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Atlantic mackerel (*Scomber scombrus* L.) in NAFO Subareas 3 and 4 in 2016

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Foreword

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

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ABSTRACT

The present stock assessment includes the best possible estimates of unreported catches and uses a new statistical catch-at-age model. The new assessment therefore provides a more realistic estimate of the spawning biomass. According to the results of this assessment, the Atlantic mackerel stock in sub-regions 3 and 4 reached its lowest level in history in 2012. The statistical model suggests that catch levels in recent years have allowed slow growth from 2013 to 2016 and a slight improvement in the age structure, but does not indicate any significant recruitment episode since 1999. Projections that take into account unreported catches (estimated at 6,000 t) suggest that the probability of an increase in biomass is greater than 77% for total (declared + unreported) catches of less than 16,000 t. However, given that the stock is currently in the critical zone, priority should be given to rebuilding, and total catches should be limited to promote the increase of the spawning biomass to allow the population to at least reach the Limit Reference Point.

1. INTRODUCTION

This research document presents catches, sampling and bycatch data for Atlantic mackerel (*Scomber scombrus* L.) in NAFO subareas 3 and 4 (Figure 1) following the fishing seasons 2014, 2015 and 2016, as well as egg survey results from which an abundance index is derived. The US commercial and recreational landings are also presented for information purpose. All these data were analyzed and the main results were incorporated in the Science Advisory Report (DFO 2017) to assist in the preparation of the management plan for the 2017 and 2018 fishing seasons. For reference, the main research document of the previous stock assessment is Grégoire et al. (2014a).

2. MATERIALS AND METHODS

2.1 LANDINGS

Commercial fishery data for NAFO Subareas 3 and 4 were taken from the most recent ZIFF (Zonal Interchange File Format) files. At the time of this assessment, records for the 2015 and 2016 fishing seasons were still preliminary and landing data was missing for the Gulf Region and Nova Scotia in 2016. To facilitate their interpretation, commercial fishery data were grouped by NAFO country, province, division, subdivision, unit area and statistical district (Nova Scotia) as well as by month and gear. Catch positions by mobile and fixed gear were analyzed and presented when data was available.

Data from the US commercial and recreational fisheries - the latter having been updated due to a change in the way they are estimated - were provided by the National Fisheries Science Center in Woods Hole, Massachusetts and the Mid-Atlantic Fishery Management Council of Dover, Delaware.

2.1.1 Total Allowable Catch (TAC)

Between 1987 and 2000, the Total Allowable Catches (TAC) for the entire Northwest Atlantic was 200,000 t (Figure 1). Following low biomass estimates from the 1996, 1998 and 2000 Canadian egg survey, Canada's TAC was lowered to 150,000 t for the period 2001-2009. In 2005, TACs of over 200,000 t were proposed by the United States for the period 2006-2008. The TAC finally lowered to 80,000 t (average of landings for the 2006, 2007 and 2008 seasons) as a result of the 2009-2010 joint assessment between the United States and Canada. Following the 2010 Canadian Advisory Committee, it was decided that this TAC would be split as follows: 60,000 t for Canada and 20,000 for the United States. Following the 2012 Canadian Atlantic Mackerel Advisory Committee, the TAC was set at 36,000 t. Canadian TACs were never reached before 2016 and therefore never limited fishing activities. From 2014 to 2016, the TAC was set at 8,000 t. The TAC was reached for the first time in history in 2016, which caused a closure of the fishery in October.

2.1.2 Undeclared catches

Unreported catches are an important issue in the mackerel fishery. Indeed, a significant amount of commercial fishery catches are sold directly between harvesters and bait fishing for personal use are not accounted for in DFO statistics. Catches from the recreational fishery, which is very popular during the summer months, are not recorded either. As this activity is practiced throughout Eastern Canada by a very large number of people including tourists - at the wharf or on chartered vessels and in some places virtually commercial - the actual mackerel catch is greatly underestimated. For several years, scientific advices on mackerel have included a recommendation to improve fisheries statistics as a whole, and to reflect on how to estimate all these catches.

As part of this assessment, the issue of unreported catches was first examined using a synthesis of available data on bait requirements and recreational fisheries. The results of this research have estimated an approximate maximum of unreported catches for each management region and how these catches may have changed over time. In addition, an informal Internet survey for all Canadian mackerel fishermen provided a rough estimate of the proportion of unreported catches (bait, discards and recreational catches). The study included 476 respondents from the four Atlantic provinces and Quebec, who fished mackerel for bait or for recreational or commercial purposes (Van Beveren et al. 2017a). The results indicate that more than half of the mackerel used as bait in 2016 was used primarily for lobster fishing, but other species including bluefin tuna (*Thunnus thynnus*), snow crab (*Chionoecetes opilio*) and Atlantic halibut (*Hippoglossus hippoglossus*). Recreational fishing, usually with the hand line, can also be practiced semi-professionally with jigs and gill nets, so it should not be neglected. In addition, according to respondents, 1.9% of the catches were discarded, mainly because of the small size of the fish.

The two approaches used (bait requirement synthesis and online survey) suggest that, due to the use of bait, recreational fishing and discards, the total mackerel catch could range from 150% to 200% of the total reported, and that this ratio varies by province and over time.

2.2 COMMERCIAL SAMPLING

Mackerel is monitored annually by the commercial sampling program. Length measurements and biological samples are collected at the main landing ports for the main fishing gears. The lengths are measured with an accuracy of ± 5 mm. In the laboratory, fish from biological samples are thawed, measured (± 1 mm) and weighed (± 0.1 g). The gonads are sexed and weighed (± 0.01 g), the stage of maturity is determined and the otoliths are taken for age determination. The latter has been the subject of a recent comparison with the Woods Hole laboratory (Grégoire et al. 2009).

Length measurements were grouped by division, gear and quarter and then weighted by the corresponding landings. The results made it possible to follow the evolution of the sizes and to calculate the average annual lengths of the catches by fishing gear. Length measurements were also grouped by quarter and converted to catch-at-age using age-length keys from the analysis of biological samples. Catch-at-age was calculated out using an application written in Visual Basic (VB) and developed at the Maurice Lamontagne Institute in 2011-2012. The basic equations used in this application were derived from CATCH APL functions (Anonymous 1986).

Annual biomasses of catch at age - that is, the product of catch at age by the corresponding weights at age - were compared to commercial landings for the purpose of detecting possible errors grouping or weighting in the catch at age calculation.

Maturity ogives have been updated using the Logistic and Probit procedures of SAS (version 9.3) (SAS Institute Inc. 2011). These ogives were used to determine age and size at 50% of maturity (A_{50} and L_{50}). The L_{50} values were also compared to the minimum allowable size of capture which went up from 250 to 263 mm in 2014.

2.3 EGG SURVEY AND ABUNDANCE INDEX

A relative index of abundance of the spawning stock biomass of mackerel that spawns in the southern Gulf of St. Lawrence is calculated from data from an annual egg survey conducted in conjunction with an oceanographic survey of the Atlantic Zonal Monitoring Program (AZMP). This index has been used since 1983 to monitor the relative abundance of mackerel in Canadian waters (NAFO Subareas 3-4). In addition, this index is used to calibrate analytical stock assessments (example: Sequential Population Analyses, Grégoire et al. 2013). The latest Canadian assessment of mackerel was based on survey results from 2008 to 2013 (Grégoire et al. 2014b).

2.3.1 Sampling at sea

Offshore collection of plankton and mackerel eggs and larvae was carried out using a Bongo sampler equipped with two Nitex nets with 333 µm mesh and an opening of 61 cm. A General Oceanics TM flowmeter was attached near the opening of each net to measure the volumes of filtered water. Tows, lasting a minimum of 10 minutes, were made following a saw tooth profile between the surface and a maximum depth of 50 m, or up to 5 m from the bottom for shallower stations. The tow profile and the position of the nets in the water column were monitored in real time using electronic equipment (BIONET^{TM}) attached to the sampler frame. A CTD (Sea-Bird SBE-19), also attached to the sampler frame, provided the temperature and salinity profiles for the sampled portion of the water column.

Back on deck, the nets were suspended and washed with salt water. Plankton samples from one of the two nets were preserved in a diluted solution (4-5%) of formaldehyde and those of the second, in concentrated ethanol (100%).

2.3.2 Laboratory analyses

Sorting plankton and mackerel eggs and larvae (formalin sample) was made at the Maurice Lamontagne Institute laboratory (Fisheries and Oceans Canada, Mont-Joli). Each sample was fractionated according to Van Guelpen's beaker method (Van Guelpen et al. 1982). The identification criteria for Atlantic mackerel eggs and larvae (and other fish species encountered) were derived from Fritzsche (1978), Elliott and Jimenez (1981), and Fahay (2007a, 2007b).

2.3.3 Calculation of egg density (n/m^2) per station

Atlantic mackerel eggs were sorted and counted by stage of development (Girard 2000). Subsequently, the counts were standardized according to the sorted fraction and the volume of filtered water (m^3) before being converted to density (number/m^2) taking into account the maximum depth sampled (m). Egg densities were analyzed as a function of water temperature using an approach similar to Perry and Smith (1994).

2.3.4 Calculation of incubation time (h)

Incubation times of eggs stages 1 and 5 (stage 1 broken or dead egg) were calculated according to the Lockwood et al. (1977) model for mackerel in the Northeast Atlantic. This model is described as follows:

$$I = (e^{[-1.61\, Ln(T) + 7.76]})$$

where *T* is the average temperature (°C) of the first 10 meters of water . During surveys, this layer of water is generally above the thermocline. The choice to add stage 5 to stage 1 eggs is from Maguire (1981).

2.3.5 Calculation of daily egg production (n/m^2) per station

Daily egg production (n/m^2) per station was calculated as follows:

$$\frac{\text{Density (stages 1 \& 5) (n/m}^2\text{)}}{\text{Incubation time (h)}} \text{ x 24 h}$$

2.3.6 Calculation of daily egg production (n/m^2) for the entire zone sampled

The sampled area of the southern Gulf of St. Lawrence has three contiguous strata defined by Ouellet (1987). The surface of each of these strata was used as a weighting factor in the equations related to a random stratified sampling design (Cochran 1977). The daily egg production for the sampled area as a whole corresponds to the weighted average or overall daily production (n/m^2) calculated at each station.

2.3.7 Calculation of the proportion of eggs spawned daily

The proportion of eggs spawned at the median date of the surveys was calculated using a logistic model describing the seasonal evolution of the gonado-somatic index (GSI). This index was calculated from biological data from the analysis of commercial fishery samples, mainly from Division 4T in June. This approach is preferred over the use of a normal density curve (of the same extent and having a maximum always occurring on the same date) which was used in the past. The logistic model is described as follows:

$$y = y_o + \frac{a}{\left[1 + \left(\frac{x}{x_0}\right)^b\right]}$$

where :

y = daily mean of the gonado-somatic index

x = Day of year

and y_0, a, x_0 et b, the four parameters to be modeled.

2.3.8 Calculation of the annual egg production

Annual or total egg production is defined as the average daily egg production ($n/m^{2)}$ per station (P) multiplied by the surface of the sampled area (m^2) (A), divided by the proportion of eggs spawned on the median date of the surveys (S).

2.3.9 Calculation of the relative abundance index or of the spawning stock biomass

The relative index of abundance or reproductive biomass (t) was calculated according to the basic model proposed by Saville (1977). The Total Egg Production Method (TEPM), which is a application model of Saville, is defined as follows :

$$B = \frac{P \cdot A \cdot W}{S \cdot F \cdot R \cdot 10^6}$$

where :

B = relative index of abundance or spawning stock biomass (t)

P = average daily egg production (n/m^2) per station (stratified mean)

A = Area (m^2) of the sampled area (6.945×10^{10} m^2)

W = Average weight (g) of fish from biological samples

S = Proportion of eggs spawned on the median date of the survey

F = Fecundity of females (Pelletier 1986)

R = Sex ratio (proportion of females in biological samples)

10^6 = Conversion factor from grams to tons

2.3.10 Analytical assessment

The last mackerel assessment in subareas 3 and 4 was in winter 2014. The software that was used for ASP (ICA or Integrated Catch-at-Age) has become obsolete and no longer works on recent systems. Moreover, it could not take into account the missing catches and therefore was suspected of underestimating the actual size of the mackerel stock. For this assessment, a new statistical catch-at-age population dynamics model was developed to estimate the state of the resource and to fully integrate the various sources of uncertainty, including the estimation of missing catches, as well as to allow robust reference points calculation.

This statistical catch at age model was described in detail by Van Beveren et al. (2017b) (see also expanded projections in DFO 2018) and was built in TMB programming language. The model called "censored" uses a new approach in which reported catches are explicitly considered biased, being estimated between a lower limit corresponding to reported catches and an upper limit. These maximum values for unreported catches have been informed, as far as possible, by the available information on the bait and recreational fishing industry, the order of magnitude of which has been confirmed by the survey results online (see 2.1.2, undeclared catches). In view of the uncertainty related to US catches, which could include some mackerel from the northern contingent, an exploratory analysis was conducted in which the upper limit has been increased over the period with half of the US catch.

As part of this assessment, key configurations of the model were capped selectivity from age 4, the Beverton-Holt stock recruitment relationship with two parameters which included an environmental effect from a Principal Component Analysis (Plourde et al. 2015), and the estimation of different observation errors related to catch-at-age (Van Beveren et al. 2017b).

The use of a new model may lead to differences in the estimates of stock statistics for the last assessment, and in order to provide a basis for comparison, the censored model was also applied over the period 1968-2013. These estimates are for information purposes only and should not be used for other purposes.

3. RESULTS

3.1 LANDINGS

3.1.1 Historical perspective

In the late 1960s, Atlantic mackerel landings in the Northwest Atlantic (NAFO subareas 2 to 6) increased significantly with the arrival of a flotilla of foreign vessels. Historical maxima over 250,000 t per year were reached between 1970 and 1976. Landings decreased considerably in 1977 when the 200 mile Exclusive Economic Zone (EEZ) was introduced. However, following agreements in the early 1980s between the United States and the USSR, they again increased to 86,891 t in 1990 (Table 1; Figure 2). Subsequently, landings experienced another significant decline as a result of a gradual reduction in US quota allocations to the USSR and the complete cessation of this fishery in 1992.

3.1.2 In the Northwest Atlantic

Between 2008 and 2010, Atlantic mackerel landings in the Northwest Atlantic (Canada + USA) ranged from 49,388 t to 65,470 t, which represents a significant decrease compared to the previous five years (Table 1). In 2011 landings totaled 12,863 t. Those of 2012, 2013 and 2014 were 12,487 t, 12,681 t and 13,373 t. The 2015 (preliminary) landings were 10,917 t, the lowest since 1963.

3.1.3 In American waters

US commercial landings increased significantly between 2000 and 2006. From 2006 to 2007, they declined from 56,640 t to 25,547 t before reaching 9,877 t in 2010 (Table 1). In 2011 landings were 531 t only, the lowest on record since 1960. Landings for the 2012 and 2013 winter fisheries were 5,336 t and 4,408 t. Between 2007 and 2011, US recreational catches varied from 584 t to 932 t (Table 1). Between 2012 and 2015, they ranged from 668 t to 1,157 t.

No offshore fishing has been conducted in US waters by foreign vessels since 1992. This fishery, based on agreements between the United States and the USSR, was responsible for the increase in landings in the 1980s (Figure 2).

3.1.4 In Canadian waters

Between 2008 and 2010, Canadian (reported) landings ranged from 29,671 t and 42,231 t to reach only 11,400 t in 2011, 6,582 t in 2012 and 8,663 t in 2013 (Table 1). Landings amounted to 6,680 t in 2014 and 4,143 t in 2015 (preliminary), the lowest ones since 1964. By contrast, the 8,000 t TAC was reached in 2016, which resulted in a closure of the commercial fishery (in October) for the first time in history.

3.1.5 By Canadian province

During the 2008-2010 period, landings in Newfoundland ranged from 23,036 t and 34,237 t which represents 78% to 86% of all Canadian landings (Table 2, Figures 3, 4A). Of the 4,143 t of mackerel caught in Canadian waters in 2015, only 17% (700 t) were landed in Newfoundland, while this proportion averaged 71% from 2001 to 2010 and 54% since 2011. However, in 2016, 4,513 t were landed in Newfoundland (more than half the TAC), of which 1,710 t in 4R and 2,803 t in 3K, while there had been no significant landings in 3K since 2010 .

3.1.6 By fishing gear

The main fishing gear used in 2015 was hand lines (with 1,377 t over a total of 4,143 t), while in 2016 the main gear was the small purse seine with 3,657 t (Table 3, Figures 4B, 5).

3.1.7 By Region, Division unit area

Between 2008 and 2010, landings in the Gulf of St. Lawrence (Divisions 4RST) varied between 18,913 t and 28,792 t and for the Scotian Shelf (Divisions 4VWX5YZ), between 552 t and 1,173 t. For the same period, landings from the east and south coasts of Newfoundland (3KLP Divisions) ranged from 9,295 t and 19, 288 t. In 2011, for these same regions, they were 8,962 t, 409 t and 2,031 t. In 2012 and 2013, landings in the Gulf of St. Lawrence were 5,418 t and 6,876 t compared to 692 t and 365 t for the Scotian Shelf and 359 t and 190 t for the east and south coasts of Newfoundland.

Since 2013, most landings came from Divisions 4R and 4T (Table 4). Notably, landings in 3K reached 2,803 t in 2016. High catches in this Division had not been recorded since 2010. Recent landings by division, subdivision and unit area are presented in Table 5 and in Table 5 and Figure 6.

3.1.8 By division, gear, and month

In 2013, most landings in Divisions 3K and 4R were made using purse seines and "Tuck" seines" between September and December (Table 6). In Division 4T, they were primarily made using lines (all types) and gillnets between June and September and on the Scotian Shelf in Division 4X using the trap during the month of June.

Since 1995, the seine (all types) is the main gear Divisions 3K, 3L, 3P and 4R (Table 7; 7A, 7B, 7C and 7D). In Division 4S, seine and trap are the main fishing gear (Figure 7E) compared to the gillnet and the line (all types) for Division 4T (Figure 7F). In Divisions 4V and 4W, the trap has gradually replaced the gill net and the line (Figures 7G and 7H) and remains the main gear used in Division 4X (Figure 7I).

3.1.9 Allocations by fleets and TAC

For several years, 40% of the Canadian TAC is allocated to mobile gear over 19.8 m (65 feet) and exploratory fisheries and 60% of mobile gear less than 65' as well as fixed gear such as traps, gillnets, and lines, and weirs (Table 8). In the first case, from 1 to 49% of the quota has been reached since 2000 and in the second case, up to 94% in 2004, 110% in 2005, 106% in 2006 and 98% in 2007. The quota overruns in 2005 and 2006 represent a first since the introduction in 1987 of a TAC for mackerel in NAFO subareas 3 and 4. These quota overruns were caused by the large catches of small purse seiners and certain fixed gear (Table 8).

In the case of large purse seiners, only 10% of their allocation was caught in 2015 and 3% in 2016.

3.2 BIOLOGY

3.2.1 Catch-at-age

The catch-at-age calculation was carried out without major errors as indicated by the similarity between the landings and the biomasses of the catch (Figure 8). Catch-at-age of 2014, 2015 and 2016 was dominated by fish under 5 years old. Mackerels more than 6 years old are very rare (Figures 9, 10 and 11). The average age of capture has also been declining since the 1990s to around 2.5 years in 2016 (Figure 9B).

The 1967, 1974, 1982, 1988 and 1999 year-classes are the most important year-classes in commercial catches. Some of these age classes dominated the fishery for several years. This was the case of the 1999 year-class between 2000 and 2004, the importance of which declined rapidly from 2005 onward to make room for subsequent year-classes of lower abundance.

3.2.2 1999 Year-class

Between 2000 and 2003, annual landings attributed to the 1999 year-class ranged from 5,920 t to 36,182 t, which corresponds to 41% and 77% of all Canadian landings (Figure 12A). Landings associated with this year-class increased to 31,029 t (61%), 24,961 t (45%) and 11,212 t (21%) in 2004, 2005 and 2006 and only 3,426 t (6%) and 748 t (2%) in 2007 and 2008. Among the age-classes during dominated the fishery, the 1999 year-class is the one with the greatest the cumulative catch (Figure 12B). At age 9 (2008), the cumulative catches attributed to this single year-class were 157,669 t.

