trend groupings tried were 2-4, 5+; 3-5, 6+; 3-6, 7+, and 3-7, 8+. A three-trend model (3-5, 6-8 and 9+) also provided a good fit, but we chose the more parsimonious 2-trend model for presentation here.

Parameters to be estimated were abundance at ages 4-14+ at the start of 2012, log catchability at age ($q_a$) to the RV survey at ages 3-11 and the various *M* parameters. Ln($q_a$) was constrained to be within the range -5.0 to -0.4 (corresponding to $q_a$=0.00674 to 0.670). Given incomplete survey coverage of the stock area and the fishing efficiency of the gear, it was considered very improbable that $q_a$ could exceed 0.6-0.7.

Parameters were estimated by minimizing an objective function with the following components:

1. residuals between observed and predicted abundance indices:

$$f_1 = 0.5 \cdot \sum_{a,y} (\log(I_{a,y} / (q_a N_{a,y})) / s_{a,y})^2 + \sum_{a,y} \log(s_{a,y})$$

where

$$s_{a,y} = (\log(1 + cv_{a,y}^2))^{0.5}$$

where *I* is an abundance index, *N* is estimated population abundance, *q* is catchability, *cv* is the coefficient of variation for the index, *a* indexes age, and *y* indexes year. cv was set to a constant value of 0.3, and thus had no effect on the minimization (except for its effect on the weight attributed to this component of the objective function).

2. random-walk deviates

$$f_2 = 0.5 \cdot (\sum_{j,y} M\text{dev}_{j,y}^2) / s\text{dev}^2$$

This component penalizes large deviations in *M*.

3. prior value for initial *M*

$$f_3 = 0.5\left( \frac{M\text{init}_j - M\text{prior}_j}{0.05} \right)^2 + \log(0.05)$$

where the prior for *M* in 1976 was set at 0.5 for ages 3-8 and 0.3 for ages 9+.

Posterior distributions for quantities of interest were approximated using the Markov chain Monte Carlo method (MCMC); 100,000 MCMC simulations were made, with every 20th simulation saved.

## RESULTS

Residuals between the abundance indices and model predictions included a cohort effect for the 1971 year class (a tendency to overestimate its strength relative to survey observations) and a number of year effects, but residual patterns were generally not severe (Figure 20). The survey indices at age were somewhat noisy, particularly for younger ages in the 1990s and 2000s and for older ages in the 1970s (Figure 21). Nonetheless, the model estimates matched the main trends in the q-corrected survey data for age groups 3-5, 6-8 and 9-11. Catchability was not estimated for ages 12-14+. Using the estimated age-11 q to adjust the survey indices for these ages results in model estimates that are considerably greater than the corresponding survey estimates in the 2000s. However, the contribution of these ages to population abundance and spawning stock biomass (SSB) is negligible.

There was no retrospective pattern in estimated abundance at ages 5-11 yr (Figure 22 and 23). However, compared to estimates with additional data, the 2002 year-class was strongly overestimated at ages 3 and 4 in analyses ending in 2006, as was the 2006 year-class in analyses ending in 2009 and 2010. This retrospective pattern in the strength of the 2006 year-class resulted in a retrospective pattern in estimated SSB in 2009 and 2010.

Estimated catchability of winter flounder to the September RV survey was dome shaped, with maximum catchability at ages 8 and 9 (Figure 24). The estimates for ages 3 and 8-9 were at the lower and upper bounds permitted for *q*, respectively.

Estimated abundance of age-3 recruits and the 3-5 yr age group increased sharply in the late 1980s, with peaks in abundance in the early 1990s and the late 1990s and early 2000s (Figure 25 and 26). In contrast, abundance of flounder aged 6-11 years decreased sharply in the early to mid 1980s (Figure 26). A sharp peak in model abundance of ages 12+ occurred in the mid 2000s (Figure 26), but this is not reflected in the survey catches (Figure 21); these ages were not calibrated to the survey index and form a negligible portion of the population. Although peaks in estimated SSB occurred at roughly decadal intervals over the 1973-2011 period, there was a general decline in SSB over the time series (Figure 25). Moreover, the composition of this SSB has changed dramatically over this time period, with SSB dominated by older (6+) fish in the 1970s and early 1980s and by young (3-5 year old) fish since then (Figure 26). The decadal peaks in SSB were the result of changes in the biomass of mature 3-5 year olds, not older fish.

Estimates of fishing mortality (*F*) show sharp interannual fluctuations which likely reflect errors in the catch (Figure 27). Nonetheless, some clear trends are evident. *F* for ages 3-5, though estimated to be very low in all periods, declined sharply from the mid 1970s to values very close to 0 in the early 2000s. For ages 6-8 and 9-11, estimated *F* increased starting in the mid 1980s, reaching a relatively high level in the late 1980s and early 1990s, and then declined to a low level in the 2000s. For ages 12+, estimates of *F* fluctuated widely but have been very low throughout the 2000s.

Estimated *M* of ages 3-8 increased from the early 1970s to the early 1990s and has remained high (Figure 28). Estimated M of this age group has been above 1 since the early 1990s. Estimated M of ages 9+ rose to levels above 1.5 in the mid to late 1970s and then declined, reaching minimum levels near 0.2 in the early 2000s. Estimated M of these older fish has since increased, reaching values above 0.6 in recent years.

## DISCUSSION

Except for the very low 1984 value (which presumably reflects an error in the landing statistics), reported landings fluctuated at about the same level from the early 1970s to the early 1990s (Figure 2). During this period of roughly constant landings, estimated abundance of older flounder (ages 6-11) declined sharply in the early 1980s and then stabilized at a low level. The model cannot attribute this decline to the reported landings. *F* is estimated to be low in all periods. For the older flounder which declined in abundance, especially the 9-11 age group, *F* is estimated to be particularly low in the 1970s and early 1980s (during the decline) and relatively high in the late 1980s and early 1990s (when abundance stabilized at a low level). Thus, the model attributes this decline to high natural mortality, particularly for the older 9+ fish. It is difficult to identify a cause of high natural mortality of large winter flounder in the 1970s and early 1980s. Grey seals, an important predator of winter flounder (Hammill 2011), were at a relatively low level of abundance at that time (Hammill and Stenson 2011). Likewise, the abundance of large cod, the dominant piscivorous fish in the southern Gulf ecosystem, was relatively low in the mid 1970s, when estimated 9+ *M* was highest, compared to the late 1970s and early 1980s, when estimated 9+ *M* was lower (Swain et al. 2009). Adult white hake, an important piscivore in inshore areas of the southern Gulf, was also at lower abundance in the mid 1970s than in the 1980s (Swain et al. 2012).

It is possible that much of this high mortality is due to under-reporting of the landings, though this would imply a very high degree of under-reporting. Prior to 1996 there was no TAC for winter flounder; consequently, it is possible that catch monitoring was less rigorous in the past, particularly in the 1970s and 1980s when this species was of minor commercial importance. Furthermore, the fishery for winter flounder was primarily a bait fishery, with the catch often retained for personal use or sold privately to other fish harvesters; much of this catch may not have been recorded prior to the onset of dockside monitoring in the mid 1990s. Finally, the bait fishery for winter flounder may have been particularly intense in the mid 1970s when herring, another important source of bait for the lobster fishery, had collapsed in the southern Gulf.

Natural mortality appeared to dominate the mortality of all ages of winter flounder throughout the time series. While it is possible that unreported catch contributed to the estimates of natural mortality, particularly for older flounder early in the time series, predation by grey seals is likely to be an important component of this mortality.  Winter flounder are an important prey of grey seals and are concentrated in areas heavily used by foraging grey seals in summer (Harvey et al. 2011). Grey seal abundance increased to high levels in the southern Gulf in the 1990s and 2000s, and is continuing to increase (Hammill and Stenson 2011). Estimated *M* of ages 3-8 was at a high level throughout this period, and estimated *M* of older winter flounder has been increasing throughout the 2000s. Given the high and increasing abundance of grey seals, *M* of winter flounder can be expected to remain high or increase further.

Catchability of very young winter flounder (in particular ages 3 and 4) to the September survey was estimated to be very low. This is likely to be partly attributable to the inshore distribution of winter flounder, with a particularly high proportion of the smallest and youngest fish occurring inshore of the survey area. However, this low catchability implies a very high abundance of young winter flounder. Further work is needed to determine whether this high abundance is plausible given the amount of suitable habitat available for winter flounder in the southern Gulf.

Despite the decline in the abundance of large winter flounder in the spawning stock, estimated abundance of age-3 recruits increased sharply in the early 1990s and remained high throughout the 1990s and most of the 2000s. This suggests improved survival of very small winter flounder. It is possible that this increase has been overestimated, if 3-year olds have become more available to the survey due to an expansion or shift of their distribution into greater depths as their abundance increased. However, increases in the abundance of small fish in the 1990s and 2000s have occurred throughout the marine fish community in the southern Gulf (Benoît and Swain 2008). This increase has been attributed in part to a decline in the abundance of large piscivorous demersal fish (Benoît and Swain 2008).

# OTHER SURVEY INDICES

## NORTHUMBERLAND STRAIT SURVEY

There are few sustained surveys of inshore areas in the southern Gulf of St. Lawrence, habitat that is critical to winter flounder and that is not fully covered in the annual ecosystem survey. We reported in the last assessment on a trawl survey of Northumberland Strait that extends to depths of less than 10 m (Morin et al. 2002). This survey was established in 2000 to evaluate American lobster abundance and recruitment (Hanson 2001). It was conducted yearly until 2009 in July-August aboard the Canadian Coast Guard vessel *Opilio* using standardized gear and sampling procedures. The sampling gear was a Number 286 otter trawl with rockhopper footgear, used in tows of 15-minute duration at a vessel speed of 2.5 knots.

The survey area has been divided into nine strata (Figure 29). The number of valid tows in this survey has varied between 143 and 255, a more intensive sampling relative to the annual ecosystem survey. However, coverage has been variable: strata 1-5 were sampled yearly; stratum 6 began to be sampled in 2003, but was inadequately covered in 2004; the remaining strata were not fully sampled every year. As a result, our analysis centred on strata 1-5 in all years and strata 1-6 in 2003 and 2005-2009. Sampling in strata 1-5 has varied between 139 and 190 valid tows. Note, however, that stratum 1, an important area for winter flounder abundance, was incompletely covered in the 2002 and 2005 surveys.

Winter flounder were distributed throughout Northumberland Strait, but were most abundant in the northwestern part of the strait across all depths and in the shallow waters east of Pictou (Figure 29).

The previous analysis of data on winter flounder from this survey used a geostatistical approach to estimate the abundance index (i.e. kriging; Morin et al. 2002). Analyses of winter flounder abundance by kriging or by stratified averaging have been shown to produce very similar results (T. Surette, DFO Moncton, pers. comm.).

Northumberland Strait is a dynamic area with strong tidal currents and large seasonal fluctuations in temperature and salinities. This may account for the large fluctuations in abundance and biomass indices of winter flounder in the Northumberland Strait survey (Figure 30). Twofold fluctuations in abundance occurred between at least three periods (between 2003 & 2004, 2006 & 2007, 2008 & 2009). The most notable year effect occurred in 2006, when winter flounder appeared in increased abundance and biomass throughout Northumberland Strait. This increase could not be attributed to an increase due to a recruiting size class (Figure 31). In general, there was no apparent trend in abundance, biomass or length composition of winter flounder in this survey over the 10-year series.

### SENTINEL SURVEY

The sentinel program was initiated in 1994 to evaluate the abundance of Atlantic cod during a moratorium on fishing that species initiated in 1993. The survey design up to 2002 was based on blocked areas that were identified by fish harvesters as important areas to monitor for cod recovery. In an analysis of mobile gear sentinel program, Morin et al. (2002) found that winter flounder appeared in relatively few sets, that only a small number of sentinel vessels regularly captured winter flounder, and that the survey did not cover areas of highest winter flounder abundance. It was difficult to resolve conflicting results that depended on the vessel, gear and mesh size used.

Following an internal review in 2002 (Gillis 2002), DFO modified the mobile gear sentinel program, adopting a stratified random sampling design. Since 2003, the revised mobile gear sentinel program has used four commercial trawlers each year, deployed in the same sampling design as is used in the annual ecosystem survey (Figure 9). The sampling protocol is presented by Savoie (2011). All vessels fish with a standard 300 Star Balloon otter trawl, fitted with a 40-mm liner in the codend. Tow speed and duration are 2.5 knots and 30 minutes. The vessels overlap in their coverage in order to compare and calibrate their catch rates. Eight vessels have participated in the survey since 2003 (Savoie 2011). In this report, we use the unadjusted catch rates.

The distribution of winter flounder in the mobile gear sentinel program is comparable to that of the annual ecosystem survey (Figures 32 and 16). Sentinel catch rates for abundance and biomass follow a common trend that indicates a decline from 2003 to 2006, followed by a consistently low level of stock abundance and biomass from 2006 to 2011 (Figure 33). The annual ecosystem survey also recorded low biomass since 2002, but with fluctuations in abundance that were not observed in the sentinel program. The length frequencies of winter flounder in the sentinel program were uni-modal and not any more inclined than the ecosystem survey or the Northumberland Strait survey to reflect incoming recruitment modes (Figure 34). Length frequencies in the sentinel program have not shown any evident shift towards smaller size since 2003, as was shown for the longer survey time series.

## IMPACTS OF WINTER FLOUNDER FISHING

As for most exploited fishes, conflicts may arise when different targeted species are found in the same area or are exploited by different gear types. For a coastal species like winter flounder, fishing in the southern Gulf can impact several important inshore species, including lobster, herring and other groundfish species like cod and white hake. In some areas, the potential for conflict is resolved by restricting winter flounder fishing to specific depths, areas or months. While directed fishing for winter flounder may affect other species, the reverse can also happen when winter flounder is caught incidentally by other fisheries.

Some aspects of the life history of winter flounder can lead to impacts on other species. Winter flounder concentrate on the egg beds of spawning capelin and herring. This is well known in the southern Gulf and a specialized fishery using tangle nets has developed to harvest winter flounder feeding on herring spawning beds each spring and fall. Tangle nets are not believed to affect the viability of herring roe, a possibility if they caused eggs to become crushed or detached from the bottom. To our knowledge, the issue has not been studied. During herring spawning, trawling for winter flounder on herring egg beds is an activity that has been vigorously opposed by herring harvesters in the past.

Table 7 lists the landed catch of each species in the directed 4T winter flounder fishery since 1985. As previously stated, by-catch limits on cod and other groundfish came into effect in 1994. The winter flounder fishery was historically associated with white hake, cod and plaice fishing. The 4T white hake stock was closed to commercial fishing in 1995; before 1994, white hake was a dominant by-catch in winter flounder-directed fisheries, reaching close to 20% of the landed winter flounder catch in some years (Table 7). Cod by-catch was also important up to the 1993 moratorium when it dropped in landing statistics. American plaice has been landed in winter flounder-directed fishing at a rate that rarely exceeds about 7% of winter flounder landings. Yellowtail flounder and windowpane have grown in importance in the winter flounder fishery, mainly due to the concentration on bait fisheries around the Magdalen Islands.

Observers aboard fishing vessels record the species composition of catches before unwanted bycatch species are returned to the water. Observer coverage of the winter flounder-directed fishery began in 1991 and low catches since 2006 have resulted in fewer than five vessel trips observed per year (none in 2008). As a result, we aggregated the observer data since 2006.

The species composition of winter flounder-directed catches obtained by observers provides a different perspective on the potential impact of the fishery from that obtained by the landed catch. Atlantic cod was the dominant bycatch species in most years until 2000 (Table 8), occurring in a ratio of more than 1:10 of the winter flounder catch. In 1991 and 1998, the cod catch was over 60% of the winter flounder catch according to observers. American plaice and yellowtail flounder were the main flatfish bycatch species; together, these two species were over 10% of the winter flounder catch in most years. American lobster was recorded as bycatch in the winter flounder-directed catches, usually at about 1% of the winter flounder catch. Lobster catches were exceptionally high in 1995, totalling about 1.4 tonnes for over 25 tonnes of winter flounder (approx. 5%). Lobster catches (always recorded by observers as returned to the sea) appeared in all gear types that were observed, including trawls, seines and gill nets.

## IMPACTS OF FISHING ACTIVITIES FOR OTHER SPECIES ON WINTER FLOUNDER

Winter flounder occurs as bycatch in other groundfish fisheries of the southern Gulf, including the species mentioned above. In the white hake-directed fisheries before the closure of the hake fishery in 1995, winter flounder landings were over 100 tonnes yearly (data since 1985), reaching 316 tonnes in 1991. Winter flounder catches in the cod-directed fishery reached over 160 tonnes before the cod moratorium in 1993. Observers on boats directing for 4T cod since 1991 estimate winter flounder bycatch as less than 1% of cod catches. Winter flounder landings from plaice-directed fishing reached 170 and 259 tonnes in the 1986 and 1987 fisheries, respectively; however, in all other years since 1985 catches of winter flounder have been well below 100 tonnes and less than 10 tonnes yearly through most of the 2000s. Observer record winter flounder bycatch as about 1.5% of plaice-directed catches in 4T. The only significant recent source of winter flounder bycatch is the yellowtail flounder fishery. This fishery has produced winter flounder bycatch of over 100 tonnes in several years since 2000. Observers estimate winter flounder bycatch as 47% of the yellowtail-directed catch.

Winter flounder may also be captured by sport fishers or in other small, unregulated fisheries where bycatch may not be consistently recorded. An example of the latter is the smelt fishery in the Miramichi River estuary that was described by Bradford et al. (1997). In the open water smelt fisheries in 1994 and 1995, from October 15 to ice formation in December, they estimated the magnitude of winter flounder bycatch at 3 or 4 tonnes. Current regulations delay the onset of this fishery to early November, mainly to avoid bycatch of striped bass (DFO 2007). The smelt fishery also extends into the winter period with gear set under the ice cover, presumably resulting in further bycatch of winter flounder that has not been quantified with any precision. Although the Mirimichi watershed is the most important area of smelt fishing, there are 15 other zones along the New Brunswick coastline identified with similar smelt fisheries (DFO 2007).

## ECOSYSTEM COMPONENTS MODIFYING SPECIES ABUNDANCE AND POPULATION DYNAMICS

There is limited information on the precise role that winter flounder plays in trophic dynamics of the southern Gulf of St. Lawrence. Savenkoff et al. (2004) described inputs to a multispecies mass-balance model for the southern Gulf ecosystem. Winter flounder were included in a functional grouping that included witch flounder, yellowtail flounder and windowpane. Diet studies of winter flounder and yellowtail (unpublished data) were used to characterise the feeding of the functional flounder group. Flounder diets were composed of 11 trophic groups, dominated by echinoderms and molluscs.

Savenkoff et al. (2007) used the same mass-balance models to compare ecosystem dynamics in the 1980s and 1990s, before and after the collapse of southern Gulf groundfish stocks. Overfishing removed large-bodied demersal predators, leaving seals and cetacea as top predators of many fish species by the mid-1990s. Large-bodied demersal fishes declined in biomass between the two periods, while pelagic species increased. The functional flounder group declined slightly. The model of Savenkoff et al. (2007) estimated no change in primary production and a slight increase in secondary production between the two time periods. In the 1980s, predation on the functional flounder group was composed of 10% fishing, 25% seals and the remainder due to large cod and other predators. By the mid-1990s, the mass-balance models estimated seal predation as 49% of flounder mortality, with fishing contributing 5%.

Winter flounder has been observed in grey seal diets in a few studies in the Gulf of St. Lawrence. Consumption of winter flounder by grey seals in the southern Gulf was estimated at 6,600 tons in 1975, peaking to 19,200t in 1996, and tapering off to 9,900 t in 2001 (Hammill and Stenson 2002). A study in the northern and southern Gulf found winter flounder to be an important part of grey seal diet in late summer (Hammill et al. 2007). Another study found that winter flounder was an important part of grey seal diet in the Northumberland Strait, Miramichi River area and the west side of Cape Breton Island (Hammill 2011). Mean length of winter flounder consumed in this study was 18.9 cm (SD=12.7, N=721).

Seabirds may also be potential predators of winter flounder. In the southern Gulf of St. Lawrence, most seabirds are found inshore (Cairns et al. 1991). Major inshore breeding species include the great cormorant (*Phalacrocorax carbo*) and the double-crested cormorant (*P. auritus*). Cairns et al. (1991) reported that flounder (mostly unidentified to species) were prominent in cormorant diets, with winter flounder contributing up to 35% of the diet of the double-crested cormorant in some areas. A more recent compilation of cormorant diet information (Cairns 1998) provides less direct evidence of predation on winter flounder in the southern Gulf, but with unspecified flounder prominent in the diets of great cormorants on the Magdalen Islands. Cairns (1998) underlines the preliminary nature of these data, due to biases originating from variable digestion rates, prey identification and inadequate sampling coverage. Savenkoff et al. (2004) provided estimates of the number of breeding great cormorants in the southern Gulf at approximately 5,000 and of double-crested cormorants at about 78,000. The population of non-breeders and nestlings of the two species were estimated at an additional 3,470 and 54,600, respectively.

## SOURCES OF UNCERTAINTY

The annual surveys of 4T do not sample the full distribution of winter flounder. Small, young winter flounder are found shoreward of the area sampled by the survey. Catch rate analyses of the annual survey assume 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 a constant availability to the survey would not be appropriate.

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 4T. Some degree of mixing may be expected due to the pelagic larval stage and straying of adult winter flounder.

Uncertainty in landing statistics, including unreported catches and possibly discarding at sea, may mean that some high estimates of *M*, particularly in the period before the 1990s, may be due to unaccounted fishing rather than natural mortality. Since the early 1990s, improvements were made to logbooks and several management measures were introduced (e.g. at-sea observers, dockside monitors, small fish protocols), improving landing statistics for this resource.

Several biological characteristics of 4T winter flounder are not fully known. This assessment presents data on the age composition of commercial and survey catch-at-age; however, age determinations were only available in 16 of 40 years of survey data (2003 survey excluded). This was resolved by applying combined age-length keys to years without appropriate data. No age determinations have been made on winter flounder otoliths collected from commercial fisheries. More ageing information would improve estimates of the age composition and resulting estimates of mortality and growth.

A constant maturity schedule was assumed for winter flounder, based on 1975 to 1982 samples. Limited data sources since that period suggest that this may be an appropriate assumption; however, further validation is required.

Length-frequencies of winter flounder from the research survey do not signal incoming recruitment, nor do they track size modes that indicate year-class strength. Despite these weaknesses, the annual survey provides trends in stock abundance that extend over 40 years.

Catchability (*q*) was a model parameter, estimated for ages 3-11, which related survey catch-at-age to the estimated population-at-age. *q* was constrained to be estimated within a range of values. The model estimates of *q* for ages 3 and 8-9 years were at the lower and upper limits of their respective constraints. More research is required to determine whether the estimates of *q* are reasonable, particularly at younger ages, given the trawl used in the annual survey and the extent of winter flounder habitat covered by the survey. The estimates for young ages imply a high abundance of young winter flounder. Work is needed to determine whether these high abundance estimates are plausible given the area of suitable habitat for winter flounder in the southern Gulf.

## ASSESSMENT RESULTS

Nominal landings of 4T winter flounder have fluctuated widely in the past, averaging 1,481 tonnes since 1960. For most of the past two decades, landings have been well below the long-term average and in the last 10 years they have been consistently below 500 tonnes. The 1,000-tonne TAC that was imposed in 1996 was last reached in 1997. Fishing effort is low in most sectors of 4T due to several factors that include market conditions for winter flounder and high operating costs.

Two large scale surveys cover NAFO 4T and provide indices of abundance and biomass of winter flounder; however, neither survey covers the inshore habitat where the species is known to occur. Despite the low level of harvests, there is no evidence from groundfish surveys that the resource is rebounding anywhere in the southern Gulf. Length frequency data collected since 1971 indicate a progressive shift in their size distribution, with fewer and fewer large winter flounder and more and more winter flounder of small size. This shift towards smaller size is consistent with a generalized increase in the abundance of small-bodied fish species over the past 40 years in the southern Gulf, as large-bodied species decline.

