Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2017/023

Quebec Region

The status of the redfish stocks (*Sebastes fasciatus* and *S. mentella*) in Unit 1 (Gulf of St. Lawrence) in 2015

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May 2017

Foreword

This series documents the scientific basis for the assessment of aquatic resources and ecosystems in Canada. It addresses the issues of the day in the time frames required. The information provided should not be considered as definitive statements on the subjects addressed, but rather as progress reports on ongoing investigations.

Research papers are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Brassard, C., Bourdages, H., Duplisea, D., Gauthier, J., and Valentin, A. 2017. The status of the redfish stocks (*Sebastes fasciatus* and *S. mentella*) in Unit 1 (Gulf of St. Lawrence) in 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/023. ix + 53 p.

Aussi disponible en français :

Brassard, C., Bourdages, H., Duplisea, D., Gauthier, J., et Valentin, A. 2017. L’état des stocks de sébaste (Sebastes fasciatus et S. mentella) de l’unité 1 (golfe du Saint-Laurent) en 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/023. ix + 55 p.

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ABSTRACT

Redfish fishing in the Gulf of St. Lawrence (Unit 1) targets two species, *Sebastes mentella* and *S. fasciatus*. Between the mid-1950s and 1993, it was marked by three more intense exploitation episodes that were closely linked to recruitment of one or several strong year-classes. A sudden drop in landings and the absence of recruitment led to the imposition of a moratorium in 1995. Redfish fishing is still under a moratorium in Unit 1 and an index fishery has been authorized there since 1998. Total allowable catches have been 2,000 t per year since 2006.

According to surveys conducted in the Gulf of St. Lawrence, abundance and biomass indices for *Sebastes fasciatus* and *S. mentella* were low and stable since the mid-1990s. Since 2013, we have seen a significant increase in the abundance of small redfish in the surveys, which meant an increase in the abundance and biomass indices of the immature portion of redfish stocks in 2014 and 2015.

Genetic testing showed that these new strong redfish cohorts (2011, 2012 and 2013) are made up of the *S. mentella* species, whose genetic signature indicates that these cohorts belong to stock from the Gulf of St. Lawrence.

In recent years, we have seen a significant arrival of young specimens, in particular the 2011 cohort. This one is far more abundant than those seen in the past. Based on redfish growth estimates and assuming the population is balanced, 12% of the 2011 year-class would be more than 20 cm and nearly 50% of the fish in this cohort should be over 22 cm, the minimum harvest size, by 2018. By 2020, 51% of fish in the 2011 cohort should be over 25 cm, size at sexual maturity. There should also be large quantities of fish less than 25 cm from the 2011, 2012 and 2013 cohorts.

According to the reference points of the precautionary approach of 2011, both stocks have improved. However, the mature biomasses are still in the critical zone and this fact should not change over the course of the next three years.

In support of the redfish stock assessment survey (*S. fasciatus* and *S. mentella*) of Units 1 and 2 in 2015, this document describes the data and methods use for the stocks of Unit 1 under the responsibility of the Science Branch, Quebec Region of the Department of Fisheries and Oceans.

RÉSUMÉ

La pêche au sébaste dans le golfe du Saint-Laurent (unité 1) vise deux espèces, *Sebastes mentella* et *S. fasciatus*. Entre le milieu des années cinquante et 1993, elle a été marquée par trois épisodes d'exploitation plus intenses qui étaient étroitement liés au recrutement d'une ou quelque fortes classes d'âge. Une chute rapide des débarquements et l'absence de recrutement a entraîné la mise en place d'un moratoire en 1995. La pêche au sébaste est toujours sous moratoire dans l'unité 1 et une pêche indicatrice y est autorisée depuis 1998. Les totaux autorisés de captures sont de 2 000 t par année depuis 2006.

Selon les relevés réalisés dans le golfe du Saint-Laurent, les indices d'abondance et de biomasse de *Sebastes fasciatus* et de *S. mentella* étaient bas et stables depuis le milieu des années 90. Depuis 2013, on observe une augmentation importante de l'abondance de petits sébastes dans les relevés qui s'est traduite par une augmentation des indices d'abondance et de biomasse de la fraction immature des stocks de sébastes en 2014 et 2015.

Des analyses génétiques ont démontré que ces nouvelles fortes cohortes de sébaste (2011, 2012 et 2013), sont constituées de l'espèce *S. mentella* et que leur signature génétique indique que ces cohortes appartiennent au stock du golfe du Saint-Laurent.

Ces dernières années, on observe une importante arrivée de jeunes individus, en particulier la cohorte de 2011. Celle-ci est nettement plus abondante que celles observées par le passé. Selon des estimations de la croissance des sébastes et l'hypothèse d'une population à l'équilibre, 12 % de la classe d'âge de 2011 aurait plus de 20 cm et près de 50 % des poissons de cette cohorte devraient être de taille supérieure à 22 cm en 2018, soit la taille minimale dans la pêche. En 2020, 51 % des poissons de la cohorte 2011 devraient être plus grands que 25 cm, soit la taille à la maturité sexuelle. Il devrait aussi y avoir de grandes quantités de poissons de taille inférieure à 25 cm correspondant aux cohortes de 2011, 2012 et 2013.

Selon les points de référence de l'approche de précaution de 2011, les deux stocks se sont améliorés. Toutefois, les biomasses matures sont encore dans la zone critique et ce constat ne devrait pas changer au cours des trois prochaines années.

En appui à l'évaluation des stocks de sébastes (*S. fasciatus* et *S. mentella*) des unités 1 et 2 en 2015, le présent document décrit les données et les méthodes utilisées pour les stocks de l'unité 1 qui sont sous la responsabilité de la Direction des Sciences de la région du Québec de Pêches et Océans Canada.

INTRODUCTION

Redfish fishing in the Gulf of St. Lawrence has been marked by episodes of intense exploitation (1954-56, 1965-1976 and 1987-1992). Following a rapid drop in landings in 1993 and 1994, the directed fishery was closed from 1995 onwards. An index fishery was implemented in 1998 in Unit 1 with total allowable catch (TAC) of 1,000 t. This fishery is still in effect, with a TAC of 2,000 t per year since 1999.

In 2010, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the deepwater redfish (*S. mentella*) from the Gulf of St. Lawrence and Laurentian Channel Designatable Unit (DU) (management units 1 and 2) as endangered and Acadian redfish (*S. fasciatus*) in the Atlantic DU (which includes Units 1 and 2) as threatened (Figure 1). The results of a recovery potential assessment of each of these populations in 2011 indicated that the spawning stock biomass of each of the two species was in the critical zone (DFO 2011).

Based on the reference points established in 2011 (Duplisea et al. 2012) and according to 2010 estimates, redfish spawning stocks (*S. fasciatus* and *S. mentella*) of Unites 1 and 2 are in the critical zone under their respective limit reference points.

The peer review in conjunction with the redfish stock assessment (*Sebastes fasciatus* and *S. mentella*) of Units 1 and 2 in 2015 took place on March 3, 2016. In support of this report (DFO 2016a), and although the assessment of these stocks has been done for Units 1 and 2, this document describes the information for Unit 1 that is under the responsibility of the Regional Science Branch of the Department of Fisheries and Oceans (DFO), Quebec Region. The previous research document on this topic was published in 2001 (Morin et al. 2001).

BASIC INFORMATION

BIOLOGY

Redfish inhabit cold waters along the slopes of banks and deep channels at depths ranging from 100 to 700 m. *S. fasciatus* is typically found in shallower waters than *S. mentella*. In the Gulf of St. Lawrence and Laurentian Channel region, *S. mentella* predominates in the main channels at depths ranging from 350 to 500 m. In contrast, *S. fasciatus* dominates at depths of less than 300 m, along the slopes of channels and on the banks, except in the Laurentian Channel (Laurentian Fan, Figure 1) where it inhabits deeper waters. Redfish generally live near the bottom. However, various studies have shown that these species migrate vertically during the day, leaving the sea floor at night to follow their prey as they migrate. Juvenile redfish feed mainly on various species of crustaceans, including several species of shrimp. The adult redfish diet is more varied and includes fish. Redfish have slow growth and high longevity (Campana et al. 1990). *S. fasciatus* grows more slowly than *S. mentella*, although this difference in growth rates becomes obvious only after 10 years of age. In both species, females grow faster than males after about 10 years of age. On average, it takes redfish seven to eight years to reach the 22 cm minimum legal catch size.

Males reach sexual maturity between 1 and 2 years before females (*S. fasciatus*, mature males at 7 years (L_{50}:19.6 cm) and mature females at 9 years (L_{50}: 24.1 cm); *S. mentella*, mature males at 9 years (L_{50}: 22.8 cm) and mature females at 10 years (L_{50}: 25.4 cm)) (Gascon 2003).

In redfish, fertilization is internal and females are ovoviviparous. Internal fertilization takes place in the fall; spermatozoa are maintained in a state of physiological dormancy inside females until the maturity of ovaries in February-March (Hamon 1972). Larval extrusion occurs from April to July, depending on the area and species (Ni and Templeman 1985). Mating and larval extrusion do not necessarily occur in the same locations. In the Gulf of St. Lawrence, *S. mentella* releases its larvae approximately three to four weeks earlier than *S. fasciatus*. Larva are generally found in the surface layer and their growth is optimal at temperatures between 4 and 11 °C. They make daily vertical migrations (10 to 30 m during the day and less than 10 m at night). Juveniles make more use of deeper environments (temperatures of 5 to 10 °C) under the cold intermediate water layer (Gascon 2003), although less deep than the adults. Redfish migrate to the Cabot Strait area in winter and return to the Gulf in spring. Migration can start as early as November (Atkinson and Power 1991, Morin et al. 1994, Power 2003).

The large predators of the St. Lawrence (seals, cod, Atlantic halibut, Greenland halibut (turbot) and adult redfish) feed on different sizes of redfish.

SPECIES IDENTIFICATION CRITERIA

Two redfish species of commercial concern, *Sebastes fasciatus* and *S. mentella*, are present in Units 1 and 2. These species have been traditionally assessed as "*Sebastes sp.*" due to difficulties posed by their identification. As part of the multidisciplinary research program on redfish (1995–1998), various meristic, morphometric and genetic tools were assessed in order to distinguish the two species, with the aim of documenting their specific life history and identify distribution and recruitment patterns specific to each species (Gascon 2003). Only microsatellite genetic markers were able to clearly distinguish the species, with a minimum of 4 loci required to assign individuals to a species (Roques et al. 1999). However, analysis of microsatellite markers remains costly and logistically challenging, which restricts their use for monitoring the specific composition of catches.

Three characteristics were traditionally used to distinguish *S. mentella* and *S. fasciatus* in the Northwest Atlantic: the number of soft rays on the anal fin (anal fin count or AFC), extrinsic gasbladder muscle passage patterns (EGM) and the genotype at the malate dehydrogenase locus (*MDH-A**). In the absence of information about microsatellites, the *MDH-A** genotype has historically been considered the genetic reference criterion. In general, *S. mentella* is characterized by the homozygous genotype *MDH-A*11*, an EGM between ribs 2 and 3 and an AFC ≥ 8. *Sebastes fasciatus* usually has the homozygous genotype *MDH-A*22,* an EGM between ribs 3 and 4 and an AFC ≤ 7. However, it should be measured that an AFC = 8 is not exceptional for this species; for example, nearly 10% of *S. fasciatus* specimens from the Gulf of Maine and from Unit 3 (regions where *S. mentella* is absent) have an AFC = 8 (Gascon 2003). These three criteria (*MDH-A*,* AFC, EGM) were used to describe the geographic range of the species in the North Atlantic. In Units 1 and 2, it was concluded that *S. mentella* dominates the main channels, while *S. fasciatus* prefers shallower depths, along the slopes of channels and on banks, except in the Laurentian Fan, where *S. fasciatus* dominates at all depths (Valentin et al. 2006). Excluding the Laurentian Fan area, data from summer surveys of Units 1 and 2 indicated that the depth of transition between the two species is situated at about 300 m (DFO 2010; Figure 1).

It was also observed that the consistency among the three characteristics (MDH-A*, AFC, EGM) in a given individual is high (97%) in regions inhabited by allopatric populations (regions with one species), but decreases in regions inhabited by sympatric populations (regions with both species) such as Units 1 and 2 (56% and 68% respectively; Valentin et al. 2006). In addition, in Units 1 and 2, we see an increased frequency of specimens with intermediate traits for the criteria *MDH-A** (e.g., heterozygous genotype *MDH-A*12*) and EGM (e.g., bifid muscle passing between ribs 2-3 and 3-4). Valentin et al. (2006) demonstrated that the geographic and bathymetric distribution of heterozygotes (*MDH-A*12*) and their EGM and AFC patterns resembled those observed for *S. mentella* (*MDH-A*11*), which historically justified the choice of assigned the heterozygotes (*MDH-A*12*) to *S. mentella* in the absence of other distinguishing criteria.

The reduced consistency among the three criteria and the significant presence of heterozygotes *MDH-A*12* and intermediate specimens for EGM in Units 1 and 2 are attributed to introgressive hybridization between *S. fasciatus* and *S. mentella* (Rubec et al. 1991). The phenomenon of introgressive hybridization involves cross-fertilization between individuals from two species (hybridization) producing viable hybrids (F1). These F1 hybrids subsequently reproduce preferentially with a partner from either species. Then, their offspring do the same. Over generations, this results in the integration of genes from one species into the gene pool of the other. Thus, observation of the heterozygous genotype *MDH-A*12* implies that the individual is of hybrid origin, but does not necessary mean that it is a first generation hybrid (F1). Indeed, the heterozygous genotype can be maintained over generations, through classic Mendelian transmission, as half of the descendants of a heterozygous individual will be heterozygous, regardless of the genotype of the other parent. Analysis performed on different genetic markers show results consistent with the theory of introgressive hybridization between species (e.g., Desrosiers et al. 1999 for ribosomal DNA). Based on 8 microsatellite loci, Roques et al. (2001) demonstrated the presence, limited to Units 1 and 2, of a group of introgressed individuals in each species, in the absence of F1 hybrids. They suggested that hybridization was rare and followed an asymmetrical, bidirectional, recurrent introgression (biased in favour of the incorporation of *S. fasciatus* genes into the *S. mentella* genome).

In 2009, assessments of stock in Units 1 and 2 was performed by species for the first time, with the species being identified based on the anal fin count (AFC) (DFO 2010). Although AFCs are imprecise for individual assignment, particularly in the presence of introgressive hybridization, they nonetheless represent a criterion in which the pattern varies between the two species and which is easily identifiable, especially during research surveys. For this reason, it was selected as a practical, economical alternative to genetic analysis for estimating the specific composition of catches. The method developed by the DFO is based on a tow-by-tow approach; therefore, it takes into consideration the tendency of redfish to be distributed in the form of aggregations. For each tow, the anal fin count (AFC) is conducted on a sub-sample of 30 fish, in order to obtain an observed distribution of AFCs. The form of this distribution is dependent on the percentage of the two species in the sample. To determine this percentage, we use the theoretical distribution of AFCs, calculated by species, in Units 1 and 2. These theoretical distributions were determined, beforehand, based on 4,342 specimens harvested during the multidisciplinary program on redfish (Gascon 2003) in Unit 1 (in August, from 1994 to 1997, n = 1,562) and in Unit 2 (in July-November, from 1995 to 1998, n = 2,780). The 4,342 were first assigned to a species based on genotype at locus *MDH-A**, considering heterozygotes as belonging to *S. mentella*. Then, for each species, individuals belonging to each class of AFC were counted to establish the theoretical distribution of AFCs by species. Thus, the specific composition of the sub-sample of 30 fish is estimated by determining (using a Chi-squares test) the percentage of the two species needed to minimize the variance between the observed distribution and the theoretical distribution of AFCs for this percentage.

GENETIC STOCK STRUCTURE

An analysis of genetic variation (13 microsatellite loci) was conducted on a total of 1,091 adult individuals (16 samples of *S. mentella* and 19 samples of *S. fasciatus*) harvested in the Northwest Atlantic (Appendix 1). The results suggest that Units 1 and 2 correspond to a single population of *S. mentella* (red tags, Appendix 1), characterized by introgression from the other species (not shown, but available in Valentin et al. 2014). This population is itself distinct from other populations of *S. mentella* distributed in the Northwest Atlantic Ocean (black tags,

Appendix 1). For *S. fasciatus*, the results suggest the presence of five populations in the Northwest Atlantic. A first *S. fasciatus* population is found in the area covered by Units 1 and 2, excluding the southern edge of Unit 2 (orange tags, Appendix 1). This population is characterized by introgression from the other species (not shown, but available in Valentin *et al.* 2014). The *S. fasciatus* samples collected at the southern edge of Unit 2, including the mouth of the Laurentian Channel, belong to a second population of *S. fasciatus*. Its distribution extends along the continental shelf break (green tags, Appendix 1), from the Grand Banks of Newfoundland (3LNO) to Nova Scotia (4W), which we will refer to as "the Atlantic population of the continental shelf break". A third *S. fasciatus* population has been identified in the eastern inlet of the Bonne Bay fjord, on the west coast of Newfoundland (turquoise tag, Appendix 1). Microsatellites have also revealed the presence of a fourth genetic group in *S. fasciatus*. It includes a group of three samples (one each from Units 1 and 2 and one in Unit 3; pink tags, Appendix 1), which, unlike the others, does not correspond to a population that is well-defined spatially on a regional scale. Analysis of additional samples will be required in order to document this group. Samples collected in the Gulf of Maine suggest the presence of a fifth genetically-distinct population in that region. A detailed discussion is available in Valentin et al. (2014).

ECOSYSTEM

Every year, Fisheries and Oceans Canada’s Atlantic Zone Monitoring Program (AZMP) assesses prevailing physical oceanographic conditions in the Gulf of St. Lawrence. Conditions encountered in the northern Gulf in the last five years (2011 to 2015) were generally warmer than historical average surface and deep water temperatures. However, the 2014 and 2015 winters were colder than average, which means that the characteristics of the cold intermediate layer in the summers of 2014 and 2015 were more representative of the historical average. In 2015, deep water temperatures were warmer than the historical average. Consequently, temperatures at 200 and 300 m have increased in most areas since 2014, especially in the Anticosti Channel at 200 m and in the estuary, northwestern Gulf and central Gulf at 300 m. (Galbraith et al. 2016).

The various herring stocks (4R, 4S, 4T) are healthy (DFO 2016b), and the Gulf capelin stock (4RST) is stable (DFO 2015), while the mackerel stock (subareas 3 and 4) is low (DFO 2014). Greenland Halibut stock (4RST) is stable (DFO 2016c) while Atlantic Halibut stock (4RST) is increasing (DFO 2016d). The southern Gulf of St. Lawrence cod stock (4T) is very low and stable (DFO 2016e). The cod stock is also low but has increased slightly in the Northern Gulf (3Pn, 4RS) (DFO 2016f). The Northern Shrimp stock in the Estuary and Gulf of St. Lawrence is high and has remained in the healthy zone for several years (DFO 2016g), while redfish stock has been low and stable since the moratorium was imposed.

MANAGEMENT MEASURES

In the late 1950s, a directed Redfish fishery developed in the Gulf of St. Lawrence and the Laurentian Channel outside the Gulf. Prior to 1993, the Redfish fishery was managed as three units, based on the divisions established by NAFO (Northwest Atlantic Fisheries Organization): Divisions 4RST, Division 3P and Divisions 4VWX. In 1993, these management units were redefined primarily to take new knowledge and the Gulf Redfish stock’s winter migration to the Cabot Strait area into account. The resulting management units were divided as follows: Unit 1 included Divisions 4RST and Subdivisions 3Pn4Vn from January to May; Unit 2 included Divisions 3Ps4Vs, Subdivisions 4Wfgj, and Subdivisions 3Pn4Vn from June to December; and Unit 3 included Divisions 4WdehklX (Figure 1).

