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Redfish (*Sebastes mentella* and *S. fasciatus*) stocks status in Unit 1 in 2017

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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

Redfish fishing in the Gulf of St. Lawrence (Unit 1) targets two species, *Sebastes mentella* and *S. fasciatus*. Between the mid-1950s and 1993, the fishery was marked by three 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 establishment of a moratorium in 1995. Redfish fishing is still under a moratorium in Unit 1 and an index fishery has been authorized since 1998. Total allowable catch (TAC) for this fishery is 2,000 tons per management year since 1999.

According to surveys conducted in the Gulf of St. Lawrence, abundance and biomass indices for *Sebastes mentella* and *S. fasciatus* were low and stable since the mid-1990s. Juvenile Redfish abundance from the 2011 to 2013 cohorts has increased dramatically in research surveys. These cohorts are the most abundant ever observed. These individuals are largely dominated by *S. mentella* and show the genetic signature of the Units 1 and 2 adult population. In the summer 2017, the 2011 to 2013 Redfish cohorts' modal size was 20 cm. If the anticipated growth of these cohorts continues, close to 50% of the individuals (59% biomass) of the 2011 cohort should be larger than 22 cm in 2018, the minimum regulatory size. By 2020, 51% of the individuals of the cohort (62% biomass) should be larger than 25 cm. In Unit 1, total minimum trawlable biomass of Redfish greater than 22 cm in length began to increase in 2017. It was estimated to be 349,000 tons and 89,000 tons for *S. mentella* and *S. fasciatus*, respectively. However, biomass of Redfish greater than 25 cm in length has not yet started to increase in survey. By 2019, biomass of Redfish greater than 25 cm is expected to increase substantially. Prospects for Redfish stocks are extremely positive. The strong recruitment and biomass increase may allow higher catches of *S. mentella* in Unit 1 by 2018, while it is preferable to remain cautious for *S. fasciatus*.

In support of the Redfish stock assessment survey (*S. mentella* and *S. fasciatus*) of Units 1 and 2 in 2017, 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.

INTRODUCTION

Two Redfish species are present in Unit 1 namely: Deepwater Redfish (*Sebastes mentella*) and Acadian Redfish (*S. fasciatus*). Occasionally, Golden Redfish (*S. norvegicus*) are found, but since it is rare in the region (Nozères et al. 2010), it will not be discussed in this document. These two species are members of the Scorpenidae family and are difficult to differentiate morphologically. Although conservation objectives are species-specific, the fishing industry regards *S. mentella* and *S. fasciatus* as a single entity.

In the late 1950s, a Redfish directed fishery was developed in the Gulf of St. Lawrence and the Laurentian Channel outside the Gulf. Prior to 1993, the Redfish fishery was managed as three Divisions established by the Northwest Atlantic Fisheries Organization (NAFO): Divisions 4RST, Division 3P and Divisions 4VWX. In 1993, these management Units were redefined to provide a stronger biological basis and take various factors into account, including the winter migration to the Cabot Strait area of the Gulf Redfish stocks. The resulting management Units were divided as follows: Unit 1 included Divisions 4RST and Subdivisions 3Pn4Vn from January to May; Unit 2 included Subdivisions 3Ps4Vs, Subdivisions 4Wfgj, and Subdivisions 3Pn4Vn from June to December; and Unit 3 included Subdivisions 4WdehklX (Figure 1). Genetic studies have demonstrated that only one biological entity of *S. mentella* and *S. fasciatus* resides in Units 1 and 2 (Roques et al. 2002, Valentin 2006).

The Redfish fishery in the Gulf of St. Lawrence was marked by three intense exploitation episodes (1954-56, 1965-1976, and 1987-1992). Bottom and midwater trawls, especially in the early 1990s, were the most common fishing gear. In Unit 1, the Redfish stocks total allowable catches (TACs), established under the management modality defined in 1993, were 60,000 t. After rapid landings decrease in 1993 and 1994, a moratorium was declared in Unit 1 in 1995. An index fishery started in 1998 with a 1,000 t TAC. Since 1999, the TAC has been maintained at 2,000 t. Presently, Redfish conservation measures for the fishery include: implementation of a protocol for protecting small fish (< 22 cm), 100% dockside monitoring, mandatory hail reports upon departure and arrival, imposition of a level of coverage by at-sea observers and, implementation of a bycatch protocol. Closure periods were also introduced, 1) to protect Redfish copulation (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 Atlantic Cod spawning (Divisions 4RS). In addition, since the index fishery was introduced in 1998, fishing is allowed only between longitudes 59° and 65° at depths > 182 m (100 fathoms), and to avoid Greenland Halibut bycatch, an area has been closed in Division 4T since August 2009.

In 2010, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Deepwater Redfish (*S. mentella*) as endangered and Acadian Redfish (*S. fasciatus*) as threatened. 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). According to 2010 estimates, Duplisea et al. 2012 established reference points and concluded that spawning stocks of *S. mentella* and *S. fasciatus* of Units 1 and 2 were in the critical zone, under their respective limit reference points.

Redfish recruitment success is highly variable, with large year classes being produced at irregular intervals (5-12 years). The 1980 cohort was the last important cohort in Unit 1 until three cohorts arrived in 2011, 2012 and 2013. The prospects for the Unit 1 Redfish stocks are very encouraging in the short term given these strong cohorts. These fish would begin to considerably recruit to the fishery from 2018 to 2020, which could lead to a rapid increase of Redfish biomass available to the fishery. In fact, the abundance of juvenile Redfish, largely dominated by *S. mentella*, has increased massively in research surveys since 2013. In the northern Gulf of St. Lawrence in 2017, the abundance of *S. mentella* and *S. fasciatus* juveniles were 230 times and 4 times higher than their respective average abundances for the period 1993-2012. The first strong cohort, that of 2011, had a modal size of 17 cm in the summer of 2015 and 20 cm in the summer of 2017. If the anticipated growth of these cohorts continues, close to 50% of the individuals (59% biomass) of the 2011 cohort should be larger than 22 cm in 2018, the minimum regulatory size. By 2020, 51% of the individuals of that cohort (62% biomass) should be larger than 25 cm.

The peer review in conjunction with the Redfish stock assessment (*S. mentella* and *S. fasciatus*) of Units 1 and 2 in 2017 took place on March 14-15th, 2017. In support of this report (MPO 2018a), 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 2017 (Brassard et al. 2017)

BACKGROUND

SPECIES IDENTIFICATION

Traditionally, *S. mentella* and *S. fasciatus* have been assessed as "*Sebastes spp.*" 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 (approximatively 10 dollars per individual) and logistically challenging, which restricts their use for monitoring specific composition of catches at a large scale.

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. *S. fasciatus* usually has the homozygous genotype *MDH-A*22,* an EGM between ribs 3 and 4, and an AFC ≤ 7 (Gascon 2003). These three criteria (AFC, EGM, and *MDH-A**) were used to describe the species geographic range 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 (*i.e.,* deep valley in the southern part of Unit 2), 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).

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. mentella and S. fasciatus* (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, stock assessment in Units 1 and 2 was performed by species for the first time. Systematic species identification based on AFC (DFO 2010) was conducted for research surveys, but not for commercial catches. Although AFC 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, this criterion was selected as a practical, economical alternative to genetic analysis for estimating catches specific composition. 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.

STOCK GENETIC 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 (Figure 2). The results suggest that Units 1 and 2 correspond to a single population of *S. mentella* (red tags, Figure 2), 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, Figure 2). 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, Figure 2). 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, Figure 2), 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, Figure 2). 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, Figure 2), 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).

DISTRIBUTION AND HABITAT

Redfish inhabit cold waters along the slopes of banks and deep channels at depths ranging from 100 to 700 m. *S. mentella* is typically found in deeper waters than *S. fasciatus*. 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) where it inhabits deeper waters. Redfish generally live near the bottom. 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. Vertical migration appears to be a feeding strategy in which Redfish follow the migration of their prey such as krill. Annual migrations are also observed. Logbook data suggest Redfish migrations back and forth from the Gulf to the Cabot Strait. These migrations appear to begin in mid-November southward and in mid-April northward. Redfish cluster together to form an increasingly dense concentration in 4Vn and 4Vs throughout April, at about the same time as the northward migration towards the Gulf. This concentration persists at a high density until the end of June. Another aggregation is formed at the limit of 3Pn and 3Ps in mid-September; it disperses as early as mid-October, just before the southward migration towards the Cabot Strait (Gascon 2003, Figure 1).

GROWTH AND REPRODUCTION

Redfish are slow-growing and long-lived species. Indeed, Redfish can easily reach 40 years and can exceed 75 years of age, at which point it measures about 42 cm. On average, Redfish take seven to eight years to reach minimum legal catch size of currently 22 cm. Growth of *S. mentella* is faster than *S. fasciatus*, although this difference in growth rates only becomes evident after the age of ten. In both species, females grow faster than males at about ten years of age. Males *S. mentella* mature at 9 years (L50: 22.8 cm) and females at 10 years (L50: 25.4 cm), whereas males *S. fasciatus* mature at 7 years (L50: 19.6 cm) and females at 9 years (L50: 24.1 cm).

Redfish are ovoviviparous, it conducts internal fertilization and fertilization, resulting in lecithotrophic larvae, feeding exclusively on the yolk of the egg. Copulation takes place in the fall, most probably between September and December. 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). Absolute fecundity is ranging from 3 330 to 107 000 larvae per female and increases with female size (Gascon 2003). 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*. Larvae develop in surface waters and the young migrate gradually deeper during their development. Larvae 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 shallower 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).

Redfish recruitment success is highly variable, with large year-classes being produced at irregular intervals, for example in Unit 1: 1946, 1956-1958, 1970, 1980, 1985, 1988, 2003, and 2011-2013. In addition, the 1985, 1988, and 2003 year-classes, which were very abundant at ages 2 to 4 in research survey data, were not subsequently detected and never considerably contributed to the fishery, potentially because they bore the genetic signature of the populations of the Grand Banks of Newfoundland where they returned subsequently. If we assume that the quantities of larvae released are similar from one year to the next, different mortality must therefore occur between their extrusion and the moment they are one year old. On the Flemish Cap (area about 140 m deep in 3M NAFO Division), Redfish larvae feed mainly on copepod immature stages, *Calanus finmarchicus* (Runge and de Lafontaine 1996). Growth was faster, and metamorphosis occurred earlier in 1980, when there was a close match between Redfish larvae hatching and *Calanus finmarchicus* spawning, compared to 1981 when the hatching of *Calanus* occurred 7 weeks earlier (Anderson 1994). The production of an abundant year-class may depend on a close correspondence between the predator and its prey. Other possible factors affecting survival during the pelagic phase are unknown. For example, the presence of abundant Redfish year classes may coincide with particular climatic conditions, which may affect not only the environment physical conditions where the larvae are released, but also the quantity and quality of their preferred prey.

RECRUITMENT

In the Northwest Atlantic, Redfish are characterized by significant variability in recruitment. Genetic analysis results indicated that around 1980, Units 1 and 2 produced the last strong year-class of *S. mentella* that greatly contributed to the fishery afterwards. Until 2011, all other strong year-classes found in Units 1 and/or 2 (1974, 1985, 1988, and 2003) were identified as *S. fasciatus* with the genetic signature of the Atlantic population of the continental shelf break. Consequently, these *S. fasciatus* year-classes, which seemed strong in their early stages, particularly in Unit 1, decreased significantly within a few years without contributing significantly to adult populations and the fishery. Ocean currents and aged-based spatial and temporal abundance trends suggest that this *S. fasciatus* population uses the Gulf of St. Lawrence as a nursery. The larvae/juveniles apparently drifted to the Gulf of St. Lawrence, and 5 to 6 years later the older juveniles returned to the Atlantic population of the continental shelf break.

The most recent DFO research surveys indicated that there were three abundant Redfish year-classes in Unit 1, the 2011, 2012 and 2013 cohorts. Genetic analyses performed on the 2011 and 2012 cohort indicated that 91% of these fish belonged to the *S. mentella* species within the adult population of Units 1 and 2. This information suggested that these Redfish will remain in the area and should promote the recovery of *S. mentella* in Units 1 and 2. Juvenile Redfish abundance from the 2011 to 2013 cohorts has increased dramatically in both DFO (Unit 1) and Groundfish Enterprise Allocation Council (Unit 2) research surveys. These cohorts are the most abundant ever observed in the research surveys in Units 1 and 2.

ECOSYSTEM

Fisheries and Oceans Canada annually assesses the physical oceanographic conditions prevailing in the Gulf of St. Lawrence with the Atlantic Zone Monitoring Program (AZMP). Conditions encountered in the northern Gulf from 2011 to 2017 were generally warmer than historical averages, particularly for surface and deep-water temperatures. Deep-water temperatures in the Gulf have been increasing in recent years. Overall, temperatures at 250 and 300 m have reached a series high since 1915. The bottom area covered by waters warmer than 6°C decreased in 2016 in Anticosti Channel and Esquiman Channel, but increased sharply in Central Gulf and made its first appearance in the northwest Gulf (Galbraith et al. 2017).

The Gulf of St. Lawrence ecosystem is composed of a diverse fish community whose abundance varies over time and space. For example, the various Herring stocks are declining (DFO 2016a, DFO 2017a) and the Mackerel stock is a record low level (DFO 2017b). The indicators of Greenland Halibut (4RST) stock decreased in 2017 (DFO 2018b), while Atlantic Halibut (4RST) is at its highest historical and stable level since 2013 (DFO 2018c). The Atlantic Cod stock in the southern Gulf of St. Lawrence (4T) is very low but stable (DFO 2016b), whereas the northern Gulf (3Pn, 4RS) is also low, but slightly increasing (DFO 2017c). The Northern Shrimp stock in the Estuary and Gulf of St. Lawrence has been in the healthy zone for several years, but is declining since 2010 (DFO 2018d).

COMMERCIAL FISHERY

HISTORY

The Redfish fishery in the Gulf of St. Lawrence has been characterized by three episodes of high landings (1954-56, 1965-1976, and 1987-1992 (Table 1 and Figure 2). The Redfish history is described based on the Zonal Interchange Format File (ZIFF) and considers all fisheries directed or not towards Redfish. From 2000 to 2017, 91% of the reported Redfish catches came from the directed Redfish fishery. Average annual landings were 43,000, 79,000, and 59,000 tons for each of these respective periods, while TACs ranged from 16,000 to 60,000 tons (first TAC was put in place in 1976). The maximum annual landings value was observed in 1973, when 136,101 tons of Redfish were landed (Table 1 and Figure 3). These landings represent the sum of reported Redfish catches in all types of fisheries, whether directed to Redfish or not. Prior to 1999, Redfish management cycle was from January 1 to December 31 and the TAC was allocated for this period. In 1999, the management cycle continued until May 14, 2000 and from May 15th of the current year to May 14th of the following year. The TAC is established for a management cycle.

In 1995, a moratorium on the Unit 1 Redfish fishery was introduced due to low stock abundance and lack of sufficient recruitment. From 1995 to 1997, Redfish landings were reduced and were associated to fisheries directed to other species. An index fishery began in 1998 with a TAC of 1,000 tons that increased to 2,000 tons in 1999. This index fishery takes place between June 15 and October 31 for a management cycle that runs from May 15th to May 14th of the following year. It is carried out on traditional fishing grounds using bottom trawls similar to those used before the moratorium, between longitudes 59° and 65° at depths over 182 meters (100 fathoms) with 90 mm minimum mesh size (Brassard et al. 2017). From 1999 to present, the TAC for this fishery has remained at 2,000 tons per management year. However, TACs in Unit 1 are not fully harvested. On average, since 2003, 550 tons of Redfish are caught annually (Table 1).

From 1953 to 1990 (prior to the moratorium), landings came mainly from NAFO Divisions 4R and 4S (Table 1 and Figure 2). Between 1999 and 2005, 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, efforts were directed in Division 4S of the Laurentian Channel. Since 2006, the majority of the index fishery effort was concentrated in Division 4T (Table 1 and Figure 4). Since 2012, an annual Redfish landing decrease was observed, reaching only 192 tons in 2017 (preliminary data, Table 1 and Figure 3).

Traditionally, substantial Redfish landings have been observed year-round (Figure 5). From 1985 to 1992, there was an increase in winter (month of January to March) landings from 5% in 1985 to 45% in 1992 (Figure 5). These landings came mainly from Divisions 3Pn and 4R. Since the moratorium, the majority of Redfish are caught in summer during the indicator fishery, which runs from June 15th to October 31st. Small quantities of Redfish are also caught outside of the index fishery season, as bycatch of fisheries directed to other species.

From 1985 to 1994, Redfish were mainly caught using bottom and midwater trawls. Several vessels used the Diamond 6 sides' midwater trawl, equipped with Suberkrüb midwater panels, and made of braided nylon. Since the 1995 moratorium, the midwater trawl fleet is no longer present in the Gulf and therefore does not participate in the index fishery. From 1998 to 2006, the majority of fishing effort was conducted using bottom trawls, and since 2007, there has been a sharp increase in the proportion of catches by Scottish seines (Figure 6). These two gears have 90 mm minimum mesh size. In 2017, some research projects were initiated to reintroduce the midwater trawl into Unit 1 Redfish fishery. This gear is considered to be minimally invasive for fish habitat, as there is no or little contact with the seabed.

From 1985 to 1994, approximately 80% of the catches were made using large vessels over 100 feet in length (Figure 7). After the moratorium, vessels between 65 to 100 feet took the majority of the catches. During this period, vessels of less than 65 feet appeared in Unit 1. Since the 2000s, vessels measuring from 65 to 100 feet in length have become more important in the Redfish fishery (Figure 7).

SIZE FREQUENCY

From 1981 to 1988, commercial catch size frequency in Unit 1 indicated that catches primarily consisted of Redfish born in the early 1970s. From 1988 to 2008, catches predominantly consisted of Redfish born in the early 1980s (Figure 8). From 1999 to 2016, most Redfish caught were larger than 30 cm. Since 1999, commercial catch size frequency has been more difficult to establish because landings have dropped significantly (especially since 2006). As a result, fewer Redfish were measured by at-sea observers and through DFO sampling programs. However, it appears that the 1980 year-class began to be recruited to the fishery in 1987 and remained in catches to date.

CATCH PER UNIT EFFORT (CPUE)

Following the recommendation of the Fisheries Resource Conservation Council aiming at addressing the lack of Redfish data with the 1995 moratorium, an index fishery was established in 1998. The information obtained within the framework of this fishery by logbooks gathered by fishermen, the at-sea observer program and the DFO's commercial catch sampling program consists of data on landings, fishing effort, bycatch, and the Redfish catches size frequency. When it launched in 1998, the index fishery was carried out by two groups of vessels using bottom trawls; vessels over 100 feet and vessels under 65 feet. The number of participants in each of these groups has varied over the years. Prior to 2007, between 1 and 5 vessels over 100 feet participated in the index fishery. Subsequently, no vessels from this group took part, except for one in 2010. For vessels from the under 65 feet group, between 6 and 13 vessels have taken part in this fishery annually, with the exception of 2007 when there was only one vessel (Brassard et al. 2017). This low rate of participation came from an external problem, so the 2007 data are not included in the index.

Catch rates from commercial fishery (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. The fishing events retained for this analysis are conducted with a bottom trawl between May and October. These data represent on average over 85% of the landings associated with directed Redfish fishery using bottom trawls in Unit 1. This standardization takes into account changes in the fishing season (months), NAFO divisions, and vessels size. This model weighs the effect of these factors, making the CPUEs comparable across years. This index shows high CPUEs prior to the moratorium, followed by a marked decrease in 1994 (Figure 9). Between 1999 and 2003, the index was below the average of the series (1981-2017). From 2003 to 2014, CPUE were quite stable and comparable to the average. Based on the main stakeholder input, management measures, market conditions, small Redfish size and moratorium impact limited fishing effort in the past few years in Unit 1

BYCATCH

Although commercial fishing attempts to maximize the capture of the target species, bycatch of other species than the target one is often captured. Two data sources have been combined to provide an overall picture of bycatch: the ZIFFs and the at-sea observer program. ZIFFs provide complete information on total reported landings. The at-sea observer program covers a certain percentage of fishing trips and therefore provides partial information on bycatch. However, this program is the only source of data on discarded at sea catches which are not counted in ZIFF files. In addition, this program provides information on the size of the fish caught and the data are associated with specific fishing activities, either a trawl set or the lifting of a fixed gear.

On the one hand, based on ZIFFs, Redfish catches reported in fisheries directed to other commercial fisheries conducted in Unit 1 from 2000 to 2017 were examined using dockside monitoring program. This analysis revealed that 91% of the reported Redfish catches came from the directed Redfish fishery. Fisheries targeting Greenland Halibut and Atlantic Cod were responsible for 3% and 2% of Redfish landings, respectively (Figure 10). On the other hand, from 2000 to 2017, bycatch landings in the directed Redfish fishery using mobile bottom gears represented 9% of Redfish landings (Figure 11). The most common bycatch were Greenland Halibut, White Hake, and Atlantic Cod (Figure 12).

From 1999 to 2016, 1 633 fishing activities were sampled by the at-sea observer program (Figure 13). The most frequent bycatch species were Greenland Halibut (caught in 73% of fishing activities directed to Redfish), White Hake (58%), Witch Flounder (41%), and Atlantic Cod (38%, Table 2). Between 84 and 100% of those species catches was landed. For each bycatch species, catches represented less than 5% of Redfish catches (Table 2). Knowing spatio-temporal distribution and depth preferences of these species, as well as improving gear selectivity, can help to reduce the occurrence of bycatch in Redfish fishery.

