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Unit 1 Redfish (*Sebastes mentella* and *S. fasciatus*) stock status in 2019 and updated information on population structure, biology, ecology, and current fishery closures

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Foreword

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

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ABSTRACT

The Redfish fishery 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 the recruitment of one or several strong year-classes. A sudden drop in landings and the absence of strong recruitment led to the establishment of a moratorium in 1995. Redfish fishing is still under moratorium in Unit 1 and an index fishery has been authorized since 1998. The total allowable catch (TAC) for this fishery has been 2,000 tonnes (t) per management year since 1999. Since 2018, an experimental fishery was established with an additional TAC of 2,500 t for 2018-2019 and 3,950 t for 2019-2020, which can be harvested all year round. The objectives of the experimental fishery were to target *S. mentella*, which is actually more abundant than *S. fasciatus*, to investigate ways to limit bycatch and the harvesting of undersize Redfish, and to better understand the spatio-temporal distribution of Redfish and bycatch species.

According to surveys conducted in the northern Gulf of St. Lawrence (nGSL), abundance and biomass indices for *S. mentella* and *S. fasciatus* were low and stable since the mid-1990s. Abundance of juvenile Redfish from the 2011 to 2013 cohorts has increased substantially in the Fisheries and Oceans Canada (DFO) research surveys. These cohorts are the most abundant ever observed in the nGSL.The minimum trawlable biomass of both species combined increased by 72% since the last biomass estimate in 2017, to reach 4.3 million t in 2019. These individuals are largely dominated by *S. mentella* with a genetic identity specific to Units 1 and 2. Unit 1 includes Divisions 4RST and from January to May Subdivisions 3Pn4Vn while Unit 2 includes Subdivisions 3Ps4Vs, Subdivisions 4Wfgj, and from June to December Subdivisions 3Pn4Vn. In the summer of 2019, the modal length of Redfish was 23 cm, slightly over the regulatory minimum size of 22 cm. If the anticipated growth of these cohorts continues, by 2020, 51% of the individuals of the 2011 cohort (62% biomass) should be larger than 25 cm.

In support of the Redfish stock assessments (*S. mentella* and *S. fasciatus*) of Units 1 and 2 in 2020, this document describes the data and methods used to analyse the status of the stocks found in Unit 1 and updates information on population structure, biology, ecology, and current fishery closures, which fall under the responsibility of the Science Branch of DFO Quebec Region.

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 also found, but are rare in the region (Nozères et al. 2010) and are not be discussed further in this document. *S. mentella* and *S. fasciatus* are members of the Scorpenidae family and are difficult to differentiate morphologically.

In the late 1950s, a directed fishery for Redfish was developed in the Gulf of St. Lawrence (GSL) and the Laurentian Channel outside the GSL. Prior to 1993, the Redfish fishery in the Gulf and neighboring areas was managed as three management Units established by the Northwest Atlantic Fisheries Organization (NAFO): Divisions 4RST, Division 3P, and Divisions 4VWX. In 1993, these management Units were redefined to ensure a stronger biological basis for management by taking various factors into account, including movement of Redfish inhabiting the GSL in summer to the Cabot Strait in winter. The resulting management Units were divided as follows: Unit 1 included Divisions 4RST and from January to May Subdivisions 3Pn4Vn; Unit 2 included Subdivisions 3Ps4Vs, Subdivisions 4Wfgj, and from June to December Subdivisions 3Pn4Vn; and Unit 3 included Subdivisions 4WdehklX (Figure 1A and B).

The Redfish fishery in the GSL was marked by three intense exploitation episodes (1954-1956, 1965-1976, and 1987-1992). The first total allowable catches (TAC) for Redfish, set according to the 1993 management structure, were 60,000 t in Unit 1 and 28 000 t in Unit 2. After rapid decreases in landings in 1993 and 1994, a moratorium was declared in Unit 1 in 1995. An index fishery started in 1998 with 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 of landings, mandatory hail reports upon departure and arrival, imposition of a level of coverage by at-sea observers (ASO, 10-25%) and, implementation of a bycatch protocol. Closure periods were also introduced 1) to protect Redfish copulation (fall) and larval extrusion (spring) periods, 2) to minimize catches of Unit 1 Redfish moving in NAFO Subdivisions 3Pn4Vn at the end of fall and winter, and 3) to protect Atlantic Cod (*Gadus morhua*) spawning (NAFO Divisions 4RS). In addition, since the index fishery was introduced in 1998, fishing has only been allowed between longitudes 59°W and 65°W at depths > 182 m (100 fathoms) and to avoid Greenland Halibut (*Reinhardtius hippoglossoides*) bycatch, and an area has been closed in NAFO Division 4T since August 2009 (Figure 2). Since 2018, an experimental fishery in Unit 1 was established with an additional TAC of 2,500 t for 2018-2019 and 3,950 t for 2019-2020, which can be harvested all year round. The objectives of the experimental fishery were to target *S. mentella*, actually more abundant than *S. fasciatus*, to investigate ways to limit bycatch and harvest of undersize Redfish, and to better understand the spatio-temporal distribution of Redfish and bycatch species.Historically, the fishing industry has not discriminated *S. mentella* and *S. fasciatus,* although conservation objectives are species-specific. Since 2018, in Unit 1 and 2, information has been collected in the fishery to determine the species composition of catches (see section SPECIES IDENTIFICATION IN RESEARCH SURVEYS AND THE COMMERCIAL FISHERY for more details).

In 2010, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) identified four designable units (DU) in the Atlantic Canadian waters for the two main *Sebastes* species and three of these are located in Unit 1. The Deepwater Redfish of Gulf of St. Lawrence – Laurentian Channel Population (*S. mentella*), the Acadian Redfish Atlantic Population (*S. fasciatus*), and the Acadian Redfish Bonne Bay Population (*S. fasciatus*) were classified as endangered, threatened, and special concern, respectively (COSEWIC 2010, DFO 2011). The Bonne Bay population was considered of special concern because of its limited distribution range. According to the 2010 biomass 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 (LRP).

Redfish recruitment success is highly variable, with large year classes observed at irregular intervals. The 1980 cohort was the last important cohort in Unit 1 until three large cohorts arrived in 2011, 2012, and 2013. In 2019, the biomass of both species combined increased by 72% compared to the 2017 estimate. This increase was mostly due to *S. mentella.* In the summer of 2019, the modal length of Redfish was 23 cm. If the anticipated growth of these cohorts continues, by 2020, 51% of the individuals of the 2011 cohort (62% biomass) should be larger than 25 cm.

The stock assessment peer review meeting of Units 1 and 2 Redfish (*S. mentella* and *S. fasciatus*) took place on January 20-22nd, 2020. This research document supports the most recent Science advisory report for Unit 1 (DFO 2020), which fall under the responsibility of the Science Branch of Fisheries and Oceans Canada (DFO) Quebec Region. An update on population stocks status, genetic structure, species identification, biology, ecology, landings, bycatch, and current fishery closures are also presented. The previous research document on this topic was published in 2019 (Senay et al. 2019).

BACKGROUND

SPECIES IDENTIFICATION IN RESEARCH SURVEYS AND THE COMMERCIAL FISHERY

In Canada, Redfish species are morphologically very similar and often not distinguished in both scientific surveys and the commercial fishery, thus quotas are not species-specific even if conservation objectives are. In Unit 1, many studies have focused on finding morphological and genetic features to allow species identification. Starting in 2010, the Redfish stock assessment in Units 1 and 2 described trends for each species separately (DFO 2010). Since 2018, in Units 1 and 2, information has been collected in the fishery to determine catch species composition.

S. mentella and *S. fasciatus* are morphologically very similar and no single trait can discriminate species at the individual level. These species may however be discriminated using meristic traits and fine morphological differences at the catch level or genetics at the individual level (see section STOCK DEFINITION AND SPECIES IDENTIFICATION USING GENETICS AND GENOMICS for more details). In the recent decades, these different approaches to discriminate species have been improved and now allow identification at the catch level during research surveys at an affordable cost.

Several studies were performed as part of the multidisciplinary research program on Redfish between 1995 and 1998 (Gascon 2003) in an effort to select the most efficient method of discriminating between both species at a reasonable cost. Three different methods were traditionally used to distinguish the two species in the Northwest Atlantic: the number of soft rays on the anal fin (AFR), the extrinsic gas bladder muscle passage patterns (EGM), and the genotype at the malate dehydrogenase locus (*MDH-A**). In general, *S. mentella* is characterized by the homozygous genotype *MDH-A*11*, an EGM between ribs 2 and 3, and an AFR ≥ 8. *S. fasciatus* usually has the homozygous genotype *MDH-A*22,* an EGM between ribs 3 and 4, and an AFR ≤ 7 (Rubec et al. 1991, Gascon 2003).Unfortunately, the coherence among these three methods in a given individual is variable. Agreement between the measures can be high (97%) in allopatric zones (regions with one species), but decreases substantially in sympatric zones (regions with both species) such as Units 1 and 2 (56% and 68% respectively; Valentin et al.

2006). Units 1 and 2, also showed 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), presumably attributed to historical introgressive hybridization between *S. mentella and S. fasciatus*. Thus, a forth method that could tackle the issue of introgression had to be used to discriminate species and be used as a reference for the three first method. Roques et al. (1999) developed eight microsatellite markers capable of discriminating species reliably. Those markers confirmed the capacity of the AFR method to discriminate species at the catch level. The AFR count method using an external character that can be assessed rapidly, without the use of specialized tool or complex training, is optimal for efficiency in surveys. The two other methods, *MDH-A** or the EGM, require samples to be processed in the lab or complex dissection to expose the muscle, respectively.

The AFR count was used to provide species-specific information for stock assessment since 2010, but the methodology was never described in details in previous research documents. The distribution of AFR numbers is species-specific, but there is overlap for *S. mentella* and *S. fasciatus*. AFR is a meristic trait and there are five possible numbers (or states) of AFR in these *Sebastes* species (six to ten rays). The proportion of every state in a given group of fish (observed catch) can be represented by a multinomial distribution of AFR proportions. If the theoretical multinomial distribution for both species is known beforehand, we can also create a theoretical distribution for every possible mix of both species by weighting the proportion of both species' distribution according to their contribution to the mix. This creates a unique theoretical multinomial distribution for all possible species compositions with which to compare the catch AFR distribution by calculating the Chi square criterion for all possibilities. The lowest calculated Chi square represents the most likely species composition of the observed catch.

To be able to use the method, two sets of species-specific theoretical distributions were estimated for each Unit. To do so, 4,342 specimens were harvested during the multidisciplinary program on Redfish (Gascon 2003). In Unit 1, 1,562 individuals were collected (in August and September from 1994 to 1997) and 2,780 in Unit 2 (in July-November from 1995 to 1998). The 4,342 individuals were first assigned to a species based on genotype at the *MDH-A** locus, considering heterozygotes as belonging to *S. mentella*. Indeed, Valentin et al. (2006) demonstrated that the geographic and bathymetric distribution of heterozygotes (*MDH-A*12*) and their EGM and AFR patterns resembled those observed for *S. mentella* (*MDH-A*11*), which justifies the choice of assigning the heterozygotes (*MDH-A*12*) to *S. mentella* in the absence of other distinguishing criteria. Then, for each species, individuals belonging to each class of AFR were counted to establish the theoretical distribution of AFRs by species for each Units independently. This allowed the development of two different sets of theoretical distributions to estimate species composition depending on the Unit from which the catch originated (Table 1).

The AFR method was first used in 2010, as part of the stock assessment in Units 1 and 2 (DFO 2010) based on data collected since 1984. Species identification based on AFR has been performed for research surveys, using a sample of 30 random Redfish per length classes in order to estimate species composition in each tow. As of 2018, a similar sampling protocol has been implemented for the commercial fishery. Species composition of fishery catches is estimated based on subsampling of 50 individual Redfish for AFR per catch sample during routine sampling by DFO port samplers or ASO. The R code (R Core Team 2019) to estimate species composition per sample for each Unit based on AFR is presented in Appendix A.

STOCK DEFINITION AND SPECIES IDENTIFICATION USING GENETICS AND GENOMICS

In the last two decades, analyses of population genetics highlighted reproductively isolated entities in Redfish. The genetic markers used to assess population structure had critical implications for fisheries management including the redefinition of management Units. In 1993, Redfish management Units were redefined to provide a stronger biological basis (i.e. population structure) and take various factors into account, including the winter movement to the Cabot Strait area (see section FISHERY CLOSURES for more details). The resulting management Units were divided as follows: Unit 1 included NAFO 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 A and B).

Genetic or genomic markers also allowed for species identification at the individual level using either microsatellites or single nucleotide polymorphisms (SNPs). The 13 microsatellite markers suggested seven to eight different genetic groups or biological units along the Canadian coast, and four of these in Unit 1 (Valentin et al. 2014). A single genetic group of *S. mentella*, characterized by introgression from *S. fasciatus* was identified in Units 1 and 2. For *S. fasciatus*, the results suggested the presence of three genetic groups in Unit 1. The first group was detected in Units 1 and 2, and characterized by introgression from *S. mentella*. A second genetic group was identified in Units 1 and 2 to the Scotian shelf. The third genetic group was identified in in the eastern inlet of the Bonne Bay fjord, on the west coast of Newfoundland.

Recently, use of thousands of genomic markers confirmed some genetic groups identified with microsatellites and described new ones (Benestan et al. 2020). Population structure of these species was reinvestigated at a higher resolution using genome-wide markers. A total of 64 locations from 28 sites were sampled in the Northwest Atlantic Ocean between 2001 and 2015, of which 860 individuals were genotyped at 24,603 single nucleotide polymorphisms (SNPs). Classification with SNPs and microsatellites show that SNPs were as powerful as microsatellites to detect species, and more powerful than microsatellites to distinguish among genetic groups for both species. New SNP markers confirmed the pronounced genetic distinction between *S. mentella* and *S. fasciatus*, which is typical of interspecific differentiation (Figure 3). This new method also found high genetic differentiation between three genetic groups of *S. mentella*. The term ecotypes was used to describe these genetically well-differentiated groups due their habitat specificity. Two of these ecotypes are *S. mentella* shallow (light blue dots in Figure 3) and *S. mentella* deep (dark blue), which inhabit specific depths along the continental slope in eastern Canada between 300-500 m and greater than 500 m, respectively (Figure 3). Similar genetic groups have been identified in the Northeast Atlantic (Saha et al. 2017). The *S. mentella* GSL (cyan) ecotype was characterized as a biological unit and the only ecotype present in Units 1 and 2 (Figure 3). All individuals of the *S. mentella* GSL ecotype have a fixed nuclear genome component of *S. fasciatus* (18%). Five populations of *S. fasciatus* populations were identified, and three of these were located in Unit 1 (Figure 3). The three populations in Unit 1 are an introgressed population with a fixed proportion of *S. mentella* (6%) spreading in the northern distribution of the species (purple), a wide spread population (red), and the Bonne Bay population (green). Note that the small sample size and number precluded the detection of all populations of *S. fasciatus* in Units 1 and 2. SNPs confirmed the presence of a single biological unit for *S. mentella* and of at least three biological units of *S. fasciatus* in Unit 1.

Population genomics results also showed that Unit 1 was not isolated demographically from 2G and 3K NAFO Divisions. A total of 33 individuals of *S. mentella* GSL ecotype were sampled outside the Units 1 and 2, in *S. mentella* shallow sampling sites, suggesting the presence of a mixed ecotypes composition in NAFO Divisions 2G to 3K (Figure 3). Similarly, the introgressed population of *S. fasciatus* detected in Unit 1 was also detected off northeast Newfoundland. The distributions of genetic groups on both sides of the Belle Isle Strait in both species suggested gene flow between the GSL and the southern Labrador Sea. This outcome highlighted connectivity between management Units, which is critical to consider for optimal management.

Given the important recent increase in *S. mentella* biomass in Unit 1, this stock could expand to adjacent areas, stressing the need to pursue large scale genomic studies at least during the expansion of the population to understand the temporal variation of species, their ecotypes, and population distributions.

DISTRIBUTION AND HABITAT

In the northwest Atlantic, 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 GSL and Laurentian Channel regions, Typically, *S. mentella* tends to predominate in the main channels at depths ranging from 350 to 500 m. In contrast, *S. fasciatus* dominates at depths less than 300 m, along the slopes of channels and banks, except in the entrance of the Laurentian Channel (Laurentian Fan) where it inhabits deeper waters. Redfish are demersal. These species migrate vertically during the day, leaving the sea bottom at night to follow their preys as they migrate. Juvenile Redfish mainly feed on various species of crustaceans, including several species of shrimp. The adult Redfish diet has greater diversity and includes fish. Vertical migration appears to be a feeding strategy in which Redfish follow the migration of their prey such as krill.

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 they can measure about 42 cm. On average, Redfish take seven to eight years to reach minimum regulatory size (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 after their first ten years of life. Ages and lengths at 50% maturity occur at 9 years and 22.8 cm for male, 10 years and 25.4 cm for female *S. mentella*, and at 7 years and 19.6 cm for male, and 9 years and 24.1 cm for female *S. fasciatus* (Gascon 2003).

Redfish are ovoviviparous, meaning they fertilize internally, resulting in lecithotrophic larvae feeding exclusively on the yolk of the egg. Copulation takes place in the fall, probably between September and December. Spermatozoa are maintained in a state of physiological dormancy inside females until their ovaries mature in February to March (Hamon 1972). Larval extrusion occurs from April to July, depending on the area and species (Ni and Templeman 1985). Absolute fecundity ranges from 3,330 to 107,000 larvae per female and increases with female length (Gascon 2003). Mating and larval extrusion do not necessarily occur in the same locations. In the GSL, *S. mentella* releases its larvae approximately three to four weeks earlier than *S. fasciatus*. Larvae develop in surface waters and juveniles gradually migrate deeper as they grow. Larvae are generally found in the water 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) found under the cold intermediate water layer (Gascon 2003), though less so than the adults, which occupy deeper waters. Redfish are located in the Cabot Strait area in winter and return to the GSL in spring. This movement out of the GSL can start as early as November (Atkinson and Power 1991, Morin et al. 1994, Power 2003).

RECRUITMENT

In the Northwest Atlantic, Redfish are characterized by significant variability in recruitment. For example, the main abundant cohorts in Unit 1 were born in 1946, 1956-1958, 1970, 1980, 1985, 1988, 2003, and 2011-2013. In contrast, 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 (Senay et al. 2019, Licandeo et al. 2019). It was hypothesized that they returned to the Grand Banks since they bore the genetic identity of that population based on microsatellites, although this population was not identified as distinct with SNPs. Ocean currents and age-based spatial and temporal abundance trends indicate that *S. fasciatus* may use the GSL as a nursery.

On the Flemish Cap (area about 140 m deep in 3M NAFO Division), Redfish larvae feed mainly on immature copepod 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 larval extrusion and *C. finmarchicus* spawning, compared to 1981 when *C. finmarchicus* spawning occurred 7 weeks earlier (Anderson 1994). Hence, the production of an abundant year-class may depend on a close co-occurrence between the predator and its prey. Other possible factors affecting survival during the pelagic phase are uncertain. 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 extruded, but also the quantity and quality of their preferred prey.

Genetic analyses performed on the abundant 2011 cohort indicated that 91% of these fish belonged to the *S. mentella* species within the adult population of Units 1 and 2. This information suggests that these Redfish will remain in the area and should promote the recovery of *S. mentella* in Unit 1. Juvenile Redfish abundance from the 2011 to 2013 cohorts has increased dramatically. These cohorts are the most abundant ever observed in the research surveys in Unit 1.

ECOSYSTEM

DFO annually assesses the physical oceanographic conditions prevailing in the GSL with the Atlantic Zone Monitoring Program (AZMP). Conditions encountered in the nGSL from 2011 to 2018 were generally warmer than historical averages, particularly for surface and deep-water temperatures. Overall, temperatures at 250 and 300 m have reached the highest values observed in the series which began in 1915. The bottom area covered by waters warmer than 6°C remained high in 2018 in Anticosti Channel and Esquiman Channel and Central GSL, and increased sharply in the northwest GSL to reach a series record (Galbraith et al. 2019).

The GSL ecosystem is composed of a diverse fish community whose component abundances vary over time and space. For example, the various Herring stocks (*Clupea harengus*) are declining (DFO 2017, DFO 2018a) and the Mackerel stock (*Scomber scombrus*) is at a record low level (DFO 2018b). The indicators for the Greenland Halibut (4RST) stock decreased in 2018 (DFO 2018c), while the Atlantic Halibut (*Hippoglossus hippoglossus*) 4RST stock indicators are among the highest values of the historical time series (DFO 2019a). The Atlantic Cod stock in the southern GSL (4T) is at very low abundance and under moratorium since 2009 (DFO 2019b), whereas the nGSL (3Pn, 4RS) Cod stock is also low and has been declining since 2016 (Brassard et al. 2020). The Northern Shrimp (*Pandalus borealis*) stock in the Estuary and GSL has been in the healthy zone for several years, but is declining since 2010 (DFO 2018d).

FISHERY CLOSURES

Redfish *(S. mentella* and *S. fasciatus)* are managed as two different management Units (Unit 1 - NAFO Divisions 4RST, Jan-May 4Vn3Pn; Unit 2 - 3Ps4VsW, June - Dec 4Vn3Pn; Figure 1 A and B). NAFO Subdivisions 4Vn and 3Pn are considered part of Unit 1 from January to May, and part of Unit 2 from June to December. Annually for Unit 1 Redfish, there is a copulation closure from November 1st to March 31st, and a larvae extrusion closure from April 1st to June

15th to protect reproduction and promote Redfish recovery. For Unit 2, there is a spawning closure from April 1st to June 30th, and a mixing closure for 4Vn and 3Pn from October 1st to June 30th (in which these Subdivisions are part of Unit 1 from January 1st to May 30th, Figure 2).

There has been a strong increase in Redfish biomass, particularly *S. mentella*, following the recruitment of the 2011-2013 cohorts, so it is currently unknown if the seasonal management shift for 3Pn and 4Vn and the copulation and spawning closures remain necessary to protect Redfish movement and reproduction to promote species recovery. Given the strong increase in Redfish biomass, this section aims to highlight the current known information on Redfish movement and reproduction, and the information required to inform the merits of the current conservation closures for Redfish.

CURRENT KNOWLEDGE ON REDFISH MOVEMENT AND REPRODUCTION

There is some evidence that Unit 1 Redfish move from the GSL to deep waters of the Cabot Strait to overwinter (Figure 1). This movement was supported by the analysis of the winter surveys in NAFO Divisions 3P4RST from 1978 to 1993, which indicated that adult Redfish were more concentrated in the Cabot Strait area in January-February and that these concentrations overlapped the NAFO Subdivisions 3Pn and 3Ps boundary (Morin et al. 1994). Small Redfish do not appear to move as far south as larger Redfish. On average, during the 1981-1990 period, the mixing of Redfish from the GSL (4RST) with those in the NAFO Subdivisions 3Pn4Vn primarily occurred during the January through May period. In June, Redfish appeared to have returned to the GSL (Atkinson and Power 1991). The location of winter commercial catch rates from 1990 to 1993 corroborated this Redfish movement. In May, fishing shifted north into the GSL and to the west side of the Laurentian Channel (4Vn and 4Vs boundary) until October (Morin et al. 1994). The concentration of Redfish aggregation may be more of less dense from year to year (Atkinson 1984).

The reasons underlying this behavior are currently unknown. Some current hypotheses explaining this movement are water temperature, food availability, ice cover, related to mating events. However, it is unlikely that Redfish need to migrate to avoid cold temperatures, as temperature remains constant year round at their typical depth ranges (Atkinson 1984). Food availability is a possibility, particularly as Redfish migrate vertically to shallower depths on a diurnal basis, presumably to feed on euphausiids and myctophids. A similar movement in Atlantic Cod has been attributed to avoiding ice cover, which may be related to light availability on the bottom or in the water column (Fréchet 1990). Equally plausible is the possibility that winter migration occurs in response to endocrine-driven cues leading eventually to spawning, as has been observed in Atlantic Cod (Comeau et al. 2002). Some authors argued that this movement directly corresponds to a spawning migration as females are bearing larvae ready to be extruded over the winter months (St-Pierre and de Lafontaine 1995). Others mentioned that these aggregations did not appear to be associated with copulation as this occurs in October - November prior to completion of the southward movement (Atkinson and Power 1991). Atkinson and Power (1991) also noted that Redfish movement was not associated with larval extrusion as the fish normally begin to redistribute throughout the GSL prior to this event. Although the reproductive biology of Redfish from the GSL is not fully understood, copulation (transfer of spermatozoa from male to female) probably takes place during late fall or early winter. Fertilization and embryogenesis occur in winter, and larvae hatch internally and are extruded during late spring and early summer (St-Pierre and de Lafontaine 1995). However, extrusion times seem to differ between *S. mentella* and *S. fasciatus* (Sévigny et al. 2000), which could further complicate the timing of closures in these areas.