The TAC of Redfish stocks set according to the new management method defined in 1993 were 60,000 t in Unit 1 for the period from January 1, 1993 to May 14, 1994. The Unit 1 fishing moratorium was subsequently imposed in 1995. Since 1999, the TAC is now 2,000 t for index fishing in Unit 1 for the management cycle that runs from May 15 to May 14 of the following year.

Redfish conservation measures include: implementation of a protocol for protecting small fish (22 cm), 100% dockside monitoring, mandatory radio reports upon departure and arrival, imposition of a level of coverage by observers (25% or 10% with the Vessel Monitoring System (VMS) in Unit 1), and the implementation of a bycatch protocol (5% to 15% in Unit 1). Closure periods were also introduced: 1) to protect Redfish mating (fall) and larval extrusion periods (spring), 2) minimize catches of Unit 1 Redfish migrating in Subdivisions 3Pn4Vn at the end of fall and winter, and 3) protect spawning cod (Divisions 4RS). In addition, since the index fishery was introduced in 1998, fishing is allowed only between longitudes 59° and 65° (W) at depths greater than 182 m (> 100 fathoms), and to avoid Greenland Halibut bycatch, an area has been closed in Division 4T since August 2009 (Fishing Plan - index fishery of Unit 1 - 2016).

FISHERIES

The Redfish fishery in the Gulf of St. Lawrence has been characterized by three periods of high landings (1954-56, 1965-1976 and 1987-1992 (Table 1 and Figure 2). From 1960 to 1969, annual landings averaged 46,000 t; and reached an average of 82,000 t between 1970 and 1976 (Table 1). Annual landings peaked at 136,000 t in 1973. Subsequently, from 1977 to 1994, average annual landings were 37,000 t. In 1995, a moratorium was imposed on the Redfish fishery of Unit 1 because of low stock abundance and lack of recruitment.

An index fishery began in 1998 with a TAC of 1,000 t that increased to 2,000 t in 1999. This index fishery takes place between June 15 and October 31. It is carried out on traditional fishing grounds using bottom trawls similar to those use before the moratorium, between longitudes 59° and 65° (W) at depths over 182 m (100 fathoms) with 90 mm mesh size. From 1999 to date, the TAC for this fishery has remained at 2,000 t per year. Between 2004 and 2008, the average annual landings from the index fishery and bycatches reached 626 t. From 2010 to 2015, average annual landings were 481 t (preliminary data for 2014 and 2015).

From 1954 to 1990 (prior to the moratorium), landings came mainly from divisions 4R and 4S (Table 1 and Figure 2). From 1982 to 1992, winter landings increased from 5% in 1982 to 45% in 1992 (Table 2 and Figure 3). These catches came mainly from divisions 3Pn and 4R. After the moratorium and subsequent to the implementation of an index fishery, the spatial distribution of the fishing effort varied. Between 1999 and 2003, most of the effort was expended in divisions 4T and 4R, along the slopes of the Laurentian Channel, north of the Cabot Strait. In addition to these fishing sites, from 2004 to 2006 efforts were directed in division 4S of the Laurentian Channel. Later, the majority of the index fishery effort was concentrated in division 4T (Figures 4 and 7).

During the period from 1985 to 1994, redfish catches were made primarily using midwater and bottom trawls. Following the 1995 moratorium, the fleet using midwater trawls was no longer present in the Gulf and did not, therefore, participate in the index fishery. From 1998 to 2006, most fishing efforts were made using bottom trawls and from 2007 onwards we have seen a sharp increase in the percentage of effort made using Scottish seines (Figure 8). Both types of gear have a mesh size of 90 mm.

Redfish catches in directed fisheries for most commercial fisheries conducted in Units 1 from 1985 to 2014 were examined (with data for 2015 being preliminary). This analysis revealed that more than 90% of the reported redfish catches came from the directed redfish fishery. Figure 9 presents the spatial distribution of total redfish landings from Unit 1 for all fisheries.

CATCHES PER UNIT EFFORT (CPUE)

Following the recommendation of the Fisheries Resource Conservation Council (FRCC) aimed at addressing the lack of redfish data after the 1995 moratorium, an index fishery was established in 1998. The information obtained within the framework of this fishery by the at-sea observer program and the DFO's commercial catch sampling program consists of data on landings, fishing effort, bycatches and the size of redfish caught. When it launched in 1998, the index fishery was carried out by two groups of vessels using bottom trawls; boats over 30.48 m (100 feet) and boats under 18.29 m (65 feet). The number of participants in each of these groups has varied over the years. Prior to 2007, between 1 and 5 boats over 30.48 m participated in the index fishery. Subsequently, no boats from this group took part, except for one in 2010. For boats from the under 18.29 m group, between 6 and 13 boats have taken part in this fishery annually, with the exception of 2007 when there was only one boat (Figure 10). This low rate of participation came about due to an external problem, so the 2007 data are not included in the index.

Catch rates from commercial fisheries (prior to the moratorium) and those from the index fishery were standardized using a multiplicative model (Gavaris 1980) to produce an index representing fishing performance before and after the moratorium (Appendices 2 and 3).

This standardization takes into account changes in the fishing season (months), differences between sectors (NAFO unit area), regions and size of vessels. This model weighs the effect of these factors, making the CPUEs comparable across the years. These analyses were conducted using the GLM procedure of the SAS software (9.3). The activities used for these analyses are those carried out with a bottom trawl between May and October. The data used represent on average more than 85% of landings made with a bottom trawl in redfish fishing from Unit 1. Note that there are no measures that allow the proportion of each of the two species of redfish in this fishery to be distinguished.

This index shows high CPUEs prior to the moratorium, followed by a marked decrease in 1994. Between 1999 and 2003, the index was below the average of the series (1981-2014). Since then, it has been reasonably stable and comparable to the average. 2015 data are preliminary (Figure 11). According to industry representatives, poor market conditions and management measures (restricted areas) have had a major impact on low catch levels.

SIZE FREQUENCY OF CATCHES

From 1981 to 1988, the commercial catch at length indicated that catches primarily consisted of fish born in the early 1970s. From 1988 to 1994, catches predominantly consisted of fish born in the early 1980s (Figure 12). From 1999 to 2015, most fish caught were larger than 30 cm. Since 1999, catch size frequency has been more difficult to establish because fishing has dropped significantly (especially since 2006). As a result, fewer fish are measured by observers and through DFO sampling programs. However, it appears that the 1980 year-class, consisting primarily of *S. mentella* began to be recruited to the fishery in 1987 and has remained in catches to date. In recent years (2006-2015), the contribution to the fishery by the most recent year-classes is indicated by the presence of fish between 25 and 35 cm.

SURVEYS

DFO RESEARCH SURVEY

Since 1984, DFO has conducted a multidisciplinary research survey (groundfish and shrimp) on the entire northern Gulf of St. Lawrence using a bottom trawl. This survey involves the use of a stratified random sampling plan (Figure 13). From 1984 to 1990, the DFO conducted these research surveys aboard the vessel Lady Hammond, using a Western IIA bottom trawl. Recent analysis of data from comparative fishing conducted in 1990, allowed the catches from the Lady Hammond survey to be converted into data equivalent to that of the Teleost survey.

In 2004 there was another change in fishing vessel and gear type, and comparative fishing was carried out to ensure continuity of the series (Bourdages et al. 2007). Since 2004, the fishing gear has been a Campelen 1800 shrimp trawl with Rockhopper foot gear. A detailed description of the fishing and sampling protocol and calculation methods are presented in Bourdages et al. (2016). This entire data set (Lady Hammond, Needler and Teleost) extended the historical series of redfish abundance and biomass indices to the 1984 to 2015 period.

In 2015, 190 fishing stations were successful, 58 in 4R, 84 in 4S and 48 in 4T. Coverage of the study area was very good, all strata were sampled with a minimum of two stations (Bourdages et al. 2016). Note that this sampling plan includes the redfish distribution area consisting of divisions 4RST (Figure 13), which correspond to Unit 1. Results are presented by species for immature and mature specimens.

The determination of redfish species is based on anal fin count (AFC) on a maximum number of 60 redfish per tow. The anal fin count (AFC) is less accurate for specimens under 15 cm. Genetic testing is therefore essential for confirming the identification and proportion of each of the two species when new cohorts arrive. Tables 3 and 4 present the abundance and biomass indices for *S. fasciatus* and *S. mentella* respectively.

Determination of the number of mature specimens from a given species is based on the proportion of mature fish at length by sex according to a logistic growth curve. The equation of the curve is as follows:

$$Proportion\ mature = (e^{a+b*L50})\ /\ (1+\ e^{a+b*L50})$$

The variables are:

S. fasciatus female	a = -10.605	b = 0.441	L_{50} = 24.1
S. fasciatus male	a = -10.687	b = 0.545	L_{50} = 19.6
S. mentella female	a = -9.550	b = 0.377	L_{50} = 25.4
S. mentella male	a = -7.521	b = 0.330	L_{50} = 22.8

Acadian redfish, *Sebastes fasciatus*

The average numbers and average weights per trawl tow for *S. fasciatus* dropped between 1990 and 1994 (Figure 14). They remained at a low, but stable, level until 2004. The increase observed in the immature population between 2005 and 2007 essentially stem from recruitment from the strong 2003 year-class, the abundance of which decreased from 2008 because it left the Gulf. Subsequently, average numbers and weights have remained at a low level. From 2013 onwards, we see a significant increase in the abundance and biomass indices in the immature population due to the arrival of new cohorts. The average number and average weight per trawl tow in 2015 are above their average for the 1984-2014 period (Figure 14). For the mature population of *S. fasciatus*, the average numbers and weights per tow are still low and below the series average.

The size frequency distributions indicate low abundances of large size specimens since 1994 (Figures 15 and 16). The strong 2003 cohort, present between 2005 and 2008, is no longer visible in the data from the 2009 survey at the expected size of 20 cm. Genetic testing demonstrated that the fish from the 2003 cohort came from the Atlantic population (see the recruitment section for additional information).

Note that the decrease in the number of young observed in 2015 is probably caused by greater accuracy in the fin ray count in specimens over 15 cm, which would have facilitated the identification of more *S. fasciatus* in 2013 and 2014, while genetic testing confirmed that the new cohorts (2011 and 2012) are essentially composed of *S. mentella*.

In the early 1990s, large concentrations of adults were observed to the north and east of Anticosti Island, as well as in the southwest sector of the area inventoried. Subsequently, distribution was concentrated to the southeast of Anticosti Island and in the southern part of the Esquiman Channel (Figure 17). From 2011 to 2015, distribution of the species approaches that observed in the early 1990s, with high catch rates to the west and south of Anticosti Island, as well as in the Esquiman Channel.

Atlantic redfish, *Sebastes mentella*

The average numbers and average weights per trawl tow for *S. mentella* were stable in the late 1980s. These indices dropped between 1990 and 1994 and remained low and stable until 2012. From 2013 onwards, we see a significant increase in these indices in the immature portion of the population due to the arrival of strong new cohorts. In 2015, the indices are well above the average for the 1984-2014 period at values never seen before (Figure 18). For the mature population, this significant increase is only visible in the numbers index and should spread to the weight index in the coming years.

The size frequency distributions indicate low abundances of large size specimens since 1994 (Figures 15 and 16). The 10 cm mode observed in 2013 becomes the 13 cm modal in 2014 and 16 cm in 2015. Several specimens of about 10 cm are also present in 2015. The spatial distribution pattern of adult *S. mentella* observed in the early 1990s indicates a wide distribution extending to the south and east of Anticosti Island. Subsequently, the distribution was more restricted with large concentrations to the southeast of Anticosti Island, particularly in the deeper waters of the Laurentian Channel. From 2011 to 2015, we see a distribution that extends toward the east of Anticosti Island and to the east around the Esquiman Channel (Figure 19).

From 2011 to 2015, the distribution pattern of young *S. fasciatus* and *S. mentella* size < 20 cm extended further throughout the Gulf. High catch rates were recorded in the Esquiman Channel, the southwest of Newfoundland, the southeast of Anticosti Island, toward the estuary and in the western sector of the Gulf (Sept-Îles) (Figure 20).

SENTINEL FISHERY SURVEY

Established since 1994 in Eastern Canada, the sentinel fisheries program is a collaboration program between the DFO Science Sector and fishers, created in order to address the lack of information on cod stocks. Fisheries are conducted by fishers (contracts awarded following an invitation to tender) in accordance with scientific protocols developed by DFO Science. In the northern Gulf of St. Lawrence, this program consists of two components: mobile gear (trawl) and fixed gear (gillnet and longline). Only the trawl survey is used for the redfish abundance index.

DFO Science ensures that data are validated, analyzed and interpreted. Data from the sentinel fisheries program are available on the St. Lawrence Global Observatory website.

This survey is conducted every July. It mainly targets cod, redfish, Atlantic halibut and Greenland halibut. It includes close to 300 stations distributed based on a stratified random sampling plan (Figure 13). Calculation methods take into account the weight of each stratum in the same way as the DFO research survey. The fishing gear is a *Star Balloon 300*-type trawl mounted on a *Rockhopper* bicycle. The trawl's mesh is 145 mm with a lining at the cod end of 40 mm. Standard tows of 30 minutes duration are done at a speed of 2.5 knots. The 30-minute time frame is calculated from when the winches are stopped (after the gear is deployed) to when they are reactivated to raise the trawl. Note that unlike the DFO survey, the sentinel survey does not cover the St. Lawrence Estuary.

The average number of redfish per tow index was stable and the same as the average (1995-2014) from 1996 to 1999 (Figure 21). It then decreased and was under average until 2005. We note an increase in the index between 2006 and 2007 with the passing of the large 2003 cohort. With the disappearance of this cohort, the index decreased and was below average from 2009 to 2013. In 2014 and 2015, the index showed a large increase with values well above average and at levels never seen in this survey. This strong increase is due to the arrival of the abundant 2011 cohort that we see in the size frequencies of 8 and 9 cm in 2013 (Figure 22). The 2012 and 2013 cohorts also have very high abundance in this survey.

The average weight per tow index was high, stable and above average from 1996 to 1999, then dropped in 2000 and continued to decrease gradually until 2013 when it was below average of the 1995-2014 series throughout the entire period (Figure 21). In 2014 and 2015 the average weight per tow index was increasing and in 2015, it is above average at a value comparable to that of 1997 (Figure 21).

RECRUITMENT

In the Northwest Atlantic, redfish is characterized by significant variability in recruitment (Valentin et al. 2015). Redfish recruitment was low in Units 1 and 2 throughout years 1990 and 2000. Certain year-classes, which seemed strong at early ages in the research surveys, particularly in Unit 1, decreased significantly within a few years without contributing significantly to adult populations and the fishery. Genetic testing was conducted to: 1) determine the species composition of strong year-classes that contributed significantly to the fishery, or disappeared before contributing, in order to determine whether the success or failure of redfish recruitment could be attributed to one of two species in particular; and 2) evaluate the temporal variability of the distribution of redfish species and the stock structure. The required information was obtained through DNA analysis (using 13 microsatellite markers) of material adhering to archived otoliths, belonging to juveniles from historically strong year-classes of redfish (*Sebastes* spp.) sampled in Units 1 and 2 and adjacent regions. Five relatively strong waves of recruitment were selected using data from scientific surveys. In total, 970 juveniles specimens were individually assigned to the species, based on microsatellites (Appendix 1), then regrouped by year-class (1973, 1980, 1985, 1988 and 2003) and region (Unit 1, north of Unit 2, south of Unit 2, 3O and 3N). Genetic data from 18 samples thus obtained were analyzed together with those used to describe the structure of adult populations (Valentin et al. 2015).

The results showed that the specific composition of a year-class constitutes key information for understanding the dynamics of recruitment, revealing that the redfish species populations have their own distinct patterns of spatial dispersion (see Valentin *et al.* 2015 for discussion in detail). In the region of the Gulf of St. Lawrence (Unit 1) and the south of Newfoundland (Unit 2), the most recent strong year-class (that of 1980, which supported the fishery for more than 30 years) belonged to *S. mentella*. This year-class (red triangle in Annex 1) was genetically identical to the adult population, itself genetically homogeneous, distributed in Units 1 and 2. This observation suggests a local origin of the 1980 year-class. However, the four year-classes (1973, 1985, 1988 and 2003) that seemed abundant at a young age in the research surveys of Units 1 and 2, but which contributed only marginally to the adult population and fishing in the region belonged to *S. fasciatus* (green symbols in Appendix 1) and bore the genetic signature of the adult Atlantic populations of the continental shelf break. Ocean currents and aged-based spatial and temporal abundance trends suggest that this population using the Gulf of St. Lawrence as a nursery; the larva and/or young juveniles drifted to the Gulf of St. Lawrence, then 5 to 6 years later the older juveniles returned their birthplace in the Atlantic along the continental shelf break.

The most recent surveys in Unit 1 indicate the presence of two strong consecutive year-classes produced in 2011 and 2012. A total of 770 juveniles, of a size corresponding to these year-classes, were collected in 2013 and in 2014 in Units 1 and 2 (2011 year-class in Unit 1: 2013 DFO survey, average length of 9.1 ± 0.7 cm; 2011 year-class in Unit 2: *Groundfish Enterprise Allocation Council* (GEAC) survey 2014, average length 14.3 ± 0.9 cm; 2012 year-class in Unit 1: 2014 DFO survey, average length 9.0 ± 0.7 cm; stars in Appendix 1). Genetic testing was conducted on these specimens, using the same 13 microsatellite loci as those analyzed in the juveniles of historical year-classes and adults. Cluster analyses performed on the genetic data showed that 91% of specimens analyzed belonged to *S. mentella*, which suggests that the abundant 2011 and 2012 year-classes are dominated by *S. mentella* (histograms in Appendix 1). Note that this percentage cannot be used to accurately estimate the percentage of each species in this new cohort. The results also showed that the samples of *S. mentella* (red stars in Appendix 1) bore the genetic signature of the adult population distributed in Units 1 and 2. These observations suggested that redfish from the 2011 and 2012 year-classes would not leave the region and could therefore facilitate the reestablishment of the *S. mentella* population of Units 1 and 2. The *S. fasciatus* juveniles of the 2011 and 2012 year-classes (orange stars in Appendix 1) bore the genetic signature of introgression with *S. mentella*, characteristic of adults from the region, which also suggests a local origin.

ANALYSES

EXPLOITATION RATE INDICATOR

A relative exploitation rate indicator (or relative F) was estimated for the redfish. This rate is expressed as a percentage of annual commercial catches relative to exploitable biomass estimated using data from DFO surveys. The annual numbers of fish (commercial fisheries) according to length was converted into exploitable numbers at length using a selectivity curve for a bottom trawl with a mesh size of 88 mm (Lisovsky et al. 1995). These numbers were then converted into exploitable biomass using a weight–length ratio. From 1984 to 1994, the exploitation rate indicator (Figure 23) varied between 0.05 and 0.25 and has remained at less than 0.03 since the moratorium.

PRECAUTIONARY APPROACH

The reference points of the 2011 precautionary approach (DFO 2012) derived from a Bayesian surplus production model on mature biomass were reviewed in December 2015, which only led to minor changes (McAllister and Duplisea 2016). According to these reference points, the situation of both stocks has improved. However, mature biomasses are still in the critical zones: *S. mentella*, 32 kt (216 kt Biomass limit (Blim)); *S. fasciatus*, 43 kt (147 kt Blim) (Figure 24). This finding should not change over the next three years.

PERSPECTIVES

The current assessment is not based on a population model which makes projection of year class strength into the future difficult. Survey indices show that the 2011, 2012 and 2013 year-classes of *S. mentella* and the 2011 year class of *S. fasciatus* well above average since the survey began. It is therefore expected that these year-classes will have a strong impact on recruited and mature biomass in the coming years. We therefore performed an analysis based on individual growth and its variation but not year-class strength to show when these year classes could be expected to recruit to the fishery and when they might become quite valuable to the fishery. Therefore, we can say something about when they are likely to become most important to the fishery but not how important in numerical terms.