Spatial distribution of redfish and bycatch catch rates in the Redfish directed fishery from 1999 to 2016 has been mapped (Figure 14). These maps could be used to identify locations to avoid, minimizing bycatch in the Redfish directed fishery. For example, West of the 64° parallel, catch rates of Greenland and Atlantic Halibut are high, while Redfish catch rates are among the lowest. Specific depths may also be prescribed to target and avoid certain species. For instance, White Hake and Atlantic Cod are caught at a shallower depth than Redfish (Figure 15 and Table 3). At-sea observers also measure fish length in Redfish directed fishery. From 1999 to 2016, Redfish measured from 15 to 50 cm (mode = 30 cm), Greenland Halibut from 25 to 65 cm (mode = 40 cm), White Hake from 25 to 75 cm, the Atlantic Cod from 25 to 80 cm (mode = 40 cm), and Atlantic Halibut from 15 to 165 cm (Figure 16).

TRAWLS SELECTIVITY

Fishing gear selectivity is an important feature since it contributes substantially to targeting certain species and organisms sizes. Trawl selectivity can be influenced by several criteria, including the position of the gear in the water column, the size and shape of the mesh, the materials used, or the presence of a sorting grid. What will actually be harvested by a fishing gear is also dependent on the organisms available for fishing at a given place and time. From 1987 to 1994, midwater trawl was used extensively in Redfish fishery, but has become less prevalent since the moratorium, unlike the bottom trawl which has persisted over time. These two fishing gear codend have a minimum mesh of 90 mm. Recently, the interest in midwater trawls has been renewed, mainly because there is no (or very little) contact between the fishing gear and the seabed, which makes it a method of choice to minimize the impact on habitat and benthic organisms.

In order to assess the selectivity of these two types of trawl, in terms of Redfish size, size frequency of data collected by at-sea observers during 7 489 fishing activities in Units 1 and 2 from 1978 to 2016 have been analyzed. Raw data are shown in Figure 17 and suggest that, based on the mode of the two size frequency distributions, bottom trawls would catch larger individuals than the midwater trawl. Redfish catches size frequencies were quantified using five quantiles (Q10, Q25, Q50, Q75, and Q90). Quantile distributions were normally distributed and homoscedastic, therefore, an analysis of variance (ANOVA) was used (Scherrer 2007). The effect of a triple interaction between trawl type, Unit, and year was tested for each quantiles. A backward selection of the ANOVA factors was performed by excluding the non-significant factors one at a time in order to retain only significant factors in the ANOVA. The difference percentages between trawl types and Units were calculated (i.e., ANOVA coefficients ratios between trawl, midwater versus bottom, and Units, Unit 1 versus Unit 2, Table 4).The models obtained for each quantile were highly significant (p.value = 2.2E-16) and explained between 22 and 25% of the variance. Significant interactions were identified in all cases, suggesting that the effect of trawl type on captured Redfish size frequency varied by Unit and/or year. The effect of trawl types was not the same for all quantiles, indicating that Redfish caught by midwater trawl tended to be larger for smaller sizes (Q10, Q25, and Q50), while they were smaller for larger sizes (Q75 and Q90) compared to bottom trawl. Differences between trawl types were small, ranging from 0.3 to 5%, suggesting little gear effect on size frequency distribution of catches once differences between Units and years were considered. The effect of Units was also different depending on the quantiles. Redfish caught in Unit 1 were smaller for smaller sizes (Q10 and Q25) and larger for larger sizes (Q50, Q75, and Q90). Again, the magnitude of these differences was small (0.4 - 2%). The differences between years contributed most to the size variations of the fish caught.

A variation partitioning based on partial ANOVAs (Legendre and Legendre 2012) among trawl types, Units and years indicated that, by itself, the effect of years, independently of trawl types and Units, accounted for between 16 and 21% of the quantiles variance (Figure 18). The recruitment of different cohorts supporting the commercial fishery over time may explain these temporal variations. From 1981 to 1988 in Unit 1, the size frequency of commercial catches indicates that the catches were mostly Redfish born in the early 1970s. From 1989 to 1994, Redfish born in the early 1980s were the dominant catch in the fishery. From 1999 to 2015, the majority of Redfish caught were larger than 30 cm. Since 1999, size frequency is more difficult to establish because the fishery is very small (especially since 2006) and consequently, a smaller number of Redfish were measured by at-sea observers. However, it appears that the 1980 year-class, consisting mainly of *S. mentella,* began to recruit to the fishery in 1987 and has remained in catches to date. From 2006 to 2017, the contribution to the fishery of more recent year-classes is indicated by the presence of Redfish between 25 and 35 cm (Figure 8, Brassard et al. 2017). Overall, these results suggest that, in the Redfish fishery specific case, fish of similar size can be caught using bottom and midwater trawls, regardless of Units, depending on Redfish size classes available to the fishery during a given period.

DFO RESEARCH SURVEYS

Since 1984, DFO has conducted a multidisciplinary research survey (groundfish and shrimp) across the northern Gulf of St. Lawrence using a bottom trawl. The survey covers the waters of the Laurentian Channel and north of it, from the Lower Estuary in the west to the Strait of Belle Isle and the Cabot Strait in the east, namely, NAFO divisions 4R, 4S, and the northern part of 4T (Figure 1). The study area is 116 115 km^2. Over the years, different vessels and fishing gears have been used. From 1984 to 1990, research surveys were conducted aboard the vessel CCGS Lady Hammond using a Western IIA bottom trawl. From 1990 to 2005, the vessel CCGS Alfred Needler and a URI 81 '/ 114' bottom trawl were used. Finally, from 2004 to 2017, the vessel CCGS Teleost and a Campelen 1800 bottom trawl are utilized. All of these data (CCGS Lady Hammond, CCGS Alfred Needler, and CCGS Teleost) were compared to establish conversion factors and thus, extended the historical series of Redfish abundance and biomass indices from 1984 to 2017 (Bourdages et al. 2007). This research survey uses a stratified random sampling design. This technique involves subdividing the study area into more homogeneous strata. The study area is divided into 54 strata of which 52 have been visited each year. Delimiting strata was done based on depth, NAFO Divisions, and substrate type (Figure 19). For this survey, an initial allocation of 200 trawling stations was allocated proportionately to the strata surface area, with a minimum of two stations per stratum. The positions of the stations were determined randomly within each of the strata. For each station, the catch was sorted and weighed by taxon and biological data were collected on a Redfish sample: size, sex, anal fin soft rays number, stomach, otoliths, and tissue samples. A detailed description of the fishing and sampling protocol, and the calculation methods are presented in Bourdages et al. (2018).

In 2017, the survey took place from August 2nd to September 2nd aboard the vessel CCGS Teleost. During this mission, 170 tows were successful, 47 in 4R, 83 in 4S, and 40 in 4T. The study area coverage was very good, only two strata were not sampled with a minimum of two stations (Bourdages et al. 2018). It should be noted that this sampling plan includes Redfish distribution range in Divisions 4RST, which corresponds to Unit 1. The results are presented by species, *S. mentella* and *S. fasciatus*, for mature and immature individuals, or for different size classes.

MATURITY DETERMINATION

The relationship between maturity and length of an individual was determined from the data presented in Gascon (2003), where 434 individuals from Unit 1 and 983 from Unit 2 were collected between 1996 and 1999. Species, age, maturity stage, and length were recorded. The determination of the number of mature individuals of a given species is based on the proportion of mature fish at length by sex according to a logistic curve. For mature females of both species, the shortest length at maturity was around 23 to 24 cm. The length range of female reproducers for the 1996-1999 period was greater in the case of *S. mentella* than *S. fasciatus*. Indeed, while *S. mentella* females measured 24 to 47 cm in length, very few females of *S. fasciatus* were larger than 35 cm. In general, males reach sexual maturity one to two years before females. Males *S. mentella* mature at 9 years (L50: 22.8 cm) and females at 10 years (L50: 25.4 cm), whereas males *S. fasciatus* mature at 7 years (L50: 19.6 cm) and females at 9 years (L50: 24.1 cm).

During DFO surveys, a sample of individuals is measured (maximum 200 individuals), sexed (30 individuals), and species identification is based on the number of soft rays of the anal fin (see section Species identification for more details). The proportion of mature individuals by species and sex is determined from the sample and extrapolated to the entire catch.

The logistic equation of the curve is as follows :

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

The constants are:

S. fasciatus	female	*a* = -10.605	*b* = 0.441	*L50* = 24.1
S. fasciatus	male	*a* = -10.687	*b* = 0.545	*L50* = 19.6
S. mentella	female	*a* = -9.550	*b* = 0.377	*L50* = 25.4
S. mentella	male	*a* = -7.521	*b* = 0.330	*L50* = 22.8

These equations allow determining the mature fraction of the stock according to the length of the individuals that compose it, and thus inform, for example, the reference points stemming from the precautionary approach. It is recommended to update these equations since the data used date back to the 1990s and mature non-zero proportions are predicted for individuals smaller than the minimum size at which mature individuals were observed (Figure 20). Of course, any modifications to these equations could lead to variations in mature biomass estimates and stock status relatively to reference points. Therefore, size class estimates are also presented.

BIOMASS INDICES AND SIZE FREQUENCY

According to the DFO research survey in Unit 1, *S. mentella* and *S. fasciatus* abundance and biomass declined sharply from the late 1980s to 1994 (Figure 21 and Table 5). Subsequently, the indices of small and large Redfish remained low and stable. The new cohorts (2011-2013), mainly dominated by the 2011 year-class, started being caught by the research trawl in 2013, and biomass of juvenile Redfish (0-22 cm) has increased substantially since then. These juveniles were largely dominated by *S. mentella*, with the genetic signature of the adult population of the northern Gulf of St Lawrence. In 2017, total minimum trawlable biomass was estimated to be 2,166,000 t for *S. mentella*, the highest value observed since 1984. Total biomass of *S. fasciatus* estimated to be 346,000 t is of the same order of magnitude as the highest value since 1984. The biomass of juvenile *S. mentella* and *S. fasciatus* was 60 and 10 times higher, respectively, than their mean biomass for 1995-2015. Minimum trawlable biomass of Redfish greater than 22 cm in length began to increase in 2017. It was estimated to be 349,000 t and 89,000 t for *S. mentella* and *S. fasciatus*, respectively. However, biomass of Redfish greater than 25 cm in length has not yet started to increase in the survey. By 2019, biomass of Redfish greater than 25 cm is expected to increase substantially. In the summer 2017, Redfish modal size was 20 cm (Figure 22).

SPATIAL DISTRIBUTION

Redfish biomass (kg/tow) spatial distribution maps show a continuous distribution of Redfish between Units 1 and 2 along the Laurentian Channel to the head of the Esquiman, Anticosti, and Laurentian Channels in the Gulf of St. Lawrence (Figures 23-26). These maps indicate that *S. fasciatus* occupies shallower waters than *S. mentella*, with the exception of the Laurentian Fan area where *S. fasciatus* inhabits deeper waters. The spatial distribution of Redfish catch rates in the DFO survey indicated that between 1984 and 1995 the Laurentian, Esquiman and Anticosti Channels were densely populated by both species (Figures 23-26). Subsequently, there was a substantial decrease in the density of mature individuals in both Redfish species, in particular west of Anticosti Island and north of Esquiman (Figures 24 and 26). Immature *S. mentella* have shown an increase in density from 2011-2017, particularly in the Esquiman, Anticosti and Laurentian Channels, and the Southwestern edge of Cabot Strait. Immature *S. fasciatus* have also shown a recent increase in density (2011-2017), albeit less so than in *S. mentella*.

GROWTH PROJECTION

The current assessment is not based on a population model which makes projection of year class strength into the future difficult. Survey indices show a massive recruitment composed of the 2011, 2012, and 2013 year-classes. It is therefore expected that these year-classes will have a strong impact on abundance and biomass of mature individuals 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 1980 Unit 1 cohort and subject to a constraint on maximum size ($L_{infinity}$) of 42 cm (Figure 27). Although there were no modal estimates from this cohort at this size, there are numerous catch records in this stock for fish larger than 42 cm. To account for the uncertainty in length at age, a range of different curves were used. These reflect both free and constrained fittings to the 1980 cohort as well as fits from other studies. Most studies are from the Northwest Atlantic. The purpose of bringing in the other studies was to incorporate uncertainty for the size at age in broader sense than parameter fitting uncertainty. Because cohorts potentially grow differently putting a coefficient of variation on length at age derived from several studies, times, and adjacent areas allows for a greater range in uncertainty in growth for new cohorts. 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 6 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 of length on age. In the summer 2017, the 2011 to 2013 Redfish cohorts' modal size was 20 cm. If the anticipated growth of these cohorts continues (Figure 27), close to 50 % of the individuals (59% biomass) of the 2011 cohort should be larger than 22 cm in 2018, the minimum regulatory size. By 2020, 51% of the individuals of that cohort (62% biomass) should be larger than 25 cm (Table 6).

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

DEPTH EFFECT ON DISTRIBUTION

Based on the August research survey in Unit 1, both Redfish species are distributed according to depth. Although the depth distributions of the two species overlap, *S. mentella* is found deeper (200-400 m) than *S. fasciatus* (150-300 m) (Figure 28).

In addition, it is recognized that larger Redfish tend to be deeper in comparison to smaller ones. This relationship was explicitly tested using size frequency data from Redfish found in strata of different depths during DFO surveys from 1984 to 2017. Catch size frequencies for each stratum was quantified using five quantiles (Q10, Q25, Q50, Q75, and Q90). These quantiles were analyzed using different mixed models, controlling for time and/or space (Table 7). The models' performance was compared according to the Akaike Information Criterion (AIC). AIC values should be minimized to find the most parsimonious model, explaining a large fraction of variation while using as few variables as possible. In these models, the five quantiles, representing size frequencies, corresponded to the response variables. Mixed models include two types of explanatory variables, the fixed effects, those whose impact on the response variable are of interest and tested, and the random effects, corresponding to grouping factors for which the effect is controlled in the model without looking at their specific effect on the response variable (Zuur et al. 2009).

Some models were developed with no fixed effects (~ 1), while others included depth and/or year (Table 7). Depth variable corresponded to five depth categories: 37 to 90 m, 91 to 182 m, 183 to 273 m, 274 to 365 m, and > 366 m. Different random effects were also tested, either year and/or stratum. For all quantiles, the best model (smaller AIC) included depth and year as fixed effects, and stratum as a random effect. Mixed models conditions of application were verified, namely obtaining residuals' normal distribution, and the absence of a relationship between model predicted and residual values (Zuur et al. 2009). The marginal R^2 quantifies the response variable variation explained by fixed effects. Depth and year accounted for 34 to 41% and 8 to 11%, respectively, of the variation in the five quantiles. Conditional R^2 quantifies the variation explained by fixed and random effects. Thus, the subtraction of R^2 makes it possible to quantify the variation taken into account by the random effects. Strata accounted for 11 to 12% of the variation, regardless of depth (Table 7). It is possible that differences in strata, such as temperature, food resources, or the presence of competitors, affect Redfish size. Figure 29 illustrates the effect of depth categories on Redfish median size (Q50). The other quantiles are not presented, but showed a similar pattern. *A posteriori* test, comparing depth categories one by one, indicated that all depth categories were significantly different from one another, with the exception of depths between 37 and 90 m, and 91 and 182 m, which were similar (p.value > 0.05), and that indeed larger Redfish were found deeper (Figure 29 A). These results suggest that by fishing in deeper areas, the probability of catching larger Redfish is higher. However, 2017 data indicate median sizes that are smaller than those of the entire time series (Figure 29 B).

Redfish biomass was calculated for 3 size classes (0-22 cm, 22-25 cm, and > 25 cm) as a function of depth from 1984 to 2017. Areas identified as "Deep" included strata greater than 274 meters and located between 59°W and 65°W (where the index fishery is permitted), while the "Shallow" areas include the rest of the study area. From 1984 to 1994, 83% of the biomass corresponded to individuals larger than 25 cm distributed evenly between deep and shallow areas. Between 1995 and 2012, Redfish biomass decreased substantially and the stock was then composed of large Redfish concentrated in deep areas. Since 2013, the arrival of new cohorts has increased the biomass of Redfish smaller than 22 cm, mainly in shallow areas. In 2017, the strong recruitment of new cohorts means that the biomass of individuals smaller than 22 cm dominates at all depths (Figure 30).

DIET

The massive arrival of Redfish cohorts from 2011 to 2013 has many implications for the Gulf of St. Lawrence ecosystem and community, including a predation increase on several organisms. In order to specify the species subject to this predation, Redfish diet has been quantified. From 2015 to 2017, during the Unit 1 August DFO survey, 2,172 Redfish stomachs from 5 to 50 cm were collected (Figure 31) and the mass percentages of the prey were quantified. Stomachs were dissected in the laboratory. Each prey found in a stomach was identified at the most precise possible taxonomic level and the state of digestion of the prey was evaluated. The analyses were limited to prey that could be identified and excluded for example, prey that were too digested for identification, parasites or sand. Then, mass percentage of different categories of prey present in the stomachs was calculated. Percentages of different types of prey are presented according to Redfish size (Figure 32). Redfish summer diet in Unit 1 varies according to fish size. Redfish less than 20 cm consume mostly zooplankton and shrimp (Northern Shrimp and Pink Glass Shrimp) when they grow over 20 cm. When Redfish reach a size of 25 cm, they start consuming fish, including Redfish. The massive increase in Redfish has important repercussions for the ecosystem. For example, increasing predation is contributing to the Northern Shrimp decline in the Estuary and Gulf of St. Lawrence.

Redfish predation on Northern Shrimp is of great interest given the value of this fishery and its apparent decline in recent years. For this reason, ecosystem models have been used to quantify annual shrimp consumption by Redfish of different sizes. Shrimp proportion in the diet (P) and Redfish biomass (B) were used to estimate the annual consumption of Northern Shrimp by Redfish (Q), based on the following equation:

$$Q = B * P * Q/B$$

where Q/B represents a theoretical ratio from the ecosystem models available for the northern Gulf of St. Lawrence for different periods (Savenkoff et al. 2004, Savenkoff and Rioual (unpublished data)). These analyses demonstrated that the estimated values of Northern Shrimp consumption by Redfish begin to increase sharply as juveniles grow in length (Figure 33). On average, 86,000 tons of Northern Shrimp were consumed annually by Redfish from 2015 to 2017. Consumption has doubled year after year, which appears to reflect the growth of the large Redfish cohorts and the increase in the use of Northern Shrimp as a prey of importance.

According to Unit 1 DFO surveys in 2017, Redfish modal class was 20 cm, a size where the diet consists mainly of zooplankton and small crustaceans. Based on growth projections, 62% of the 2011 cohort biomass is expected to be 25 cm or more by 2020, and by 2022, 92% of the 2011 cohort biomass will be greater than 25 cm (Table 6 B). In the meantime, a diet shift should happen, where small Redfish cannibalism and predation on shrimp should increase if these prey are still available. Indeed, Redfish diet could be modified if, for example, the absence of new Redfish cohort implies that there are no more small individuals available for consumption, or if the Northern Shrimp decline is such that it is too expensive for Redfish to find and consume these prey. Redfish diet study will continue in the coming years to better understand the effect of predation on other organisms in the Gulf of St. Lawrence based on their distribution and availability.

PERSPECTIVE

The imminent arrival of Redfish cohorts from 2011 to 2013 at sizes greater than the minimum regulatory size is generating strong interest from a number of stakeholders, for example, provincial and federal governments, industry (fishing, processing, and marketing), first nations, and environmental groups. Thus, the commercial fishery reopening in Unit 1 motivates the development of numerous research projects and management tools.

For about a decade, the Gulf of St. Lawrence waters have warmed rapidly (Galbraith et al. 2017) and the ecosystem, dominated by cold-water crustaceans (Northern Shrimp, Snow Crab) for 25 years, is returning to a state where it is dominated by groundfish. This situation has led to joint projects, which will focus on groundfish return, including Redfish, with Ressources Aquatiques Québec, a group of researchers from different universities. The main objectives are to 1) describe fish and invertebrate communities spatial and temporal structure changes, 2) evaluate environment and fishing effects on these changes, 3) measure the consequences of these changes on predator-prey relationships, 4) develop community composition indicators, and 5) measure ecosystem changes impacts on fishery activities. In addition, several studies in partnership with the industry aim to develop an effective and sustainable Redfish fishery using a midwater trawl instead of a bottom trawl. The purpose of these projects is to minimize bycatch (other species and small Redfish), while minimizing contact between gear and the bottom, as well as to improve our knowledge of Redfish distribution patterns in time and space, and according to depth.

Given the expected opening of Redfish commercial fishery in the near future, a Management Strategy Evaluation process for Units 1 and 2 has been completed in 2018 (DFO 2018e). Management strategy evaluation is a structured decision-making process for testing management options and choosing which options provide acceptable outcomes relative to explicit conservation and fishery objectives. Five candidate management procedures of an initial set of 21 were selected for further consideration by the working group in March 2018. All candidate management procedures used the same harvest control rule, but differed in the year in which the harvest control rule was first implemented, limits on the magnitude of interannual changes in total allowable catch and with respect to the presence or absence of: maximum in total allowable catch caps, adjustment of harvest control rule catch limits by a factor of 0.8 and the use of fixed total allowable catches in early years. Four management procedures met the working group objectives. This Management Strategy Evaluation provides an effective tool for resource sustainable management based on the best scientific knowledge currently available.

Another challenge in managing Redfish populations is the lack of data of commercial fishery species composition. Indeed, although conservation issues, reference points stemming from the precautionary approach, and operating models of the Management Strategy Evaluation are determined specifically for each species, very few sampling and monitoring programs exist to effectively partition commercial catches between *S. mentella* and *S. fasciatus*. This lack of information complicates resource management since the proportion of individuals that is harvested for each species is not known. An accurate and systematic count of anal fin soft rays of a sub-sample of the catches, covering a significant fraction of the fishing activities in time and space, would make it possible to estimate what is actually taken by the industry for each species.