Given the absence of winter surveys and year-round commercial fishing since the mid-1990s, it is not possible to determine if these inferred movement patterns persist and whether the winter closures are still necessary to promote Redfish recovery. The lack of recent data brings uncertainty and stresses the need to gather more recent information on distribution during the winter, by carrying-out winter surveys, or conducting collaborative scientific fishing between DFO and the industry. Despite the lack of recent winter data for Redfish, other tools may assist in confirming habitat location of Redfish during their life cycle. Using the elemental fingerprints of otoliths as a natural tag, Campana et al. (2007) found that *S. mentella* tended to move out of the GSL in winter and that pattern was less apparent for *S. fasciatus*. Their results indicated that the southeasterly movement from the GSL into the 3Pn area extended to at least the 3Ps border. This suggests that the mixing area may be more extensive than what is currently defined by the management Units, which leaves the possibility that overwintering Unit 1 Redfish could be fished as part of the Unit 2 quota. The movement of Redfish observed in that study suggested that large-scale management areas for Redfish may increase the risk of locally overfishing what are essentially semi-isolated Redfish aggregations, even if they share a genetic origin (Campana et al. 2007). A similar study is being conducted and should provide new insights on Redfish movements once the study is completed.

ECOSYSTEM CONSIDERATIONS

The GSL and Laurentian Channel are important habitats for Redfish and many other groundfish species including Greenland Halibut, White Hake (*Urophycis tenuis*), Atlantic Cod, and Atlantic Halibut. Notably, in winter Redfish may overlap with areas of aggregation for 3Pn4RS and 4T Atlantic Cod, and 4T White Hake, which are all depleted stocks, with the latter two considered at high risk of extirpation. Copulation closures in the areas of 4Vn and 3Pn might benefit these other groundfish species that may otherwise be taken as bycatch in a directed Redfish fishery during this period. For instance, winter spawning of Greenland Halibut is believed to occur between January and March in the deep Laurentian Channel (NAFO Subdivisions 3Pn4Vn, Templeman 1973, Ouellet et al. 2011) and historically, adult Greenland Halibut were captured in abundance in January in this region. Data on the distribution of Greenland Halibut larvae and post-larvae also support the conclusion of late-winter spawning in the GSL, possibly over an area located in the deep Laurentian Channel southwest of Newfoundland (Ouellet et al. 2011). In summer and early fall, White Hake in the southern GSL occur either in shallow inshore waters or in deeper water along the slope of the Laurentian Channel and in the Cape Breton Trough. In winter, White Hake is known to occur in the Laurentian channel and east of Cabot Strait, making them vulnerable as bycatch (Swain et al. 2016). In summer, Atlantic Cod of the northern GSL stock (3Pn, 4RS) are distributed throughout the northern GSL at depths ranging from 50 to 200 m. In winter, Atlantic Cod gather south-west (3Pn) and south (3Psad) from Newfoundland at depths between 300 and 500 m (Brassard et al. 2020). Similarly, the southern GSL (4T and 4Vn from November to April) stock of Atlantic Cod overwinters in dense aggregations in relatively warm waters along the southern slope of the Laurentian Channel in the Southern GSL and the neighbouring Cabot Strait area (Swain et al. 2019). Atlantic Halibut have been shown to perform seasonal migrations from summer feeding areas on the continental shelf to fall-winter potential spawning areas in deep water along the continental slope (Neilson et al. 1993, Armsworthy et al. 2014). A tagging study by Le Bris et al. (2018) supports that Atlantic Halibut displayed seasonal migrations, moving from deeper offshore waters in the winter to shallower nearshore waters in the summer.

While it is unclear whether the current fishery closures are still required to promote Redfish recovery, these closures appear beneficial to limit bycatch of other groundfish species, including depleted stocks. In addition, this closure period is not expected to provide much benefit to *S. fasciatus*, actually being at lower levels of biomass compared to *S. mentella*, because of the species-specific differences in movement patterns, where *S. fasciatus* movement out of the GSL seemed more limited compared to *S. mentella* (Campana et al. 2007). Information on the seasonal distribution of other species susceptible to being captured in a Redfish fishery needs to be updated via new seasonal information, if seasonal closures are to be used to mitigate bycatch.

COMMERCIAL FISHERY

HISTORY

The history of Redfish commercial fishery is described based on data from the Zonal Interchange Format File (ZIFF) database. The TAC is established for a management cycle. Prior to 1999, Redfish management cycle was from January 1st to December 31st and the TAC was allocated for this period. In 1999, the management cycle continued until May 14th, 2000. Subsequent management cycles have been from May 15th of the current year to May 14th of the following year. The Redfish fishery in the Gulf of St. Lawrence has been characterized by three episodes of high landings (1954-1956, 1965-1976, and 1987-1992, Table 2 and Figure 4). Average annual landings were 43,000, 79,000, and 59,000 t for each of these respective periods. The maximum annual landings value was observed in 1973 with 136,101 t (Table 2 and Figure 4). From 1953 to 1990 (prior to the moratorium), landings originated mainly from NAFO Divisions 4RS (Table 2 and Figure 4).

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 mainly originated from fisheries directed to other species. An index fishery began in 1998 with a TAC of 1,000 t that increased to 2,000 t the following year. Still active, this index fishery takes place between June 15th and October 31st. It is carried out on traditional fishing grounds using bottom trawls similar to those used before the moratorium, between longitudes 59°W and 65°W at depths over 182 m (100 fathoms) with 90 mm minimum mesh size. From 1999 to present, the TAC for the index fishery has remained at 2,000 t per management year. Between 1999 and 2005, most of the effort was expended in Divisions 4RT along the slopes of the Laurentian Channel and north of the Cabot Strait. In addition to these fishing sites, effort was directed in Division 4S of the Laurentian Channel. Since 2006, the majority of the index fishery effort was concentrated in Division 4T, except for 2019 when landings in Division 4R were the highest (Table 2 and Figure 4). TACs in Unit 1 are not fully harvested. On average since 2010, 500 t of Redfish are caught annually (Table 2).

Following the Management Strategy Evaluation (DFO 2018e, Licandeo et al. 2019), the 2018 Stock Assessment, and the Advisory Committee, an experimental fishery was established with an additional TAC of 2,500 t for 2018-2019 and 3,950 t for 2019-2020, which can be harvested year round. The objectives of the experimental fishery are to target *S. mentella*, actually more abundant than *S. fasciatus*, to investigate ways to limit bycatch of other species and of undersized Redfish, and to better understand the spatio-temporal distribution of Redfish and bycatch species. The additional experimental quota resulted in a small increase in landings, with 748 and 592 t landed in 2018 and 2019, respectively (Table 2 and Figure 4).

Traditionally, Redfish landings occurred year-round (Figure 5). From 1985 to 1992, there was an increase in the percentage of landings occurring in winter (January to March), from less than 5% in 1985 to 25% in 1992 (Figure 5). These landings came mainly from NAFO Subdivision 3Pn and Division 4R. Since the moratorium, the majority of Redfish were caught in summer during the index fishery, which runs from June 15th to October 31st. Small quantities of Redfish were also caught outside of the index fishery season as bycatch or as part of the experimental fishery. Although the experimental fishery has allowed fishing all year round, most landings have occurred between May and July since the moratorium.

From 1985 to 1994, Redfish were mainly caught using bottom and midwater trawls (Figure 6). Several vessels used the Diamond 6 sides braided nylon midwater trawl equipped with Suberkrüb midwater doors. Following the 1995 moratorium, the midwater trawl fleet was no longer present in the GSL and therefore did not participate in the index fishery. From 1998 to 2006, the majority of landing were made 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 2018, research projects were initiated to reintroduce the midwater trawl into Unit 1 Redfish fishery. This gear is considered to be minimally impactful on benthic habitat, as there is no or little contact with the seabed during normal operations. Since 2018, less than 5% of the landings were attributed to midwater trawl.

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 have generated most of the landings. During this period, vessels less than 65 feet appeared in Unit 1.

LENGTH FREQUENCY

Commercial catch length frequencies were quantified by combining data from ASO and port sampling (Figure 8). From 2010 to 2019, ASO and port sampler data were combined based on total landings of all sampled trips by each program. Length frequencies representative of the index fishery were estimated using only ASO data and selecting trips comparable to that fishery (bottom trawl from June to October, inclusively) (Figure 9). Discarding of small Redfish is illegal and is not expected during trips covered by ASO. However if discarding occurs during trips not sampled by ASO, length frequencies obtained in the port sampling program may underrepresent the catches of small fish.

From 1981 to 1987, commercial catch length 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. Redfish larger than 30 cm were less frequent from 2017 to 2019 (Figures 8 and 9). Since 1999, commercial catch length frequency has been more difficult to establish because landings have dropped significantly (especially since 2006). As a result, fewer Redfish were measured by ASO and through port sampling programs.

CATCH PER UNIT EFFORT (CPUE)

The information obtained from logbooks gathered by fishermen, ASO, and port samplers consisted of data on landings, fishing effort, bycatch, and Redfish catches length frequency. Given the low rate of participation in 2007, data were excluded. 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 were conducted with a bottom trawl between May and October. This standardization accounts for the effects of years, fishing season (months), NAFO Divisions, regions (*e.g.*, Gulf, Québec, Maritimes, and Newfoundland), and vessels size. All these factors were accounted for in the model, making the CPUEs comparable across years. This index shows high CPUEs prior to the moratorium, followed by a marked decrease in 1994 (Figure 10). Between 1999 and 2007, CPUEs were below or close to the average of the time series (1981-2019). Standardized CPUEs started increasing in 2018, with an estimate in 2019 that was 6.7 times greater than that of 2017 (Figure 10). This CPUE increase was caused by both an increase in catches from 2017 to 2019 and a decrease in effort from 2015 to 2019 (Figure 11).

BYCATCH

Bycatch of other species is common although commercial fishing attempts to maximize the capture of the target species. Two data sources have been combined to provide an overall picture of bycatch: the ZIFF and the ASO data. ZIFF data provided complete information on total reported landings. The ASO program covers a certain percentage of fishing trips. However, this program is the only source of data on at-sea discards. In addition, this program provides information on the length of fish caught and the data are associated with specific fishing activities, either a trawl set or the lifting of a fixed gear.

Data from the dockside monitoring program recorded in ZIFF indicate that 93 % of the reported Redfish catches from 2000 to 2019 came from the directed Redfish fishery conducted in Unit 1 (index and experimental fishery combined). Fisheries targeting Greenland Halibut and Atlantic Cod were responsible for 3% and 2% of Redfish landings, respectively on average (Figure 12). Species other than Redfish have comprised 9 % on average of landings in the directed Redfish fishery since 2000 (Figure 13). The most common bycatch were Greenland Halibut, White Hake, Atlantic Halibut, and Atlantic Cod (Figure 14).

Juvenile Redfish are often caught as bycatch and discarded in the Northern Shrimp fishery in the nGSL. Discarded Redfish are often dead because of decompression. Management measures for the fishery include mandatory 5% ASO coverage. The quantity, the location and the length frequency of Redfish caught in the Northern Shrimp fishery were estimated for 2000 to 2019 (see methods in Savard et al. (2013) and Bourdages and Marquis (2019)). The ratio between the quantity of Redfish caught as bycatch and research survey minimum trawlable biomass of Redfish smaller than 20 cm to estimate exploitation rate on fish of those lengths (see section DFO RESEARCH SURVEYS for more details). In 2013, the amount of Redfish caught in the Northern Shrimp fishery increased substantially, and continued to increase until 2016 (Figure 15). The amounts have since decreased as the lengths of Redfish in the 2011-2013 have increased, allowing them to avoid retention in the gear via the Nordmore grate. From 2000 to 2010, bycatch rates of Redfish in the shrimp fishery were low and covered a large spatial area (Figure 16). In 2018 and 2019, bycatch rates were considerably higher and concentrated over a smaller spatial area (Figure 16). The length range of Redfish caught as bycatch in the Northern Shrimp fishery was from 5 to 20 cm (Figure 17). Starting in 2013, juveniles from the 2011-2013 cohorts started to be captured. The ratio between the quantity of Redfish caught as bycatch and research survey minimum trawlable biomass of Redfish smaller than 20 cm provides an estimate of the maximum exploitation rate on fish of those lengths. The ratio has not exceeded 0.6% since 2000 (Figure 18). This ratio increased above the average of the time series in 2013 and has been below the average since 2015, most probably because the 2011-2013 Redfish cohorts are now large enough to escape via the Nordmore grate.

In order to identify potential drivers of bycatch rates in Redfish directed fishery, the influence of gear, depth, season, and geographic areas on Redfish and most common bycatch species (i.e. Greenland Halibut, Atlantic Halibut, Atlantic Cod, and White Hake) CPUE was tested. The regions defined by DFO in the Quebec and Gulf regions for the application of the ecosystem approach (EA areas) were used as the geographical unit (Figure 19). To do so, ASO data from 1986 to 1990 inclusively have been used, which represents the only period for which there are available data when Redfish biomass and landings were relatively high, and when the fishery was conducted at a large spatial scale all year round using both bottom and midwater trawls. For each species (or Redfish spp.), tow catches (t) were divided by fishing effort (hours) to obtain CPUE, which corresponded to the response variables. Bottom and midwater trawls were tested as a gear effect treated as factor. Water column depth was used as a continuous numerical explanatory variable. Two seasons were compared: summer (May to October) and winter (November to April). The design of the EA areas was based on the Atlantic Zone

Monitoring Program (AZMP, Galbraith et al. 2018) and biological and chemical characteristics (Blais et al. 2019). In the present study, three EA areas were used: Center, North-eastern Gulf (NE Gulf), and Laurentian hermitage.

CPUE included numerous zeros and small values. Therefore, a two-step model (also known as delta method) was used, with first a binomial generalized linear model (glm) to analyze presence-absence. This step identifies the probabilities of capturing a species. Subsequently, a log-normal generalized linear model was used to analyze the positive CPUE values and determine fishing strategies maximizing Redfish CPUE and minimizing bycatch CPUE. For each step, a full model was run and non-significant variables were removed one at the time until only significant ones were retained, therefore minimizing Akaike information criterion (AIC). Model assumptions were assessed mainly by visually inspecting the normality of residuals, and at the relationship between residuals and fitted values (Zuur et al. 2009).

The probability of capturing Redfish was greater with bottom trawl, while greater CPUE were obtained when using midwater trawl, and smaller CPUE were obtained at greater depth and in the Laurentian hermitage EA area (Table 3). The probability of capturing Greenland Halibut was greater with bottom trawl. at greater depth, and during winter, but smaller in the Laurentian hermitage EA area. Greater Greenland Halibut CPUE were obtained with bottom trawl, at greater depths, and during winter. Gear effect could not be tested for Atlantic Halibut, given that this species was not caught by midwater trawl. The probability of capturing Atlantic Halibut was smaller at greater depths and in the NE Gulf EA area. Greater Atlantic Halibut CPUE were obtained in the Laurentian hermitage EA area. The probability of capturing Atlantic Cod was greater with midwater trawls, at shallower depths, during the winter, and in the Laurentian hermitage EA area, while greater CPUEs were obtained with bottom trawls, during the winter, and in the Laurentian hermitage EA area. The probability of capturing White Hake was greater with midwater trawl at greater depths in both the Laurentian hermitage and NE Gulf EA areas, while greater CPUE were obtained greater depths during the summer in both the Laurentian hermitage and NE Gulf EA areas.

In general, model outputs suggested that bycatch rates could be minimized by using midwater trawls, and avoiding fishing during winter in the Laurentian hermitage AE area, however such fishing strategies may not be beneficial for White Hake (Figure 20). Reducing bycatch rates of multiple species simultaneously is definitively a challenge. However, these results are dependent of each stock status which has changed in all cases since the studied period (1986-1990). Given the limited number of observed fishing trips using midwater trawl across time and space in recent years, similar analyses were not possible for the current period in order to confirm that similar trends would be obtained. The impact of different trawl types within the bottom and mid-water trawl categories could not be assessed. Furthermore, because the abundance of different bycatch species has changed since 1990, this result should only be interpreted as indicating potential mitigation measures. These conclusions should be validated with more recent data as soon as they are available.

From 1999 to 2019, 1 731 sampled tows by the ASO program were retained based on the index fishery management measures (June to October in 4RST, Figure 21). The most frequent bycatch species were Greenland Halibut (caught in 72% of fishing activities directed to Redfish), White Hake (58%), Witch Flounder (*Glyptocephalus cynoglossus*, 41%), and Atlantic Cod (37%) (Table 4). Between 85 and 100% of those species catches was landed. For each bycatch species, catches represented less than 5% of Redfish catches (Table 4).

The spatial distribution of Redfish catch and other species bycatch rates in the Redfish directed fishery from 1999 to 2019 were mapped, amongst other things to identify locations to avoid, minimizing bycatch in the Redfish directed fishery (Figure 22). For example, West of the 64th

meridian, 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 23, Table 5). ASO also measured fish length in the Redfish directed fishery. From 1999 to 2019, Redfish measured from 15 to 50 cm (mode = 32 cm), Greenland Halibut from 25 to 65 cm (mode = 40 cm), White Hake from 25 to 75 cm, Atlantic Cod from 25 to 80 cm (mode = 45 cm), and Atlantic Halibut from 15 to 165 cm (Figure 24).

RECENT TRAWL SELECTIVITY EXPERIMENTS

In July of 2019, Memorial University conducted a covered codend experiment in Unit 1 to compare the retained catch length composition of a traditional, diamond-shaped mesh codend with a 90 mm mesh opening. These catches were compared to the length compositions for three different T90 codends with mesh sizes of 90, 100, and 110 mm. A T90 mesh codend turns the mesh 90° in the direction of the tow and has been shown to reduce the capture of small roundfish (Madsen et al. 2012, Bayse et al. 2016). Results, based on short (less than 20 min) tows, showed that the traditional codend was not size selective, catching greater than 97% of Redfish across all length classes available (Cheng et al. 2020). Compared to the traditional codend, the T90 codend (90 and 100 mm mesh) would retain 30% fewer undersized Redfish (< 22 cm), while limiting reductions of regulatory-sized Redfish to 16%. The T90 codend with 110 mm mesh would retain 50% fewer undersized and 40% fewer Redfish larger than 22 cm. The T90 codend could therefore reduce the retention of small Redfish. However, commercial users of the T90 codend and preliminary results suggested a significant increase in the number of Redfish that were caught in the meshes (meshing). Although the number of fish was small, it could be higher in a commercial fishing application involving longer tows (> 2 hrs). Furthermore, the survival of Redfish passing through the mesh at depths is not known and could generate some unaccounted mortality. In contrast, mortality from the traditional codend is largely accounted for in the landings data. In both cases, small Redfish mortality could potentially be managed by implementing protocols such as catch caps and temporary spatial closures to avoid catch once unacceptable levels have been observed.

DFO RESEARCH SURVEYS

Since 1984, DFO has conducted an ecosystem bottom-trawl research survey (groundfish and shrimp) of the nGSL. The survey covers 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, specifically, NAFO Divisions 4RS, and the northern part of 4T (Bourdages et al. 2020, Figure 25). Over the years, different vessels and fishing gears have been used. From 1984 to 1990, research surveys were conducted aboard the Lady Hammond using a Western IIA bottom trawl. From 1990 to 2005, the Canadian Coast Guard Ship (CCGS) *Alfred Needler* and a URI 81 '/ 114' bottom trawl were used. Since 2004, the CCGS *Teleost* equipped with a Campelen 1800 bottom trawl has been used. Comparative fishing experiments were conducted in 1990 and 2004-2005 (Bourdages et al. 2007) to establish the conversion factors required to maintain continuity in the time-series, providing a standardized Redfish abundance and biomass index series from 1984 to 2019. This nGSL DFO survey uses a stratified random sampling design. Since 2008, the study area is divided into 56 strata (Figure 25) of which 52 have typically been visited every year. Strata were defined based on depth, NAFO Divisions, and substrate type. For this survey, an annual initial allocation of 200 trawling stations is allocated proportionately to stratum surface area, with a minimum of two stations per stratum. The positions of the stations is determined randomly within each stratum. At each station, the catch is sorted and weighed by taxon and biological data are collected by subsampling. For Redfish the following characteristics are recorded or collected: length, sex, AFR counts, stomach content composition, otoliths, and tissue samples. The study area used for calculating Redfish indices encompassed the 52 strata surveyed yearly, covering 116,115 km^2.

In some years, some strata were not sampled by a minimum of two successful tows. A multiplicative model was used to estimate the catch rates in number and mass using data from the current year and the previous three years. A detailed description of the fishing and sampling protocol, and the calculation methods are presented in Bourdages et al. (2020).

In 2019, 128 fishing stations were successfully completed, 36 in NAFO Division 4R, 59 in 4S and 33 in 4T (Figure 26), which is 40 stations less than in 2018 and the year with the fewest successful stations since 1990. The decrease in the number of stations completed was due to the shortened duration of the survey by 12 days. The coverage of the study area was therefore affected. Seventeen strata were not sampled with a minimum of two stations. These partially or uncovered strata are mainly off the southern portion of the west coast of Newfoundland, in the Laurentian Channel and the Strait of Belle Isle (Bourdages *e*t al. 2020).

The results are presented by species, *S. mentella* and *S. fasciatus*, for mature and immature individuals, or for different length classes.

MATURITY DETERMINATION

The length at maturity relationships were presented in Gascon (2003), based on data for 434 individuals from Unit 1 and 983 from Unit 2 collected between 1996 and 1999. Species, age, maturity stage, and length were recorded. In Gascon (2003), species identification was based on AFR, *MDH-A**, and EGM. The proportion mature as a function of length is modelled using a logistic curve. For mature females of both species, the shortest length at maturity was around 23 to 24 cm. In general, males reach sexual maturity one to two years before females. Ages and lengths at 50% maturity occur at 9 years and 22.8 cm for male, 10 years and 25.4 cm for female *S. mentella*, and at 7 years and 19.6 cm for male, and 9 years and 24.1 cm for female *S. fasciatus* (Gascon 2003).

During DFO surveys, a sample of individuals is measured, sexed, and species identification is based on the number of soft rays of the anal fin. The proportion of mature individuals by species and sex is determined from the sample and extrapolated to the entire catch.

Estimation of the proportion mature is based on the logistic equation as follows :

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

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* = -9.555	*b* = 0.377	*L50* = 25.4
S. mentella	male	*a* = -7.521	*b* = 0.330	*L50* = 22.8

These equations allow the determination of the mature fraction of the stock based on the length of the individuals that compose it.

The data used to estimate the parameters of these equations date back to the 1990s. A deficiency of these relationships is that they predict significant non-zero proportions of mature individual at small lengths for which no mature individuals were observed (Figure 27). A project was initiated in 2018 to update the maturity ogive based on histological analysis and to create a visual chart of maturity stages, however conclusions were not available in time for this document.

SURVEY INDICES AND LENGTH FREQUENCY

Survey biomass indices for *S. mentella* and *S. fasciatus* declined sharply from the late 1980s to 1994 (Figure 28). Subsequently, the indices of small and large Redfish remained low and stable (Figure 29, Table 6). The new cohorts (2011-2013), mainly dominated by the 2011 year-class, started being caught in the survey in 2013. These juveniles were largely dominated by *S. mentella*, with the genetic signature of the GSL ecotype.

In 2019, total minimum trawlable biomass was estimated to be 4,365,000 t for *S. mentella*, the highest value ever observed in the series that started in 1984. Total minimum trawlable biomass of *S. fasciatus* was estimated to be 78,000 t, suggesting a decrease from 2017 to 2019 to values comparable to the 2014-2016 period (Figure 28). Both species of Redfish accounted for 90% of the sampled biomass during the survey in 2019 as compared to 15% between 1995 and 2012 (Figure 30). The biomass of both species combined increased by 72% over the 2017 estimate.

Minimum trawlable biomass of Redfish greater than 22 cm in length began to increase in 2017. In 2019, it was estimated to be 3,044,000 t for *S. mentella*, an important increase. In contrast, minimum trawlable biomass was estimated to be 57,000 t for *S. fasciatus*, indicating a decrease from 2018 to 2019. Biomass of *S. mentella* greater than 25 cm in length increased from 56,000 t in 2017 to 497,000 t in 2019, whereas biomass of *S. fasciatus* decreased from 56,000 t in 2017 to 18,000 t in 2019 (Figure 29, Table 6). In the summer 2019, Redfish modal length was 23 cm (Figure 31), suggesting that both species are following their anticipated growth curve.

Different hypothesis can contribute to the explanation of the decrease of *S. fasciatus* in the survey biomass estimates. Given the greater abundance of *S. mentella*, it is possible that *S. fasciatus* moved to shallower habitats not accessible to the survey or out of its study area, that it may be harder to get a representative random sample of both species, or that the species identification method is less accurate when one species dominates. Another potential explanation could be that some *S. mentella* were identified as *S. fasciatus* in previous years.