A single growth curve was developed for *S. mentella* for determining when a cohort could be expected to recruit to a particular size-class. The primary growth parameters were taken from modal estimates of size for the 1981 Unit 1 cohort and subject to a constraint on $L_{infinity}$ > 42 cm. Though there were no modal estimates from this cohort at this size, there are numerous catch records in this stock for fish > 42 cm. However, to account for the uncertainty in length at age, a range of different curves were used (Annexe 4). These reflect both free and constrained fittings to the 1981 cohort as well as fits from other studies. Most but not all of these are from the Northwest Atlantic. The purpose of bringing in the other studies was to incorporate uncertainty at size at age in broader sense than parameter fitting uncertainty. Because cohorts potentially grow differently putting a coefficient of variation (CV) on length at age derived from several studies, times, and adjacent areas allows for a greater range in uncertainty in growth for new cohorts. The CV on length at age 8 was used as age 8 is an age where most *S. mentella* stocks have newly recruited and thus have recently become important to the fishery. Therefore, for this analysis, growth curve parameters were developed from data for this stock specifically while uncertainty around length at age was derived from several studies.

Table 5 shows the proportion of a cohort which could be expected to recruit to different lengths with age given a von Bertalanffy growth curve and a coefficient of variation (CV) of length on age. This CV is assumed to be symmetric about the mean (normally distributed). The minimum legal size for redfish is 22 cm and it can be seen from Table 5 that 48% of the large 2011 cohort could be expected to be recruited to this size by 2018 but only 5.6% of this cohort will be > 25 cm then. With these growth parameters and uncertainty, 91.6% of the cohort will be recruited to the minimum legal size of 22 cm by age 9 in 2020.

Proportion of abundance at legal size and biomass at legal size show important differences especially at the smaller sizes (Table 5). By 2018, 38.7% of the cohort’s biomass is expected to be of legal size. Similar to abundance, 89% of the 2011 cohort's biomass should be 22 cm by age 9 in 2020. More interestingly for the fishery which prefers larger and more valuable fish, 68.6% of the 2011 cohort's biomass should be 25 cm or larger by 2021 and by 2023 92.4% of the 2011 cohort's biomass will be > 25 cm.

Since this is a steady state calculation and does not depend of cohort abundance, this table applies equally to all cohorts if generalised to age, i.e. the 2012 has the same values but is just shifted one year forward. The 2011, 2012 and 2013 cohorts of *S. mentella* are all above average and if taken as a whole, by age 12, > 90% of cohort's biomass and abundance will be > 25 cm. Therefore in the period 2023-2025 important catches *S. mentella* could be taken from this stock if fishing mortality on these cohorts between now and then is not too heavy and if natural mortality does not increase.

The present analysis is mostly focused on the 2011 year class of *S. mentella*. The growth parameters are not markedly different between these two species and therefore, given the general nature of the present analysis, we expect that this could be roughly applied to *S. fasciatus* as well.

This calculation is not a population projection. It contains certain assumptions such as the constancy of mortality rate (M) over ages and in time and it does not account for changes in the population size distribution which would be caused by fishing.

ACKNOWLEDGEMENTS

The authors would like to thank Sylvie Brulotte and Martin Castonguay for revising the manuscript. We would like to highlight the excellent collaboration of all stakeholders from various organizations (fishers' associations, scientists, directors) in ensuring the success of the research surveys. We would also like to extend our thanks to the crew members and scientists supporting the DFO surveys on the *Teleost* and to the Quebec, Maritimes and Newfoundland sampling teams.

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TABLES

Table 1. Annual redfish landings (t) by NAFO division in Unit 1 from 1953 to 2015.

Year	4R	4S	4T	3Pn Jan. - May	4Vn Jan. - May	Total
1953	5,981	48	2,337	0	0	8,366
1954	12,867	3,048	16,853	0	0	32,768
1955	38,520	8,739	2,598	0	0	49,857
1956	25,675	17,900	3,259	0	0	46,834
1957	17,977	13,365	2,989	0	0	34,331
1958	9,716	11,076	1,778	0	0	22,570
1959	9,744	5,620	1,614	0	135	17,113
1960	5,512	4,678	2,028	0	612	12,830
1961	3,927	4,482	1,982	2	669	11,062
1962	1,609	3,444	1,532	5	561	7,151
1963	6,908	9,674	3,212	443	580	20,817
1964	9,967	16,843	2,890	243	581	30,524
1965	20,115	23,517	5,195	3,232	770	52,829
1966	33,057	24,133	8,025	1,881	866	67,962
1967	30,855	30,713	8,468	995	874	71,905
1968	43,643	40,228	7,092	668	3,633	95,264
1969	36,683	41,352	10,840	1,912	1,533	92,320
1970	37,419	40,917	9,252	1,521	1,394	90,503
1971	27,954	43,540	7,912	593	2,190	82,189
1972	26,084	46,788	7,457	128	2,135	82,592
1973	68,074	47,594	14,496	1,521	4,416	136,101
1974	30,896	25,684	6,909	1,505	2,087	67,081
1975	30,838	28,499	6,064	3,378	1,273	70,052
1976	19,963	16,394	1,626	4,523	1,872	44,378
1977	5,620	7,906	2,314	772	460	17,072
1978	3,084	6,352	4,155	1,067	276	14,934
1979	3,763	7,629	3,642	1,185	206	16,425
1980	4,809	8,125	1,898	527	180	15,539
1981	7,685	10,173	2,691	973	523	22,045
1982	9,410	13,824	3,222	63	212	26,731
1983	10,463	11,495	2,547	322	147	24,974
1984	12,123	12,700	9,988	936	80	35,827
1985	11,479	13,029	3,559	201	65	28,333
1986	11,151	18,479	3,963	2,540	281	36,414
1987	11,547	16,772	5,992	3,234	5,901	43,446
1988	15,518	14,480	8,828	6,917	6,149	51,892
1989	17,805	15,419	9,755	5,440	4,063	52,482
1990	26,985	17,740	5,397	5,671	6,141	61,934
1991	40,661	3,984	6,494	10,349	6,039	67,527
1992	30,000	11,385	8,151	14,111	14,106	77,753

Table 1. (continued).

Year	4R	4S	4T	3Pn Jan. - May	4Vn Jan. - May	Total
1993 [1]	16,475	4,769	4,132	17,387	8,392	51,156
1994	2,745	2,378	5,166	5,085	4,211	19,586
1995 [2]	27	8	13	0	2	50
1996	28	3	41	1	0	74
1997	6	10	20	0	1	38
1998 [3]	118	86	190	0	5	399
1999	589	63	456	0	2	1,110
2000	794	53	258	11	1	1,117
2001	711	6	370	84	3	1,173
2002	689	50	466	13	6	1,224
2003	484	65	288	0	1	838
2004	486	34	413	0	9	941
2005	562	87	325	0	2	975
2006	126	52	512		4	694
2007	5	22	78	0	0	106
2008	62	9	348	0	1	420
2009	95	15	525	0	0	635
2010	164	53	330	0	2	549
2011	113	42	475	0	1	630
2012	148	172	378	0	1	699
2013	65	121	280	0	0	466
2014 [4]	37	34	287	0	9	366
2015 [4]	4	55	120	0	0	179

[1] Start of Redfish Management Unit 1
[2] Start of moratorium
[3] Start of implementation of index fishery
[4] Preliminary data

Table 2. Monthly redfish landings (t) by month in Unit 1 from 1985 to 2015.

Year	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
1985	853	398	16	378	1,906	3,205	3,888	3,254	4,788	6,247	2,936	793
1986	2,020	194	183	1,240	2,576	4,934	6,041	5,265	3,909	4,612	2,907	1,767
1987	3,183	1,621	2,760	3,010	3,824	4,988	5,429	5,514	4,905	3,249	2,314	2,719
1988	4,464	3,239	3,455	5,244	5,743	3,271	5,019	3,376	4,137	5,977	3,416	1,650
1989	4,995	2,292	1,439	4,496	6,794	4,220	4,926	3,111	4,173	6,879	5,693	3,724
1990	8,260	4,619	1,222	2,955	4,837	4,600	3,536	2,484	4,677	7,542	6,157	4,274
1991	9,174	5,927	6,259	6,428	1,976	2,228	5,911	5,328	6,298	6,823	6,595	4,410
1992	11,329	9,755	5,846	10,377	6,891	3,743	7,774	5,159	4,807	4,676	4,414	2,686
1993	4,263	8,013	6,658	4,362	4,330	2,337	5,682	5,042	3,833	3,013	557	3,383
1994	2,154	1,275	3,510	2,064	540	1,971	3,865	1,916	1,299	843	188	85
1995				2	1	5	26	14	1	1	0	
1996	1	1	2	1	1	27	24	13	0	4	0	1
1997	2	2	2	3	1	5	14	3	3	2	1	2
1998	5			0	1	11	228	138	16	5	4	
1999			2		1	230	523	214	63	75	3	
2000	10		1	0	2	151	346	99	273	167	68	0
2001	72	12		2	2	170	464	145	266	37	2	0
2002	16	0	2	1	3	224	391	350	148	89	1	
2003			0	0	2	31	435	155	145	70	1	
2004	9			0	1	213	239	181	178	108	6	5
2005		1		0	2	136	306	416	61	49	1	4
2006	4			0	1	233	168	246	21	5	12	5
2007	0	0		0	2	84	7	5	3	4	1	0
2008	0			0	2	171	169	22	52	1	2	1
2009				0	2	216	338	63	15	1	0	0
2010	2	0		0	1	257	206	66	15	2	0	
2011				0	3	306	259	56	5	0	0	
2012	0		0	0	3	312	293	72	17	0	0	0
2013				1	2	181	234	45	1	1	0	1
2014*	7	2		1	1	168	164	5	10	8	0	
2015*				0	1	44	57	69	8	0	0	

*Preliminary data

Table 3. Abundance and biomass index of S. *fasciatus during the DFO research survey in NAFO divisions 4RST (Unit 1) from 1984 to 2015.*

Year	Abundance (1,000,000)			Biomass (tons)		
	Immature	Mature	Total	Immature	Mature	Total
1984	4,049.0	525.8	4,604.3	122,641	232,456	362,001
1985	1,256.6	423.3	1,681.1	63,399	147,658	303,334
1986	618.5	432.7	1,050.8	51,871	138,294	189,759
1987	1,149.0	421.7	1,570.5	35,271	125,699	160,941
1988	812.5	1,059.5	1,872.0	55,618	352,356	407,910
1989	592.2	1,053.0	1,646.8	46,629	355,229	400,934
1990	2,622.8	714.0	3,339.7	59,272	265,644	325,351
1991	4,284.3	511.9	4,792.8	107,273	188,851	295,856
1992	716.6	505.7	1,222.5	36,018	208,156	244,181
1993	182.5	324.8	507.2	18,546	108,978	127,521
1994	72.7	142.1	213.8	6,269	71,229	77,270
1995	51.6	25.7	77.3	2,526	11,320	13,772
1996	51.6	24.2	75.9	2,209	10,181	12,375
1997	79.0	55.5	134.6	3,583	26,247	29,836
1998	251.4	149.7	401.0	14,343	48,128	62,468
1999	188.1	34.2	222.2	7,393	13,265	20,659
2000	301.9	49.8	351.8	11,722	19,045	30,749
2001	192.7	47.9	241.5	6,404	21,796	28,271
2002	143.0	41.1	183.7	6,635	15,198	21,781
2003	232.5	194.0	427.1	13,944	72,103	86,256
2004	119.8	46.9	165.7	7,929	14,492	22,535
2005	4,394.0	65.9	4,465.8	47,014	24,433	71,451
2006	1,899.6	130.8	2,031.3	78,908	37,642	116,550
2007	1,901.6	128.5	2,032.1	78,920	24,090	103,010
2008	496.7	142.1	639.9	25,579	52,679	78,258
2009	244.3	57.0	301.5	10,913	18,465	29,382
2010	236.3	61.3	304.0	13,771	23,129	37,167
2011	122.3	71.5	193.9	9,038	28,263	37,302
2012	252.4	77.1	318.8	10,806	24,964	35,770
2013	2,430.0	108.8	2,538.9	25,251	44,478	69,771
2014	3,138.2	136.6	3,274.8	71,832	38,752	110,602
2015	1,434.9	177.2	1,612.0	58,757	44,381	103,134

Table 4. Abundance and biomass index of S. mentella during the DFO research survey in NAFO divisions 4RST (Unit 1) from 1984 to 2015.

Year	Abundance (1,000,000)			Biomass (tons)		
	Immature	Mature	Total	Immature	Mature	Total
1984	1,919.4	751.9	2,676.4	74,617	371,166	446,958
1985	631.9	480.8	1,111.7	48,995	250,292	375,753
1986	692.6	570.4	1,262.7	75,394	274,216	348,863
1987	1,073.5	976.7	2,049.0	147,699	418,125	565,677
1988	494.2	816.1	1,310.3	73,303	316,118	389,407
1989	328.1	737.4	1,065.6	56,971	289,149	346,190
1990	865.1	963.8	1,828.9	64,188	442,953	507,133
1991	1,455.8	460.7	1,916.2	52,104	208,745	260,826
1992	278.1	323.4	601.5	25,735	144,296	170,030
1993	67.2	217.3	284.5	9,566	93,652	103,217
1994	49.6	107.8	155.8	5,745	56,014	61,208
1995	39.4	131.4	170.7	5,800	73,625	79,388
1996	42.6	103.6	146.2	4,533	59,241	63,774
1997	37.5	95.7	133.2	4,000	54,211	58,211
1998	44.2	46.6	90.8	2,959	27,030	29,989
1999	61.0	76.9	137.9	4,093	47,858	51,951
2000	80.2	82.1	162.3	5,110	49,547	54,655
2001	44.8	68.0	112.9	3,832	43,549	47,396
2002	34.6	119.0	153.4	3,778	75,997	79,741
2003	83.2	210.8	294.1	14,157	96,813	111,024
2004	17.5	37.8	53.5	1,934	24,798	26,079
2005	150.6	70.7	221.2	4,036	46,169	50,204
2006	93.3	35.2	128.7	10,629	25,193	35,822
2007	509.9	67.4	578.1	26,594	28,034	54,626
2008	53.0	167.9	220.9	12,847	79,352	92,199
2009	5.6	16.0	21.5	624	11,624	12,257
2010	49.4	140.8	190.0	11,200	61,461	72,483
2011	30.0	45.3	75.3	2,781	32,998	35,779
2012	23.1	50.5	73.7	1,660	38,528	40,188
2013	5,343.6	116.9	5,460.8	50,023	53,862	103,830
2014	5,188.6	207.0	5,395.8	139,014	64,396	203,391
2015	7,943.0	567.3	8,510.3	364,410	80,365	444,778

*Table 5. Proportion of abundance (A) and biomass (B) of Sebastes mentella for each cohort (2011, 2012 and 2013) estimated for different size classes in different years (Example: "**0.48"** indicates that 48% from the 2011 cohort would be more than 22 cm in 2018 and 48% of fish from the 2012 cohort would be more than 22 cm in 2019).*

A)

2013 cohort	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
2012 cohort	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
2011 cohort	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
	Age 5	**Age 6**	**Age 7**	**Age 8**	**Age 9**	**Age 10**	**Age 11**	**Age 12**	**Age 13**	**Age 14**	**Age 15**	**Age 16**
>20 cm	0.12	0.52	0.84	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
>21 cm	0.04	0.31	0.68	0.89	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00
>22 cm	0.01	0.14	**0.48**	0.77	0.92	0.97	0.99	1.00	1.00	1.00	1.00	1.00
>23 cm	0.00	0.05	0.29	0.60	0.82	0.93	0.97	0.99	1.00	1.00	1.00	1.00
>24 cm	0.00	0.01	0.14	0.42	0.69	0.85	0.94	0.97	0.99	0.99	1.00	1.00
>25 cm	0.00	0.00	0.06	0.25	0.51	0.73	0.87	0.94	0.97	0.99	0.99	1.00
>26 cm	0.00	0.00	0.02	0.12	0.34	0.58	0.76	0.87	0.93	0.96	0.98	0.99
>27 cm	0.00	0.00	0.00	0.05	0.19	0.41	0.62	0.77	0.87	0.93	0.96	0.98
>28 cm	0.00	0.00	0.00	0.02	0.10	0.26	0.46	0.64	0.77	0.86	0.92	0.95
>29 cm	0.00	0.00	0.00	0.00	0.04	0.14	0.31	0.49	0.65	0.76	0.85	0.90
>30 cm	0.00	0.00	0.00	0.00	0.01	0.07	0.18	0.34	0.50	0.64	0.75	0.83

Table 5. (continued).

B)

2013 cohort	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
2012 cohort	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**
2011 cohort	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
	Age 5	**Age 6**	**Age 7**	**Age 8**	**Age 9**	**Age 10**	**Age 11**	**Age 12**	**Age 13**	**Age 14**	**Age 15**	**Age 16**
>20 cm	0.07	0.41	0.77	0.94	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
>21 cm	0.02	0.21	0.59	0.85	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00
>22 cm	0.00	0.09	0.39	0.71	0.89	0.96	0.99	1.00	1.00	1.00	1.00	1.00
>23 cm	0.00	0.03	0.21	0.53	0.78	0.91	0.97	0.99	0.99	1.00	1.00	1.00
>24 cm	0.00	0.01	0.09	0.34	0.62	0.82	0.92	0.97	0.99	0.99	1.00	1.00
>25 cm	0.00	0.00	0.03	0.19	0.45	0.69	0.84	0.92	0.96	0.98	0.99	1.00
>26 cm	0.00	0.00	0.01	0.08	0.28	0.52	0.72	0.85	0.92	0.96	0.98	0.99
>27 cm	0.00	0.00	0.00	0.03	0.15	0.35	0.57	0.74	0.85	0.92	0.95	0.97
>28 cm	0.00	0.00	0.00	0.01	0.07	0.21	0.41	0.60	0.75	0.84	0.91	0.94
>29 cm	0.00	0.00	0.00	0.00	0.03	0.11	0.26	0.44	0.61	0.74	0.83	0.89
>30 cm	0.00	0.00	0.00	0.00	0.01	0.05	0.15	0.30	0.46	0.61	0.73	0.81