This assessment also provides evidence that the size-at-age of southern Gulf winter flounder has declined over time. That the population is composed of increasingly smaller individuals and that they are growing more slowly, reaching smaller size and weight at each age, point to a loss of stock productivity.

An age structured population model for 4T winter flounder was presented for the first time in this assessment. This model describes the dynamics of the 4T winter flounder stock since 1973. The spawning stock biomass (SSB) has peaked at intervals over the 1973-2011 period, fuelled largely by young mature fish, but exhibits a strong downward trend over the past 20 years. Combined with a reduction in the SSB is a shift in the age composition of spawners from older (age-6+) fish to 3 to 5-year-old fish. Recruitment, quantified as the abundance of age-3 winter flounder, increased in the 1990s and reached a high in 2000. Recruitment has since declined, reaching a 25-year low in 2011. Fishing mortality (*F*) has been mainly concentrated on ages 6-11, reaching its highest level in the late 1980s and early 1990s, declining afterwards.

Natural mortality (*M*) appears as the driving factor in the dynamics of the winter flounder stock. *M* on ages 3-8 has increased up to the 1990s and has remained at a high level since then. *M* on age-9+ winter flounder reached extreme values >1.5 in the 1970s, possibly due to confounding with under-reported landings, declined to 0.2 in the early 2000s and has risen to 0.6 in recent years. Given the low level of harvests throughout the 2000s, grey seal predation is considered as a possible source of high *M* for most of the past two decades.

In view of high natural mortality and declines in growth rates of winter flounder, the prognosis for recovery of this stock is not good in the short term. Given the level of harvesting of winter flounder throughout most of NAFO 4T, it is unlikely that commercial harvesting at current levels will impact the resource significantly. However, the use of winter flounder for bait leaves the potential for misreporting and it will be necessary to ensure adequate monitoring of all removals.

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*Table 1. Yearly landings (tonnes) of winter flounder in NAFO Division 4T by major gear types. Gear codes: OTB=otter trawls, PTB=paired trawls, SNU=seines, GNS=gillnets, LLS=longlines.*

| YEAR | OTB | PTB | SNU | GNS | LLS | OTHER | TOTAL |
|---|---|---|---|---|---|---|---|
| 1960 | 730 | 0 | 137 | 0 | 17 | 16 | 900 |
| 1961 | 1043 | 0 | 452 | 1 | 2 | 98 | 1596 |
| 1962 | 1407 | 0 | 642 | 115 | 8 | 140 | 2312 |
| 1963 | 2324 | 0 | 697 | 66 | 15 | 46 | 3148 |
| 1964 | 2247 | 0 | 546 | 0 | 0 | 209 | 3002 |
| 1965 | 4026 | 0 | 217 | 12 | 89 | 68 | 4412 |
| 1966 | 2640 | 0 | 300 | 53 | 0 | 63 | 3056 |
| 1967 | 1870 | 0 | 464 | 58 | 33 | 19 | 2444 |
| 1968 | 424 | 0 | 107 | 16 | 2 | 1 | 550 |
| 1969 | 1263 | 0 | 51 | 0 | 12 | 368 | 1694 |
| 1970 | 1809 | 0 | 576 | 142 | 21 | 136 | 2684 |
| 1971 | 1769 | 0 | 572 | 79 | 23 | 378 | 2821 |
| 1972 | 1193 | 0 | 533 | 36 | 44 | 16 | 1822 |
| 1973 | 1806 | 0 | 390 | 29 | 42 | 33 | 2300 |
| 1974 | 1329 | 0 | 388 | 23 | 4 | 176 | 1920 |
| 1975 | 1577 | 0 | 254 | 35 | 3 | 141 | 2010 |
| 1976 | 2142 | 0 | 96 | 24 | 3 | 142 | 2407 |
| 1977 | 903 | 0 | 48 | 24 | 6 | 254 | 1235 |
| 1978 | 744 | 0 | 104 | 77 | 13 | 183 | 1121 |
| 1979 | 1280 | 0 | 52 | 64 | 10 | 179 | 1585 |
| 1980 | 1264 | 0 | 80 | 274 | 147 | 211 | 1976 |
| 1981 | 1605 | 0 | 30 | 215 | 16 | 75 | 1941 |
| 1982 | 1652 | 0 | 32 | 579 | 1 | 41 | 2305 |
| 1983 | 1413 | 0 | 131 | 231 | 7 | 17 | 1799 |
| 1984 | 43 | 0 | 32 | 13 | 4 | 57 | 149 |
| 1985 | 935 | 51 | 56 | 97 | 38 | 3 | 1180 |
| 1986 | 1167 | 80 | 243 | 538 | 6 | 10 | 2044 |
| 1987 | 824 | 62 | 307 | 526 | 85 | 7 | 1811 |
| 1988 | 783 | 0 | 280 | 321 | 20 | 10 | 1414 |
| 1989 | 1191 | 0 | 392 | 469 | 37 | 0 | 2089 |
| 1990 | 1171 | 0 | 274 | 588 | 32 | 12 | 2077 |
| 1991 | 1875 | 120 | 181 | 344 | 12 | 3 | 2535 |
| 1992 | 1242 | 235 | 140 | 350 | 3 | 3 | 1973 |
| 1993 | 774 | 29 | 65 | 460 | 2 | 28 | 1358 |
| 1994 | 737 | 0 | 28 | 408 | 2 | 5 | 1180 |
| 1995 | 388 | 3 | 9 | 262 | 0 | 0 | 662 |
| 1996 | 487 | 1 | 12 | 332 | 0 | 0 | 832 |
| 1997 | 542 | 10 | 63 | 514 | 0 | 0 | 1129 |
| 1998 | 313 | 13 | 7 | 258 | 48 | 7 | 646 |
| 1999 | 362 | 73 | 12 | 200 | 0 | 0 | 647 |
| 2000 | 299 | 22 | 114 | 142 | 0 | 0 | 577 |
| 2001 | 331 | 1 | 77 | 163 | 0 | 0 | 572 |
| 2002 | 307 | 10 | 56 | 67 | 0 | 0 | 440 |
| 2003 | 274 | 4 | 71 | 119 | 0 | 0 | 468 |
| 2004 | 177 | 15 | 85 | 105 | 0 | 0 | 382 |
| 2005 | 211 | 0 | 77 | 95 | 0 | 0 | 383 |
| 2006 | 85 | 0 | 89 | 69 | 0 | 3 | 246 |
| 2007 | 96 | 5 | 49 | 39 | 0 | 4 | 193 |
| 2008 | 128 | 0 | 29 | 36 | 0 | 4 | 197 |
| 2009 | 117 | 1 | 33 | 55 | 0 | 4 | 210 |
| 2010 | 170 | 0 | 57 | 68 | 0 | 6 | 301 |
| 2011 | 201 | 0 | 31 | 62 | 6 | 2 | 302 |
| MEAN | 1033 | 14 | 188 | 170 | 16 | 61 | 1481 |

*Table 2. The number of responses in the annual telephone opinion survey of active fish harvesters to questions relating the abundance of winter flounder in the current year relative to abundance in the previous year, to abundance in the 5 previous years, and to abundance in all previous years in their experience. Upper panel shows the number of responses; lower panel presents results expressed as percent.*

| | Previous year | | | Previous 5 years | | | All previous years | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Less | Same | More | Less | Same | More | Less | Same | More |
| 1995 | 11 | 11 | 16 | 18 | 12 | 9 | 23 | 8 | 6 |
| 1996 | 21 | 28 | 17 | 31 | 26 | 16 | 35 | 25 | 13 |
| 1997 | 10 | 18 | 19 | 18 | 14 | 13 | 19 | 15 | 11 |
| 1998 | 16 | 9 | 18 | 15 | 8 | 11 | 16 | 5 | 7 |
| 1999 | 3 | 7 | 9 | 6 | 10 | 6 | 7 | 12 | 4 |
| 2000 | 7 | 12 | 5 | 7 | 14 | 4 | 8 | 9 | 7 |
| 2001 | 4 | 7 | 4 | 6 | 6 | 3 | 8 | 5 | 3 |
| 2002 | 6 | 11 | 2 | 7 | 8 | 4 | 7 | 11 | 2 |
| 2003 | | | | | | | | | |
| 2004 | 6 | 14 | 3 | 8 | 9 | 6 | 10 | 12 | 4 |
| 2005 | 6 | 7 | 3 | 6 | 10 | 1 | 10 | 8 | 0 |
| 2006 | 8 | 14 | 1 | 13 | 10 | 1 | 15 | 9 | 0 |
| 2007 | 13 | 8 | 2 | 14 | 9 | 1 | 17 | 7 | 0 |
| 2008 | 4 | 7 | 5 | 5 | 7 | 3 | 6 | 6 | 4 |
| Percent | | | | | | | | | |
| 1995 | 29 | 29 | 42 | 46 | 31 | 23 | 62 | 22 | 16 |
| 1996 | 32 | 42 | 26 | 42 | 36 | 22 | 48 | 34 | 18 |
| 1997 | 21 | 38 | 40 | 40 | 31 | 29 | 42 | 33 | 24 |
| 1998 | 37 | 21 | 42 | 44 | 24 | 32 | 57 | 18 | 25 |
| 1999 | 16 | 37 | 47 | 27 | 45 | 27 | 30 | 52 | 17 |
| 2000 | 29 | 50 | 21 | 28 | 56 | 16 | 33 | 38 | 29 |
| 2001 | 27 | 47 | 27 | 40 | 40 | 20 | 50 | 31 | 19 |
| 2002 | 32 | 58 | 11 | 37 | 42 | 21 | 35 | 55 | 10 |
| 2003 | | | | | | | | | |
| 2004 | 26 | 61 | 13 | 35 | 39 | 26 | 38 | 46 | 15 |
| 2005 | 38 | 44 | 19 | 35 | 59 | 6 | 56 | 44 | 0 |
| 2006 | 35 | 61 | 4 | 54 | 42 | 4 | 63 | 38 | 0 |
| 2007 | 57 | 35 | 9 | 58 | 38 | 4 | 71 | 29 | 0 |
| 2008 | 25 | 44 | 31 | 33 | 47 | 20 | 38 | 38 | 25 |

*Table 3. Summary of sampling used to determine commercial catch-at-length: number of port samples and observer trips (n), number of specimens measured and amount of landings from which the samples were drawn. Gear codes: OTB otter trawls; SNU seines; FIX gillnets & longlines; MOB trawls and seines combined; SEN sentinel program (either trawl, seine, combined mobile, or fixed gear).*

| Year | Gear | n | Measured | Landings | Year | Gear | n | Measured | Landings | Year | Gear | n | Measured | Landings |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1973 | MOB | 5 | 1000 | 2196 | 1990 | OTB | 4 | 550 | 1171 | 2002 | MOB[1] | 18 | 3154 | 370 |
| | FIX | | | 71 | | SNU | 5 | 757 | 274 | | FIX | 11 | 2497 | 67 |
| 1974 | MOB | 8 | 1550 | 1717 | | FIX | 2 | 206 | 620 | | SNU_SEN | 6 | 521 | 0.6 |
| | FIX | | | 27 | 1991 | OTB | 1 | 225 | 1995 | | MOB_SEN[2] | | | 3 |
| 1975 | MOB | 12 | 3550 | 1831 | | SNU | 4 | 701 | 181 | 2003 | OTB | 19 | 6379 | 278 |
| | FIX | | | 38 | | FIX | 4 | 179 | 356 | | SNU | 6 | 803 | 71 |
| 1976 | MOB | 16 | 3599 | 2238 | 1992 | OTB | 12 | 1562 | 1477 | | FIX | 8 | 1871 | 119 |
| | FIX | | | 27 | | SNU | 4 | 373 | 140 | | OTB_SEN | 11 | 3382 | 0.3 |
| 1977 | MOB | 11 | 3249 | 951 | | FIX | 4 | 434 | 353 | 2004 | OTB | 22 | 6223 | 191 |
| | FIX | | | 30 | 1993 | OTB | 4 | 790 | 803 | | SNU | 4 | 605 | 85 |
| 1978 | MOB | 5 | 849 | 848 | | SNU | 2 | 394 | 65 | | FIX1 | 13 | 2749 | 105 |
| | FIX | | | 90 | | FIX | 7 | 661 | 462 | | OTB_SEN | 10 | 2271 | 0.7 |
| 1979 | MOB | 2 | 328 | 1332 | 1994 | OTB | 11 | 9965 | 737 | 2005 | OTB | 15 | 4957 | 211 |
| | FIX | | | 74 | | SNU | 3 | 969 | 28 | | SNU | 3 | 672 | 77 |
| 1980 | MOB | 7 | 974 | 1344 | | FIX | 3 | 363 | 410 | | FIX1 | 12 | 2821 | 95 |
| | FIX | 2 | 400 | 421 | 1995 | OTB | 15 | 9039 | 391 | | OTB_SEN | 10 | 1459 | 0.3 |
| 1981 | MOB | 6 | 774 | 1635 | | SNU | 1 | 162 | 9 | 2006 | OTB | 4 | 1034 | 85 |
| | FIX | 2 | 400 | 231 | | FIX | 10 | 1634 | 262 | | SNU | 5 | 648 | 89 |
| 1982 | OTB | 4 | 510 | 1652 | 1996 | MOB | 23 | 8024 | 498 | | FIX | 2 | 429 | 69 |
| | SNU | 1 | 136 | 32 | | FIX | 13 | 3220 | 331 | | OTB_SEN | 11 | 851 | 0.2 |
| | FIX | 2 | 400 | 580 | | MOB_SEN | 10 | 1378 | 2 | 2007 | OTB | 17 | 2460 | 100 |
| 1983 | OTB | 17 | 2722 | 1413 | | FIX_SEN | 49 | 1213 | 1 | | SNU | 8 | 902 | 49 |
| | SNU | 1 | 234 | 131 | 1997 | OTB | 25 | 3793 | 552 | | FIX | 5 | 1160 | 39 |
| | FIX | 4 | 362 | 242 | | SNU[1] | 6 | 1304 | 63 | | OTB_SEN | 11 | 925 | 0.2 |
| 1984 | OTB | 9 | 1430 | 43 | | FIX[1] | 37 | 4023 | 514 | 2008 | OTB | 7 | 747 | 128 |
| | SNU | 2 | 163 | 32 | | MOB_SEN | 4 | 413 | 1 | | SNU | 4 | 224 | 29 |
| | FIX | 3 | 289 | 17 | 1998 | OTB[1] | 21 | 3347 | 326 | | FIX | 6 | 1304 | 36 |
| 1985 | OTB | 6 | 1280 | 986 | | SNU[1] | 3 | 554 | 7 | | OTB_SEN | 9 | 628 | 0.1 |
| | SNU | 1 | 258 | 56 | | FIX[1] | 29 | 4638 | 306 | 2009 | OTB | 12 | 1956 | 117 |
| | FIX | 1 | 227 | 135 | | MOB_SEN | 3 | 117 | 1 | | SNU | 5 | 686 | 33 |
| 1986 | OTB | 7 | 1684 | 1247 | 1999 | MOB[1] | 12 | 2417 | 446 | | FIX | 12 | 2075 | 55 |
| | SNU | 2 | 300 | 243 | | FIX[1] | 15 | 2126 | 200 | | OTB_SEN | 9 | 941 | 0.2 |
| | FIX | 12 | 847 | 544 | | MOB_SEN | 4 | 121 | 1 | 2010 | OTB | 10 | 1590 | 170 |
| 1987 | OTB | 24 | 3051 | 886 | 2000 | OTB[1] | 20 | 3426 | 320 | | SNU | 2 | 360 | 57 |
| | SNU | 54 | 7063 | 307 | | SNU[1] | 5 | 1015 | 114 | | FIX | 9 | 1500 | 68 |
| | FIX | 2 | 233 | 611 | | FIX[1] | 24 | 4316 | 142 | | OTB_SEN | 9 | 741 | 0.1 |
| 1988 | OTB | 1 | 183 | 783 | 2001 | OTB[1] | 15 | 2767 | 330 | 2011 | OTB | 14 | 2849 | 201 |
| | SNU | 2 | 280 | 280 | | SNU[1] | 4 | 620 | 77 | | SNU | 4 | 584 | 31 |
| | FIX | 2 | 143 | 341 | | FIX[1] | 25 | 4131 | 163 | | FIX | 15 | 2209 | 68 |
| 1989 | OTB | 10 | 1645 | 1191 | | OTB_SEN[2] | | | 3 | | OTB_SEN | 7 | 466 | 0.1 |
| | SNU | 4 | 587 | 392 | | | | | | | | | | |
| | FIX | 3 | 358 | 506 | | | | | | | | | | |

[1] commercial and sentinel samples (unlined codends) combined. [2] sentinel lined catches estimated from survey data in same year.

*Table 4. Winter flounder commercial catch-at-age in thousands 1973-2011.*

| | AGE | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15+ |
| 1973 | 0.0 | 0.0 | 2.8 | 18.9 | 257.3 | 1031.2 | 1393.0 | 1131.5 | 562.2 | 362.2 | 107.0 | 75.9 | 10.9 | 0.0 | 4.9 |
| 1974 | 0.0 | 3.0 | 43.6 | 129.9 | 391.0 | 973.6 | 1139.0 | 875.6 | 417.1 | 251.1 | 76.3 | 51.5 | 7.3 | 0.0 | 3.3 |
| 1975 | 0.0 | 3.7 | 87.4 | 438.3 | 1019.4 | 1524.5 | 1318.0 | 848.9 | 331.9 | 154.3 | 58.2 | 20.8 | 2.2 | 0.0 | 2.0 |
| 1976 | 0.0 | 29.1 | 331.7 | 955.2 | 1611.4 | 1999.3 | 1550.9 | 941.4 | 341.6 | 140.3 | 56.5 | 15.4 | 1.8 | 0.0 | 1.8 |
| 1977 | 0.0 | 15.0 | 168.7 | 490.7 | 865.0 | 1085.8 | 820.6 | 490.0 | 172.2 | 72.4 | 28.8 | 7.3 | 0.9 | 0.0 | 0.9 |
| 1978 | 0.0 | 52.6 | 473.3 | 820.9 | 900.0 | 993.8 | 733.0 | 454.2 | 175.6 | 89.9 | 27.2 | 9.7 | 1.6 | 0.0 | 0.7 |
| 1979 | 0.0 | 0.0 | 40.8 | 231.9 | 1158.2 | 2020.8 | 1433.5 | 811.5 | 234.9 | 83.9 | 34.4 | 4.7 | 1.1 | 0.0 | 0.2 |
| 1980 | 0.0 | 0.0 | 37.7 | 206.2 | 1115.4 | 2139.0 | 1635.7 | 961.4 | 299.7 | 110.0 | 46.2 | 7.3 | 1.7 | 0.0 | 0.6 |
| 1981 | 0.0 | 0.0 | 33.6 | 186.4 | 1032.0 | 2055.8 | 1603.9 | 956.3 | 289.0 | 98.3 | 45.0 | 6.0 | 1.4 | 0.0 | 0.3 |
| 1982 | 0.0 | 0.0 | 29.0 | 116.1 | 981.4 | 2457.5 | 1948.3 | 1160.9 | 332.5 | 103.3 | 47.9 | 5.2 | 1.0 | 0.0 | 0.7 |
| 1983 | 0.0 | 4.9 | 36.3 | 173.7 | 613.9 | 1344.6 | 1522.0 | 1078.5 | 511.8 | 229.6 | 82.5 | 26.1 | 5.5 | 0.1 | 2.9 |
| 1984 | 0.0 | 0.3 | 8.6 | 57.5 | 126.8 | 158.7 | 116.8 | 67.5 | 21.9 | 8.0 | 3.0 | 0.7 | 1.0 | 0.0 | 0.1 |
| 1985 | 0.0 | 0.3 | 6.5 | 36.5 | 144.8 | 458.1 | 703.1 | 585.3 | 323.7 | 163.2 | 53.3 | 19.9 | 6.6 | 0.1 | 1.9 |
| 1986 | 0.0 | 2.2 | 53.3 | 273.1 | 783.5 | 1409.0 | 1288.5 | 880.7 | 371.6 | 167.5 | 57.3 | 29.0 | 7.6 | 0.2 | 2.5 |
| 1987 | 0.0 | 2.7 | 57.5 | 416.9 | 1005.3 | 1514.7 | 1339.3 | 873.4 | 354.9 | 137.6 | 51.1 | 13.7 | 2.7 | 0.1 | 1.4 |
| 1988 | 0.0 | 3.0 | 76.6 | 464.7 | 1112.5 | 1446.7 | 1060.8 | 599.9 | 203.8 | 69.3 | 29.5 | 5.8 | 1.2 | 0.0 | 1.4 |
| 1989 | 0.0 | 0.7 | 23.8 | 163.7 | 712.2 | 1533.1 | 1493.4 | 1001.5 | 424.8 | 181.1 | 66.4 | 23.8 | 4.0 | 0.2 | 2.3 |
| 1990 | 0.0 | 2.0 | 30.5 | 281.7 | 971.8 | 1607.6 | 1425.6 | 916.8 | 430.8 | 162.5 | 52.0 | 18.3 | 2.9 | 1.2 | 4.3 |
| 1991 | 0.0 | 7.1 | 83.5 | 683.0 | 1881.0 | 2460.3 | 1686.9 | 960.6 | 393.6 | 140.0 | 42.9 | 13.4 | 3.5 | 0.8 | 5.6 |
| 1992 | 0.6 | 10.5 | 61.2 | 372.9 | 993.8 | 1461.7 | 1271.6 | 878.7 | 426.1 | 166.1 | 54.4 | 25.1 | 7.9 | 0.7 | 8.4 |
| 1993 | 0.0 | 1.4 | 23.1 | 206.4 | 617.3 | 974.1 | 903.2 | 612.0 | 305.3 | 122.6 | 37.8 | 19.7 | 3.2 | 0.9 | 4.6 |
| 1994 | 0.3 | 5.9 | 38.3 | 256.1 | 707.2 | 1026.0 | 848.7 | 530.7 | 221.8 | 75.3 | 23.1 | 7.3 | 2.4 | 0.1 | 2.2 |
| 1995 | 0.0 | 0.4 | 9.7 | 81.7 | 250.0 | 430.1 | 431.9 | 319.1 | 160.2 | 63.1 | 19.2 | 9.5 | 1.7 | 0.3 | 3.1 |
| 1996 | 0.0 | 0.7 | 12.7 | 112.4 | 342.3 | 585.7 | 577.5 | 424.8 | 220.3 | 88.0 | 27.2 | 13.7 | 2.4 | 0.5 | 3.9 |
| 1997 | 0.0 | 1.5 | 23.7 | 204.0 | 606.5 | 969.8 | 878.3 | 594.0 | 269.7 | 96.6 | 27.5 | 12.4 | 1.8 | 0.1 | 3.9 |
| 1998 | 0.0 | 1.0 | 9.5 | 90.7 | 287.6 | 483.0 | 435.1 | 341.0 | 194.4 | 86.4 | 30.7 | 15.2 | 2.4 | 2.6 | 1.8 |
| 1999 | 0.0 | 0.9 | 8.3 | 84.1 | 280.9 | 497.6 | 467.0 | 358.5 | 198.5 | 81.2 | 29.9 | 13.0 | 1.8 | 2.4 | 1.0 |
| 2000 | 0.1 | 1.8 | 16.8 | 107.3 | 284.3 | 440.6 | 391.3 | 305.7 | 173.9 | 76.7 | 28.6 | 13.4 | 2.2 | 1.9 | 1.4 |
| 2001 | 0.0 | 2.1 | 16.4 | 103.7 | 287.5 | 452.2 | 393.7 | 300.9 | 165.8 | 70.6 | 25.4 | 11.9 | 1.8 | 2.1 | 1.4 |
| 2002 | 0.1 | 4.5 | 25.3 | 112.7 | 262.8 | 376.3 | 311.6 | 230.3 | 120.1 | 46.2 | 17.2 | 6.4 | 1.0 | 1.3 | 0.6 |
| 2003 | 0.0 | 1.7 | 19.4 | 136.9 | 343.0 | 466.8 | 342.5 | 234.2 | 109.4 | 36.8 | 12.4 | 4.7 | 0.6 | 1.3 | 0.3 |
| 2004 | 0.0 | 0.8 | 1.8 | 31.2 | 141.2 | 304.4 | 279.1 | 270.5 | 174.5 | 73.9 | 29.9 | 12.4 | 1.9 | 3.6 | 0.0 |
| 2005 | 0.0 | 1.6 | 4.3 | 47.3 | 187.5 | 370.1 | 303.4 | 282.2 | 164.8 | 59.0 | 22.5 | 8.5 | 1.1 | 3.2 | 0.0 |
| 2006 | 0.0 | 0.6 | 1.7 | 26.3 | 106.1 | 219.9 | 187.4 | 179.4 | 110.2 | 42.9 | 16.9 | 6.4 | 0.7 | 1.8 | 0.0 |
| 2007 | 0.0 | 1.2 | 4.8 | 27.0 | 91.1 | 177.4 | 151.3 | 142.8 | 85.5 | 30.9 | 11.5 | 4.5 | 0.5 | 1.9 | 0.0 |
| 2008 | 0.2 | 4.3 | 6.0 | 20.6 | 76.9 | 164.7 | 149.2 | 145.1 | 89.9 | 33.2 | 13.4 | 5.0 | 0.6 | 1.8 | 0.0 |
| 2009 | 0.0 | 2.4 | 6.3 | 29.0 | 98.8 | 193.3 | 157.0 | 146.8 | 85.1 | 30.4 | 11.7 | 4.8 | 0.5 | 1.7 | 0.0 |
| 2010 | 3.7 | 15.2 | 83.0 | 185.7 | 274.6 | 315.9 | 215.4 | 180.6 | 104.7 | 40.8 | 15.5 | 6.6 | 1.1 | 2.4 | 0.0 |
| 2011 | 0.1 | 6.8 | 50.8 | 132.9 | 260.7 | 368.5 | 254.4 | 213.8 | 117.4 | 41.2 | 15.4 | 6.7 | 1.1 | 2.3 | 0.0 |