In 2010, the COSEWIC designated the GSL and Laurentian Channel designatable unit (DU) of *S. mentella* (equivalent to the Units 1 and 2 stock) as *endangered,* based on a 98% decline in mature fish abundance in the survey in Unit 1 (COSEWIC 2010). Since 2016, the abundance of mature *S. mentella* in the survey has exceeded the levels observed prior to the decline, and abundance in 2019 was several folds higher than those levels (Figure 32A). A revision of the status by COSEWIC of this *S. mentella* DU appears warranted.

The Atlantic Population DU of *S. fasciatus* was designated as *threatened* by COSEWIC in 2010, based on a 99% decline in mature fish abundance over two generations (COSEWIC 2010). Units 1 and 2 *S. fasciatus* were believed to constitute a majority of the DU, which also includes the Labrador, Newfoundland and Scotian shelves. Abundance trends in the survey in Unit 1 were therefore influential in establishing the designation. Although the abundance of mature *S. fasciatus* in the survey in Unit 1 increased from 2013 to 2017, declines in the estimates in 2018 and 2019 suggest that it would be premature for COSEWIC to revisit the status of the DU (Figure 32B).

NEW COHORT SPECIES COMPOSITION AND MAGNITUDE

In the nGSL DFO survey, new cohorts of Redfish are monitored annually to determine species composition and recruitment strength. For each tow when feasible, a sample of juvenile Redfish of less than 110 mm was frozen. This length corresponds to fish of ages 1+ and 2+.

Genotyping using 4 microsatellites (SEB09, SEB25, SEB31, and SEB33) was later performed and individuals were then assigned as either *S. mentella* or *S. fasciatus* using the “naiveBayes” method from the R package *assignPOP* (Chen et al. 2018). As reference groups, *S. fasciatus* and *S. mentella* specific to the GSL were used. Every fish was classified to species when the assignation probability was 95% or more. If the probability of belonging to either species was less than 95%, the individual was classified as undetermined and excluded from further analysis. Genomic analyses (using thousands of genomic markers) would be required to perform identification of *S. mentella* ecotypes and *S. fasciatus* populations.

During the 2018 nGSL survey, 830 individuals from the 2016-2017 cohorts, ranging in length from 60 to 113 mm, were collected over 27 tows. Because of cost limitations, 640 Redfish were later selected for genetic identification. A few adjacent tows from the Estuary, located less than 82 km apart and of similar depths, were merged together in order to obtain a minimum of 20 individuals per location, for a total of 15 locations (Table 7). In such cases, average location characteristics were computed for latitude, longitude, and depth. Following genomic analyses, a total of 154 individuals were classified as undetermined, leaving 486 individuals associated to either species at the 95% threshold. Sample size for the 15 locations ranged from 21 to 44 with a mean of 32.4, while depth ranged from 136 m to 346 m, with a mean of 277 m. Redfish fork length ranged from 60 to 108 mm, with a mean of 84 mm. Most locations were largely dominated by one species. Figure 33 shows the geographical location of all 15 locations in the GSL overlaid with the species composition in a pie chart, where depth was indicated. The relationship between species composition and depth was also illustrated in Figure 34. Both a spatial gradient (Figure 33) and a depth gradient (Figure 34) were apparent, where *S. mentella* was mainly observed West from 61°W and at greater depth than *S. fasciatus,* which was mostly collected on the West coast of Newfoundland at depth lower than 175 m. Based on the nGSL DFO survey, the 2018 biomass of Redfish less than 11 cm was 3.7 % of the maximum value observed in 2013, when the 2011 cohort started to be captured in the survey (Figure 35).

SPATIAL DISTRIBUTION

The spatial distribution of catch rates in the nGSL DFO survey, illustrated in maps created using inverse distance weighting, indicated that between 1984 and 1996, the Laurentian, Esquiman and Anticosti Channels were populated by both species (Figures 36-39). Subsequently, there was a substantial decrease in the density of mature individuals in both species particularly west of Anticosti Island and north of Esquiman Channel (Figures 37 and 39). Recently, density of immature and mature *S. mentella* has increased in the Esquiman, Anticosti, and Laurentian Channels, and the southwestern edge of Cabot Strait (Figures 36 and 37). Immature *S. fasciatus* have also shown an increase in density, albeit less so than in *S. mentella,* and decreased in the past two years.

The size of the catch and median length of Redfish (both species combined) from 2017 to 2019 are shown in Figure 40. The largest catches in tonnes were obtained in deep channels south of Anticosti and in Esquiman. In 2017, 92% of catch median lengths were below 22 cm, whereas 55% of median lengths were below 22 cm and 44% were between 22 and 25 cm in 2019.

Stratified cumulative frequency distributions of catches (Perry and Smith 1994) indicated that between 2015 and 2019, *S. mentella* were preferentially located at depths greater than 200°m, at temperatures between 5 and 7 °C, and at lower levels of dissolved oxygen (Figure 41). On the other hand, most *S. fasciatus* were caught preferentially at shallower depths between 100 and 300°m, at temperature between 2 and 6 °C, and at higher levels of dissolved oxygen (Figure 42).

RELATIONSHIP BETWEEN DEPTH AND LENGTH DISTRIBUTION

Redfish biomass was calculated for three length classes (0-22 cm, 22-25 cm, and > 25 cm) as a function of depth for1984 to 2019. Areas identified as "Deep" included strata greater than 274 meters and located between 59°W and 65°W (where the index fishery is permitted, therefore representing biomass that could be available to the fishery), while the "Shallow" areas include the rest of the study area. As Redfish grow, larger individuals appear to concentrate in deeper areas (Figure 43). 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, the stock was at low abundance and 50% of the biomass was composed of fish larger than 25 cm in deep areas. During this period, Redfish smaller than 22 cm corresponded on average to 20% of the biomass. In 2013, the arrival of new cohorts increased the biomass of Redfish smaller than 22 cm mainly in shallow areas (up to 77% in 2015). The percentage of the biomass composed of Redfish larger than 22 cm located in deep areas accessible to the fishery has been increasing steadily since 2017, reaching about 50% in 2019.

SOUTHERN GSL AND SENTINEL SURVEYS

The southern Gulf of St. Lawrence (sGSL) survey consists of a stratified random groundfish bottom trawl survey conducted annually in September since 1971 in Division 4T (Figure 44). Fishing was performed using the E.E. Prince equipped with a Yankee 36 trawl from 1971 to 1985, with the Lady Hammond using a Western IIA trawl from 1985 to 1991, and by the CCGS *Alfred Needler* using a Western IIA trawl from 1992 to 2002. Stratified abundance estimates for 2004 and 2005 were calculated by averaging catches of the two vessels that occurred at the same location. Since 2004 surveys are done by the CCGS Teleost (Savoie 2016). To maintain the consistency of the time series, comparative fishing experiments were conducted and conversion factors were applied where necessary to account for gear, vessel, and/or timing changes (Nielsen 1994, Swain et al. 1995, Benoît and Swain 2003, Benoît 2006).

A mobile gear sentinel survey is carried out in Subdivision 3Pn and Divisions 4RST every July since 1995.The survey is performed by commercial fishermen and follows a depth-based stratified random survey plan similar to the nGSL DFO survey. The fishing gear used is a Star Balloon 300 trawl mounted on a Rockhopper footgear. The trawl mesh size is 145 mm with a 40 mm mesh liner in the codend (Brassard et al. 2020).

Relative indices of Redfish biomass from nGSL DFO research surveys, sGSL, and mobile sentinel survey were scaled to their maximum values and trends were compared. Similar trends can be observed across surveys, where relative biomasses were higher prior to the mid-1990s (when available), then decreased and stayed at low levels until the 2011-2013 cohorts started to be captured around 2013 (Figure 45). In 2019, both sGSL and mobile sentinel surveys suggested a decrease, but not the nGSL DFO research survey. The sGSL survey covers shallower depths than the nGSL survey. As Redfish grows, they may be moving to the deeper channels of the GSL. During the sentinel survey in 2019, many tows (16.5%) were shorter than the 30 minutes standard protocol, this value is greater than the 2015-2018 average (9.9%). In the sentinel survey, tow durations are measured from the start of the winch engine until it stops, therefore shorter tows spent less time on the bottom. This difference in methodology may have generated a bias in 2019.

In 2019, sampled were collected during the survey and AFR counts were performed by DFO-Québec region. During the mobile sentinel surveys, industry technicians, DFO technicians and ASO counted AFR at sea. Species composition in the sGSL survey showed a similar depth profile compared to the one observed in the nGSL survey, where *S. mentella* (> 225 m) was observed at deeper depths than *S. fasciatus* (< 225 m, Figure 46). This pattern was not observed in the mobile sentinel survey (Figure 47). Inconsistencies in the manner in which AFR were counted resulting from a lack of proper training for the ASO probably explains the absence of relationship between species composition and depth in the mobile sentinel survey. Comparatively, when looking at species composition as a function of depth based on nGSL DFO research surveys in 2019, *S. fasciatus* was present at shallower depths compared to *S. mentella* (Figure 48).

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 valuable to the fishery.

A von Bertalanffy growth curve was developed for *S. mentella*, although similar growth characteristics are expected for *S. fasciatus*. The primary growth parameters were estimated based on modal estimates of length for the 1980 Unit 1 cohort and subject to a constraint on maximum length ($L_{infinity}$) of 42 cm (Figure 49). Uncertainty in length at age was generated by incorporating information on growth from other studies to better account for the potential uncertainty in growth trajectories, 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 length 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 8 shows the proportion of each cohort which could be expected to reach different lengths as a function of age given the estimated von Bertalanffy growth curve and a coefficient of variation of length on age. In the summer 2019, the modal length for the 2011 to 2013 Redfish cohorts was 23 cm. If the anticipated growth of these cohorts continues (Figure 49), by 2020, 51% of the individuals of the 2011 cohort (62% biomass) should be larger than 25 cm (Table 8). The growth modelling assumes constant age and length-invariant mortality, and therefore may not accurately predict future length at age.

EMPIRICAL REFERENCE POINTS

Based on the Management Strategy Evaluation, the biomass of both species was estimated to be out of the critical zone in 2017, with *S. mentella* was in the Healthy Zone and *S. fasciatus* was in the Cautious Zone (DFO 2018e, Licandeo et al. 2019). Given that the Management Strategy Evaluation was not implemented as a management approach and that the Operating Models were not peer-reviewed as assessment models, the reference points established in that process could not be implement for the assessment, and empirical references points were therefore proposed in 2019.

The biomass that produces maximum sustainable yield (B_{msy}) is unknown for both Redfish species, moreover the concept of B_{msy} may not apply for species producing such sporadic recruitment. Indeed, Units 1 and 2 Redfish do not display classical stock-recruitment dynamics and the concept of recruitment over-fishing appears difficult to apply. Throughout its history, periods of high Redfish biomass have been sustained by a very small number of large recruitment events. Redfish have recovered from low levels of spawning stock biomass (SSB). However, there are SSB levels from which recovery will become unlikely or impossible, although these levels are unknown. Consequently, a LRP was estimated as the smallest SSB from which there has been a recovery (B_{rec}) for *S. mentella* and *S. fasciatus*, the SSB that produced recruitment that would likely produce recovery if those recruits were to not emigrate from the ecosystem. For both species, B_{rec} was estimated as the geometric mean of 2010-2012 SSB in the nGSL DFO survey, i.e. the SSB which produced the 2011-2013 cohorts. The proposed LRP based on B_{rec} is based on a recent period of low SSB occurring in warm and apparently favorable environmental conditions for Redfish that may not be unusual in the future, although the relationship with the environment is unknown. B_{rec} has been deemed an acceptable basis for the LRP for species with recruitment dynamics like Redfish (*e.g.*, scallops, Smith and Hubley 2012).

A proposed Upper Stock Reference (USR) point was defined based on nGSL DFO survey for a period of relatively high SSB and landings, considered to be a favorable period for the fishery: 1984-1990 for *S. mentella* and 1984-1992 for *S. fasciatus*. USRs were estimated as 80% of the SSB geometric mean during these periods. While these are not founded in recruitment-overfishing concepts, they do provide a defensible baseline for what has previously been considered a “healthy” stock.

For *S. mentella*, LRP and USR were estimated at 43 kt and 265 kt, respectively. In 2019, *S. mentella* SSB was estimated at 1,718 kt, 6.5 times larger than the USR, indicating that *S. mentella* is in the Healthy Zone of the Precautionary Approach (PA, Figure 50A). For *S. fasciatus*, LRP and USR were estimated at 25 and 168 kt, respectively. *S. fasciatus* SSB in 2019 was estimated at 49 kt, which is twice as large as the LRP and a third of the USR, indicating that *S. fasciatus* is presently in the Cautious Zone of the PA (Figure 50B).

The Unit 2 survey was not used to define these reference points, as it only started in 2000, long after the target period used to define the USRs. Proposed reference points will need to be revised in the near term once new information is accumulated on the recruitment and dynamics of the Redfish species in Unit 2.

DIET

The massive arrival of 2011-2013 Redfish cohorts has many implications for the GSL ecosystem, including predation and competition increase with several taxa. In order to specify the species subjected to this predation, Redfish diet has been quantified in the nGSL DFO survey. Every summer since the early 1990s, stomachs have been collected during the survey (Bourdages et al. 2020). Main species studied for stomach contents are Atlantic Cod, Redfish (*Sebastes* spp.), Greenland Halibut, and Atlantic Halibut. Only successful tows (good deployment of the trawl and sufficient duration) are considered for stomach sampling. For a given set and species, a specimen is selected for stomach sampling when it fulfills these three criteria (Ouellette-Plante et al. 2020):

1. The given set is amongst the targeted ones for that species. For example, even- and odd-numbered sets are frequently used to decide when to collect stomachs for a species x during surveys.
2. The length of the specimen considered falls into a length class where all samples have not yet been collected. The length classes and the number of stomachs targeted for each class may differ from one species to another and from year to year.

3. The specimen considered does not show obvious signs of regurgitation, such as the presence of prey items in its mouth.

Selected specimens approximately < 15 cm are frozen whole in individual plastic bags containing an identification label, while the stomachs of larger specimens are excised at sea and placed whole into identified plastic bags to maximize the use of space in freezers.

Back in the laboratory, the stomachs are thawed just before their examination. Each stomach is weighed and its content is removed and also weighed. The stomach content is then sorted and identified to the lowest practical taxonomic level, then assigned to one or more stages of digestion before weighing and recording in a datasheet. A nearly undigested taxon is entered as stage 1; a partially digested taxon, but usually still identifiable to species level, as stage 2; and prey with estimated mass loss due to digestion estimated to be 50% or more (including traces such as fish bones and otoliths), or impossible to identify to species level due to digestion, as stage 3. The mass is recorded in grams (0.001 g). Intact prey (stage 1) are measured, while the otoliths of digested specimens of commercial species are retained in order to estimate the length of ingested prey.

The percentage of empty stomachs (*PES*), the mass contribution (*MC*), the partial fullness index (*PFI*), the contribution to the total fullness index (*CTFI*) and the frequency of occurrence (F_{occ}) are the five measures that were used to classify the importance of the different taxa found in the diet of a predator species. These measures come from the method presented for Greenland Halibut in Bernier and Chabot (2013).

For a stomach sample, the percentage of empty stomach (*PES*) is calculated as:

$$PES = \frac{N_e}{N} \cdot 100 \tag{1}$$

where *Ne* is the number of empty stomachs and *N* is the total number of stomachs in a sample. The mass contribution (*MC*) of a taxon *i* in a sample of *N* stomachs is calculated as follows:

$$M_i = \sum_{j=1}^{N} M_{ij} \tag{2}$$

$$M_{tot} = \sum_{i=1}^{I} M_i \tag{3}$$

$$MC_i = \frac{M_i}{M_{tot}} \cdot 100 \tag{4}$$

Where M_{ij} is the mass of the taxon *i* (from a total of *I* taxa) in the stomach *j*, M_i is the total mass of this taxon in the *N* stomachs of the sample, and M_{tot} is the total mass of the stomach contents of the same sample, all expressed as a percentage. As pointed out in Bernier and Chabot (2013), the use of *MC* alone has certain disadvantages:

1. For a stomach sample, the sum of the *MCi* of all the taxa found gives 100%. This implies an interdependence between the *MCi* of the different taxa, where a high value found for a given taxon may reflect a decline in the abundance of alternative taxa and not an increase in the abundance of this taxon in the diet of the predator.

2. The taxa found in small specimens have less influence on the description of the diet because they contribute less to *Mtot* than stomachs from larger specimens.
3. The MC does not take into account empty stomachs.

To reduce these shortfalls, the partial fullness index for each prey *i* (PFI_i) was used to describe diet. This index is first calculated for each fish (PFI_{ij}), and then the average value for the sample is calculated. This index adjusts the amount of each taxon found in a stomach taking into account the effect of the fish's length:

$$PFI_{ij} = M_{ij} \cdot L_j^{-b} \cdot 10^4 \quad (5)$$

$$TFI_j = \sum_{i=1}^{I} PFI_{ij} \quad (6)$$

$$PFI_i = \frac{1}{N} \cdot \sum_{j=1}^{N} PFI_{ij} \quad (7)$$

Where *Lj* is the length of the fish associated with the stomach, in cm, and *b* is the allometric exponent. A constant (10^4) makes it possible to maintain the majority of the calculated values between 0 and 10. A of 3 for the *b* parameter was used here as it has often been used in the literature (Bowering and Lilly 1992, Orr and Bowering 1997, Hovde et al. 2002).

The partial fullness index of a taxon *i* in a sample is easier to interpret if it is expressed as a percentage of the total fullness index for the sample (TFI_{tot}):

$$TFI_{tot} = \sum_{i=1}^{I} PFI_i = \frac{1}{N} \cdot \sum_{j=1}^{N} TFI_j \quad (8)$$

PFI and *TFI* can be calculated by including or rejecting empty stomachs. Empty stomachs were included in this study. *TFI* calculated by including empty stomachs can normally be used as a stomach fullness index and is a measure of feeding intensity. Unfortunately, this is not the case for Redfish stomachs. This species suffers from extensive barotrauma when the trawl is brought back to the surface causing many Redfish partly or completely regurgitate their prey. Redfish have a physoclistous swim bladder, meaning that it does not communicate with the esophagus. This has the effect of preventing gas from escaping during Redfish's ascent in the trawl. The swim bladder therefore expands and often the stomach contents are regurgitated in whole or in part. In some cases, the stomach is completely everted into the mouth of the fish (Figure 51). Even if the sampling protocol indicates to reject individuals that have the stomach in the mouth or that show signs of regurgitation, it is probable that a part of the stomach contents of some individuals judged suitable for sampling has been regurgitated, which invalidates the percentage of empty stomachs and even the fullness indices as indices of feeding intensity due to overestimation of *PES* and underestimation of *TFI* and all *PFIs*. Nevertheless, stomach contents obtained make it possible to estimate the relative importance of the different taxa in Redfish diet. We assume that the probability of regurgitation of all taxa is the same, and that the relative contribution of each taxa to the diet is therefore valid.

The contribution of prey *i* to stomach filling in the sample, $CTFI_i$, expressed as a percentage, is then calculated as follows:

$$CTFI_i = \frac{PFI_i}{TFI_{tot}} \cdot 100 \quad (9)$$

The frequency of occurrence F_{occ} of a taxon *i* is calculated as follows:

$$F_{occ} = \frac{N_i}{N} \cdot 100 \quad (10)$$

where N_i is the number of stomachs in the sample containing the taxon *i*. Identified contents corresponding to parasites or wastes (*e.g.,* rock, sand, liquid, mucus) were excluded from the analysis. Stomachs collected outside August and September were eliminated from the analysis. Prey from all stages of digestion were used in the analysis.

A general description of Redfish diet is presented. Furthermore, given the potential importance of predation by Redfish on Northern Shrimp a, total consumption was estimated for the last three years of the 1990s and 2015-2019 periods. We based the consumption estimates on *Q/B* ratios provided by ecosystem models available from other studies for the nGSL, where *Q* is the total annual consumption ($t \cdot km^{-2} \cdot yr^{-1}$) and B the Redfish biomass (t wet mass$\cdot km^{-2}$). For the 1990s, we used a *Q/B* ratio of 1.036 yr^{-1} (Savenkoff et al. 2004), while we used a value of 0.75 yr^{-1} for the 2015-2019 period. This last value comes from an unpublished document from Savenkoff and Rioual similar to other reports published by Savenkoff and colleagues for the ecosystem models they developed. This unpublished document focussed on the 2006-2010 period, so the *Q/B* ratio used for the 2015-2019 period could be erroneous as there is a considerable time lag between the two periods. However, this is the best value currently available and the scientific literature shows a broad range of values going from 1.3 yr^{-1} to 6.0 yr^{-1} to choose from (Savenkoff et al. 2004). By using a value of 0.75, we are conservative with the estimates provided for this period.

To calculate Northern Shrimp consumption by Redfish for a given year in one of the two periods, we pooled Redfish biomass into *k* 5 cm length classes to correspond to length-dependant diet estimates. Redfish biomass estimates are based on the results of the nGSL DFO survey carried out in August each year. Annual consumption for each 5 cm length class k was calculated as:

$$Q_k = B_k \cdot {}^{Q}/_{B} \quad (11)$$

Q_k represents the total annual consumption per squared kilometer. Shrimp consumption alone, Q_k must be multiplied by the proportion of shrimp in the diet of Redfish of length class k, or the mass contribution (MC_k) by length classes derived from stomachs collected in all years from each period (1990s and 2015-2019). Consumption of *P. borealis* shrimp for each 5-cm class was estimated using stomach contents collected in both periods because shrimp consumption was similar in both periods and this increased sample size for each length class. When fewer than 20 stomachs were available, Northern Shrimp consumption by Redfish was not estimated:

$$Q_k = Q_k \cdot MC_k \begin{cases} 0 \text{ if sample size} < 20 \text{ stomachs} \\ \text{else } MC_k \end{cases} \quad (12)$$

At this point, annual Northern Shrimp consumption for a given year can be obtained as follows:

$$Q = \sum_{k=1}^{K} Q_k \qquad (13)$$

Redfish (*S. mentella* and *S. fasciatus* are not distinguished here) were targeted for stomach samples for twelve years over the period 1993-2019, excluding 2000 to 2014, from which 7 150 stomachs were analyzed in the laboratory (Figure 52). The geographic coverage of stomach samples is depicted in Figure 53 and shows the Strait of Belle Isle being the only region were no Redfish, hence no stomach, were collected, regardless of the period considered.

Redfish stomachs were obtained from specimens ranging from 4 to 52 cm in length, with an average length of 25 cm (Table 9). With the recent strong cohorts, the mean and median lengths of Redfish from which stomachs were collected in the 2015-2019 period were smaller than in the 1990s.

Almost half of the stomachs were empty when ignoring periods and length classes (Table 9). After the elimination of waste products, parasites and empty stomachs, the average mass of Redfish stomach contents in the 1990s was more than the double (4.4 g) that of recent years (1.7 g). This was in part caused by larger median and average fish length in the 1990s, but the *TFI*, which corrects for the effect of fish length, also shows a greater amount of food in the stomachs collected in the 1990s than those from recent years (0.63 compared to 0.44, Table 9).

One hundred twelve taxa were found in the stomach contents of the 7,150 Redfish used in the analysis (Tables 9-10), of which almost half were zooplankton taxa. The group of prey contributing the most to *TFI* in Redfish is zooplankton (32%), followed in second and third ranks by shrimp (29%) and other invertebrates (17%), respectively (Table 10). Among the zooplankton, which were found in almost one third of all stomachs analysed, *Euphausiidae* and *Hyperiidae* families had the greatest importance in Redfish diets. At the species level, Northern Krill (*Meganyctiphanes norvegica*) is the most abundant zooplankton taxon.

Fourteen shrimp taxa were recorded in the stomachs. Taking all species together, shrimp were observed in just over 10% of stomachs. The Pink Glass Shrimp was the most important taxon in Redfish diet, all prey combined, contributing to 14% of the total food intake (Table 10, F_{occ} of 7%). Northern Shrimp (F_{occ} of 3%) was second in importance among the 112 taxa reported with a *CTFI* of 9%. The third most important species was capelin, which, even if rarely observed (F_{occ} < 1 %), contributed to 5% of Redfish diet.

Less than 5% of analyzed Redfish stomachs contained fish prey, accounting for 14% of Redfish intake. Redfish can be cannibalistic, with Redfish occurrences in stomachs accounting for 3% of *CTFI*.

Diet as a function of length

There was an ontogenetic shift in Redfish diet, with high consumption of zooplankton at small lengths to increased consumption of fishes and shrimp as length increases (Figures 54-55). Feeding intensity appeared to be greater for smaller and bigger specimens, with individuals in the 15-35 cm length range having lower fullness indices (Figure 54). In order avoid excessively large tables, three length groups were created to summarise these results in Table 11: <20, [20-30], and ≥ 30 cm.

Small (< 20 cm) Redfish are mainly zooplanktivorous (53% of their intake, Table 11). The *other invertebrates* group ranks second in importance, but does not bring any interesting information since taxa contributing greatly to the *TFI* are prey in advanced stages of digestion where thorough taxonomic identification was not possible (ex: crustaceans, amphipods, etc.).