FIGURES

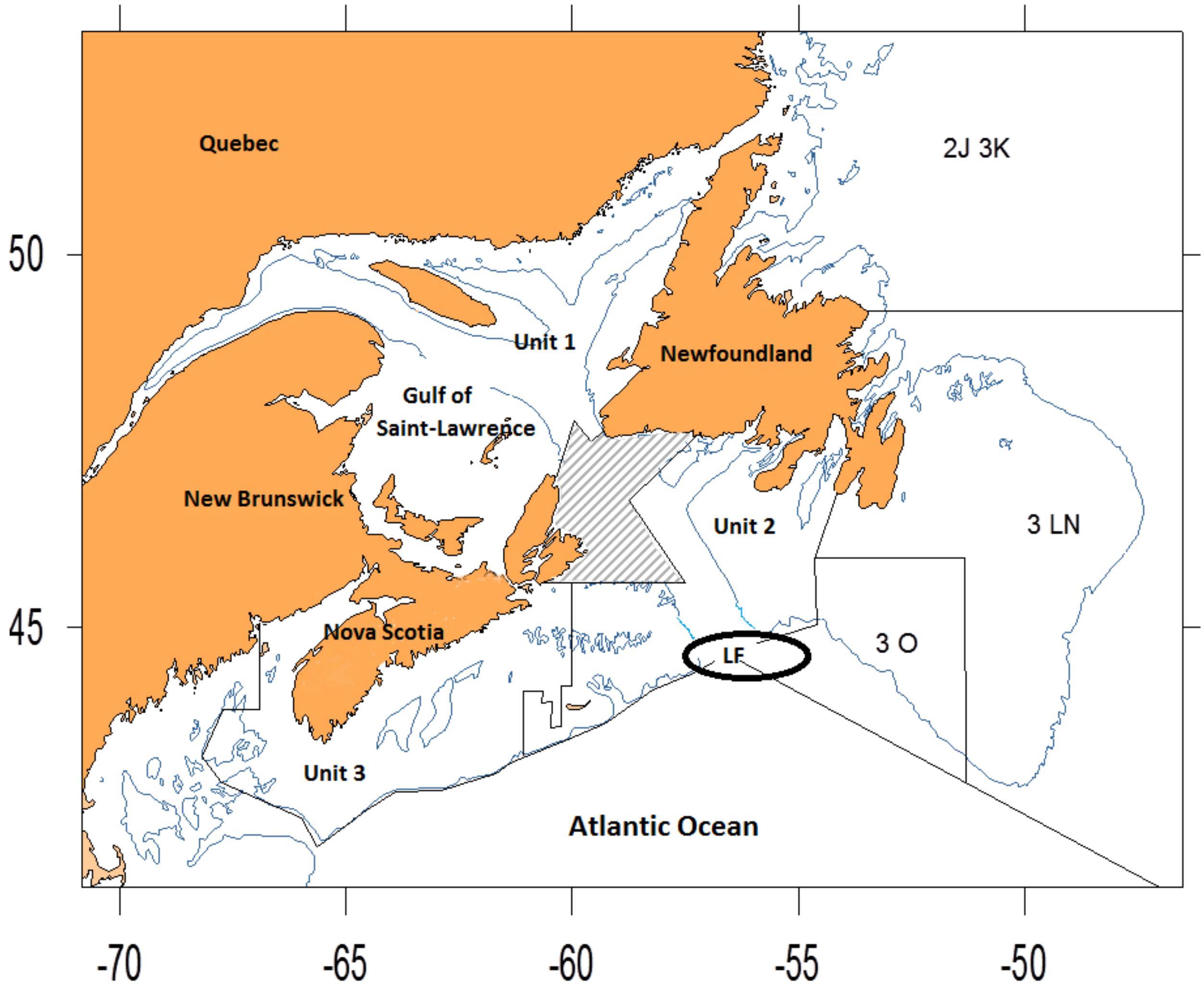
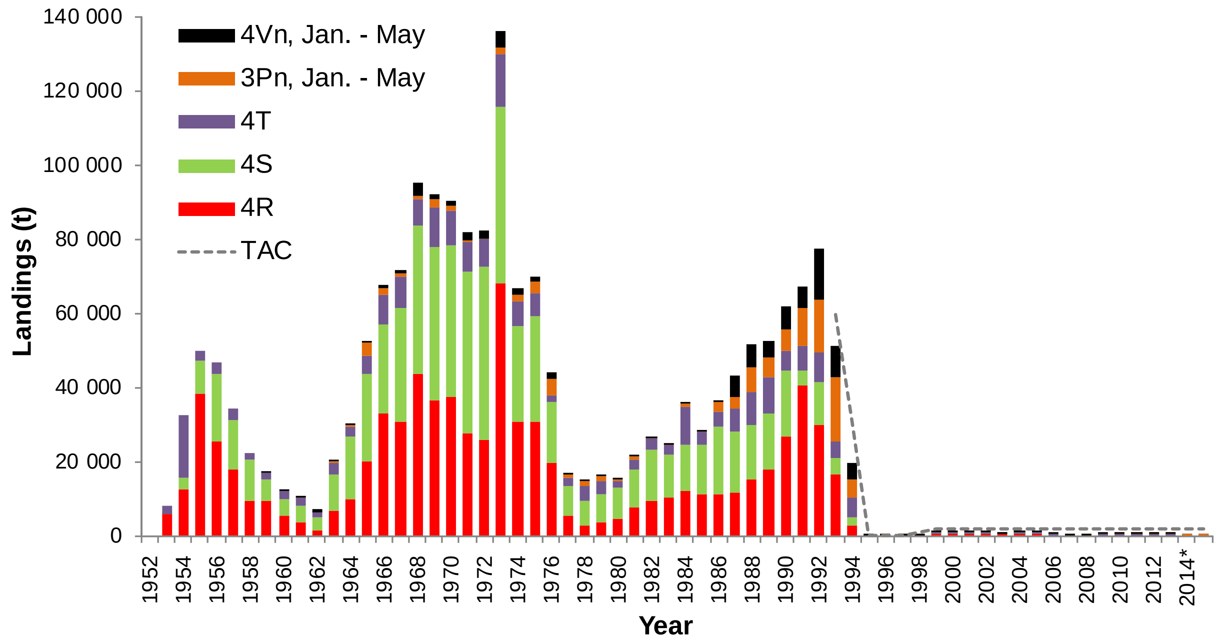


Figure 1. Map of Northwest Atlantic indicating the boundaries of the current redfish management units in NAFO divisions. The area associated with NAFO subdivisions 3Pn and 4Vn (shaded) correspond to the areas of seasonal overlap between units 1 and 2 (LF circled: Laurentian Fan sector).

A)



B)

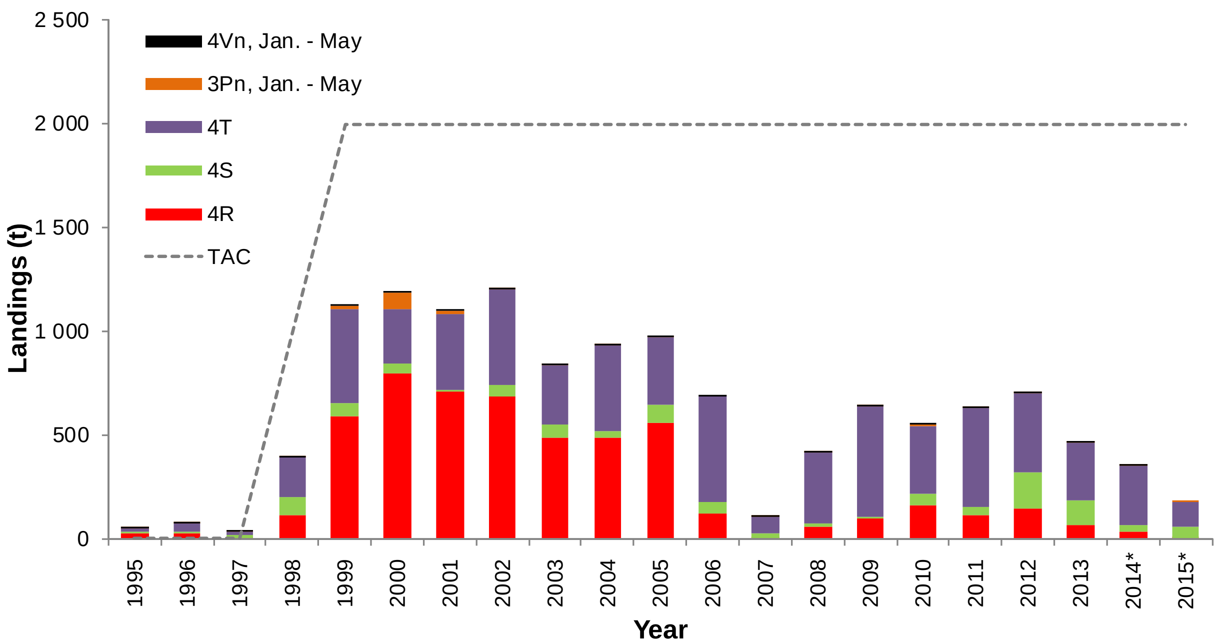


*Figure 2. Annual landings of redfish by NAFO division and subdivision, A) from 1952 to 2015 and B) total allowable catches (TAC) and landings from 1995 to 2015 (*preliminary data).*

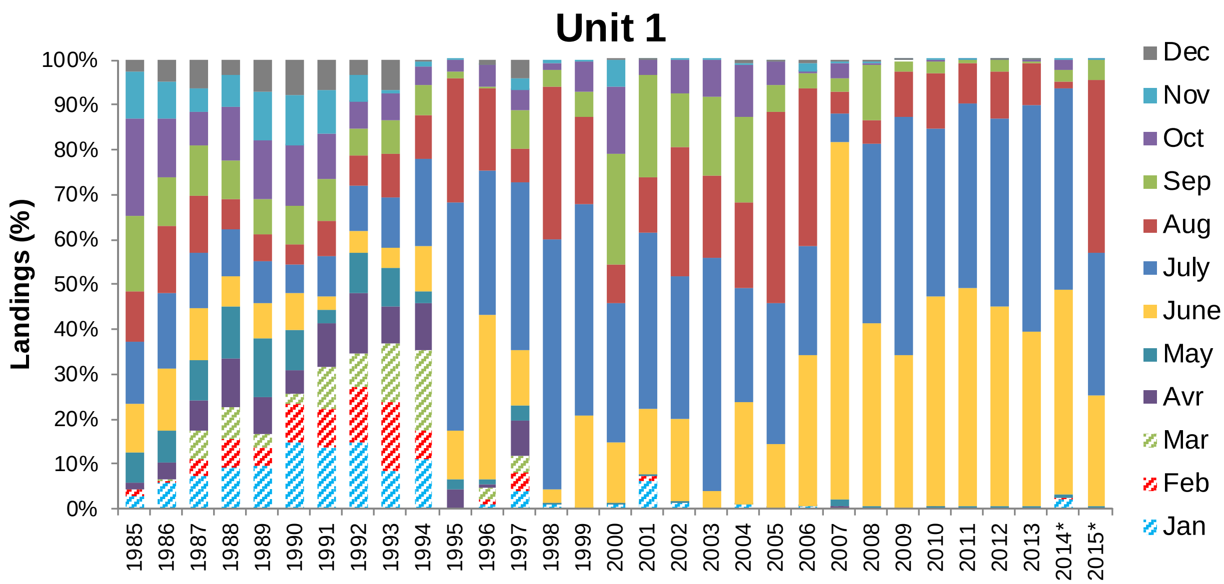


Figure 3. Monthly redfish landings (percentage) by month in Unit 1 from 1985 to 2015.

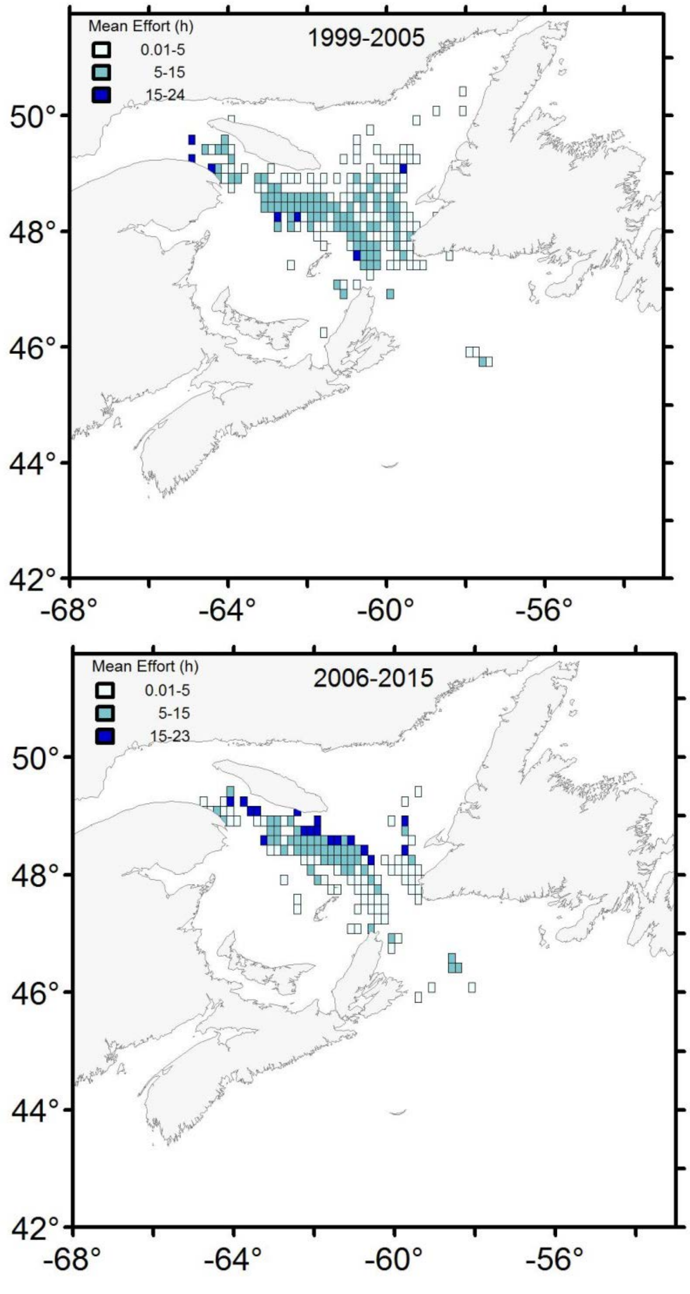


Figure 4. Spatial distribution of the average fishing effort (hours) per grid of the redfish index fishery in Unit 1 for the 1999-2005 and 2006-2015 periods.

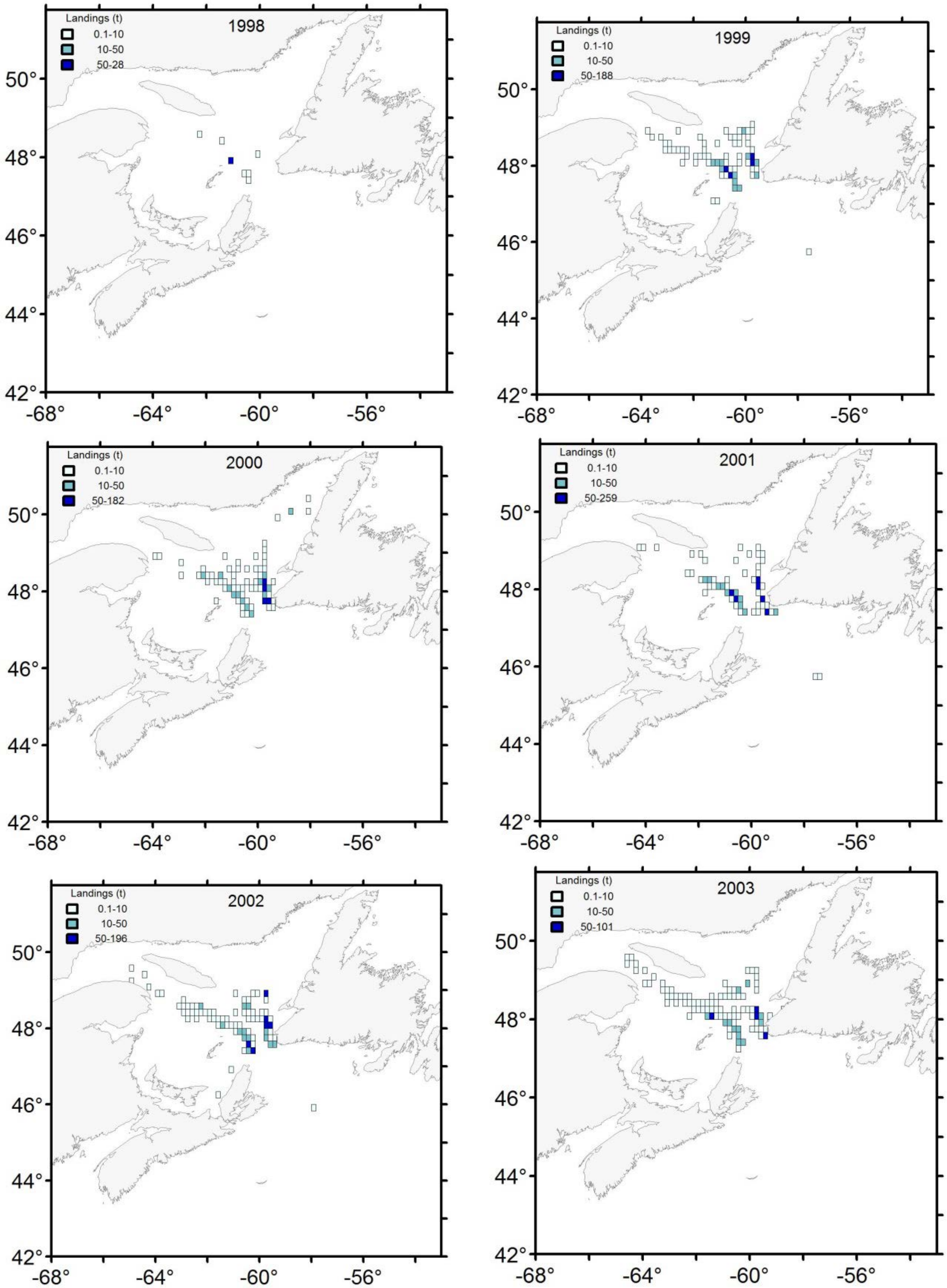


Figure 5. Spatial distribution of redfish landings (t) from the index fishery in Unit 1 from 1998 to 2003.

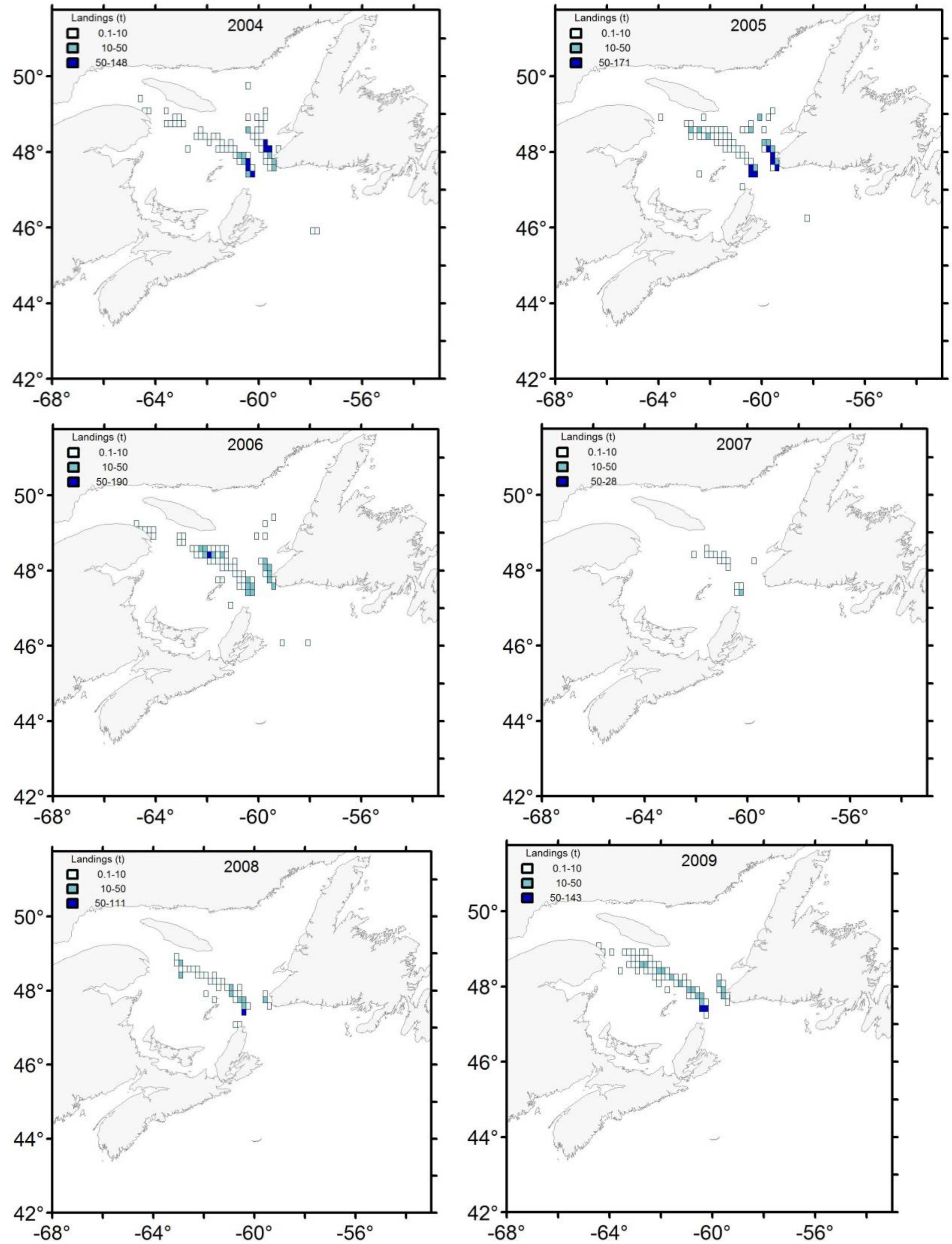


Figure 6. Spatial distribution of redfish landings from the index fishery in Unit 1 from 2004 to 2009.