Gaps remain in government's fundamental knowledge of how to manage this resource. One of the critical elements of Redfish life cycle is its sporadic recruitment, where reproductive success is highly variable between years. A better understanding of what affects reproductive success would refine the long-term projections of the stock and better delineate fishing season opening and closing times and areas, in order to limit exploitation of the resource pressure induced by the fishery during reproduction. In addition, the maturity ogive estimates the mature biomass of the stock and thus assesses the reference points stemming from the precautionary approach. Redfish reproduction period and maturity ogive most recent data in Units 1 and 2 are from the 1990s (Gascon 2003). Revising these parameters has been identified as a priority by DFO's Groundfish Working Group managers on many occasions, including November 2016 and October 2017, among others. This unprecedented Redfish population increase also provides an opportunity to study how density-dependent factors can affect population dynamics. Indeed, when a population is approaching its support capacity and resources become scarce, it is common to observe changes in life cycle traits, such as a decrease in the maximum size, an increase in mortality or a reduction in growth.

REFERENCE

Anderson, J.T. 1994. Feeding ecology and condition of larval and pelagic juvenile redfish Sebastes spp. Mar. Ecol. Prog. Series 104: 211-226

Atkinson, D.B., and Power, D. 1991. The redfish stock issue in 3P, 4RST, and 4VWX. CAFSAC Res. Doc. 91/38, 47 p.

Bourdages, H., L. Savard, D. Archambault and S. Valois. 2007. Results from the August 2004 and 2005 comparative fishing experiments in the northern Gulf of St. Lawrence between the CCGS Alfred Needler and the CCGS Teleost. Can. Tech. Rep. Fish. Aquat. Sci. 2750: ix + 57 p.

Bourdages, H., Brassard, C., Desgagnés, M., Galbraith, P., Gauthier, J., Nozères, C., Senay, C., Scallon-Chouinard, P.-M. and Smith, A. 2017. Preliminary results from the groundfish and shrimp multidisciplinary survey in August 2017 in the Estuary and northern Gulf of St. Lawrence. Secr. can. de consult. sci. du MPO. Doc. de rech. 2018/036. iv + 90 p.

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 + 52 p.

Desrosiers, B., Sévigny, J.-M., and Chanut, J.-P. 1999. Restriction fragment length polymorphism of rDNA in the redfishes *Sebastes fasciatus* and *S. mentella* (Scorpaenidae) from the Gulf of St. Lawrence. Can. J. Zool. 77 : 267–277.

DFO. 2010. Assessment of redfish stocks (*Sebastes fasciatus* and *S. mentella*) in Units 1 and 2 in 2009. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/037.

DFO. 2011. Recovery potential assessment of redfish (*Sebastes fasciatus* and *S. mentella*) in the northwest Atlantic. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/044. (Erratum: June 2013)

DFO. 2016a. Assessment of the West Coast of Newfoundland (Division 4R) herring stocks in 2015. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2016/024.

DFO. 2016b. Assessment of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence (NAFO Div. 4T-4Vn (Nov. – April)) to 2014. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/061.

DFO. 2017a. Assessment of the Quebec North Shore (Division 4S) herring stocks in 2016. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/027.

DFO. 2017b. Assessment of the Atlantic Mackerel Stock for the Northwest Atlantic (Subareas 3 and 4) in 2016. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/034.

DFO. 2017c. Assessment of the Northern Gulf of St. Lawrence (3Pn, 4RS) Cod Stock in 2016. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/042.

DFO. 2018a. Assessment of Redfish Stocks (*Sebastes mentella* and *S. fasciatus*) in Units 1 and 2 in 2017. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/032.

DFO. 2018b. Assessment of the Greenland Halibut stock in the Gulf of St. Lawrence (4RST) in 2017. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/035.

DFO. 2018c. Stock Assessment of Atlantic Halibut of the Gulf of St. Lawrence (4RST) in 2016. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/052.

DFO. 2018d. Assessment of Northern Shrimp stocks in the Estuary and Gulf of St. Lawrence in 2017. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/015.

DFO. 2018e. Units 1+2 Redfish Management Strategy Evaluation. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/033.

Duplisea, D.E., Power, D., and Comeau, P. 2012. Reference points for eastern Canadian redfish (*Sebastes*) stocks. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/105. ii + 22 p.

Galbraith, P.S., Chassé, J., Caverhill, C., Nicot, P., Gilbert, D., Pettigrew, B., Lefaivre, D., Brickman, D., Devine, L., and Lafleur, C. 2017. Physical Oceanographic Conditions in the Gulf of St. Lawrence in 2016. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/044. v + 91 p.

Gascon, D. (ed.). 2003. Multidisciplinary research program on redfish (1995-1998): Final report. Can. Tech. Rep. Fish. Aquat. Sci. 2462: xiv + 148 p.

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. Can J. Fish. Aquat. Sci. 37 : 2272-2275.

Hamon, P-Y. 1972. Redfish, *Sebastes marinus* sp. Fishing sites, biology, exploitation. Rev. Trav. Inst. Pêches marit. 36(3), 1972, p. 337−352.

Legendre, P., and Legendre, L.F. 2012. Numerical ecology, vol 20. Elsevier, Amsterdam.

Morin, B., Power, D., and Gagnon, P. 1994. Distribution of redfish (*Sebastes* spp.) in the Gulf of St. Lawrence and in Laurentian Channel based on RV surveys and commercial fishery catch rates. DFO Atl. Fish. Res. Doc. 94/91, 52 p

Ni, I-H., and Templeman, W. 1985. Reproductive cycles of Redfishes (Sebastes) in Southern Newfoundland waters. J. Northw. Atl. Fish. Sci., 6: 5763.

Nozères, C., Archambault, D., Chouinard, P.-M., Gauthier, J., Miller, R., Parent, E., Schwab, P., Savard, L., and Dutil, J.-D. 2010. Identification guide for marine fishes of the estuary and northern Gulf of St. Lawrence and sampling protocols used during trawl surveys between 2004 and 2008. Can. Tech. Rep. Fish. Aquat. Sci. 2866: xi + 243 p.

Power, D. 2003. Retrospective analysis of redfish catch distribution: Inferences on redfish migrations through an analysis of commercial logbook information for management Units 1-3 from 1988-1992. Pages 57–70. In: Gascon, D. (ed.). 2003. Multidisciplinary research program on redfish (1995-1998): Final report. Can. Tech. Rep. Fish. Aquat. Sci. 2462: xiv + 148 p.

Roques, S., Duchesne, P., and Bernatchez, L. 1999. Potential of microsatellites for individual assignment: the North Atlantic redfish (genus *Sebastes*) species complex as a case study. Mol. Ecol. 8: 1703–1717.

Roques, S., Sévigny, J.-M., and Bernatchez, L. 2001. Evidence for broadscale introgressive hybridization between two redfish (genus *Sebastes*) in the Northwest Atlantic redfish: a rare example. Mol. Ecol. 10: 149–165.

Roques, S., Sévigny, J.-M., et Bernatchez, L. 2002. Genetic structure of deep-water redfish, Sebastes mentella, populations across the North Atlantic. Mar. Biol. 140: 297-307.

Rubec, P. J., McGlade, J.M., Trottier, B.L., and Ferron, A. 1991. Evaluation of methods for separation of Gulf of St Lawrence beaked redfishes, *S. fasciatus* and *S. mentella*: malate deshydrogenase mobility patterns compared with extrinsic gasbladder muscle passages and anal fin ray counts. Can. J. Fish. Aquat. Sci. 48 : 640–660.

Runge, J. A., and Y. de Lafontaine. 1996. Characterization of the pelagic ecosystem on the northern Gulf of St. Lawrence in early summer: the larval redfish – *Calanus* – microplankton interaction. Fish. Oceanogr. 5:21-37.

Savenkoff, C., Bourdages, H., Castonguay, M., Morisette, L., Chabot, D., et Hammill, M. O. 2004. Input data and parameter estimates for ecosystem models of the northern Gulf of St. Lawrence (mid-1990s): Can. Tech. Rep. Fish. Aquat. Sci. 2531: vi+93 pp.

Scherrer, B. 2007. Biostatistique. Volume 1. Gaetan Morin.

Valentin, A., Sévigny, J.-M., Power, D., Branton, R.M., and Morin, B. 2006. Extensive sampling and concomitant use of meristic characteristics and variation at the MDH-A* locus reveal new information on redfish species distribution and spatial pattern of introgressive hybridization in the Northwest Atlantic. J. Northwest Atl. Fish. Sci. 36 : 1–16.

Valentin, A.E., Penin, X., Chanut, J.-P., Power, D., and Sévigny, J.-M. 2014. Combining microsatellites and geometric morphometrics for the study of redfish (*Sebastes* spp.) population structure in the Northwest Atlantic. Fish. Res. 154 : 102–119. doi.org/10.1016/j.fishres.2014.02.008.

Zuur, A., Ieno, E.N., Walker, N., Saveliev, A.A., and Smith, G.M. 2009. Mixed effects models and extensions in ecology with R. Springer, Berlin.

TABLES

Table 1. Annual landings (January 1st to December 31st) and total allowable catches (TAC) per management cycle (See section History) of Sebastes spp. (ton) per NAFO Division and Subdivision in Unit 1 from 1953 to 2017. Data include fisheries directed to all species. No Redfish directed fishery took place from 1995 to 1997. 2016 and 2017 data are preliminary.

Landings (ton)							
Year	4R	4S	4T	3Pn Jan. - May	4Vn Jan. - May	Total	TAC
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	30 000
1977	5 620	7 906	2 314	772	460	17 072	18 000
1978	3 084	6 352	4 155	1 067	276	14 934	18 000
1979	3 763	7 629	3 642	1 185	206	16 425	16 000
1980	4 809	8 125	1 898	527	180	15 539	16 000
1981	7 685	10 173	2 691	973	523	22 045	20 000
1982 [1]	9 410	13 824	3 222	63	212	26 731	31 000
1983 [1]	10 463	11 495	2 547	322	147	24 974	33 000
1984	12 123	12 700	9 988	936	80	35 827	33 000
1985	11 479	13 029	3 559	201	65	28 333	50 600
1986	11 151	18 479	3 963	2 540	281	36 414	55 600
1987	11 547	16 772	5 992	3 234	5 901	43 446	50 000
1988	15 518	14 480	8 828	6 917	6 149	51 892	56 000

Landings (ton)							
Year	4R	4S	4T	3Pn Jan. - May	4Vn Jan. - May	Total	TAC
1989	17 805	15 419	9 755	5 440	4 063	52 482	57 000
1990	26 985	17 740	5 397	5 671	6 141	61 934	57 000
1991	40 661	3 984	6 494	10 349	6 039	67 527	57 000
1992	30 000	11 385	8 151	14 111	14 106	77 753	57 000
1993 [2]	16 475	4 769	4 132	17 387	8 392	51 156	60 000
1994	2 745	2 378	5 166	5 085	4 211	19 586	30 689
1995 [3]	27	8	13	0	2	50	0
1996	28	3	41	1	0	74	0
1997	6	10	20	0	1	38	0
1998 [4]	118	86	190	0	5	399	1 000
1999	589	63	456	0	2	1 110	2 000
2000	794	53	258	11	1	1 117	2 000
2001	711	6	370	84	3	1 173	2 000
2002	689	50	466	13	6	1 224	2 000
2003	484	65	288	0	1	838	2 000
2004	486	34	413	0	9	941	2 000
2005	562	87	325	0	2	975	2 000
2006	126	52	512		4	694	2 000
2007	5	22	78	0	0	106	2 000
2008	62	9	348	0	1	420	2 000
2009	95	15	525	0	0	635	2 000
2010	164	53	330	0	2	549	2 000
2011	113	42	475	0	1	630	2 000
2012	148	172	378	0	1	699	2 000
2013	65	121	280	0	0	466	2 000
2014	37	34	287	0	9	366	2 000
2015	8	55	366	0	0	429	2 000
2016 [5]	65	47	231	0	9	352	2 000
2017 [5]	29	32	120	11	0	192	2 000

[1] TAC Changed during the year
[2] 1993 Start of Redfish management Unit 1
[3] 1995 Moratorium
[4] 1998 Start of the index fishery
[5] Preliminary data

Table 2. Occurrence percentage (%), biomass (kg), reported catches percentage (%), and percentage of each species biomass by Redfish biomass (%) based on at-sea observer data for the Redfish directed fishery from 1999 to 2016.

Name	Occurrence (%)	Biomass (kg)	Reported (%)	Bycatch / Redfish (%)
Redfish	99.4	1875423	99.8	100
Greenland Halibut	73.3	79049	99.8	4.2
White Hake	57.7	22712	84.5	1.2
Witch Flounder	40.8	3455	98.1	0.1
Atlantic Cod	37.5	26205	99.3	1.4
Thorny Skate	33.6	6821	21	0.4
Atlantic Halibut	25.3	8553	84	0.5
Skates	25.1	5893	1.4	0.3
Norway King Crab	20.9	1289	1.4	0.1
Monkfish	19.7	1554	90.4	0.1
Spiny Dogfish	14.2	3933	0.1	0.2
Black Dogfish	14.2	9944	7.3	0.5
American Plaice	10.8	689	99.4	0.03

Table 3. Percentile describing depth distribution of Redfish, Greenland Halibut, White Hake, Atlantic Cod, and Atlantic Halibut based on at-sea observer data for the Redfish directed fishery from 1999 to 2016.

Percentile	Redfish	Greenland Halibut	White Hake	Atlantic Cod	Atlantic Halibut
p5	252	247	246	204	215
p10	263	265	251	209	234
p25	280	305	276	215	273
p50	308	366	298	235	300
p75	369	415	320	271	331
p90	426	433	347	304	416
p95	445	437	379	318	429

Table 4. Analysis of variance (ANOVA) results testing the effect of a triple interaction between trawl types, Units and years on quantiles (Q10, Q25, Q50, Q75, and Q90) describing the size frequency of Redfish caught by the commercial fishery and sampled by at-sea observers from 1978 to 2016. Only significant factors are presented. The explained variance (AdjR2) and the percentages of difference (%) between the trawls and the Units are indicated.

	Factor	p.value	$AdjR^2$	Trawl % Difference	Unit % Difference
Q10	Trawl*Year + Unit*Year	2.2E-16	0.22	Midwater 5% > Bottom	Unit 1 2% < Unit 2
Q25	Trawl*Year + Unit*Year	2.2E-16	0.23	Midwater 3% > Bottom	Unit 1 0.4% < Unit 2
Q50	Trawl*Unit*Year	2.2E-16	0.25	Midwater 0.3% > Bottom	Unit 1 1% > Unit 2
G75	Trawl*Unit*Year	2.2E-16	0.25	Midwater 3% < Bottom	Unit 1 2% > Unit 2
Q90	Trawl*Unit*Year	2.2E-16	0.24	Midwater 4% < Bottom	Unit 1 2% > Unit 2

Table 5. Abundance (1,000,000 individuals, A) and biomass (1,000 t, B) indices in DFO research surveys from 1984 to 2017 for S. mentella, S. fasciatus, and Sebastes spp.,measuring between 0 and 22 cm, more than 22 cm, more than 25 cm, and total.

A)

Year	Abundance (1 000 000 individuals)											
	S. mentella				*S.fasciatus*				*Sebastes spp.*			
	0-22 cm	>22 cm	>25 cm	Total	0-22 cm	>22 cm	>25 cm	Total	0-22 cm	>22 cm	>25 cm	Total
1984	1 922	758	741	2 680	4 166	474	436	4 640	6 088	1 232	1 177	7 320
1985	512	444	395	956	1 135	275	238	1 410	1 647	719	634	2 365
1986	685	572	459	1 257	706	344	272	1 050	1 390	916	731	2 306
1987	702	1 349	763	2 051	1 168	403	325	1 571	1 869	1 752	1 089	3 622
1988	203	1 107	889	1 310	679	1 193	898	1 872	883	2 299	1 787	3 182
1989	131	934	876	1 065	488	1 155	1 049	1 644	619	2 089	1 925	2 709
1990	718	1 111	1 091	1 829	2 597	739	707	3 336	3 315	1 850	1 798	5 165
1991	1 425	491	481	1 916	4 319	473	447	4 792	5 744	963	929	6 708
1992	232	370	353	602	698	524	480	1 222	930	894	833	1 824
1993	49	236	233	284	153	355	280	507	201	591	513	792
1994	41	115	113	156	71	142	136	214	112	257	249	370
1995	31	139	136	171	52	25	20	76	83	164	156	247
1996	37	109	105	146	54	22	18	76	91	131	123	222
1997	33	100	97	133	80	55	50	135	112	155	148	268
1998	43	48	46	91	241	160	92	401	285	207	138	492
1999	58	80	77	138	192	30	25	222	251	110	101	360
2000	80	82	78	162	315	36	30	351	395	118	109	513
2001	45	68	66	113	199	42	36	241	244	110	101	354
2002	31	123	118	153	149	34	27	184	180	157	145	337
2003	48	246	233	294	234	190	172	424	282	436	406	718
2004	16	39	37	56	129	38	28	167	146	77	64	223
2005	147	74	67	221	4 410	47	39	4 458	4 557	121	107	4 679
2006	94	35	33	128	1 924	106	78	2 030	2 018	141	111	2 159
2007	536	41	38	577	1 991	39	28	2 030	2 527	80	66	2 607
2008	16	205	186	221	525	114	104	639	541	319	290	860
2009	5	16	16	21	261	40	32	301	267	56	48	323
2010	16	175	155	191	255	44	34	299	271	219	189	490
2011	27	48	42	75	132	62	48	194	159	110	90	269
2012	19	54	50	73	257	58	44	315	276	112	94	388
2013	5 375	81	77	5 456	2 445	99	88	2 544	7 820	180	165	7 999
2014	5 308	88	83	5 396	3 180	95	74	3 275	8 487	183	157	8 670
2015	8 424	87	75	8 510	1 500	112	79	1 612	9 924	199	154	10 122
2016	21 477	177	92	21 654	1 132	106	79	1 238	22 609	283	171	22 892
2017	19 466	2 028	160	21 494	3 041	345	146	3 386	22 507	2 373	305	24 880

B)

Year	Biomass (1,000 t)											
	S. mentella				*S.fasciatus*				*Sebastes spp.*			
	0-22 cm	>22 cm	>25 cm	Total	0-22 cm	>22 cm	>25 cm	Total	0-22 cm	>22 cm	>25 cm	Total
1984	57	388	385	445	121	234	227	355	178	622	612	800
1985	28	236	228	264	54	120	115	174	82	357	343	439
1986	61	288	271	349	54	136	124	189	115	423	395	538
1987	52	514	398	566	32	129	116	161	84	643	514	727
1988	8	382	345	389	23	385	334	408	31	767	679	797
1989	5	341	331	346	18	384	367	402	23	725	698	748
1990	15	492	488	507	44	281	275	325	59	773	763	832
1991	34	227	226	261	102	194	189	296	136	421	415	557
1992	8	162	158	170	25	219	211	244	33	381	369	414
1993	2	101	100	103	8	119	105	128	11	220	206	231
1994	2	59	59	61	4	73	72	77	6	132	131	138
1995	2	77	77	79	2	12	11	14	4	89	88	93
1996	2	62	61	64	2	10	10	12	4	72	71	76
1997	2	57	56	58	3	27	26	30	4	84	82	88
1998	2	28	28	30	10	53	39	62	12	81	67	92
1999	2	50	49	52	7	14	13	21	9	63	62	73
2000	4	51	50	55	12	19	18	31	16	70	68	85
2001	3	45	44	47	6	22	21	28	9	67	65	76
2002	2	78	77	80	7	15	14	22	8	93	91	102
2003	2	109	106	111	11	75	71	86	13	184	178	197
2004	1	25	25	27	8	15	12	22	9	40	37	49
2005	3	48	47	50	47	24	23	71	50	72	69	122
2006	10	25	25	36	78	39	33	117	88	64	58	152
2007	27	27	27	55	83	20	17	103	110	47	44	158
2008	1	91	87	92	27	51	49	78	28	142	136	170
2009	0	12	12	12	12	17	16	29	12	29	28	42
2010	1	72	68	73	15	21	19	37	17	93	87	110
2011	2	34	33	36	9	28	25	37	11	62	58	73
2012	1	40	39	40	12	24	22	36	12	64	60	76
2013	49	55	55	104	25	45	43	70	73	101	98	174
2014	141	62	61	203	72	38	34	111	214	100	96	314
2015	391	54	52	445	62	42	35	103	453	95	87	548
2016	1 510	61	47	1 572	63	39	34	102	1 574	100	81	1 674
2017	1 817	349	56	2 166	257	89	56	346	2 075	438	112	2 513

Table 6. Proportion of abundance (A) and biomass (B) of S. mentella for each cohort (2011, 2012 and 2013) estimated for different size classes in different years. For example, 0.48, in bold in the table (A) indicates that 48% of the fish 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)

Cohort 2013	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Cohort 2012	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Cohort 2011	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

B)

Cohort 2013	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Cohort 2012	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Cohort 2011	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	0.19	0.63	0.90	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
>21 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
>22 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
>23 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
>24 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
>25 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
>26 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
>27 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
>28 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
>29 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
>30 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

Table 7. Mixed models results evaluating depth, year, and stratum effects on different quantiles (Q10, Q25, Q50, Q75, and Q90) describing Redfish size based on DFO research surveys from 1984 to 2017. Fixed and random effects, AIC values, and marginal and conditional R2 are presented.