3.2.3 Length frequencies

Most age classes are associated with modes that are observed in the length frequencies. This is the case for the 1974, 1982, 1988, and 1996 year-classes (the latter is absent from 4R seine samples), 1999, 2003, 2005, 2007 (present only in Division 4T line samples), 2008 and 2010 (Figure 13).

Mean lengths of gillnet catches varied very little between 1987 and 2008 (Figure 14A). The smallest average lengths for this gear have been measured since 2009. The smallest mackerel are usually caught with lines with an average length (1985-2012) of 319.1 mm (Figure 14B). The average lengths associated with this fishing gear have decreased since 1993 and the values measured from 2004 are the lowest in the series. The average length (1987-2012) of catches on the west coast of Newfoundland is 347.7 mm (Figure 14C). Values higher than this mean were measured between 1987 and 1999. Smaller values were measured afterwards, except in 2004, 2008, and 2013 (Figure 14C). Very low values and an increase in mean lengths were seen between 2000 and 2004, due to the increasing importance of catches from the 1999 year-class. On Newfoundland's East Coast (Divisions 3KL), the mean length (2000-2009) of seine catches was estimated to be 322.9 mm. Mean annual values were smaller in 2000 and 2004 and larger between 2005 and 2007 and in 2010 (Figure 14D). Annual length frequencies and annual means of all fishing gears (weighted by catches) (Figure 15) show similar patterns to those of the purse seine in western Newfoundland (Figure 14A) since this gear makes up most catches.

The examination of length frequencies by fishing gear indicates that fish length varied little when a year-class dominates the fishery. This was the case for the 1982 and 1987 and 1988 and 1999 year-classes in 2003 (Figure 15). In addition, the length frequencies associated with the line, a relatively non-selective gear, allows a faster identification of a dominant year-class. This is what was seen in 1990 for the dominant 1988 year-class compared to 1991 for gillnets, a very selective fishing gear. A similar situation for the 1999-2000 and 2001 year-class in length frequencies associated with line and purse seine fisheries. The 1999 year-class did not appear until 2002 in the gillnet length frequencies (Figure 15). In 2015, there are two modes in the main lines of 4T while in 2016 there is a mode for the hand lines in 4T and a mode centered at 26 cm in 4R (Figure 16A). We distinguish the arrival of the 2015 class in the length frequencies of purse seines in 4R in 2016 (Figure 16A). Length frequencies by division in 2016 also illustrate the presence of the 2015 class in 4R (Figure 16B).

3.2.4 Weights-at-age

The lowest weight-at-age (ages 1-7) were observed in the 1960s and 1970s (Figure 17A) while all weights-at-age increased between 1976 and the beginning of the 1980s (Figure 17B). After a decline until the mid-1980s, weights-at-age have remained relatively stable.

3.2.5 Maturity-at-age

The proportion of fish mature at age changed very little over the years (Figure 18A). Age at 50% maturity (A_{50}) increased from 1.35 in the 1980s to 1.48 and 1.40 in the 1990s and 2000s (Figure 18B). Between 2010 and 2015, A_{50} was estimated at 1.39 years.

3.2.6 Maturity-at-length and minimum allowable size of capture

The proportion of fish mature at length fluctuated substantially over the years (Figure 19A). The length at 50% maturity (L_{50}) went from 272.91 mm to 259.57 mm from the 1970's to the 1980's (Figure 19B). This length was 266.17 mm in the 1990s to reach a minimum of 245.03 mm in the 2000s. Between 2010 and 2015 , L_{50} was 266.47 mm. L_{50} was greater than the minimum allowable catch size of 250 mm for most years of the period between 1974-2013 (Figure 20). L_{50} remained slightly over the minimum size allowed of 263 mm in the catch since 2014.

3.3 EGG SURVEY AND ABUNDANCE INDEX

Mackerel abundance is estimated from data from an egg survey which takes place annually of the main spawning site, in the southern Gulf of St. Lawrence. During surveys in 2013 and 2014, the highest egg densities (n/m ^{2}) were found in the northwest of the sampled area (Figure 21). In 2015 and 2016, egg distribution was more extensive, particularly towards the center and south of the study area, although much less widespread than egg distributions observed in the 1980s and 1990s.

Taking into account water temperature and incubation time, as well as the weight and fecundity of female mackerel in biological samples, egg densities allow us to calculate an abundance index of the spawning stock biomass (SSB). This index increased on three occasions over the years due to the arrival of the dominant year-classes of 1982, 1988 and 1999 (Figure 22). The index fell significantly between 1993 and 1998 and again after 2002, reaching its lowest level in 2012 (14,568 t). It rose slowly to 52,667 t in 2016. This value remains much lower than abundance indices of 750,000 t observed in the 1980s.

In 2015 and 2016, five additional surveys were conducted in White and Notre-Dame Bays, on the northeast coast of Newfoundland (3K), following observations of young mackerel by industry. These surveys, repeated several times during the summer, were designed to identify additional spawning areas. However, no evidence of mackerel spawning was detected, and the southern Gulf of St. Lawrence remains the only spawning area used in this assessment for subareas 3 and 4.

3.4 ANALYTICAL ASSESSMENT

3.4.1 « Censored » model

The « censored » model, calibrated with the egg abundance index and accounting for uncertainty around undeclared catches, confirms that mackerel declined following high exploitation rates in the 1990s and 2000s, and reached a historical minimum in 2012 (20,000 t). According to the model, the SSB increased slowly thereafter to reach around 40,000 t in 2016 (Figure 23A).

In addition, the model suggests that additional (non declared) catches (difference between estimated total and reported catches) average 6,000 t over the last 5 years (Figure 23B).

3.4.2 Reference points

According to the Canadian Precautionary Approach framework, the Limit Reference Point (LRP) for this stock represents 40% of the biomass corresponding to the maximum sustainable yield (B_{MSY}). However, since there is no clear stock-recruitment relationship in this pelagic stock, B_{MSY} is based on an approximation from $F_{40\%}$ as obtained from a yield-per-recruit analysis. According to the statistical model, the LRP would be equal to 103,000 t, and the stock would therefore be in 2016 at 40% of the LRP (Duplisea and Grégoire 2014, DFO 2017).

3.4.3 Projections

Three-year projections were made based on the censored model to estimate the impacts of the various total (declared + undeclared) catch scenarios for 2017, 2018 and 2019. These projections use the parameters of the last three years (ex: weight-at-age, maturity) and random recruitment (which does not consider the possibility of an extreme recruitment event). Among other things, these projections suggest that the probability of an increase in biomass is greater than 80% for total catch levels below 14,000 t per year (Table 9). The choice of TAC must take into account the uncertainty as to the actual level of undeclared catches, which are not known but estimated by the model at around 6,000 t per year for the period 2011-2016.

3.4.4 Comparison with a model that includes US catches

A sensitivity analysis of the upper limit was carried out to estimate the potential impact of ignoring unknown catches of northern contingent (Canadian) mackerel in the US fishery (Figure 24). Including total US catch in the uncertainty of the censored model would carry too much uncertainty and hence only half of US catches were used to increase the upper limit. However the biomass estimation was not influenced significantly by this increase, with the pre 1975 period being the only one where the biomass was clearly higher. Few differences were found regarding catches as the model estimated a higher number only between 2002-2004, 1985-1992 and before 1975.

3.4.5 Comparison with the ICA model

It is difficult to compare in depth the old analytical evaluation model (ICA) and the approach presented here because of some basic differences between the models. It is also not possible to run the ICA model again to perform a quantitative comparison. However, the general patterns of reproductive biomass and fishing mortality trends are similar and the overall conclusions about the stock trajectory are the same (Figure 25). However, the ICA model estimated a larger biomass before 1985 and during the period 2000-2008. The censored TMB model estimates higher biomass for the period 1985-2000 and for years after 2008 (Figure 25).

Both censored and uncensored TMB models have a retrospective pattern inferior to the ICA model (rho = 0.29 for reproductive biomass and rho = -0.16 for F_{3-5}). For the abundance index from the egg survey, the residues of the censored informed model (RSS = 3.7) are slightly lower than those of the ICA model (RSS = 4.3). Catch-at-age residuals are difficult to compare directly because they are not on the same scale (log vs. continuation ratio logit). Overall, their patterns between years are similar and the differences are less pronounced within the TMB model.

The censored approach, in addition to being more plausible given the information available on unreported catches, also mitigates one of the problems of the previous assessment that reported catches which represented a large proportion of the SSB estimated by the ICA model (up to 87% in some years). As the reported catches are known to be underestimated, this would imply that the total catches in recent years would be equal to or even greater than the stock biomass, which undermined the credibility of the assessment. The TMB model, and in particular the censored version, significantly reduces this problem (Figure 26). The ICA model also predicted that fishing mortality decreased for the oldest age group, which was unlikely for the Atlantic mackerel fishery. This problem does not appear in TMB versions.

4. DISCUSSION

4.1 SOURCES OF UNCERTAINTY

Unreported catches of bait and recreational fisheries continue to be an important source of uncertainty in the assessment of the mackerel stock. The development and use of a censored statistical catch-at-age model that takes into account the uncertainty surrounding catches allows for a more realistic estimate of total catches, spawning biomass and stock exploitation rate. However, this statistical tool does not predict future unreported catches and is not a substitute for the imperative need to better account for total catches in the mackerel fishery.

Releases of small mackerel whose length is below the minimum allowable catch size (263 mm) are also a problem. The extent of discards and the impact of this activity on the abundance of age groups at older ages are difficult to quantify. The average length at 50% maturity (L_{50}) has varied considerably over the years. L_{50} was above the minimum allowable catch size of 250 mm for most years of the 1974-2013 period, suggesting that significant fishing pressure was exerted on immature fish. The increase of the minimum allowable catch length from 250 to 263 mm, which took effect in 2014, and the application of the small fish protocol developed for mackerel, should increase the reproductive potential by reducing this pressure. Following its increase in recent years, L_{50} has remained slightly above the minimum allowable catch length of 263 mm since 2013, suggesting that the minimum catch size could be further increased slightly (about 1 cm) to reach L_{50}. Setting the minimum catch size to L_{50} allows 50% of the fish to reproduce before being targeted by the fishery.

There are several deficiencies in the commercial fishery biological sampling program, particularly in the DFO Maritimes Region. The absence of samples in recent years, particularly in the pre-spawning period, limits our ability to describe the spawning period and the condition of the fish, which may have an impact on the calculation of the abundance index measured from the egg survey.

When a major recruitment episode occurs, it is difficult to detect it in the scientific data (fishery sampling, egg survey) before the corresponding cohort reaches the age of 2 years. However, a peak frequency of small fish, corresponding to mackerel in the 2015 year class, was observed in the 4R fishery in 2016. In addition, about half of the fishermen who responded to the line indicated that the small mackerel was very abundant in 2016. These signals could indicate that recruitment in 2015 was more important than those observed in recent years.

5. CONCLUSIONS AND ADVICE

According to available data, the 1999 year-class supported the fishery as no year-class has ever achieved. Despite the uncertainties associated with fishery statistics, it appears that year-classes that have appeared in the fishery since 1999 are not as important.

Grégoire et al. (2014a) pointed out that the previous scientific advice was biased because it did not include an estimate of unreported catches. The scientific advice presented here includes the best possible estimates of unreported catches using a new censored statistical catch-at-age model. This model therefore provides a more realistic estimate of the spawning stock biomass than the 2014 model.

Based on the results of the assessment, the mackerel stock in sub-regions 3 and 4 reached its lowest historical level in 2012. The statistical model suggests that catch levels in recent years have allowed slow growth from 2013 to 2016 and a slight improvement in the age structure, but indicate no significant recruitment episode since 1999.

Projections that take into account unreported catches suggest that the probability of an increase in biomass is greater than 80% for total (declared + unreported) catch levels below 14,000 t. However, given that the stock is currently in the critical zone, priority should be directed to rebuilding and total catches should be limited so as to favour the increase of the spawning biomass to allow the stock to reach and exceed the Limit Reference Point (LRP). The mackerel LRP for subareas 3 and 4 was recently set at 103,000 t (Duplisea and Grégoire 2014, DFO 2017). In 2016, the stock was therefore in a critical zone, at 40% of the LRP.

In addition, the choice of TAC must take into account unreported catches, the exact amount of which is unknown, but estimated at 6,000 t per year. Thus, a TAC of 10,000 t would result in a 77% probability of biomass growth and a probability of reaching the LRP of 26% by 2019, assuming unreported catches of around 6,000 t in 2017 and 2018 (Table 9). Note that the TACs were set at 10,000 t in 2017 and 2018.

However, subsequent versions of the population model indicate that the projections in Table 9 appear optimistic because they assume a high probability of high recruitment (DFO 2018). In other words, the probability of the stock going back to the LRP in 2019 is probably lower than the 26% reported in Table 9. In addition, the fact that the model does not take into account US catches can also lead to biases in the projections.

It is particularly important to address gaps in commercial fisheries sampling in some areas, to speed up the compilation of landing statistics and to improve the collection of unreported catch data.

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8. TABLES

Table 1. Annual Atlantic mackerel catches (t) in NAFO Subareas 2 to 6 [1].

Year	CANADA		USA [4]			TOTAL
	Canadian vessels[2]	Foreign vessels[3]	Commercial	Recreational	Other countries	
1960	5 888	0	1 396	2 478	0	**9 762**
1961	5 458	11	1 361	-	11	**6 841**
1962	6 901	64	938	-	175	**8 078**
1963	6 363	99	1 320	-	1 299	**9 081**
1964	10 786	174	1 644	-	801	**13 405**
1965	11 185	405	1 998	4 292	2 945	**20 825**
1966	11 577	1 244	2 724	-	7 951	**23 496**
1967	11 181	62	3 891	-	19 047	**34 181**
1968	11 134	9 720	3 929	-	65 747	**90 530**
1969	13 257	5 379	4 364	-	114 189	**137 189**
1970	15 710	5 296	4 049	16 039	210 864	**251 958**
1971	14 942	9 554	2 406	-	355 892	**382 794**
1972	16 254	6 107	2 006	-	391 464	**415 831**
1973	21 619	16 984	1 336	-	396 759	**436 698**
1974	16 701	27 954	1 042	-	321 837	**367 534**
1975	13 544	22 718	1 974	5 190	271 719	**315 145**
1976	15 746	17 319	2 712	-	223 275	**259 052**
1977	20 362	2 913	1 377	-	56 067	**80 719**
1978	25 429	470	1 605	-	841	**28 345**
1979	30 244	368	1 990	3 588	440	**36 630**
1980	22 136	161	2 683	2 364	566	**27 910**
1981	19 294	61	2 941	3 233	5 361	**30 890**
1982	16 380	3	3 330	666	6 647	**27 026**
1983	19 797	9	3 805	3 022	5 955	**32 588**
1984	17 320	913	5 954	2 457	15 045	**41 689**
1985	29 855	1 051	6 632	2 986	32 409	**72 933**
1986	30 325	772	9 637	3 856	26 507	**71 097**
1987	27 488	71	12 310	4 025	36 564	**80 458**
1988	24 060	956	12 309	3 251	42 858	**83 434**
1989	20 795	347	14 556	1 862	36 823	**74 383**
1990	19 190	3 854	31 261	1 908	30 678	**86 891**
1991	24 914	1 281	26 961	2 439	15 714	**71 309**
1992	24 307	2 417	11 775	284	0	**38 783**
1993	26 158	591	4 666	600	0	**32 015**
1994	20 564	49	8 917	1 705	0	**31 236**
1995	17 706	0	8 468	1 249	0	**27 424**
1996	20 394	0	15 812	1 340	0	**37 547**
1997	21 309	0	15 403	1 737	0	**38 449**
1998	19 334	0	14 525	690	0	**34 548**
1999	16 561	0	12 031	1 335	0	**29 927**
2000	16 080	0	5 649	1 448	0	**23 177**
2001	24 429	0	12 340	1 536	0	**38 305**
2002	34 662	0	26 530	1 294	0	**62 485**
2003	44 736	0	34 298	770	0	**79 804**
2004	53 777	0	54 990	473	0	**109 240**
2005	54 621	0	42 187	1 032	0	**97 840**
2006	53 649	0	56 640	1 511	0	**111 801**
2007	53 016	0	25 547	584	0	**79 147**
2008	29 671	0	21 734	783	0	**52 188**
2009	42 231	0	22 635	603	0	**65 470**
2010	38 753	0	9 877	759	0	**49 388**
2011	11 400	0	531	932	0	**12 863**
2012	6 582	0	5 333	668	0	**12 487**
2013	8 663	0	4 372	867	0	**12 681**
2014 [5]	6 680		5 905	788		
2015 [5]	5 357		5 616	1157		
Mean: (1978-2014)	**26 284**	**372**	**15 031**	**1 629**	**7 122**	**50 191**

[1] Source : NAFO 1960-1964; ZIFF 1996-2016
[2] Includes at sea sales
[3] Includes catches with Canadian allocations
[4] Source : Northeast Fisheries Science Center, Woods Hole, MA et Mid-Atlantic Fishery Management Council, Dover, DE
[5] Preliminary

Table 2. Annual landings (t) of Atlantic mackerel by province (NAFO Subareas 3 and 4) from 2013 to 2016.

PROVINCE	YEAR				MEAN (1995-2014)
	2013	2014	2015 [1]	2016 [1]	
Nova Scotia	450	770	1 183	-	**3 455**
New Brunswick	766	449	571	-	**1 464**
Prince Edward Island	825	527	643	-	**3 541**
Québec	1 453	1 502	1 045	844	**2 756**
Newfoundland	5 169	3 432	701	4 513	**17 516**
Non determined	0	0	0	-	**5**
TOTAL	**8 663**	**6 680**	**4 143**	**5 357**	**-**

[1] Preliminary. Data from Nova Scotia, New Brunswick and PEI missing at the time of the March 2017 assessment.

Table 3. Annual landings of Atlantic mackerel (NAFO Subareas 3 and 4) by gear from 2013 to 2016.

GEAR	YEAR				MEAN (1995-2014)
	2013	2014	2015 [1]	2016 [1]	
Trawl	5	6	2	0	**14**
Midwater trawl[2]	0	0	0	0	**1**
Tuck Seine	266	321	355	326	**1009**
Purse seine < 65'	3 470	2298	339	3657	**10783**
Purse seine > 65'	1 529	724	320	111	**4258**
Other seines	0	0	16	231	**872**
Gillnet	618	506	644	231	**4041**
Trap	470	596	440	250	**2668**
Longlines	0	0	0	0	**11**
Handlines	1 679	1306	1377	403	**4005**
Jig	20	0	0	0	**552**
Mechanized jigger	393	514	410	0	**166**
Weir	0	0	0	0	**27**
Others	212	409	242	148	**317**
Non determined	-	-	-	-	**13**
TOTAL	**8 663**	**6680**	**4143**	**5357**	

[1] Preliminary

[2] Midwater trawl: exploratory fishery in Nova Scotia in 2006 and 2007

Table 4. Annual landings (t) of Atlantic mackerel per NAFO Division and region from 2013 to 2016.

DIVISION AND REGION	YEAR 2013	2014	2015 [1]	2016 [1]	MEAN (1995-2014)
2J	4	0	0	0	**5**
3K	191	6	208	2 803	5 391
3L	0	25	54	0	**1 190**
3O	0	0	0	0	**1**
3P	26	246	0	0	**741**
4R	4 909	3 155	438	1 710	**10 190**
4S	245	20	29	63	**54**
4T	2 748	2 389	2 242	750	**8 374**
4V	146	143	58	0	**382**
4W	17	220	186	0	**210**
4X	241	340	682	0	**2 146**
Non determined	137	135	0	31	**51**
Scotian Shelf (4VWX5YZ)	**403**	**703**	**1 172**	**0**	**2 738**
Gulf of St. Lawrence (4RST)	**7 902**	**5 564**	**2 710**	**2 523**	**18 646**
South and East Coasts of Newfoundland (2J3KLOP)	**221**	**278**	**262**	**2 803**	**7 314**
TOTAL	**8 663**	**6 680**	**4 143**	**5 357**	

[1] Preliminary. Note that as of August 23, 2018, 2015 and 2016 landings were 4772 t and 6579 t, respectively.