Observed in 3 % of small Redfish stomachs, shrimp represented about 10% of small Redfish food intake. Fish contribution to small Redfish diet is almost nil (*CTFI* of 0.79%) and capelin is the only fish identified at the species level.

In contrast to small individuals, Redfish 20-30 cm long have a considerably greater intake of fishes and shrimp, at the expense of zooplankton and other invertebrates (Table 11). In particular, the importance of capelin in the diet was 23 time larger than for Redfish < 20 cm length. The importance fishes and shrimp in the diet is even greater for Redfish ≥ 30 cm in length. Shrimp intake was close to 50% of the *TFI*, and Pink Glass Shrimp and Northern Shrimp were the two contributing taxa.

When pooled into taxonomic groups, the 112 taxa recorded in the 7,150 stomachs can be summarised in 14 groups shown in Figure 56. The contribution of all zooplankton taxonomic groups to the *TFI* decreases with increased Redfish lengths, while with an opposite trend for fishes and shrimp.

Diet as a function of period

A major difference between the 1990s and 2015-2019 periods was an increase in the taxonomic resolution for identified prey (Table 12). This improvement could explain why the intake of zooplankton in Redfish diet seemed to have increased in recent years.

For larger preys such as shrimp and fish, results were similar between periods. In fact, shrimp intake still represented about 30% of the *TFI* in recent years. Pink Glass Shrimp was the most important shrimp taxon followed by the Northern Shrimp in Redfish diet, regardless of the period considered. Fish intake contributed more in the 2015-2019 period, mainly as a result of cannibalism (Table 12, Figure 57).

The *TFI* of specimens grouped into 5 cm length classes showed similar trends between the two periods, namely small and large individuals having higher feeding intensity than mid-sized individuals (15-35 cm length, Figure 58). Smaller specimens from the recent period had a lower feeding intensity than their counterparts from the 1990s, which could be attributable to intra-species competition created by the massive 2011-2013 cohorts.

Northern shrimp consumption

Estimates of Northern Shrimp consumption by Redfish increased as a result of increased Redfish biomass in the length classes that consume shrimp (Figure 59). Approximately 9,500 t of Northern Shrimp were estimated to have been consumed annually during the period 1997-1999, compared to 81,000 t for the 2017-2019 period, corresponding to a 8.5 fold increase. Northern Shrimp consumption roughly doubled year after year for the period 2017-2019, which reflecting the long-term growth of the 2011-2013 Redfish cohorts. These estimates differ from the previous one (Senay et al. 2019) because additional stomachs were collected and added to the analysis, resulting in a reduced proportion of Northern Shrimp in the Redfish diet than was estimated previously.

SOURCE OF UNCERTAINTY

The arrival of the 2011 to 2013 Redfish cohorts at lengths greater than the minimum regulatory size (22 cm) 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. Reopening of the commercial fishery in Unit 1 has motivated the development of numerous research projects and management tools.

The absence of species identification in the commercial fishery is a major gap in the assessment of these stocks. Effort should be continued to provide training to ASO and port samplers to obtain the reliable AFR counts required to determine species composition. Error in species attribution based on the counts should be quantified and the potential role of species misidentification in the perceived recent declines of *S. fasciatus*, the lesser abundant of the two species, should be investigated. Efforts should also be invested in developing an effective and economical genetic identification procedure for monitoring application.

New genomic analyses could not confirm or refute the distinct population of *S. fasciatus* located in the Laurentian Fan area, included in the southern edge of Unit 2. A population was previously described as belonging to the Atlantic population of the continental shelf break in this area. Larger sample size and better spatial coverage of the area could improve inferences on populations structure based on genomics.

Bottom-trawl surveys only capture fish occurring a maximum of about 5 m above the seabed when the trawl is fishing on bottom. Some vertical herding of animals towards the bottom may occur. However, acoustics indicate that Redfish in the nGSL are distributed from the bottom up to hundreds of meters in the water column, suggesting that the bottom-trawl index may considerably underestimate total biomass. A project aiming to develop Redfish acoustic indices should provide a more accurate estimate of stock biomass by including fish distributed throughout the water column, and would assess whether bottom trawl survey biomass is representative of actual biomass.

The nGSL ecosystem is changing and impacts on Redfish are mostly unknown. Important gaps in our understanding could be filled by research aimed at understanding the relationships between these changes (*e.g.,* increase in temperature, decrease in dissolved O_2, density-dependent responses) and Redfish physiology (*e.g.,* metabolism, growth) and demographic rates (*e.g.,* recruitment, mortality).

Most of the recent information for Redfish in Unit 1 comes from summer trawl surveys. There is little information for other seasons on Redfish diet, distribution and movements. Lack of seasonal diet information precludes an accurate estimate of Redfish consumption of prey, which is important for understanding the predatory and competitive interactions with other species. Lack of information on the seasonal distribution of Redfish and potentially co-occurring species is hindering efforts to estimate the potential bycatch of other species in an eventual expanded Redfish fishery.

Reference points were defined for each species in Unit 1 and 2, exclusively using indices from the Unit 1 survey given that the Unit 2 survey only starts in 2000, after the target period used to define the USRs. Furthermore, the strong recruitment for the 2011-2013 cohort evident in the Unit 1 survey and used to define the LRP based on B_{rec}, is not as evident in the Unit 2 survey. Efforts should be made to include information on Unit 2 in the PA for the two species, therefore proposed reference points will need to be revised in the near-term once new information is accumulated.

CONCLUSION

Prospects for *S. mentella* in Unit 1 are positive due to the large cohorts from 2011, 2012 and 2013 that are now mostly larger than the minimum regulatory size of 22 cm. The strong biomass increase may allow higher catches of *S. mentella* in Unit 1, however *S. fasciatus* is still in the Cautious Zone. This increase of *S. mentella* may have important repercussions on other species, through predation and competition interactions.

There are concerns about impacts of an expanded Redfish fishery on depleted bycatch species. Analyses of historical data have identified factors associated with catch rates of incidentally captured species from which management measures aimed at reducing bycatch could be developed. However, contemporary fishery dependent (at-sea observer sampling) and research data (winter surveys) are required to refine the scientific advice on bycatch, particularly as regards vulnerable species.

Although the recent strong cohorts continue to reach minimal regulatory size, there remains a proportion of Redfish biomass comprising undersized individuals. Minimizing fishing mortality on small Redfish was identified as a key priority in a recent Management Strategy Evaluation for Units 1 and 2 Redfish (DFO 2018e). Recent selectivity research has shown that the capture of undersized Redfish can be reduced through modification to codend meshes. However, undocumented mortality of escaping fish at depth during trawling may be a concern for mechanical sorting devices. If undersized individuals escape at depth then this mortality may be limited, but could be higher if escape occurs during haul-back. Additional research on the potential magnitude of through-mesh survival, possibly via a review of information available elsewhere, and on the magnitude of fish meshing in commercial fishing applications is recommended.

Full implementation of the PA will require the definition of a fishing limit (removal) reference and harvest control rules. Information from both Units 1 and 2 should be considered to ensure that the PA represents the entire stock for each of the two Redfish species.

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TABLES

Table 1. Number of individuals (occurrence) assigned to S. mentella, S. fasciatus or heterozygotes by soft anal fin ray (AFR) counts, as well as the theoretical distribution (proportion) of AFR per species used in the Chi square test used to estimate species composition. These individuals were collected in Unit 1 (A) in August and September 1994-1997 and in Unit 2 (B) in July to November 1995-1998.

A

AFR	Occurrence				Proportion			
	S. mentella	Heterozygotes	*S. mentella* + Heterozygotes	*S. fasciatus*	*S. mentella*	Heterozygotes	*S. mentella* + Heterozygotes	*S. fasciatus*
6	0	1	1	5	0	0.0046	0.0010	0.0078
7	64	35	99	415	0.0912	0.1606	0.1076	0.6464
8	479	153	632	215	0.6823	0.7018	0.6870	0.3349
9	158	28	186	7	0.2251	0.1284	0.2022	0.0109
10	1	1	2	0	0.0014	0.0046	0.0022	0

B

AFR	Occurrence				Proportion			
	S. mentella	Heterozygotes	*S . mentella* + Heterozygotes	*S. fasciatus*	*S. mentella*	Heterozygotes	*S. mentella* + Heterozygotes	*S. fasciatus*
6	1	1	2	19	0.0010	0.0037	0.0016	0.0124
7	71	29	100	1160	0.0724	0.1070	0.0799	0.7592
8	594	178	772	330	0.6055	0.6568	0.6166	0.2160
9	295	60	355	19	0.3007	0.2214	0.2835	0.0124
10	20	3	23	0	0.0204	0.0111	0.0184	0

Table 2. Annual landings (t) per. Northwest Atlantic Fishery Organization (NAFO) Division or Subdivision and total allowable catches (TAC) per management cycle of Sebastes spp. in Unit 1 from 1953 to 2019. Data include fisheries directed to all species. No Redfish directed fishery took place from 1995 to 1997. 2018 and 2019 values are preliminary.

Year	Landings (tonnes)						TAC
	4R	4S	4T	3Pn Jan.-May	4Vn Jan.-May	Total	
1953	5 981	48	2 337	0	0	8 366	-
1954	12 867	3 048	16 853	0	0	32 768	-
1955	38 520	8 739	2 598	0	0	49 857	-
1956	25 675	17 900	3 259	0	0	46 834	-
1957	17 977	13 365	2 989	0	0	34 331	-
1958	9 716	11 076	1 778	0	0	22 570	-
1959	9 744	5 620	1 614	0	135	17 113	-
1960	5 512	4 678	2 028	0	612	12 830	-
1961	3 927	4 482	1 982	2	669	11 062	-
1962	1 609	3 444	1 532	5	561	7 151	-
1963	6 908	9 674	3 212	443	580	20 817	-
1964	9 967	16 843	2 890	243	581	30 524	-
1965	20 115	23 517	5 195	3 232	770	52 829	-
1966	33 057	24 133	8 025	1 881	866	67 962	-
1967	30 855	30 713	8 468	995	874	71 905	-
1968	43 643	40 228	7 092	668	3 633	95 264	-
1969	36 683	41 352	10 840	1 912	1 533	92 320	-
1970	37 419	40 917	9 252	1 521	1 394	90 503	-
1971	27 954	43 540	7 912	593	2 190	82 189	-
1972	26 084	46 788	7 457	128	2 135	82 592	-
1973	68 074	47 594	14 496	1 521	4 416	136 101	-
1974	30 896	25 684	6 909	1 505	2 087	67 081	-
1975	30 838	28 499	6 064	3 378	1 273	70 052	-
1976	19 963	16 394	1 626	4 523	1 872	44 378	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

Year	Landings (tonnes)						TAC
	4R	4S	4T	3Pn Jan.-May	4Vn Jan.-May	Total	
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	11 497	13 276	3 594	226	60	28 653	50 600
1986	10 964	18 203	3 954	2 219	269	35 608	55 600
1987	11 553	16 774	5 992	3 221	5 901	43 442	50 000
1988	14 835	14 169	7 578	6 440	5 762	48 784	56 000
1989	16 831	16 112	10 016	5 057	3 746	51 763	57 000
1990	23 421	16 497	3 929	5 644	5 569	55 060	57 000
1991	40 430	3 991	6 503	5 755	5 755	62 433	57 000
1992	30 088	11 193	8 198	13 901	13 946	77 326	57 000
1993 [2]	16 475	4 769	4 132	17 568	8 392	51 337	60 000
1994	2 745	2 378	5 173	5 081	4 014	19 392	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]	127	77	200	0	5	409	1 000
1999	589	63	456	10	3	1 123	2 000
2000	794	53	258	85	3	1 192	2 000
2001	710	6	370	13	5	1 105	2 000
2002	689	50	465	0	1	1 205	2 000
2003	484	65	288	0	10	847	2 000
2004	486	34	413	0	2	934	2 000
2005	562	87	325	0	5	978	2 000
2006	126	52	512	0	0	690	2 000
2007	5	22	78	0	0	105	2 000

Year	Landings (tonnes)						TAC
	4R	4S	4T	3Pn Jan.-May	4Vn Jan.-May	Total	
2008	62	9	348	0	1	421	2 000
2009	95	16	524	0	2	637	2 000
2010	164	53	330	0	0	548	2 000
2011	113	42	475	0	1	631	2 000
2012	148	173	378	0	1	700	2 000
2013	65	121	280	0	9	474	2 000
2014	37	32	286	0	0	356	2 000
2015	8	55	366	0	9	438	2 000
2016	65	47	231	11	0	354	2 000
2017	31	34	121	89	0	275	2 000
2018 [5, 6]	141	210	191	188	18	748	4 500
2019 [6]	325	52	214	0	0	592	5 950

[1] TAC Changed during the year
[2] 1993: Beginning of Redfish management Unit 1
[3] 1995: Beginning of the moratorium
[4] 1998: Beginning of the index fishery
[5] 2018: Beginning of the experimental fishery
[6] Preliminary data

Table 3. Relationship between Redfish and bycatch CPUE as a function of gear, depth, season, and ecosystemic approach (EA) areas. Model's output (estimate, standard error, t value, and p value) are presented for each species, binomial and log-normal models, and the intercept as well as each explanatory variable. Non-significant terms are indicated as NS and effects that could not be tested are indicated as NA.

Species	Model		Estimate	Std. Error	t value	p value
Redfish	binomial	Intercept	1.220	0.076	16.15	<2E-16
		Midwater trawl	-0.956	0.095	-10.05	<2E-16
		Depth	NS	NS	NS	NS
		Winter	NS	NS	NS	NS
		Laurentian hermitage area	NS	NS	NS	NS
		NE Gulf area	NS	NS	NS	NS
Redfish	log-normal	Intercept	7.369	0.178	41.30	< 2E-16
		Midwater trawl	0.848	0.079	10.75	< 2E-16
		Depth	-0.001	0.001	-2.02	4.35E-02
		Winter	NS	NS	NS	NS
		Laurentian hermitage area	-0.415	0.073	-5.71	1.35E-08
		NE Gulf area	NS	NS	NS	NS
Greenland Halibut	binomial	Intercept	-6.175	0.523	-11.81	< 2E-16
		Midwater trawl	-4.665	0.343	-13.61	< 2E-16
		Depth	0.014	0.001	9.84	< 2E-16
		Winter	0.438	0.196	2.24	2.53E-02
		Laurentian hermitage area	-0.771	0.269	-2.87	4.17E-03
		NE Gulf area	NS	NS	NS	NS
Greenland Halibut	log-normal	Intercept	NS	NS	NS	NS
		Midwater trawl	-1.370	0.285	-4.82	2.88E-06
		Depth	0.003	0.001	3.35	9.57E-04
		Winter	0.357	0.129	2.77	6.06E-03
		Laurentian hermitage area	NS	NS	NS	NS
		NE Gulf area	NS	NS	NS	NS

Species	Model		Estimate	Std. Error	t value	p value
Atlantic Halibut	binomial	Intercept	2.177	0.570	3.82	1.34E-04
		Midwater trawl	NA	NA	NA	NA
		Depth	-0.015	0.002	-8.36	< 2E-16
		Winter	NS	NS	NS	NS
		Laurentian hermitage area	NS	NS	NS	NS
		NE Gulf area	-0.802	0.280	-2.86	4.20E-03
Atlantic Halibut	log-normal	Intercept	2.184	0.111	19.65	< 2E-16
		Midwater trawl	NA	NA	NA	NA
		Depth	NS	NS	NS	NS
		Winter	NS	NS	NS	NS
		Laurentian hermitage area	0.746	0.242	3.08	2.73E-03
		NE Gulf area	NS	NS	NS	NS
Atlantic Cod	binomial	Intercept	1.415	0.297	4.77	1.82E-06
		Midwater trawl	0.323	0.129	2.50	1.24E-02
		Depth	-0.007	0.001	-7.79	6.99E-15
		Winter	2.011	0.113	17.74	< 2E-16
		Laurentian hermitage area	0.310	0.115	2.69	7.17E-03
		NE Gulf area	NS	NS	NS	NS
Atlantic Cod	log-normal	Intercept	1.541	0.089	17.41	< 2E-16
		Midwater trawl	-1.123	0.099	-11.32	< 2E-16
		Depth	NS	NS	NS	NS
		Winter	1.762	0.105	16.82	< 2E-16
		Laurentian hermitage area	0.424	0.096	4.44	9.93E-06
		NE Gulf area	NS	NS	NS	NS
White Hake	binomial	Intercept	-3.547	0.334	-10.63	< 2E-16
		Midwater trawl	0.884	0.129	6.87	6.40E-12
		Depth	0.006	0.001	6.21	5.23E-10
		Winter	NS	NS	NS	NS

Species	Model		Estimate	Std. Error	t value	p value
		Laurentian hermitage area	0.462	0.107	4.31	1.64E-05
		NE Gulf area	0.484	0.188	2.57	1.01E-02
White Hake	log-normal	Intercept	NS	NS	NS	NS
		Midwater trawl	NS	NS	NS	NS
		Depth	0.006	0.001	8.09	2.32E-15
		Winter	-0.284	0.087	-3.28	1.07E-03
		Laurentian hermitage area	0.553	0.090	6.15	1.28E-09
		NE Gulf area	0.476	0.182	2.62	8.88E-03

Table 4. Occurrence percentage (%), biomass (kg), landed catches percentage (%), and percentage of each species biomass as a function Redfish biomass (%) based on retained at-sea observer data for the Redfish directed fishery from 1999 to 2019. 2018 and 2019 values are preliminary.

Name	Occurrence (%)	Biomass (kg)	Reported (%)	Bycatch / Redfish (%)
Redfish	99.42	2 019 937	99.78	100.00
Greenland Halibut	71.92	81 804	99.69	4.05
White Hake	57.89	24 116	85.03	1.19
Witch Flounder	41.25	4 119	97.69	0.20
Atlantic Cod	36.86	39 063	99.59	1.93
Thorny Skate	31.60	6 750	21.35	0.33
Atlantic Halibut	27.27	10 456	84.46	0.52
Skates	24.55	6 052	1.40	0.30
Monkfish	19.58	1 654	89.60	0.08
Norway King Crab	19.30	1 281	1.41	0.06
American Plaice	12.48	884	98.98	0.04
Black Dogfish	12.31	9 703	7.47	0.48
Spiny Dogfish	12.19	3 763	0.16	0.19

Table 5. Percentile describing depth (m) 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 2019. 2018 and 2019 values are preliminary.

Percentile	Redfish	Greenland Halibut	White Hake	Atlantic Cod	Atlantic Halibut
p5	246	247	245	204	209
p10	256	263	251	209	224
p25	276	302	276	223	261
p50	306	351	298	240	297
p75	375	414	320	255	327
p90	424	433	347	292	414
p95	442	437	370	311	429

Table 6. Abundance (1,000,000 individuals, A) and biomass (1,000 t, B) indices in nGSL DFO research surveys from 1984 to 2019 for S. mentella, S. fasciatus, and Sebastes spp. by length classes.

A

Year	Abundance (1,000,000 ind.)											
	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
2018	12 815	7 545	570	20 359	1 410	492	120	1 902	14 224	8 036	690	22 261
2019	11 332	17 260	1 982	28 592	245	279	50	524	11 577	17 539	2 032	29 116

B

Year	Biomass (1,000 tonnes)											
	S. mentella				*S. fasciatus*				*Sebaste 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	8
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
2018	1 439	1 339	171	2 777	159	110	43	269	1 598	1 448	214	3 046
2019	1 283	3 044	497	4 365	21	57	18	78	1 304	3 101	515	4 324

Table 7. Species composition, mean depth of the tow (m), number of genotyped Redfish (n), mean fork length (mm), and geographical coordinates for the 15 locations used in the genomic analysis of Redfish juveniles sampled in 2018.

S. mentella (%)	*S. fasciatus* (%)	Mean depth (m)	*n*	Mean length (mm)	Latitude	Longitude
100	0	312	30	83	48.96	-63.83
100	0	243	30	87	49.62	-62.12
100	0	304	29	84	49.59	-64.74
100	0	281	33	81	49.04	-67.91
100	0	346	36	87	49.46	-65.16
100	0	211	44	85	48.88	-61.66
97	3	242	38	79	49.23	-66.87
97	3	219	36	92	49.75	-62.72
94	6	173	31	86	49.53	-62.01
75	25	175	32	85	49.94	-65.78
50	50	299	24	81	48.80	-60.28
5	95	166	37	90	50.31	-57.68
5	95	149	21	82	49.88	-58.44
3	97	136	33	74	49.46	-60.07
0	100	152	32	83	49.74	-58.58

Table 8. Growth trajectories expressed as proportion of abundance (A) or biomass (B) of S. mentella for each cohort (2011, 2012 and 2013) estimated for different length classes in different years. For example, 0.51, in bold in the table (A) indicates that 51% of the fish from the 2011 cohort would be more than 25 cm in 2020 and 51% of fish from the 2012 cohort would be more than 25 cm in 2021. The relationship between length and age was calculated with a von Bertalanffy growth curve where Linfinity = 42 cm, k = 0.086, t_0 = -1.57 and a CV on length at age of 0.078. The length-weight relationship parameters were a = 0.01, b = 3.08.

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 9. Summary information for Redfish stomachs sampling according to the different periods, length classes, and all samples combined (total). A description of Redfish length from which the stomachs were collected, total stomach contents after the elimination of waste products, parasites and empty stomachs, and the number of taxa per prey group are provided.

Parameter		Period		Length class (cm)			Total
		1990s	**2015-2019**	**< 20**	**[20-30[**	**≥ 30**	
TFI		0.63	0.44	0.56	0.3	0.64	0.53
Nb. of stomachs		3321	3829	2861	1719	2570	7150
Nb. of empty stomachs		1894	1505	1215	900	1284	3399
% of empty stomachs		57	39.3	42.5	52.4	50	47.5
Fork length (mm)	Mean	270.2	228.7	149.9	247.2	357.6	247.9
	Median	298	208	159	242	353	233
	Min	40	42	40	200	300	40
	Max	515	501	199	299	515	515
Total stomach content (g)	Mean	4.44	1.74	0.29	1.11	7	2.77
	Median	1.3	0.14	0.1	0.18	3.06	0.3
	Min	0.001	0.001	0.001	0.001	0.001	0.001
	Max	133.8	88.325	6.455	19.771	133.8	133.8
Nb. of taxa observed	Fishes	13	15	4	10	18	20
	Shrimp	9	12	10	7	9	14
	Zooplankton	31	51	47	33	31	54
	Other invertebrates	8	18	14	6	13	22
	Unidentifiable prey	2	2	2	2	2	2
	Total	63	98	77	58	73	112

Table 10. Detailed Redfish diet from the nGSL DFO survey, all periods and length classes combined.