*Table 5. Winter flounder population-at-age (thousands) from annual research surveys in 4T. Shaded areas indicate years for which winter flounder ageing was undertaken.*

| | AGE | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14+ |
| 1971 | 19.5 | 404.4 | 1351.7 | 4023.8 | 8463.6 | 8571.9 | 5976.4 | 2441.5 | 1320.8 | 432.2 | 177.5 | 28.8 | 15.3 |
| 1972 | 2.4 | 26.6 | 90.9 | 276.3 | 529.0 | 533.7 | 335.7 | 151.6 | 63.6 | 17.1 | 20.0 | 21.3 | 0.0 |
| 1973 | 472.1 | 2074.2 | 4409.2 | 5994.6 | 7698.8 | 7354.9 | 4743.0 | 2066.3 | 1098.8 | 390.4 | 154.3 | 13.2 | 19.1 |
| 1974 | 14817.5 | 7569.8 | 6712.2 | 12803.5 | 22628.4 | 27503.8 | 22141.4 | 11923.7 | 6913.7 | 1868.9 | 689.8 | 106.8 | 44.8 |
| **1975** | **160.8** | **1667.7** | **5131.9** | **9994.6** | **13939.6** | **12133.6** | **8452.2** | **3626.7** | **2042.2** | **701.9** | **339.6** | **155.7** | **35.8** |
| 1976 | 1283.6 | 15038.5 | 42438.9 | 50077.5 | 57895.5 | 47817.2 | 28091.2 | 10297.2 | 5492.4 | 1858.8 | 497.7 | 1076.0 | 61.0 |
| **1977** | **603.8** | **5188.5** | **10156.7** | **9317.6** | **7287.3** | **4554.8** | **2264.5** | **781.2** | **307.3** | **129.3** | **23.6** | **4.9** | **7.0** |
| **1978** | **125.3** | **2482.0** | **13234.0** | **23720.2** | **22304.7** | **15837.8** | **9781.8** | **4102.5** | **2117.4** | **570.7** | **203.3** | **40.5** | **20.7** |
| **1979** | **349.3** | **3604.4** | **9995.8** | **13219.1** | **14144.0** | **11001.4** | **6542.4** | **2308.6** | **1205.7** | **378.7** | **183.6** | **15.3** | **5.4** |
| **1980** | **293.3** | **3980.3** | **14264.1** | **23344.2** | **26955.0** | **20361.6** | **12153.1** | **4496.5** | **1789.0** | **663.9** | **201.9** | **18.7** | **62.9** |
| **1981** | **2471.7** | **7429.6** | **11585.0** | **16653.5** | **22375.5** | **19161.3** | **11732.8** | **4646.5** | **2325.3** | **831.2** | **263.6** | **47.5** | **27.0** |
| **1982** | **99.5** | **1570.1** | **6349.2** | **13418.9** | **19358.6** | **14694.5** | **8714.6** | **2857.9** | **838.8** | **353.2** | **85.5** | **17.7** | **2.0** |
| 1983 | 712.5 | 6474.6 | 16103.7 | 23199.2 | 24662.9 | 21055.4 | 13741.8 | 6639.2 | 3068.8 | 942.7 | 283.5 | 41.1 | 65.0 |
| 1984 | 891.9 | 3578.6 | 5836.7 | 6093.5 | 5123.0 | 4575.6 | 3488.8 | 1961.8 | 1087.2 | 335.0 | 212.7 | 25.3 | 40.3 |
| 1985 | 1286.1 | 4255.6 | 6855.1 | 8379.9 | 7984.8 | 6024.0 | 3563.4 | 1426.5 | 639.3 | 207.2 | 76.2 | 32.1 | 11.8 |
| 1986 | 1515.4 | 7778.0 | 12763.2 | 13320.6 | 11796.3 | 9237.2 | 5532.8 | 2341.4 | 1018.6 | 328.3 | 135.8 | 18.7 | 20.0 |
| 1987 | 915.1 | 5116.8 | 8665.4 | 8045.9 | 5445.9 | 3698.0 | 2046.5 | 798.4 | 339.5 | 108.6 | 36.2 | 5.9 | 18.3 |
| 1988 | 855.7 | 4491.3 | 9504.4 | 11379.0 | 9526.6 | 6603.6 | 3784.2 | 1531.1 | 543.8 | 191.9 | 50.3 | 9.5 | 11.6 |
| 1989 | 942.2 | 7653.7 | 19010.4 | 20788.9 | 14556.8 | 8251.3 | 4130.1 | 1329.2 | 574.6 | 169.5 | 60.6 | 7.4 | 8.0 |
| **1990** | **2261.8** | **11911.0** | **25418.5** | **27183.8** | **14835.3** | **7111.2** | **2982.2** | **929.0** | **264.8** | **76.3** | **29.7** | **3.5** | **3.2** |
| **1991** | **2353.9** | **11756.8** | **17132.1** | **14567.4** | **8203.7** | **4570.4** | **2329.5** | **853.0** | **270.0** | **89.0** | **36.6** | **8.1** | **13.6** |
| **1992** | **1336.2** | **8776.2** | **20134.3** | **21475.8** | **13073.0** | **7103.7** | **3619.7** | **1435.0** | **493.5** | **144.6** | **75.6** | **8.8** | **15.7** |
| **1993** | **1033.1** | **4871.1** | **9108.8** | **10165.8** | **7968.1** | **5394.5** | **3291.0** | **1671.6** | **728.5** | **194.2** | **135.5** | **30.6** | **60.5** |
| 1994 | 2635.2 | 5658.1 | 7251.7 | 8046.6 | 6099.1 | 3720.4 | 2115.1 | 817.5 | 290.5 | 79.6 | 45.3 | 7.8 | 8.5 |
| 1995 | 14869.7 | 30567.8 | 21584.7 | 14021.8 | 7573.0 | 4824.8 | 2612.6 | 1057.5 | 398.7 | 127.2 | 54.8 | 11.3 | 12.1 |
| 1996 | 3772.7 | 10344.0 | 12330.6 | 11440.7 | 7463.7 | 4592.7 | 2588.2 | 1127.3 | 440.1 | 160.8 | 64.7 | 14.0 | 13.5 |
| **1997** | **4172.4** | **12761.4** | **14590.6** | **12178.2** | **7011.7** | **4030.8** | **2127.2** | **836.8** | **285.5** | **89.6** | **36.4** | **6.5** | **7.8** |
| 1998 | 1216.8 | 7416.1 | 11534.2 | 9733.5 | 5190.8 | 2742.3 | 1571.0 | 753.4 | 293.2 | 115.6 | 42.3 | 8.8 | 16.3 |
| 1999 | 2382.8 | 10342.5 | 14027.4 | 13645.5 | 9817.0 | 5612.2 | 3415.6 | 1536.8 | 542.7 | 192.6 | 74.3 | 12.9 | 20.0 |
| 2000 | 3538.3 | 14402.0 | 19663.4 | 17909.0 | 11540.4 | 6116.9 | 3498.3 | 1504.5 | 505.8 | 167.7 | 71.4 | 9.4 | 20.4 |
| 2001 | 2173.4 | 9620.0 | 13025.1 | 12049.0 | 8046.8 | 4391.9 | 2524.4 | 1091.3 | 345.7 | 121.1 | 48.6 | 7.3 | 19.7 |
| 2002 | 4868.3 | 15741.6 | 16967.6 | 14351.1 | 10857.8 | 7604.3 | 5327.2 | 2977.1 | 1284.3 | 484.8 | 263.9 | 32.1 | 78.2 |
| **2004** | **2136.2** | **7453.0** | **10407.4** | **11359.8** | **9897.7** | **5728.8** | **4173.2** | **2148.7** | **721.5** | **259.8** | **95.9** | **15.3** | **34.8** |
| **2005** | **12479.3** | **24790.2** | **15138.1** | **13546.3** | **10777.7** | **5981.9** | **4028.1** | **1952.4** | **577.8** | **230.8** | **82.9** | **13.8** | **33.9** |
| **2006** | **2504.0** | **8371.0** | **9976.6** | **9913.4** | **8203.7** | **4647.7** | **3369.8** | **1804.4** | **681.9** | **272.1** | **137.5** | **17.8** | **29.8** |
| **2007** | **1871.2** | **8131.8** | **10258.4** | **9360.7** | **7252.6** | **4246.8** | **3202.8** | **1889.4** | **987.6** | **355.6** | **197.9** | **22.7** | **52.4** |
| 2008 | 1904.1 | 6654.2 | 7660.9 | 8078.0 | 6497.1 | 3521.2 | 2387.3 | 1130.1 | 403.1 | 153.9 | 66.9 | 7.7 | 14.2 |
| 2009 | 5817.0 | 19426.9 | 16494.5 | 11868.2 | 8981.8 | 4915.1 | 3401.7 | 1733.3 | 566.8 | 205.9 | 75.8 | 9.2 | 18.5 |
| 2010 | 1324.7 | 7660.3 | 11065.7 | 10175.3 | 7001.2 | 3687.0 | 2380.7 | 1236.6 | 477.6 | 166.0 | 60.7 | 8.2 | 20.2 |
| 2011 | 972.8 | 3203.9 | 4504.4 | 4853.8 | 3968.3 | 2296.9 | 1563.0 | 800.5 | 239.5 | 94.2 | 29.4 | 6.9 | 10.8 |

*Table 6. Stratified mean length (cm) at age of male and female winter flounder in annual surveys of 4T, with estimated coefficients of the von Bertalanffy growth curves. Linf is the estimated maximum length; K is a growth coefficient; t0 is the age at zero length.*

| Male | Year | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AGE | 1975 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1990 | 1991 | 1992 | 1993 | 1997 | 2004 | 2005 | 2006 | 2007 |
| 2 | | 16.0 | 17.0 | 16.5 | 15.4 | 14.7 | | 15.2 | 17.2 | 17.7 | 14.5 | 16.2 | 13.8 | 13.3 | 12.9 | 12.8 |
| 3 | 21.4 | 19.4 | 19.1 | 19.9 | 20.0 | 19.1 | 18.7 | 19.0 | 17.4 | 19.2 | 19.6 | 16.2 | 16.4 | 15.4 | 15.1 | 15.1 |
| 4 | 24.3 | 20.1 | 23.0 | 21.8 | 22.9 | 21.3 | 23.3 | 21.4 | 20.4 | 22.3 | 22.7 | 20.6 | 18.9 | 18.4 | 18.6 | 17.8 |
| 5 | 25.9 | 23.4 | 25.0 | 24.8 | 24.1 | 25.3 | 27.2 | 23.6 | 21.8 | 23.6 | 23.9 | 22.9 | 22.4 | 21.4 | 20.9 | 21.2 |
| 6 | 29.6 | 25.7 | 25.9 | 26.5 | 26.3 | 27.2 | 26.6 | 25.9 | 25.7 | 25.3 | 25.7 | 25.0 | 24.8 | 23.9 | 23.2 | 23.4 |
| 7 | 29.5 | 28.1 | 28.7 | 26.7 | 27.2 | 28.7 | 26.3 | 25.8 | 27.0 | 26.5 | 28.1 | 26.8 | 24.8 | 25.0 | 24.6 | 25.3 |
| 8 | 33.6 | 30.4 | 29.1 | 28.0 | 29.2 | 28.2 | 29.2 | 27.8 | 26.5 | 28.6 | 28.8 | 28.8 | 26.0 | 27.0 | 26.2 | 27.0 |
| 9 | 32.6 | 27.0 | | 30.5 | 32.6 | 32.6 | 32.6 | 29.4 | 31.6 | 29.6 | 30.0 | 30.3 | 27.6 | 28.1 | 27.2 | 27.7 |
| 10 | | 31.0 | 31.0 | 34.9 | 33.9 | | | | 31.0 | 32.9 | 31.9 | 29.4 | 25.6 | 29.5 | 28.6 | 31.3 |
| 11 | | 34.0 | | 31.0 | | | | | | 32.3 | 33.0 | 29.0 | 30.6 | 31.0 | 30.9 | 24.9 |
| 12 | | 32 | | 33.1 | | | | | 33.7 | | 37.0 | 30.0 | 31.0 | 29.4 | 31.6 | |
| 13 | | | | | | | | | | | 41.0 | | | | | |
| 14 | | | | | | | | | | | | | | | | |
| 15 | | | | | | | | | | | 36.0 | | | | | |
| Linf | 42.3 | 36.2 | 40.8 | 35.0 | 98.7 | 33.3 | 28.5 | 31.0 | 51.1 | 40.4 | 37.4 | 40.2 | 30.1 | 42.6 | 34.6 | 36.5 |
| K | 0.1422 | 0.16 | 0.112 | 0.1723 | 0.025 | 0.272 | 0.588 | 0.287 | 0.073 | 0.106 | 0.1541 | 0.138 | 0.26 | 0.113 | 0.1666 | 0.1615 |
| t0 | -1.9364 | -1.462 | -3.301 | -1.8713 | -6.192 | -0.048 | 1.045 | -0.055 | -2.979 | -3.323 | -1.7617 | -1.021 | 0.02 | -0.962 | -0.59 | -0.288 |
| Female | | | | | | | | | | | | | | | | |
| 2 | | 15.2 | 17.9 | 17.6 | 16.8 | 16.7 | | 14.7 | 16.6 | 18.3 | 15.9 | 15.1 | 14.4 | 12.8 | 13.2 | 12.8 |
| 3 | 18.9 | 19.1 | 24.2 | 20.3 | 20.5 | 18.7 | | 19.2 | 18.4 | 20.1 | 19.1 | 17.0 | 16.8 | 15.4 | 15.2 | 16.0 |
| 4 | 24.5 | 21.3 | 23.4 | 23.4 | 23.0 | 22.4 | 23.1 | 21.7 | 20.5 | 22.7 | 22.2 | 21.1 | 19.9 | 18.9 | 18.2 | 18.8 |
| 5 | 26.8 | 24.1 | 25.4 | 26.3 | 25.1 | 25.6 | 24.1 | 24.2 | 23.2 | 24.6 | 24.2 | 23.3 | 22.7 | 22.4 | 21.4 | 21.7 |
| 6 | 28.9 | 26.0 | 27.3 | 28.7 | 27.4 | 29.1 | 28.7 | 26.3 | 26.6 | 27.3 | 26.6 | 26.2 | 25.4 | 25.0 | 24.1 | 23.3 |
| 7 | 32.1 | 28.2 | 30.3 | 29.8 | 29.3 | 30.7 | 29.7 | 28.1 | 28.6 | 27.7 | 28.3 | 28.8 | 27.4 | 26.5 | 25.7 | 26.6 |
| 8 | 32.2 | 31.7 | 33.2 | 33.5 | 30.3 | 31.5 | 30.8 | 29.2 | 30.8 | 30.6 | 29.9 | 30.6 | 28.0 | 28.2 | 28.2 | 27.5 |
| 9 | 35.2 | 32.0 | 37.1 | 31.9 | 33.5 | 33.0 | 32.6 | 33.6 | 30.6 | 31.7 | 32.6 | 33.4 | 29.8 | 28.8 | 29.1 | 29.6 |
| 10 | 38.1 | 35.5 | 35.9 | 35.3 | 35.4 | 33.1 | | 36.1 | 33.2 | 34.8 | 32.5 | 34.3 | 32.4 | 30.6 | 31.9 | 32.7 |
| 11 | 39.1 | 36.5 | 32.0 | 36.0 | 32.6 | 32.9 | | 33.8 | 37.8 | 39.1 | 38.6 | 32.3 | 31.7 | 34.1 | 31.5 | 33.6 |
| 12 | 43.4 | 36.7 | | 37.0 | 39.4 | | | 40.2 | | 37.2 | 38.0 | 36.7 | 33.0 | 36.0 | 34.4 | 36.1 |
| 13 | 46.2 | 34 | | | | | | 38.0 | | | 35.0 | | | | 34.5 | 36.0 |
| 14 | | | | | | | | | | 38.0 | | | 29.0 | | | 38.0 |
| 15 | | 39.6 | | | | | | | 35.0 | | | | | | | |
| Linf | 68.1 | 50.9 | 156.8 | 41.3 | 71.1 | 37.7 | 35.7 | 41.1 | 71.5 | 58.0 | 44.8 | 58.8 | 36.7 | 41.6 | 44.3 | 44.6 |
| K | 0.0621 | 0.091 | 0.015 | 0.1632 | 0.046 | 0.22 | 0.285 | 0.145 | 0.051 | 0.063 | 0.1131 | 0.076 | 0.18 | 0.137 | 0.1134 | 0.1144 |
| t0 | -2.9862 | -2.03 | -6.282 | -1.1861 | -4.517 | -0.336 | 0.712 | -1.165 | -2.801 | -3.78 | -1.9532 | -1.667 | -0.49 | -0.421 | -0.761 | -0.735 |

*Table 7. Species landed (tonnes) when directing for winter flounder in NAFO 4T. Landings <0.5 tonne are indicated by “0”.*

| YEAR | WFL | HKW | COD | GRC | PLA | YEL | WPN | WIT | DGX | HER | GHL | MAC | SKA | SCU | LUM | RED | STU | HAL | SHA | HAD | ELA | ALE | CAT | ANG | SMR | STB | BIV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 795 | 101 | 60 | | 55 | 54 | | 1 | | 4 | | 4 | | | | | | 0 | | 1 | | | | 0 | | | |
| 1986 | 1517 | 164 | 83 | | 97 | 27 | | 3 | | 9 | 40 | | | | 2 | | 4 | 0 | 0 | 0 | | | | 0 | | | |
| 1987 | 1073 | 146 | 98 | 0 | 78 | 54 | | 1 | 0 | 1 | 0 | 1 | | | 1 | | 1 | 0 | 0 | 0 | | | | 0 | | | |
| 1988 | 928 | 168 | 101 | | 69 | 9 | | 3 | | 2 | 0 | 15 | | | 0 | 12 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | | | 8 |
| 1989 | 1439 | 171 | 100 | | 62 | 18 | | 3 | 0 | 0 | 12 | 3 | 0 | | 0 | | 0 | 0 | 0 | | 0 | | 0 | 0 | | | |
| 1990 | 1452 | 241 | 57 | | 32 | 8 | | 0 | 2 | 4 | 3 | 2 | | | 0 | | 1 | 0 | 2 | | 0 | | 0 | 0 | | | |
| 1991 | 1992 | 340 | 69 | | 45 | 7 | | 1 | 1 | 2 | 0 | 2 | 3 | | 1 | 0 | 0 | 0 | 2 | | | | 0 | 0 | 0 | | |
| 1992 | 1430 | 261 | 153 | 0 | 49 | 46 | | 0 | | 2 | | 7 | | | 2 | | 0 | 0 | 0 | | | | 0 | 0 | | | |
| 1993 | 1495 | 91 | 34 | | 22 | 63 | | 0 | 13 | 25 | | 9 | 0 | | 3 | | 0 | 0 | 0 | | 0 | | 0 | 0 | | 0 | |
| 1994 | 1153 | 49 | 33 | 0 | 24 | 11 | | 9 | 5 | 8 | 1 | 5 | 6 | | 1 | 0 | 0 | 0 | 0 | | 1 | | 0 | 0 | 0 | | |
| 1995 | 605 | 25 | 25 | 1 | 29 | 21 | | 0 | 9 | 1 | 1 | 3 | 6 | | 2 | 0 | 0 | 0 | 0 | 0 | | | | | | | |
| 1996 | 810 | 28 | 45 | 0 | 35 | 18 | | 0 | 25 | 1 | 1 | 0 | 9 | | 1 | | 1 | 0 | | | | 0 | | 0 | | | |
| 1997 | 1057 | 52 | 54 | 0 | 57 | 9 | | 3 | 39 | 1 | 0 | 2 | 3 | | 1 | 0 | 1 | 0 | | | | | | 0 | | | |
| 1998 | 599 | 28 | 34 | 0 | 44 | 18 | | 1 | 23 | 1 | | 0 | 0 | | 0 | | 0 | 0 | | 0 | | | 0 | | | | |
| 1999 | 577 | 42 | 35 | 0 | 42 | 13 | | 0 | 14 | 1 | 0 | | 0 | | 0 | | 0 | 0 | | | | | | | | | |
| 2000 | 409 | 17 | 40 | 0 | 34 | 13 | 3 | | 3 | | | 0 | 1 | 0 | 0 | | 0 | 0 | 0 | | | | 0 | | | | |
| 2001 | 450 | 19 | 31 | 0 | 25 | 32 | 5 | 0 | | 1 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 | | | | | 0 | | | | |
| 2002 | 354 | 6 | 2 | 0 | 26 | 28 | 0 | 2 | | 1 | 0 | 0 | | 2 | 0 | | | 0 | | | | | | 0 | | | |
| 2003 | 373 | 4 | 1 | | 18 | 29 | 1 | 0 | | 3 | | | | 2 | 0 | | | 1 | | | | | | | | | |
| 2004 | 273 | 4 | 0 | 0 | 19 | 14 | 1 | | | 0 | | | 0 | 1 | 0 | | | 0 | | | | | | | | | |
| 2005 | 247 | 2 | 0 | | 25 | 16 | 1 | | 0 | | | 0 | | 2 | | | | 0 | | | | | | | | | |
| 2006 | 109 | 0 | 0 | | 5 | 3 | 0 | | | 0 | | | | 2 | 0 | | | 0 | | | | | | | | | |
| 2007 | 90 | 0 | 0 | | 5 | 8 | 2 | 0 | 0 | | | | | 1 | 0 | | | 0 | | | | | | | | | |
| 2008 | 124 | 0 | 0 | | 10 | 19 | 9 | | 0 | | | | | 3 | | | | 0 | 0 | | | | | 0 | | | |
| 2009 | 120 | 0 | 0 | 0 | 1 | 19 | 8 | | 0 | 0 | | | 0 | 3 | 0 | | | 0 | 0 | | | | | | | | |
| 2010 | 193 | 0 | 0 | | 0 | 72 | 51 | | | 1 | | | 0 | 3 | | | 0 | 0 | 0 | | | | | | | | |
| 2011 | 168 | 0 | 0 | 0 | 0 | 37 | 23 | | | | | | 0 | 4 | 0 | | | 0 | | | | | | | | | |