Table 5. Atlantic mackerel landings (t) per NAFO division, unit area and subdivision from 2013 to 2016 and mean of the 1995-1999 and 2000-2014 periods.

DIVISION	Unit area, subdivision	MEAN (1995-1999)	YEAR				MEAN (2000-2014)
			2013	2014	2015 [2]	2016 [2]	
2J	2Jb	0	0	0	0	0	**1**
	2Jj	0	0	0	0	0	**1**
	2Jm	0	4	0	0	0	**5**
	Total:	***0***	***4***	***0***	***0***	***0***	**6**
3K	3Ka	0	0	0	0	0	**37**
	3Kb	0	0	0	0	0	**0**
	3Kd	1	11	4	107	160	**3 562**
	3Kg	0	0	0	0	0	**17**
	3Kh	1	94	0	34	2 418	**2 745**
	3Ki	0	86	2	67	226	**820**
	3Ku [1]	0	0	0	0	0	**6**
	Total:	***3***	***191***	***6***	***208***	***2 803***	**7 187**
3L	3La	1	0	0	0	0	**565**
	3Lb	1	0	0	0	0	**904**
	3Ld	0	0	0	0	0	**0**
	3Lf	0	0	0	54	0	**148**
	3Lg	0	0	0	0	0	**2**
	3Lj	0	0	0	0	0	**8**
	3Lq	0	0	0	0	0	**13**
	3Lu [1]	0	0	25	0	0	**6**
	Total:	***2***	***0***	***25***	***54***	***0***	**1 586**
3O	3Oa	0	0	0	0	0	**2**
	Total:	***0***	***0***	***0***	***0***	***0***	**2**
3P	3Psa	0	0	91	0	0	**99**
	3Psb	0	0	0	0	0	**69**
	3Psc	0	0	0	0	0	**76**
	3Psd	0	0	155	0	0	**27**
	3Pn	14	0	0	0	0	**706**
	3Pu [1]	32	0	0	0	0	**0**
	Total:	***46***	***0***	***246***	***0***	***0***	**972**
4R	4Ra	90	15	169	7	219	**400**
	4Rb	638	4 879	1 545	0	145	**3 191**
	4Rc	1 222	15	936	393	1 326	**4 066**
	4Rd	329	0	510	39	20	**5 170**
	4Ru [1]	0	0	0	0	0	**0**
	Total:	***2 279***	***4 909***	***3 160***	***438***	***1 710***	**12 827**
4S	4Sv	0	0	0	0	0	**0**

DIVISION	Unit area, subdivision	MEAN (1995-1999)	YEAR				MEAN (2000-2014)
			2013	2014	2015 [2]	2016 [2]	
	4Sw	0	245	20	29	62	**69**
	4Sy	1	0	0	0	0	**0**
	4Sz	7	0	0	0	0	**0**
	Total:	***9***	***245***	***20***	***29***	***63***	**69**
4T	4Tf	3 984	118	71	126	179	**1 187**
	4Tg	1 528	444	330	732	34	**1 489**
	4Th	239	71	26	26	1	**156**
	4Tj	268	127	107	146	0	**224**
	4Tl	4 248	616	283	225	0	**2 906**
	4Tm	525	613	661	379	244	**526**
	4Tn	821	713	871	592	190	**528**
	4To	27	25	35	16	100	**21**
	4Tp	0	0	1	0	0	**0**
	4Tq	0	9	0	0	0	**1**
	4Tu [1]	1	12	4	1	0	**70**
	Q [3]	0	0	0	0	0	**222**
	Total:	***11 640***	***2 747***	***2 390***	***2 242***	***750***	**7 329**
4V	4Vn	1 042	143	143	56	0	**159**
	4Vs	0	2	0	2	0	**1**
	4Vu [1]	1	0	0	0	0	**0**
	Total:	***1 044***	***146***	***143***	***58***	***0***	**161**
4W	4Wd	380	11	205	159	0	**61**
	4Wg	0	0	0	0	0	**0**
	4Wh	0	3	2	5	0	**1**
	4Wj	0	0	0	0	0	**2**
	4Wk	103	2	8	22	0	**18**
	4Wl	0	0	0	0	0	**2**
	4Wu [1]	73	0	4	0	0	**11**
	Total:	***557***	***17***	***220***	***186***	***0***	**94**
4X	4Xm	2 907	67	60	159	0	**728**
	4Xn	1	0	1	0	0	**12**
	4Xo	107	6	69	179	0	**256**
	4Xp	4	0	0	1	0	**2**
	4Xq	21	16	57	11	0	**55**
	4Xr	2	5	1	17	0	**15**
	4Xs	85	0	0	75	0	**10**
	4Xu [1]	354	147	152	240	0	**628**
	Total:	***3 482***	***241***	***340***	***682***	***0***	**1 700**

DIVISION	Unit area, subdivision	MEAN (1995-1999)	YEAR				MEAN (2000-2014)
			2013	2014	2015 [2]	2016 [2]	
5	5YZ	-	0	0	245	0	**1**
	TOTAL	**-**	**8 663**	**6 680**	**4 143**	**5 357**	

[1] "u" = unit area or subdivision non determined;

[2] Preliminary

[3] Supplementary purchase slips, Québec Region

Table 6. Atlantic mackerel monthly landings (t) in 2015 (preliminary) per NAFO division and gear.

DIVISION	GEAR	MONTH												TOTAL
		Jan.	Feb.	Mar	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
3K	Purse Seine	-	-	-	-	-	-	-	-	-	135.8	19.4	-	**155.2**
	Tuck seine	-	-	-	-	-	-	-	-	-	-	53.0	-	**53.0**
	Trap	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
	Other	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
3L	Purse Seine	-	-	-	-	-	-	-	-	-	-	53.939	-	**53.9**
	Tuck seine	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
	Trap	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
	Other	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
4R	Purse seine	-	-	-	-	-	-	-	-	-	114.3	-	-	**114.3**
	Tuck Seine	-	-	-	-	-	-	-	-	-	311.3	6.04	-	**317.3**
	Gillnet	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
	Trap	-	-	-	-	-	-	-	0.1	6.8	-	-	-	**6.9**
4S	Purse seine	-	-	-	-	-	-	12.6	3.3	-	-	-	-	**15.8**
	Gillnet	-	-	-	-	-	-	-	-	-	-	-	-	**0.0**
	Trap	-	-	-	-	-	-	11.5	1.4	-	-	-	-	**12.9**
	Other	-	-	-	-	-	-	-	0.2	-	-	-	-	**0.2**
4T	Gillnet	-	-	-	-	1.4	324.4	188.2	9.1	10.7	9.0	-	-	**542.7**
	Mechanized jigger	-	-	-	-	-	31.233	72.1	262.4	218.7	29.2	30.336	5.072	**649.0**
	Handlines (all)	-	-	-	-	-	23.8	194.3	495.1	275.3	46.5	13.133	-	**1 048.1**
	Other	-	-	-	-	-	-	-	-	2.2	-	-	-	**2.2**
4V	Lines (all)	-	-	-	-	-	-	5.933	5.091	-	0.27	-	-	**11.3**
	Trap	-	-	-	-	-	43.234	-	-	-	-	-	-	**43.2**
	Gillnet	-	-	-	-	-	0.241	-	-	-	-	2.999	-	**3.2**
	Other	-	-	-	-	0.009	-	-	0.238	-	-	-	-	**0.2**
4W	Bottom trawl	-	0.301	0.133	0.237	0.698	0.161	0.017	-	-	0.08	0.067	0.314	**2.0**
	Lines (all)	-		-	-	-	-	0.354	10.284	3.955	4.59	0.533	0.036	**19.8**
	Trap	-	-	-	-	-	62.184	80.938	11.738	3.953	-	-	-	**158.8**
	Other	-	-	-	-	-	-	-	3.108	-	-	2.677	-	**5.8**
4X	Bottom trawl	-	-	0.019	0.038	-	-	-	-	-	-	-	-	**0.1**
	Purse seine	-	-	-	-	-	-	-	-	-	-	74.793	-	**74.8**
	Gillnet	-	-	-	-	7.305	15.027	8.351	18.871	10.267	8.728	23.734	-	**92.3**
	Lines (all)	-	-	-	-	-	-	3.391	86.479	95.31	64.003	47.508	0.544	**297.2**
	Trap	-	-	-	-	4.536	80.894	62.639	-	69.035	0.771	-	-	**217.9**
	Other	0.023	-	-	-	-	-	-	-	-	-	-	-	**0.0**
5Y	Purse seine	-	-	-	-	-	-	-	-	-	-	244.91	-	**244.9**

Table 7. Annual landings (t) of Atlantic mackerel per NAFO Division and gear from 2013 to 2016 and means of the 1995-1999 and 2000-2014 periods.

DIVISION	GEAR	MEAN (1995-1999)	YEAR 2013	2014	2015 [1]	2016 [1]	MEAN (2000-2014)
2J	Purse seine < 65'	0	0	0	0	0	**6**
	TOTAL	***0***	***0***	***0***	***0***	***0***	**6**
3K	Gillnet	2	1	0	0	0	**45**
	Hand lines	0	0	0	0	0	**37**
	Longlines	0	0	0	0	0	**3**
	Mechanized jigger	0	0	0	0	0	**0**
	Purse seine < 65'	0	95	0	155	2 279	**5 626**
	Tuck seine	0	85	2	53	181	**335**
	Other seines	0	0	0	0	231	**1 016**
	Trap	0	11	4	0	112	**125**
	TOTAL	***3***	***192***	***6***	***208***	***2 803***	**7 188**
3L	Gillnet	2	0	0	0	-	**16**
	Hand lines	0	0	0	0	-	**6**
	Longlines	0	0	0	0	-	**1**
	Mechanized jigger	0	0	0	0	-	**0**
	Purse seine < 65'	1	0	0	54	-	**1 177**
	Tuck seine	0	0	25	0	-	**97**
	Other seines	0	0	0	0	-	**250**
	Trap	0	0	0	0	-	**39**
	TOTAL	***2***	***0***	***25***	***54***	***-***	**1 586**
3O	Purse seine < 65'	0	0	0	-	-	**2**
	TOTAL	***0***	***0***	***0***	***-***	***-***	**2**
3P	Gillnet	40	0	0	-	-	**41**
	Hand lines	5	0	0	-	-	**4**
	Longlines	0	0	0	-	-	**1**
	Mechanized jigger	0	0	0	-	-	**0**
	Purse seine < 65'	1	25	246	-	-	**579**
	Purse seine > 65'	0	0	0		-	**238**
	Tuck seine	0	0	0	--	-	**0**
	Other seines	0	0	0	-	-	**6**
	Trap	0	0	0	-	-	**104**
	TOTAL	***46***	***25***	***246***	***-***	***-***	**973**
4R	Gillnet	126	11	1	0	0	23
	Hand line	56	0	0	0	0	96
	Longlines	2	0	0	0	0	8
	Mechanized jigger	2	0	0	0	0	0
	Purse seine < 65'	1 262	3 218	2 040	114	1 343	6 521

DIVISION	GEAR	MEAN (1995-1999)	YEAR 2013	2014	2015 [1]	2016 [1]	MEAN (2000-2014)
	Purse seine > 65'	776	1 513	676	0	111	5 156
	Tuck seine	0	141	294	302	146	1 120
	Other seines	2	0	0	16	0	55
	Trap	55	25	143	7	110	222
	TOTAL	***2 279***	***4 908***	***3 155***	***439***	***1 710***	***12 827***
4S	Gillnet	1	1	0	0	0	5
	Hand line	0	0	0	0	0	0
	Purse seine < 65'	0	132	12	16	34	30
	Trap	0	112	9	13	28	34
	Other	8	0	0	0	1	0
	TOTAL	***9***	***245***	***20***	***29***	***63***	***69***
4T	Bottom trawl	0	0	0	0	0	0
	Gillnet	5 375	583	460	543	231	3 077
	Hand line	4 299	1 652	1 166	1 048	402	3 547
	Longline	0	0	0	0	0	0
	Jigger	1 543	20	0	0	0	221
	Mechanized jigger	0	393	514	410	0	225
	Purse seine < 65'	19	0	0	0	0	1
	Trap	21	0	0	0	0	1
	Cages	1	0	0	0	0	5
	Weir	0	0	0	0	0	0
	Q [2]	0	0	0	0	0	222
	Other	383	100	249	241	117	30
	TOTAL	***11 641***	***2 748***	***2 389***	***2 242***	***750***	***7 329***
4V	Bottom trawl	0	0	0	0	-	0
	Gillnet	55	4	0	3	-	7
	Hand line	352	3	19	11	-	10
	Longline	0	0	0	0	-	1
	Jigger	0	0	0	0	-	0
	Purse seine < 65'	16	0	0	0	-	0
	Trap	620	130	111	43	-	136
	Other	0	8	14	0	-	7
	TOTAL	***1 044***	***145***	***144***	***57***	***-***	***161***
4W	Bottom trawl	46	5	6	2	-	2
	Midwater trawl	0	0	0	0	-	1
	Gillnet	238	0	1	6	-	27
	Hand line	11	0	3	20	-	5
	Purse seine > 65'	0	0	0	0	-	2
	Trap	261	11	209	159	-	56
	Other	0	0	0	0	-	0

DIVISION	GEAR	MEAN (1995-1999)	YEAR 2013	2014	2015 [1]	2016 [1]	MEAN (2000-2014)
	TOTAL	***557***	***16***	***219***	***187***	-	***94***
4X	Bottom trawl	2	0	0	0	-	0
	Gillnet	226	17	43	92	-	125
	Hand line	42	24	117	297	-	47
	longline	0	0	0	0	-	0
	Purse seine < 65'	5	0	0	0	-	0
	Purse seine > 65'	0	16	48	75	-	23
	Trap	3 141	176	120	218	-	1 474
	Weir	65	0	0	***0***	-	14
	Other	0	7	11	0	-	17
	TOTAL	***3 482***	***240***	***340***	***682***	-	***1 700***
5YZ	Other	0	0	0	0	-	1
	TOTAL	***0***	***0***	**0**	0	-	1
Other	Other	0	143	136	245	31	27
	TOTAL	***0***	***143***	136	245	31	***27***
TOTAL	Bottom trawl	48	5	6	2	0	3
	Midwater trawl	0	0	0	0	0	1
	Gillnet	6 065	617	506	644	231	3 365
	Hand line	4 764	1 679	1 305	1 376	402	3 752
	Longline	2	0	0	0	0	14
	Jigger	1 545	20	0	0	0	221
	Mechanized jigger	0	393	514	410	0	225
	Purse seine < 65'	1 304	3 470	2 298	339	3 656	13 943
	Purse seine > 65'	776	1 529	724	75	111	5 418
	Tuck seine	0	226	321	355	327	1 179
	Other seines	2	0	0	16	231	1 326
	Trap	4 099	465	596	440	250	2 191
	Cages	1	0	0	0	0	5
	Weir	65	0	0	0	0	14
	Other	391	258	410	486	149	82
	Q [2]	0	0	0	0	0	222
GRAND TOTAL		***19 062***	***8 663***	***6 680***	***4 143***	***5 357***	***31 961***

[1] Préliminary; [2] Supplementary purchase slips, Québec Region

Tableau 8. Annual landings (t) of Atlantic mackerel by allocation and gear type and mean of the 2000-2014 period.

ALLOCATION	GEAR	MEAN (1995-1999)	YEAR 2013	2014	2015 [1]	2016 [1]	MEAN (2000-2014)
40 %	**Midwater trawl**	0	0	0	0	0	2
	Purse seine > 65'	776	1 529	724	320	111	5 418
	Total	**776**	**1 529**	**724**	**320**	**111**	**5 420**
	TAC	*40 000*	*14 400*	*4 000*	*3 200*	*3 200*	24 987
	% caught	**2**	**11**	**18**	**10**	**3**	21
60 %	**Purse seine < 65'**	1 304	3 470	2 298	339	3 657	13 935
	Others	16 982	3 664	3 658	3 484	1 589	12 575
	Total	**18 285**	**7 134**	**5 956**	**3 823**	**5 246**	**26 510**
	TAC	*60 000*	*21 600*	*6 000*	*4 800*	*4 800*	37 480
	% caught	**30**	**33**	**99**	**80**	**109**	72
	Grand Total	**19 061**	**8 663**	**6 680**	**4 143**	**5 357**	**31 930**
	TOTAL TAC[2]	**100 000**	**36 000**	**10 000**	**8 000**	**8 000**	**-**

Tableau 9. Spawning stock biomass (SSB) and stock exploitation rate projections under different total catch scenarios (reported + unreported) calculated using a censored catch-at-age statistical model. For 2019, the Table gives the probability of stock growth (SSB greater than in 2016) and the probability of exceeding the limit reference point (LRP) of 103,000 t.

Reported + unreported catches (t)		2017		2018		2019		
2017	**2018**	**SSB (t)**	**Expl. rate**	**SSB (t)**	**Expl. rate**	**SSB (t)**	**Prob. >2016**	**Prob. > LRP**
0	0	48 283	0.00	77 164	0.00	113 886	0.95	0.56
4 000	4 000	48 283	0.08	72 175	0.06	103 378	0.93	0.50
6 000	6 000	48 283	0.13	68 503	0.09	96 927	0.92	0.46
8 000	8 000	48 283	0.17	64 910	0.12	90 889	0.89	0.42
10 000	10 000	48 283	0.21	62 762	0.16	85 686	0.87	0.40
12 000	12 000	48 283	0.25	59 466	0.21	77 143	0.84	0.34
14 000	14 000	48 283	0.29	56 858	0.24	72 189	0.81	0.30
16 000	16 000	48 283	0.33	54 018	0.29	66 158	0.77	0.26
18 000	18 000	48 283	0.38	50 928	0.36	57 113	0.70	0.20
20 000	20 000	48 283	0.42	47 502	0.42	51 348	0.64	0.17
24 000	24 000	48 283	0.50	41 704	0.59	35 728	0.44	0.09
30 000	30 000	48 283	0.62	33 053	0.90	17 199	0.16	0.02

9. FIGURES

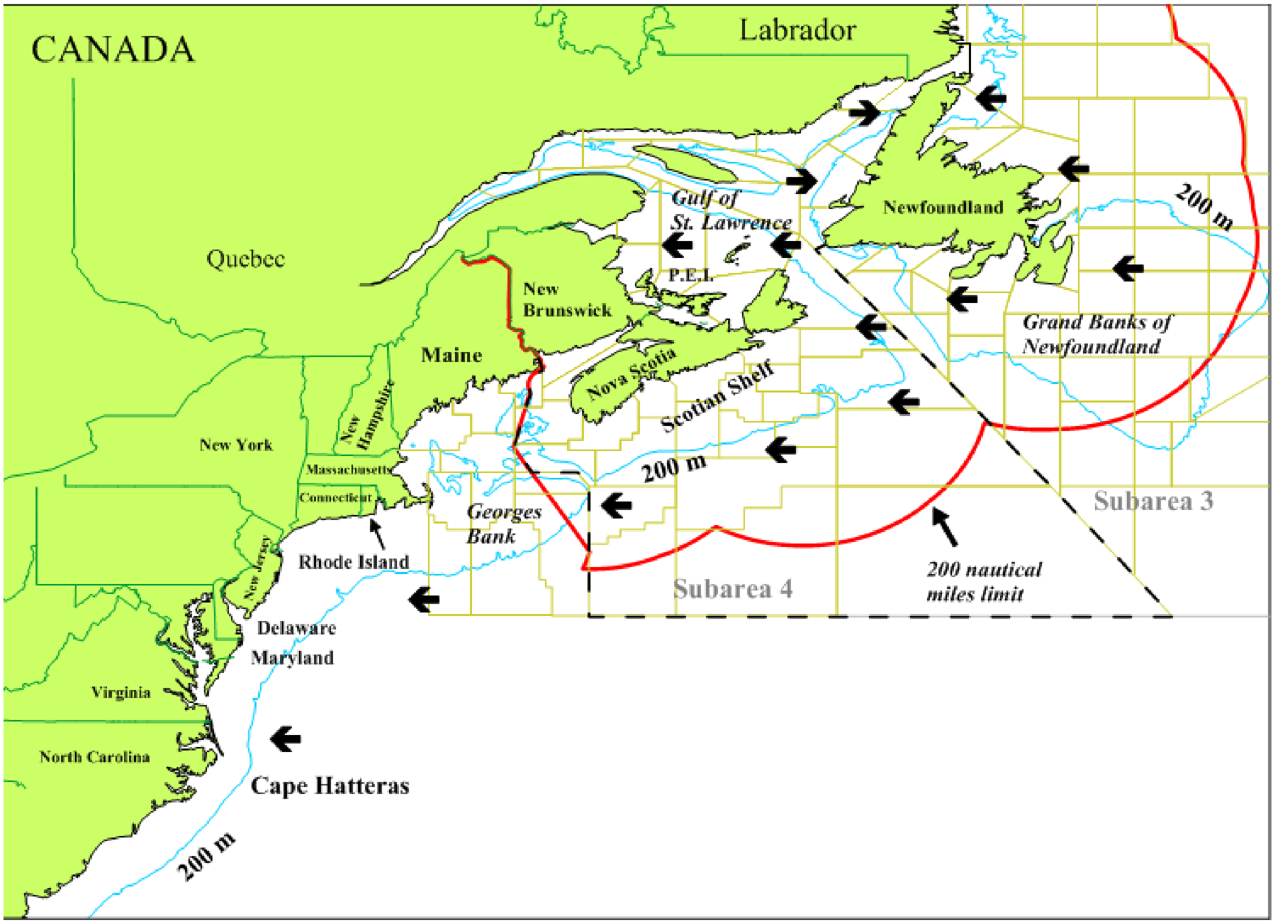


Figure 1. Atlantic mackerel distribution (Scomber scombrus L.) in the Northwest Atlantic. NAFO subareas 3 and 4 are indicated. Arrows represent the general migration pattern of mackerel.