Prey Common name	Latin name	F_{occ}	*MC*	*PFI*	*CTFI* Value	Rank
Capelin	*Mallotus villosus*	<1	8.3	0.03	5.08	6
Lanternfish	*Myctophidae*	<1	0.19	<0.01	0.09	43
Kroyer's lanternfish	*Notoscopelus kroyeri*	<1	0.48	<0.01	0.17	36
Barracudinas	*Paralepis* sp.	<1	0.07	<0.01	0.03	54
White barracudina	*Arctozenus risso*	<1	2.3	<0.01	1.09	24
Slender snipe eel	*Nemichthys scolopaceus*	<1	0.19	<0.01	0.09	41
Threespine stickleback	*Gasterosteus aculeatus*	<1	0.02	<0.01	0.02	58
Cods	*Gadus* sp.	<1	<0.01	<0.01	<0.01	75
Longfin hake	*Phycis chesteri*	<1	0.2	<0.01	0.1	40
Marlin-spike	*Nezumia bairdii*	<1	0.16	<0.01	0.09	42
Slender eelblenny	*Lumpenus fabricii*	<1	<0.01	<0.01	<0.01	79
Eelpout	*Zoarcidae*	<1	<0.01	<0.01	<0.01	89
Atlantic soft pout	*Melanostigma atlanticum*	<1	0.25	<0.01	0.15	37
Redfish	*Sebastes* spp.	<1	7.38	0.02	3.38	10
Flatfish	Pleuronectiformes	<1	0.05	<0.01	0.02	62
Digested roundfish	-	<1	1.3	<0.01	0.72	28
Fish (spawn) egg	-	<1	0.06	<0.01	0.03	57
Digested fish	-	1.5	3.96	0.01	2.13	16
Fishes, total	**-**	**4**	**26.01**	**0.07**	**13.85**	
Digested shrimp	*Dendrobranchiata / Caridea*	3.7	4.53	0.02	3.46	8
Glass shrimp	*Pasiphaeidae*	<1	0.85	<0.01	0.44	30
Glass shrimp	*Pasiphaea* sp.	<1	0.54	<0.01	0.31	33
Pink glass shrimp	*Pasiphaea multidentata*	7	22.84	0.07	13.62	1
Shrimp	*Hippolytidae*	<1	<0.01	<0.01	0.02	59
Arctic eualid	*Eualus fabricii*	<1	<0.01	<0.01	0.05	50
Greenland shrimp	*Eualus macilentus*	<1	0.02	<0.01	0.06	46
Gaimard's eualid	*Eualus gaimardii gaimardii*	<1	<0.01	<0.01	0.07	44
Parrot shrimp	*Spirontocaris spinus*	<1	<0.01	<0.01	0.05	49
Boreal red shrimps	*Pandalus* sp.	<1	1.76	<0.01	1.23	22
Northern shrimp	*Pandalus borealis*	2.7	13.87	0.05	9.1	2
Striped pink shrimp	*Pandalus montagui*	<1	0.63	<0.01	1	25
Shrimp, total	**-**	**13.2**	**45.09**	**0.16**	**29.44**	
Calanoid copepod	*Calanoida*	6	0.32	0.01	2.04	18

Prey Common name	Latin name	F_{occ}	*MC*	*PFI*	*CTFI* Value	Rank
Calanoid copepod	*Calanus* sp.	6.3	0.43	0.01	2.28	14
Calanoid copepod	*Calanus finmarchicus*	<1	<0.01	<0.01	<0.01	69
Calanoid copepod	*Calanus hyperboreus*	6.7	0.41	<0.01	1.19	23
Calanoid copepod	*Calanus glacialis*	<1	<0.01	<0.01	<0.01	112
Calanoid copepod	*Scolecithricella* sp.	<1	<0.01	<0.01	<0.01	109
Calanoide copepod	*Calanus finn. + glacialis*	<1	0.03	<0.01	0.19	35
Calanoid copepod	*Bradyidius similis*	<1	<0.01	<0.01	<0.01	80
Calanoid copepod	*Chiridius gracilis*	<1	<0.01	<0.01	<0.01	101
Calanoid copepod	*Aetideidae*	<1	<0.01	<0.01	0.07	45
Calanoid copepod	*Euchaeta* sp.	<1	<0.01	<0.01	<0.01	104
Calanoid copepod	*Paraeuchaeta norvegica*	2.3	0.04	<0.01	0.12	39
Calanoid copepod	*Metridia* sp.	1.9	0.03	<0.01	0.34	32
Calanoid copepod	*Metridia longa*	<1	<0.01	<0.01	<0.01	77
Calanoid copepod	*Metridia lucens*	<1	<0.01	<0.01	0.01	66
Hyperiid	*Hyperiidea*	<1	<0.01	<0.01	<0.01	99
Hyperiid	*Hyperiidae*	2.7	2.51	0.01	2.06	17
Hyperiids	*Themisto* sp.	6	0.8	0.01	2.16	15
Hyperiid	*Themisto abyssorum*	3.3	0.54	<0.01	1.32	20
Hyperiid	*Themisto compressa*	3.7	1.02	0.01	2.75	12
Hyperiid	*Hyperoche medusarum*	<1	<0.01	<0.01	<0.01	111
Hyperiid	*Themisto libellula*	2.5	2.37	0.01	2.5	13
Hyperiid	*Hyperia* sp.	<1	<0.01	<0.01	0.01	65
Hyperiid	*Hyperia galba*	<1	<0.01	<0.01	<0.01	72
Hyperiid	*Scina borealis*	<1	<0.01	<0.01	0.05	51
Gammarid	*Gammaridea*	<1	<0.01	<0.01	0.03	56
Gammarid	*Byblis* sp.	<1	<0.01	<0.01	0.01	68
Gammarid	*Rhachotropis aculeata*	<1	<0.01	<0.01	<0.01	87
Gammarid	*Melita* sp.	<1	<0.01	<0.01	<0.01	88
Gammarid	*Maera loveni*	<1	<0.01	<0.01	<0.01	76
Gammarid	*Lysianassidae*	<1	<0.01	<0.01	<0.01	78
Gammarid	*Neohela monstrosa*	<1	<0.01	<0.01	0.03	55
Gammarid	*Monoculodes* sp.	<1	<0.01	<0.01	<0.01	91
Gammarid	*Harpinia* sp.	<1	<0.01	<0.01	<0.01	94
Mysid	*Mysida*	<1	<0.01	<0.01	<0.01	95

Prey Common name	Latin name	F_{occ}	*MC*	*PFI*	*CTFI* Value	Rank
Mysid	*Mysidae*	1.1	0.34	<0.01	0.76	27
Mysid	*Boreomysis* sp.	4.1	1.01	0.02	3.46	9
Mysid	*Boreomysis tridens*	<1	0.02	<0.01	0.05	47
Mysid	*Boreomysis arctica*	<1	0.31	<0.01	0.91	26
Mysid	*Erythrops* sp.	<1	<0.01	<0.01	<0.01	81
Mysid	*Erythrops erythrophthalma*	<1	<0.01	<0.01	<0.01	73
Mysid	*Pseudomma* sp.	<1	<0.01	<0.01	0.02	60
Mysid	*Pseudomma* roseum	<1	<0.01	<0.01	0.02	61
Mysid	*Mysis* sp.	<1	<0.01	<0.01	0.02	64
Mysid	*Mysis mixta*	<1	<0.01	<0.01	<0.01	74
Mysid	*Stilomysis* sp.	<1	<0.01	<0.01	<0.01	82
Euphausiid	*Euphausiacea*	<1	<0.01	<0.01	<0.01	71
Euphausiid	*Euphausiidae*	2.9	1.41	0.02	3.3	11
Northern krill	*Meganyctiphanes norvegica*	4.1	2.75	0.03	4.75	7
Euphausiid	*Thysanoessa* sp.	<1	0.35	<0.01	1.58	19
Euphausiid	*Thysanoessa inermis*	<1	<0.01	<0.01	0.02	63
Arctic krill	*Thysanoessa raschii*	<1	0.07	<0.01	0.36	31
Zooplankton, total		**32.2**	**14.79**	**0.17**	**32.49**	
Invertebrate	*Invertebrata*	<1	<0.01	<0.01	<0.01	102
Arrow worm	*Parasagitta elegans*	<1	<0.01	<0.01	<0.01	110
Mollusc	*Mollusca*	<1	<0.01	<0.01	<0.01	105
Gastropod	*Gastropoda*	<1	<0.01	<0.01	<0.01	103
Shelled sea butterfly	*Limacina* sp.	<1	<0.01	<0.01	<0.01	96
Dipperclam	*Cuspidaria* sp.	<1	<0.01	<0.01	<0.01	85
Bobtail	*Rossia* sp.	<1	<0.01	<0.01	<0.01	70
Polychaete	*Polychaeta*	<1	<0.01	<0.01	<0.01	100
Sea mouse	*Aphrodita hastata*	<1	<0.01	<0.01	0.05	48
Crustacean	*Crustacea*	13.2	4.16	0.04	7.74	3
Crustacean	*Malacostraca*	<1	0.01	<0.01	0.23	34
Cumacean	*Cumacea*	<1	<0.01	<0.01	0.04	52
Isopod	*Isopoda*	<1	<0.01	<0.01	<0.01	108
Isopod	*Syscenus infelix*	<1	0.02	<0.01	0.01	67
Amphipod	*Amphipoda*	2.2	6.22	0.04	7.71	4
Crab	*Brachyura*	<1	<0.01	<0.01	<0.01	98

Prey Common name	Latin name	F_{occ}	*MC*	*PFI*	*CTFI* Value	Rank
Snow crab	*Chionoecetes opilio*	<1	<0.01	<0.01	<0.01	106
Lyre crab	*Hyas* sp.	<1	<0.01	<0.01	<0.01	107
Invertebrate egg	-	<1	<0.01	<0.01	<0.01	93
Digested invertebrates	-	<1	0.08	<0.01	0.13	38
Other invertebrates, total	**-**	**18.9**	**10.73**	**0.09**	**17.18**	**-**
Invertebrates, total	**-**	**49.1**	**70.61**	**0.42**	**79.11**	**-**
Unidentified digested material	-	5.4	3.38	0.04	7.04	5
Unidentified egg	-	<1	<0.01	<0.01	<0.01	86
Unidentifiable preys, total	**-**	**5.5**	**3.38**	**0.04**	**7.04**	**-**
Total	**-**	**-**	**100**	**0.53**	**100**	**-**

Table 11. Detailed Redfish diet from the nGSL DFO survey by length classes (cm), all periods combined.

	F_{occ}				***MC***				***CTFI***			
Prey	**< 20**	**[20-30]**	**≥ 30**	**Total**	**< 20**	**[20-30]**	**≥ 30**	**Total**	**< 20**	**[20-30]**	**≥ 30**	**Total**
Bony fish (*Actinopterygii*)	1	<1	<1	<1	<0.01	0.98	1.13	1.07	<0.01	0.79	1.21	0.64
Atlantic herring (*Clupea harengus*)	-	<1	-	<1	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Capelin (*Mallotus villosus*)	<1	<1	1.5	<1	1.19	10.62	8.44	8.3	0.48	11.19	7.68	5.08
Lanternfish (*Myctophidae*)	-	-	<1	<1	-	-	0.22	0.19	-	-	0.2	0.09
Kroyer's lanternfish (*Notoscopelus kroyeri*)	-	-	<1	<1	-	-	0.56	0.48	-	-	0.39	0.17
Barracudinas (*Paralepis* sp.)	-	-	<1	<1	-	-	0.08	0.07	-	-	0.07	0.03
White barracudina (*Arctozenus risso*)	-	<1	<1	<1	-	1.56	2.5	2.3	-	1.35	2.08	1.09
Slender snipe eel (*Nemichthys scolopaceus*)	-	-	<1	<1	-	-	0.22	0.19	-	-	0.21	0.09
Threespine stickleback (*Gasterosteus aculeatus*)	-	-	<1	<1	-	-	0.03	0.02	-	-	0.05	0.02
Cods (*Gadus* sp.)	-	-	<1	<1	-	-	0.01	<0.01	-	-	0.01	<0.01
Longfin hake (*Phycis chesteri*)	-	-	<1	<1	-	-	0.23	0.2	-	-	0.22	0.1
Marlin-spike (*Nezumia bairdii*)	-	<1	<1	<1	-	0.13	0.17	0.16	-	0.09	0.18	0.09
Slender eelblenny (*Lumpenus fabricii*)	-	<1	-	<1	-	0.04	-	<0.01	-	0.04	-	<0.01
Eelpout (*Zoarcidae*)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Atlantic soft pout (*Melanostigma atlanticum*)	-	<1	<1	<1	-	0.37	0.26	0.25	-	0.35	0.24	0.15
Redfish (*Sebastes* spp.)	-	<1	1.2	<1	-	1.15	8.4	7.38	-	0.96	7.44	3.38
Flatfish (Pleuronectiformes)	-	-	<1	<1	-	-	0.06	0.05	-	-	0.04	0.02
Digested roundfish	<1	<1	1.1	<1	<0.01	0.71	1.43	1.3	<0.01	0.59	1.47	0.72
Fish (spawn) egg	-	-	<1	<1	-	-	0.07	0.06	-	-	0.06	0.03
Digested fish	<1	<1	3.4	1.5	0.46	2.33	4.31	3.96	0.31	2.3	3.85	2.13
Fishes, total	**<1**	**2.6**	**8.9**	**4**	**1.66**	**17.89**	**28.11**	**26.01**	**0.79**	**17.66**	**25.44**	**13.85**
Digested shrimp (*Dendrobranchiata / Caridea*)	1.2	2	7.7	3.7	1.8	4.36	4.68	4.53	1.76	4.28	4.87	3.46
Glass shrimp (*Pasiphaeidae*)	-	-	<1	<1	-	-	0.99	0.85	-	-	1.01	0.44
Glass shrimp (*Pasiphaea* sp.)	-	<1	<1	<1	-	0.5	0.58	0.54	-	0.37	0.59	0.31
Pink glass shrimp (*Pasiphaea multidentata*)	<1	3	16.4	7	6.39	12.32	24.76	22.84	3.82	12.06	23.7	13.62

Prey	F_{occc}				MC				CTFI			
	< 20	[20-30]	≥ 30	Total	< 20	[20-30]	≥ 30	Total	< 20	[20-30]	≥ 30	Total
Shrimp (*Hippolytidae*)	<1	-	-	<1	0.05	-	-	<0.01	0.05	-	-	0.02
Arctic eualid (*Eualus fabricii*)	<1	-	-	<1	0.07	-	-	<0.01	0.11	-	-	0.05
Greenland shrimp (*Eualus macilentus*)	<1	-	<1	<1	0.13	-	0.02	0.02	0.1	-	0.03	0.06
Gaimard's eualid (*Eualus gaimardii gaimardii*)	<1	-	-	<1	0.17	-	-	<0.01	0.16	-	-	0.07
Parrot shrimp (*Spirontocaris spinus*)	<1	-	-	<1	0.1	-	-	<0.01	0.12	-	-	0.05
Boreal red shrimps (*Pandalus* sp.)	<1	<1	1.5	<1	0.4	2.09	1.8	1.76	0.49	1.74	1.79	1.23
Northern shrimp (*Pandalus borealis*)	<1	1.7	6.1	2.7	1.41	14.46	14.47	13.87	2.09	12.2	14.99	9.1
Striped pink shrimp (*Pandalus montagui*)	<1	<1	<1	<1	1.96	0.91	0.53	0.63	1.24	0.91	0.8	1
Sevenline shrimp (*Sabinea septemcarinata*)	-	<1	-	<1	-	0.12	-	0.01	-	0.26	-	0.04
Norwegian shrimp (*Pontophilus norvegicus*)	-	-	<1	<1	-	-	0.01	<0.01	-	-	<0.01	<0.01
Shrimp, total	**2.8**	**7.4**	**28.6**	**13.2**	**12.47**	**34.75**	**47.85**	**45.09**	**9.94**	**31.82**	**47.78**	**29.44**
Calanoid copepod (*Calanoida*)	10.4	6.3	1	6	4.38	0.71	0.06	0.32	4.34	1.07	0.11	2.04
Calanoid copepod (*Calanus* sp.)	9.9	7.6	1.3	6.3	6.68	0.89	0.05	0.43	4.85	1.31	0.07	2.28
Calanoid copepod (*Calanus finmarchicus*)	<1	-	<1	<1	0.02	-	<0.01	<0.01	0.02	-	<0.01	<0.01
Calanoid copepod (*Calanus hyperboreus*)	6.8	11.7	3.3	6.7	2.59	1.77	0.16	0.41	1.82	2.29	0.23	1.19
Calanoid copepod (*Calanus glacialis*)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Calanoid copepod (*Scolecithricella* sp.)	-	<1	-	<1	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Calanoide copepod (*Calanus finn. + glacialis*)	<1	<1	<1	<1	0.19	0.18	<0.01	0.03	0.35	0.27	<0.01	0.19
Calanoid copepod (*Bradyidius similis*)	<1	-	-	<1	<0.01	-	-	<0.01	0.01	-	-	<0.01
Calanoid copepod (*Chiridius gracilis*)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Calanoid copepod (*Aetideidae*)	<1	<1	-	<1	0.04	<0.01	-	<0.01	0.16	<0.01	-	0.07
Calanoid copepod (*Euchaeta* sp.)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Calanoid copepod (*Paraeuchaeta norvegica*)	2.6	3.1	1.4	2.3	0.24	0.17	0.02	0.04	0.19	0.22	0.03	0.12
Calanoid copepod (*Metridia* sp.)	4	1	<1	1.9	0.66	0.01	<0.01	0.03	0.78	0.02	<0.01	0.34
Calanoid copepod (*Metridia longa*)	<1	<1	-	<1	0.02	<0.01	-	<0.01	0.01	<0.01	-	<0.01
Calanoid copepod (*Metridia lucens*)	<1	-	-	<1	0.02	-	-	<0.01	0.03	-	-	0.01

Prey	F_{occ}				*MC*				*CTFI*			
	< 20	**[20-30]**	**≥ 30**	**Total**	**< 20**	**[20-30]**	**≥ 30**	**Total**	**< 20**	**[20-30]**	**≥ 30**	**Total**
Hyperiid (*Hyperiidea*)	-	<1	-	<1	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Hyperiid (*Hyperiidae*)	2.1	1.1	4.5	2.7	1.57	1.31	2.68	2.51	1.62	1.11	2.77	2.06
Hyperiids (*Themisto* sp.)	7.4	6.2	4.4	6	2.88	2.32	0.53	0.8	3.58	2.52	0.65	2.16
Hyperiid (*Themisto abyssorum*)	2.4	2.9	4.4	3.3	1.55	1.48	0.39	0.54	2.05	1.37	0.59	1.32
Hyperiid (*Themisto compressa*)	3.5	2.5	4.7	3.7	4.02	1.16	0.85	1.02	4.99	1.12	1.06	2.75
Hyperiid (*Hyperoche medusarum*)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Hyperiid (*Themisto libellula*)	1.2	2.3	4	2.5	1.82	2.93	2.35	2.37	2.09	4.09	2.4	2.5
Hyperiid (*Hyperia* sp.)	<1	-	-	<1	<0.01	-	-	<0.01	0.03	-	-	0.01
Hyperiid (*Hyperia galba*)	<1	<1	<1	<1	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
Hyperiid (*Scina borealis*)	<1	<1	<1	<1	0.1	<0.01	<0.01	<0.01	0.11	<0.01	<0.01	0.05
Gammarid (*Gammaridea*)	<1	<1	<1	<1	0.02	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	0.03
Gammarid (*Byblis* sp.)	<1	-	-	<1	0.02	-	-	<0.01	0.03	-	-	0.01
Gammarid (*Rhachotropis aculeata*)	-	<1	-	<1	-	0.02	-	<0.01	-	0.02	-	<0.01
Gammarid (*Melita* sp.)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Gammarid (*Maera loveni*)	<1	-	-	<1	0.02	-	-	<0.01	0.01	-	-	<0.01
Gammarid (*Lysianassidae*)	<1	<1	-	<1	<0.01	<0.01	-	<0.01	<0.01	0.02	-	<0.01
Gammarid (*Tmetonyx cicada*)	-	<1	<1	<1	-	<0.01	<0.01	<0.01	-	<0.01	<0.01	<0.01
Gammarid (*Hippomedon* sp.)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Gammarid (*Neohela monstrosa*)	<1	-	-	<1	0.15	-	-	<0.01	0.07	-	-	0.03
Gammarid (*Monoculodes* sp.)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Gammarid (*Harpinia* sp.)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Mysid (*Mysida*)	<1	<1	-	<1	<0.01	<0.01	-	<0.01	<0.01	<0.01	-	<0.01
Mysid (*Mysidae*)	1.6	<1	<1	1.1	1.77	0.4	0.26	0.34	1.34	0.54	0.26	0.76
Mysid (*Boreomysis* sp.)	4.2	3.1	4.6	4.1	4.78	2.38	0.67	1.01	6.41	2.82	0.77	3.46
Mysid (*Boreomysis tridens*)	<1	<1	<1	<1	0.19	0.01	<0.01	0.02	0.11	0.03	<0.01	0.05
Mysid (*Boreomysis arctica*)	<1	<1	<1	<1	0.79	0.52	0.26	0.31	1.66	0.61	0.27	0.91

	F_{occ}				MC				CTFI			
Prey	**< 20**	**[20-30]**	**≥ 30**	**Total**	**< 20**	**[20-30]**	**≥ 30**	**Total**	**< 20**	**[20-30]**	**≥ 30**	**Total**
Mysid (*Erythrops* sp.)	<1	<1	-	<1	<0.01	<0.01	-	<0.01	<0.01	0.01	-	<0.01
Mysid (*Erythrops erythrophthalma*)	<1	-	<1	<1	<0.01	-	<0.01	<0.01	0.02	-	<0.01	<0.01
Mysid (*Pseudomma* sp.)	<1	-	-	<1	0.01	-	-	<0.01	0.05	-	-	0.02
Mysid (*Pseudomma roseum*)	<1	-	-	<1	0.04	-	-	<0.01	0.05	-	-	0.02
Mysid (*Mysis* sp.)	<1	<1	-	<1	<0.01	0.08	-	<0.01	<0.01	0.1	-	0.02
Mysid (*Mysis mixta*)	<1	-	-	<1	0.03	-	-	<0.01	0.02	-	-	<0.01
Mysid (*Stilomysis* sp.)	<1	-	<1	<1	0.02	-	<0.01	<0.01	<0.01	-	<0.01	<0.01
Euphausiid (*Euphausiacea*)	<1	<1	<1	<1	<0.01	0.03	<0.01	<0.01	<0.01	0.05	<0.01	<0.01
Euphausiid (*Euphausiidae*)	3.7	2.3	2.3	2.9	6.27	4.88	0.8	1.41	5.48	4.71	0.74	3.3
Northern krill (*Meganyctiphanes norvegica*)	3.1	4.2	5	4.1	6.52	6.84	2.13	2.75	6.19	7.06	2.62	4.75
Euphausiid (*Thysanoessa* sp.)	<1	1	<1	<1	3.85	1.19	0.08	0.35	3.25	1.08	0.11	1.58
Euphausiid (*Thysanoessa inermis*)	<1	-	<1	<1	0.04	-	<0.01	<0.01	0.03	-	<0.01	0.02
Arctic krill (*Thysanoessa raschii*)	<1	<1	<1	<1	0.71	0.25	0.02	0.07	0.69	0.43	0.03	0.36
Zooplankton, total	**40.9**	**32.6**	**22.4**	**32.2**	**52.07**	**29.57**	**11.34**	**14.79**	**52.56**	**32.88**	**12.73**	**32.49**
Invertebrate (*Invertebrata*)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Arrow worm (*Parasagitta elegans*)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Mollusc (*Mollusca*)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Gastropod (*Gastropoda*)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Shelled sea butterfly (*Limacina* sp.)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Dipperclam (*Cuspidaria* sp.)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Bobtail (*Rossia* sp.)	-	-	<1	<1	-	-	0.01	<0.01	-	-	0.02	<0.01
Polychaete (*Polychaeta*)	<1	-	<1	<1	<0.01	-	<0.01	<0.01	<0.01	-	<0.01	<0.01
Sea mouse (*Aphrodita hastata*)	<1	-	-	<1	0.09	-	-	<0.01	0.12	-	-	0.05
Crustacean (*Crustacea*)	17.4	10.7	10.1	13.2	14.41	4.64	3.57	4.16	12.51	5.4	3.81	7.74
Ostracod (*Ostracoda*)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Copepod (*Copepoda*)	5	5.1	1.4	3.7	2.13	0.71	0.06	0.21	2.56	0.89	0.09	1.26

	F_{occ}				MC				CTFI			
Prey	**< 20**	**[20-30]**	**≥ 30**	**Total**	**< 20**	**[20-30]**	**≥ 30**	**Total**	**< 20**	**[20-30]**	**≥ 30**	**Total**
Crustacean (*Malacostraca*)	<1	-	<1	<1	0.2	-	<0.01	0.01	0.52	-	<0.01	0.23
Cumacean (*Cumacea*)	<1	<1	<1	<1	0.04	<0.01	<0.01	<0.01	0.09	<0.01	<0.01	0.04
Isopod (*Isopoda*)	-	<1	-	<1	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Isopod (*Syscenus infelix*)	-	-	<1	<1	-	-	0.03	0.02	-	-	0.03	0.01
Amphipod (*Amphipoda*)	1.5	1.7	3.4	2.2	6.12	7.88	6.05	6.22	9	6.2	6.91	7.71
Crab (*Brachyura*)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Snow crab (*Chionoecetes opilio*)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Lyre crab (*Hyas* sp.)	-	<1	-	<1	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Invertebrate egg	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Digested invertebrates	<1	-	<1	<1	0.19	-	0.08	0.08	0.2	-	0.1	0.13
Other invertebrates, total	**24.2**	**16.6**	**14.7**	**18.9**	**23.2**	**13.24**	**9.82**	**10.73**	**25.02**	**12.5**	**10.97**	**17.18**
Invertebrates, total	**54.4**	**45**	**45.8**	**49.1**	**87.75**	**77.56**	**69.01**	**70.61**	**87.52**	**77.2**	**71.48**	**79.11**
Unidentified digested material	6	4.9	5.2	5.4	10.58	4.54	2.88	3.38	11.69	5.14	3.08	7.04
Unidentified egg	<1	<1	<1	<1	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Unidentifiable preys, total	**6**	**4.9**	**5.2**	**5.5**	**10.59**	**4.55**	**2.88**	**3.38**	**11.69**	**5.14**	**3.08**	**7.04**
Total					**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 12. Detailed Redfish diet from the nGSL DFO survey by period, all length classes combined.