ALE: alewives/gaspareau
ANG: monkfish/baudroie d'Amérique
BIV: bivalves
CAT: catfish/ loup de mer
COD: cod/morue
DGX: dogfish/ aiguillat
ELA: eels/ anguille
GHL: greenland halibut/flétan du Groenland
GRC: rock cod/morue de roche
HAD: haddock/ aiglefin
HAL: halibut/flétan
HER: herring/hareng
HKW: white hake/merluche blanche
LUM: lumpfish/poule de mer
MAC: mackerel/maquereau
PLA: american plaice/plie canadienne
RED: redfish/sébaste
SCU: sculpin/chabot
SHA: shad/alose
SKA: skate/raie
SMR: smelt/éperlan
STB: striped bass/bar d'Amérique
STU: sturgeon/esturgeon
WIT: witch flounder/plie grise
WFL: winter flounder/plie rouge
WPN: windowpane/turbot de sable
YEL: yellowtail flounder/limande à queue jaune

*Table 8. Species composition of NAFO 4T winter flounder-directed catches, estimated by at-sea observers. The total observed catch of winter flounder (kg) is shown, followed by the 10 most abundant bycatch species. The number of observed vessel trips is indicated in the bottom line. Data since 2006 were aggregated due to low observer coverage on winter flounder-directed trips (no observations were made in the 2008 fishery).*

| | **YEAR** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SPECIES** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006-2011** |
| winter flounder | 6478 | 6065 | 80146 | 27845 | 25333 | 20736 | 11913 | 12526 | 2469 | 10415 | 14259 | 11303 | 13935 | 12778 | 7153 | 5253 |
| cod | 4006 | 752 | 3362 | 2197 | 4160 | 1771 | 86 | 9048 | 0 | 894 | 149 | | 3 | 55 | 3 | 2 |
| yellowtail flounder | 223 | 2948 | 7881 | 2168 | 4933 | 1713 | 197 | 573 | 56 | 693 | 1173 | 220 | 906 | 895 | 176 | 97 |
| spiny dogfish | | 5 | 7122 | 1761 | 756 | 3702 | 442 | 71 | 30 | 11 | 3 | 2 | | | 4 | 4 |
| American plaice | 1242 | 217 | 1640 | 382 | 902 | 645 | 533 | 199 | 206 | 653 | 1879 | 825 | 1194 | 1457 | 1493 | 138 |
| white hake | 802 | 71 | 115 | 228 | 939 | 1114 | 416 | 1435 | 398 | 489 | 933 | 59 | 172 | 249 | 68 | 30 |
| unidentified sculpin | 50 | | 2276 | 24 | 20 | 319 | 65 | 199 | 30 | 416 | 183 | 44 | 295 | 660 | 53 | 108 |
| American lobster | 14 | 303 | 1092 | 648 | 1372 | 233 | 28 | 238 | 10 | 42 | 172 | 16 | 6 | 50 | 15 | 291 |
| thorny skate | 3 | 918 | 1139 | 121 | 473 | 342 | | 33 | 24 | 141 | | | 179 | 60 | | 1 |
| skates | 320 | | 917 | 27 | 380 | 272 | 352 | 146 | 5 | 365 | 196 | 12 | 4 | 48 | 35 | 16 |
| Atlantic rock crab | 3 | 146 | 99 | 427 | 35 | 439 | 11 | 33 | | 184 | 35 | 24 | 22 | 8 | 64 | 1131 |
| **number of trips:** | 5 | 9 | 17 | 16 | 32 | 28 | 22 | 22 | 4 | 22 | 18 | 11 | 17 | 14 | 9 | 14 |

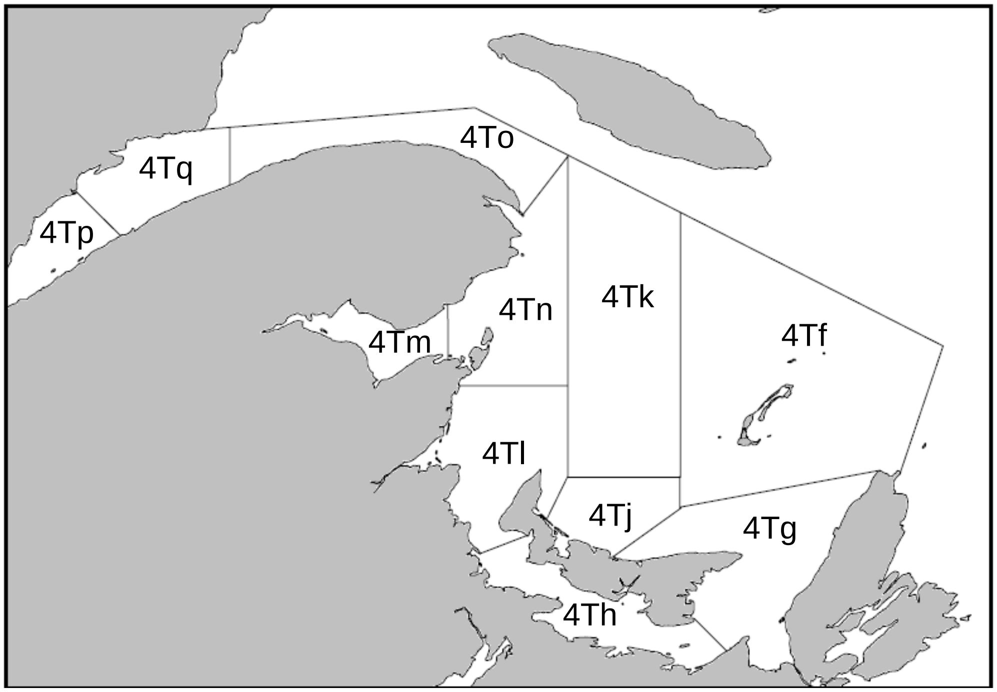


*Figure 1. Management unit areas of the southern Gulf of St. Lawrence (NAFO Division 4T).*

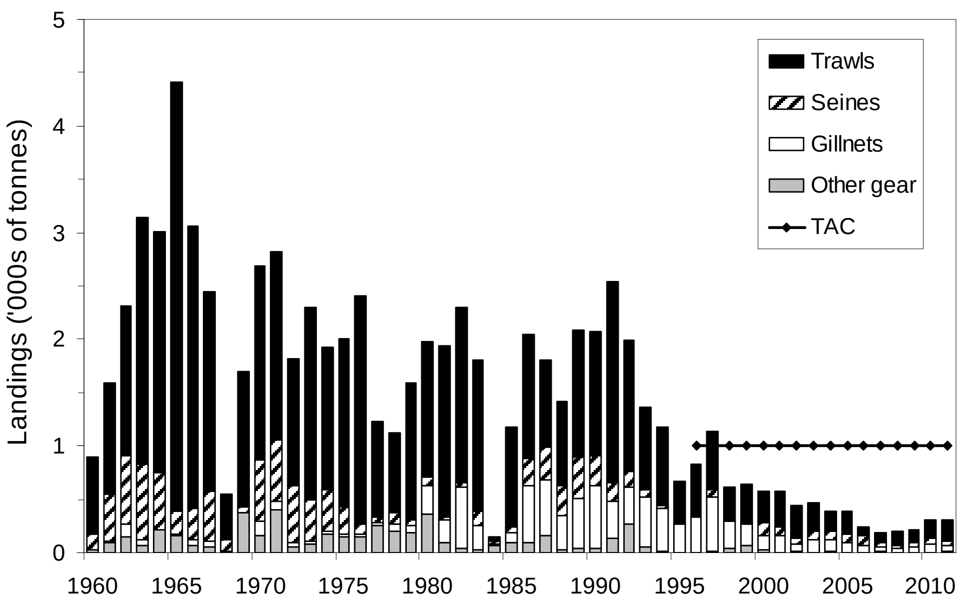


*Figure 2. Landings of winter flounder in the southern Gulf, 1960-2011. A 1,000 tonne annual quota (TAC) has been in effect since 1996.*

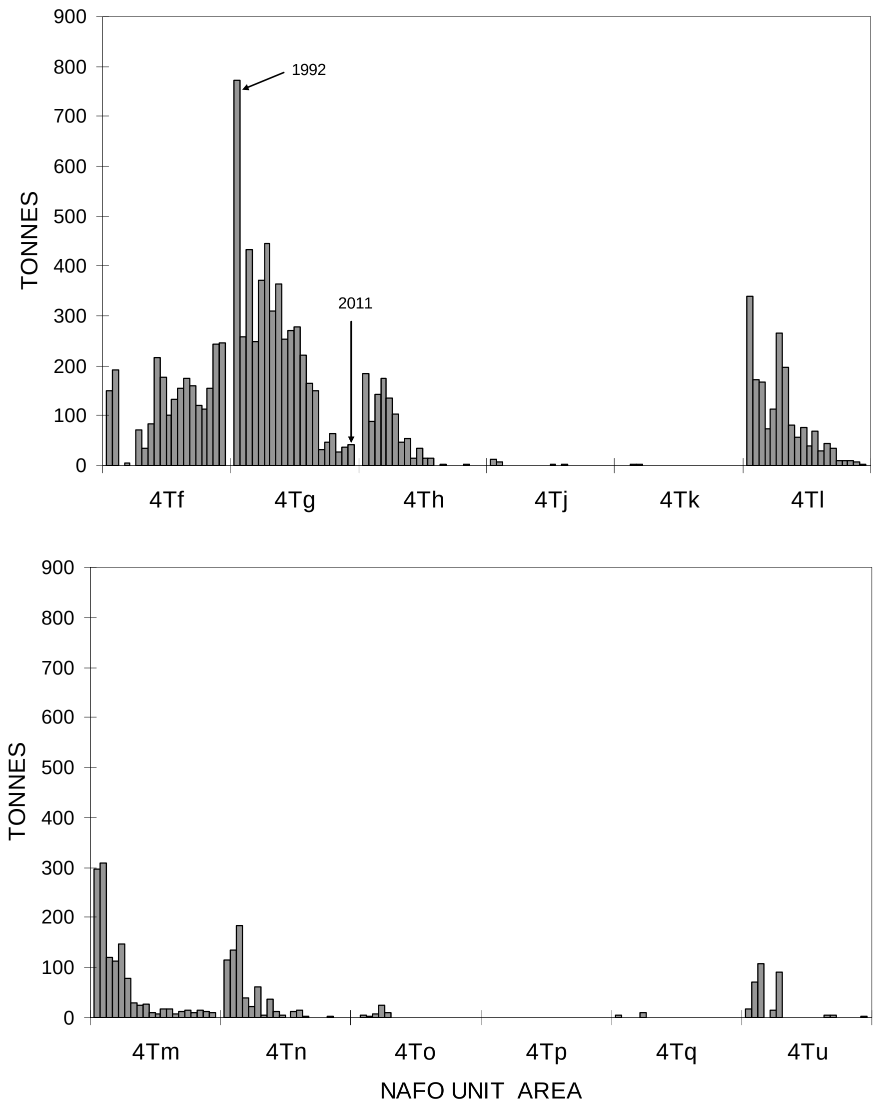


*Figure 3. Annual landings of 4T winter flounder by NAFO unit area, 1992-2011. 4Tu represents unspecified unit area.*

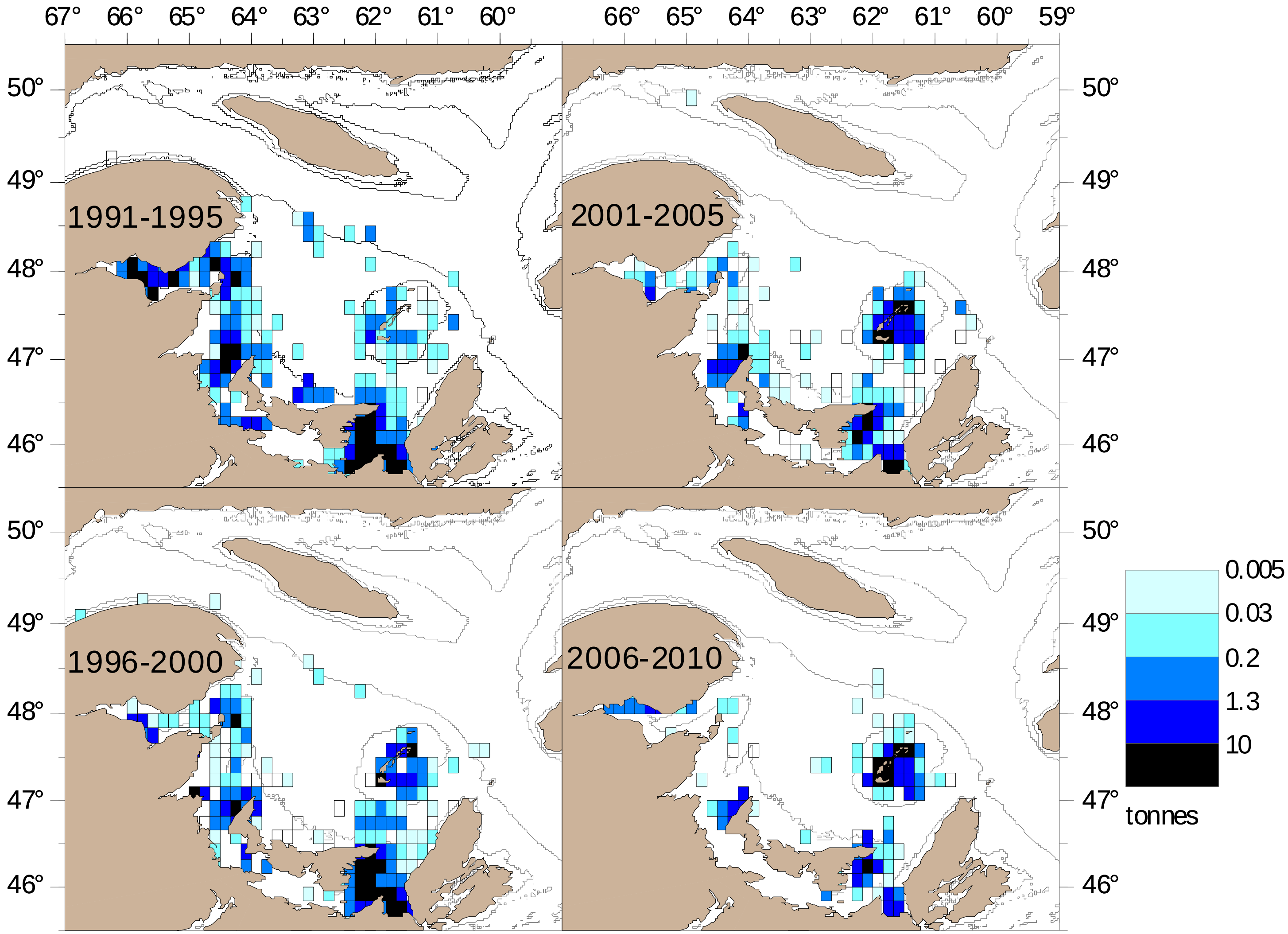


*Figure 4 Distribution of commercial catches of winter flounder in 4T since 1991. Annual catches were totaled in 10-minute squares, based on coordinates indicated in vessel logbook, then averaged over the 5-year period in each graph. The colour scale is based on the 10, 25, 50, 75 and 90$^{th}$ percentiles of mean catches over all years.*

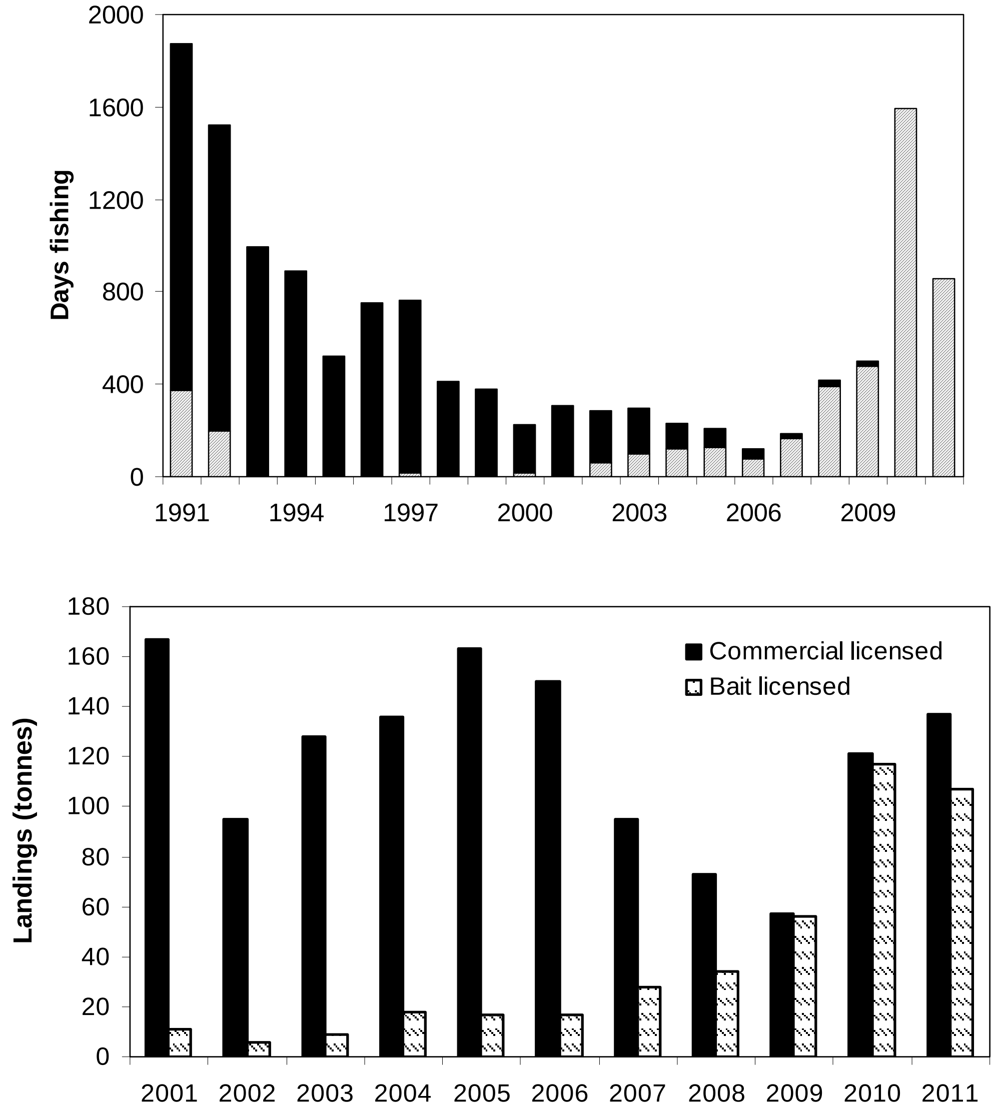


*Figure 5. The upper graph shows the fishing effort by trawlers directing for winter flounder in 4T (height of columns) and by trawlers directing for winter flounder in unit area 4Tf (Magdalen Islands fishery, hatched portion of columns). Bottom graph shows winter flounder landings since 2001 by commercially licensed boats on the Magdalen Islands, compared with landings by vessels specially licensed to fish winter flounder for bait.*

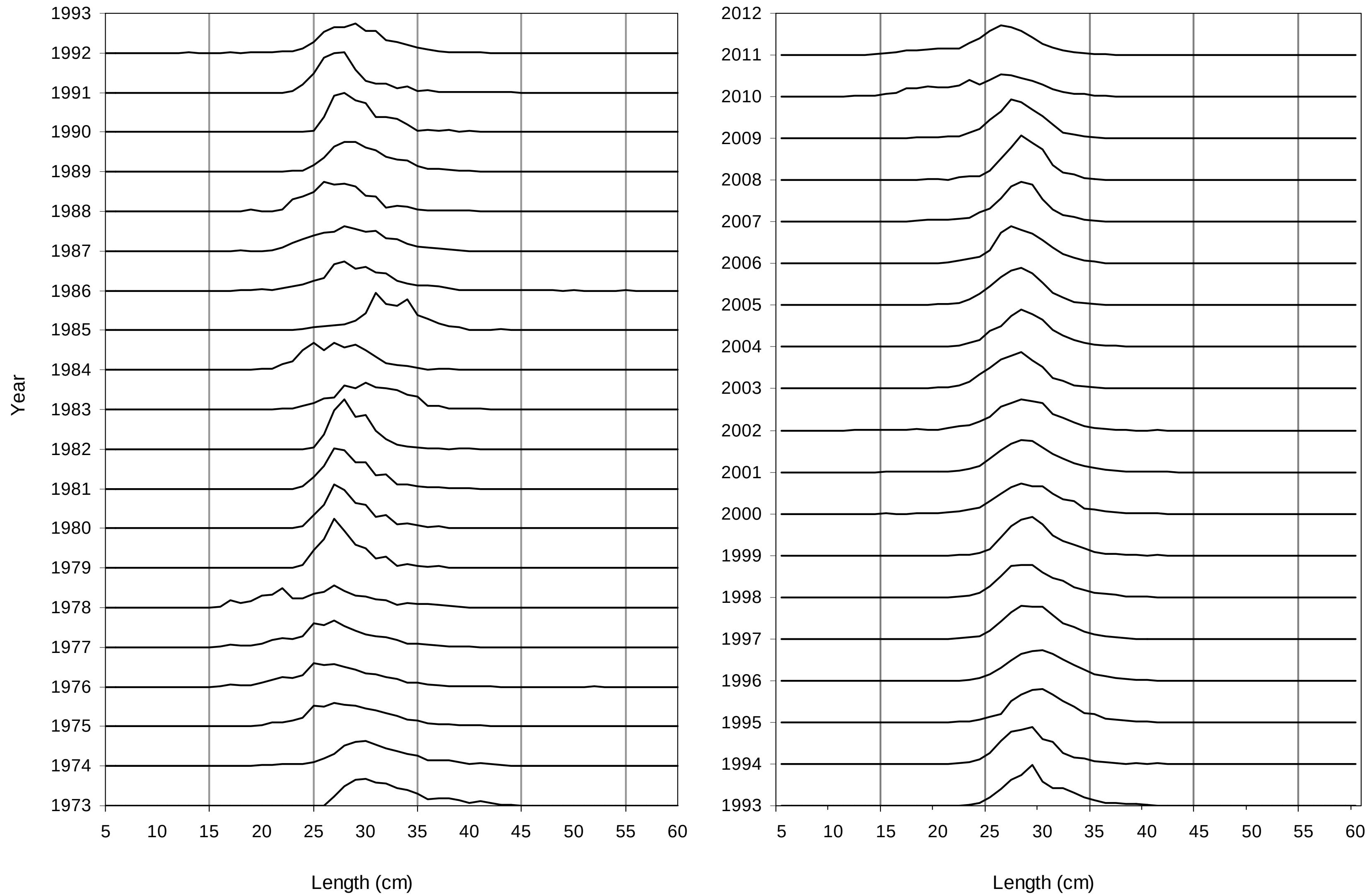


*Figure 6. The size composition of 4T winter flounder in commercial fisheries estimated from commercial catch sampling.*