Response Variable	Fixed Effect	Random Effect	AIC	ΔAIC	Marginal R^2	Conditionnal R^2
Q10	~1	Year	9 250	939	0.00	0.09
Q10	~1	Stratum	8 626	315	0.00	0.47
Q10	~1	Year/Stratum	9 252	941	0.00	0.88
Q10	Depth	Year	8 613	302	0.34	0.43
Q10	Depth	Stratum	8 558	247	0.35	0.47
Q10	Depth	Year/Stratum	8 615	304	0.34	0.93
Q10	**Depth+Year**	**Stratum**	**8 311**	**0**	**0.44**	**0.55**
Q25	~1	Year	9 570	1 039	0.00	0.08
Q25	~1	Stratum	8 840	309	0.00	0.51
Q25	~1	Year/Stratum	9 572	1 041	0.00	0.88
Q25	Depth	Year	8 855	324	0.38	0.45
Q25	Depth	Stratum	8 767	236	0.38	0.50
Q25	Depth	Year/Stratum	8 857	326	0.38	0.93
Q25	**Depth+Year**	**Stratum**	**8 531**	**0**	**0.46**	**0.58**
Q50	~1	Year	9 910	1 108	0.00	0.08
Q50	~1	Stratum	9 133	331	0.00	0.54
Q50	~1	Year/Stratum	9 912	1 110	0.00	0.88
Q50	Depth	Year	9 136	334	0.40	0.47
Q50	Depth	Stratum	9 055	253	0.41	0.52
Q50	Depth	Year/Stratum	9 138	336	0.40	0.93
Q50	**Depth+Year**	**Stratum**	**8 802**	**0**	**0.48**	**0.60**
Q75	~1	Year	10 128	1 101	0.00	0.10
Q75	~1	Stratum	9 401	374	0.00	0.54
Q75	~1	Year/Stratum	10 130	1 103	0.00	0.88
Q75	Depth	Year	9 368	341	0.39	0.48
Q75	Depth	Stratum	9 321	294	0.40	0.52
Q75	Depth	Year/Stratum	9 371	344	0.39	0.93
Q75	**Depth+Year**	**Stratum**	**9 027**	**0**	**0.49**	**0.60**
Q90	~1	Year	10 257	1 092	0.00	0.13
Q90	~1	Stratum	9 599	434	0.00	0.55
Q90	~1	Year/Stratum	10 259	1 094	0.00	0.89
Q90	Depth	Year	9 519	354	0.37	0.48
Q90	Depth	Stratum	9 517	352	0.39	0.51
Q90	Depth	Year/Stratum	9 521	356	0.37	0.93
Q90	**Depth+Year**	**Stratum**	**9 165**	**0**	**0.49**	**0.61**

FIGURES

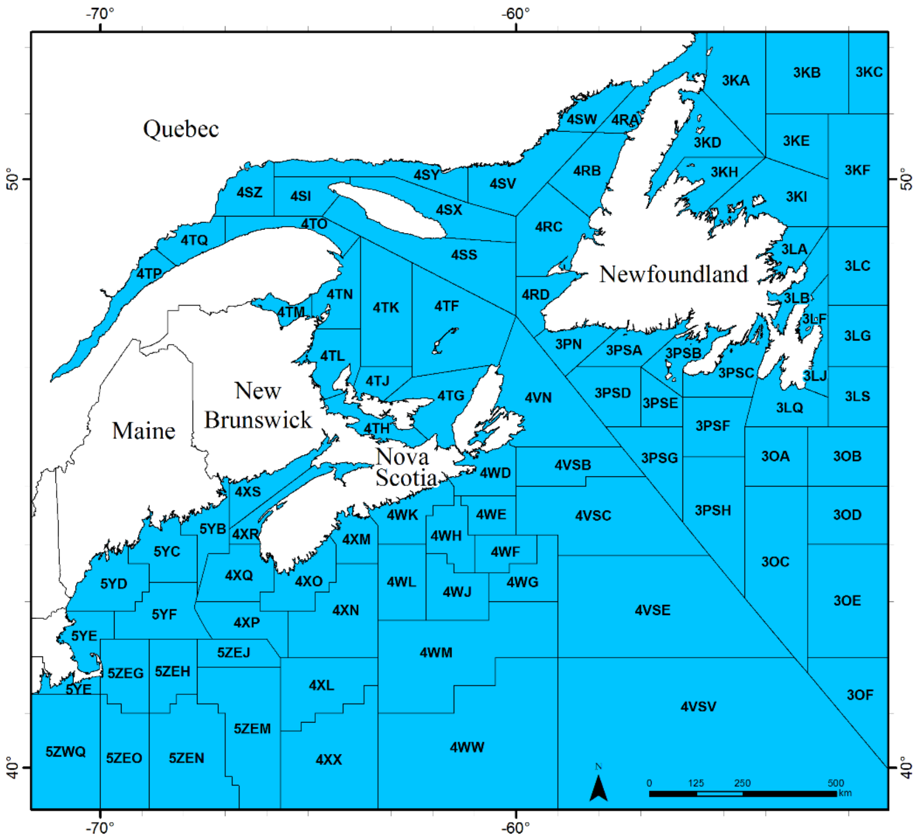

Figure 1. Northwest Atlantic Fishery Organization (NAFO) Divisions and Subdivisions.

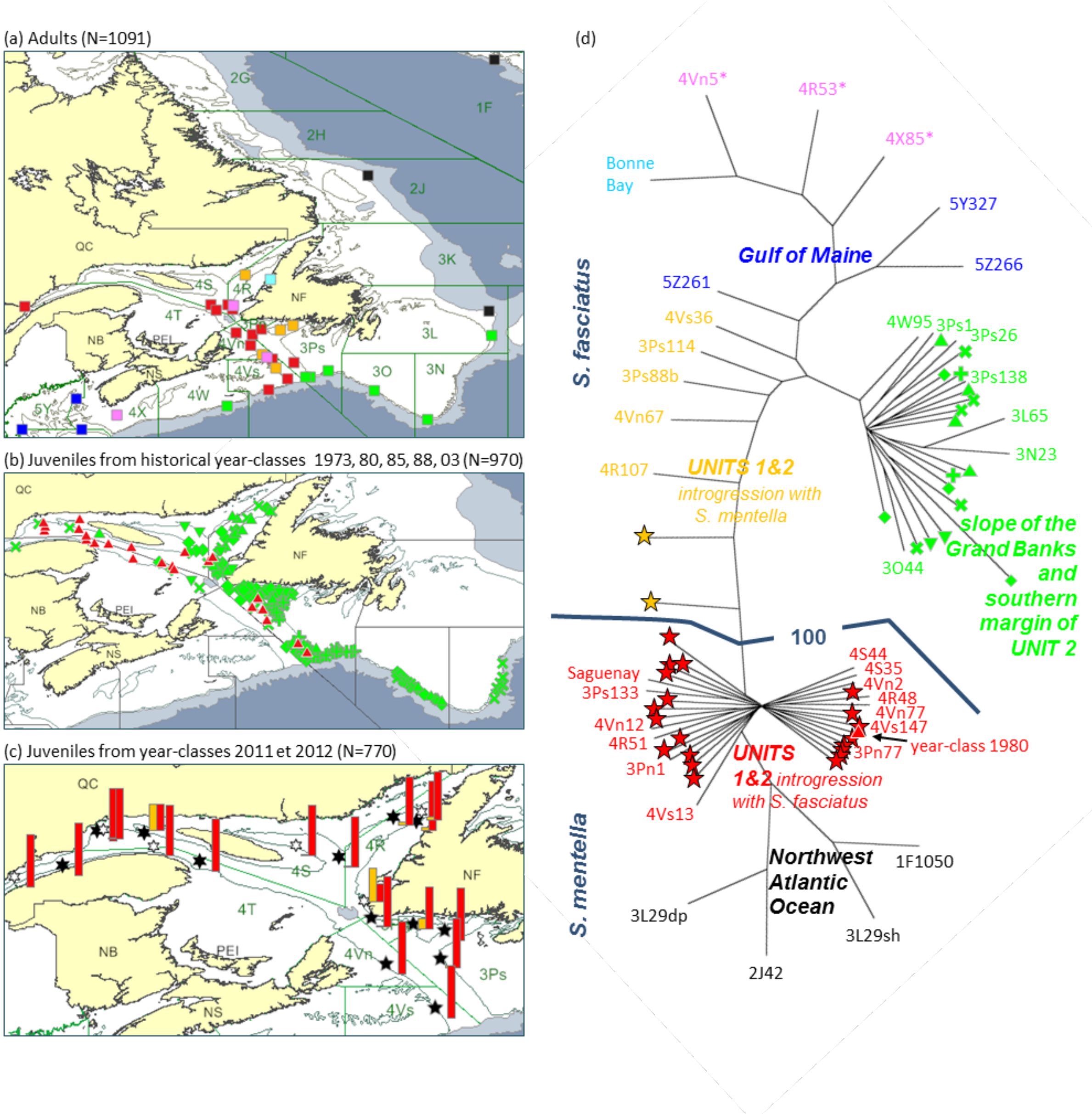

Figure 2. Geographic location of (a) 35 samples (■) of adult Redfish (16 S. mentella, n=495; 19 S. fasciatus, n=596) analyzed to describe population structures by species in the Northwest Atlantic; (b) 970 juveniles belonging to five historical year-classes [1973 (✚),1980 (▲), 1985 (◆), 1988(✖), 2003(▼)] 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.

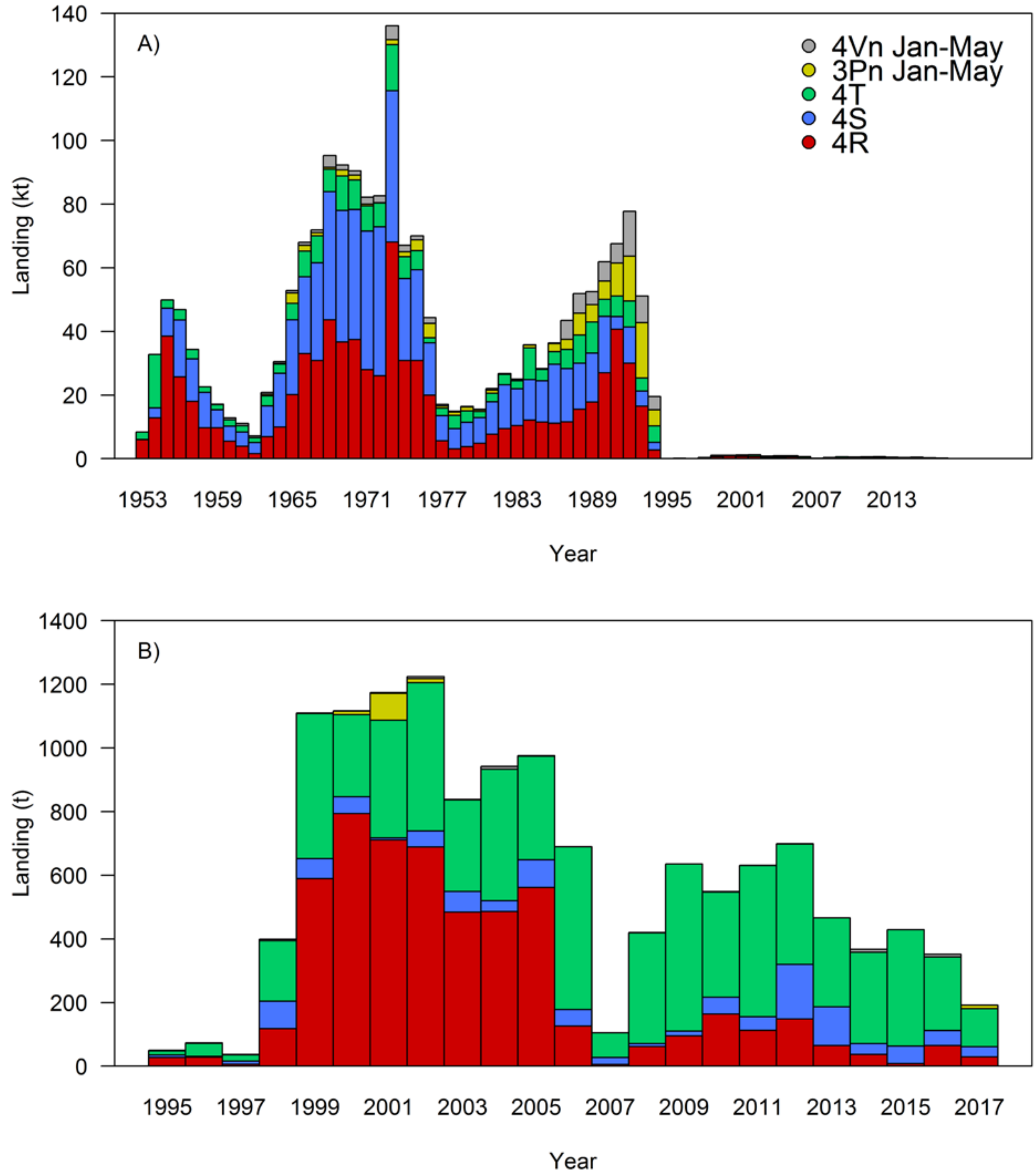

Figure 3. Commercial fishery annual Redfish landings in Unit 1 per Northwest Atlantic Fishery Organization (NAFO) Division and Subdivision from 1953 to 2017 (A in thousands of tons) and from 1995-2017 (B in ton). Data include fisheries directed to all species. No Redfish directed fishery took place from 1995 to 1997. 2016 and 2017 data are preliminary.

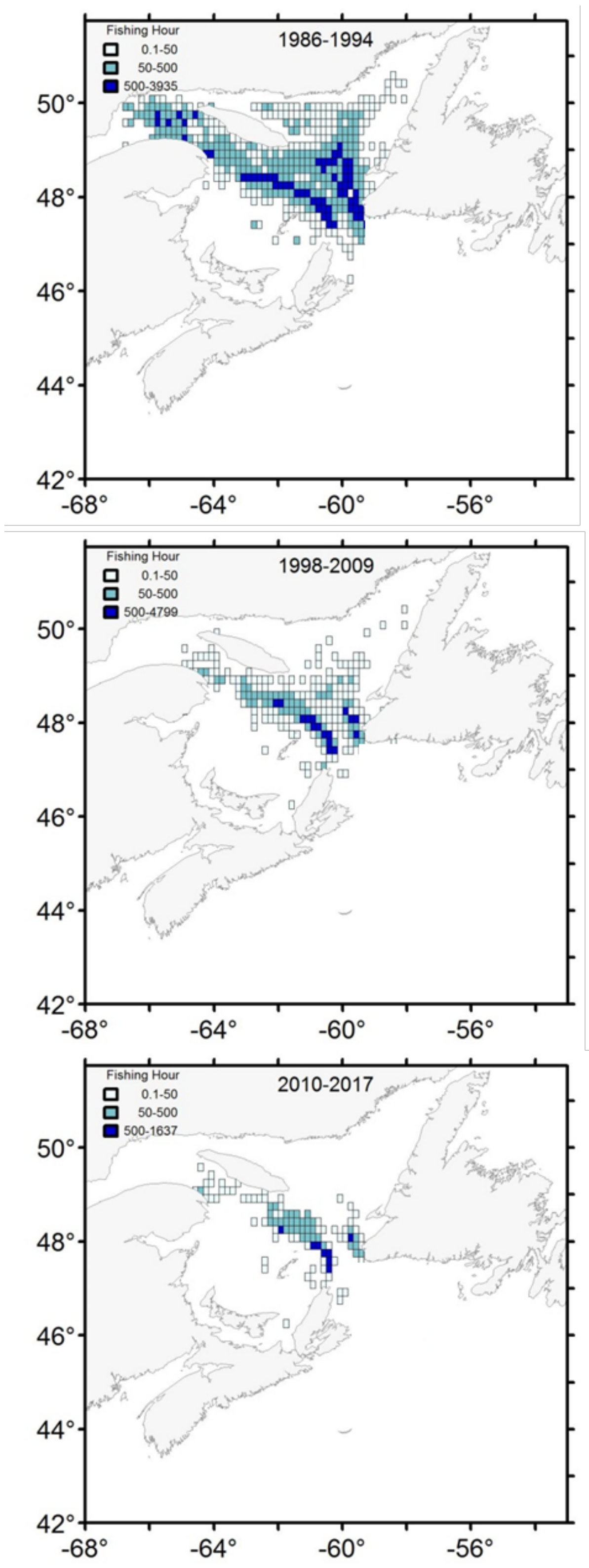

Figure 4. Spatial distribution of fishing effort (hour) of Redfish directed fishery in Unit 1 across years based on ZIFF files. Data include Redfish directed fishery exclusively. No Redfish directed fishery took place from 1995 to 1997. 2016 and 2017 data are preliminary.

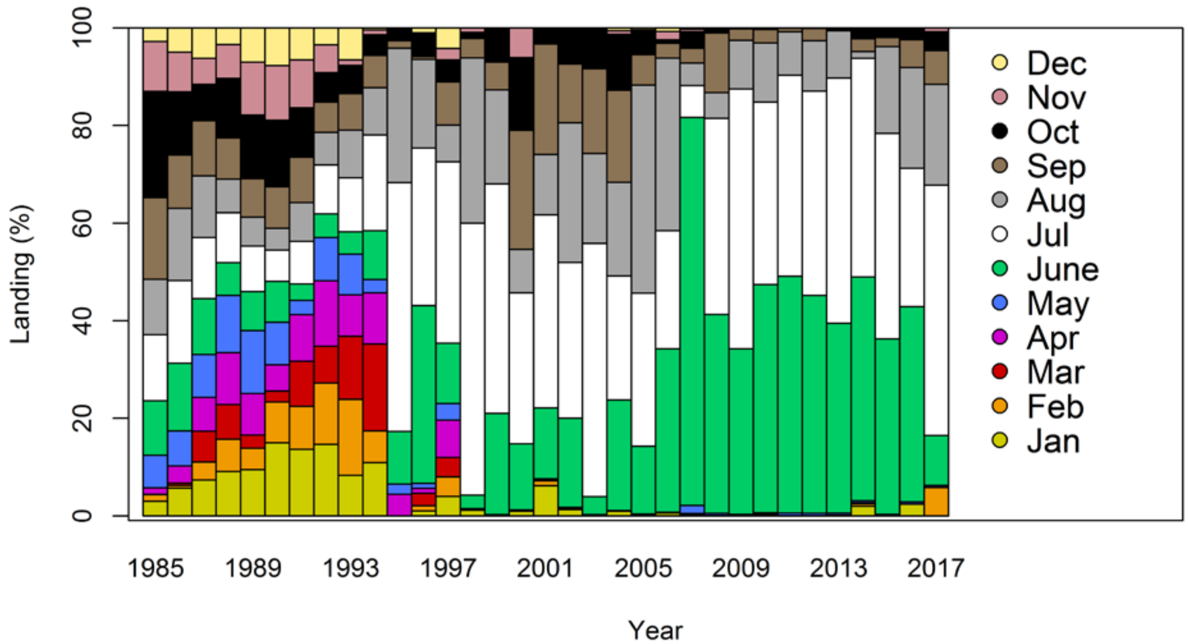

Figure 5. Monthly Redfish annual landings (biomass percentage) by month in Unit 1 from 1985 to 2017. Data include fisheries directed to all species. No Redfish directed fishery took place from 1995 to 1997. 2016 and 2017 data are preliminary.

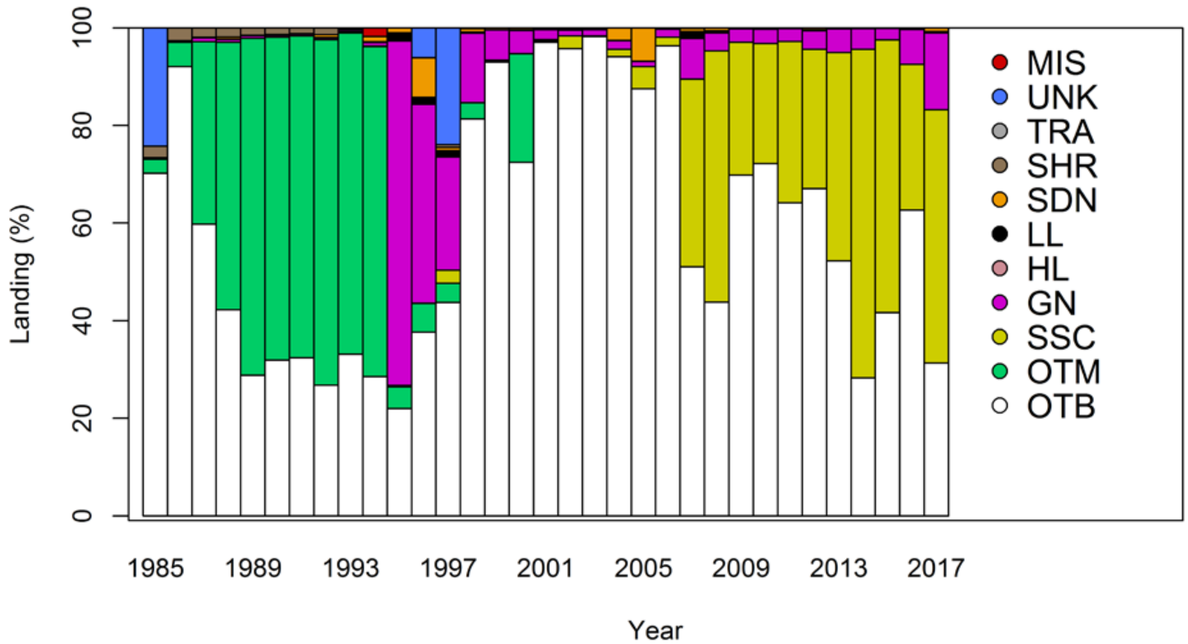

Figure 6. Redfish annual landings (biomass percentage) by gear in Unit 1 from 1985 to 2017. Data include fisheries directed to all species. No Redfish directed fishery took place from 1995 to 1997. 2016 and 2017 data are preliminary. OTB: bottom trawl, OTM: midwater trawl, SSC: Scottish seine, GN: gill net, HL: handline, LL: longline, SDN: Danish seine, SHR: shrimper, TRA: trap, UNK: unknown, and MIS: miscellaneous.