	F_{occ}			MC			CTFI		
Prey	**1990s**	**2015-19**	**Total**	**1990s**	**2015-19**	**Total**	**1990s**	**2015-19**	**Total**
Bony fish (*Actinopterygii*)	<1	-	<1	1.75	-	1.07	1.15	-	0.64
Atlantic herring (*Clupea harengus*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Capelin (*Mallotus villosus*)	<1	<1	<1	11.48	3.33	8.3	5.79	4.21	5.08
Lanternfish (*Myctophidae*)	-	<1	<1	-	0.5	0.19	-	0.2	0.09
Kroyer's lanternfish (*Notoscopelus kroyeri*)	-	<1	<1	-	1.24	0.48	-	0.38	0.17
Barracudinas (*Paralepis* sp.)	<1	-	<1	0.11	-	0.07	0.06	-	0.03
White barracudina (*Arctozenus risso*)	<1	<1	<1	0.56	5.02	2.3	0.22	2.17	1.09
Slender snipe eel (*Nemichthys scolopaceus*)	-	<1	<1	-	0.48	0.19	-	0.21	0.09
Threespine stickleback (*Gasterosteus aculeatus*)	<1	-	<1	0.04	-	0.02	0.04	-	0.02
Cods (*Gadus* sp.)	-	<1	<1	-	0.02	<0.01	-	0.01	<0.01
Longfin hake (*Phycis chesteri*)	<1	-	<1	0.33	-	0.2	0.17	-	0.1
Marlin-spike (*Nezumia bairdii*)	<1	<1	<1	0.04	0.35	0.16	0.03	0.17	0.09
Slender eelblenny (*Lumpenus fabricii*)	-	<1	<1	-	<0.01	<0.01	-	0.01	<0.01
Eelpout (*Zoarcidae*)	<1	-	<1	<0.01	-	<0.01	<0.01	-	<0.01
Atlantic soft pout (*Melanostigma atlanticum*)	<1	<1	<1	0.24	0.28	0.25	0.12	0.19	0.15
Redfish (*Sebastes* spp.)	<1	<1	<1	0.59	18	7.38	0.26	7.23	3.38
Flatfish (Pleuronectiformes)	-	<1	<1	-	0.13	0.05	-	0.04	0.02
Digested roundfish	<1	<1	<1	0.89	1.96	1.3	0.51	0.98	0.72
Fish (spawn) egg	<1	<1	<1	<0.01	0.16	0.06	<0.01	0.06	0.03
Digested fish	1.8	1.3	1.5	4.96	2.4	3.96	2.72	1.39	2.13
Fishes, total	**4.2**	**3.8**	**4**	**20.99**	**33.87**	**26.01**	**11.09**	**17.26**	**13.85**
Digested shrimp (*Dendrobranchiata / Caridea*)	5.2	2.5	3.7	6.48	1.47	4.53	5.12	1.41	3.46
Glass shrimp (*Pasiphaeidae*)	<1	-	<1	1.4	-	0.85	0.8	-	0.44
Glass shrimp (*Pasiphaea* sp.)	<1	<1	<1	0.88	0.01	0.54	0.55	<0.01	0.31
Pink glass shrimp (*Pasiphaea multidentata*)	7.1	6.9	7	19.11	28.67	22.84	11.64	16.06	13.62

Prey	F_{occc}			MC			CTFI		
	1990s	2015-19	Total	1990s	2015-19	Total	1990s	2015-19	Total
Shrimp (*Hippolytidae*)	-	<1	<1	-	<0.01	<0.01	-	0.05	0.02
Arctic eualid (*Eualus fabricii*)	-	<1	<1	-	<0.01	<0.01	-	0.11	0.05
Greenland shrimp (*Eualus macilentus*)	<1	<1	<1	0.03	0.02	0.02	0.02	0.1	0.06
Gaimard's eualid (*Eualus gaimardii gaimardii*)	-	<1	<1	-	0.02	<0.01	-	0.16	0.07
Parrot shrimp (*Spirontocaris spinus*)	-	<1	<1	-	0.01	<0.01	-	0.11	0.05
Boreal red shrimps (*Pandalus* sp.)	<1	<1	<1	2.19	1.1	1.76	1.3	1.13	1.23
Northern shrimp (*Pandalus borealis*)	3.2	2.3	2.7	13.06	15.14	13.87	8.34	10.04	9.1
Striped pink shrimp (*Pandalus montagui*)	<1	<1	<1	0.55	0.75	0.63	0.97	1.04	1
Sevenline shrimp (*Sabinea septemcarinata*)	-	<1	<1	-	0.03	0.01	-	0.08	0.04
Norwegian shrimp (*Pontophilus norvegicus*)	<1	-	<1	0.01	-	<0.01	<0.01	-	<0.01
Shrimp, total	**15**	**11.6**	**13.2**	**43.72**	**47.23**	**45.09**	**28.76**	**30.29**	**29.44**
Calanoid copepod (*Calanoida*)	<1	10.8	6	0.06	0.72	0.32	0.28	4.23	2.04
Calanoid copepod (*Calanus* sp.)	1.2	10.7	6.3	0.04	1.03	0.43	0.26	4.77	2.28
Calanoid copepod (*Calanus finmarchicus*)	<1	<1	<1	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Calanoid copepod (*Calanus hyperboreus*)	3	10	6.7	0.24	0.68	0.41	0.42	2.14	1.19
Calanoid copepod (*Calanus glacialis*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Calanoid copepod (*Scolecithricella* sp.)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Calanoide copepod (*Calanus finn. + glacialis*)	<1	<1	<1	<0.01	0.07	0.03	0.01	0.41	0.19
Calanoid copepod (*Bradyidius similis*)	<1	<1	<1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Calanoid copepod (*Chiridius gracilis*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Calanoid copepod (*Aetideidae*)	-	<1	<1	-	<0.01	<0.01	-	0.15	0.07
Calanoid copepod (*Euchaeta* sp.)	<1	-	<1	<0.01	-	<0.01	<0.01	-	<0.01
Calanoid copepod (*Paraeuchaeta norvegica*)	<1	3.7	2.3	<0.01	0.1	0.04	0.03	0.24	0.12
Calanoid copepod (*Metridia* sp.)	<1	3.2	1.9	<0.01	0.07	0.03	0.08	0.66	0.34
Calanoid copepod (*Metridia longa*)	<1	<1	<1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Calanoid copepod (*Metridia lucens*)	<1	<1	<1	<0.01	<0.01	<0.01	0.02	<0.01	0.01

Prey	F_{occ}			MC			CTFI		
	1990s	2015-19	Total	1990s	2015-19	Total	1990s	2015-19	Total
Hyperiid (*Hyperiidea*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Hyperiid (*Hyperiidae*)	5.4	<1	2.7	4.11	<0.01	2.51	3.67	0.06	2.06
Hyperiids (*Themisto* sp.)	3	8.6	6	0.44	1.35	0.8	1.17	3.37	2.16
Hyperiid (*Themisto abyssorum*)	4.1	2.5	3.3	0.77	0.19	0.54	1.99	0.49	1.32
Hyperiid (*Themisto compressa*)	3.6	3.8	3.7	0.98	1.08	1.02	1.93	3.76	2.75
Hyperiid (*Hyperoche medusarum*)	<1	-	<1	<0.01	-	<0.01	<0.01	-	<0.01
Hyperiid (*Themisto libellula*)	3.3	1.8	2.5	3.02	1.36	2.37	2.89	2.01	2.5
Hyperiid (*Hyperia* sp.)	-	<1	<1	-	<0.01	<0.01	-	0.03	0.01
Hyperiid (*Hyperia galba*)	-	<1	<1	-	<0.01	<0.01	-	0.02	<0.01
Hyperiid (*Scina borealis*)	<1	<1	<1	<0.01	0.01	<0.01	<0.01	0.1	0.05
Gammarid (*Gammaridea*)	<1	<1	<1	<0.01	<0.01	<0.01	<0.01	0.06	0.03
Gammarid (*Byblis* sp.)	-	<1	<1	-	<0.01	<0.01	-	0.02	0.01
Gammarid (*Rhachotropis aculeata*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Gammarid (*Melita* sp.)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Gammarid (*Maera loveni*)	-	<1	<1	-	<0.01	<0.01	-	0.01	<0.01
Gammarid (*Lysianassidae*)	-	<1	<1	-	<0.01	<0.01	-	0.01	<0.01
Gammarid (*Tmetonyx cicada*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Gammarid (*Hippomedon* sp.)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Gammarid (*Neohela monstrosa*)	<1	<1	<1	<0.01	<0.01	<0.01	0.03	0.03	0.03
Gammarid (*Monoculodes* sp.)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Gammarid (*Harpinia* sp.)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Mysid (*Mysida*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Mysid (*Mysidae*)	2	<1	1.1	0.56	<0.01	0.34	1.36	0.02	0.76
Mysid (*Boreomysis* sp.)	3.5	4.5	4.1	1.04	0.96	1.01	4.44	2.24	3.46
Mysid (*Boreomysis tridens*)	<1	<1	<1	0.02	<0.01	0.02	0.07	0.03	0.05
Mysid (*Boreomysis arctica*)	<1	<1	<1	0.34	0.26	0.31	0.42	1.52	0.91

	F_{occ}			MC			CTFI		
Prey	**1990s**	**2015-19**	**Total**	**1990s**	**2015-19**	**Total**	**1990s**	**2015-19**	**Total**
Mysid (*Erythrops* sp.)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Mysid (*Erythrops erythrophthalma*)	-	<1	<1	-	<0.01	<0.01	-	0.02	<0.01
Mysid (*Pseudomma* sp.)	<1	<1	<1	<0.01	<0.01	<0.01	0.04	<0.01	0.02
Mysid (*Pseudomma roseum*)	-	<1	<1	-	<0.01	<0.01	-	0.04	0.02
Mysid (*Mysis* sp.)	-	<1	<1	-	0.02	<0.01	-	0.03	0.02
Mysid (*Mysis mixta*)	<1	-	<1	<0.01	-	<0.01	0.01	-	<0.01
Mysid (*Stilomysis* sp.)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Euphausiid (*Euphausiacea*)	<1	<1	<1	<0.01	<0.01	<0.01	<0.01	0.02	<0.01
Euphausiid (*Euphausiidae*)	2.1	3.5	2.9	1.38	1.45	1.41	2.62	4.15	3.3
Northern krill (*Meganyctiphanes norvegica*)	3.2	4.8	4.1	1.51	4.67	2.75	2.57	7.46	4.75
Euphausiid (*Thysanoessa* sp.)	-	1.2	<1	-	0.88	0.35	-	3.54	1.58
Euphausiid (*Thysanoessa inermis*)	<1	<1	<1	<0.01	0.01	<0.01	<0.01	0.04	0.02
Arctic krill (*Thysanoessa raschii*)	<1	<1	<1	<0.01	0.17	0.07	<0.01	0.81	0.36
Zooplankton, total	**20.1**	**42.8**	**32.2**	**14.53**	**15.19**	**14.79**	**24.35**	**42.55**	**32.49**
Invertebrate (*Invertebrata*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Arrow worm (*Parasagitta elegans*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Mollusc (*Mollusca*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Gastropod (*Gastropoda*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Shelled sea butterfly (*Limacina* sp.)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Dipperclam (*Cuspidaria* sp.)	<1	-	<1	0.01	-	<0.01	<0.01	-	<0.01
Bobtail (*Rossia* sp.)	-	<1	<1	-	0.02	<0.01	-	0.02	<0.01
Polychaete (*Polychaeta*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Sea mouse (*Aphrodita hastata*)	-	<1	<1	-	0.01	<0.01	-	0.11	0.05
Crustacean (*Crustacea*)	10.4	15.6	13.2	5.58	1.93	4.16	8.6	6.68	7.74
Ostracod (*Ostracoda*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Copepod (*Copepoda*)	2.8	4.5	3.7	0.22	0.21	0.21	1.48	0.98	1.26

	F_{occ}			MC			CTFI		
Prey	**1990s**	**2015-19**	**Total**	**1990s**	**2015-19**	**Total**	**1990s**	**2015-19**	**Total**
Crustacean (*Malacostraca*)	<1	-	<1	0.02	-	0.01	0.41	-	0.23
Cumacean (*Cumacea*)	-	<1	<1	-	<0.01	<0.01	-	0.09	0.04
Isopod (*Isopoda*)	<1	-	<1	<0.01	-	<0.01	<0.01	-	<0.01
Isopod (*Syscenus infelix*)	-	<1	<1	-	0.06	0.02	-	0.03	0.01
Amphipod (*Amphipoda*)	4.2	<1	2.2	10.18	0.02	6.22	13.88	0.07	7.71
Crab (*Brachyura*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Snow crab (*Chionoecetes opilio*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Lyre crab (*Hyas* sp.)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Invertebrate egg	<1	-	<1	<0.01	-	<0.01	<0.01	-	<0.01
Digested invertebrates	<1	<1	<1	0.11	0.03	0.08	0.18	0.06	0.13
Other invertebrates, total	**16.9**	**20.7**	**18.9**	**16.13**	**2.29**	**10.73**	**24.56**	**8.05**	**17.18**
Invertebrates, total	**38.4**	**58.3**	**49.1**	**74.38**	**64.7**	**70.61**	**77.67**	**80.9**	**79.11**
Unidentified digested material	6.5	4.5	5.4	4.63	1.42	3.38	11.24	1.84	7.04
Unidentified egg	<1	<1	<1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Unidentifiable preys, total	**6.5**	**4.6**	**5.5**	**4.63**	**1.42**	**3.38**	**11.24**	**1.84**	**7.04**
Total	**-**	**-**	**-**	**100**	**100**	**100**	**100**	**100**	**100**

FIGURES

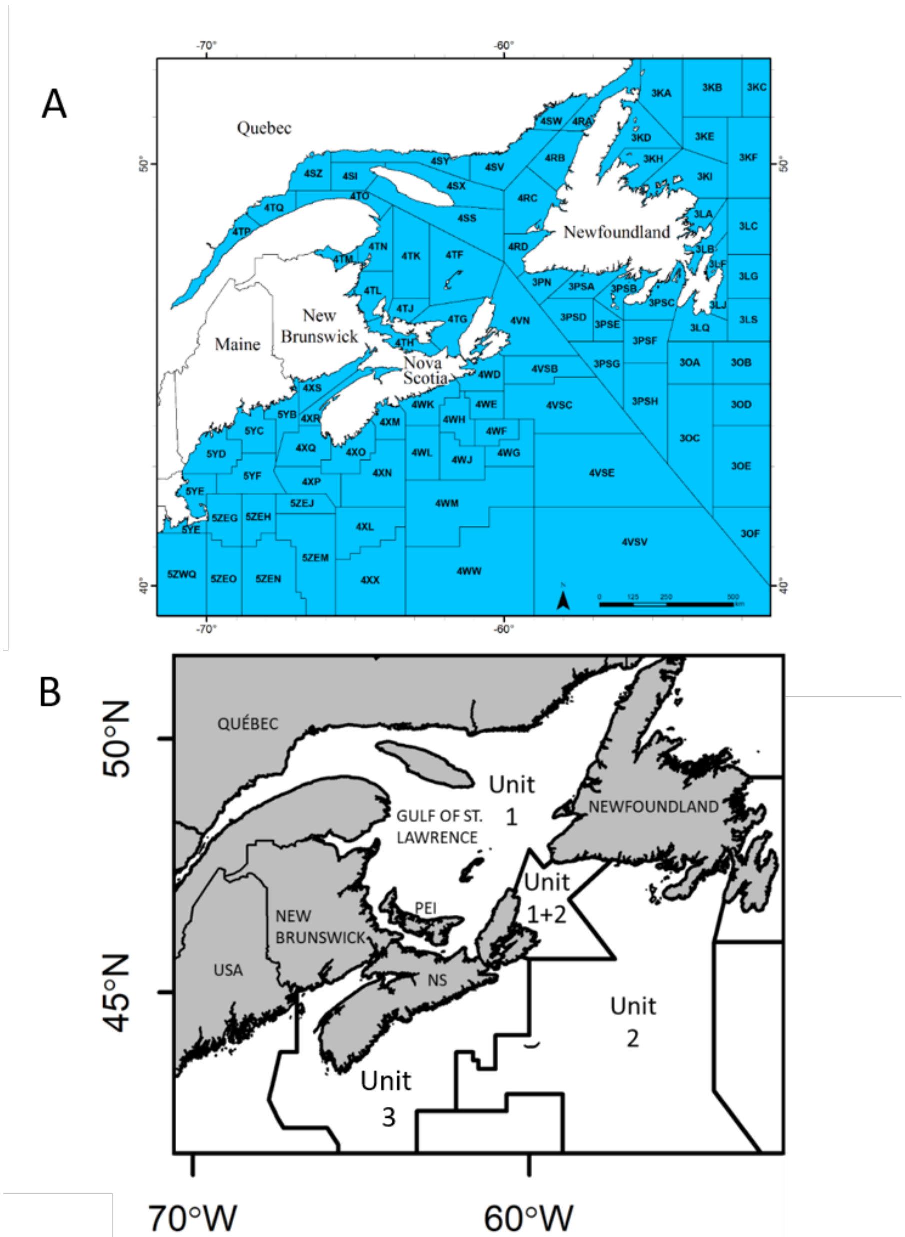


Figure 1. Northwest Atlantic Fishery Organization (NAFO) Divisions and Subdivisions (A), and management Units 1, 2, and 3 (B). PEI = Prince Edward Island, NS = Nova Scotia, USA = United States of America.

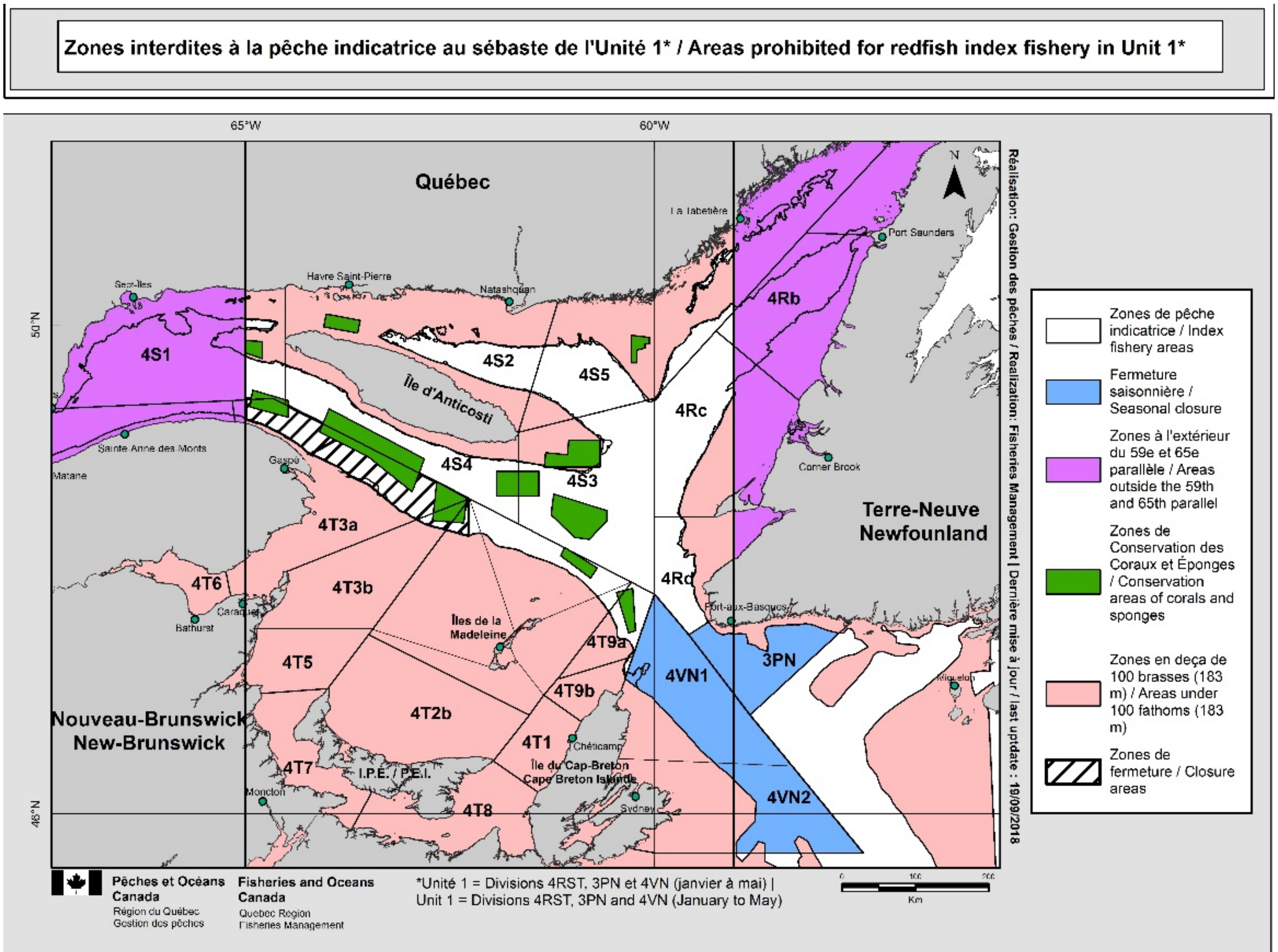


Figure 2. Closure areas pertaining to the Redfish index fishery (C). PEI = Prince Edward Island.

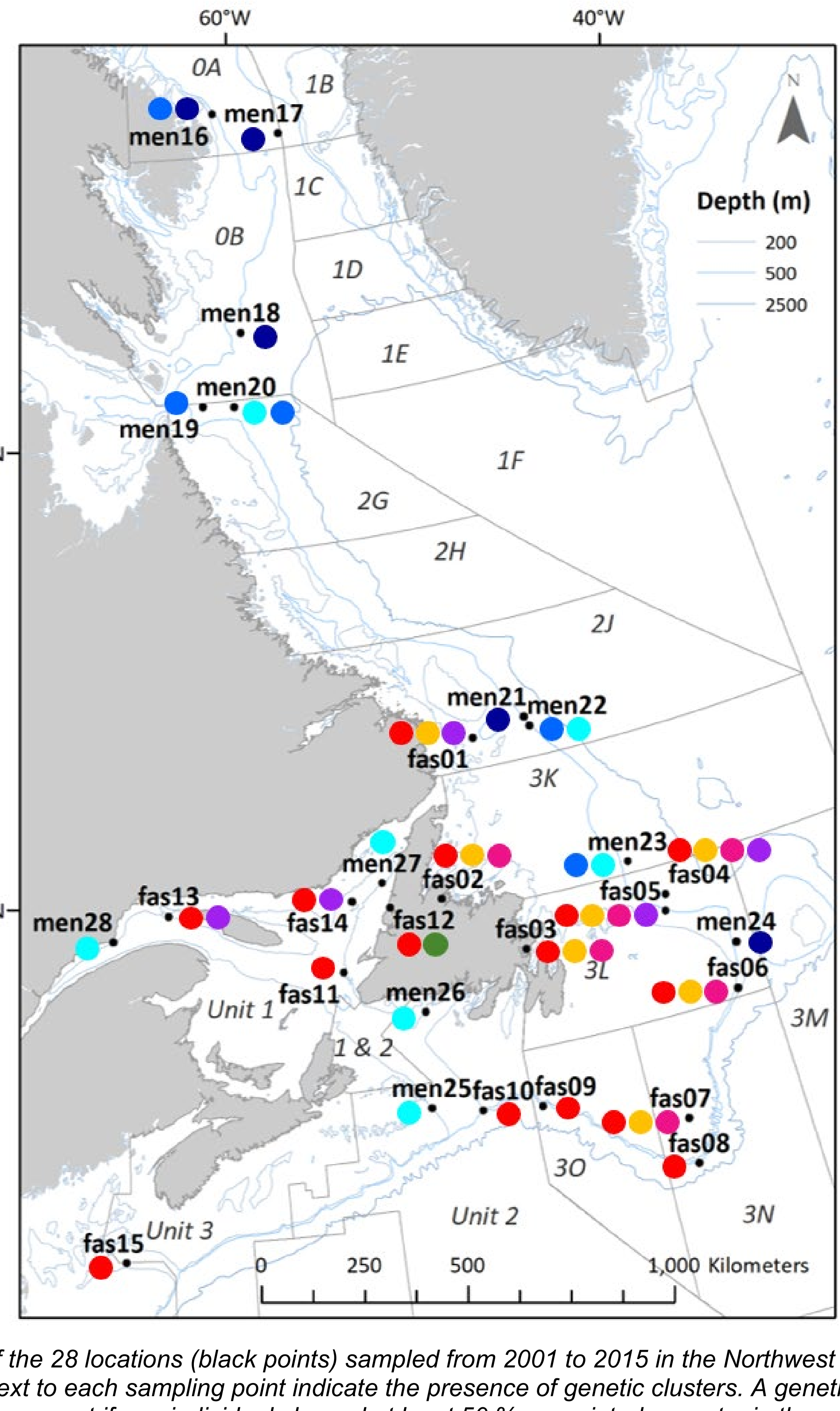


Figure 3. Map of the 28 locations (black points) sampled from 2001 to 2015 in the Northwest Atlantic. The colored points next to each sampling point indicate the presence of genetic clusters. A genetic cluster was indicated as present if one individual showed at least 50 % associated ancestry in the sampling area. Three ecotypes were described for S. mentella: GSL (cyan), shallow (light blue), and deep (dark blue). Five populations were described for S. fasciatus and are indicated by color: red, yellow, green, pink, and purple.