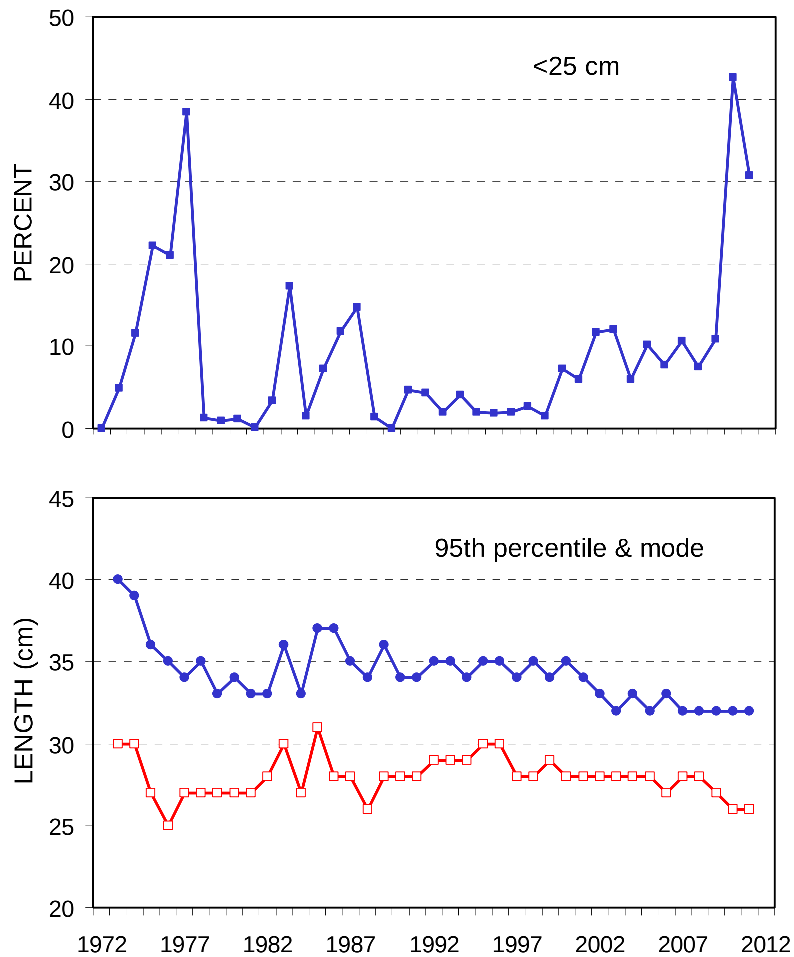


*Figure 7. Indicators of change in the size composition of winter flounder in the 4T commercial fishery since 1973. The upper graph shows the percent of annual catches below the present legal minimum size of 25 cm. The lower graph shows the 95 percentile of fish length (blue) and modal length (red) in commercial landings.*

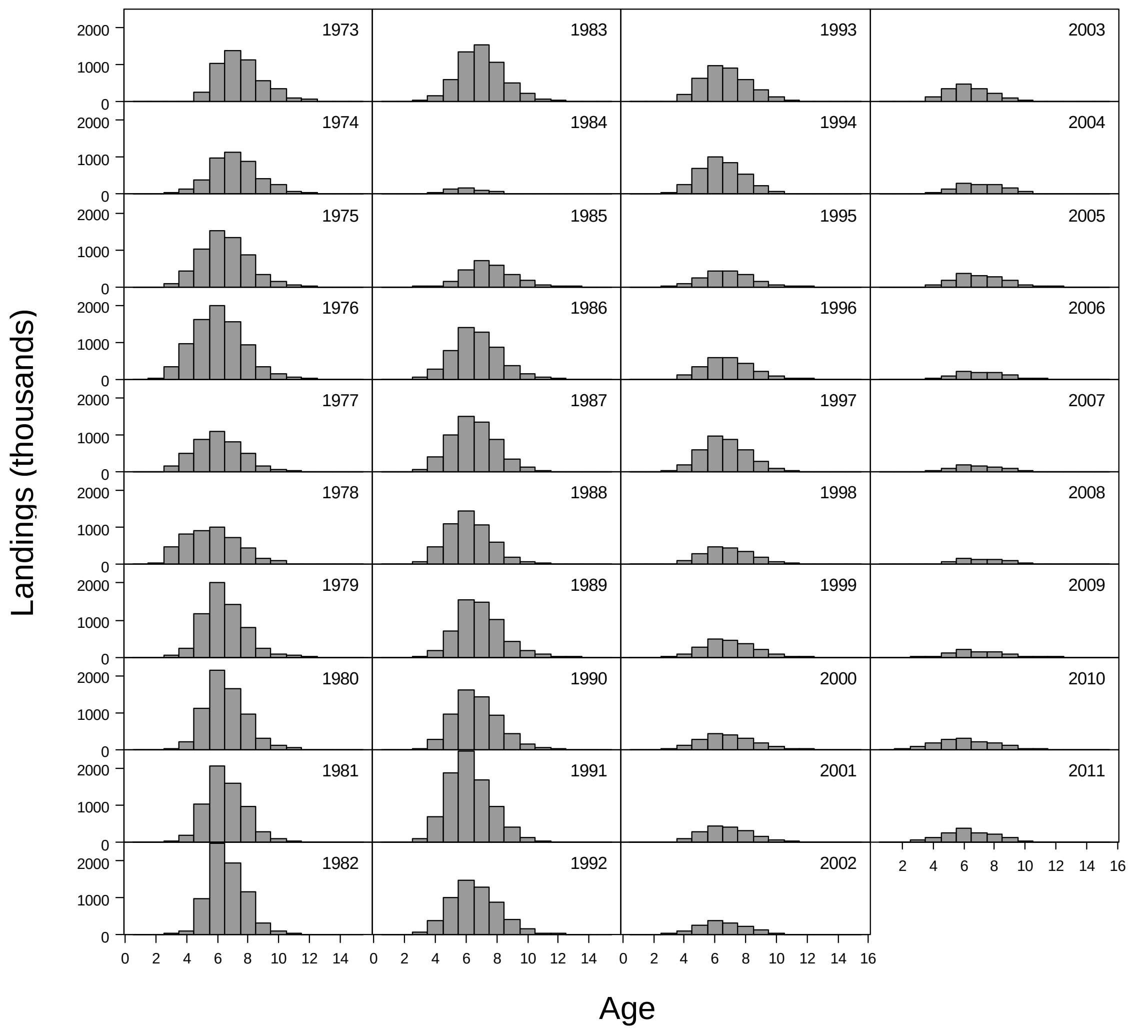


*Figure 8. Commercial catch-at-age (numbers) of NAFO 4T winter flounder.*

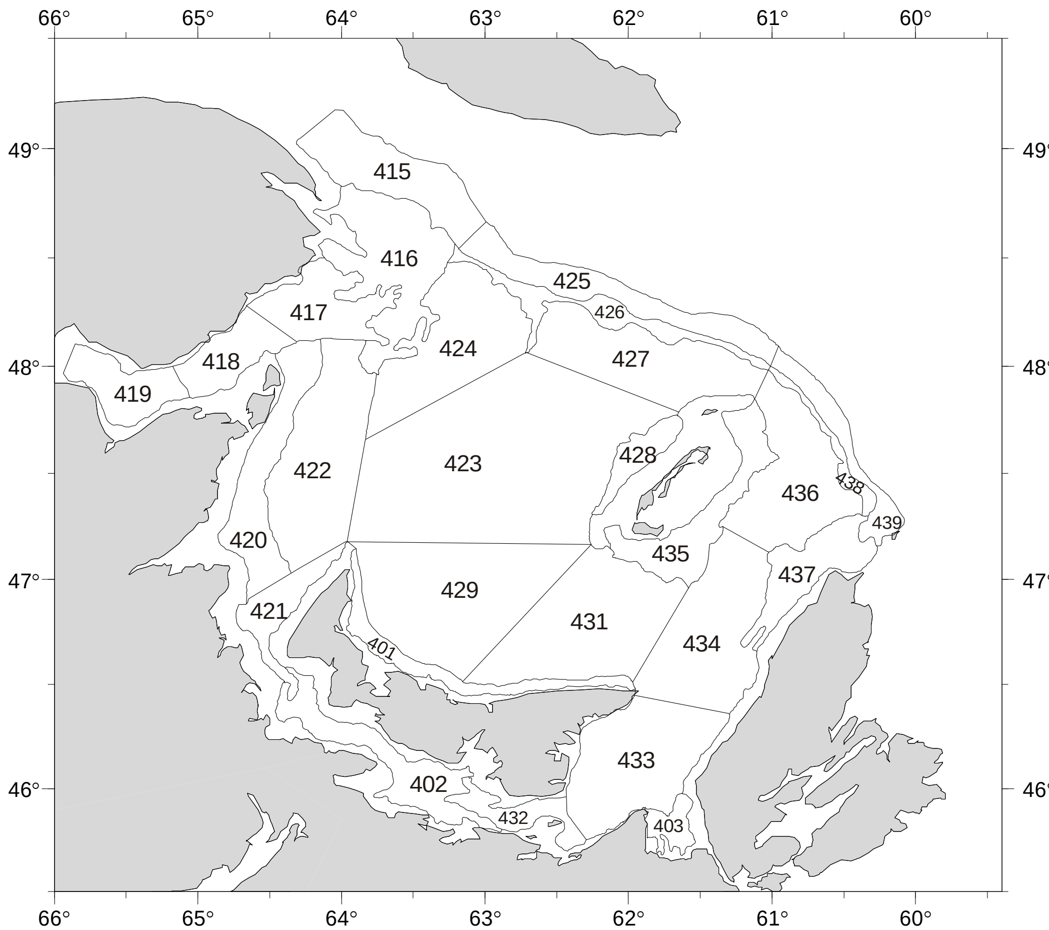


*Figure 9. Stratification of the annual ecosystem trawl survey in the southern Gulf of St. Lawrence.*

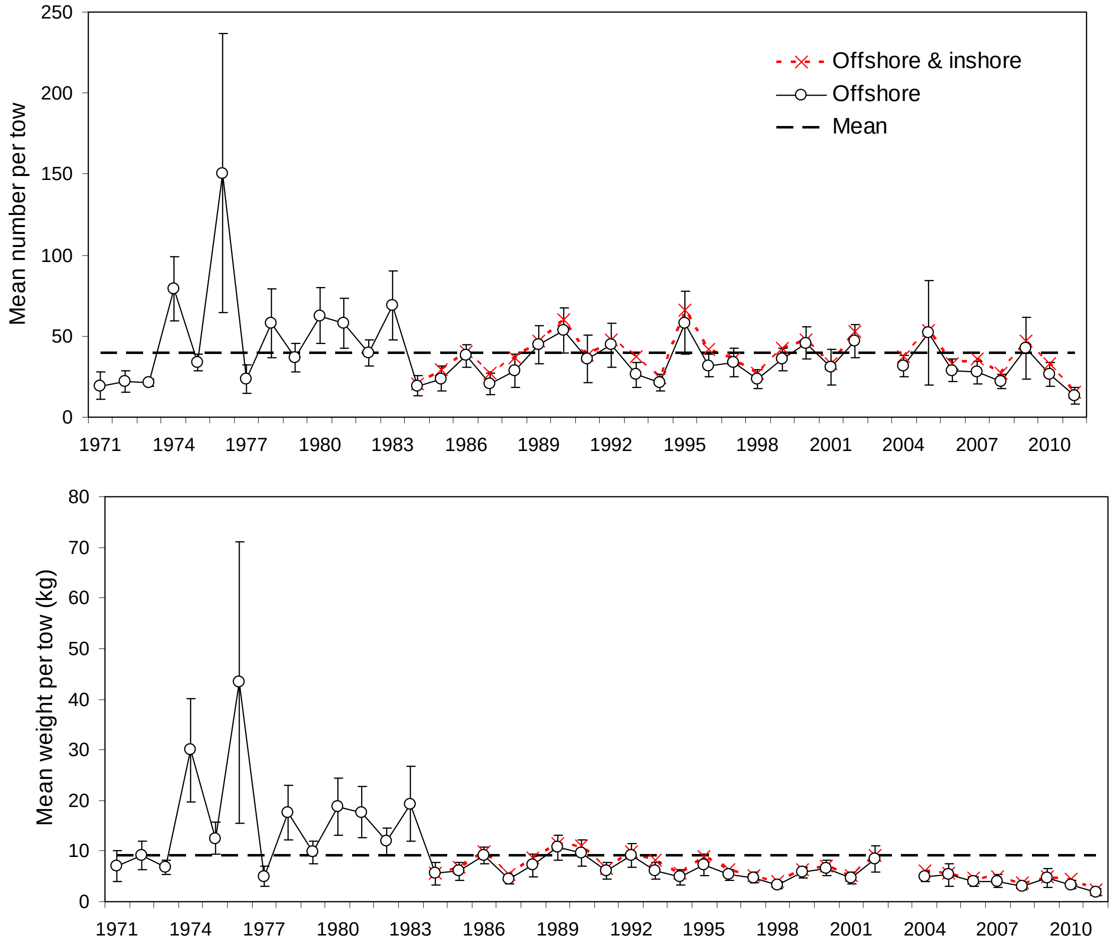


*Figure 10. Catch indices, by number and weight, of winter flounder in annual 4T surveys. Solid line indicates catch rates in strata 415-439, ± one standard deviation. Dashed red lines indicate indices with inshore strata 401-403, sampled since 1984. The horizontal dashed black line indicates the series mean.*

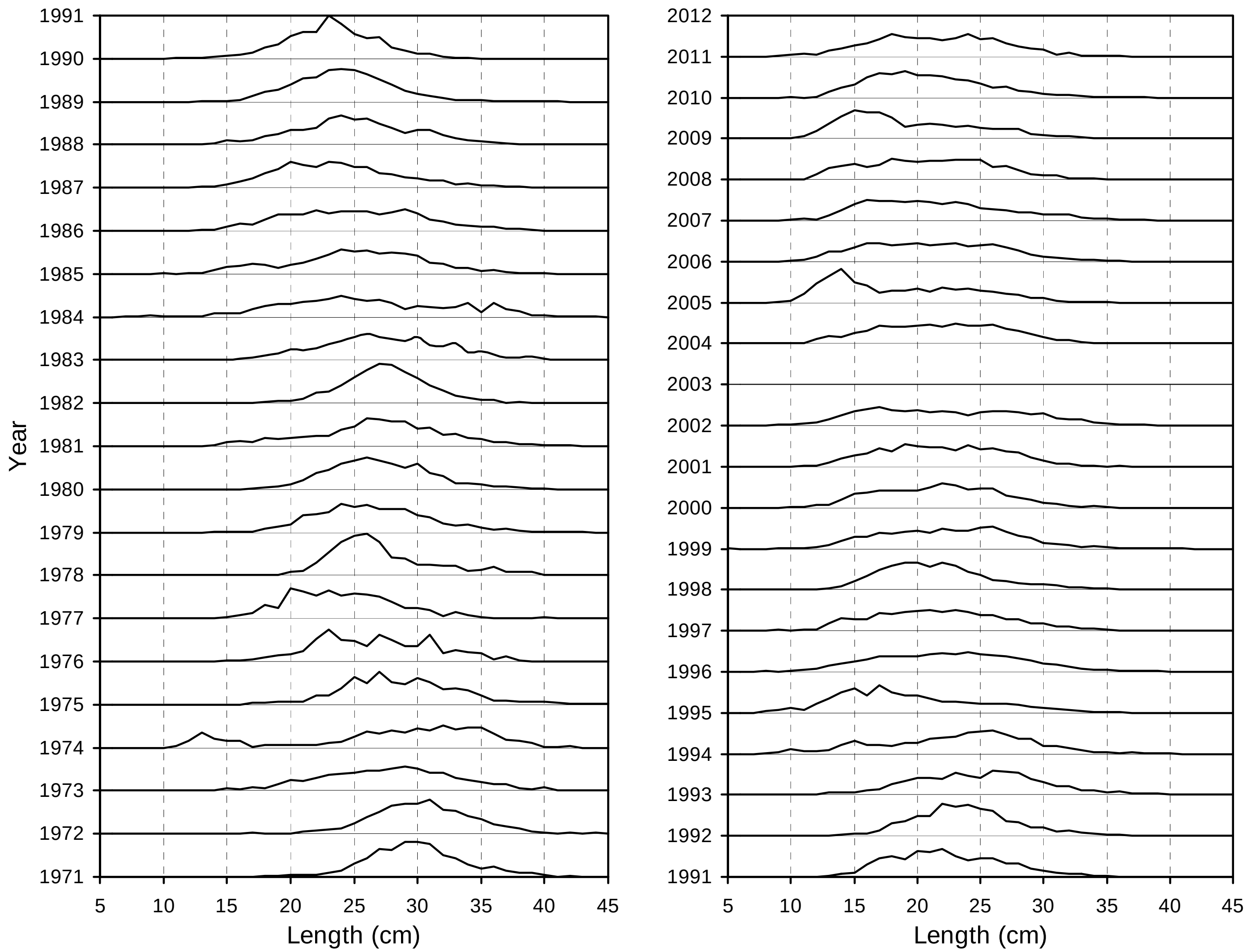


*Figure 11. The annual size composition of winter flounder from annual 4T groundfish surveys. Length frequencies are based on the annual proportion of the total catch, scaled to a maximum height of 1.*

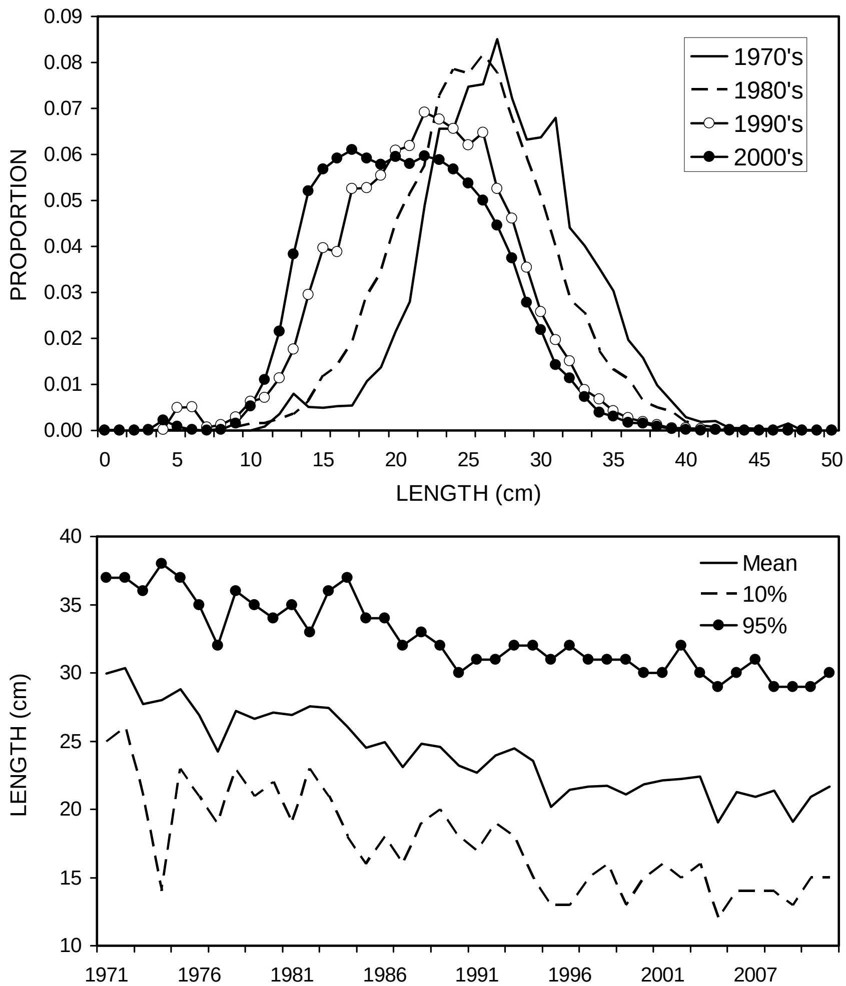


*Figure 12. Indicators of change in the length composition of 4T winter flounder in annual surveys. Upper graph shows the proportion of abundance at length with data grouped by decade. Lower graph shows annual estimates of the mean length and 10th and 95th percentiles of winter flounder lengths.*

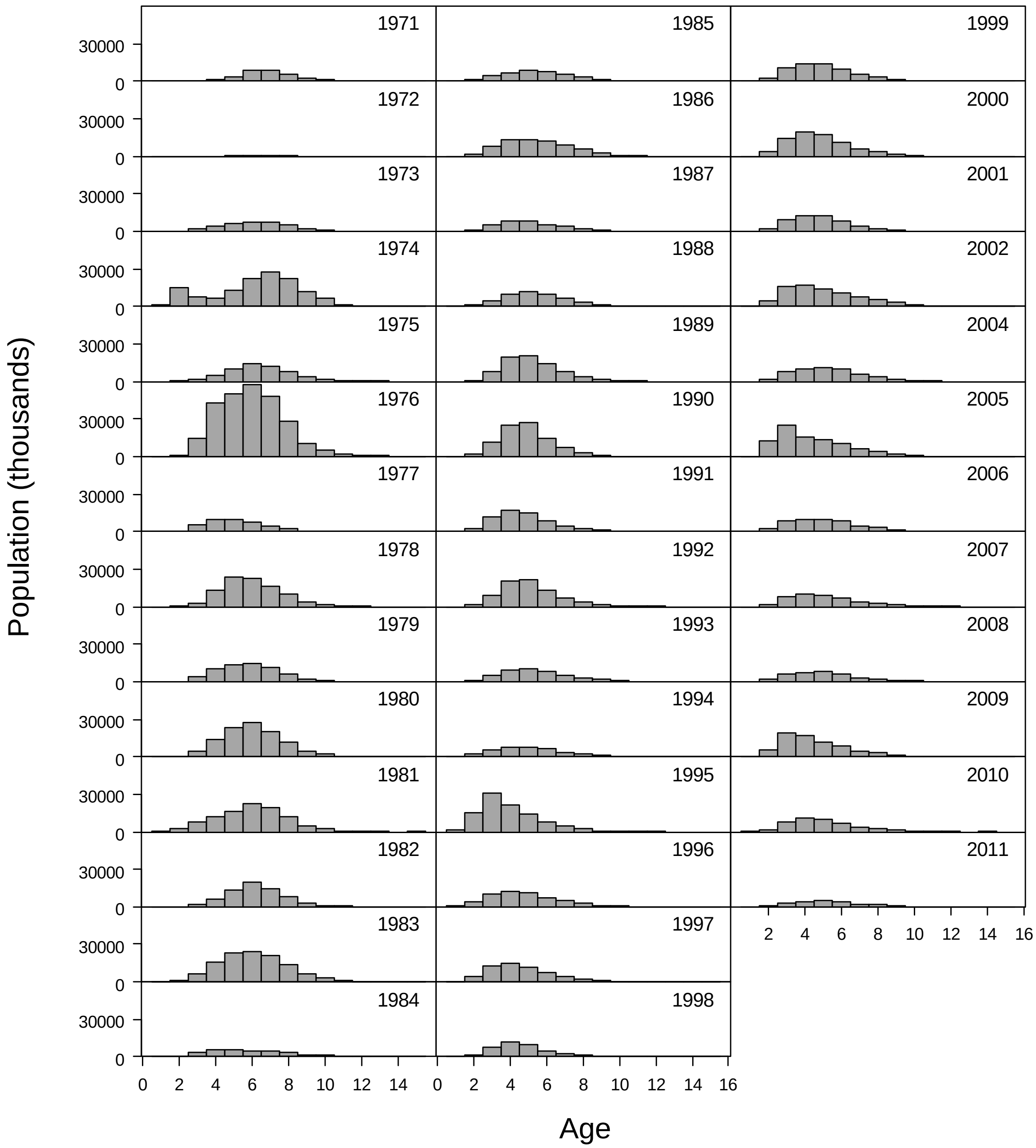


*Figure 13. Estimated survey population-at-age of 4T winter flounder, based on annual ecosystem surveys since 1971. Population estimates are unadjusted for the catchability of the survey gear.*