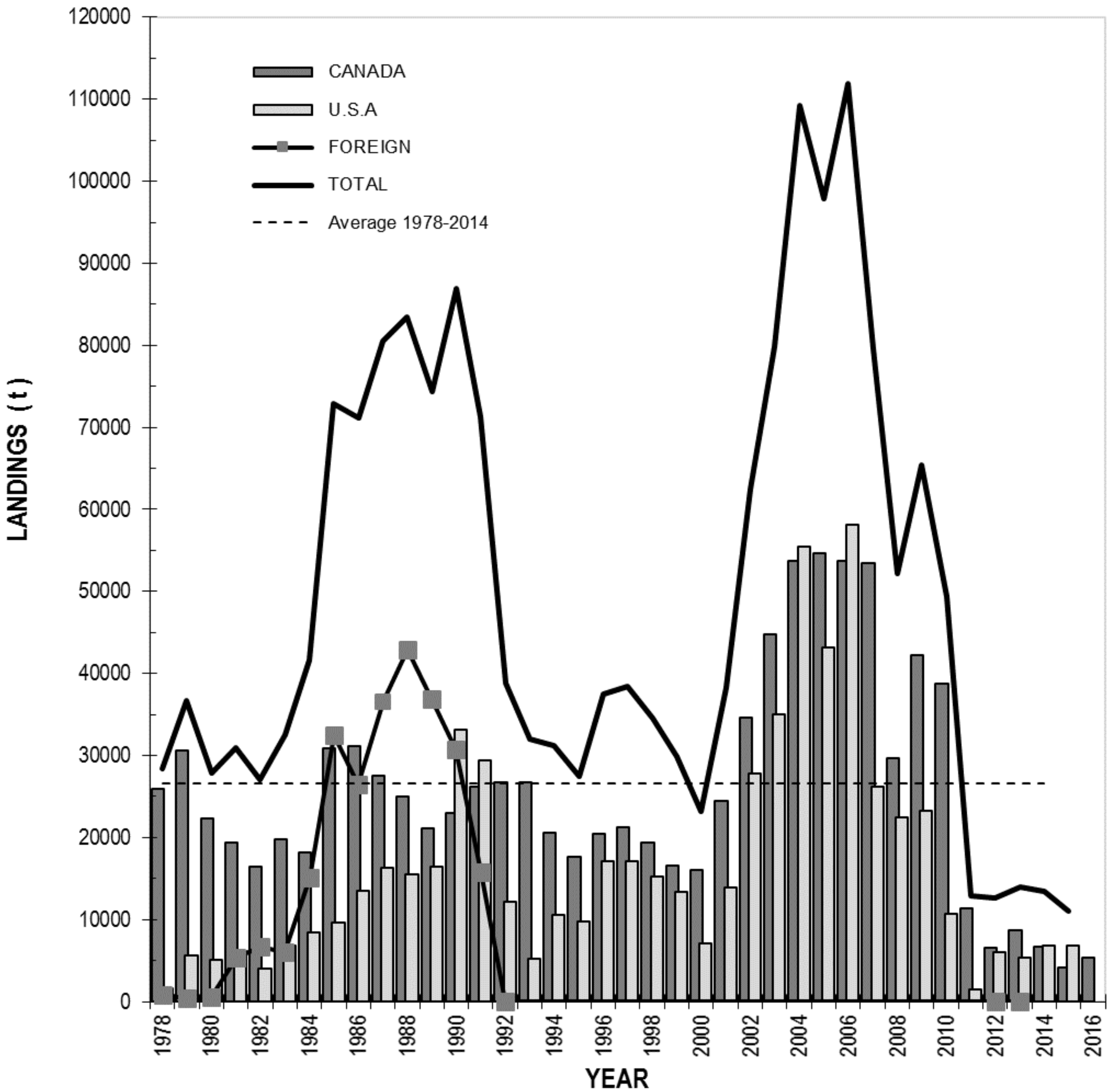
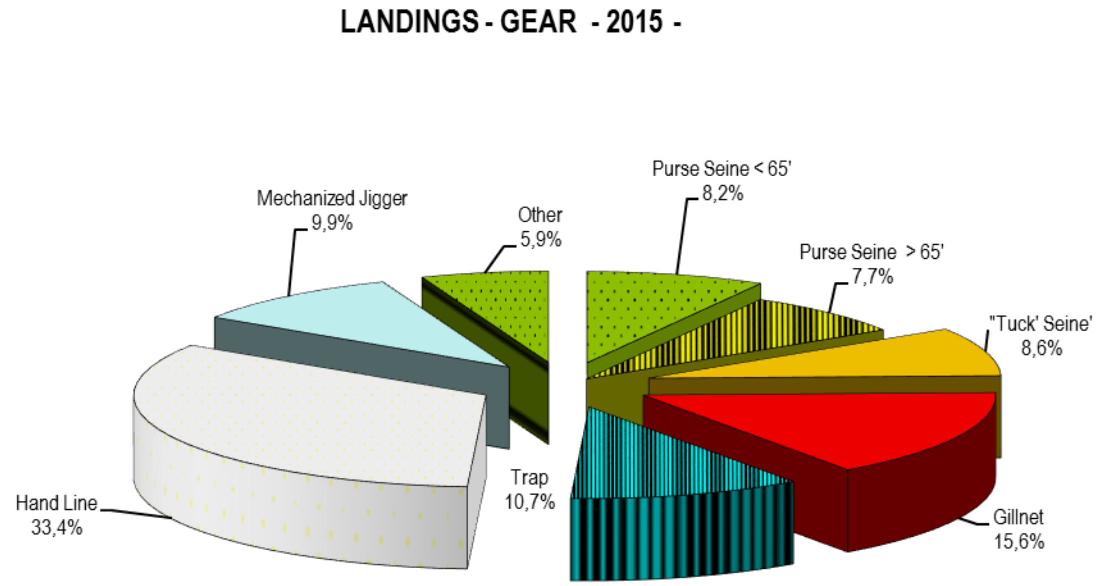


Figure 2. Atlantic mackerel catches (t) in the Northwest Atlantic since 1978 (first full year of Economic Exclusivity Zone –EEZ- of 200 nautical miles). The horizontal line represents mean Canadian landings for the 1978-2014 period (preliminary Canadian data in 2015 and 2016).

(A)



(B)

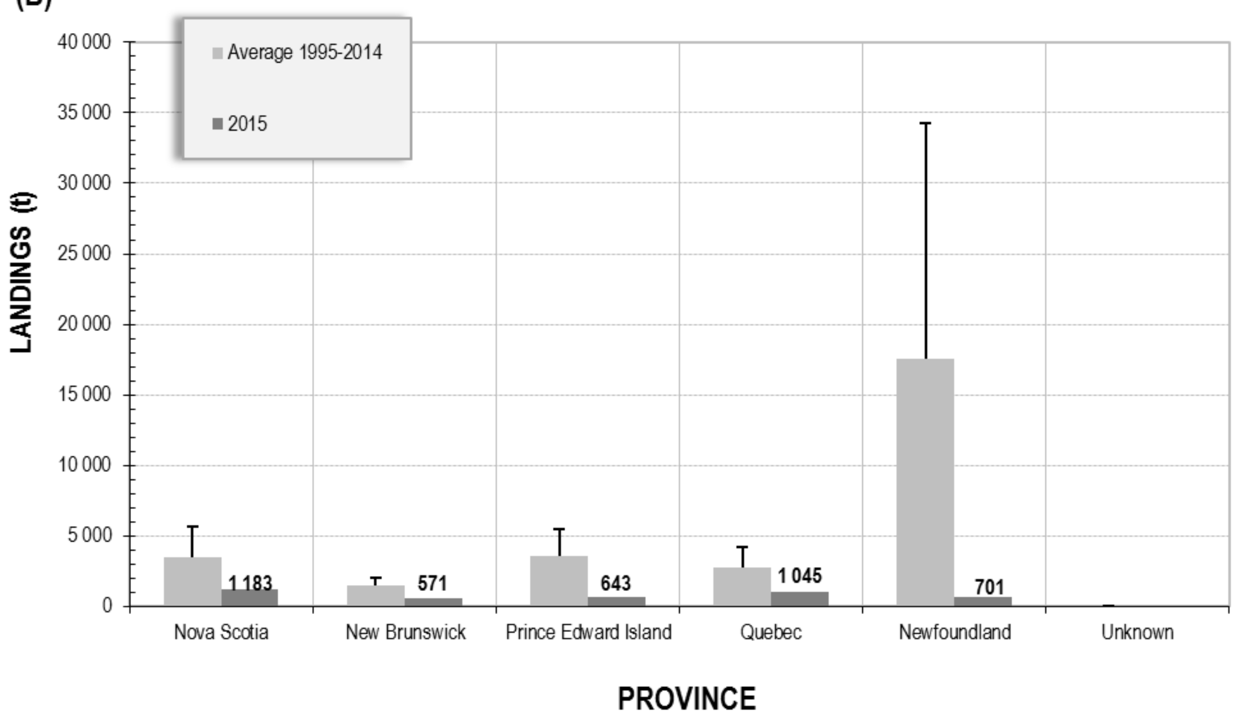


Figure 3. Atlantic mackerel landings in NAFO Subareas 3-4: (A) by province in 2015, and (B) annual means with standard deviations for the 1995-2014 period.

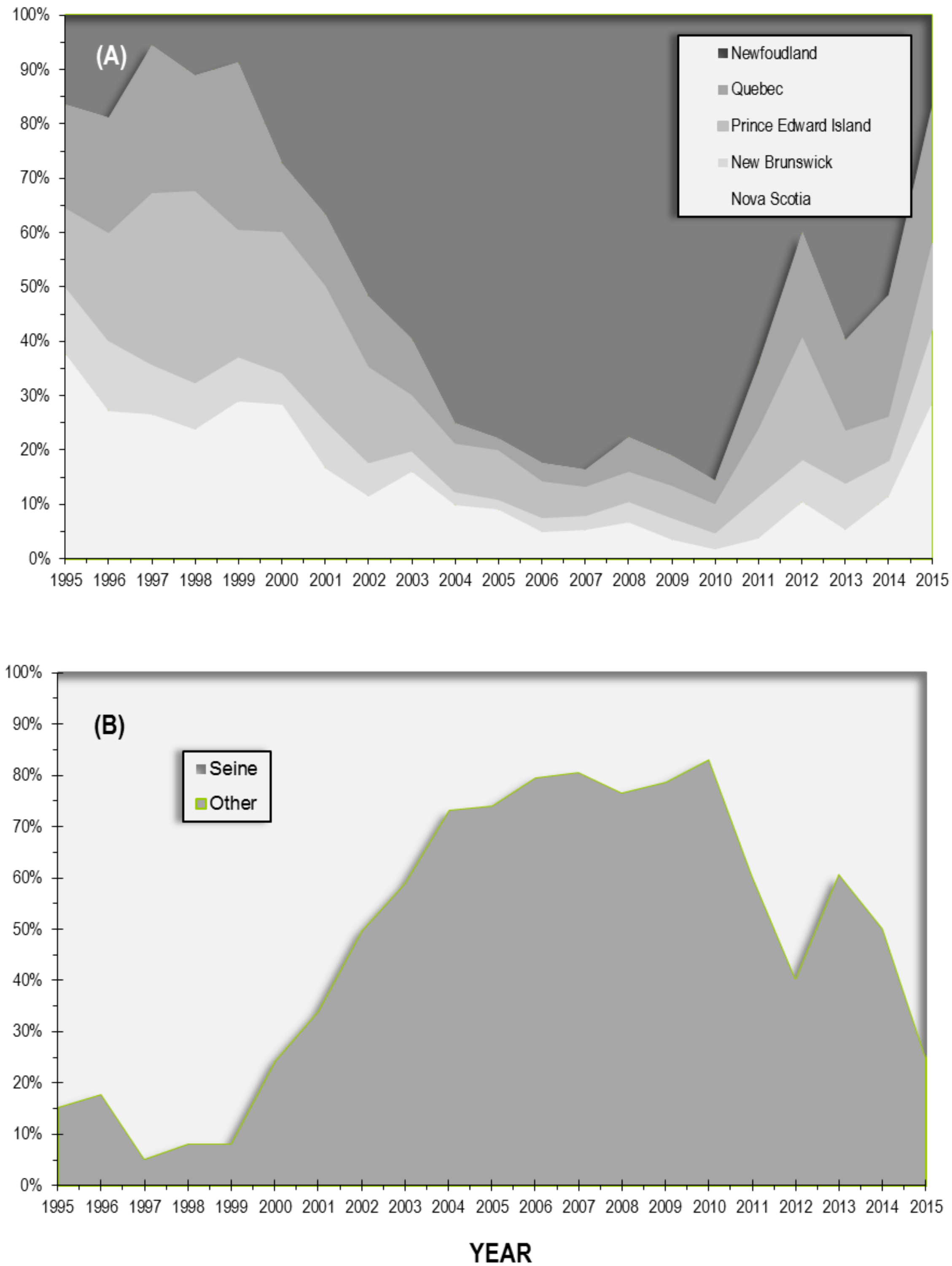
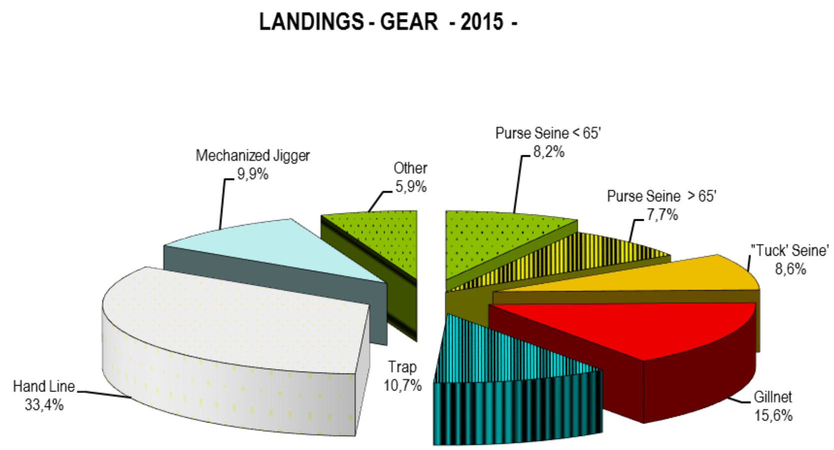


Figure 4. Atlantic mackerel landings in NAFO Subareas 3-4: (A) by province, and (B) annual % from seines and other gears since 1995.

(A)



(B)

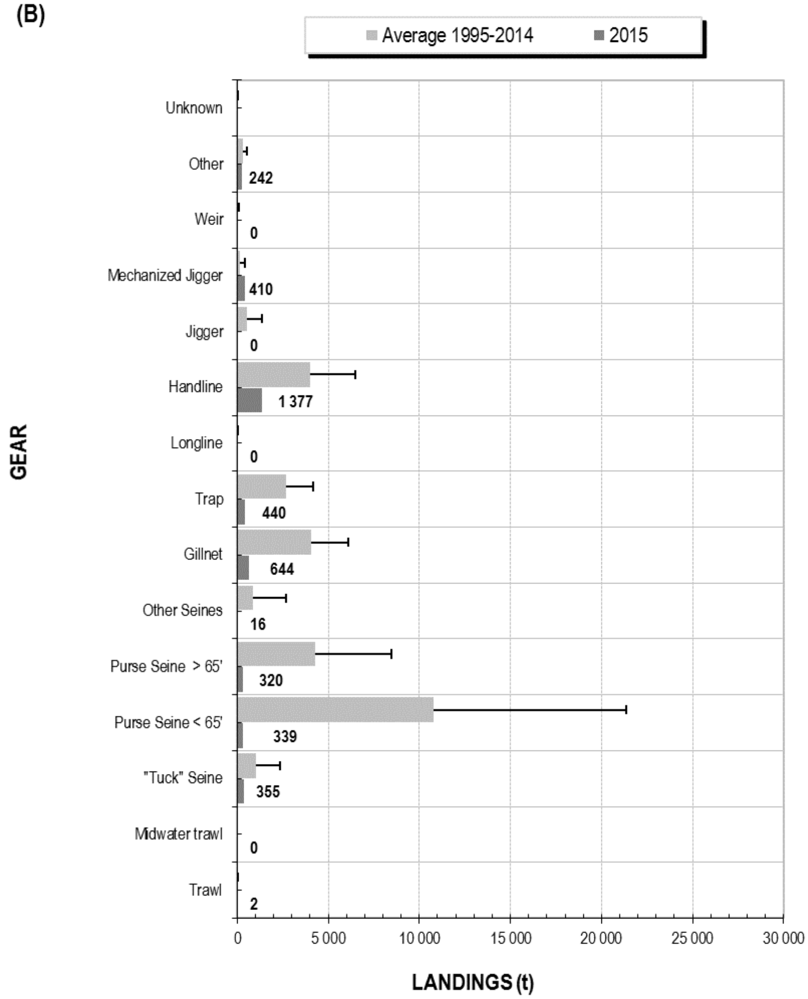
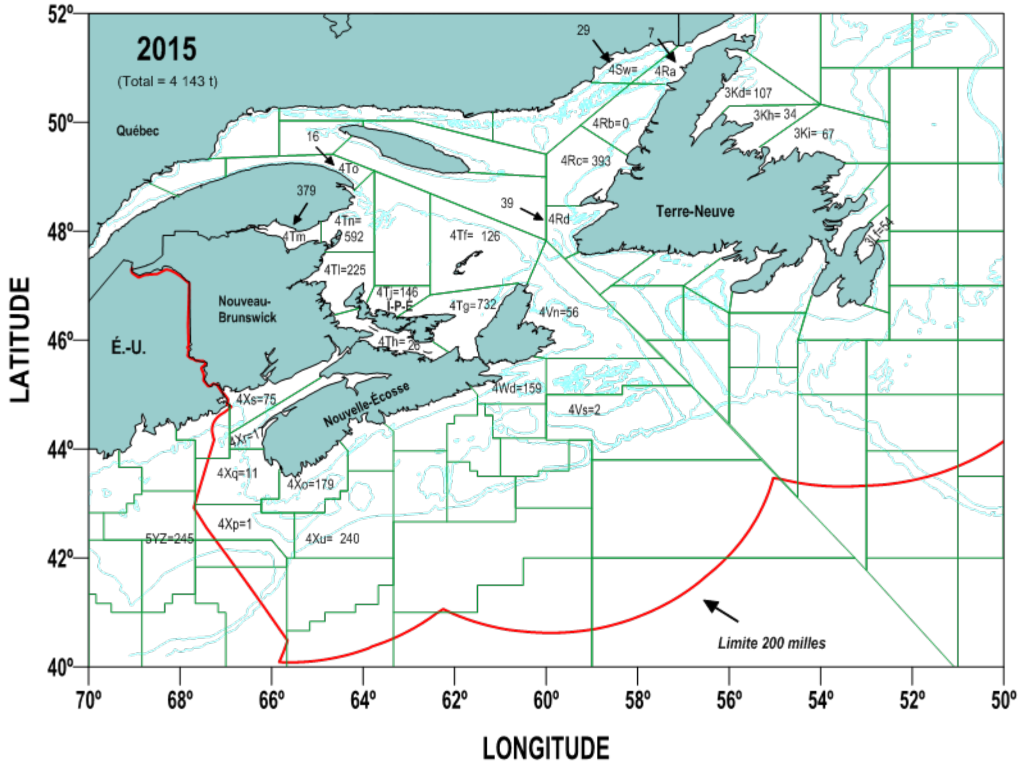


Figure 5. Atlantic mackerel landings in NAFO Subareas 3-4: (A) 5 by gear, and (B) annual means with standard deviation for the 1995-2014 period.