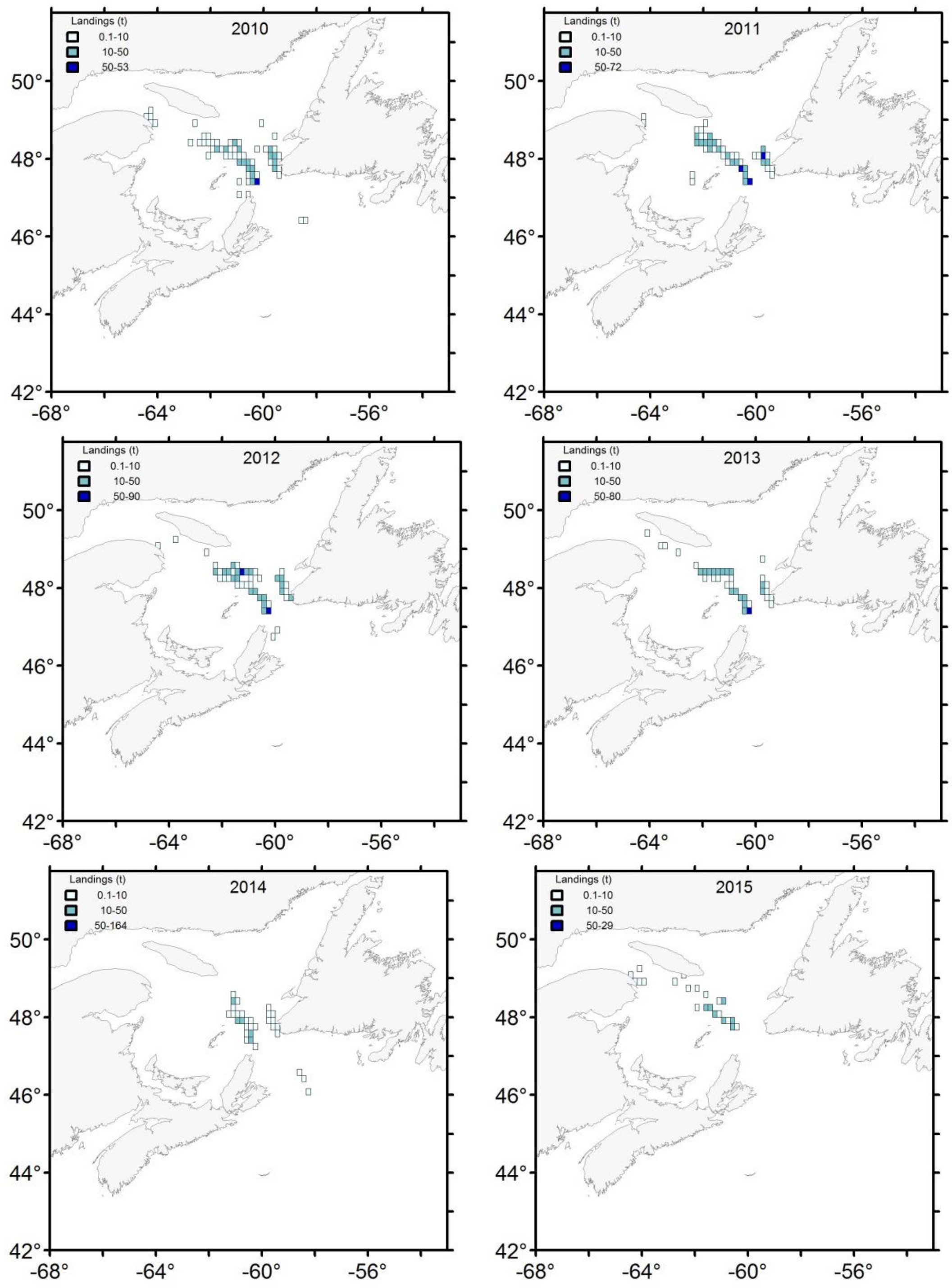
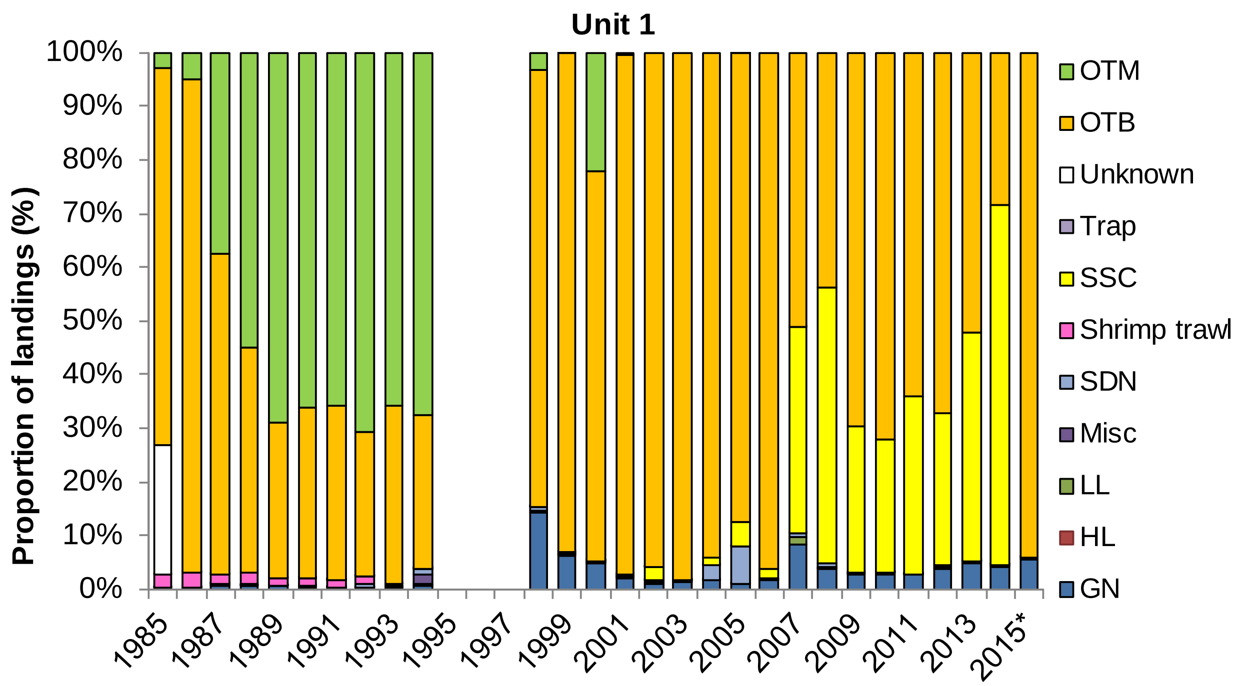


Figure 7. Spatial distribution of redfish landings from the index fishery in Unit 1 from 2010 to 2015.

A)



B)

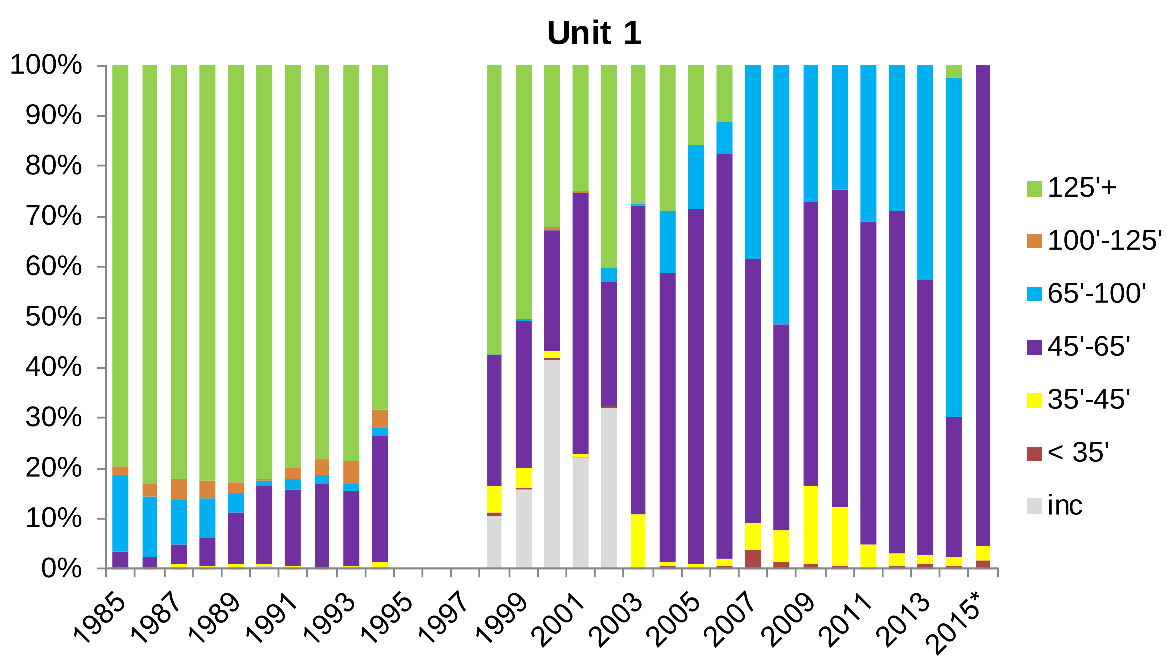
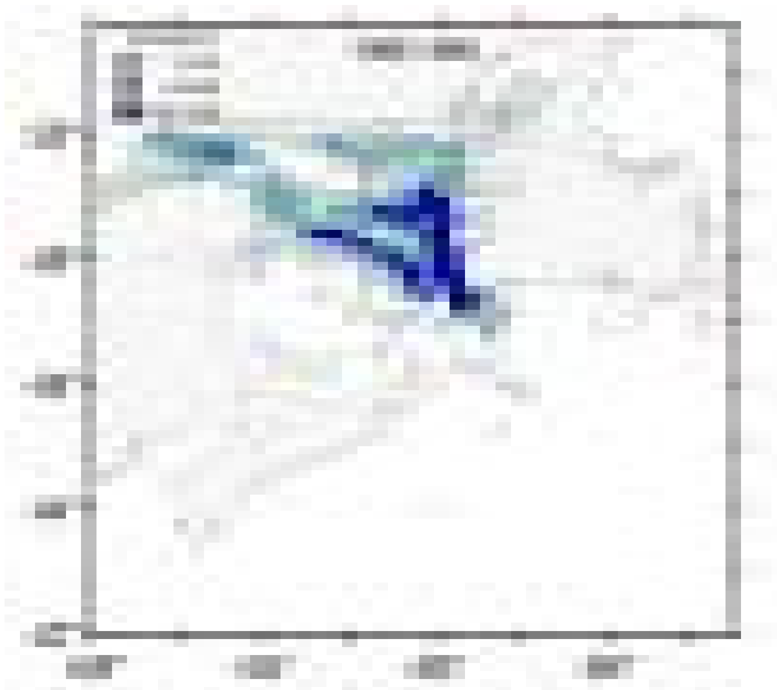


Figure 8. Percentage of redfish landings in Unit 1 from 1985 to 2015; A) by gear (OTM: midwater trawl, OTB: bottom trawl, Trap: trap, SSC: Scottish seine, SDN: Danish seine, Miscellaneous: miscellaneous, LL: longline, HL: handline and GN: gill net) and B) by boat size classes (35'=10.7m; 45'=13.7m; 65'=19.8m; 100'=30.5m; 125'=38.1m).



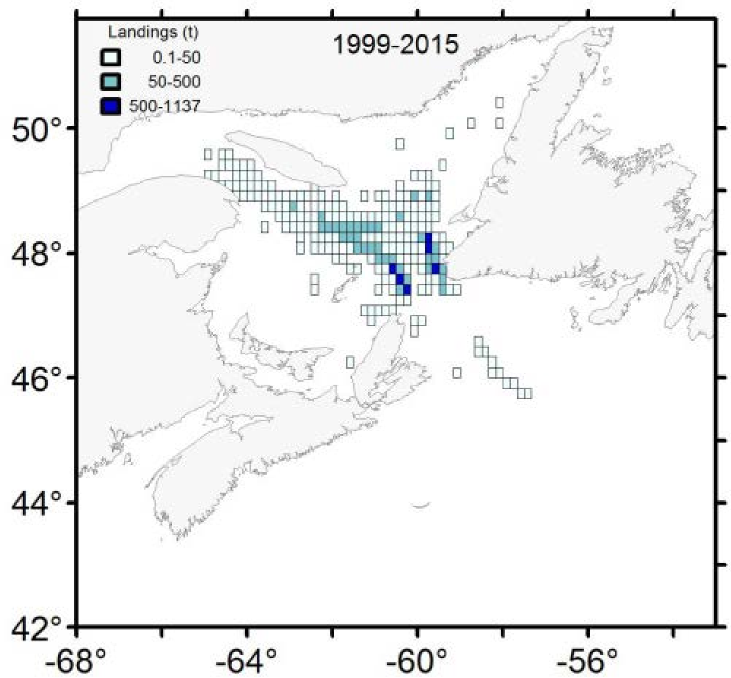


Figure 9. Spatial distribution of redfish landings for all fisheries in Unit 1 for the periods of 1986-1994 (high) and 1999-2015 (low) after the moratorium.

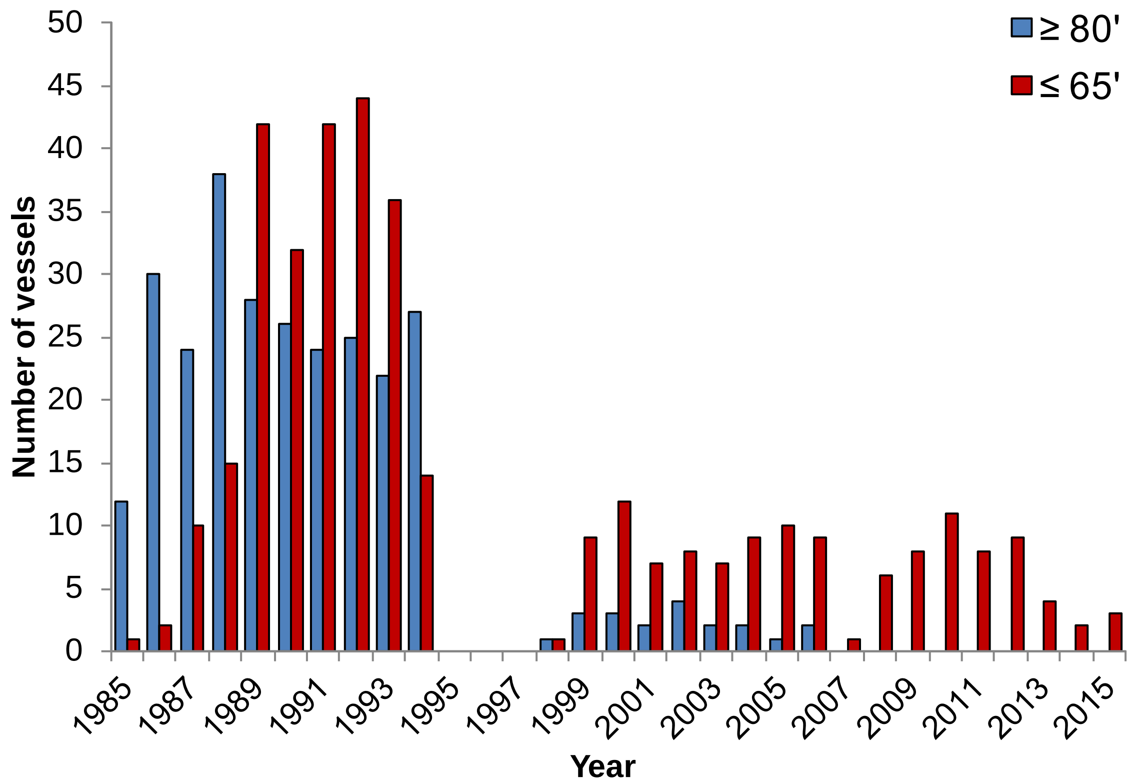


Figure 10. Number of boats per size class in directed redfish fisheries (commercial and index) meeting selection criteria for the fishery performance index in Unit 1 from 1985 to 2015 (65'=19.8m; 80'=24.4m).

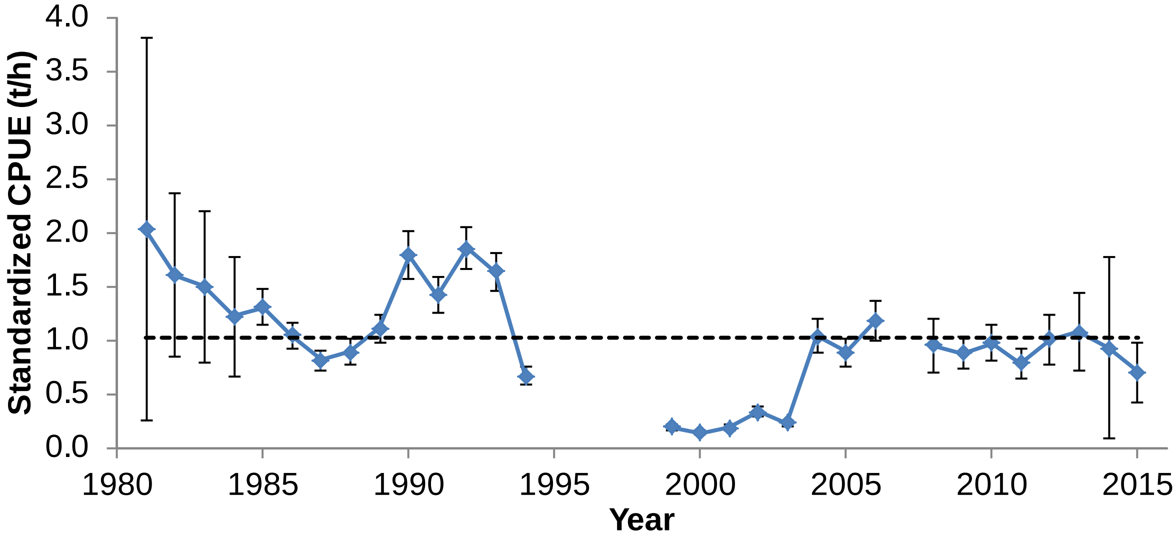


Figure 11. Standardized bottom trawl catch per unit effort (CPUE ± 95% confidence interval) in Unit 1 in the commercial fishery between May and October (1981–1994) and the index fishery (1998–2015). The solid line represents the average for the period 1981 to 2014; the dotted lines represent a ± ½ standard deviation. 2015 data are preliminary.