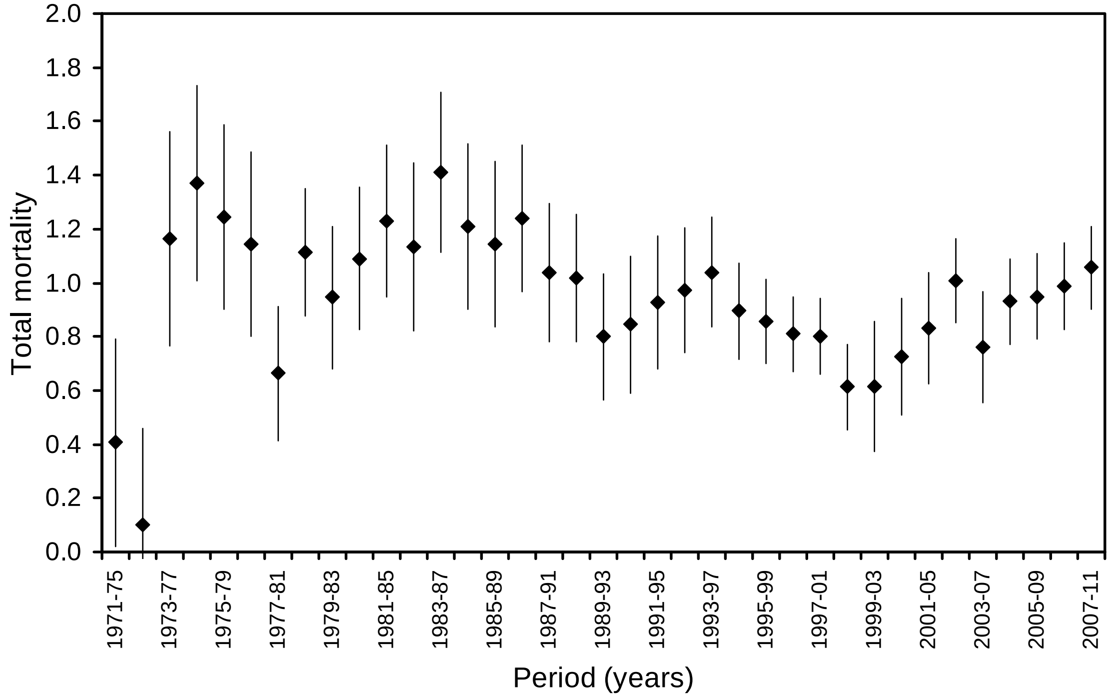


*Figure 14. Estimates of total mortality (Z ± 95% CI) based on population age structure in annual ecosystem surveys. Z was calculated on winter flounder ages 7+ in 5-year blocks.*

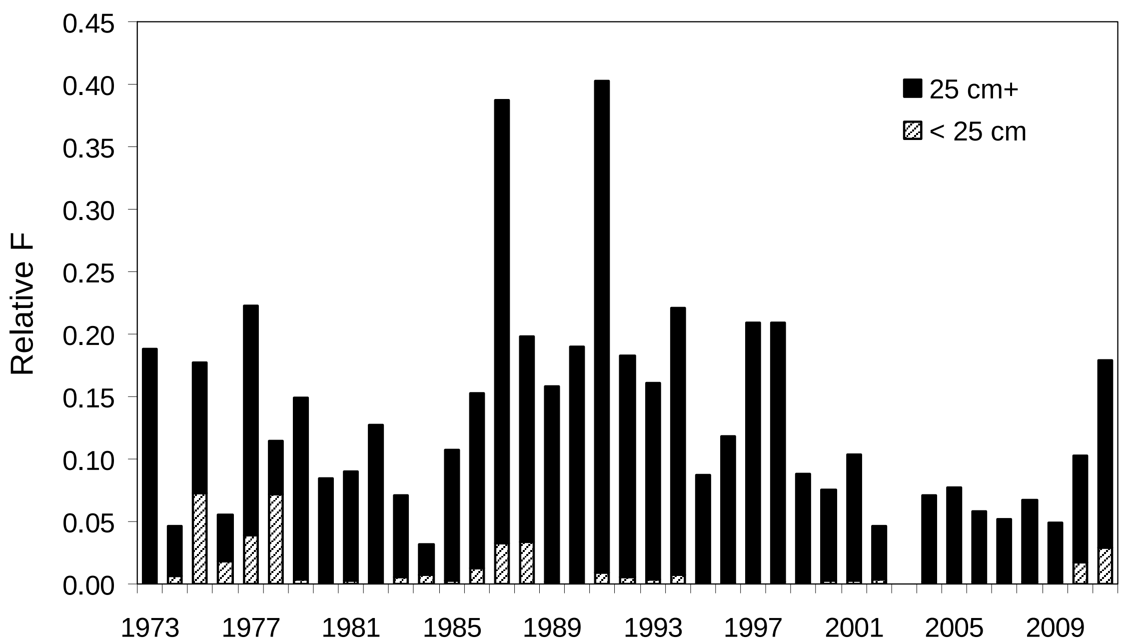


*Figure 15. Relative fishing mortality of 4T winter flounder. Relative F is the ratio of commercial catch-at-length to the survey population-at-length, shown here for two size categories.*

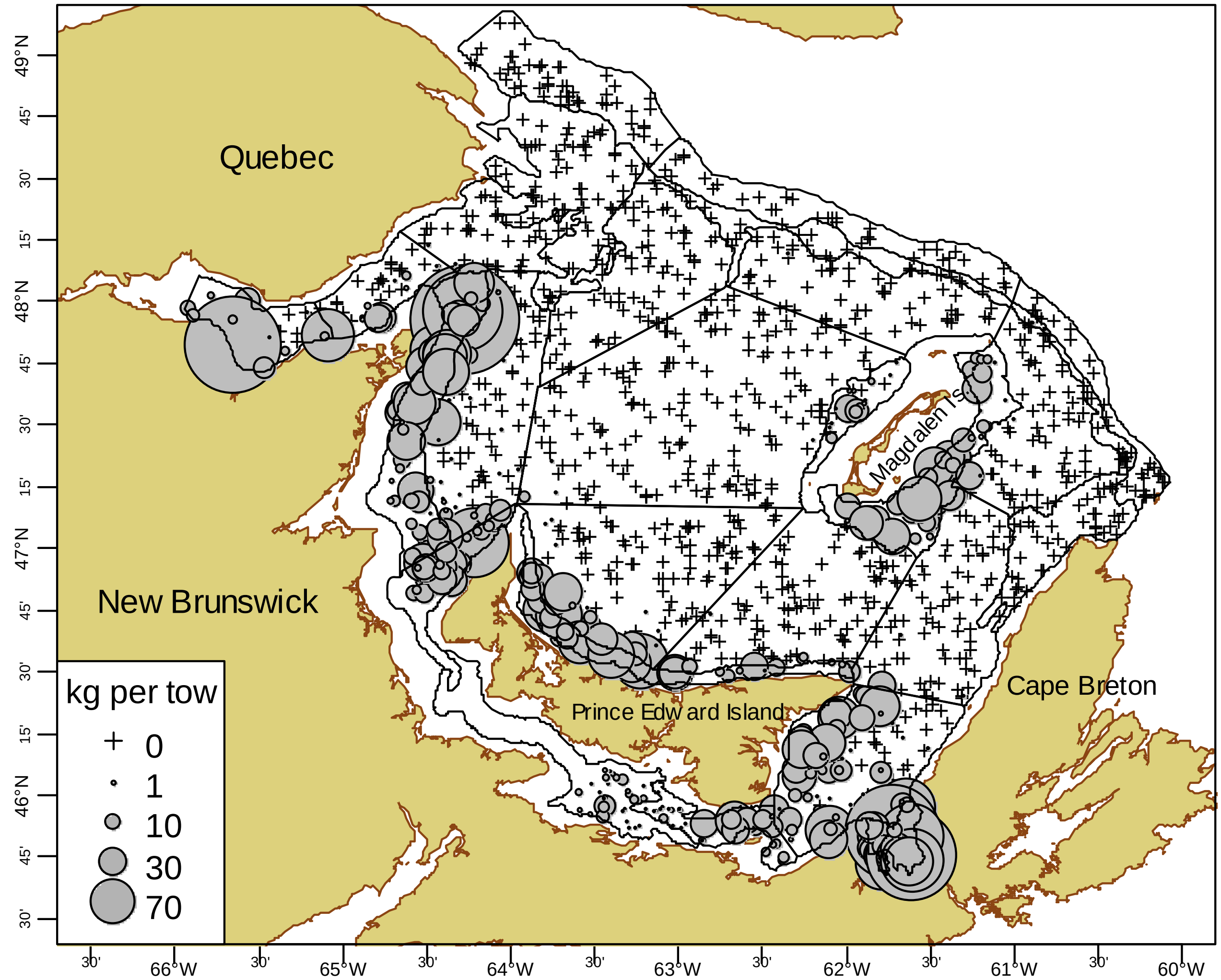


*Figure 16. Groundfish survey catches (kg per standard tow) of winter flounder for 2002 and 2004-2011. Circles indicate catches to a maximum of 424 kg per tow; + signifies a null catch.*

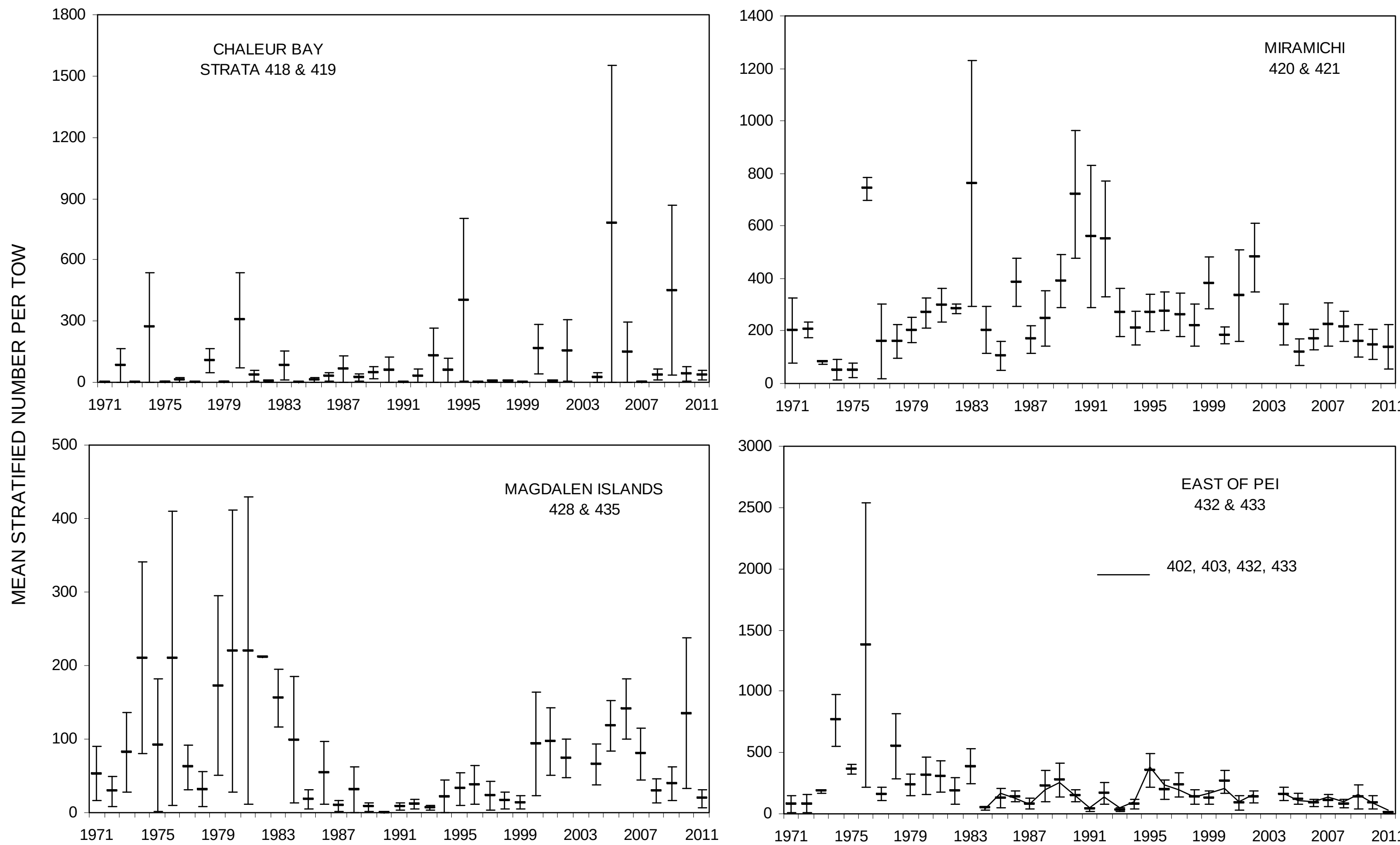


*Figure 17. Catch rates (± one standard deviation) of winter flounder in annual groundfish surveys, by sector of 4T. For the sector of PEI, the solid line indicates mean catch in the area with inshore strata that have been sampled since 1984. Note the difference in scaling for each area.*

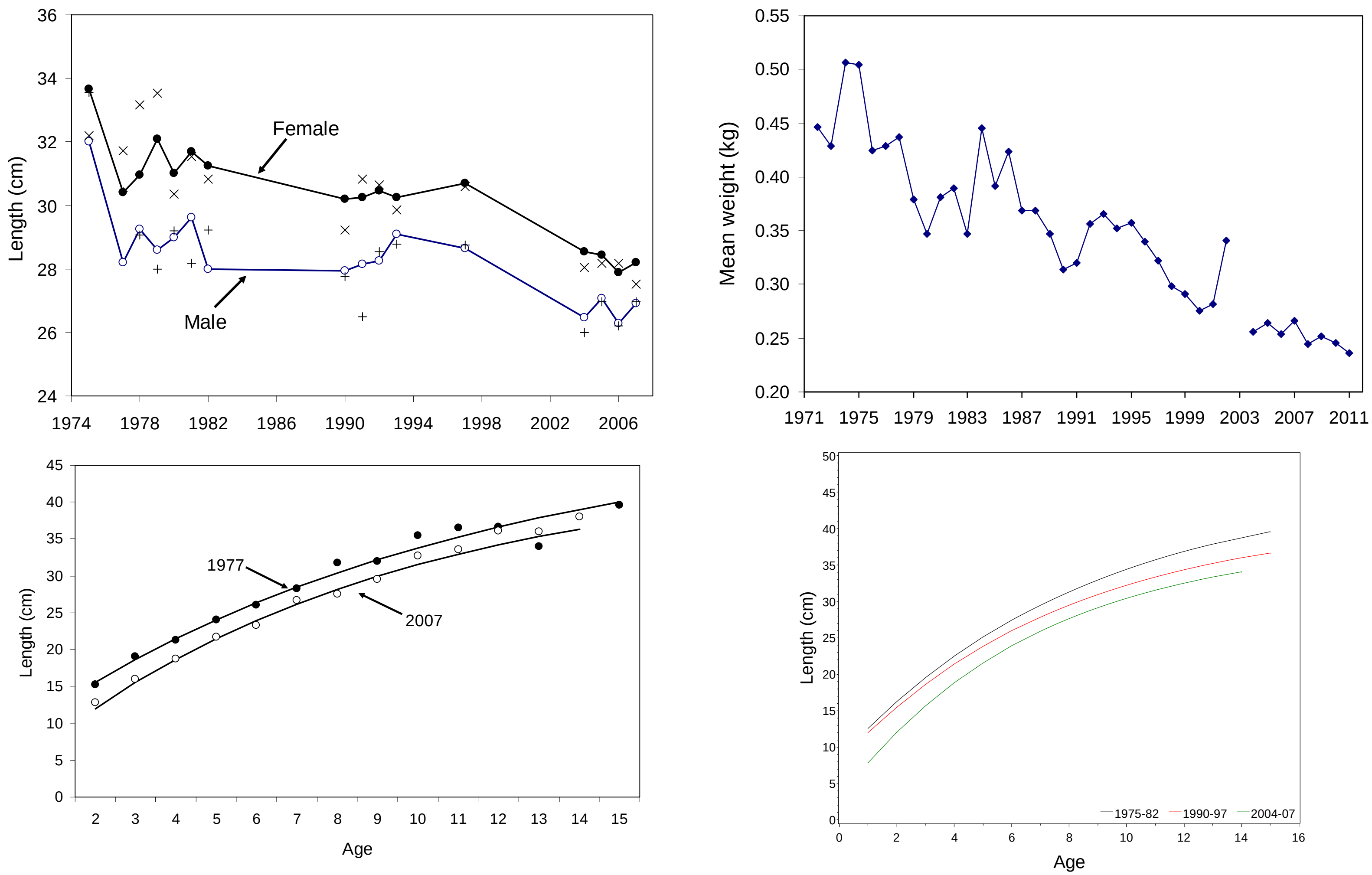


*Figure 18. Changes in the size-at-age of 4T winter flounder. Upper graphs show length and weight at 8 years-of-age (mean lengths, symbols; growth model estimates, lines). Lower graph at left shows model fits of the von Bertalanffy growth function to mean length at age for females in 1977 (closed symbols) and 2007 (open symbols); graph at lower right shows modeled growth of males and females combined in periods indicated.*

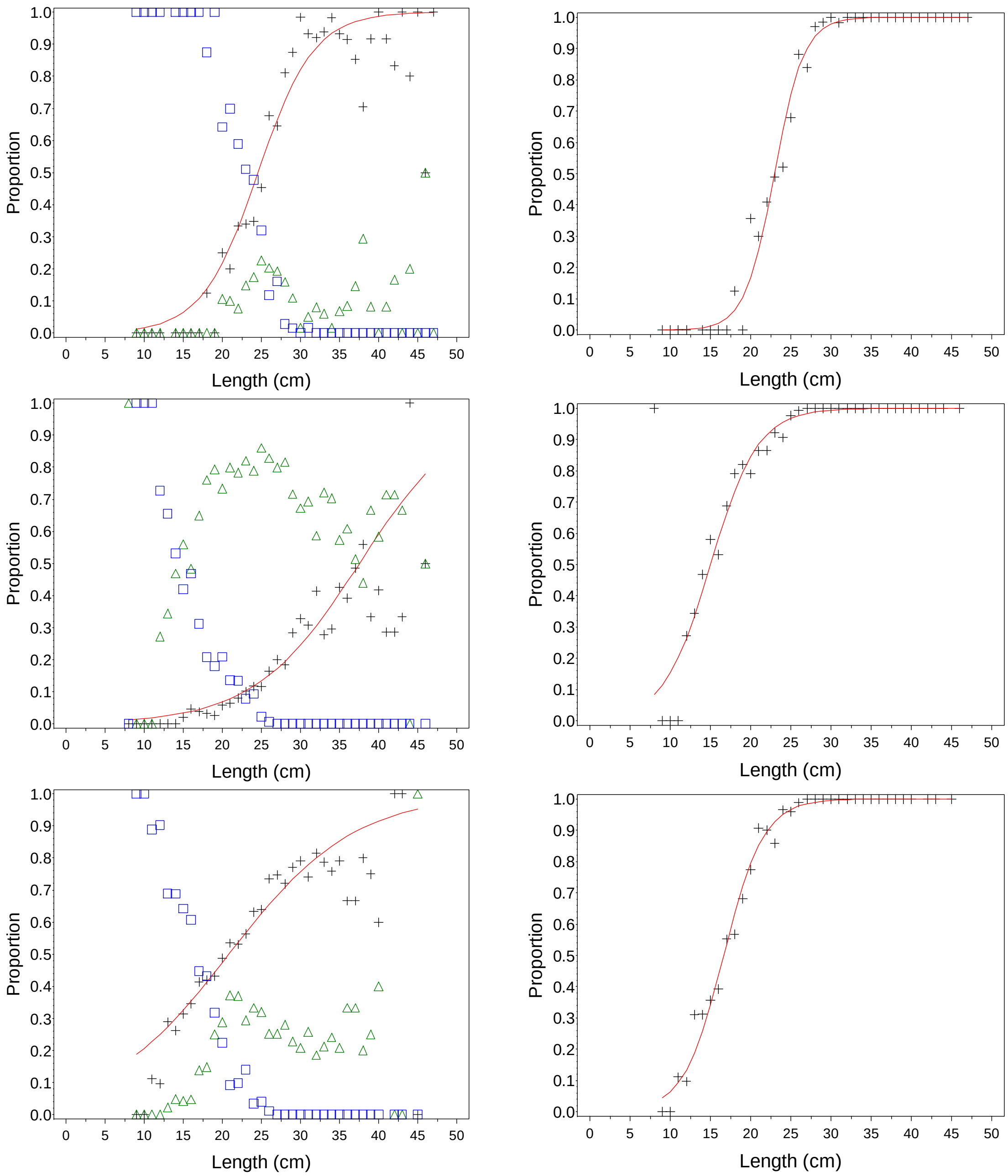


*Figure 19. Female winter flounder maturity: upper graphs 1975-1982; middle graphs 1990-1994; lower graphs 2004-2007. Graphs at left show proportion at length by maturity stages: stage 1 (immature), squares; stage8 (resting), triangles; stages 2-6 (maturing & spawning), + symbol with fitted logistic curve. Graphs at right show proportion of mature females, including stage 8.*

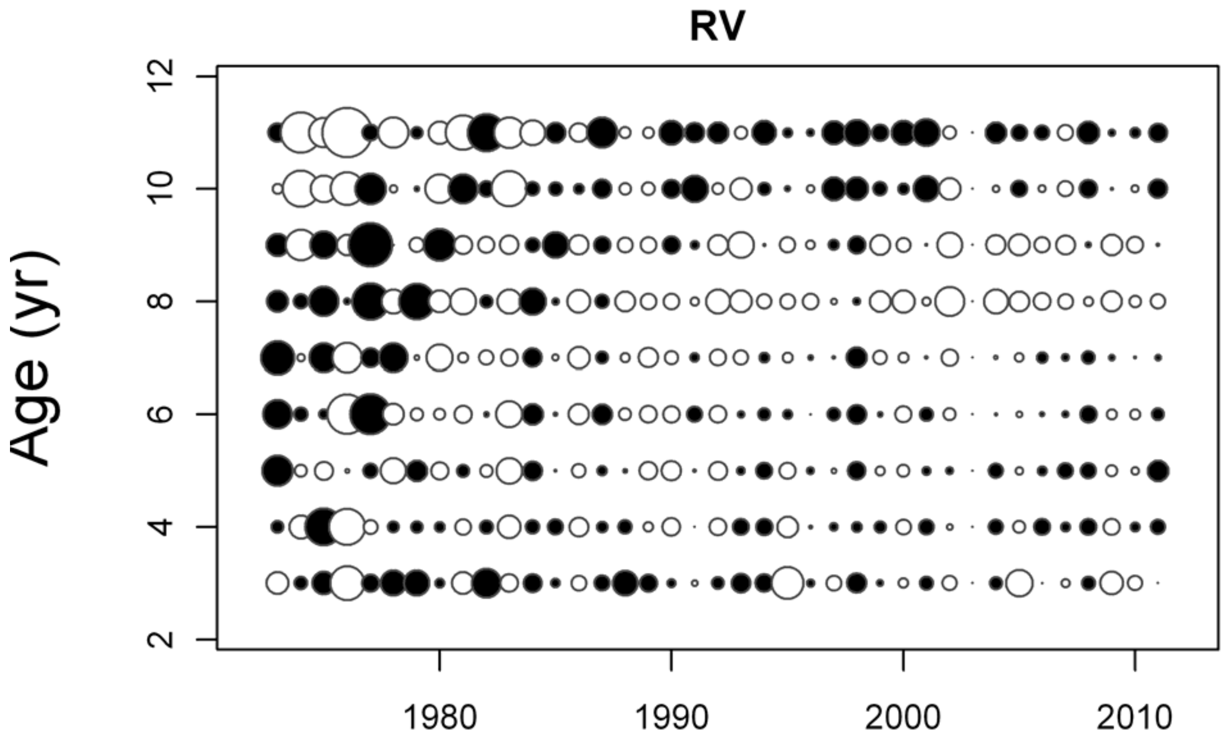

*Figure 20. Residuals between the survey (RV) indices and their predicted values from the population model. Black circles indicate negative residuals (index less than the predicted value).*