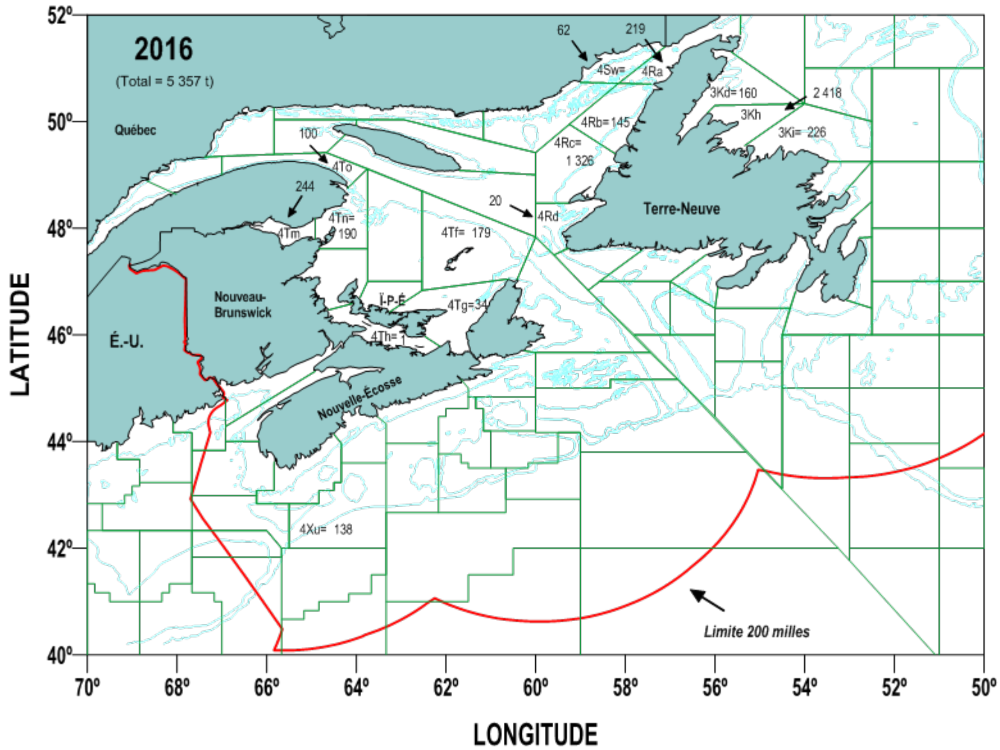


Figure 6. Map of Atlantic mackerel catches (t) in 2015 and 2016 by NAFO subdivision and unit area (u=unknown unit area).

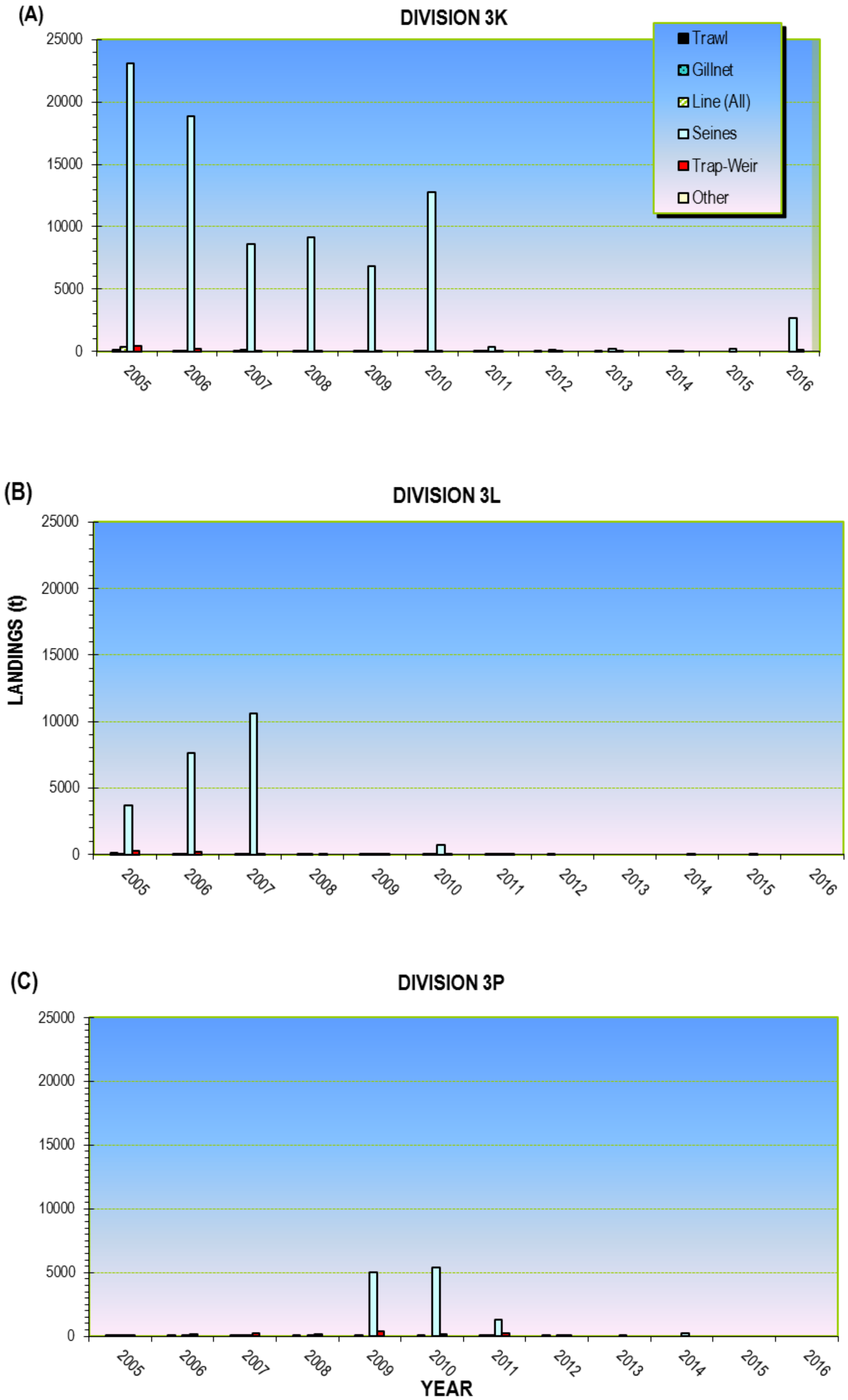


Figure 7. Atlantic mackerel landings by NAFO Division and gear since 2005 (main gears presented). For 4T, 2016 data include Québec and Newfoundland only.

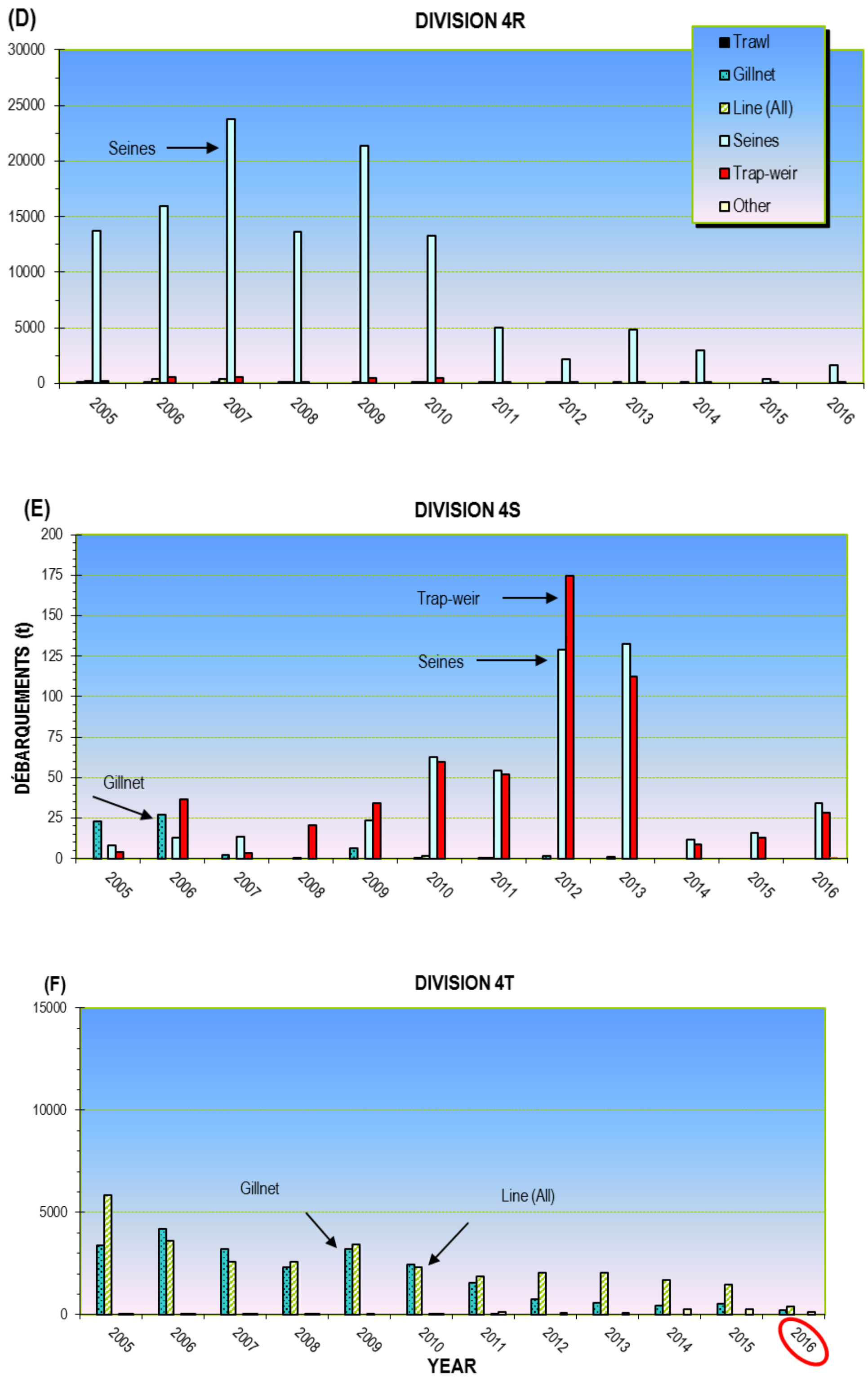


Figure 7 (continued).

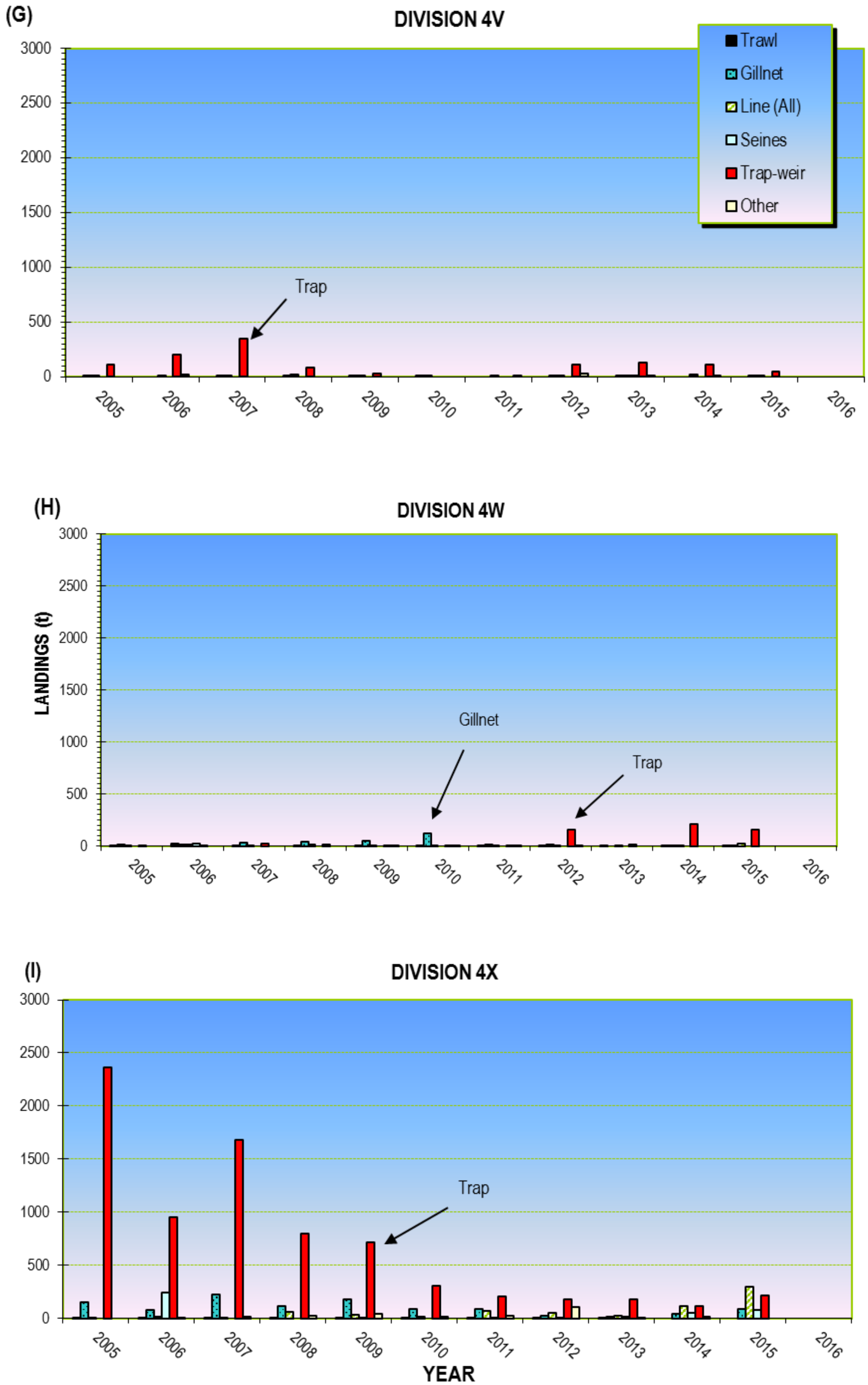


Figure 7 (continued).

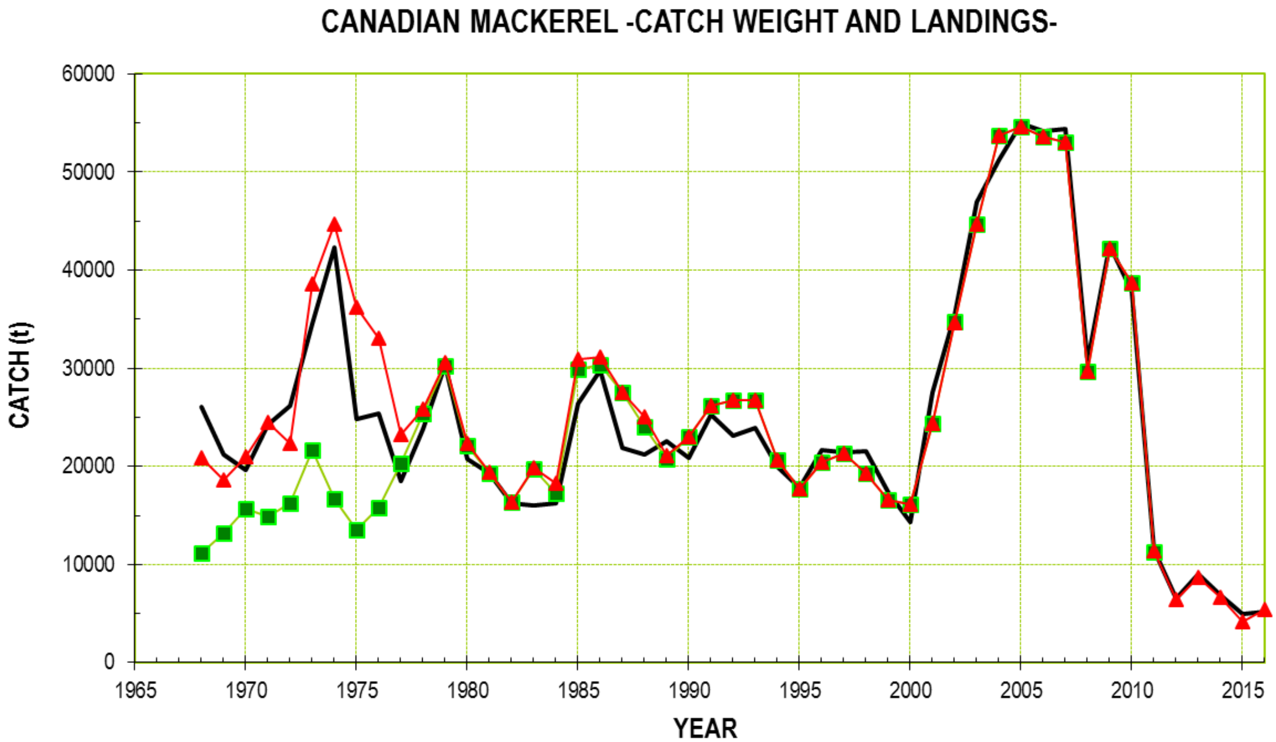
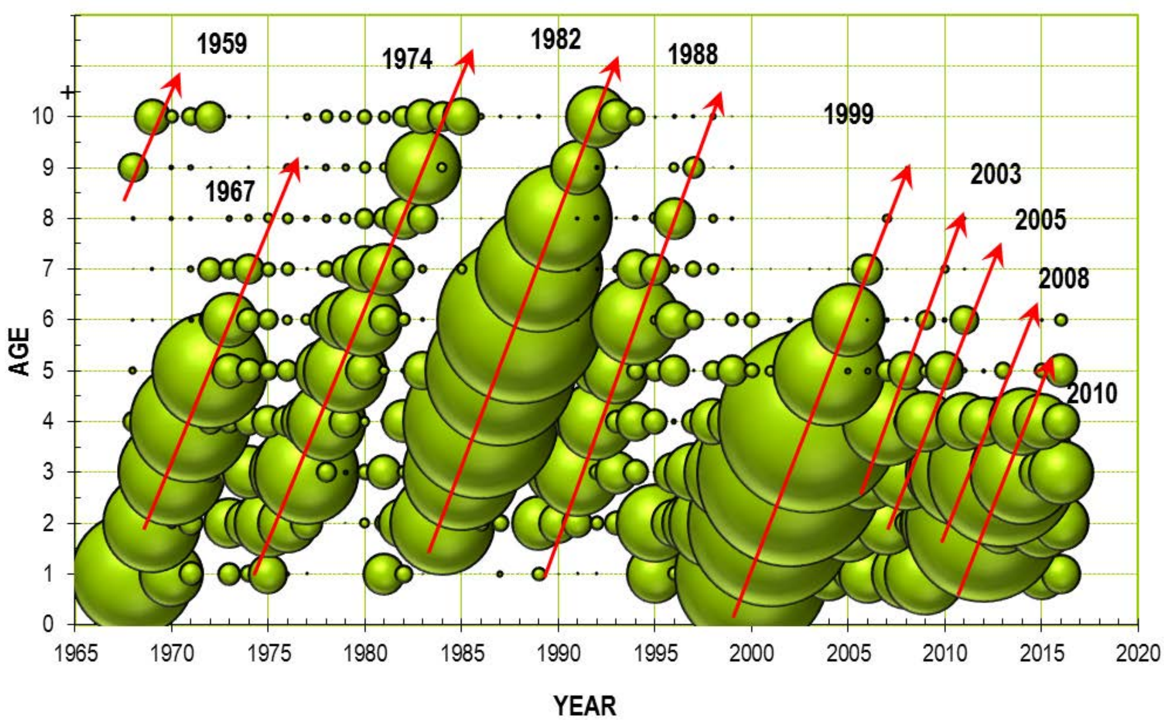


Figure 8. Landings and catch biomass of Atlantic mackerel in NAFO Subareas 3 and 4 since 1968.