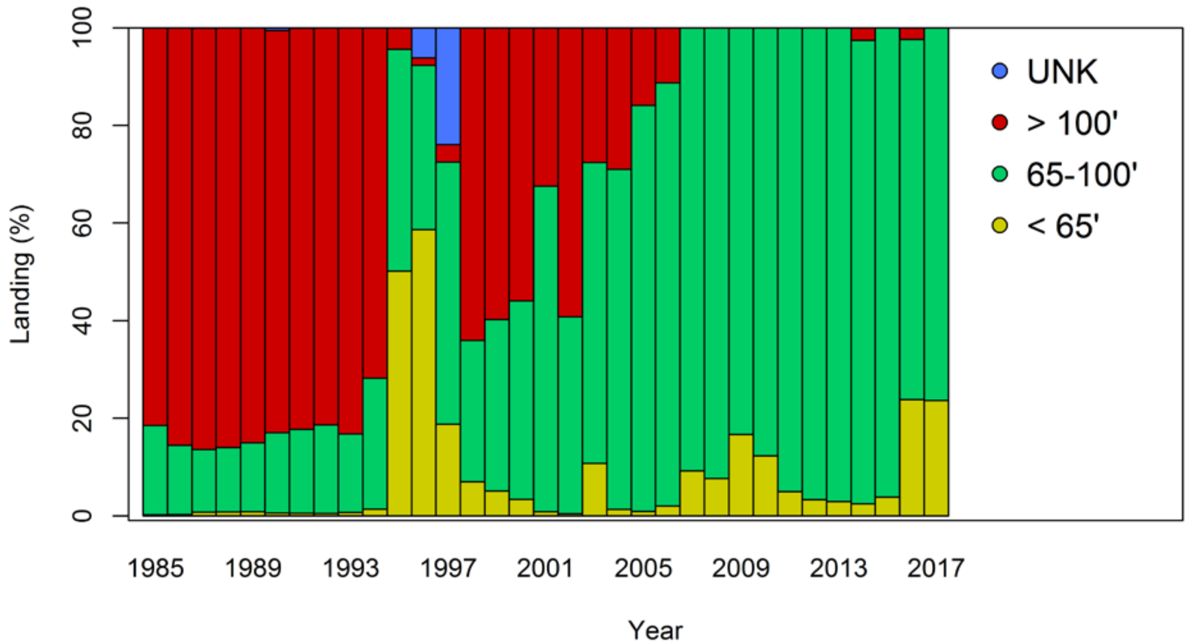

Figure 7. Redfish annual landings (biomass percentage) by boat size (in feet) in Unit 1 from 1985 to 2017. Data include fisheries directed to all species. No Redfish directed fishery took place from 1995 to 1997. 2016 and 2017 data are preliminary. UNK: unknown.

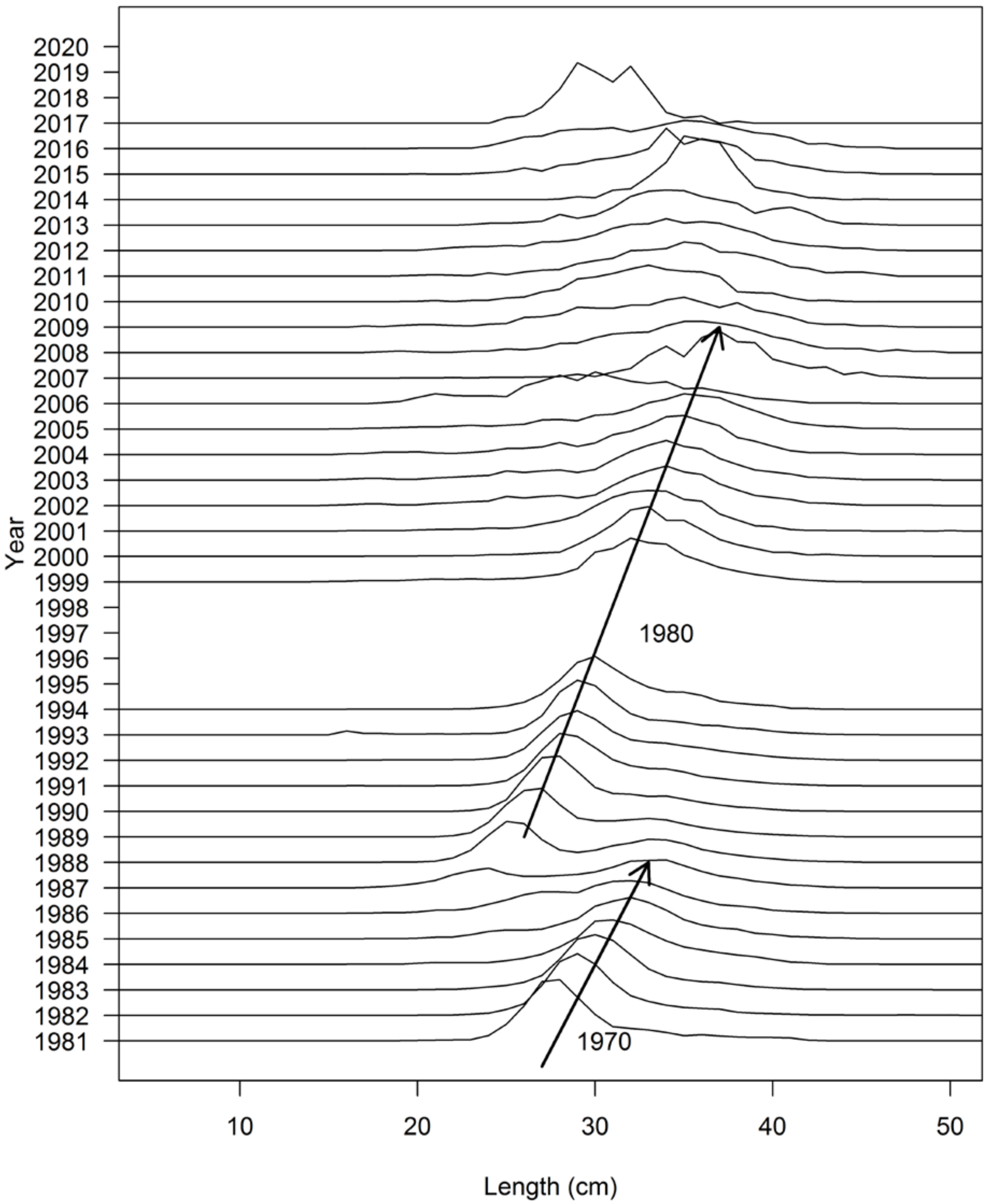

Figure 8. Commercial catch size frequency in percentage in Unit 1 from 1981 to 2017. No Redfish directed fishery took place from 1995 to 1997. 2016 and 2017 data are preliminary.

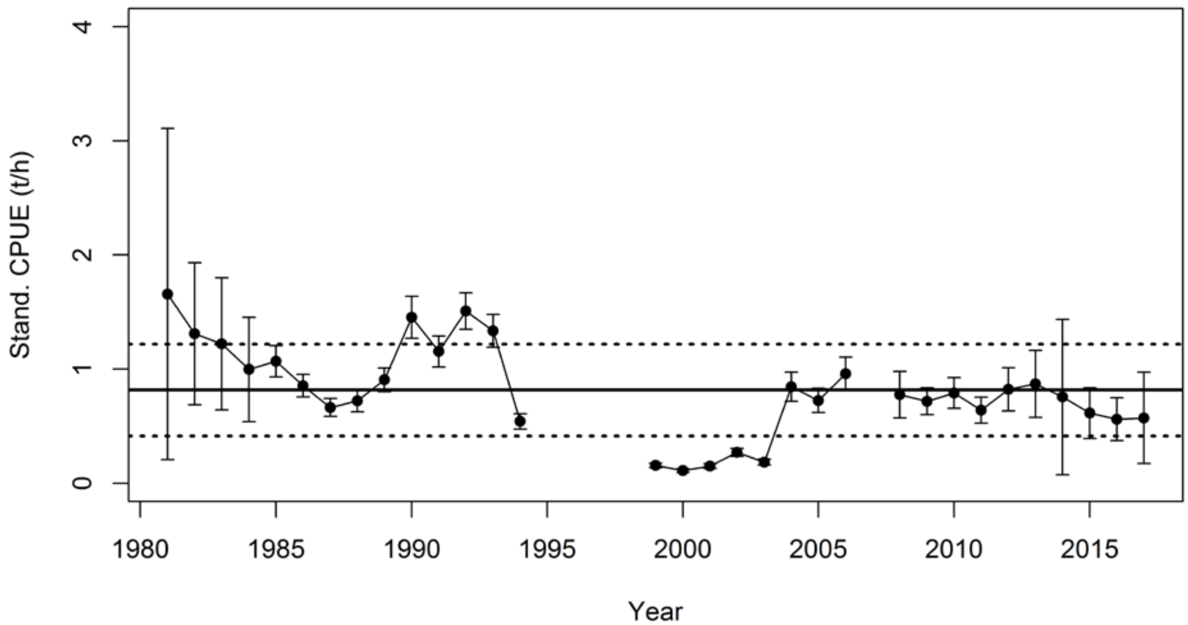

Figure 9. Standardized bottom trawl catch per unit effort (average CPUE ±95% confidence interval) in Unit 1 commercial fishery between May and October (1981–1994) and index fishery (1998–2017).

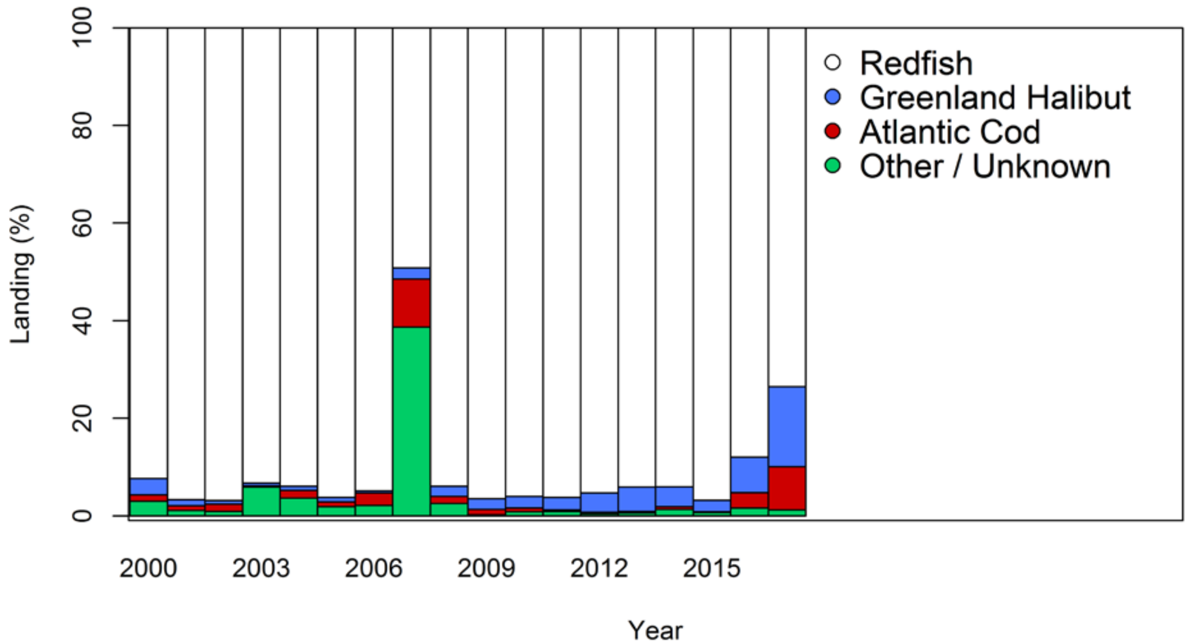

Figure 10. Redfish annual landings (biomass percentage) Unit 1 as a function of targeted species by the fishery from 2000 to 2017. 2016 and 2017 data are preliminary.

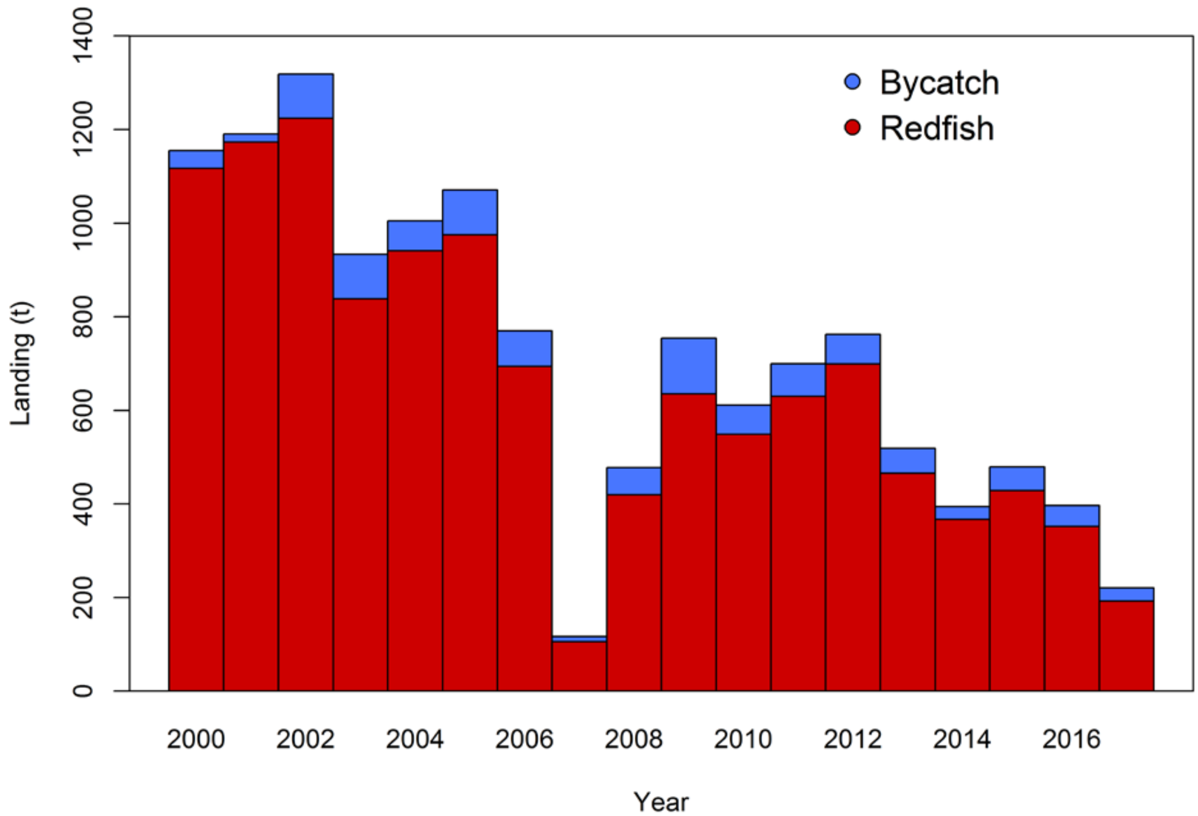

Figure 11. Annual landings of Redfish and bycatch (in tons) in the Redfish directed fishery in Unit 1 from 2000 to 2017. 2016 and 2017 data are preliminary.

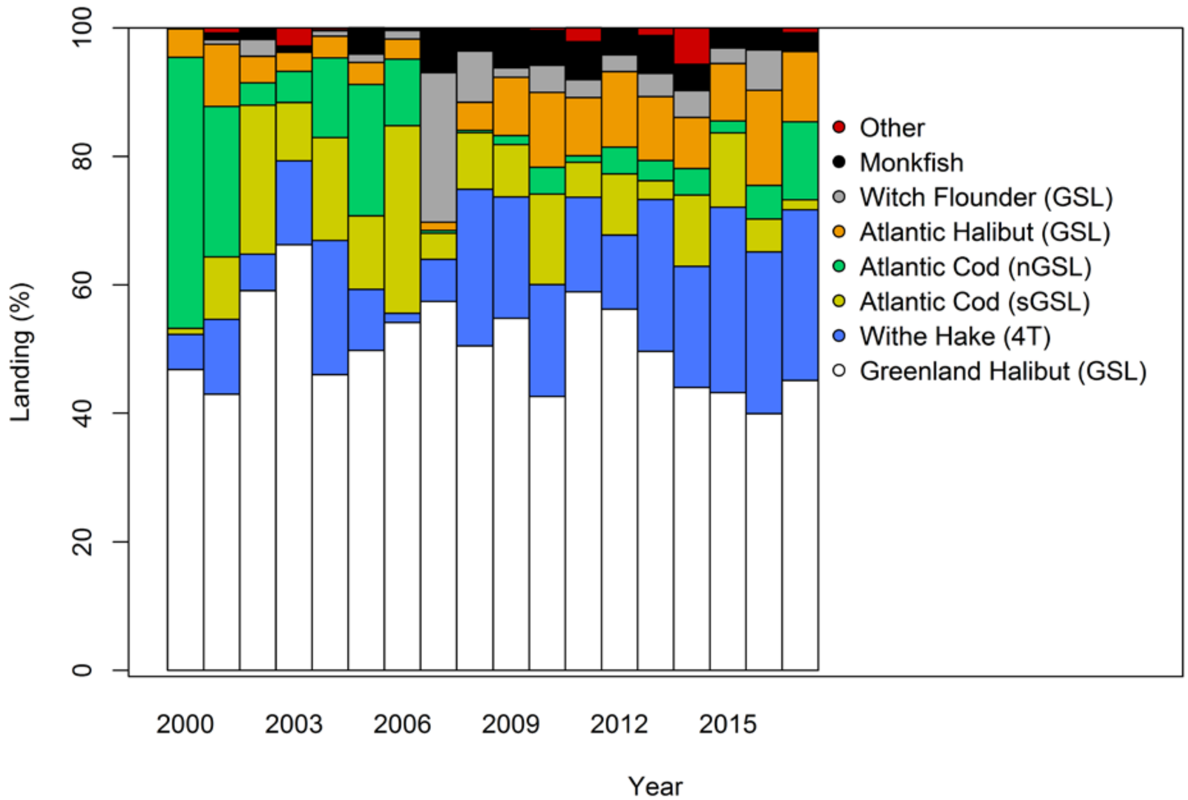

Figure 12. Annual bycatch landings (biomass percentage) by species captured in the Redfish directed fishery in Unit 1 from 2000 to 2017. 2016 and 2017 data are preliminary. Stocks are indicated in parentheses: GSL: Gulf of St. Lawrence, sGSL: South of Gulf of the St. Lawrence, nGSL: North of the Gulf of St. Lawrence.

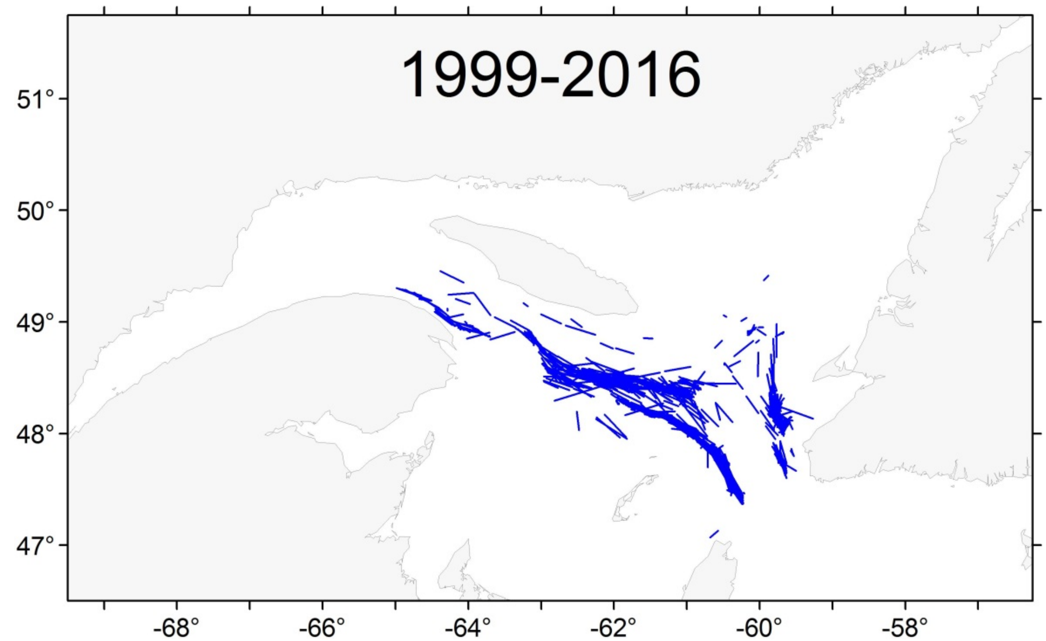

Figure 13. Position of the 1 633 fishing events sampled by at-sea observers in Unit 1 from 1999 to 2016.