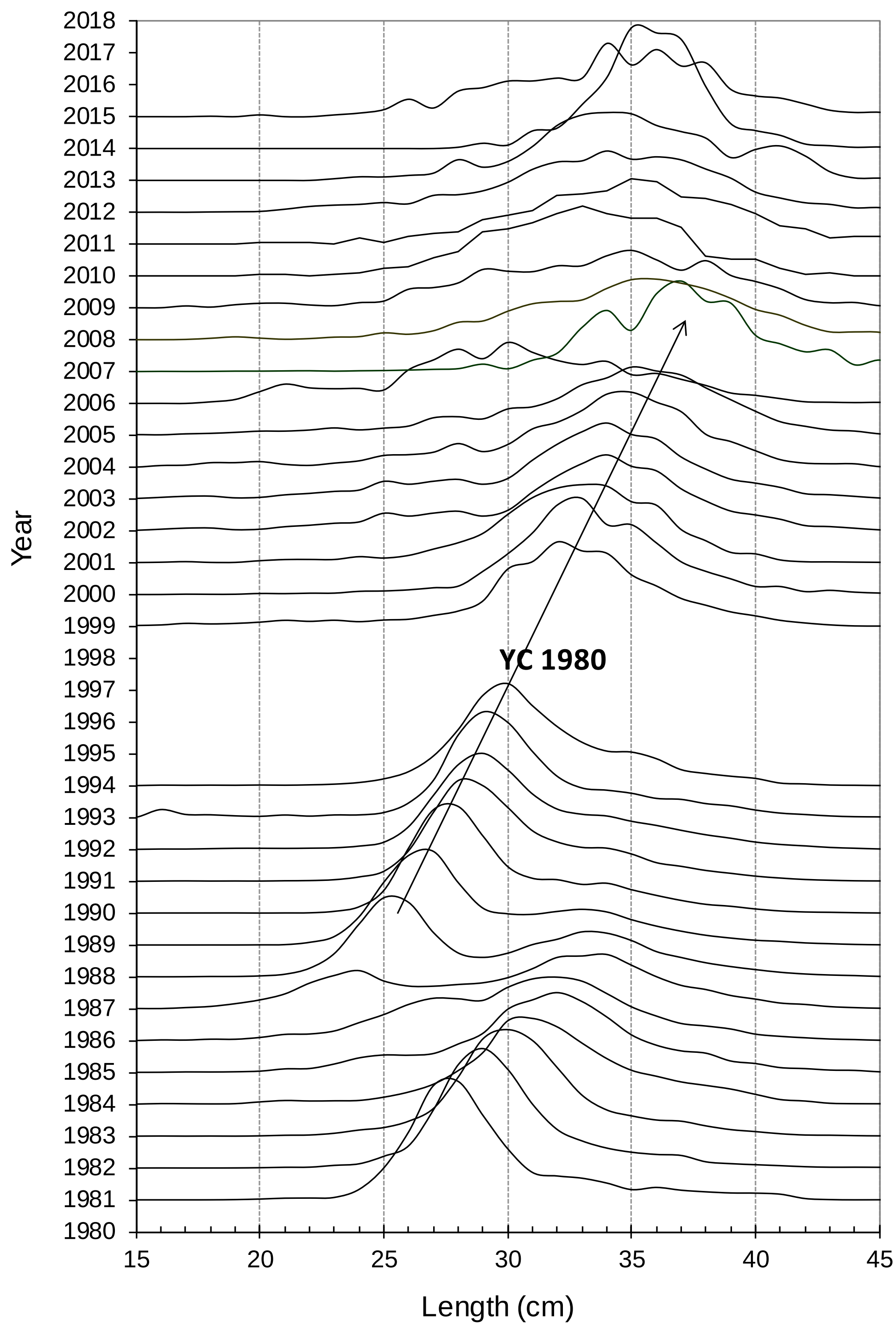


Figure 12. Size frequency (%) of redfish in commercial landings from Unit 1 from 1981 to 2015. 2015 data are preliminary. Tracking of the 1980 cohort is indicated by an arrow.

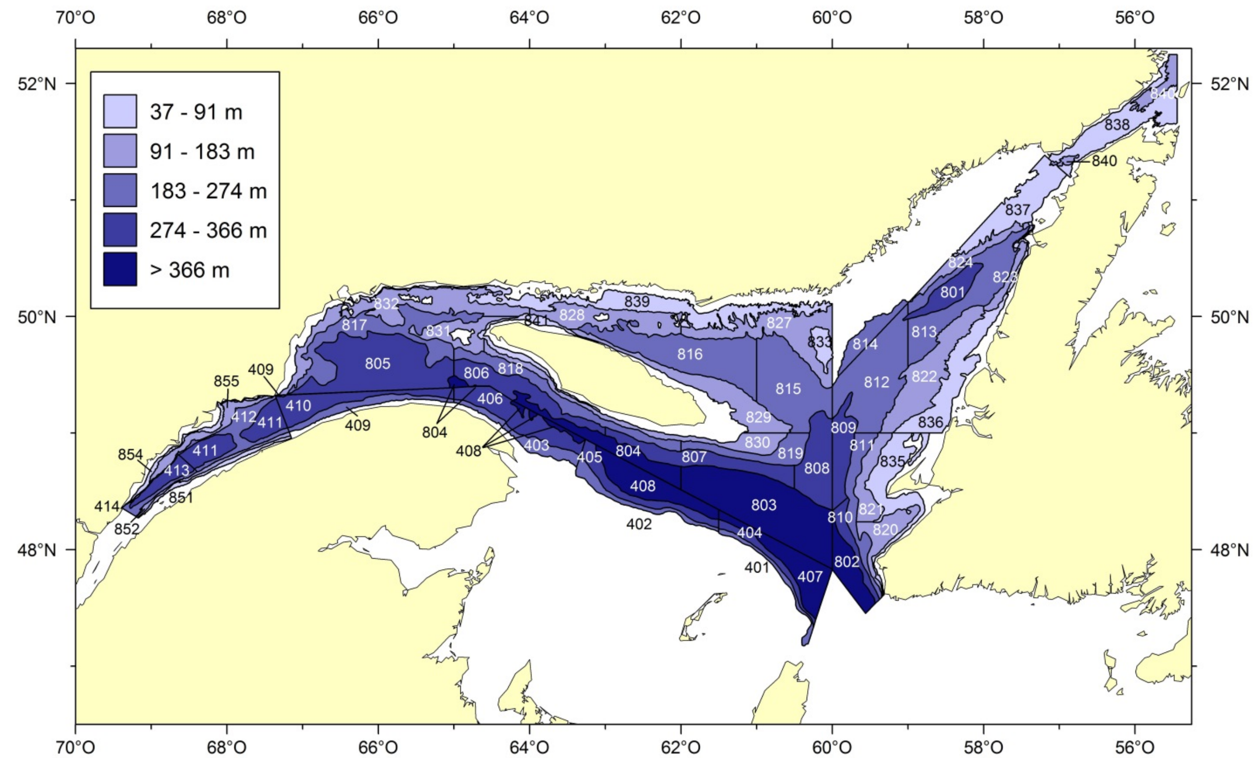


Figure 13. Stratification scheme used for the DFO multidisciplinary research survey and the mobile gear sentinel fishery survey. The strata of the estuary, upstream from stratum 410, are not covered by the sentinel fishery survey.

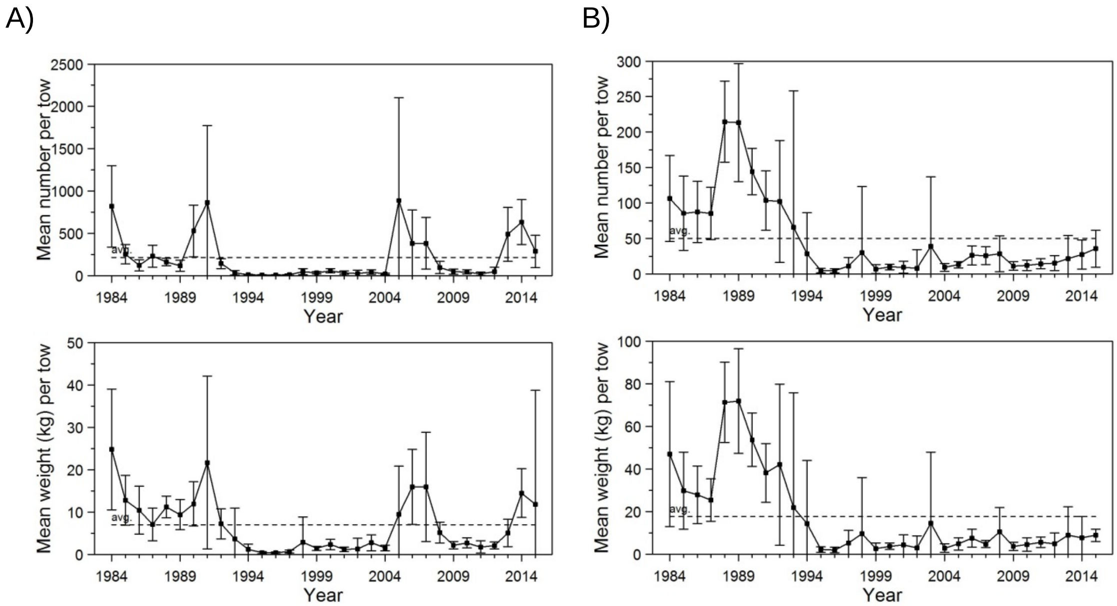


Figure 14. Mean number per tow and mean weight per tow of Sebastes fasciatus in the Unit 1 DFO research survey; A) immature population and B) mature population. The dotted horizontal line represents the mean for the 1984–2014 period.

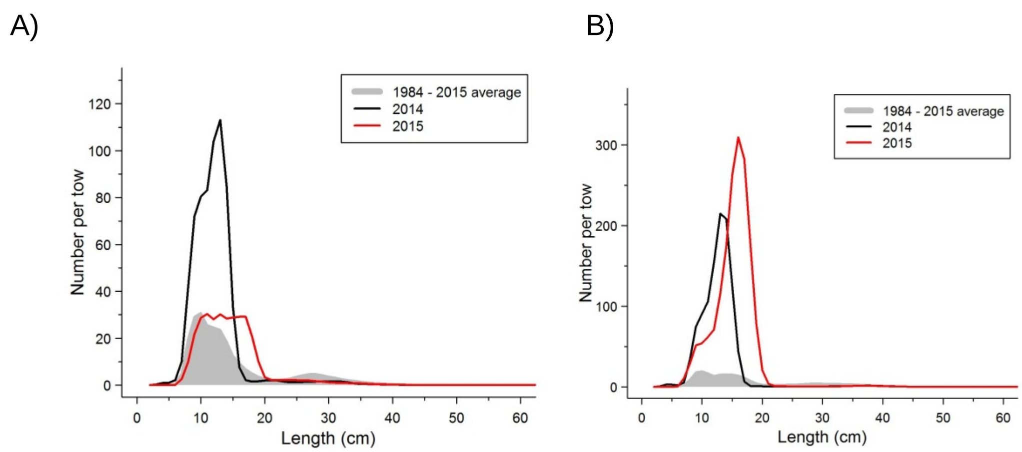
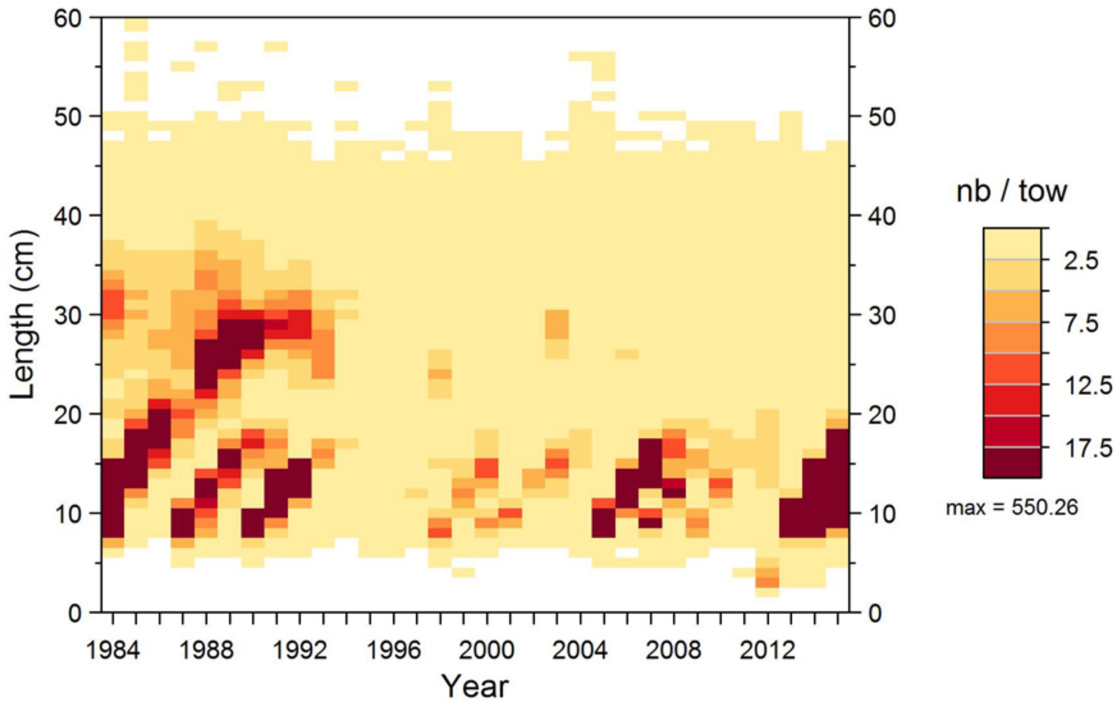


Figure 15. Size frequencies of Sebastes fasciatus (A) and S. mentella (B) in the Unit 1 DFO research survey.

A)



B)

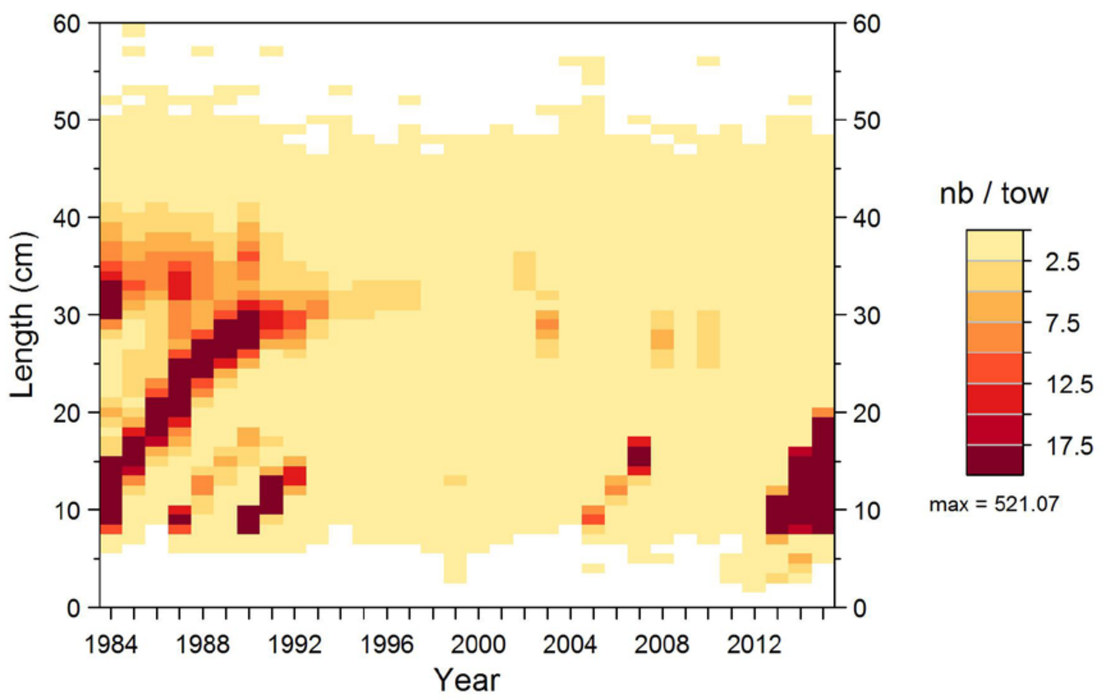
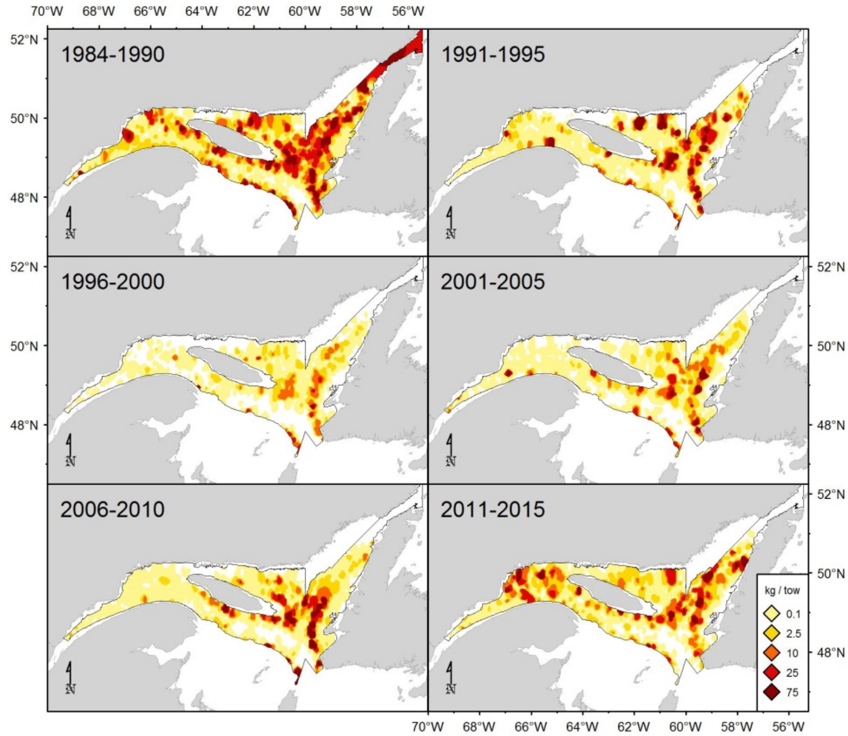


Figure 16. Mean number of tow of A) Sebastes fasciatus and B) S. mentella by length according to years in the Unit 1 DFO research survey.

A)



B)

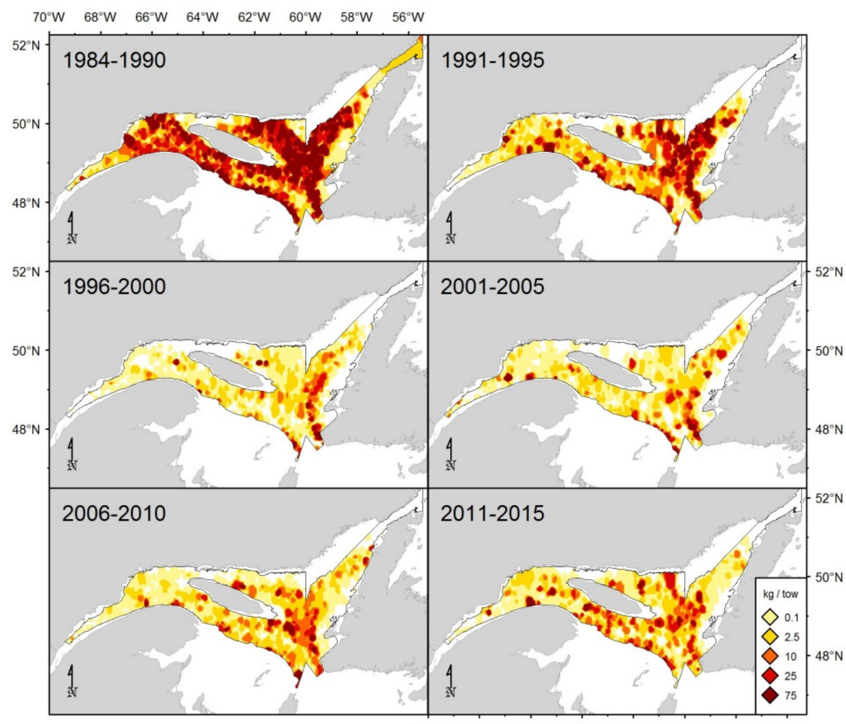


Figure 17. Spatial distribution of catch rates (kg/15 minute tow) of Sebastes fasciatus A) immature population and B) mature populations in the Unit 1 DFO research survey.