(A)



(B)

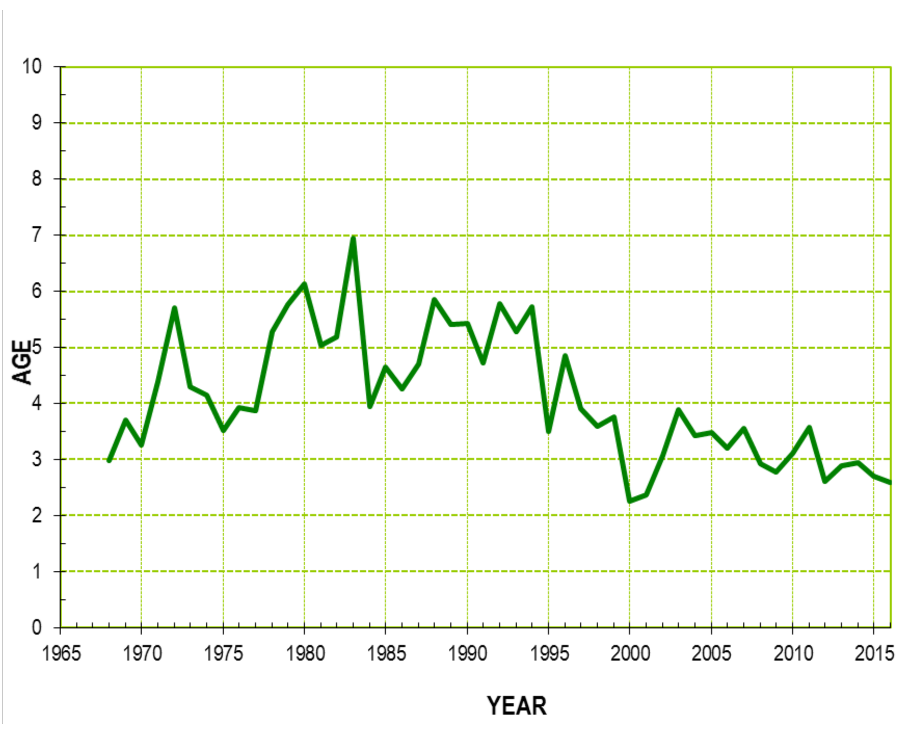


Figure 9. Catch-at-age of Atlantic mackerel in NAFO Subareas 3 and 4 : (A) in % (dominant year-classes are indicated); (B) mean age of the catch per year.

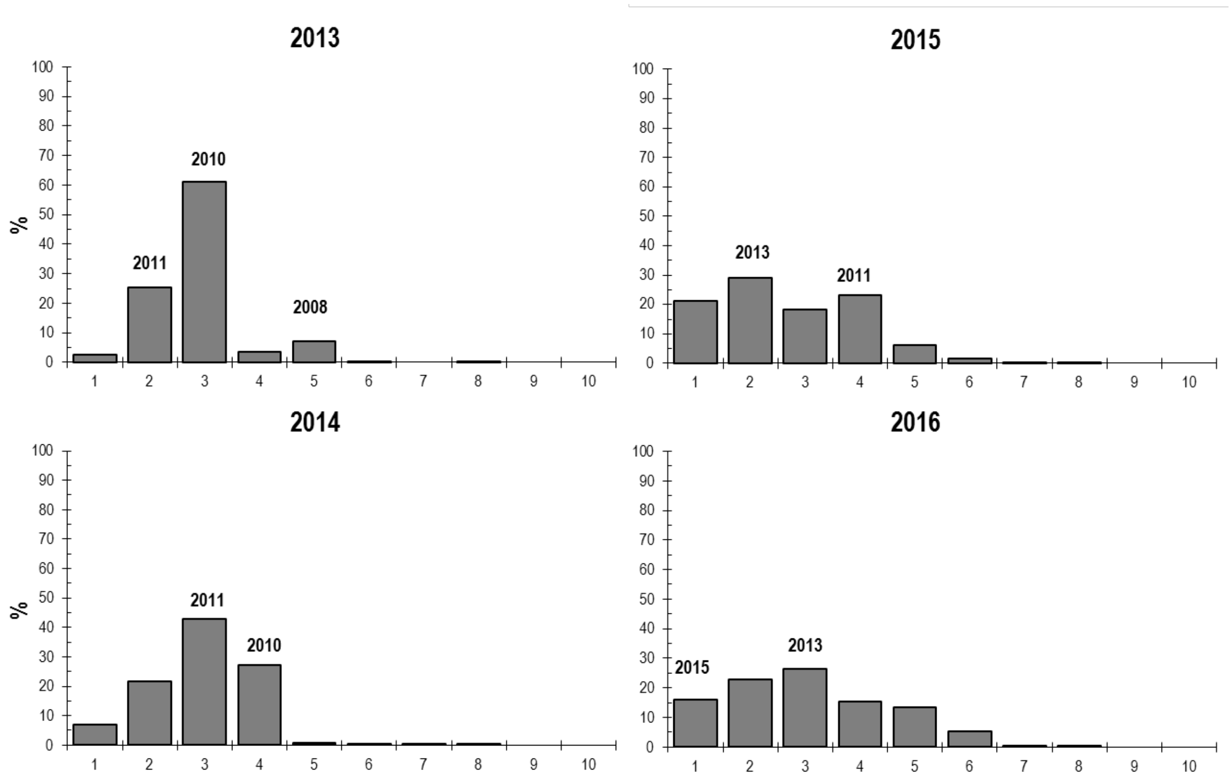


Figure 10. Catch-at-age of Atlantic mackerel in NAFO Subareas 3 and 4 (presented as %; dominant year-classes are indicated).

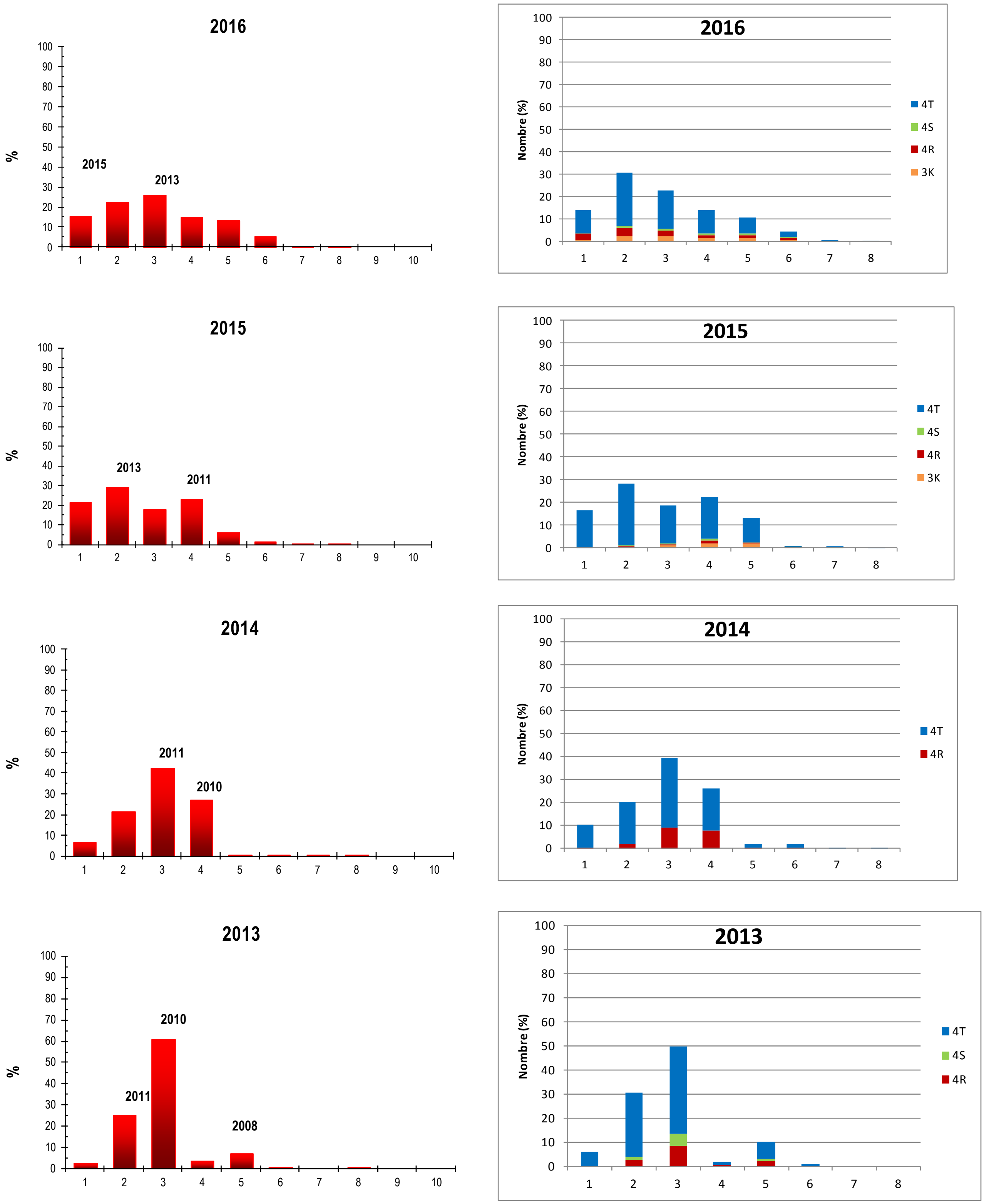


Figure 11. Catch-at-age of Atlantic mackerel in NAFO Subareas 3 and 4 (presented as %; dominant year-classes are indicated). Catch weighted data on the left and non-weighted on the right. For 2016 (weighted), only Québec and Newfoundland are accounted for.

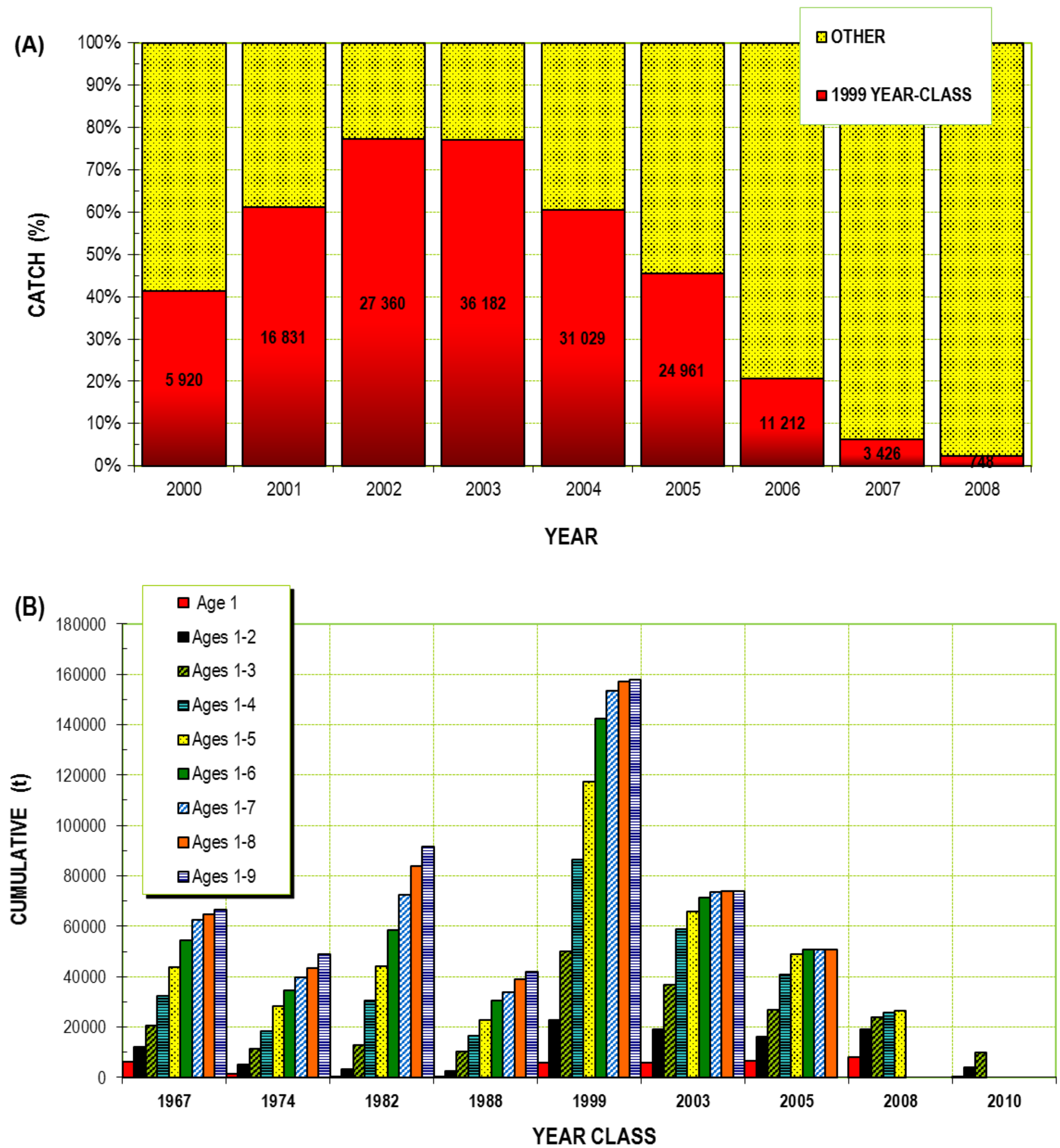


Figure 12. Atlantic mackerel catches (t) per year-class: (A) Dominant 1999 year-class (ages 1-9), and (B) cumulative catch-at-age for year-classes that dominated the fishery since the end of the 1960s.

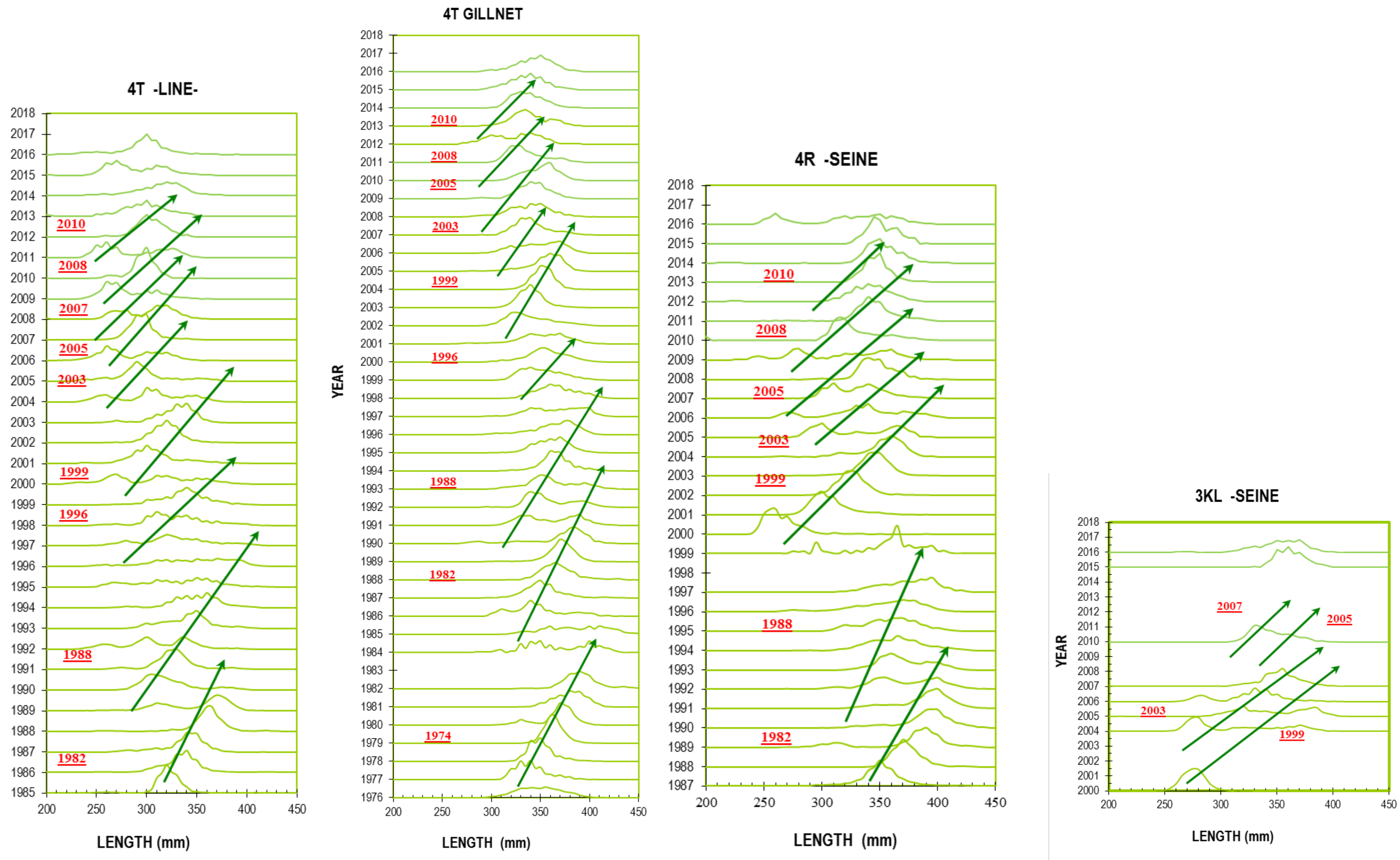


Figure 13. Annual length frequencies (mm) of Atlantic mackerel caught with gillnets and lines in Division 4T and seines in Divisions 4R and 3KL (year-classes that dominated those fisheries are indicated).