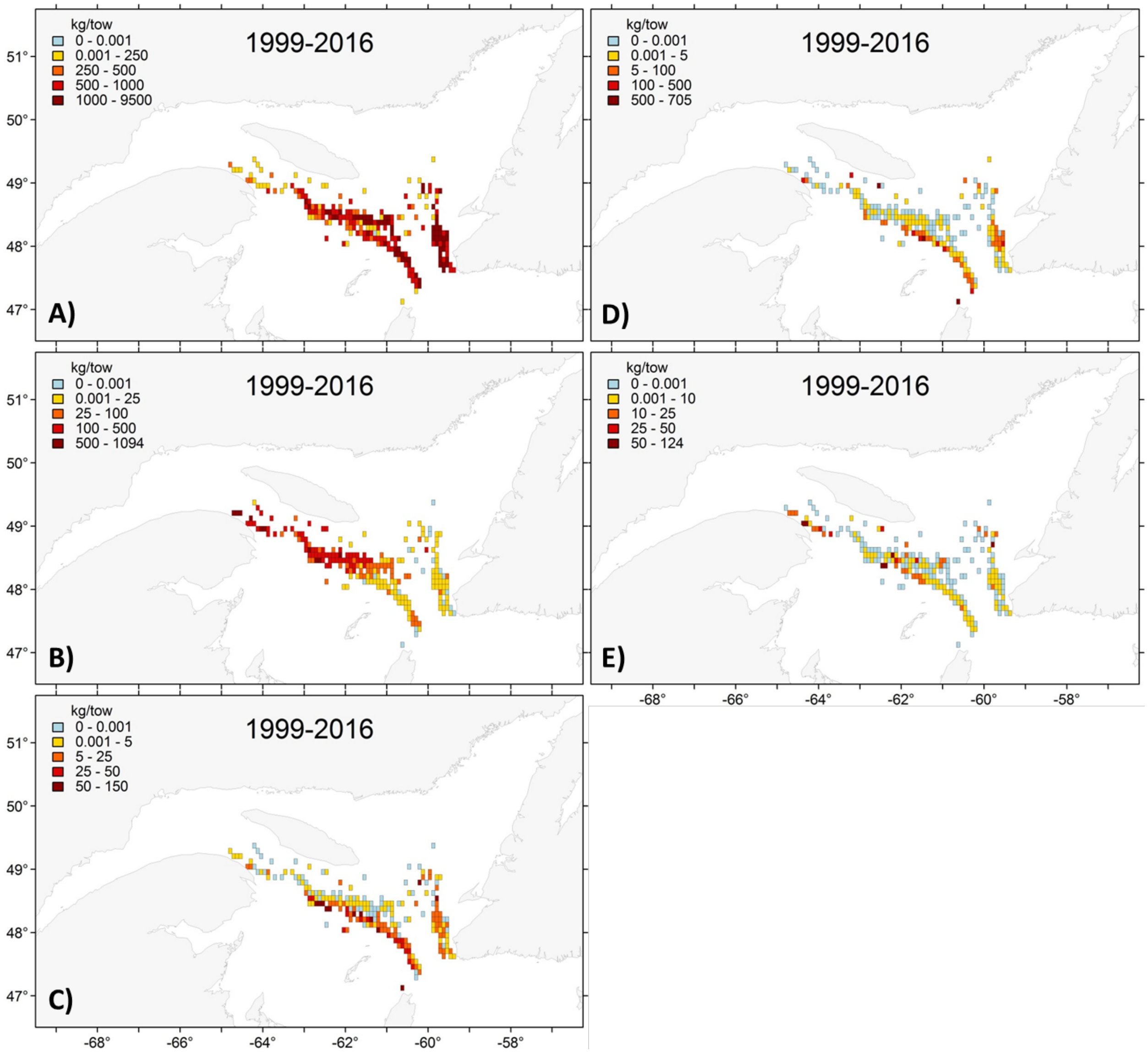

Figure 14. Catch rate (kg/tow) spatial distribution of Redfish (A), Greenland Halibut (B), White Hake (C), Atlantic Cod (D), and Atlantic Halibut (E) based on at-sea observer data in Redfish directed fishery from 1999-2016.

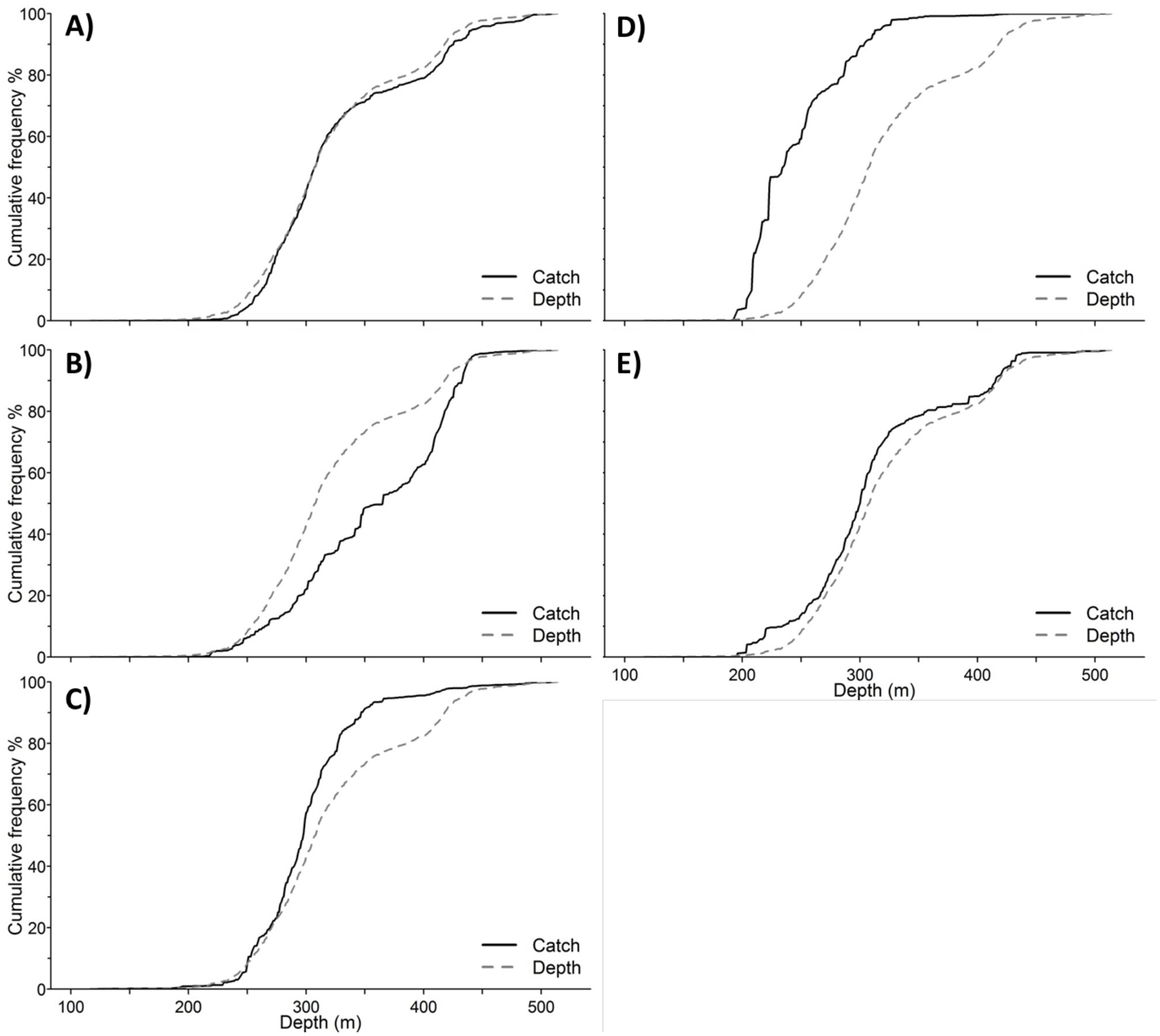

Figure 15. Cumulative frequency distribution (%) of Redfish (A), Greenland Halibut (B), White Hake (C), Atlantic Cod (D), and Atlantic Halibut (E) as a function of depth based on at-sea observer data in Redfish directed fishery from 1999-2016.

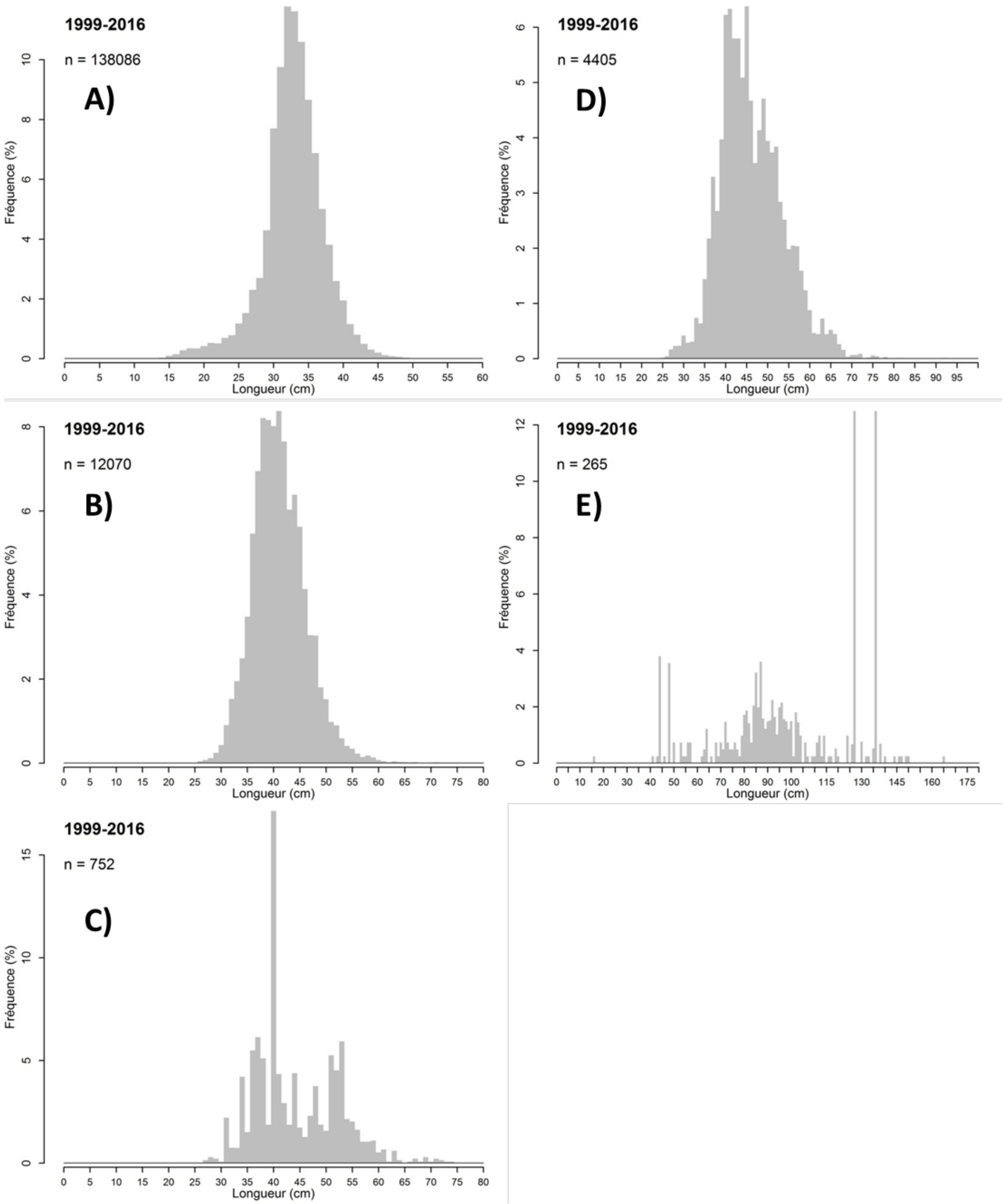

Figure 16. Size frequency distribution (%) of Redfish (A), Greenland Halibut (B), White Hake (C), Atlantic Cod (D), and Atlantic Halibut (E) based on at-sea observer data in Redfish directed fishery from 1999-2016. The numbers of fish measured are indicated (n).

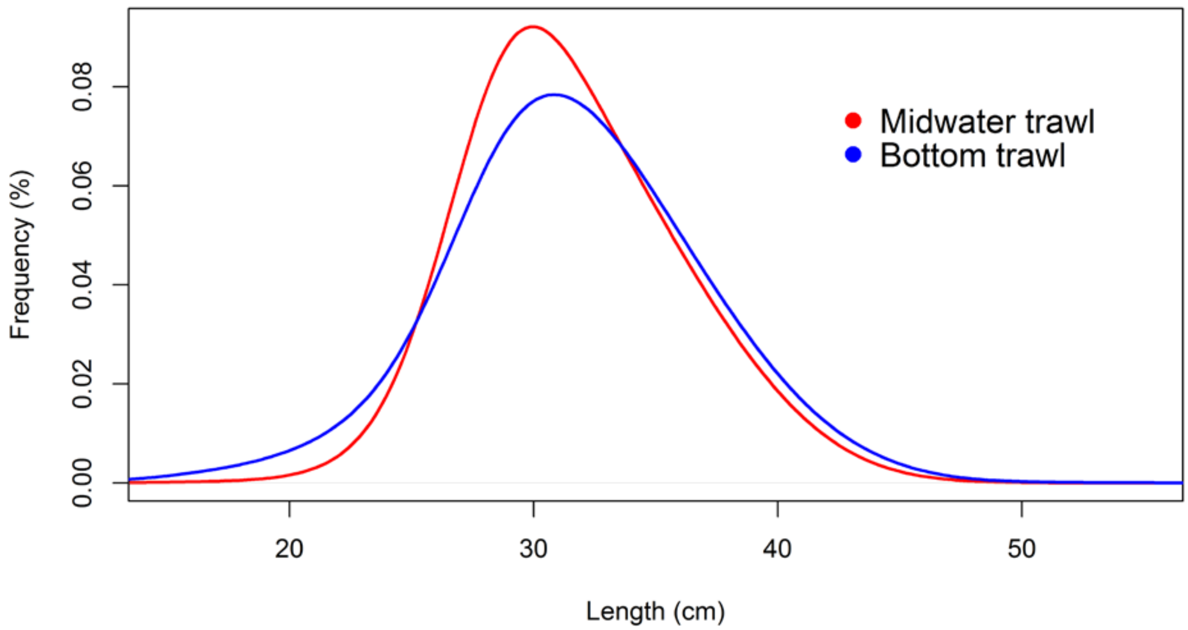

Figure 17. Raw data size frequency (%) collected by at-sea observers during 7 489 fishing activities in Units 1 and 2 between 1978 and 2016 using the midwater trawl in red and the bottom trawl in blue.

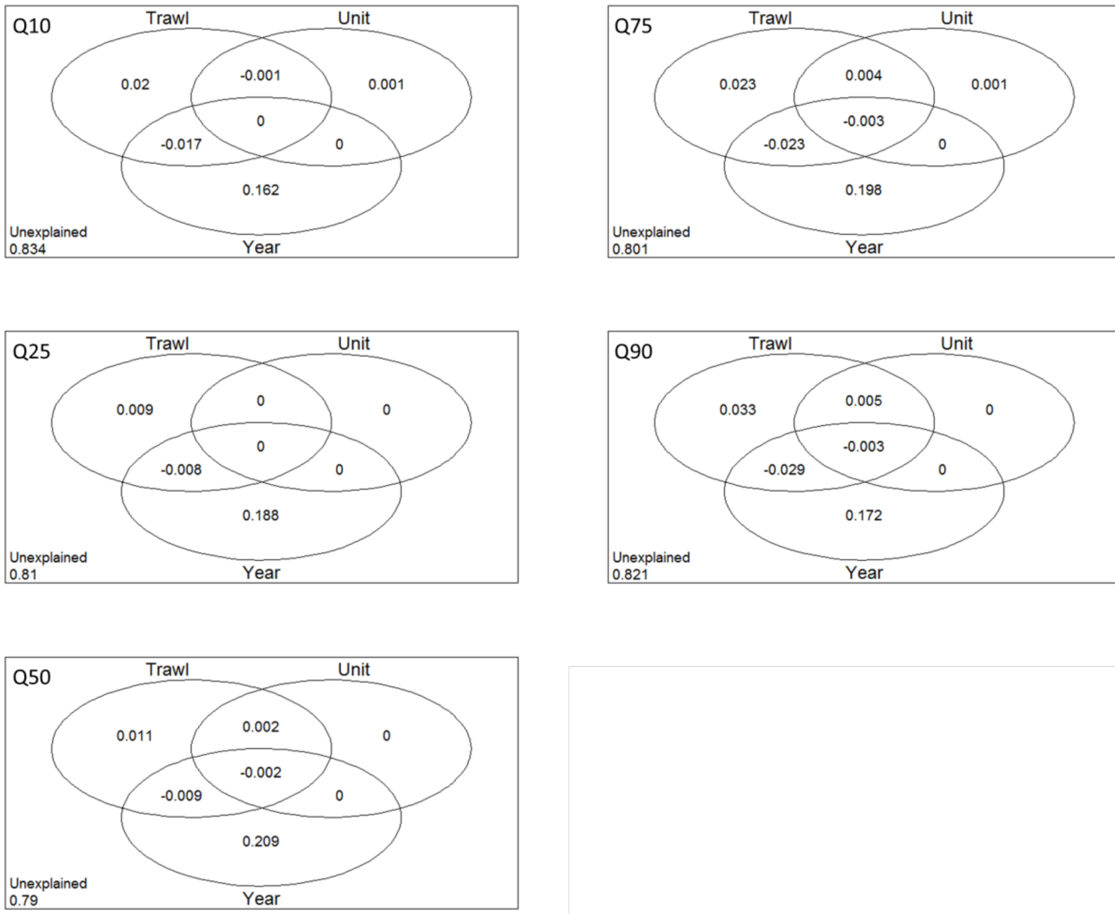

Figure 18. Illustration of the variation partitioning based on partial ANOVAs showing the fractions of the variance of size frequencies quantiles (Q10, Q25, Q50, Q75 and Q90) of captured Redfish that is explained exclusively and jointly by types of trawl, units and years (AdjR2). Residual variance is also indicated (Unexplained).

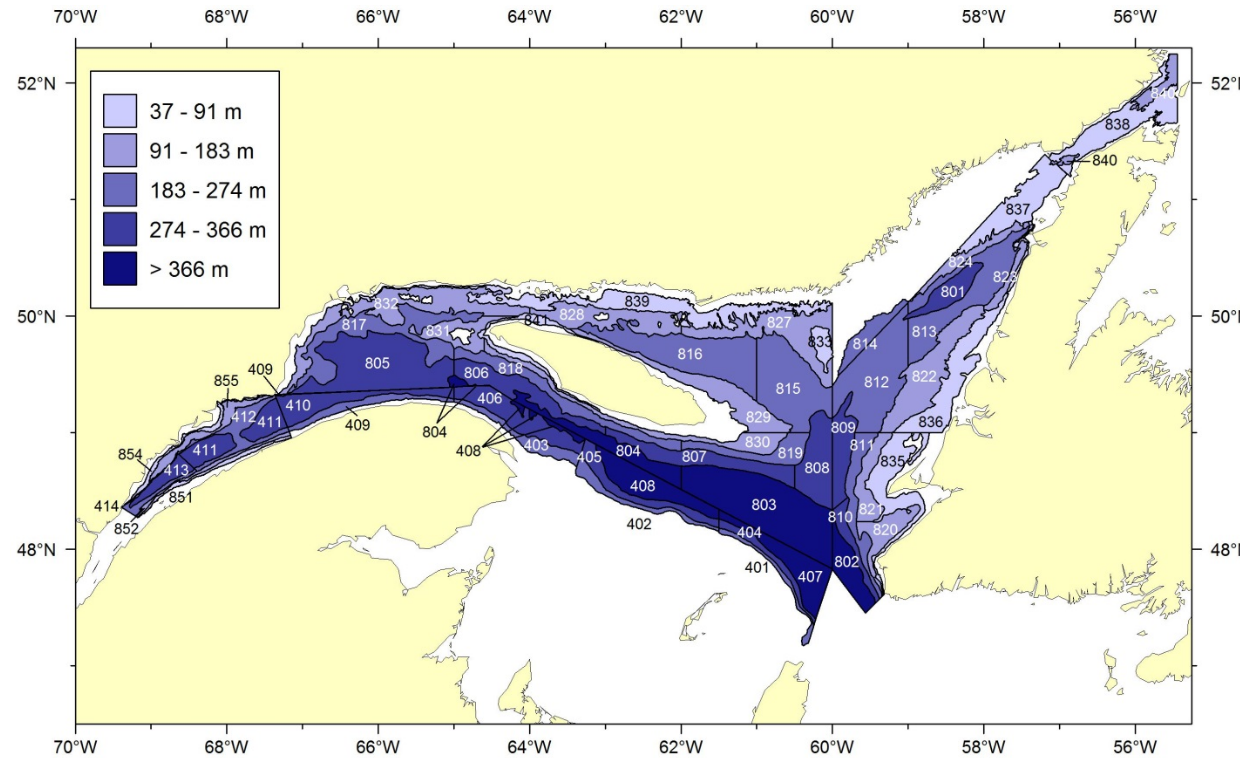

Figure 19. Stratification scheme used for the groundfish and shrimp research survey in the Estuary and northern Gulf of St. Lawrence.