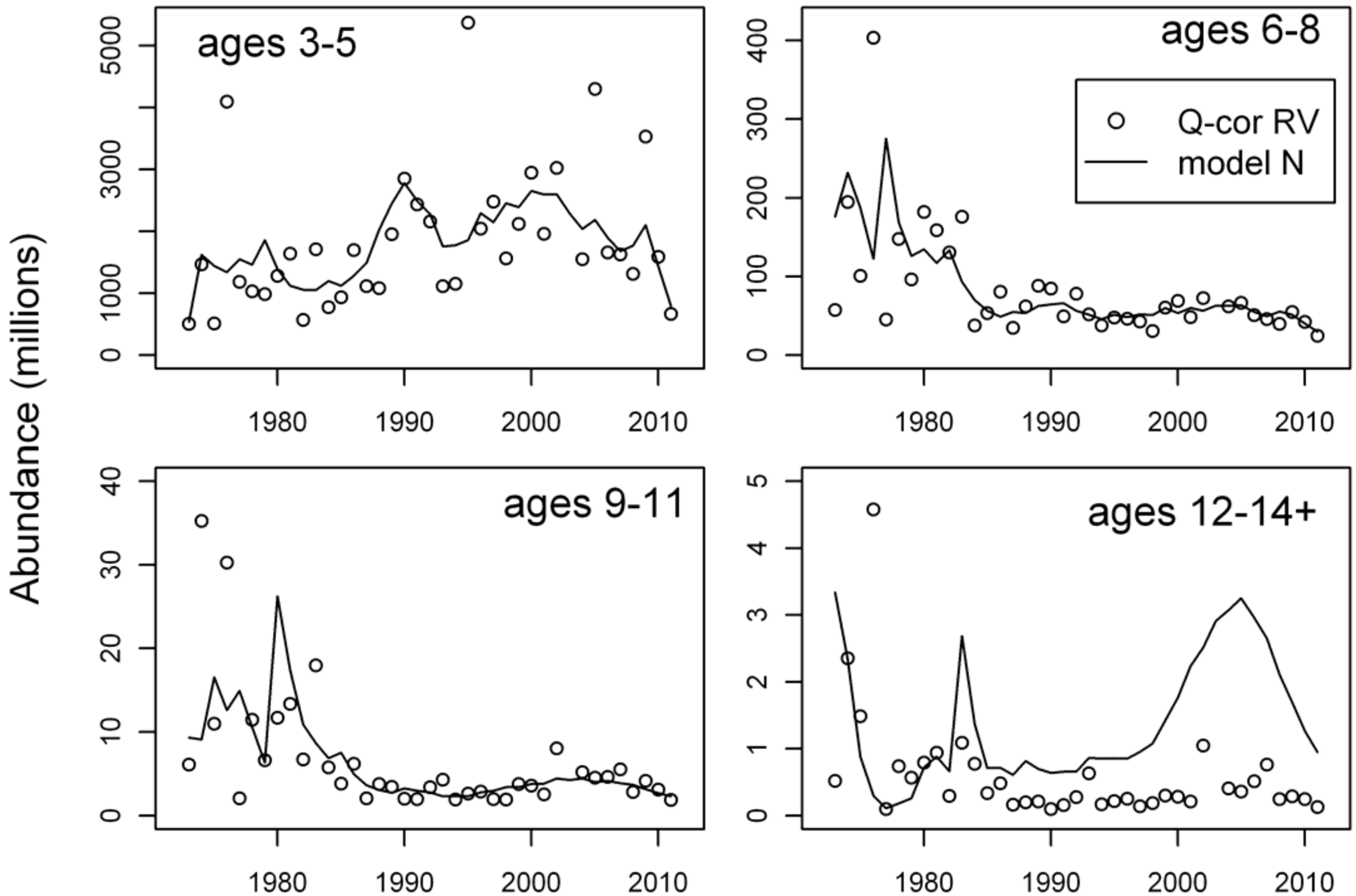


*Figure 21. Comparison between q-corrected abundance indices and model estimates of abundance (adjusted to September). Catchability for ages 12 - 14+ was assumed to equal that for age 11.*

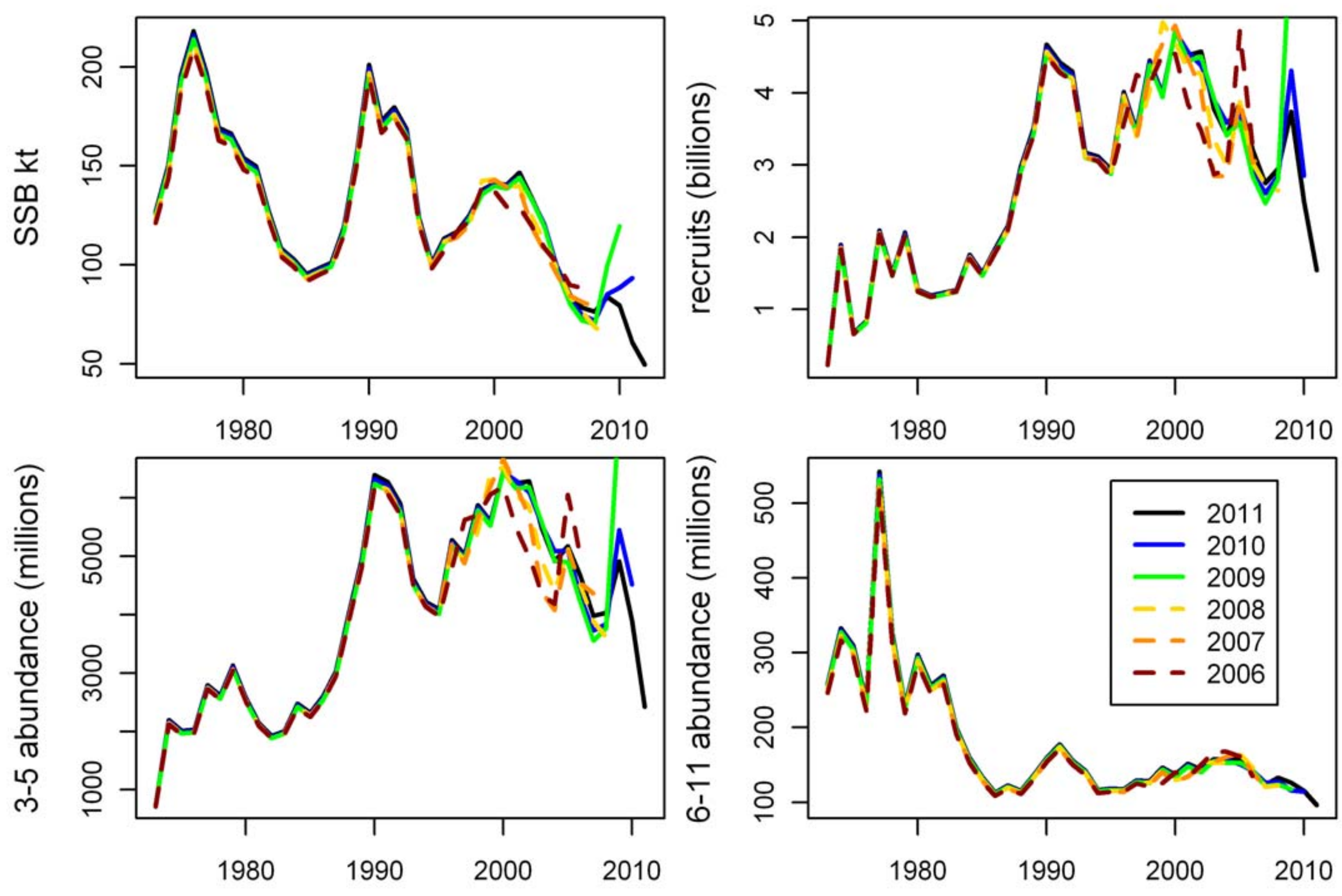


*Figure 22. Retrospective analysis for spawning stock biomass (SSB), abundances of age-3 recruits, and age groups 3-5 and 6-11 years. Legend indicates the last year included in the analysis.*

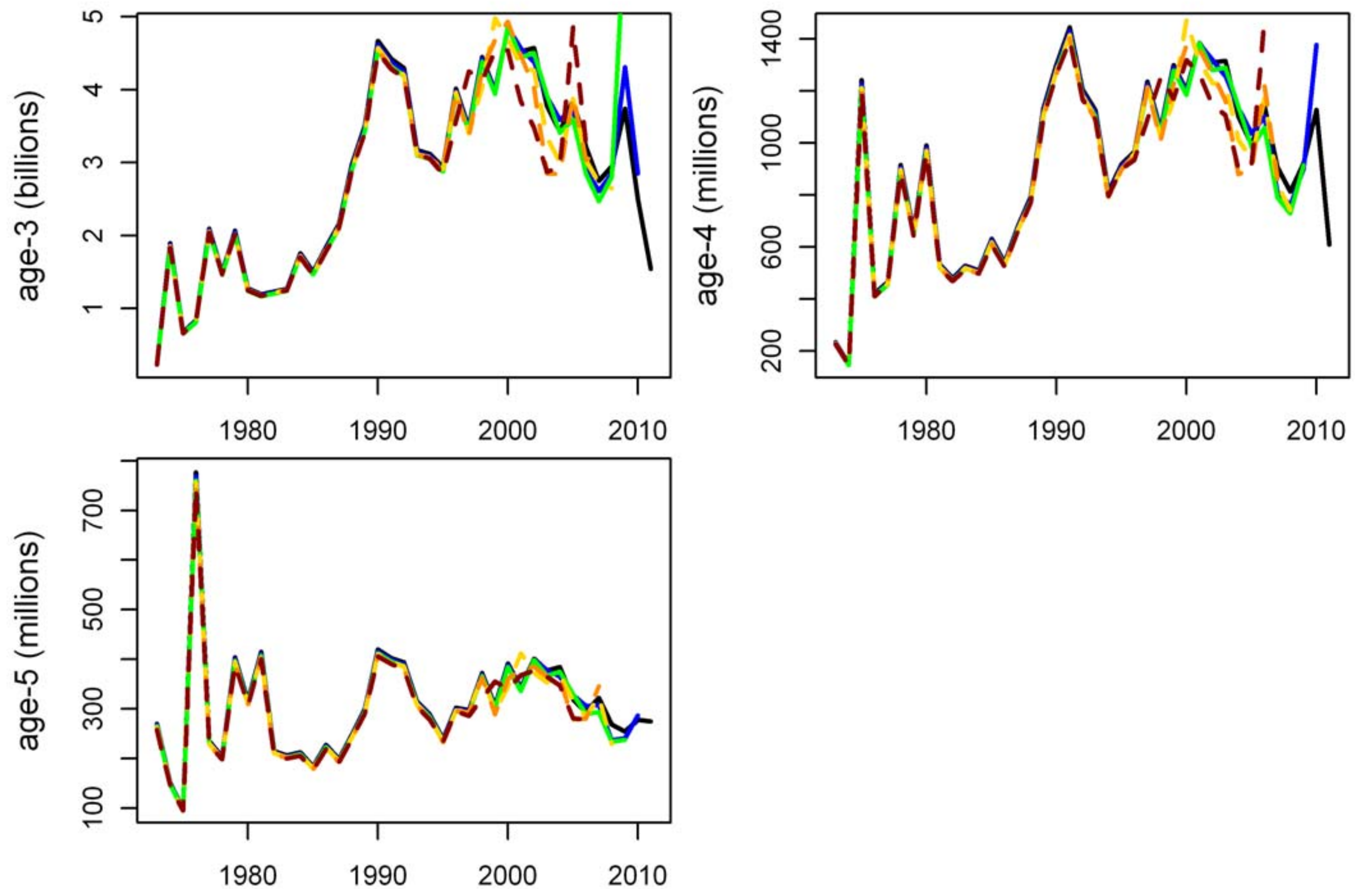


*Figure 23. Retrospective analysis for winter flounder 3, 4 or 5 years of age. Legend as in Figure 22.*

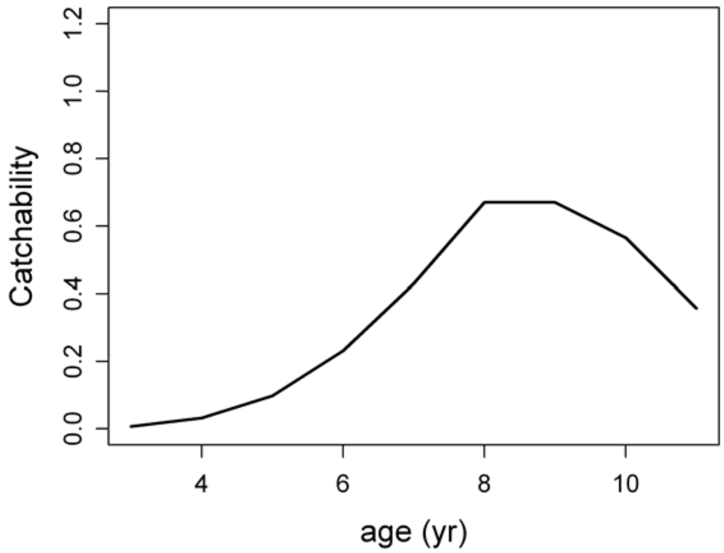


*Figure 24. Estimated catchability of winter flounder to the RV survey of the southern Gulf of St. Lawrence.*

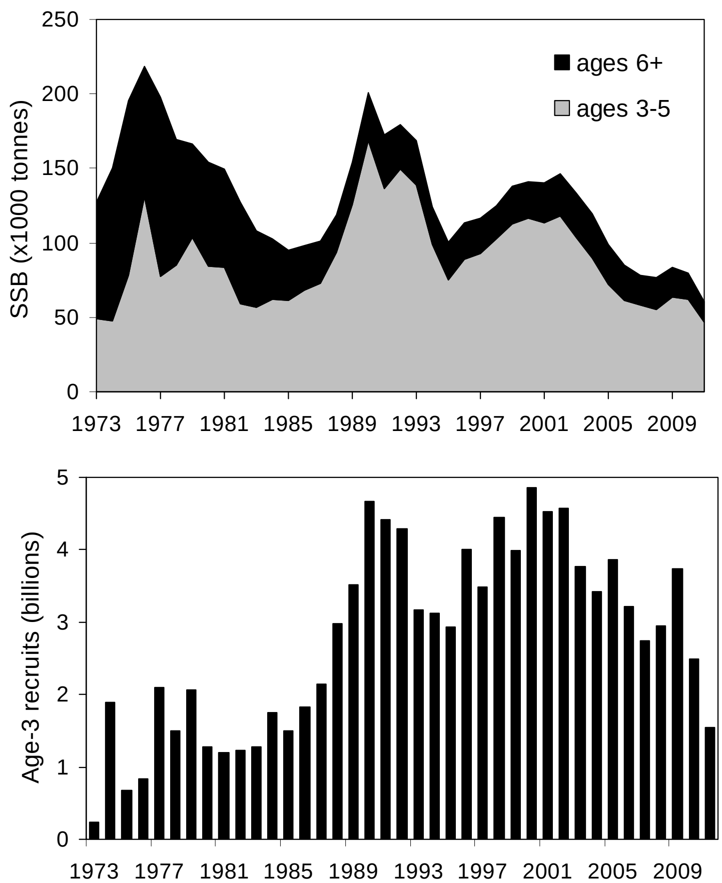


*Figure 25. Area graph showing changes in the age composition of the estimated spawning stock biomass (SSB, upper graph). The lower graph shows the abundance of age-3 recruits for winter flounder in the southern Gulf of St. Lawrence.*

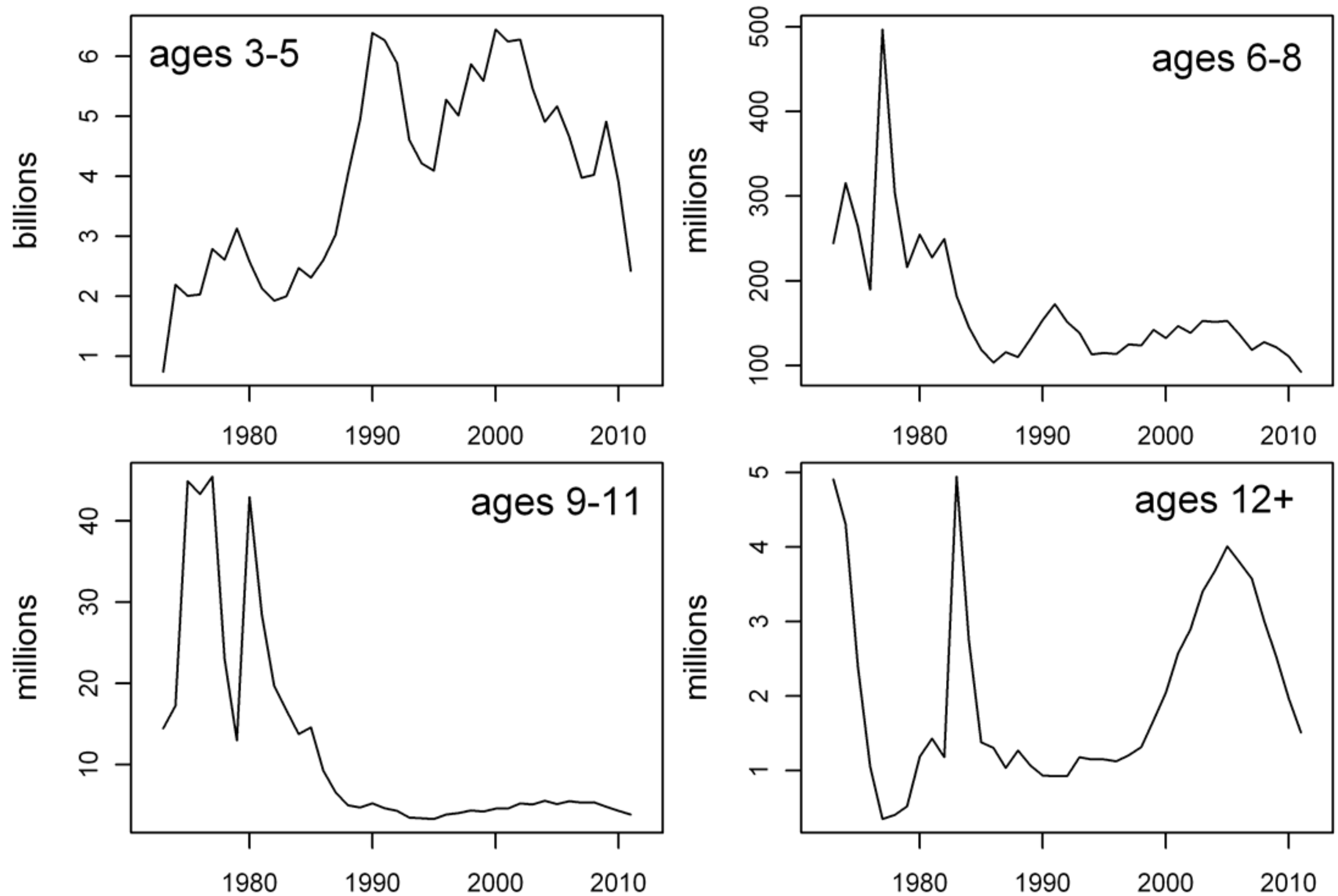


*Figure 26. Model estimates of the abundance of four age groups of winter flounder in the southern Gulf of St. Lawrence.*

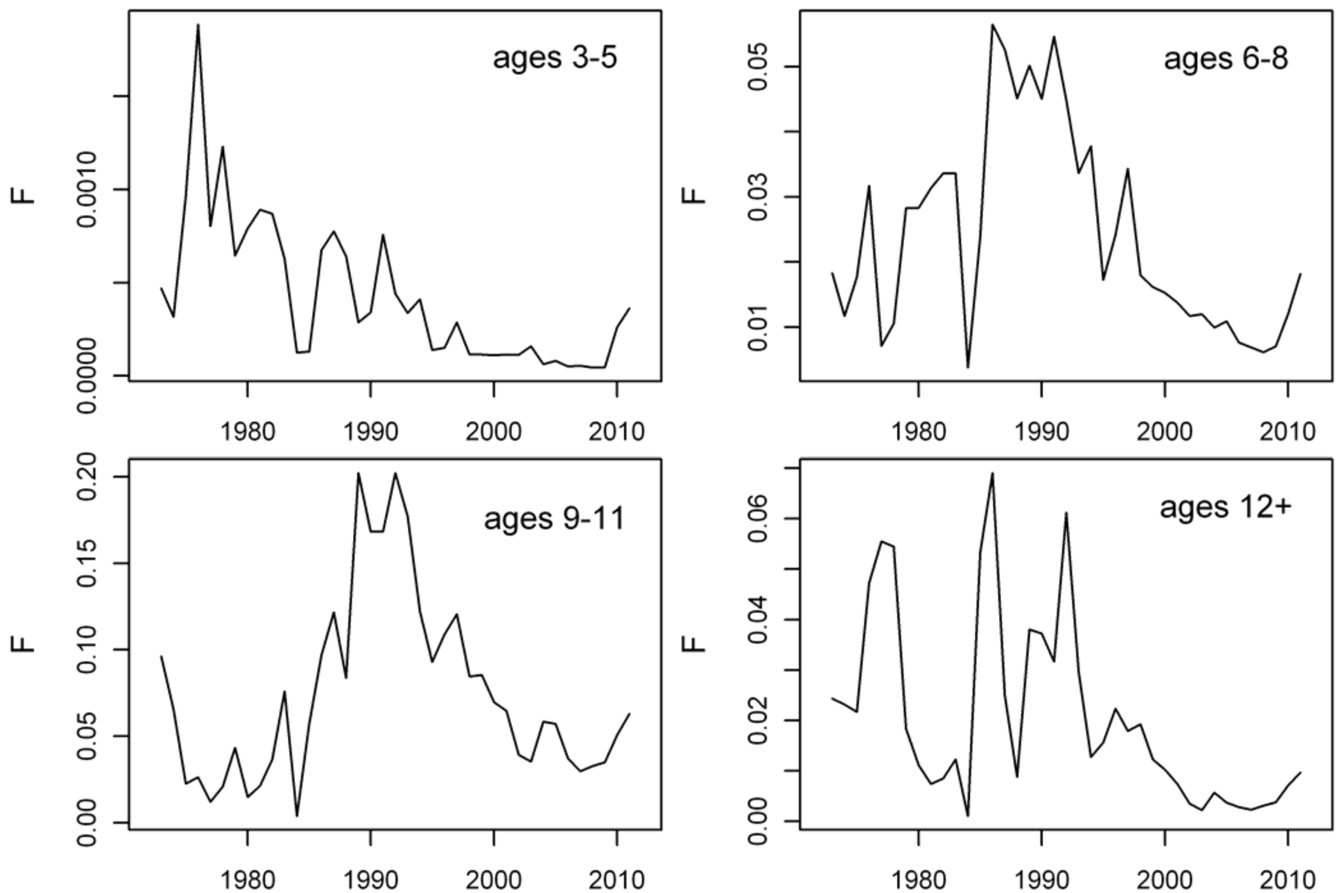


*Figure 27. Estimates of the instantaneous rate of fishing mortality (F) of four age groups of winter flounder in the southern Gulf of St. Lawrence.*