A) B)

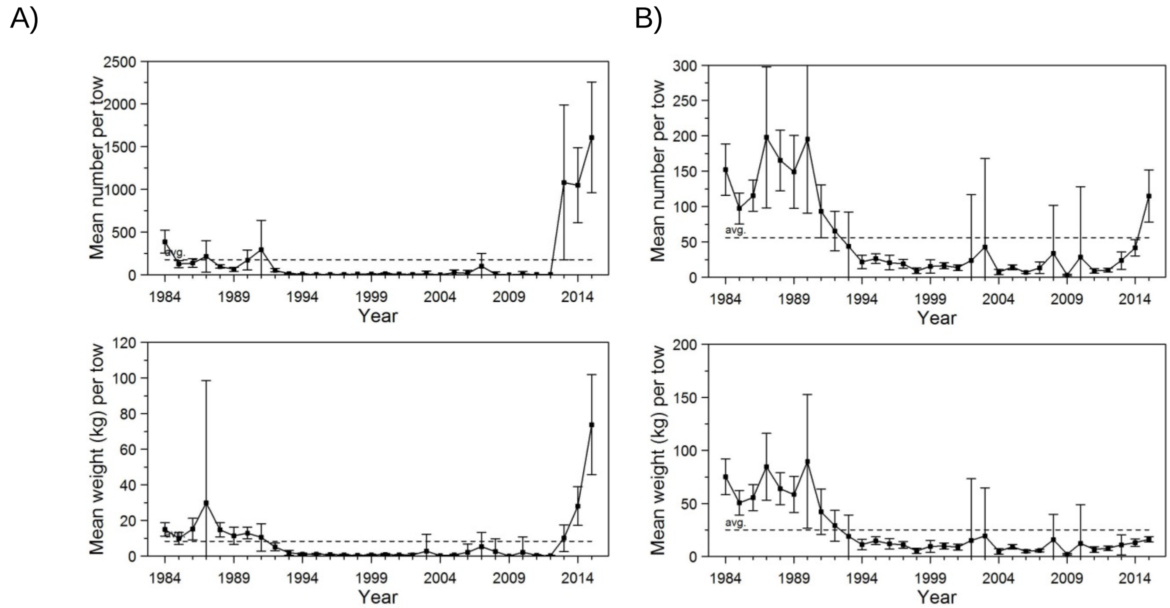
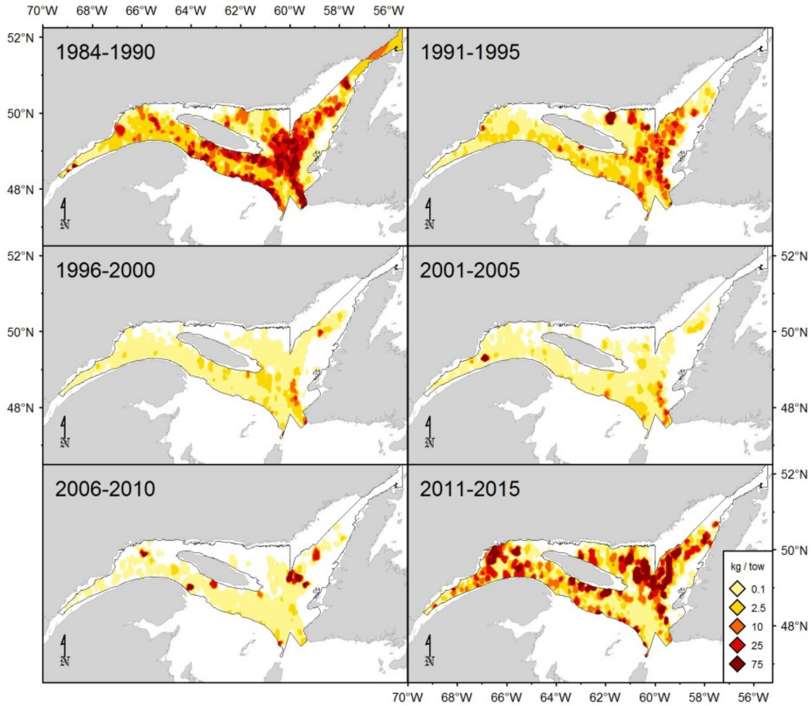


Figure 18. Mean number and mean weight per tow of Sebastes mentella A) immature population and B) mature populations in the Unit 1 DFO research survey. The dotted horizontal line represents the mean for the 1984–2014 period.

A)



B)

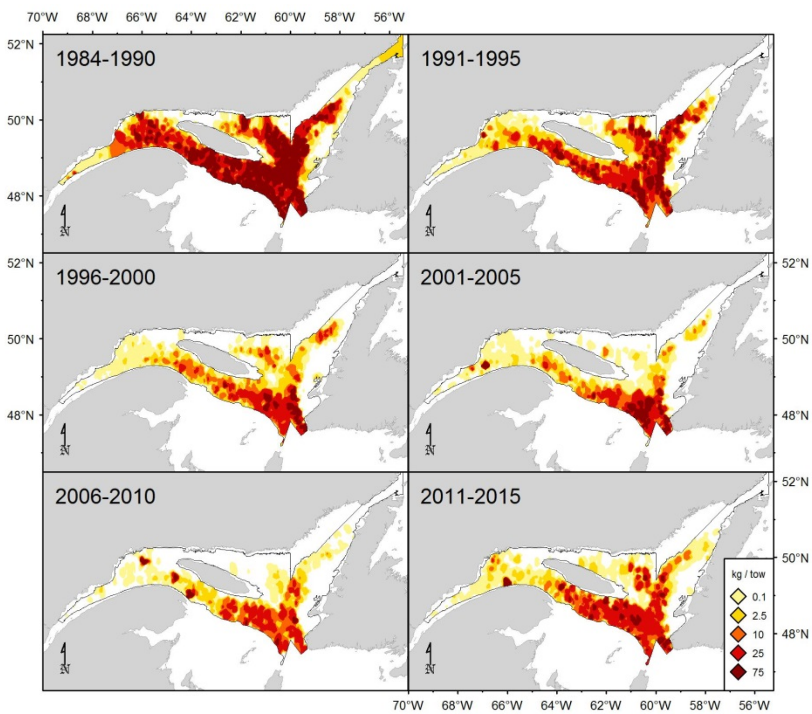


Figure 19. Spatial distribution of catch rates (kg/15 minute tow) of Sebastes mentella A) immature population and B) mature populations in the Unit 1 DFO research survey.

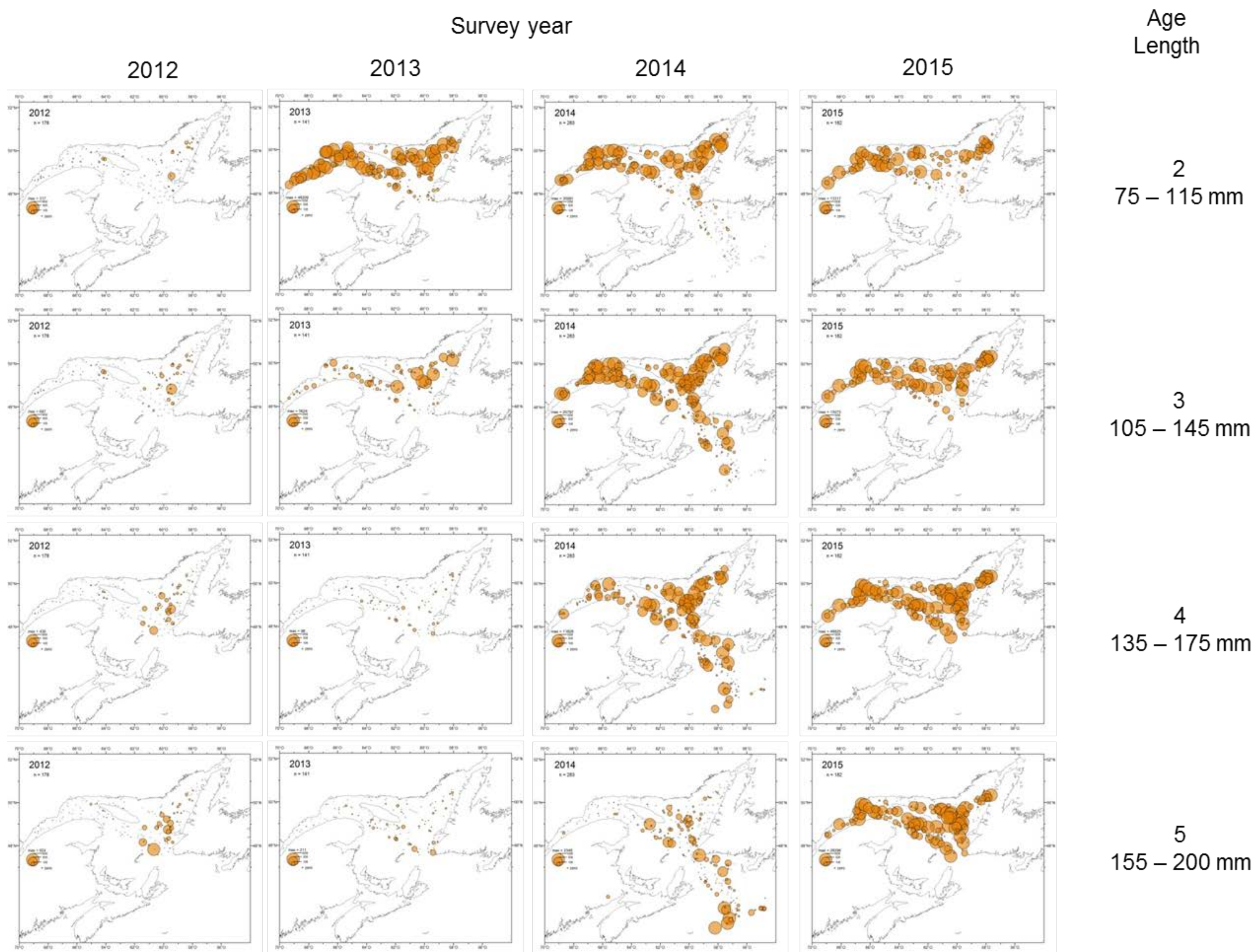
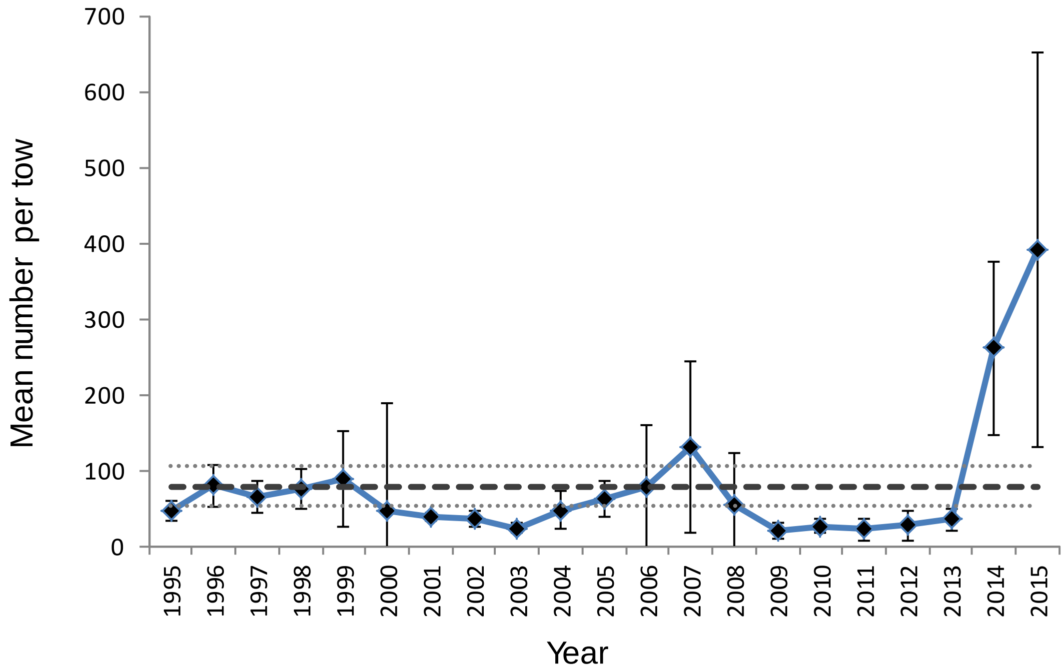


Figure 20. Distribution of catch rates (number/15 minute tow) of redfish per length class in the Unit 1 DFO research survey and the Unit 2 GEAC survey.

A)



B)

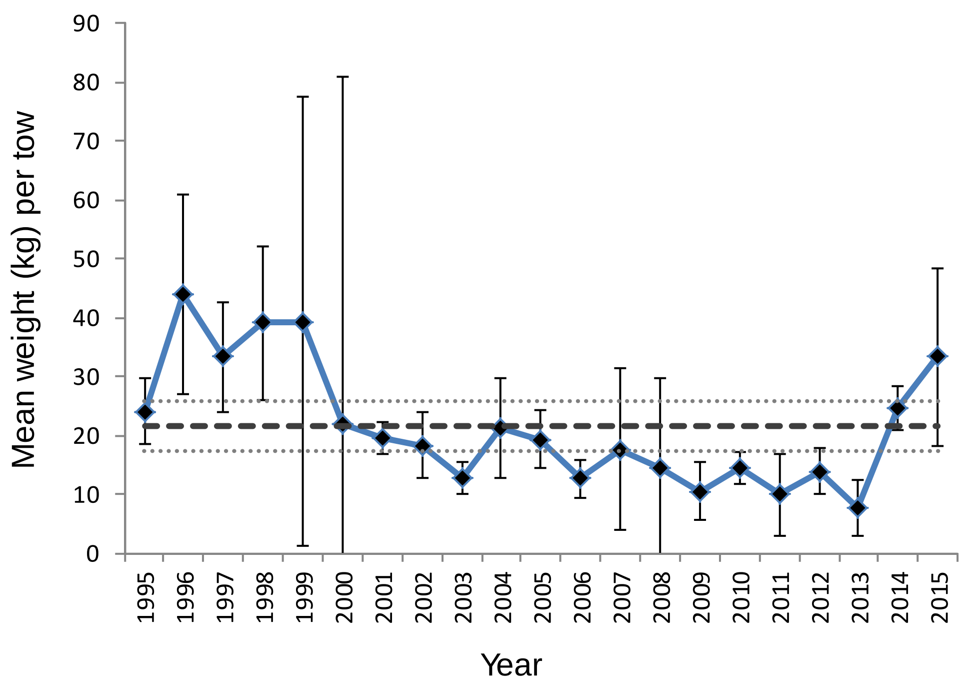


Figure 21. Mean number and mean weight per tow of Sebastes (fasciatus and mentella combined) in the Unit 1 sentinel fishery survey. The horizontal line (dark line) represents the mean for the 1995-2014 period and the finer dotted lines represent a ± ½ standard deviation.

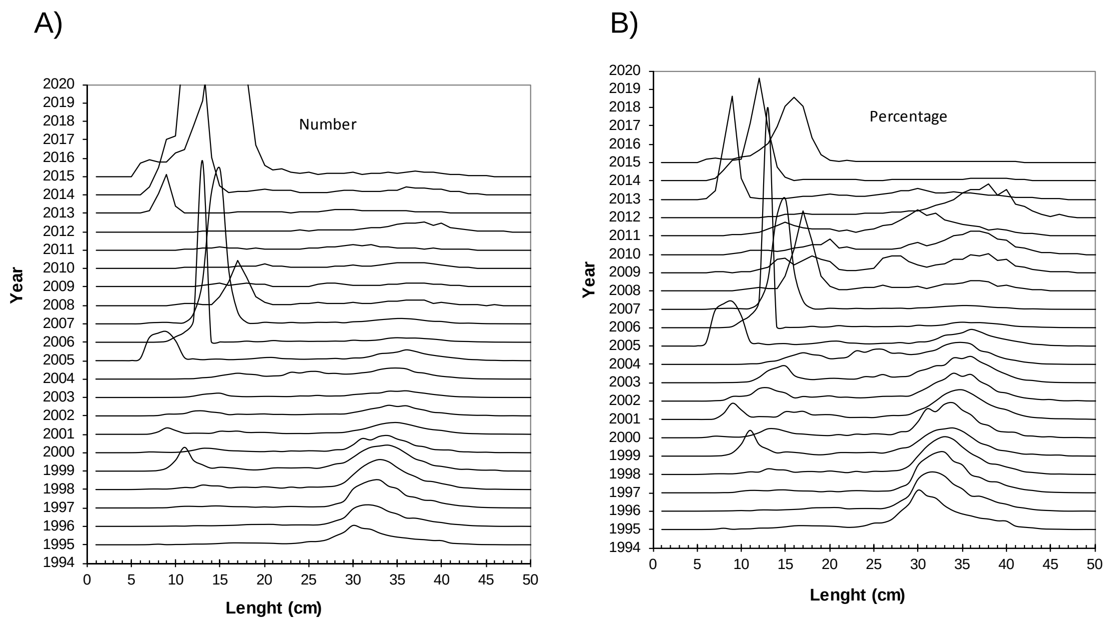


Figure 22. Size frequencies in number (A) and in percentage (B) of redfish (both species combined) in the Unit 1 sentinel fishery surveys.

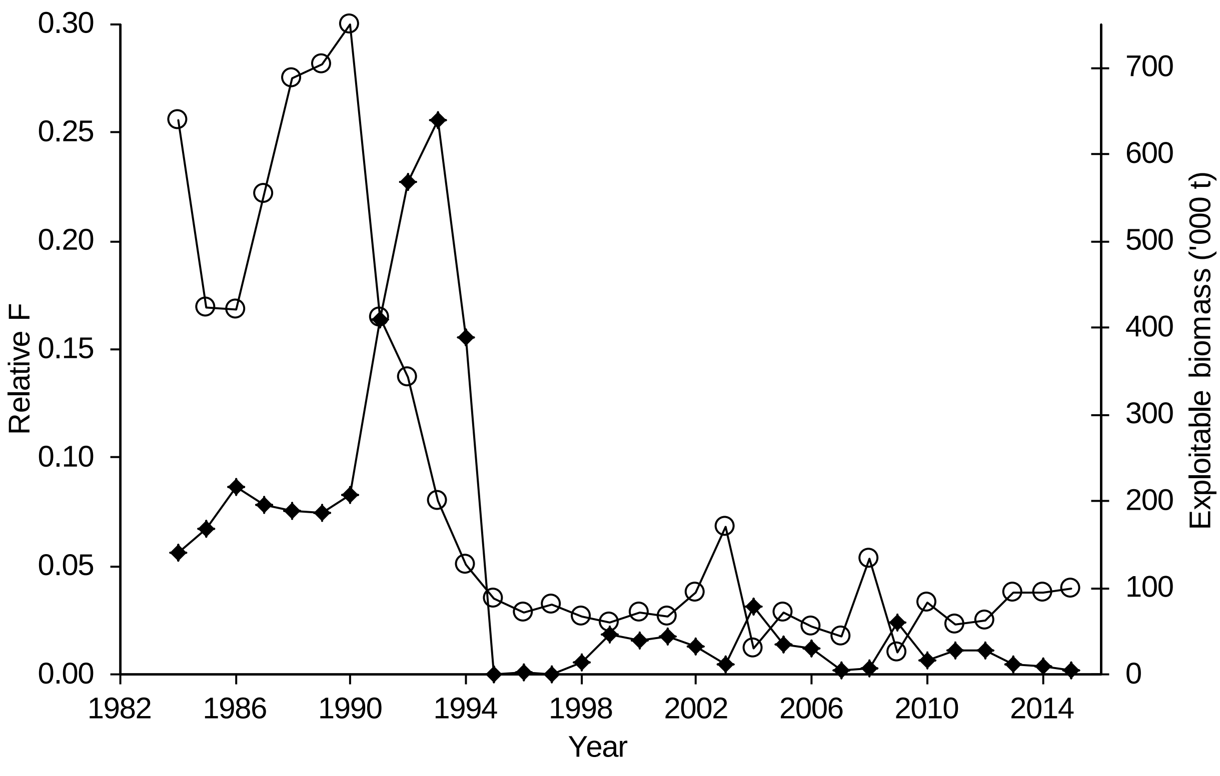


Figure 23. Indicator of relative exploitation rates (relative F) and exploitable biomass of redfish in Unit 1.