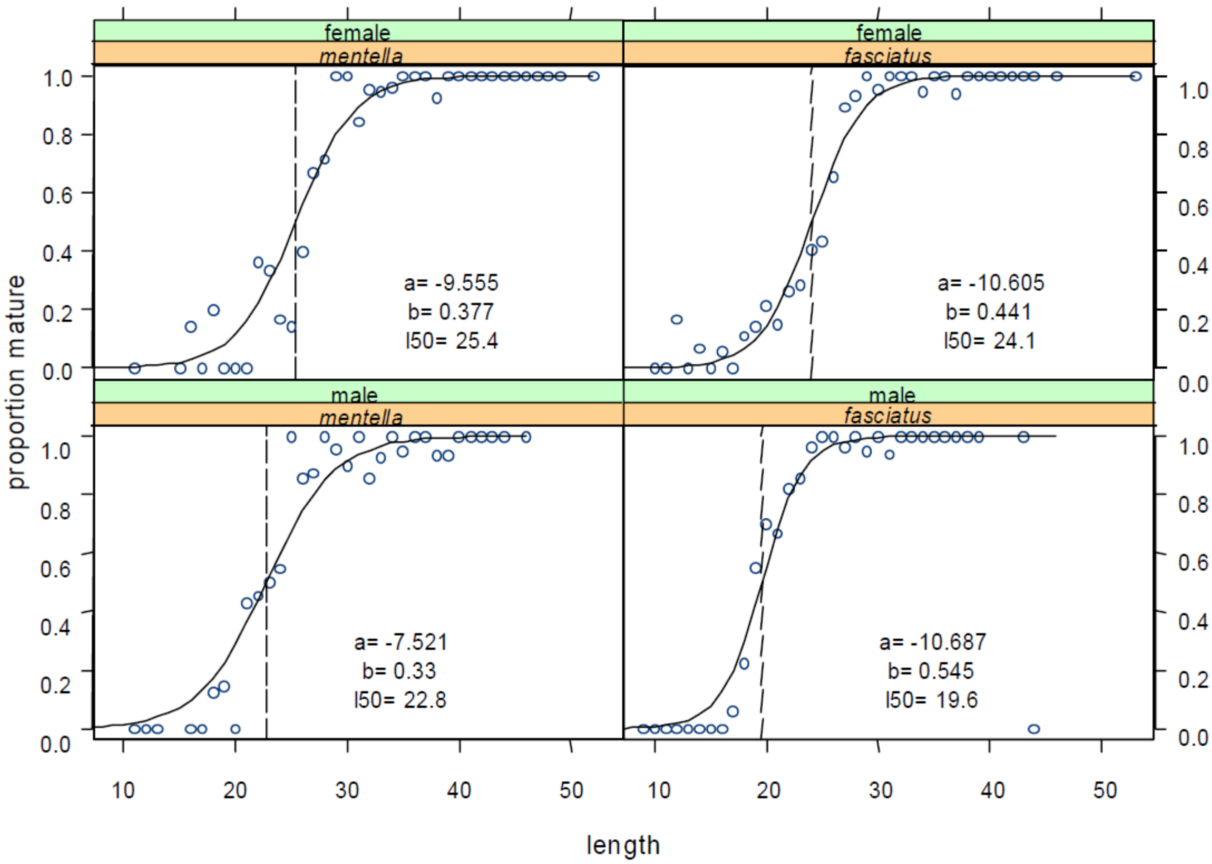

Figure 20. Redfish maturity ogive by species and sex from Gascon (2003). The proportion of mature individuals by size and the parameters of the logistic curve are indicated.

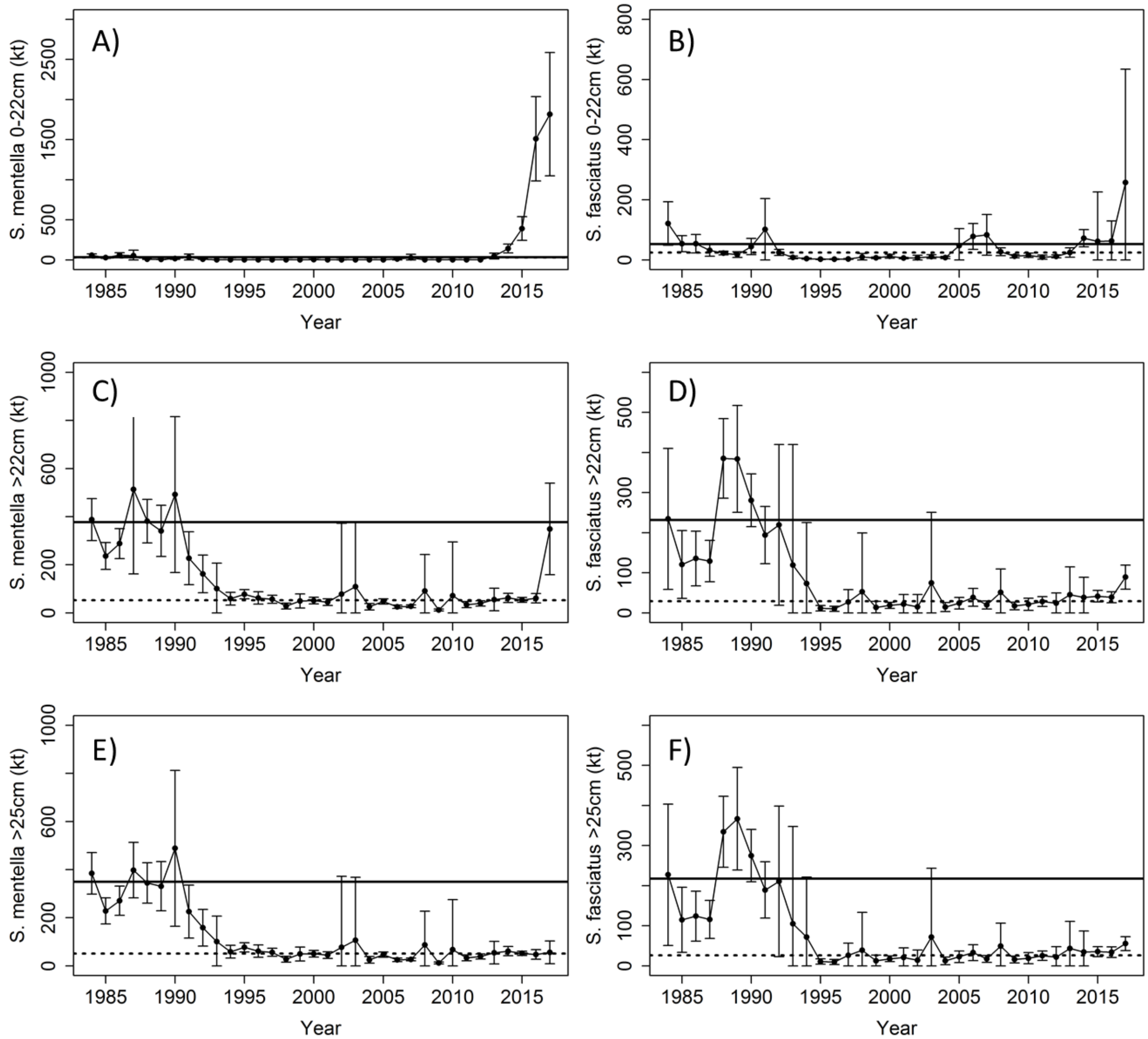

Figure 21. Minimum trawlable biomass in thousands of tons (kt) of S. mentella and S. fasciatus, 0-22 cm (A-B), >22 cm (C-D), and > 25 cm (E-F) in Unit 1 DFO survey from 1984 to 2017. The solid and dotted lines represent the mean for the 1984-1990 and 1995-2015 periods, respectively.

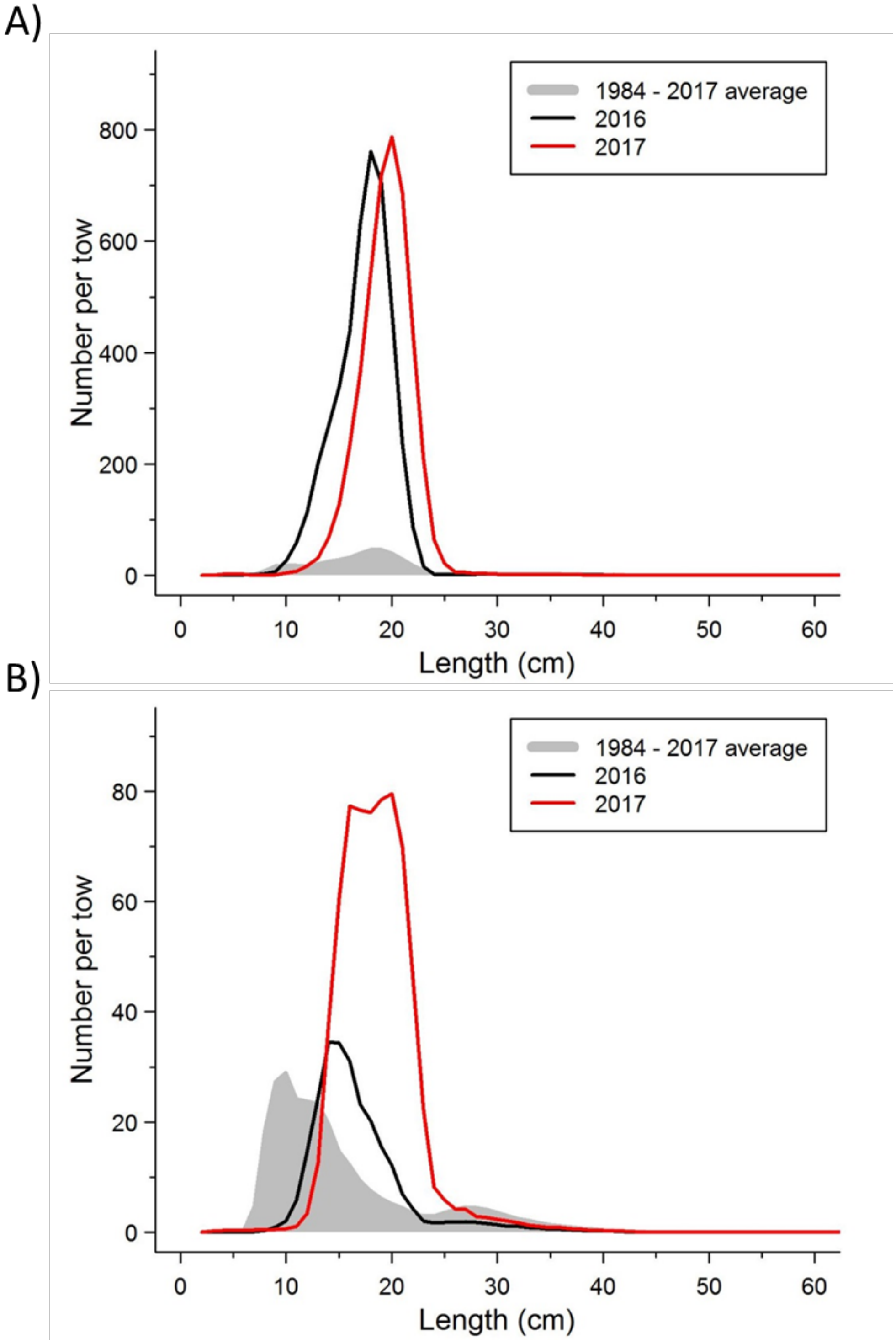

Figure 22. S. mentella (A) and S. fasciatus (B) size frequency in Unit 1 DFO research surveys from 1984 to 2017.

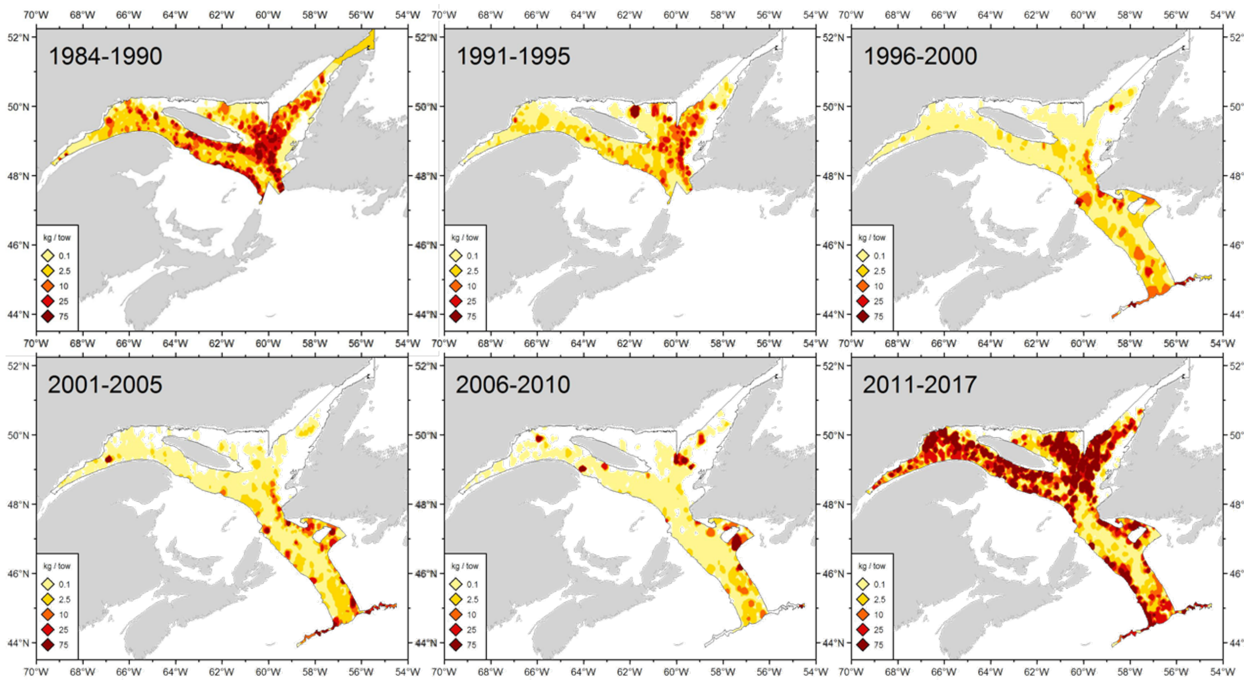

Figure 23. Catch rates distribution of immature S. mentella (kg/15-minute tow) in the Unit 1 and 2 surveys.

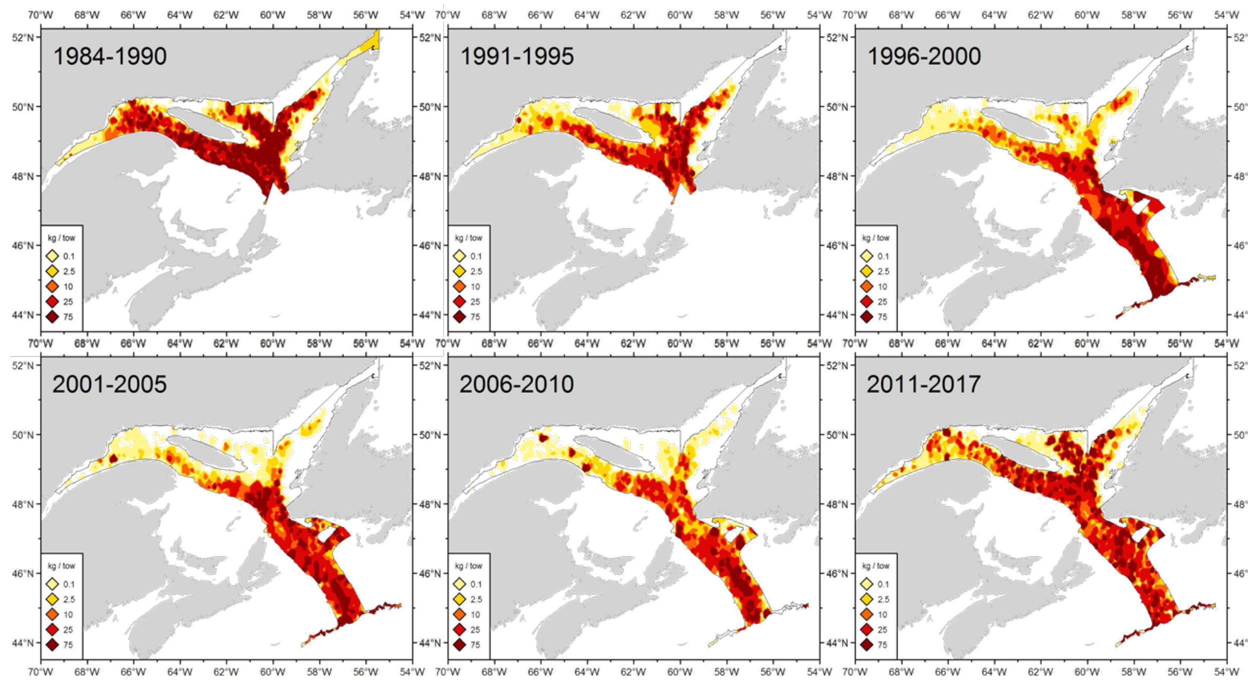

Figure 24. Catch rates distribution of mature S. mentella (kg/15-minute tow) in the Unit 1 and 2 surveys.

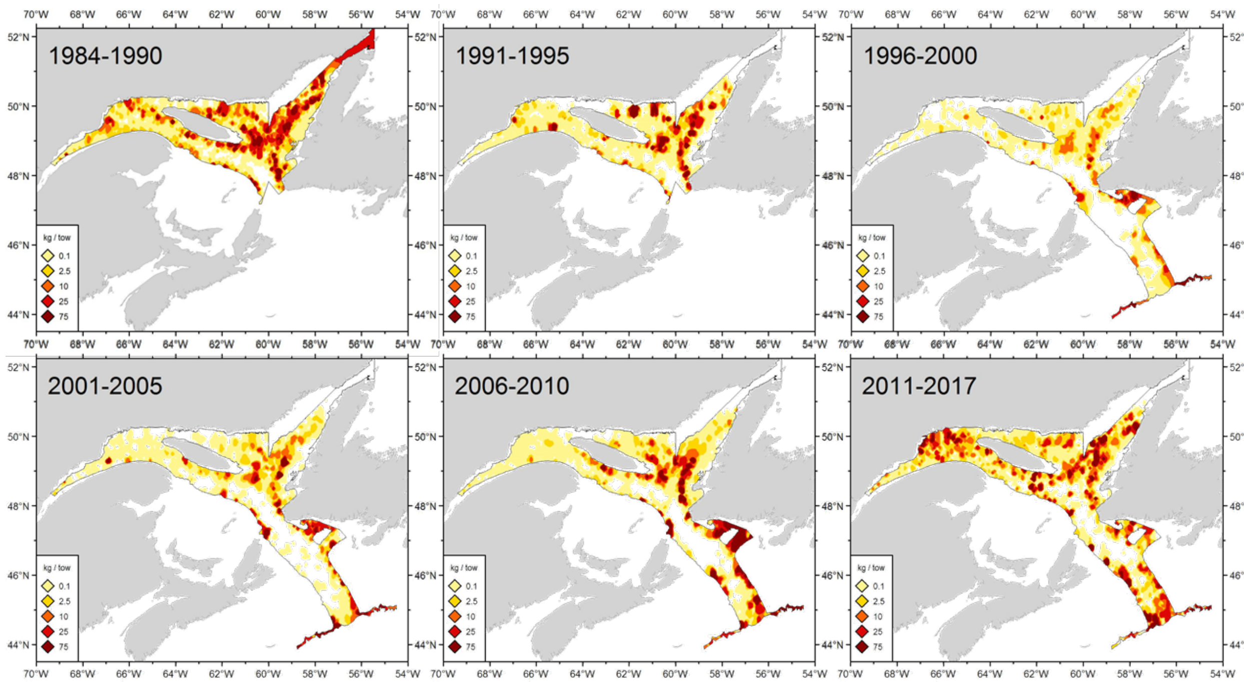

Figure 25. Catch rates distribution of immature S. fasciatus (kg/15-minute tow) in the Unit 1 and 2 surveys.

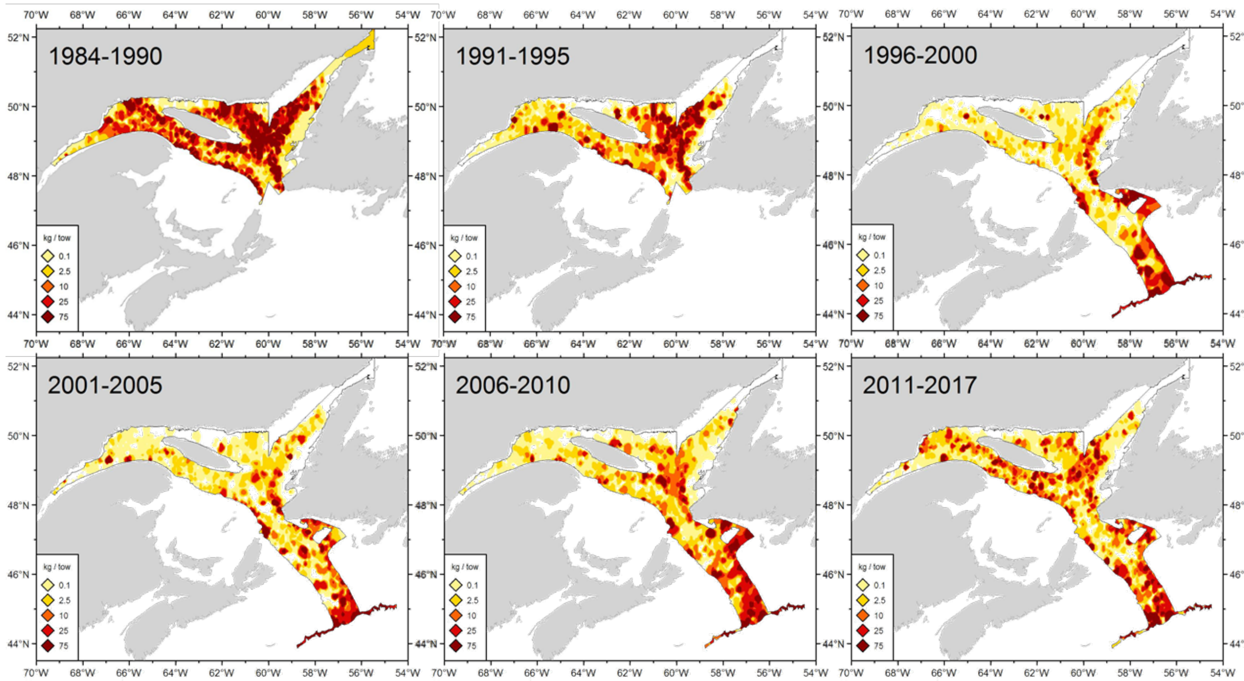

Figure 26. Catch rates distribution of mature S. fasciatus (kg/15-minute tow) in the Unit 1 and 2 surveys.