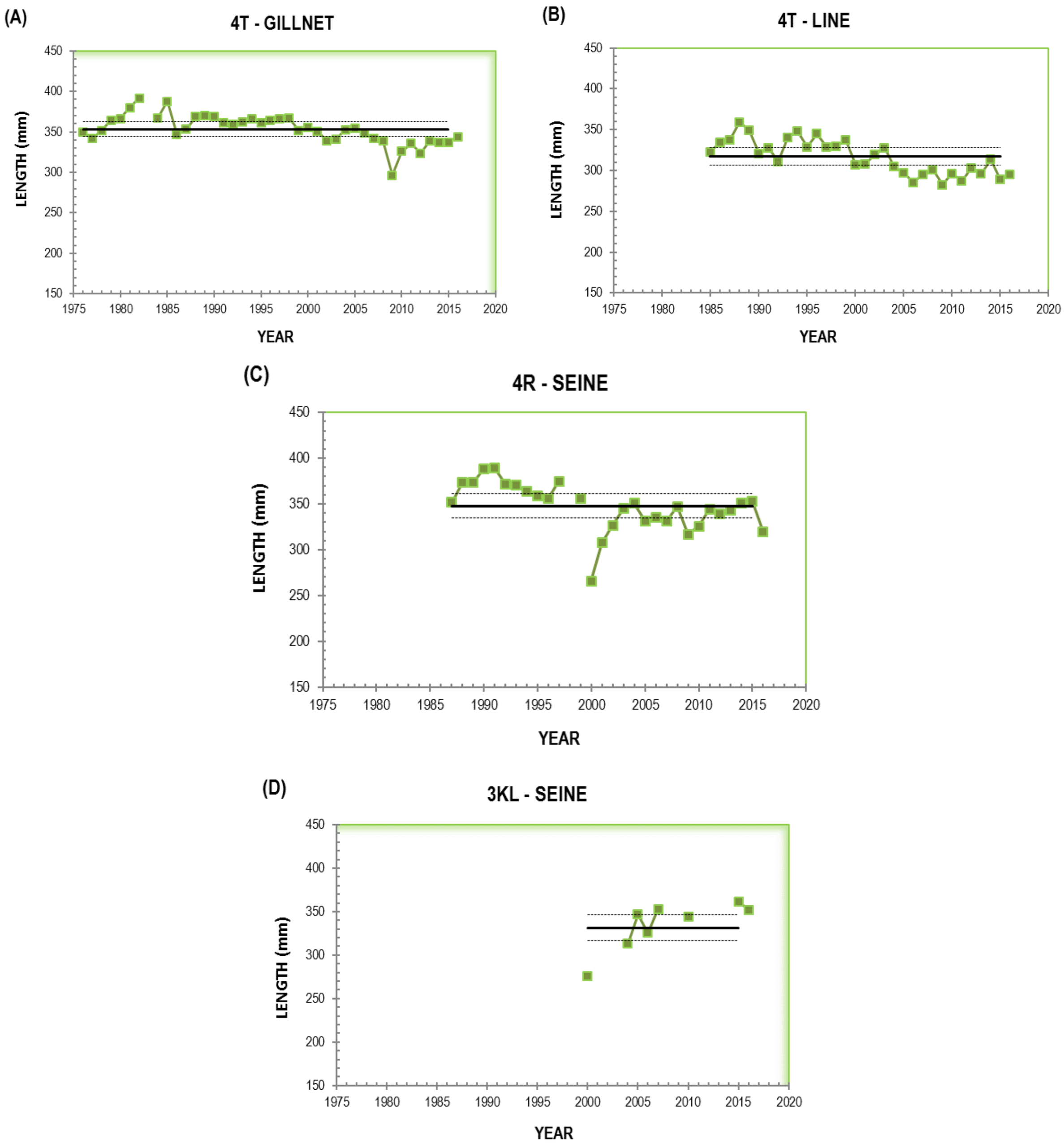


Figure 14. Mean annual length (mm) caught in NAFO Subareas 3 and 4: (A and B) gillnets and lines in Division 4T, (C) seines in Divisions 4R, and (D) seines in Divisions 3KL (horizontal lines represent mean ± 0.5 standard deviation of the period until 2015).

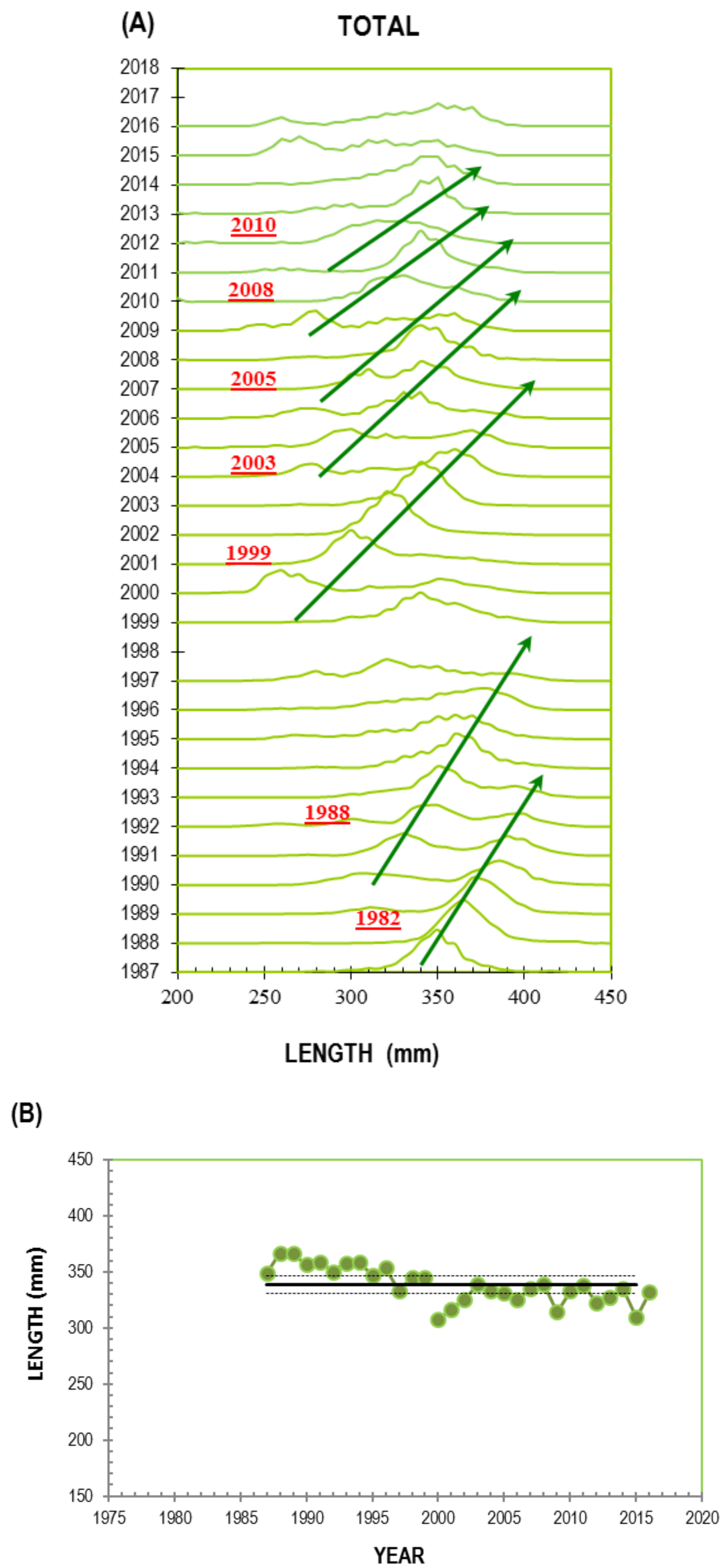


Figure 15. Lengths (mm) of Atlantic mackerel caught since 1987 in NAFO Subareas 3 and 4: (A) annual frequencies since 1987 and (B) mean annual length (horizontal lines represent mean ± 0.5 standard deviation of the 1987-2015 period.

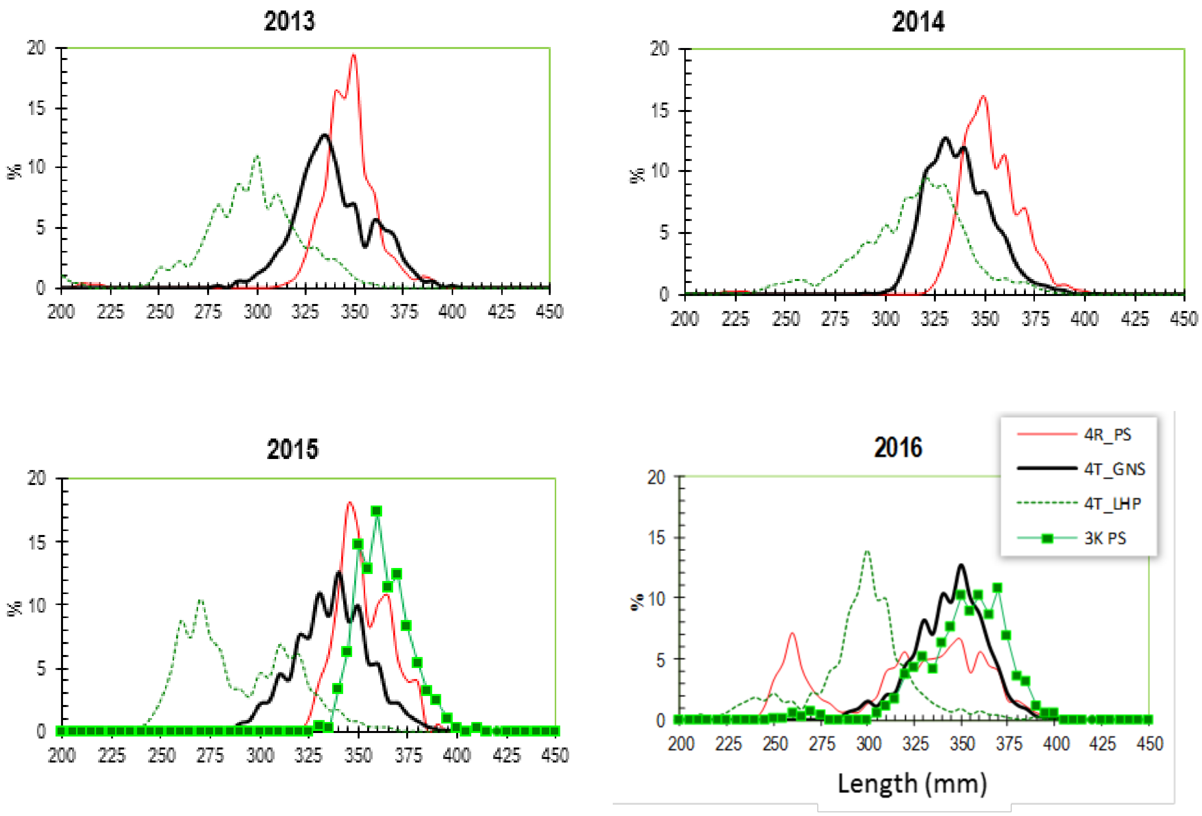


Figure 16a. Length frequencies (mm) of Atlantic mackerel caught with gillnets (GNS), lines (LHP), and purse seines (PS) in NAFO Divisions 4R, 4T, and 3KL from 2013 to 2016.

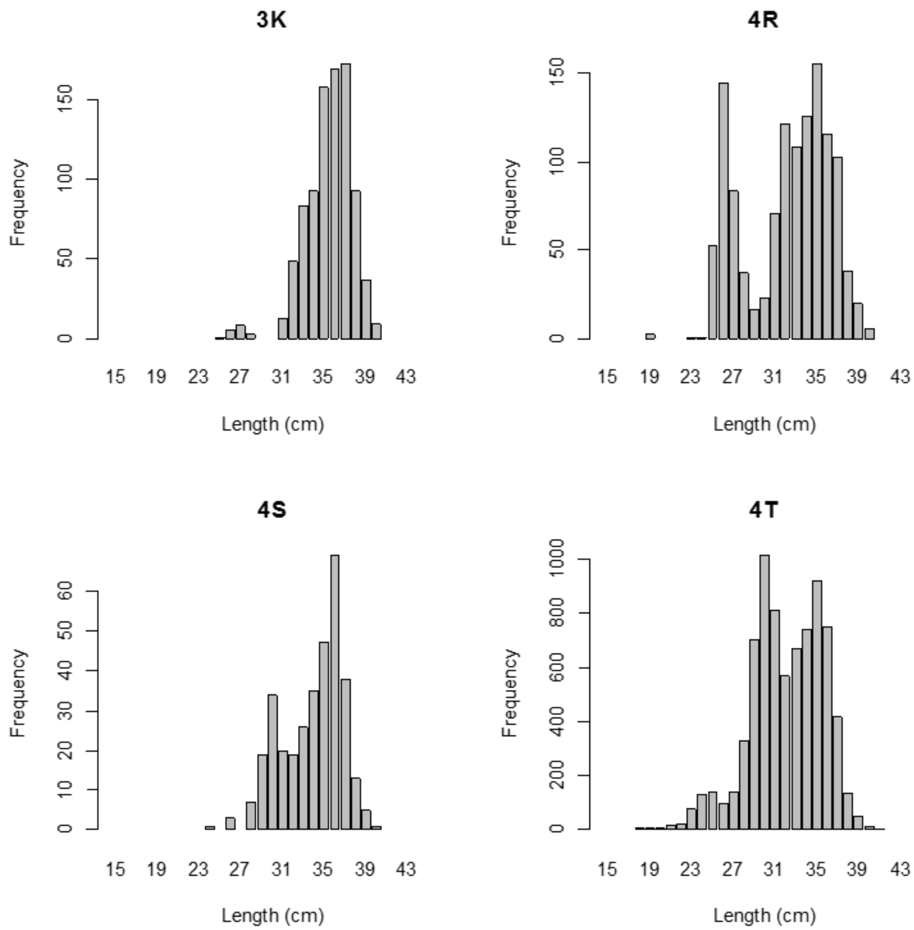


Figure 16b. Length frequencies (%) of Atlantic mackerel caught in NAFO Divisions 3K, 4R, 4S and 4T in 2016.

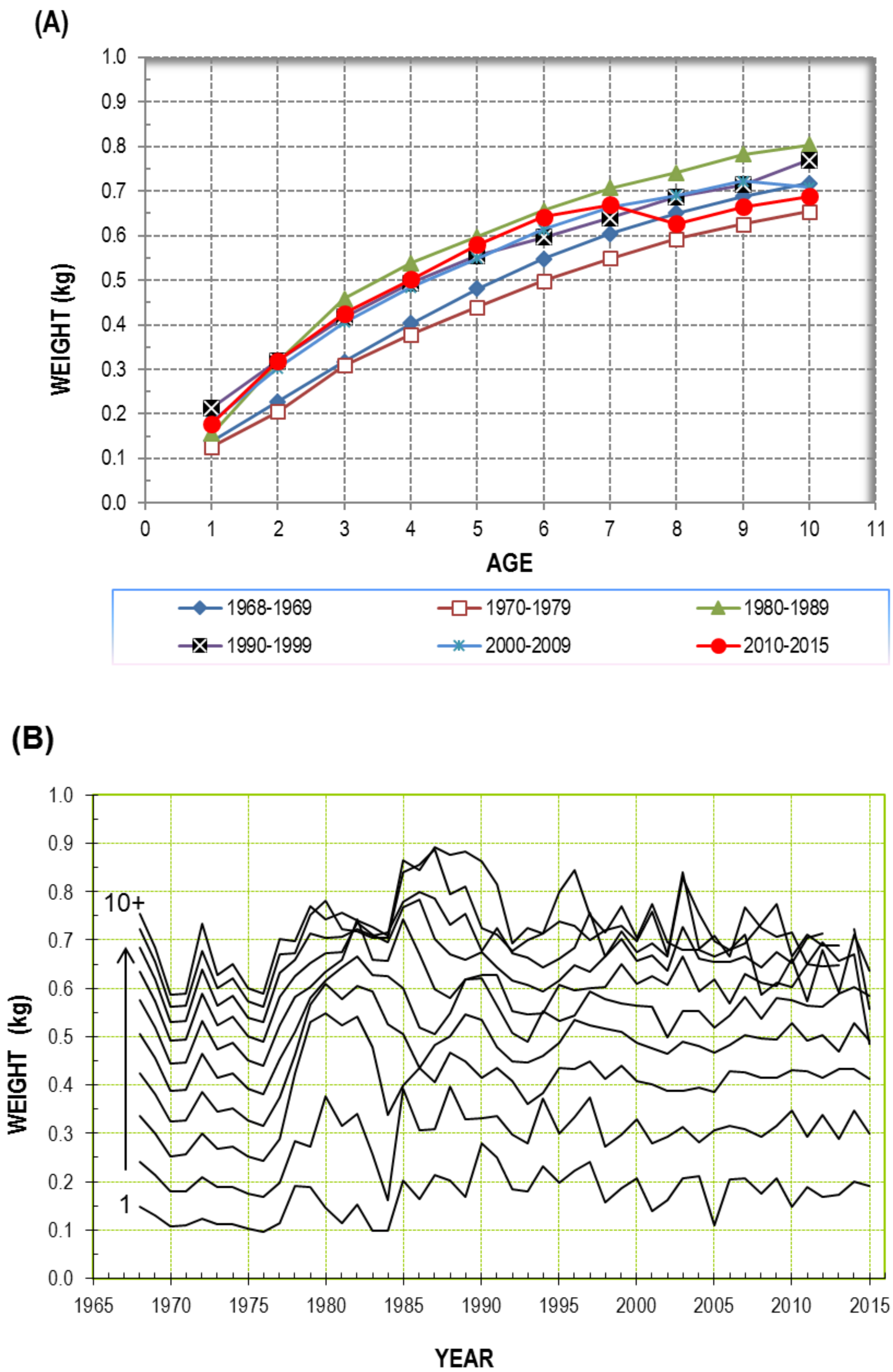
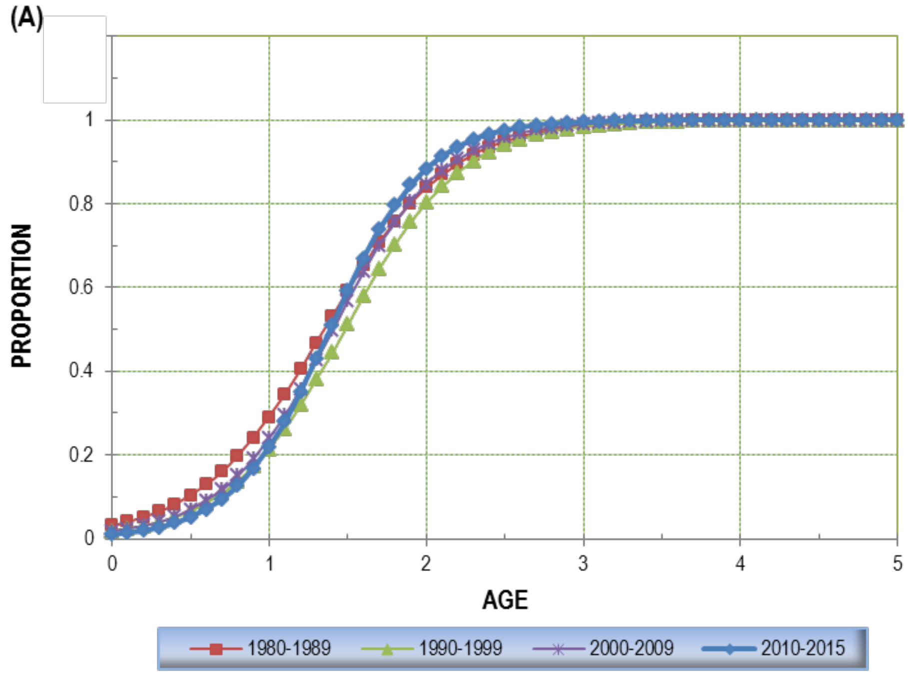


Figure 17. Atlantic mackerel biological data in NAFO Subareas 3 and 4 since 1968 : (A) mean weight-at-age by blocks of years, and weight (kg) for age groups 1-10+.



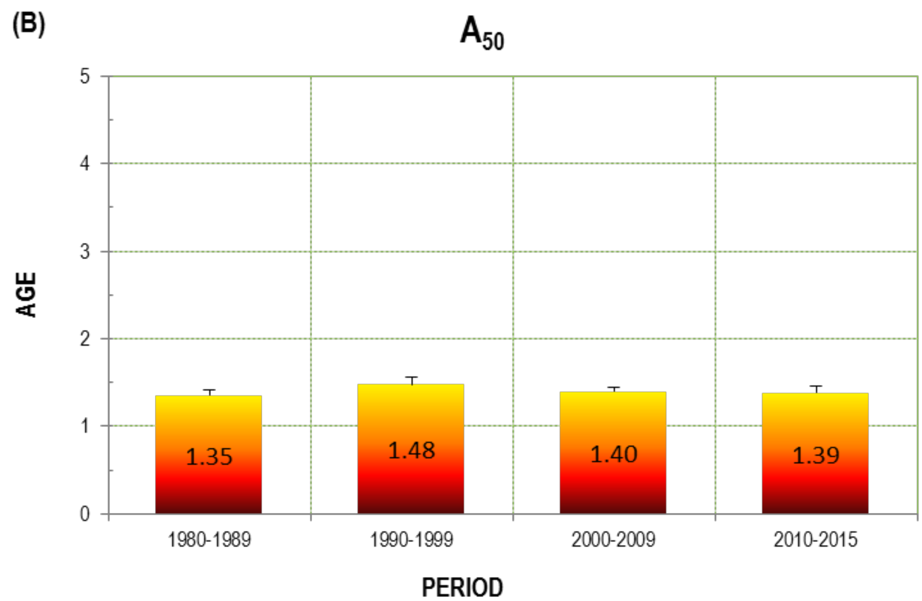


Figure 18. Atlantic mackerel biological data in NAFO Subareas 3 and 4 since 1980 : (A) proportion of maturity at age (in June and July, i.e. spawning season) by blocks of years, and (B) median age A_{50} (with 95% confidence intervals).