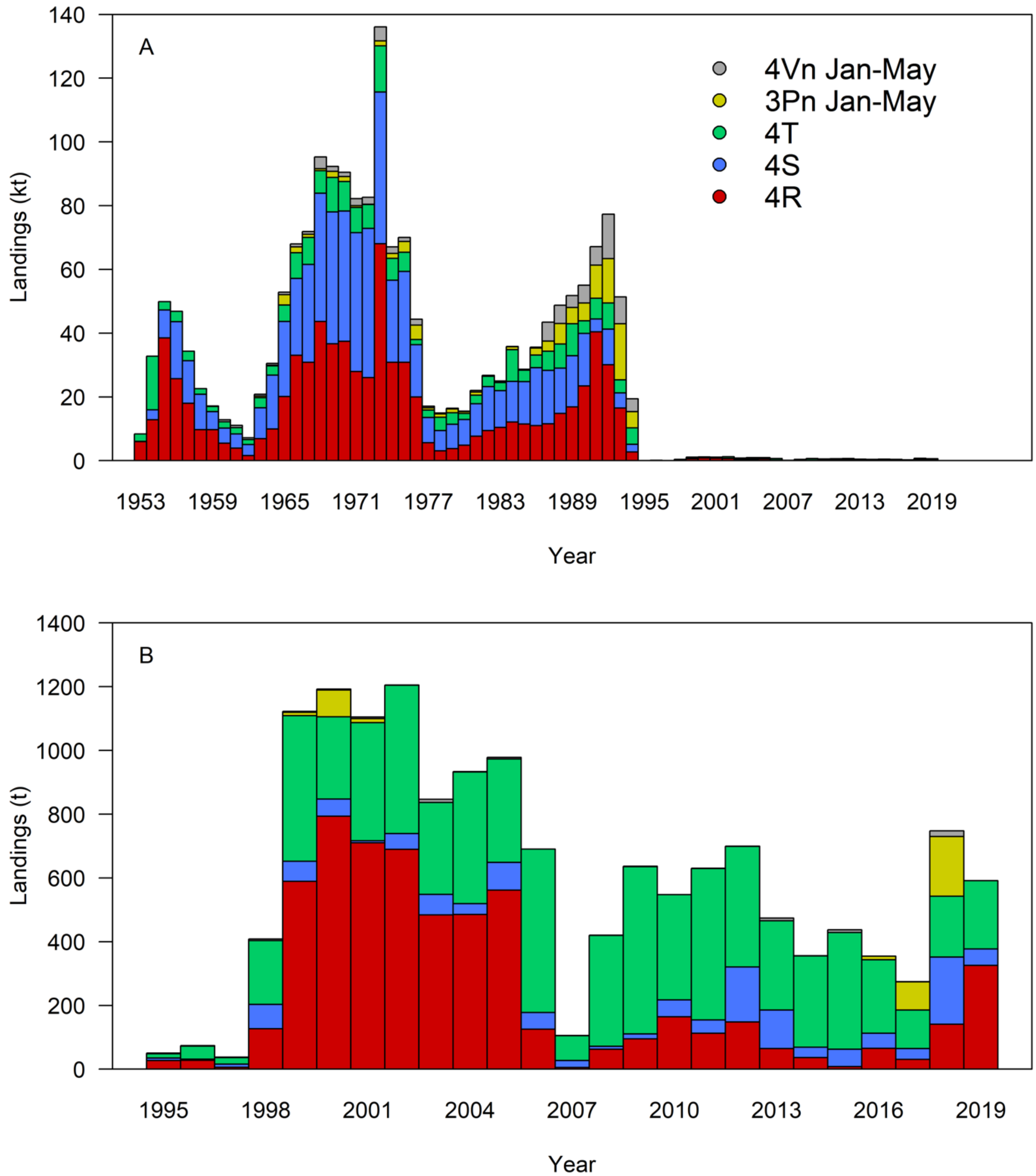


Figure 4. Commercial fishery annual Redfish landings in Unit 1 per NAFO Division or Subdivision from 1953 to 2019 (A, thousands of t (kt)) and from 1995-2019 (B, t). Data include fisheries directed to all species. No Redfish directed fishery took place from 1995 to 1997. 2018 and 2019 values are preliminary.

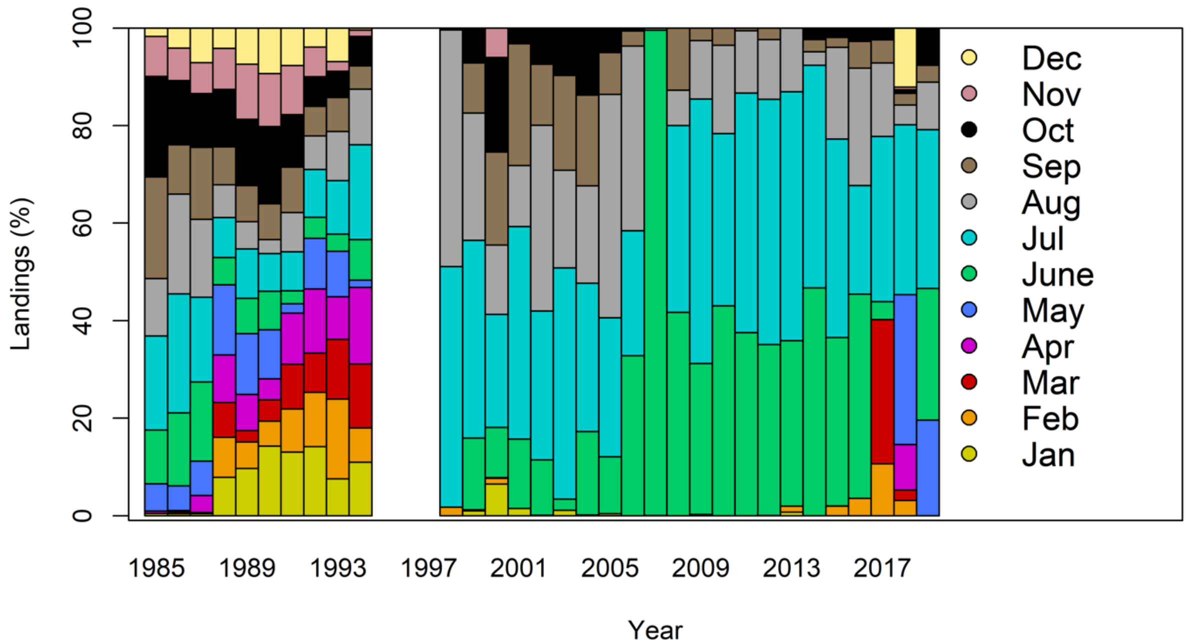


Figure 5. Redfish annual landings (biomass percentage) by month in Unit 1 from 1985 to 2019. Data include only Redfish directed fishery. No Redfish directed fishery took place from 1995 to 1997. 2018 and 2019 values are preliminary.

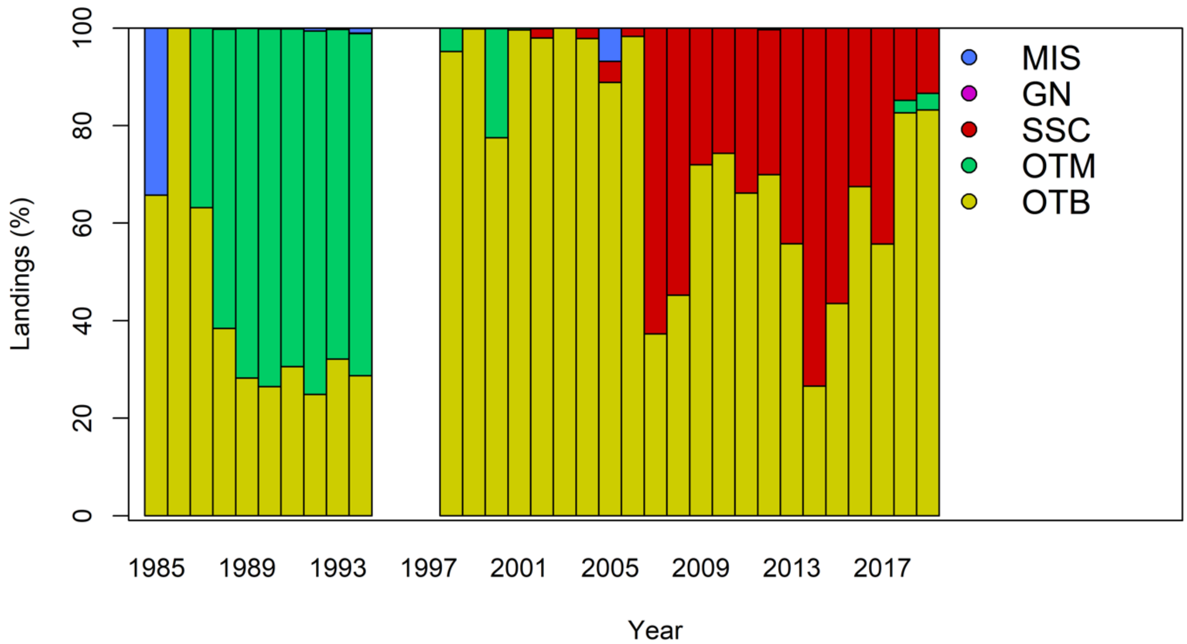


Figure 6. Redfish annual landings (biomass percentage) by gear in Unit 1 from 1985 to 2019. Data include only the Redfish directed fishery. No Redfish directed fishery took place from 1995 to 1997. 2018 and 2019 values are preliminary. OTB: bottom trawl, OTM: midwater trawl, SSC: Scottish seine, GN: gillnet, and MIS: miscellaneous.

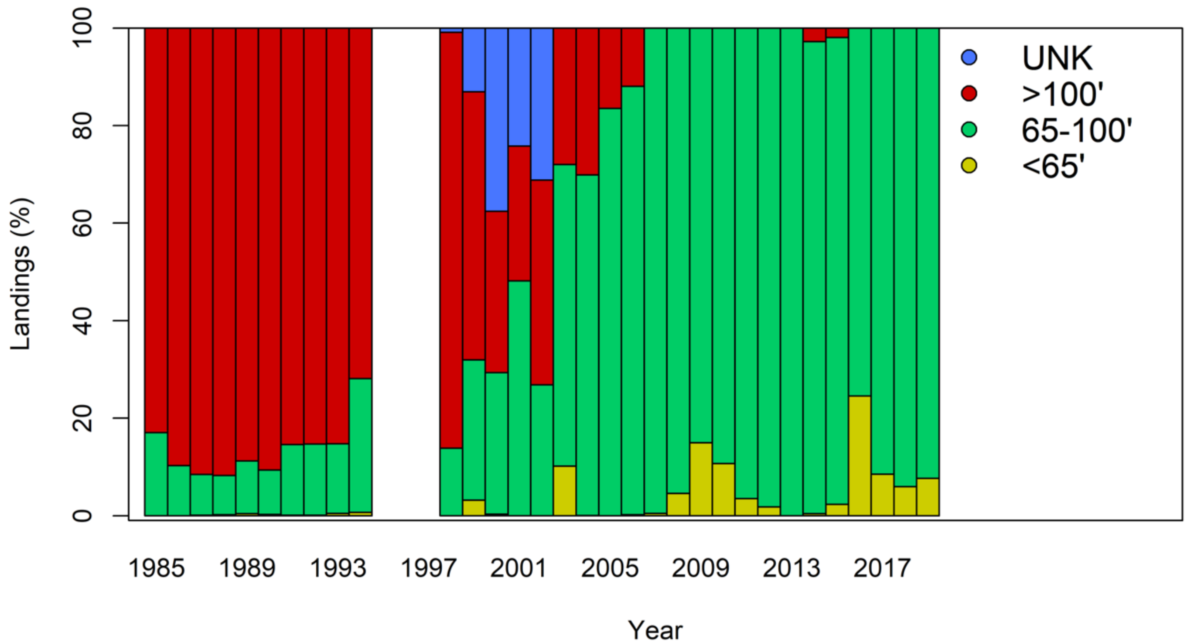


Figure 7. Redfish annual landings (biomass percentage) by boat size (feet) in Unit 1 from 1985 to 2019. Data include only the Redfish directed fishery. No Redfish directed fishery took place from 1995 to 1997. 2018 and 2019 values are preliminary. UNK: unknown.

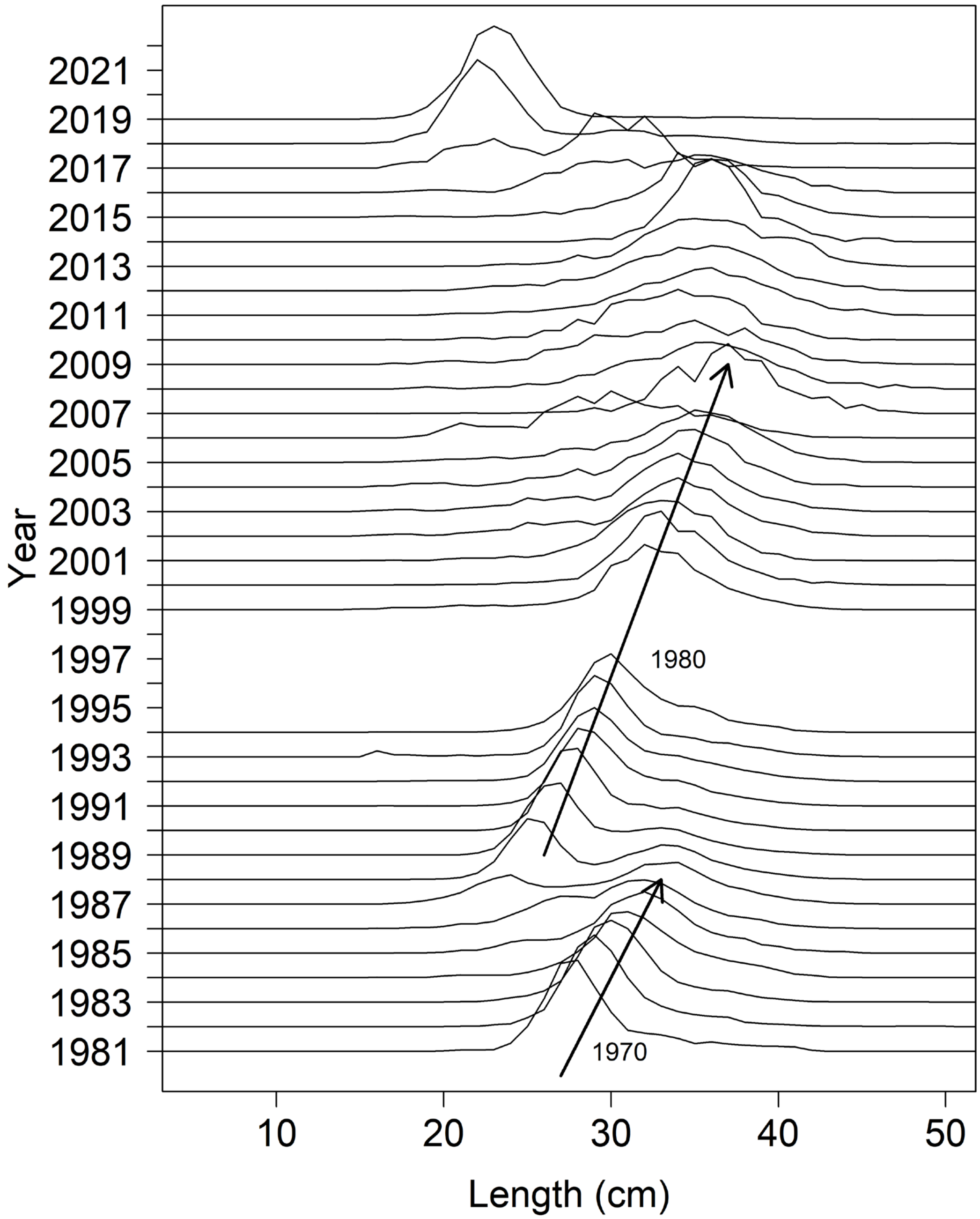


Figure 8. Commercial catch length frequency in percentage in Unit 1 from 1981 to 2019 based on at-sea-observer and port sampler data. No Redfish directed fishery took place from 1995 to 1997. The arrows indicate growth trajectories of the 1970 and 1980 cohorts. 2018 and 2019 values are preliminary.

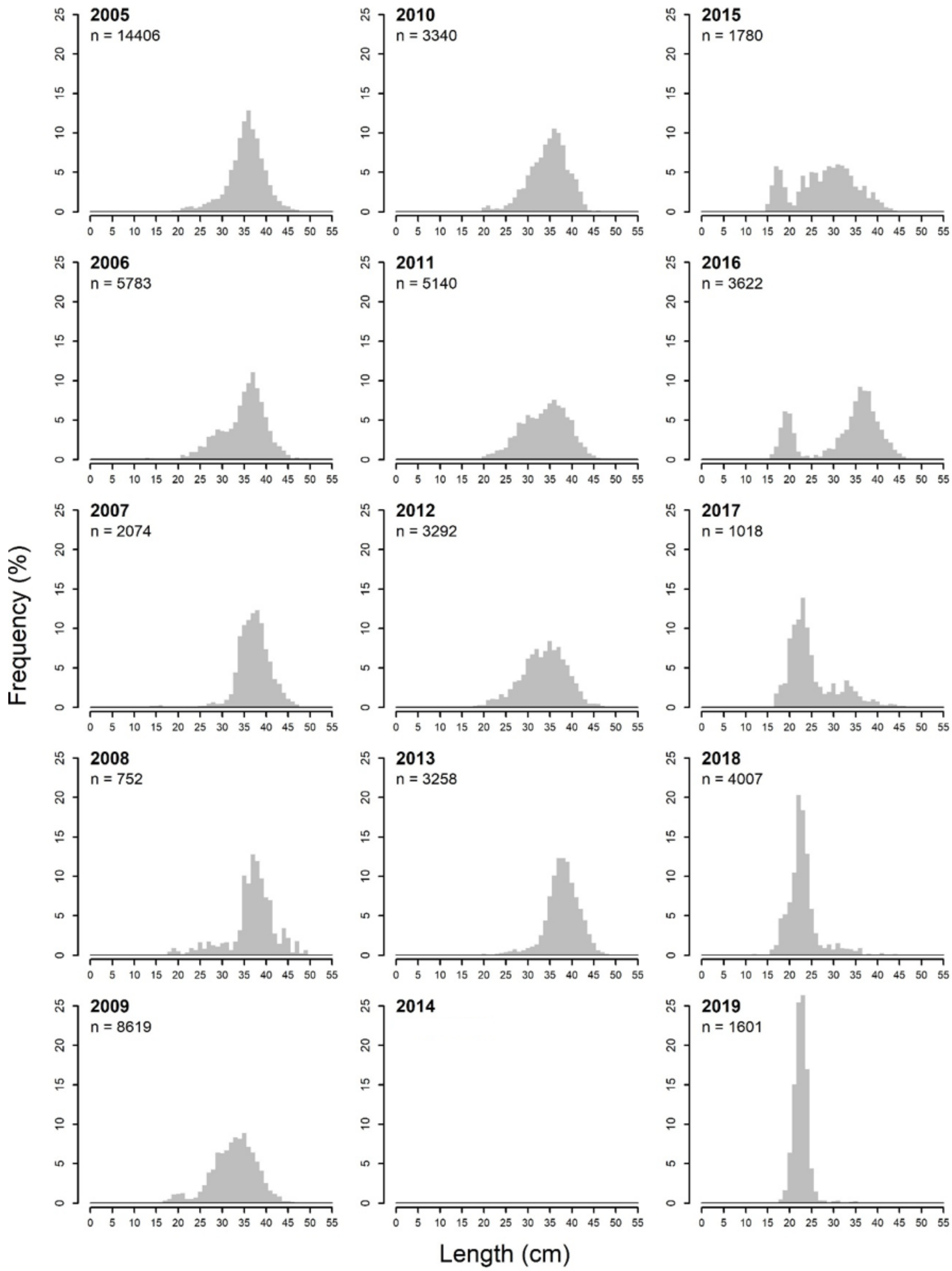


Figure 9. Redfish length frequency in percentage in Unit 1 from 2005 to 2019 based on the index fishery at-sea-observer data. Numbers of fish measured are indicated (n). No fish were sampled in 2014. 2018 and 2019 values are preliminary.

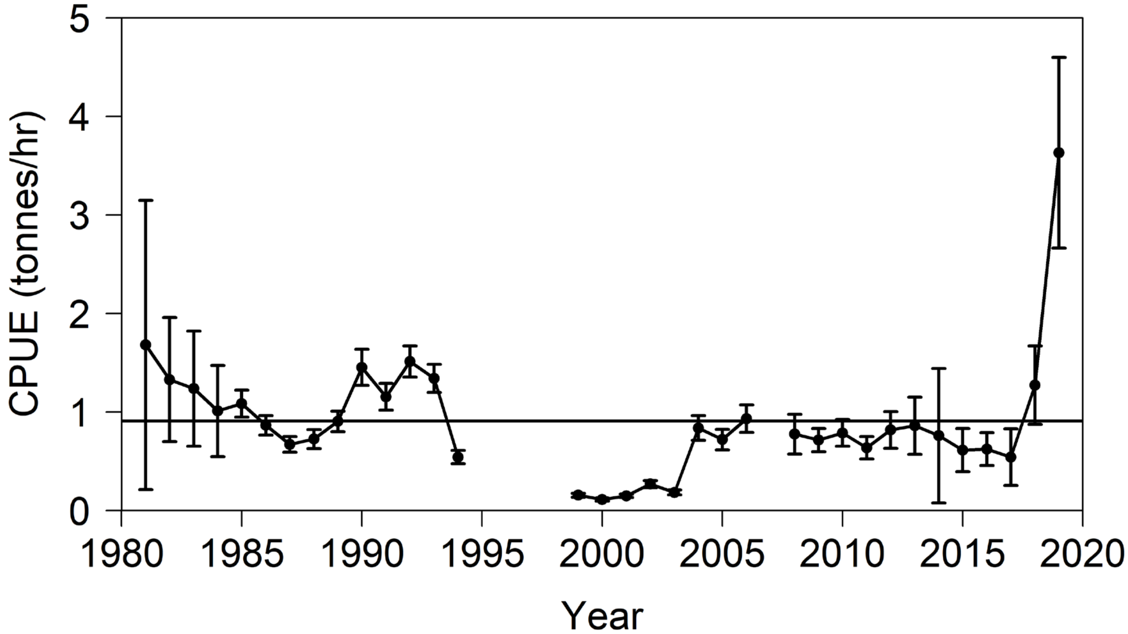


Figure 10. Standardized bottom trawl catch-per-unit-effort (CPUE with 95 % confidence intervals) in the Unit 1 commercial fishery between May and October (1981-1994) and the index fishery (1999-2006 and 2008-2019). 2007 is not presented given the very limited fishing activities. The solid line represents the series average. 2018 and 2019 values are preliminary.

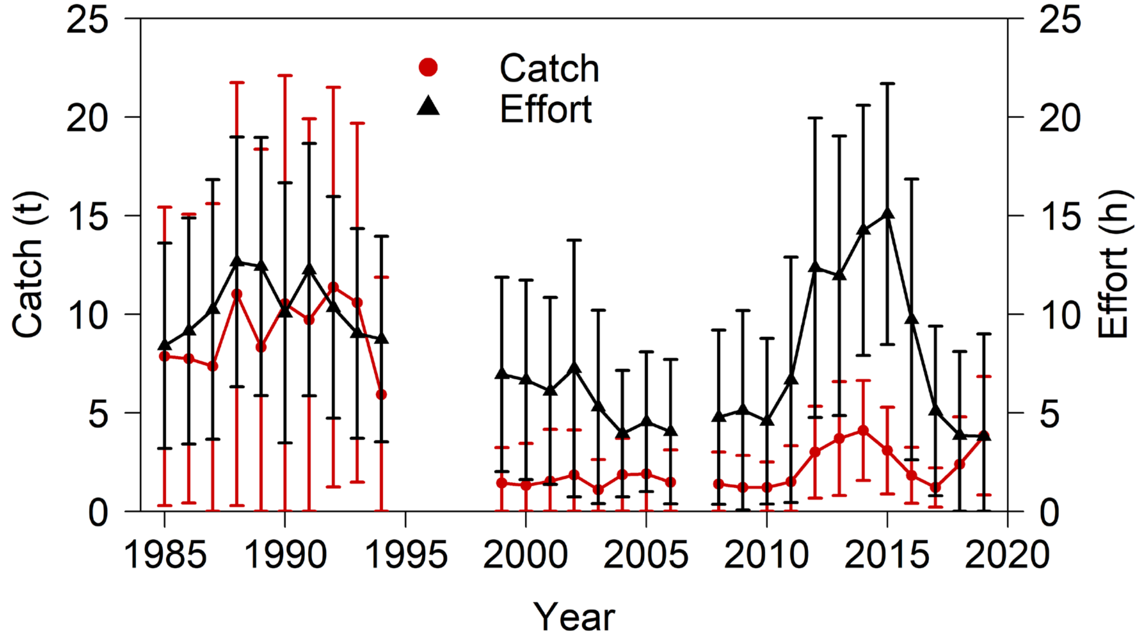


Figure 11. Average catch (red circles) and effort (black triangles) in the Redfish fishery between May and October (1985-1994) and the index fishery (1999-2006 and 2008-2019). Error bars represent standard deviation. 2018 and 2019 values are preliminary.