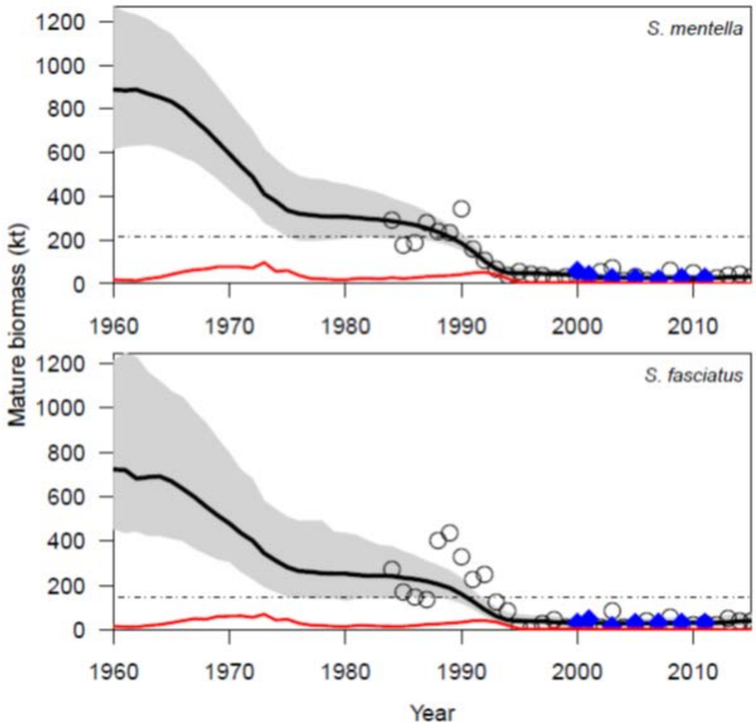
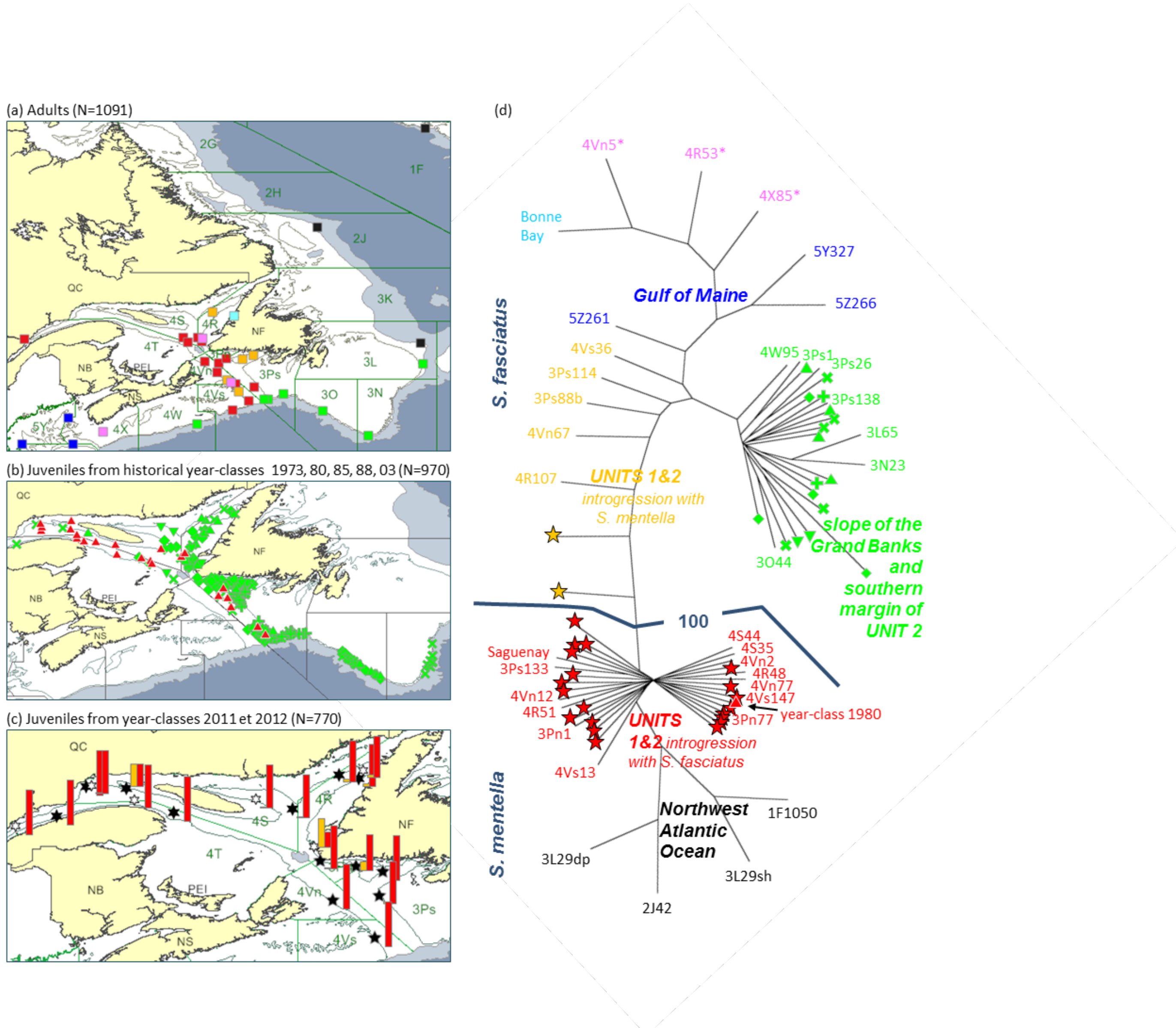


Figure 24. Adjustment of the (biomass) production model for each redfish species (solid dark line) with a 90% confidence interval (grey area), catches (solid red line), Unit 1 biomass index (clear circle) weighted with q (U1) Unit 2 biomass index (dark diamond) weighted with q (U2) and limit reference point (Blim = 40% Bmsy; dotted line).

APPENDICES

Appendix 1. Geographic location of (a) 35 samples (■) of adult Redfish (16 *S. mentella*, n=495; 19 *S. fasciatus*, n=596) analyzed to describe population structures by species in the Northwest Atlantic; (b) 970 juveniles belonging to five historical year-classes [1973 (✚),1980 (▲), 1985 (◆), 1988(✖), 2003(▼)] analyzed to document the species' recruitment dynamics and patterns; these individuals are divided into 18 samples (17 *S. fasciatus* + 1 *S. mentella*), by age and area, in the genetic tree (see panel d); (c) 20 samples that include 770 juveniles from the abundant 2011 (★) and 2012 year-classes (☆), analyzed to determine the composition of the original population. Histograms illustrate the proportion of *S. fasciatus* (■) and *S. mentella* (■). In (d) the neighbour-joining tree was built based on calculated genetic distances between each pair of samples. The separation between the species is statistically supported 100%. Adult samples are identified with a label indicating their geographic origin (management unit) and their original name; the names of the main populations identified using adult samples are indicated. Juveniles are identified with symbols identical to those on maps b and c. For all figures, the colours illustrate the genetic identity of the samples differentiated based on 13 microsatellite loci.



Appendix 2. Frequency of variables of the data set used for the standardization of the catch per unit of effort of bottom trawls in unit 1 for commercial fishing activities carried out between May and October 1981-1994 and for the index fishery from 1998 to 2015, by A) year, B) month, C) division, D) region and E) size class of the boat.

A) By year

Year	Frequency	Percentage	Cumulative frequency	Cumulative percentage
1981	13	0.08	13	0.08
1982	36	0.23	49	0.31
1983	40	0.26	89	0.57
1984	40	0.26	129	0.83
1985	972	6.22	1101	7.04
1986	1687	10.79	2788	17.84
1987	1259	8.06	4047	25.89
1988	744	4.76	4791	30.65
1989	1058	6.77	5849	37.42
1990	702	4.49	6551	41.92
1991	752	4.81	7303	46.73
1992	1055	6.75	8358	53.48
1993	1133	7.25	9491	60.73
1994	806	5.16	10297	65.88
1995	2	0.01	10299	65.9
1998	27	0.17	10326	66.07
1999	639	4.09	10965	70.16
2000	475	3.04	11440	73.2
2001	593	3.79	12033	76.99
2002	582	3.72	12615	80.72
2003	492	3.15	13107	83.86
2004	425	2.72	13532	86.58
2005	423	2.71	13955	89.29
2006	410	2.62	14365	91.91
2008	114	0.73	14496	92.75
2009	311	1.99	14807	94.74
2010	287	1.84	15094	96.58
2011	263	1.68	15357	98.26
2012	152	0.97	15509	99.23
2013	65	0.42	15574	99.65
2014	8	0.05	15582	99.7
2015	47	0.3	15629	100

B) By month

Month	Frequency	Percentage	Cumulative frequency	Cumulative percentage
5	828	5.3	828	5.3
6	2918	18.67	3746	23.97
7	4912	31.43	8658	55.4
8	3364	21.52	12022	76.92
9	2128	13.62	14150	90.54
10	1479	9.46	15629	100

C) By division (31 data missing)

Division	Frequency	Percentage	Cumulative frequency	Cumulative percentage
41	4793	30.73	4793	30.73
42	4233	27.14	9026	57.87
43	6282	40.27	15308	98.14
44	290	1.86	15598	100

D) By region

Region	Frequency	Percentage	Cumulative frequency	Cumulative percentage
1	2802	17.93	2802	17.93
2	2016	12.9	4818	30.83
3	50	0.32	4868	31.15
4	8604	55.05	13472	86.2
5	2157	13.8	15629	100

E) By size class of boat (8 data missing)

Size class of boat	Frequency	Percentage	Cumulative frequency	Cumulative percentage
2	6816	43.63	15621	100

Appendix 3. Results of the standardization (GLM proc.) of catch per unit effort of bottom trawls in Unit 1 in the commercial fishery between May and October (1981–1994) and the index fishery (1998–2015).

GLM Procedure

Class Level Information

Class	Level	Value
Year	33	1981 to 2015
Month	6	5 6 7 8 9 10
Division	4	41 42 43 44
Region	5	1 2 3 4 5
Bclass	1	1 2

Number of observations read	15663
Number of observations used	15543

Catch rate log regression with categories

GLM Procedure

Dependant variable:	CPUElog	Catch rate log			
Source	DL	Sum of squares	Mean of squares	Value of F	RP > F
Model	45	14962.8263	332.50725	176.21	<.0001
Error	15497	29242.00692	1.88695		
Corrected total	15542	44204.83322			

R-squared	Coeff. Var.	SSM root	Mean CPUElog
0.338488	-138.9523	1.373662	-0.988585

Source	DL	Type III SS	Mean of squares	Value of F	RP > F
Month	5	208.001485	41.600297	22.05	<.0001
Div	3	416.705536	138.901845	73.61	<.0001
Region	4	224.894706	56.223677	29.8	<.0001
Bclass (boat class)	1	1557.446476	1557.446476	825.38	<.0001
Years	32	6618.582507	206.830703	109.61	<.0001

Parameter	Estimated	Error	Value of t	RP > |t|
Intercept	-1.360630992 B	0.23010993	-5.91	<.0001
Month 5	-0.622647060 B	0.07204031	-8.64	<.0001
Month 6	-0.167311548 B	0.04708453	-3.55	0.0004
Month 7	-0.004523391 B	0.04351722	-0.1	0.9172
Month 8	-0.037404440 B	0.04447634	-0.84	0.4004
Month 9	0.004578877 B	0.04720847	0.1	0.9227
Month 10	0.000000000 B			
Div 41	0.164128005 B	0.10577528	1.55	0.1208
Div 42	-0.106758485 B	0.10798473	-0.99	0.3229
Div 43	-0.309576902 B	0.10802495	-2.87	0.0042
Div 44	0.000000000 B	.	.	.
Region 1	-0.184465591 B	0.04791251	-3.85	0.0001

Parameter		Estimated	Error	Value of t	RP > |t|
Region	2	0.074731902 B	0.0480037	1.56	0.1195
Region	3	-0.023264650 B	0.27742178	-0.08	0.9332
Region	4	-0.280067198 B	0.03951957	-7.09	<.0001
Region	5	0.000000000 B			

Catch rate log regression with categories
GLM Procedure

Dependant variable: CPUElog Catch rate log

Parameter		Estimated	Error	Value of t	RP > |t|
Bclass	1	0.994093847 B	0.03460195	28.73	<.0001
Bclass	2	0.000000000 B	.	.	.
Year	1981	1.156364390 B	0.51216781	2.26	0.024
Year	1982	0.839672232 B	0.31611313	2.66	0.0079
Year	1983	0.770005985 B	0.31538922	2.44	0.0146
Year	1984	0.564985705 B	0.3094112	1.83	0.0679
Year	1985	0.608369072 B	0.20865491	2.92	0.0036
Year	1986	0.384618500 B	0.20644054	1.86	0.0625
Year	1987	0.130794837 B	0.20656019	0.63	0.5266
Year	1988	0.219149843 B	0.20909707	1.05	0.2946
Year	1989	0.444320274 B	0.20570478	2.16	0.0308
Year	1990	0.918983767 B	0.20819919	4.41	<.0001
Year	1991	0.687044821 B	0.20768356	3.31	0.0009
Year	1992	0.953391267 B	0.20593504	4.63	<.0001
Year	1993	0.830953018 B	0.20602272	4.03	<.0001
Year	1994	-0.070913232 B	0.20806034	-0.34	0.7332
Year	1995	0.563021032 B	0.99284778	0.57	0.5707
Year	1998	0.364307857 B	0.33252196	1.1	0.2733
Year	1999	-1.305676257 B	0.20868276	-6.26	<.0001
Year	2000	-1.631539475 B	0.21101689	-7.73	<.0001
Year	2001	-1.347899651 B	0.2089893	-6.45	<.0001
Year	2002	-0.761353118 B	0.20954061	-3.63	0.0003
Year	2003	-1.137558441 B	0.21045588	-5.41	<.0001
Year	2004	0.379485122 B	0.21230723	1.79	0.0739
Year	2005	0.224347673 B	0.21210192	1.06	0.2902
Year	2006	0.504032154 B	0.21211994	2.38	0.0175
Year	2007	0.249430804 B	0.3902063	0.64	0.5227
Year	2008	0.301043383 B	0.23905057	1.26	0.2079
Year	2009	0.215674930 B	0.21542215	1	0.3168
Year	2010	0.311942007 B	0.21664899	1.44	0.1499
Year	2011	0.101747936 B	0.21804765	0.47	0.6408
Year	2012	0.356892524 B	0.22999905	1.55	0.1208
Year	2013	0.420801186 B	0.26388514	1.59	0.1108
Year	2014	0.382883984 B	0.52580979	0.73	0.4665
Year	2015	0.000000000 B	.	.	.

Catch rate log regression with categories
GLM Procedure
Mean of least squares

Month

	CPUElog LSMEAN	Standard error	RP > |t|
5	-1.43100747	0.07666149	<.0001
6	-0.97567196	0.06639092	<.0001
7	-0.8128838	0.06500407	<.0001
8	-0.84576485	0.06698924	<.0001
9	-0.80378153	0.06966635	<.0001
10	-0.80836041	0.07245051	<.0001

Division

	CPUElog LSMEAN	Standard error	RP > |t|
41	-0.71906515	0.06014737	<.0001
42	-0.98995164	0.06181719	<.0001
43	-1.19277006	0.06070201	<.0001
44	-0.88319316	0.11487078	<.0001

Region

	CPUElog LSMEAN	Standard error	RP > |t|
1	-1.04809749	0.05658413	<.0001
2	-0.7889	0.06017503	<.0001
3	-0.88689655	0.26330289	0.0008
4	-1.1436991	0.05201046	<.0001
5	-0.8636319	0.05732673	<.0001

Bclass

	CPUElog LSMEAN	Standard error	RP > |t|
1	-0.44919808	0.06376875	<.0001
2	-1.44329193	0.0630886	<.0001

Year

	CPUElog LSMEAN	Standard error	RP > |t|
1981	0.00923077	0.44098585	0.9833
1982	-0.30746138	0.23223951	0.1856
1983	-0.37712763	0.22480591	0.0935
1984	-0.58214791	0.22144413	0.0086
1985	-0.53876454	0.07995171	<.0001
1986	-0.76251511	0.07238187	<.0001
1987	-1.01633878	0.07341059	<.0001
1988	-0.92798377	0.07712369	<.0001
1989	-0.70281334	0.07214919	<.0001
1990	-0.22814985	0.07833197	0.0036
1991	-0.46008879	0.0770843	<.0001
1992	-0.19374235	0.07253399	0.0076

	CPUElog LSMEAN	Standard error	RP > |t|
1993	-0.3161806	0.07311838	<.0001
1994	-1.21804685	0.07761153	<.0001
1995	-0.58411258	0.97449343	0.5489
1998	-0.78282576	0.27196802	0.004
1999	-2.45280987	0.08287955	<.0001
2000	-2.77867309	0.0888808	<.0001
2001	-2.49503327	0.08459446	<.0001
2002	-1.90848673	0.08409608	<.0001
2003	-2.28469206	0.08770153	<.0001
2004	-0.76764849	0.0917032	<.0001
2005	-0.92278594	0.09174372	<.0001
2006	-0.64310146	0.09242174	<.0001
2007	-0.89770281	0.34043831	0.0084
2008	-0.84609023	0.14377891	<.0001
2009	-0.93145868	0.10017723	<.0001
2010	-0.83519161	0.10260949	<.0001
2011	-1.04538568	0.10602463	<.0001
2012	-0.79024109	0.12893484	<.0001
2013	-0.72633243	0.18267704	<.0001
2014	-0.76424963	0.49004828	0.1189
2015	-1.14713362	0.20998842	<.0001

The standard category is defined as follows:

Month=	7
Div=	41
Region=	4
Bclass=	2

In this year	The predicted catch rate is	With a standard error of
1981	2.029199	0.907429
1982	1.603552	0.388744
1983	1.495879	0.361716
1984	1.220958	0.285835
1985	1.308728	0.085654
1986	1.046728	0.062449
1987	0.81206	0.048802
1988	0.886652	0.059882
1989	1.111198	0.065024
1990	1.785567	0.115066
1991	1.416328	0.085142
1992	1.849261	0.099107
1993	1.636055	0.089497
1994	0.663589	0.042059
1995	0.780658	0.61075
1998	0.99137	0.260624
1999	0.193025	0.012476
2000	0.139267	0.010137
2001	0.185062	0.011689
2002	0.33259	0.02265
2003	0.228288	0.015869

In this year	The predicted catch rate is	With a standard error of
2004	1.040138	0.079979
2005	0.890838	0.066259
2006	1.178087	0.090713
2007	0.86556	0.283269
2008	0.955889	0.127599
2009	0.882466	0.074151
2010	0.971351	0.084984
2011	0.786955	0.071681
2012	1.012949	0.118239
2013	1.070882	0.185012
2014	0.929723	0.427211
2015	0.699148	0.140882

Appendix 4. Estimated von Bertalanffy growth parameters and average length at age 8 for *Sebastes mentella* (values underlined are those used for analysis of growth prospects for recent cohorts).

Source	$\mathbf{L_{infini}}$	**k**	$\mathbf{t_0}$	**Length at age 8 (cm)**	**Origin of fish**	**Sex**
Duplisea et al. 2016	42.0	0.086	-1.57	23.6	Units 1 and 2	undetermined
Duplisea et al. 2016	36.5	0.153	0.07	25.7	Units 1 and 2	undetermined
Duplisea et al. 2016	57.0	0.040	-4.08	21.8	Units 1 and 2	undetermined
Saborido-Rey et al. 2004	43.2	0.107	-1.07	26.9	Flemish Cap	male
Saborido-Rey et al. 2004	45.8	0.096	-1.28	27.0	Flemish Cap	female
Stransky et al. 2005	39.3	0.078	-6.80	26.9	Irminger Sea	undetermined
Campana et al. 2016	40.2	0.054	-11.00	25.8	Unit 1	undetermined
Campana et al. 2016	40.6	0.047	-17.00	28.1	3LN	undetermined
Campana et al. 2016	39.6	0.138	–2.00	29.6	2J3K	undetermined
Mean	42.7	0.1	-5.0	26.1		
CV	0.140	0.443	-1.147	0.089		