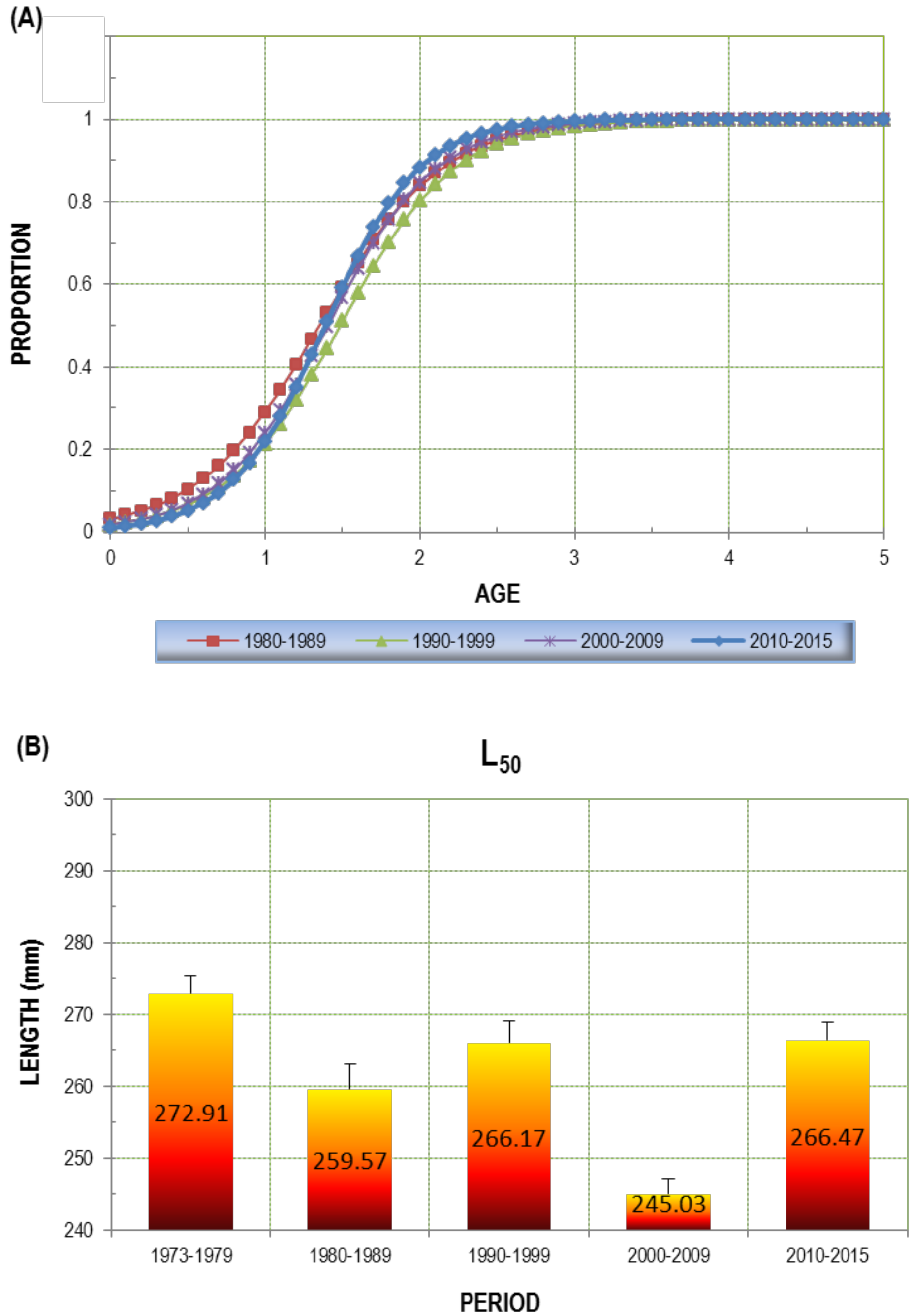


Figure 19. Atlantic mackerel biological data in NAFO Subareas 3 and 4 since 1980 : (A) proportion of maturity at length (mm) (in June and July, i.e. spawning season) by blocks of years, and (B) median length L_{50} (with 95% confidence intervals).

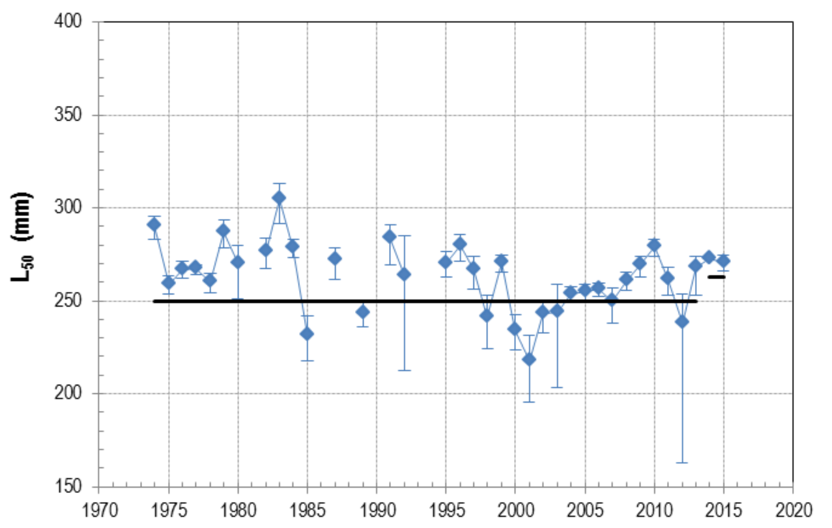


Figure 20. Median annual length L50 of Atlantic mackerel in NAFO Subareas 3 and 4 since 1973 (the horizontal line represents the minimal allowed length of capture of 250 mm until 2013 and of 263 mm starting in 2014).

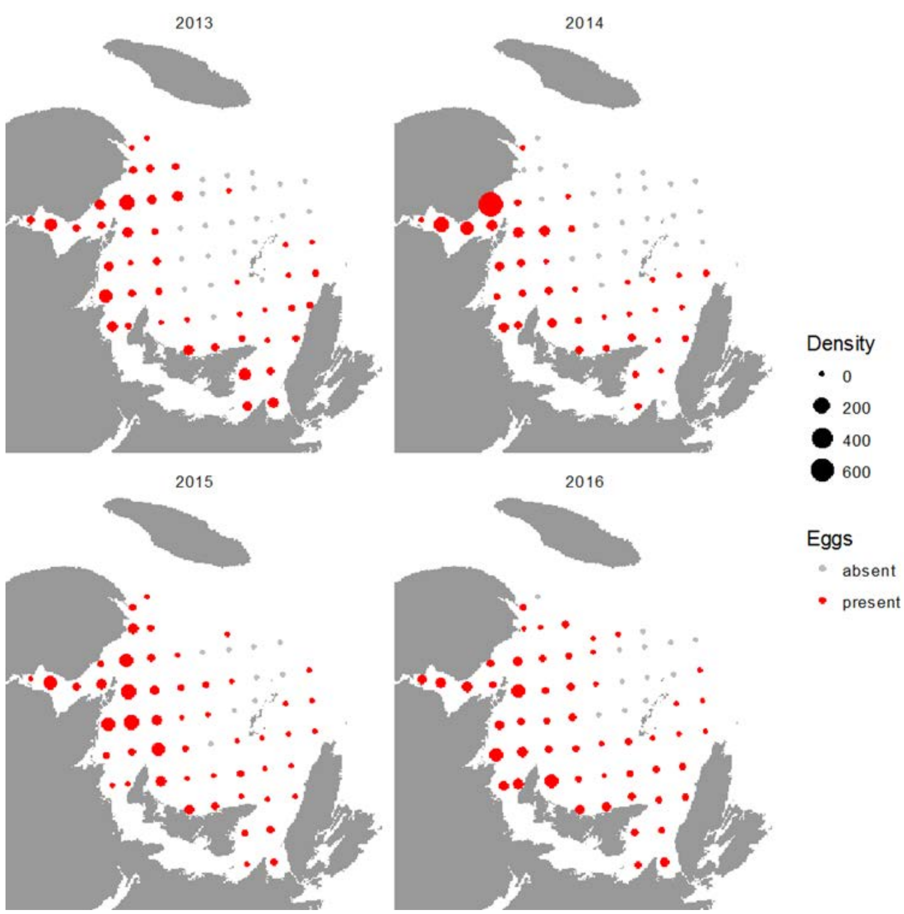


Figure 21. Distribution of Atlantic mackerel egg densities (n/m2) (stages 1 and 5) measured during surveys in the southern Gulf of St. Lawrence.

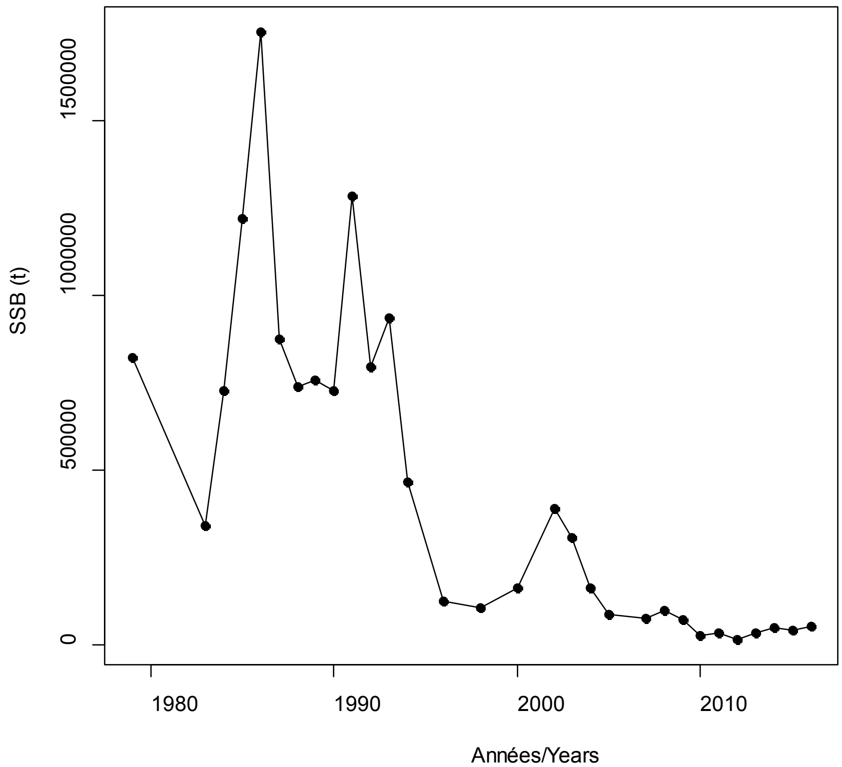


Figure 22. Abundance index of the spawning stock biomass measured according to the Total Egg Production method from the egg densities found in the southern Gulf of St. Lawrence in June.

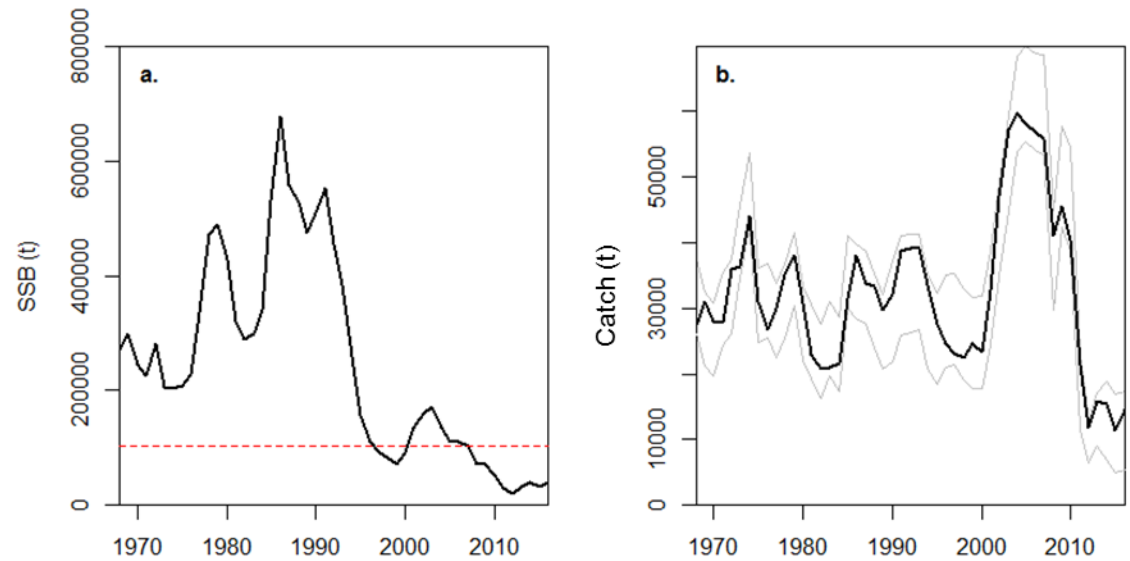


Figure 23. a) Spawning Stock Biomass of mackerel in NAFO Subareas 3 and 4 for the 1968-2013 period estimated by a « censored » statistical catch-at-age model. The red line is the Limit Reference Point. b) Catch estimated for NAFO Subareas 3-4; lower gray line: lower limit of the censored model (declared catches); upper gray line : upper limit (based on bait needs and recreational catches); black line : total catches (declared + undeclared) estimated by the model.

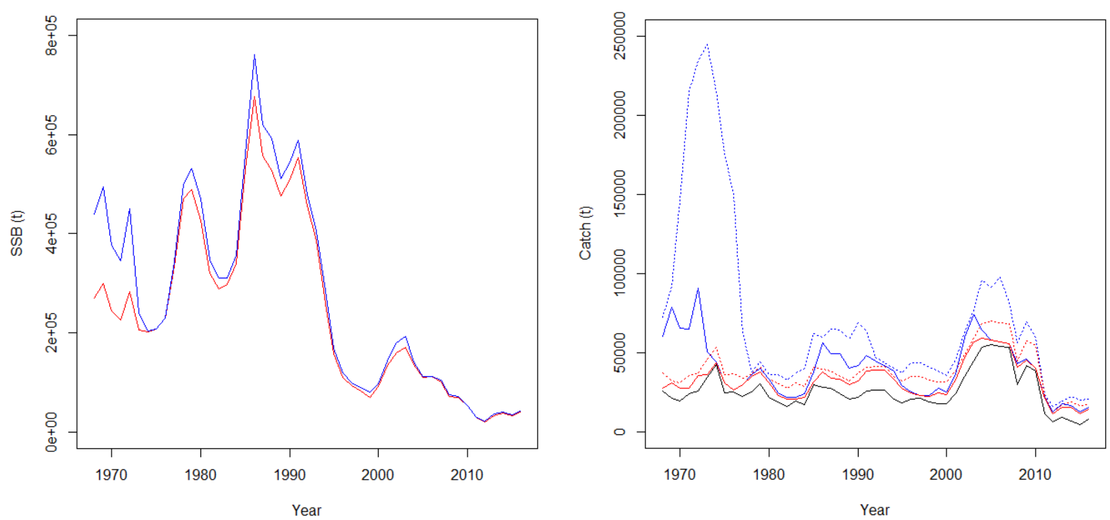


Figure 24. Biomasses and catches estimated by the model with the upper limit increased (blue) or not (red) with half of the US catches. The dotted line is the upper limit of the censored model; black line: lower limit.

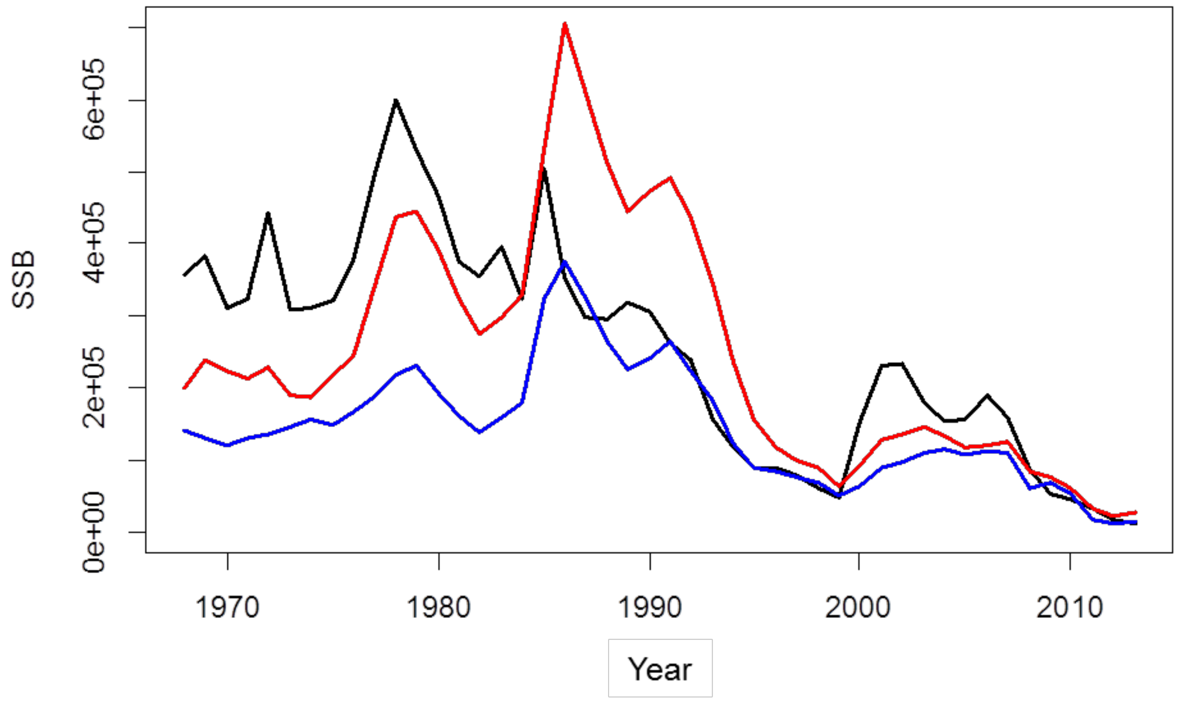


Figure 25. Spawning stock biomass estimated by the ICA model (black), the non-censored statistical catch-at-age model (blue), and the censored statistical catch-at-age model (red).

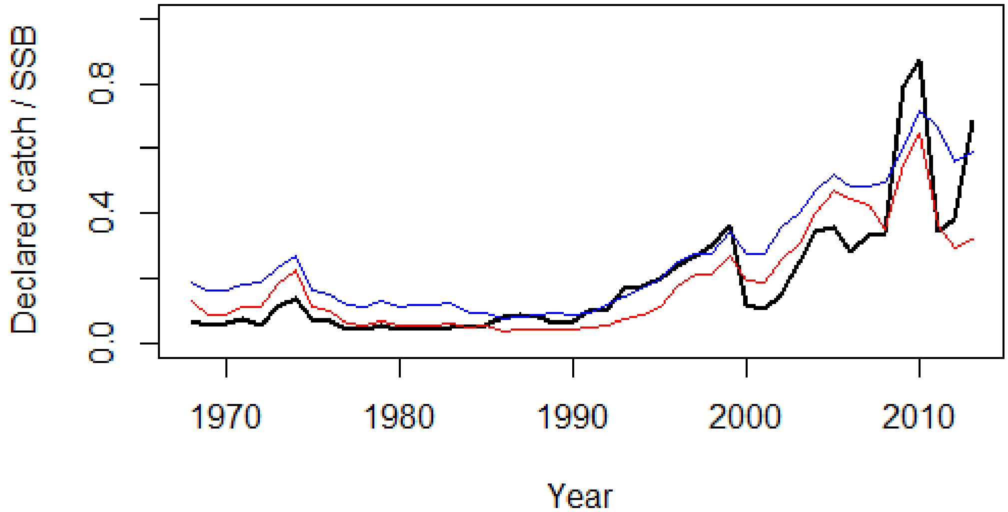


Figure 26. Ratio between declared catches and the spawning stock biomass estimated by the ICA model (black), the non-censored statistical catch-at-age model (blue), and the censored statistical catch-at-age model (red).