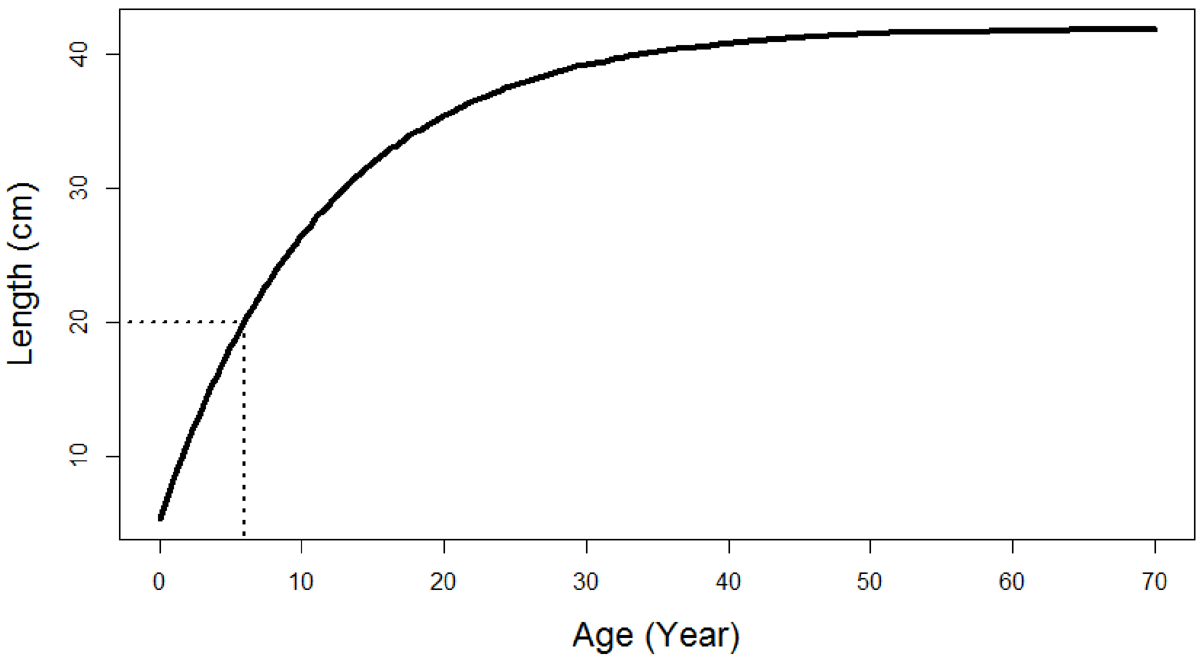

Figure 27. Von Bertalanffy growth curve illustrating Redfish relationship between length (cm) and age (year), and indicating that a 6 years old individual should measure 20 cm (dotted line).

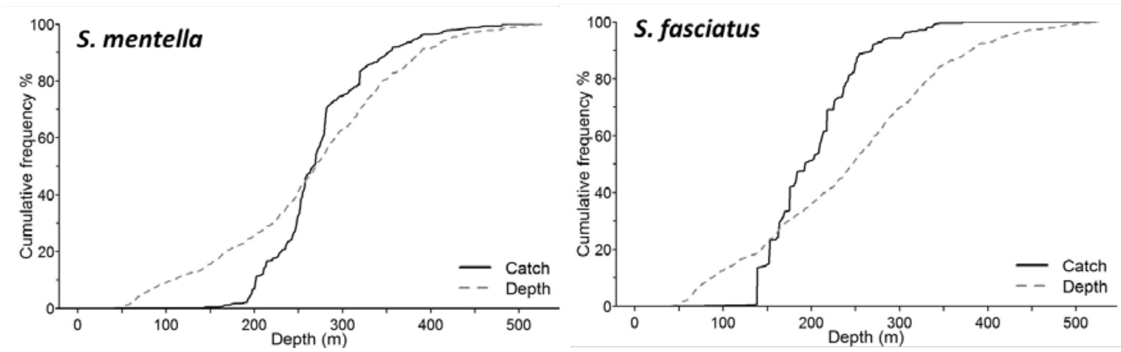

Figure 28. Depth distribution of S. mentella and S. fasciatus in Unit 1 DFO survey from 1990-2017. The solid and dotted lines represent the cumulative frequency of catches and survey stations, respectively, according to depth.

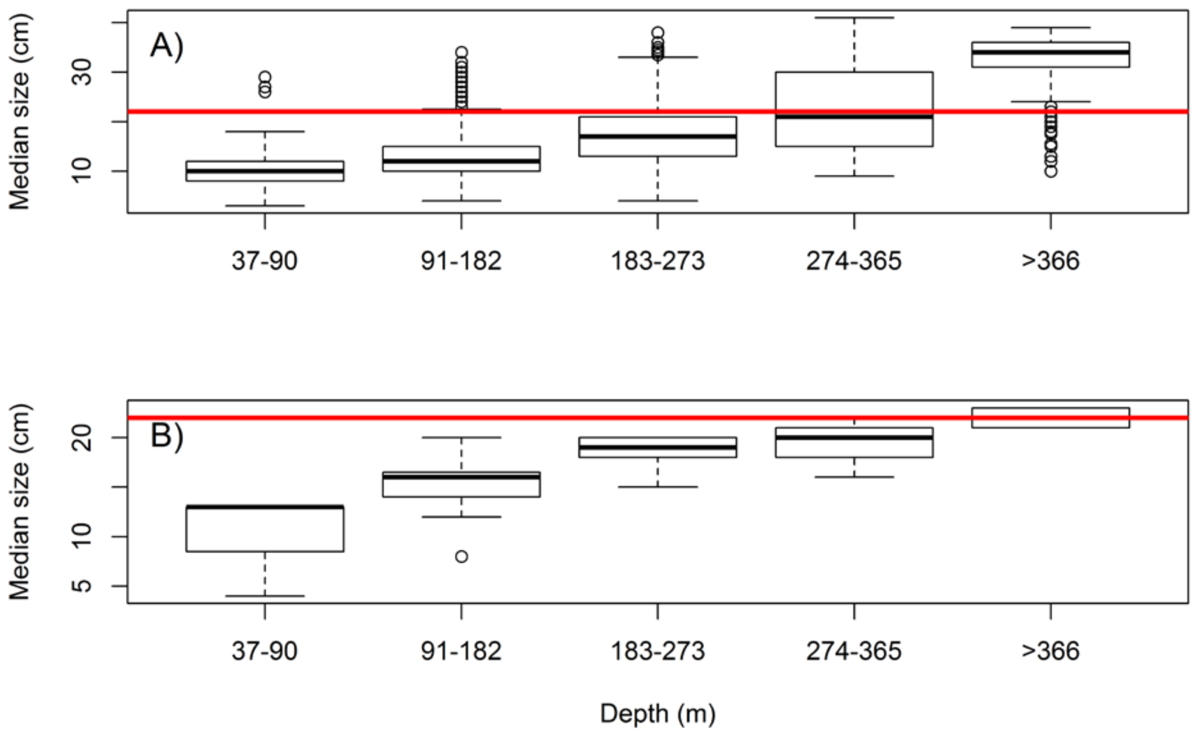

Figure 29. Illustration of the effect of depth on median size (Q50) of Redfish caught during the DFO survey from 1984-2017 in Unit 1 (A) and exclusively in 2017 (B). All depth categories (37-90, 91-182, 183-273, 274-365 and >366 metres were significantly different from one another, expect for the depth between 37-90 m and 97-181 m that were similar (p.value > 0.05). Larger Redfish were found deeper.

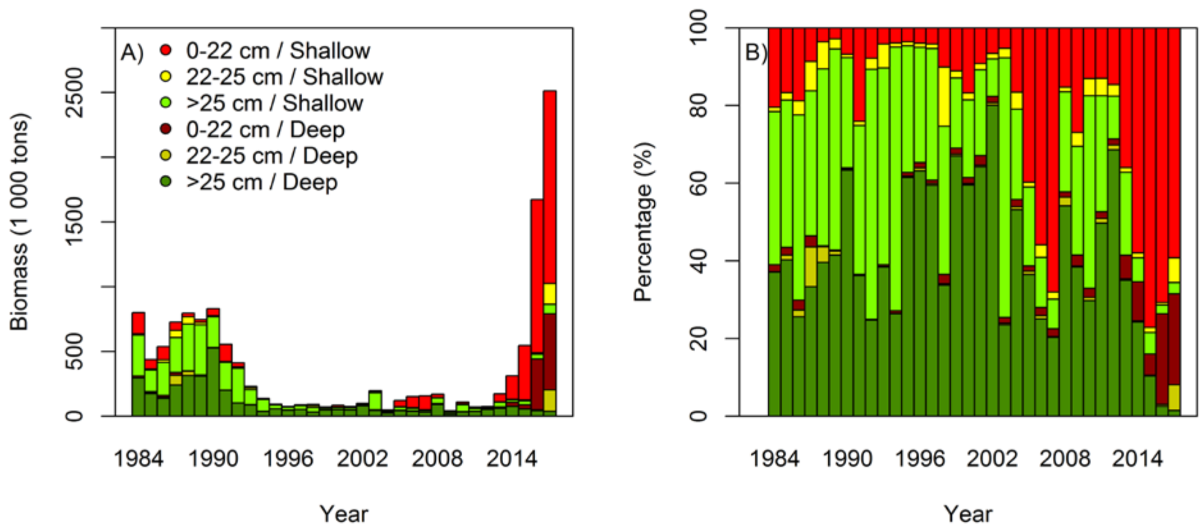

Figure 30. Redfish size classes (0-22 cm, 22-25 cm, and > 25 cm) distribution between "Deep" and "Shallow" areas in biomass (A) and percentage (B) in Unit 1 DFO survey from 1984-2017.

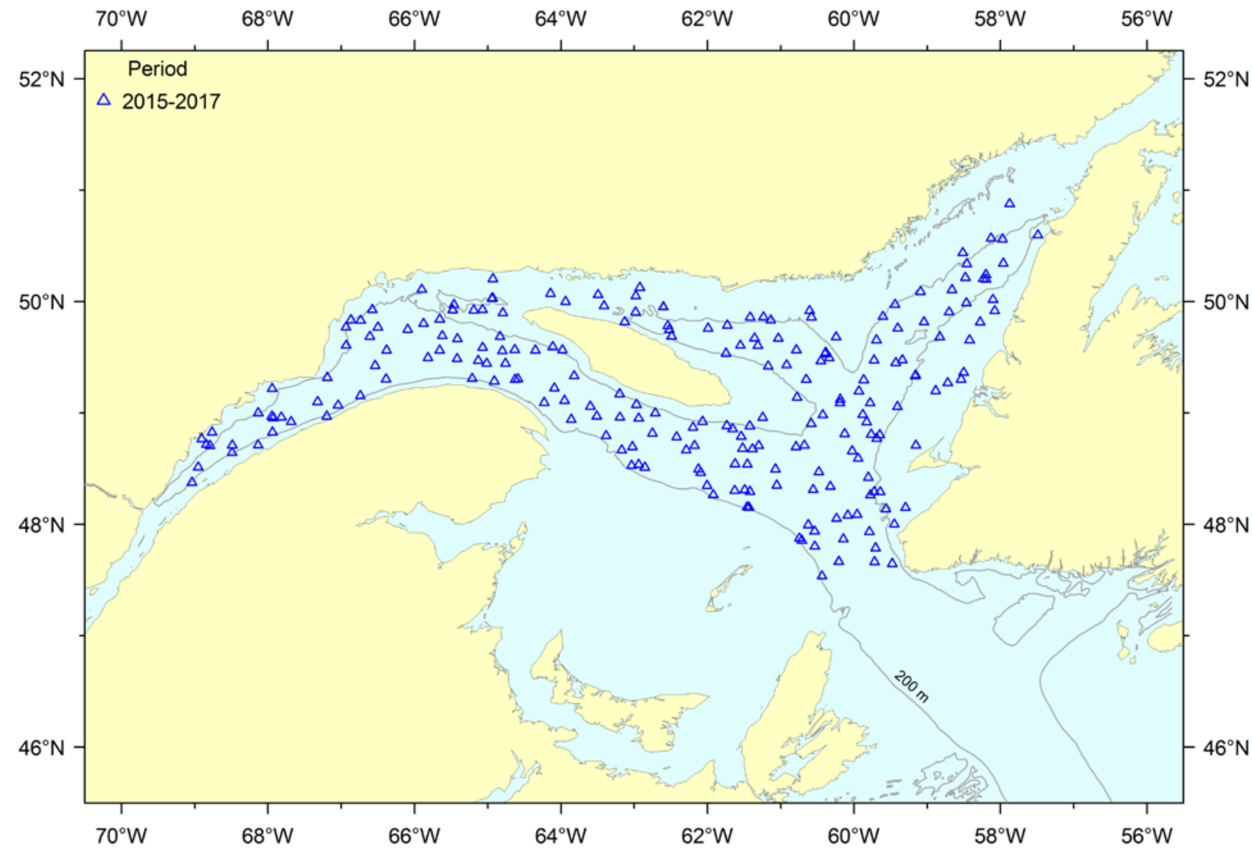

Figure 31. Spatial distribution of the 2 172 Redfish stomachs collected in August 2015 to 2017 during DFO research survey in Unit 1.

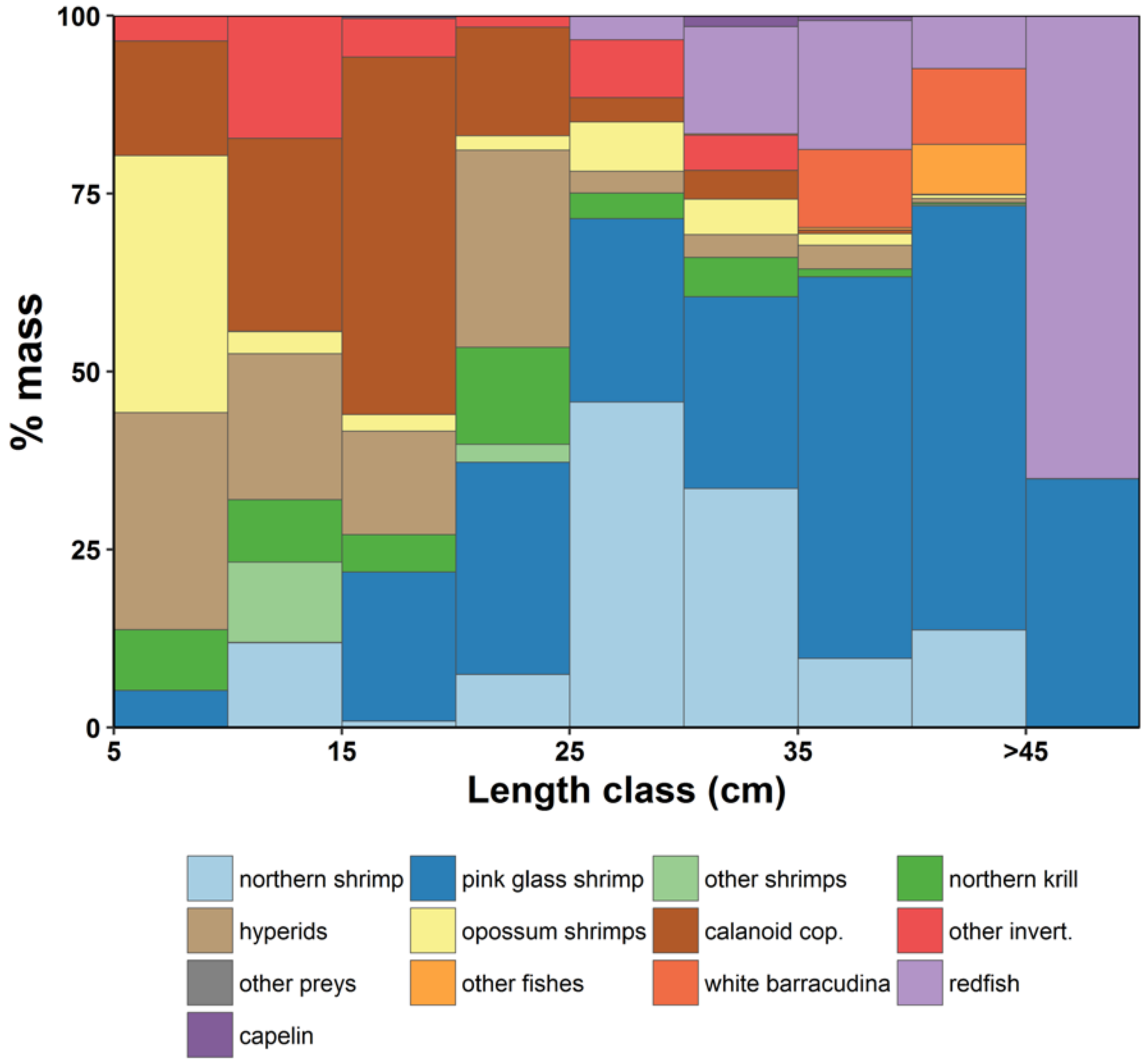

Figure 32. Description of Redfish summer diet in Unit 1 according to individual size, the mass percentages of preys are indicated.

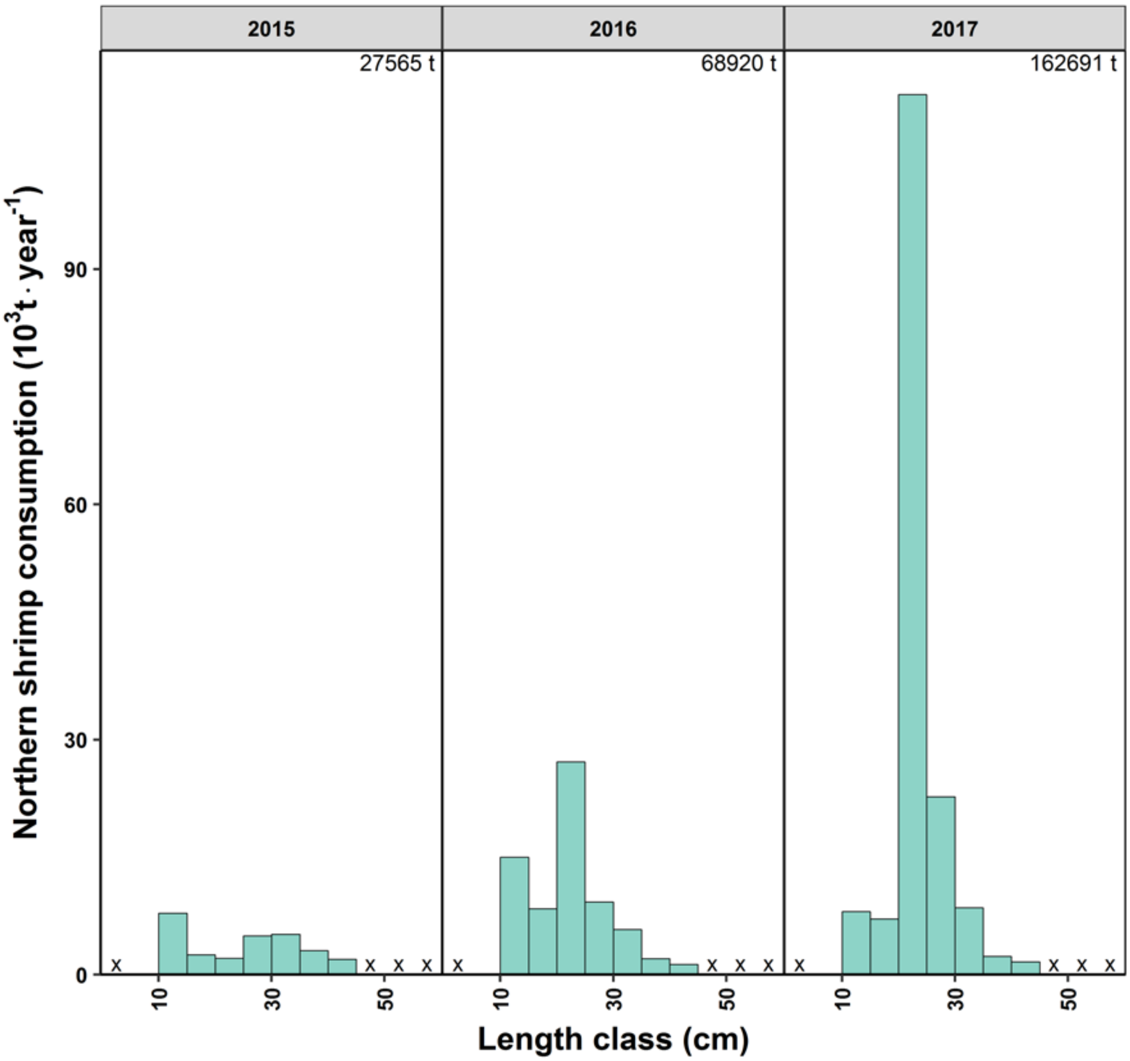

Figure 33. Estimated annual Northern Shrimp consumption by Redfish of different length classes for 2015 to 2017. The values provided in the upper part of the panels are the total estimated consumption for a given year. An "x" symbol denotes less than 20 stomachs collected for a given length class. Estimating annual consumption for these length classes is therefore impossible or unrepresentative.