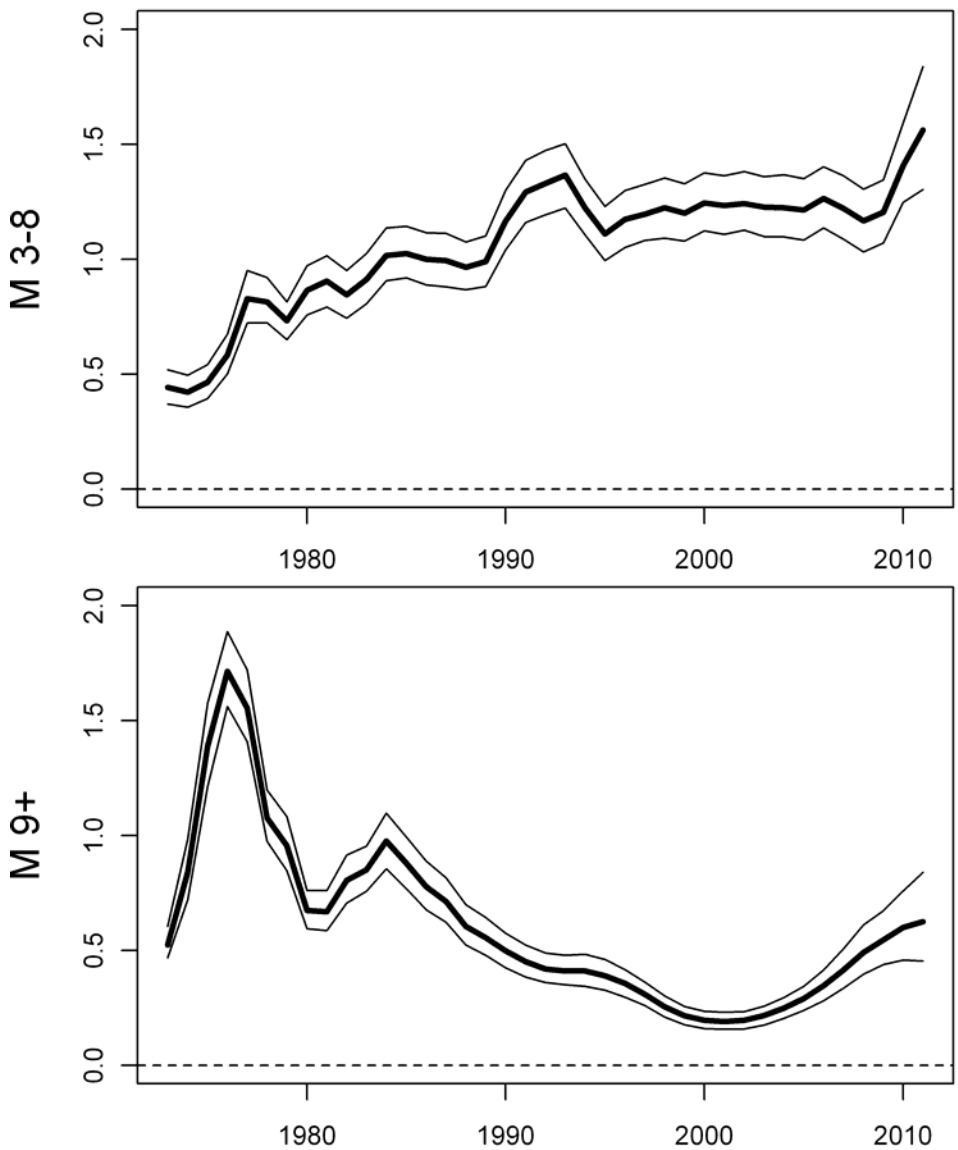


*Figure 28. Estimates of the instantaneous rate of natural mortality (M) of two age groups of winter flounder in the southern Gulf of St. Lawrence. Heavy lines show the median estimate and light lines the 2.5$^{th}$ and 97.5$^{th}$ percentiles of the posterior distribution.*

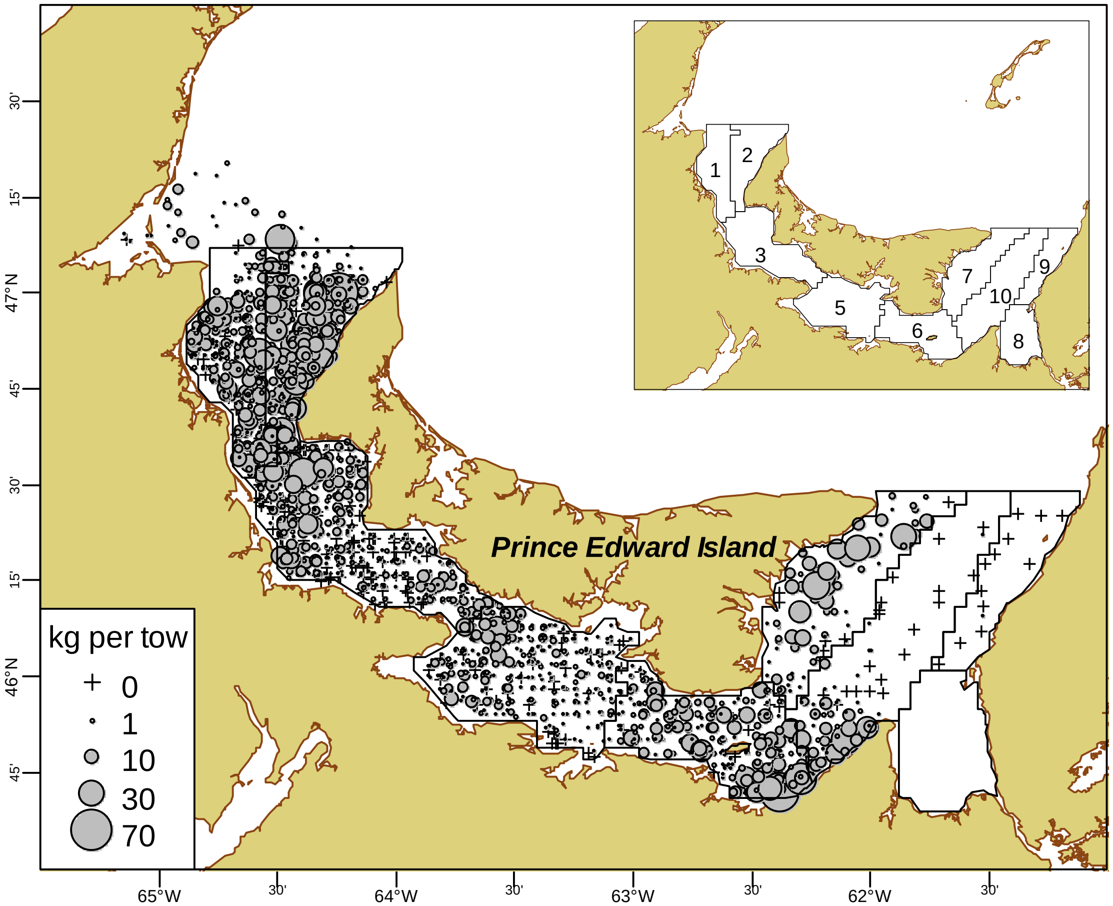


*Figure 29. Winter flounder standardized catches during the annual summer surveys of the Northumberland Strait for 2000-2009. Circles indicate catches to a maximum of 67.2 kg per tow; + signify null catches. Inset map shows the stratification scheme used for this survey.*

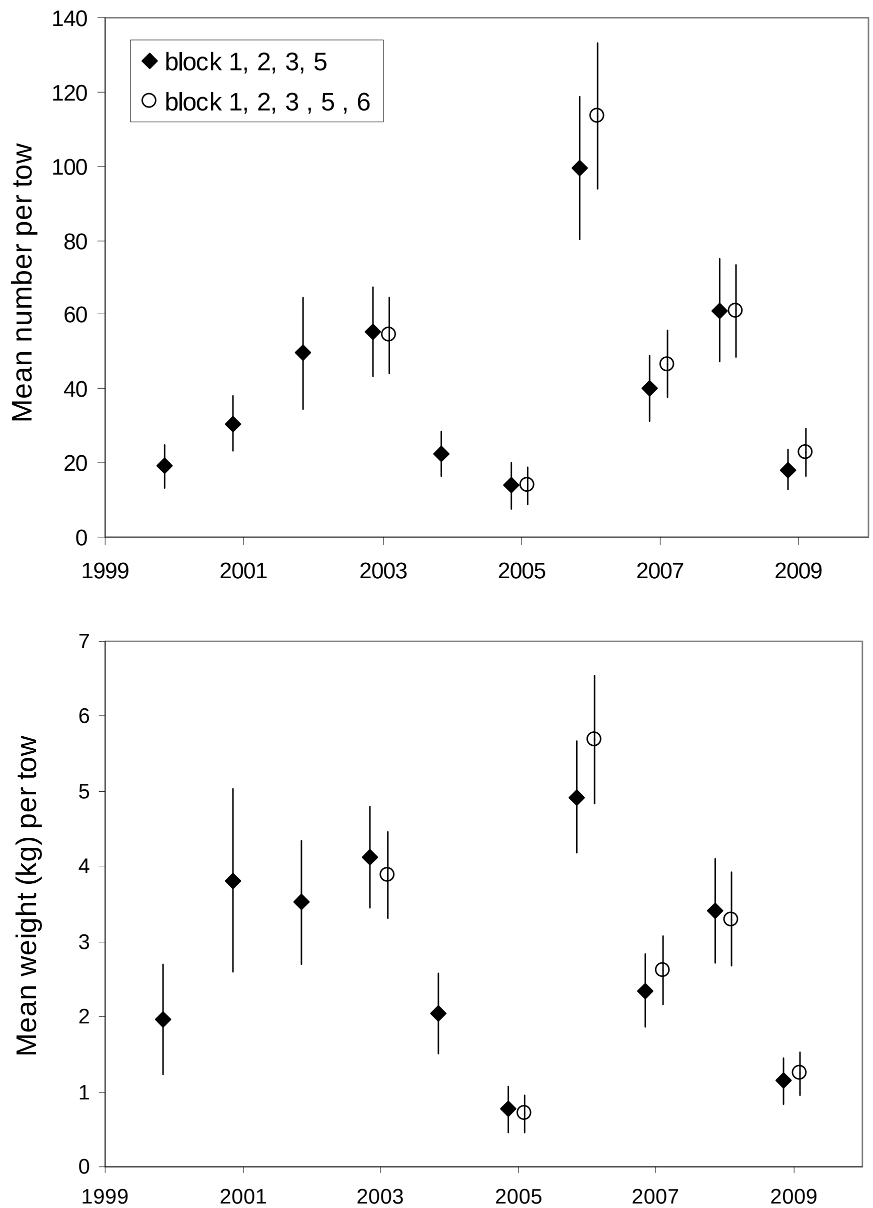


*Figure 30. Catch rates of winter flounder in the Northumberland Strait summer bottom-trawl surveys in two areas of survey coverage. Error bars indicate approximate 95% confidence intervals. Catch rates may be biased in 2002 and 2005 due to incomplete sampling in some strata.*

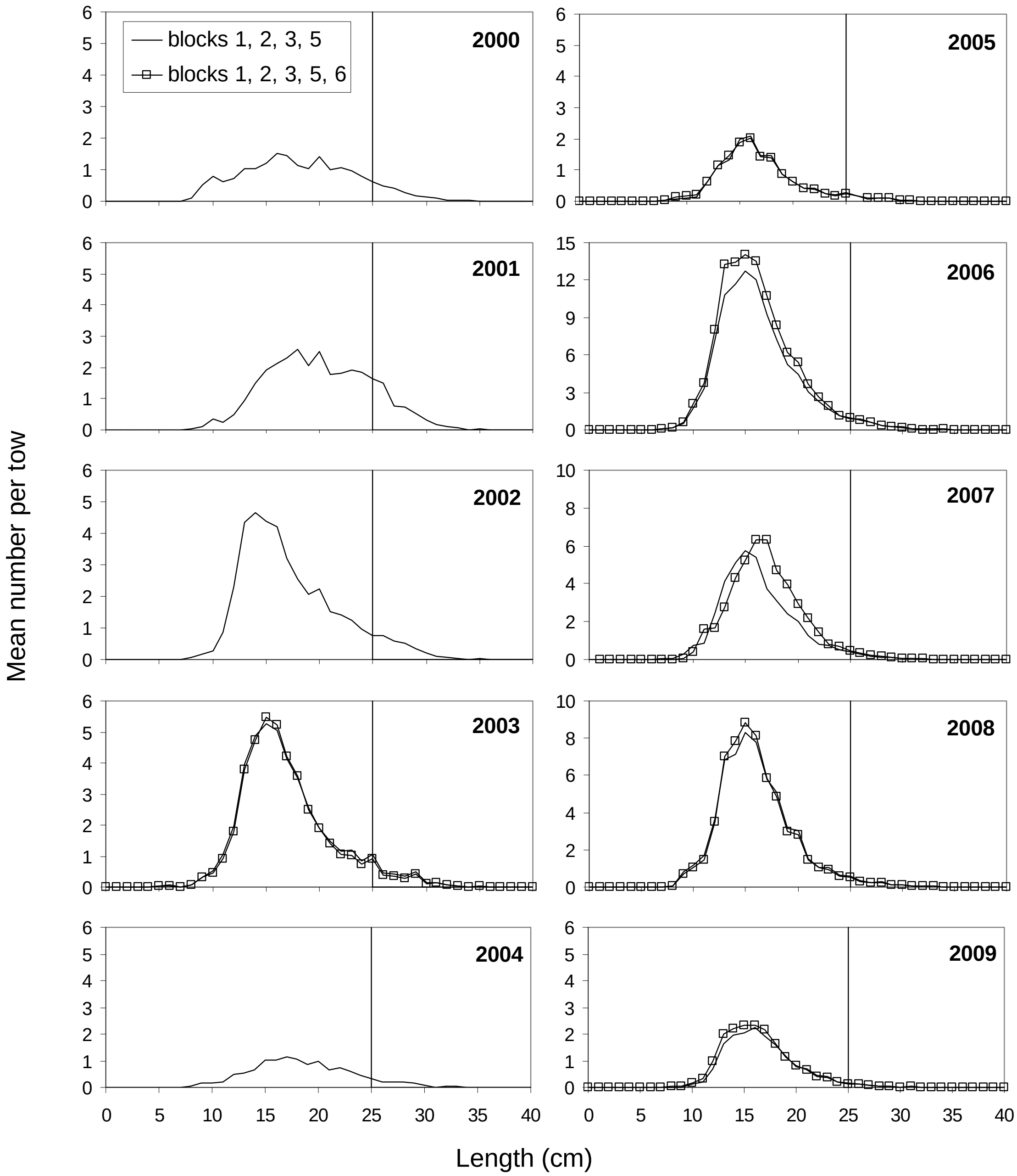


*Figure 31. Length frequencies (mean number per tow) of winter flounder caught during the Northumberland Strait surveys. The vertical line at 25 cm indicates the legal size in commercial fisheries. Note the different scales for 2006-2008.*

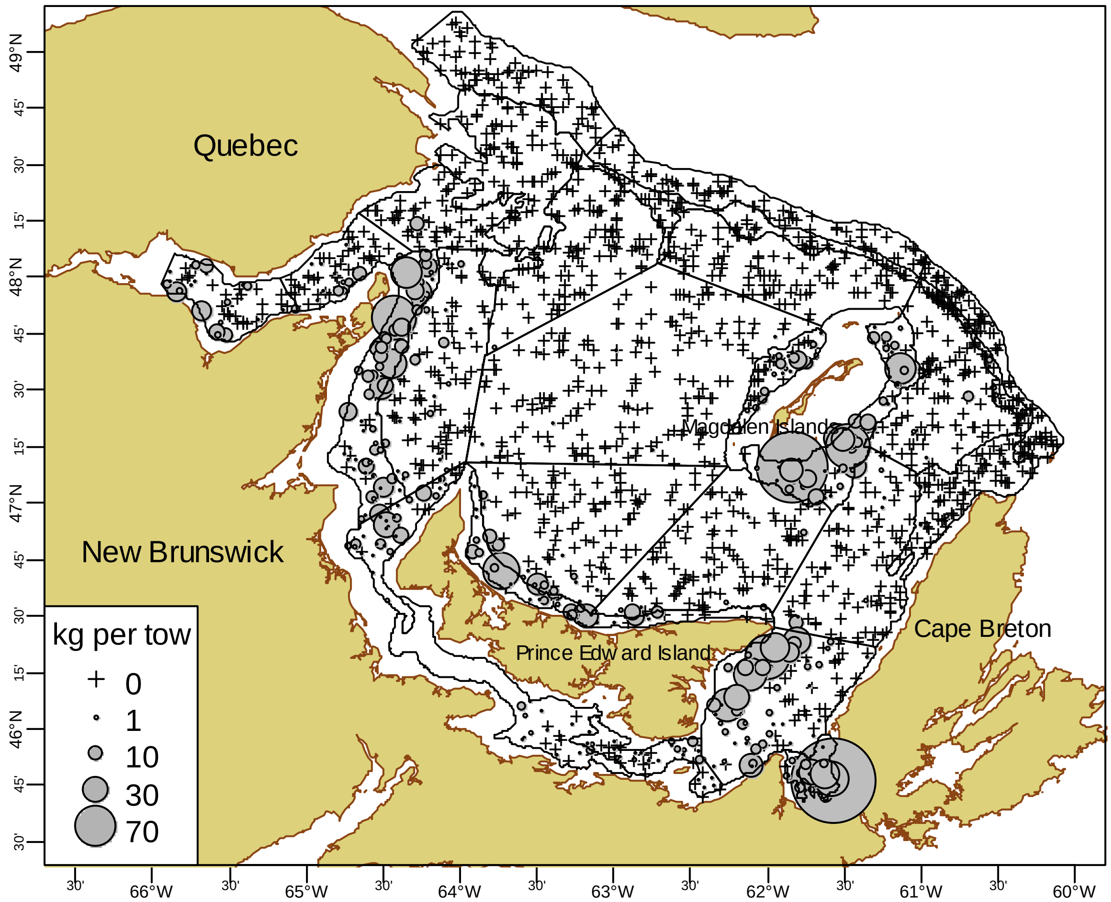


*Figure 32. Distribution of winter flounder catches (kg/tow) by 8 trawlers participating in the sentinel survey from 2003-2011. Catches are standardized for a common distance towed, but are not adjusted for possible differences in fishing efficiency between vessels.*

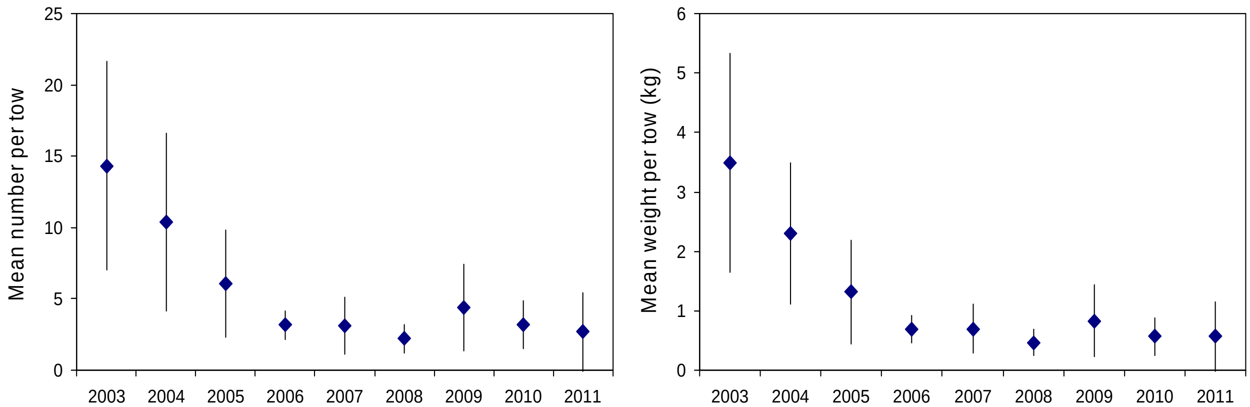


*Figure 33. Sentinel bottom-trawl survey mean annual catch abundance (left) and weight (right) per tow for winter flounder in the southern Gulf of St. Lawrence. These are unadjusted for vessel efficiency. Error bars indicate approximate 95% confidence intervals.*

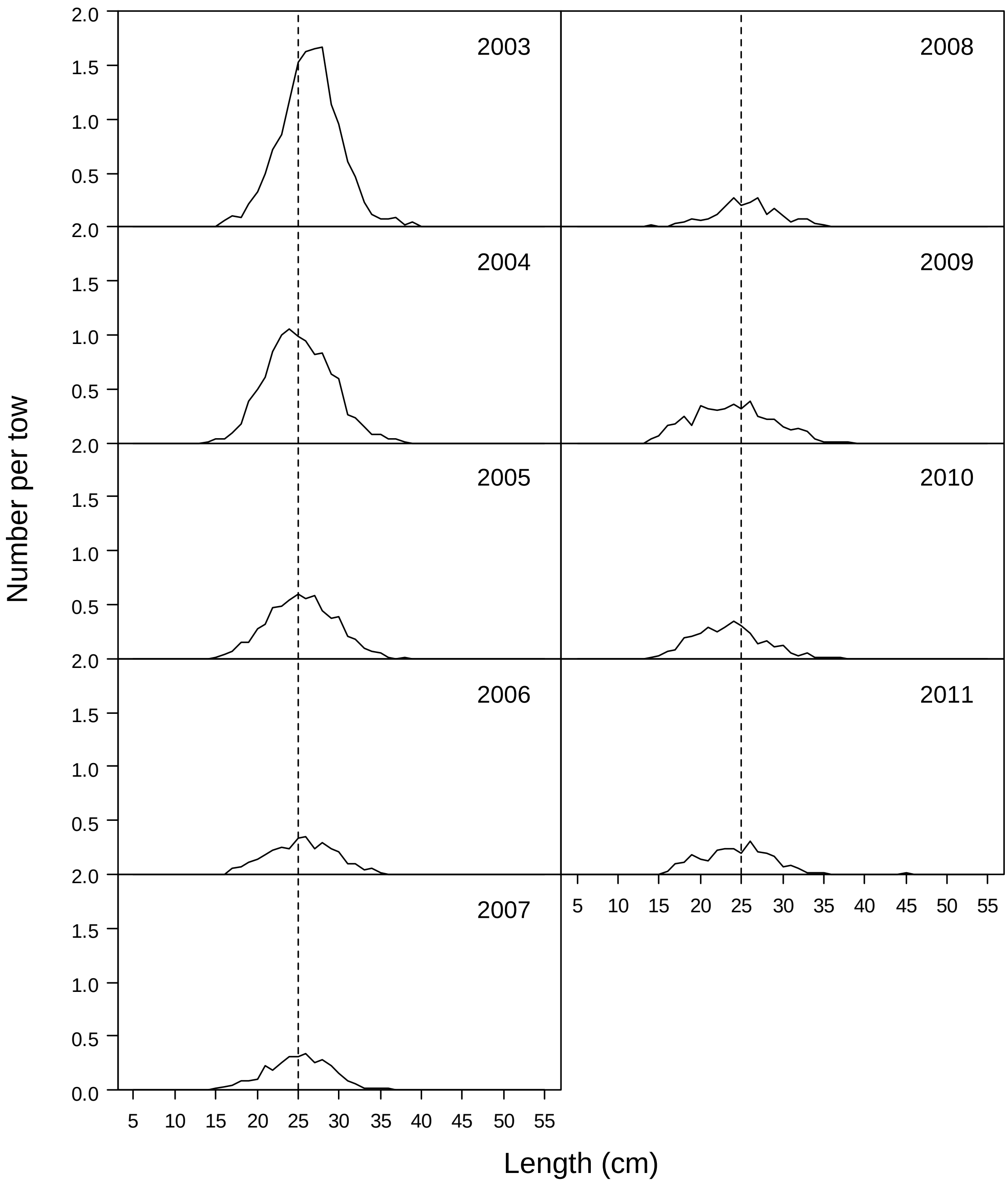


*Figure 34. Length frequency (unadjusted mean number per tow) of winter flounder by year for the sentinel bottom-trawl survey. The vertical line indicates the regulated minimum size of 25 cm.*