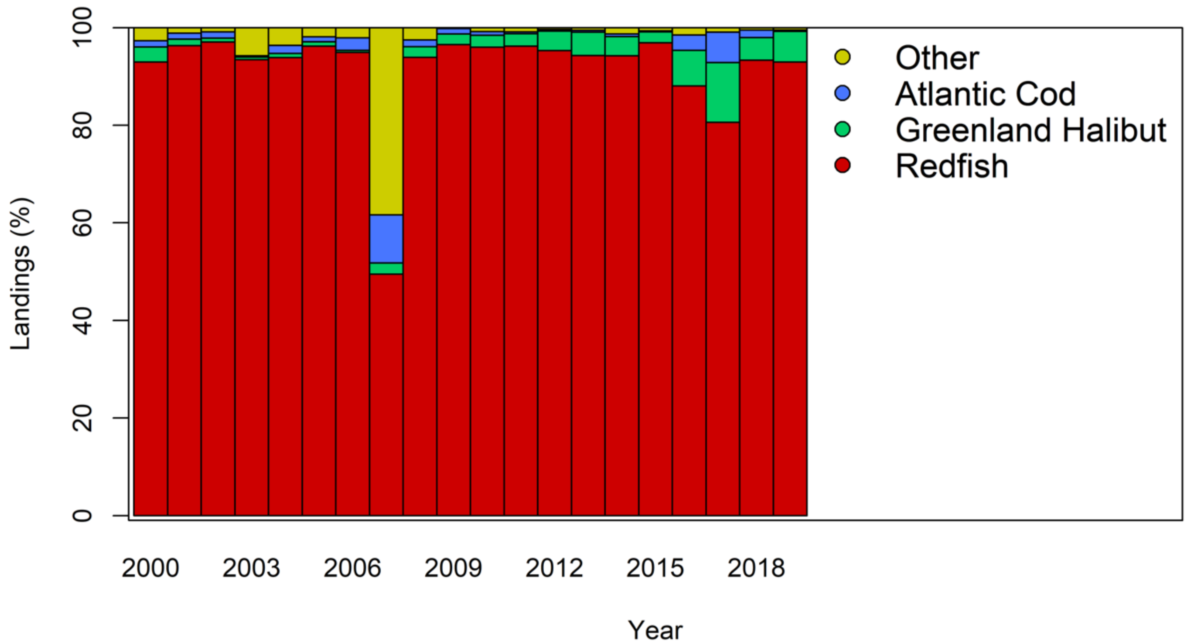


Figure 12. Redfish annual landings (biomass percentage) in Unit 1 as a function of targeted species by the fishery from 2000 to 2019. 2018 and 2019 values are preliminary.

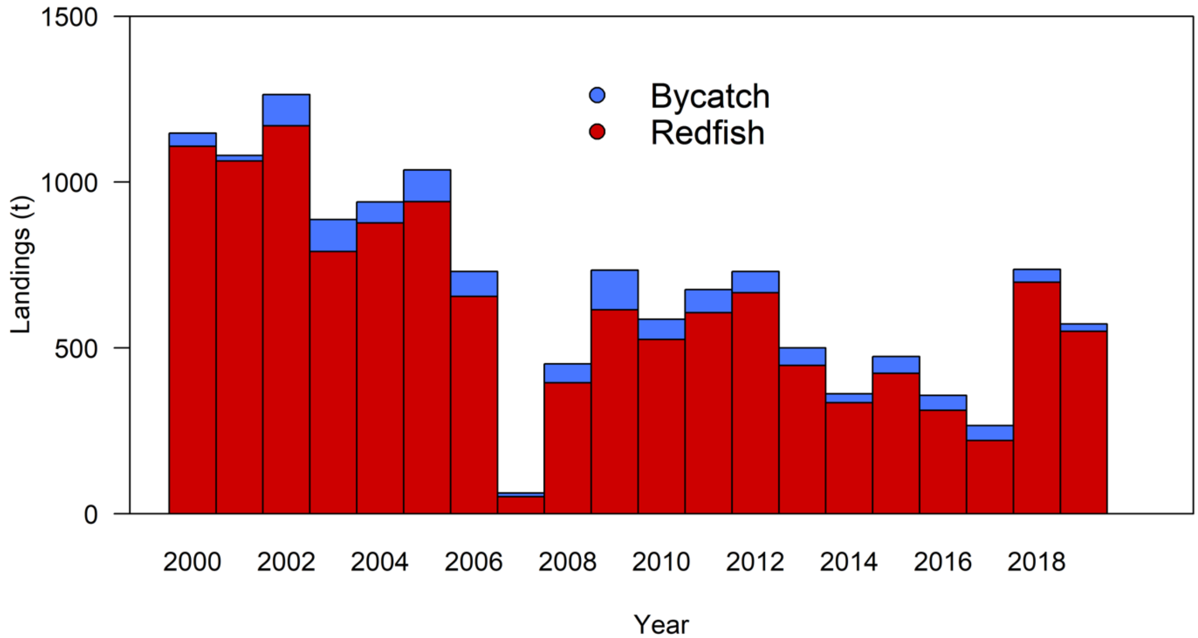


Figure 13. Annual landings of Redfish and bycatch (t) in the Redfish directed fishery in Unit 1 from 2000 to 2019. 2018 and 2019 values are preliminary.

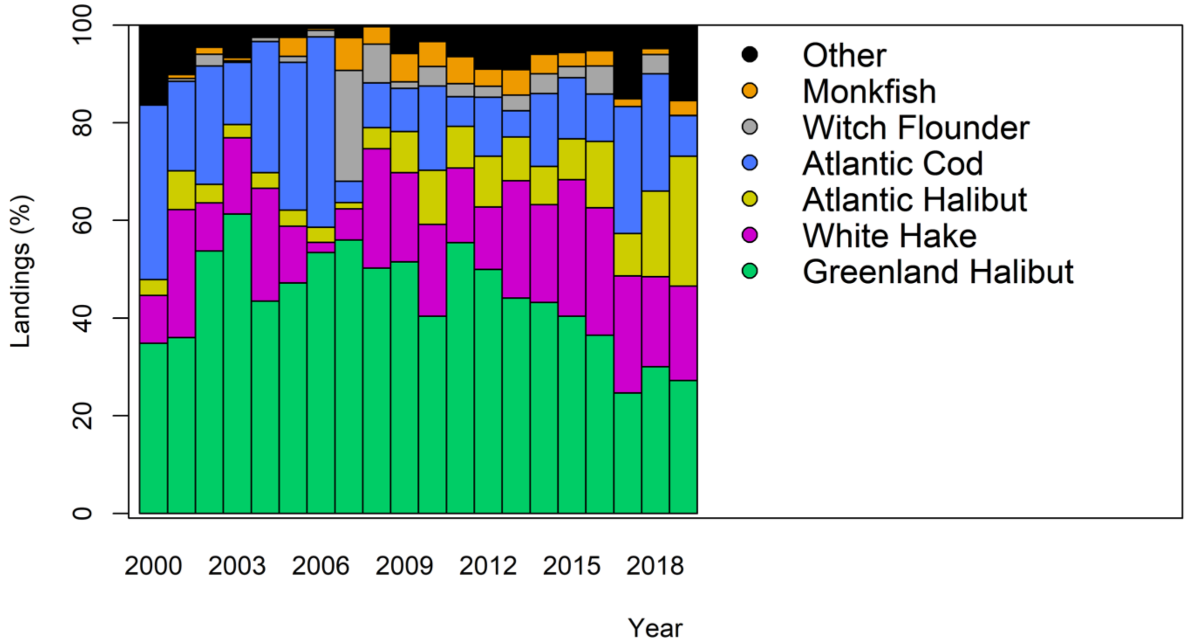


Figure 14. Annual bycatch landings (biomass percentage) by species captured in the Redfish directed fishery in Unit 1 from 2000 to 2019. 2018 and 2019 values are preliminary.

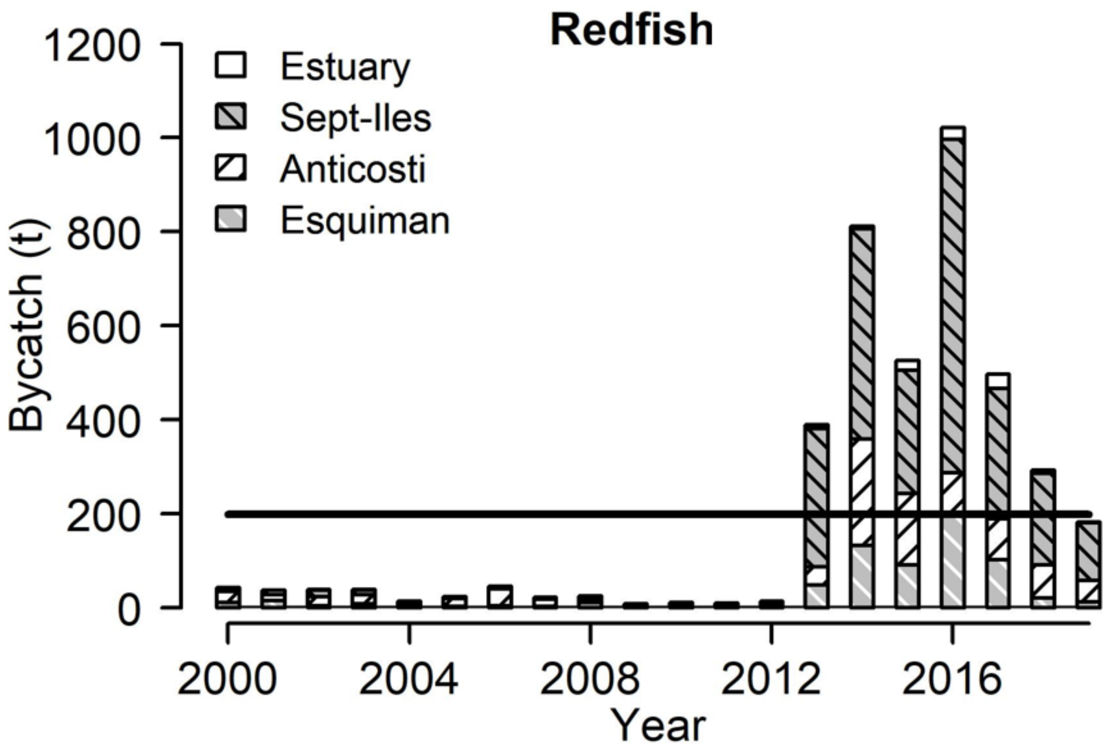


Figure 15. Annual estimated Redfish bycatch (t) in the Northern Shrimp fishery by shrimp fishing areas based on at-sea observer data. The solid horizontal line represents the 2000-2017 average. 2018 and 2019 values are preliminary.

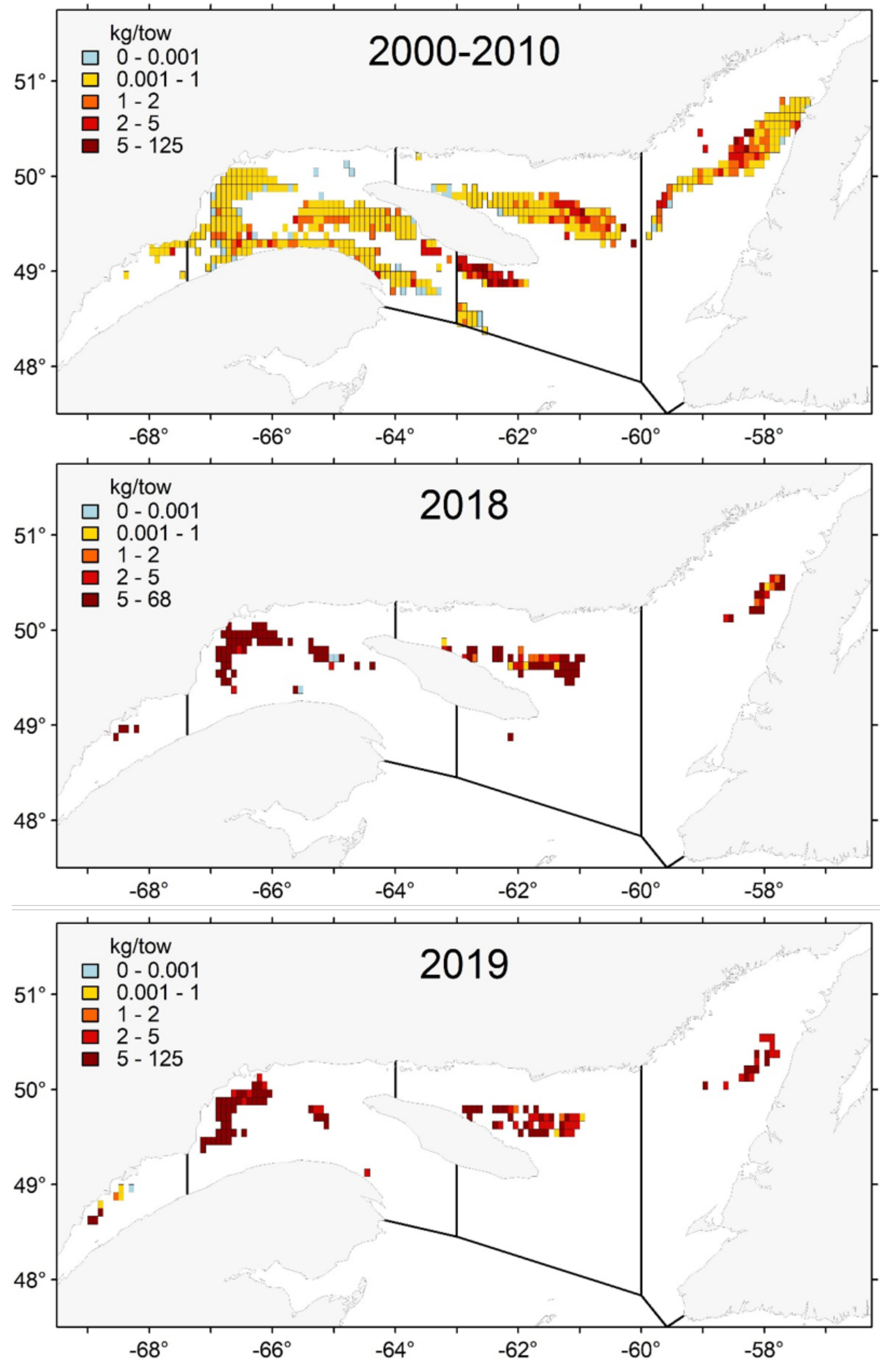


Figure 16. Redfish bycatch rate (kg/tow) distribution in the Northern Shrimp fishery from 2000-2010, 2018, and 2019. 2018 and 2019 values are preliminary.

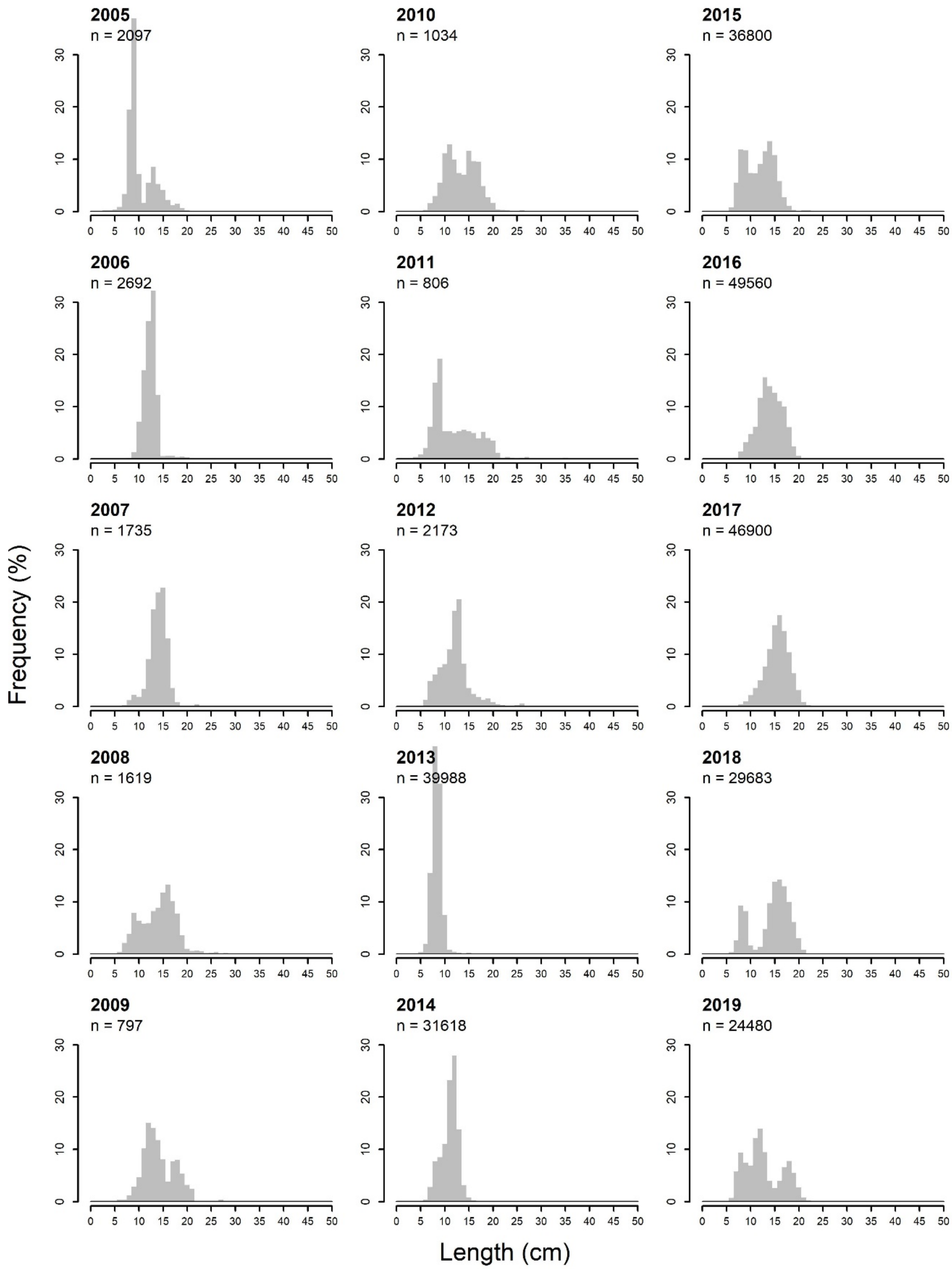


Figure 17. Length frequency of Redfish caught as bycatch in the Northern Shrimp fishery from 2005 to 2019. The numbers of fish measured are indicated (n). 2018 and 2019 values are preliminary.

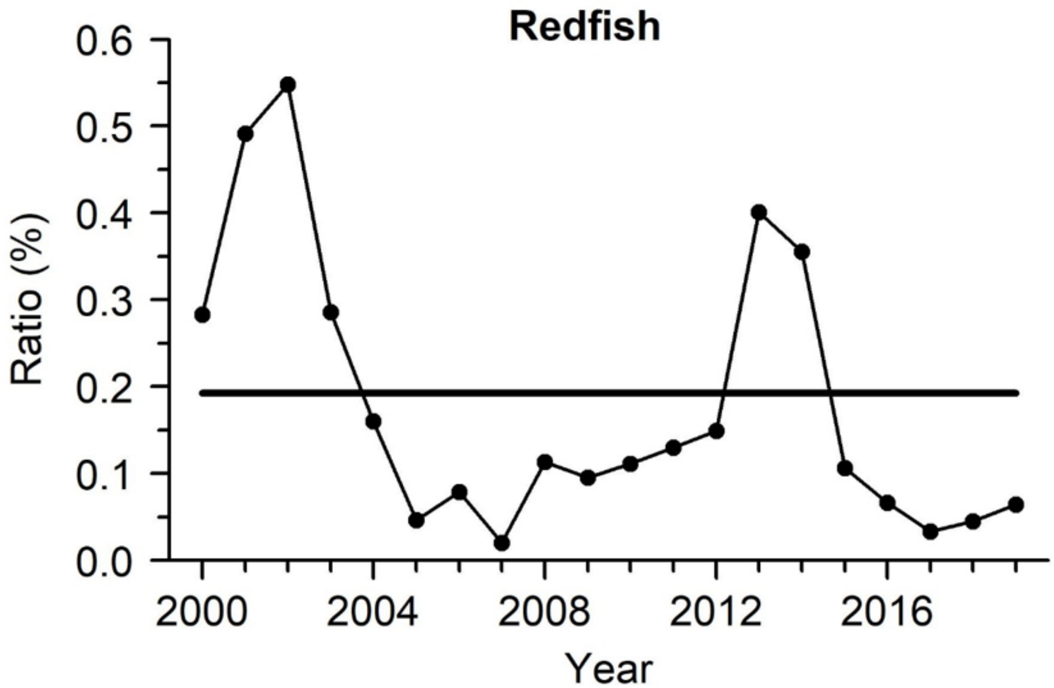


Figure 18. Ratio (%) between the quantity of Redfish caught as bycatch in the Northern Shrimp fishery and research survey minimum trawlable biomass of Redfish smaller than 20 cm from 2000 to 2019. Solid line indicates the average for the years 2000-2017. 2018 and 2019 values are preliminary.

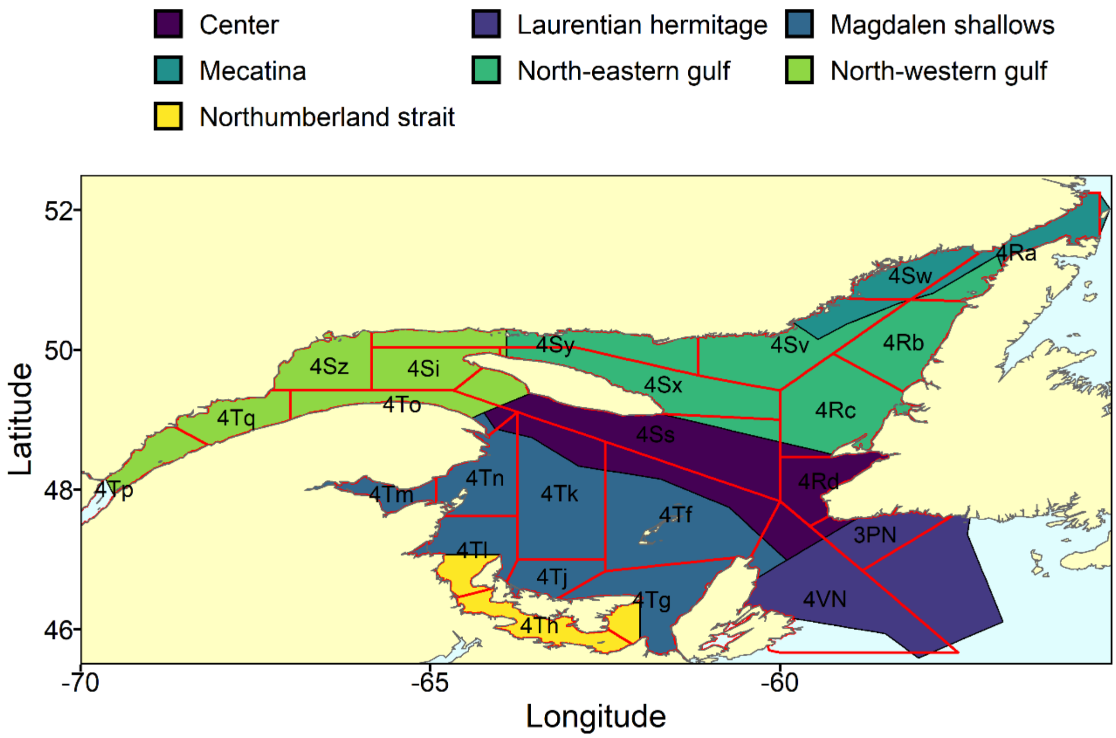


Figure 19. Map of EA areas. NAFO Divisions and EA areas are overlaid.

Model	Variable	Redfish	Greenland Halibut	Atlantic Halibut	Atlantic Cod	White Hake
binomial	Midwater trawl	↓	↓	↓	↑	↑
	Depth	-	↑	↓	↓	↑
	Winter	-	↑	-	↑	-
	Laurentian Hermitage area	-	↓	-	↑	↑
	NE Gulf area	-	-	↓	-	↑
log-normal	Midwater trawl	↑	↓	↓	↓	-
	Depth	↓	↑	-	-	↑
	Winter	-	↑	-	↑	↓
	Laurentian Hermitage area	↓	-	↑	↑	↑
	NE Gulf area	-	-	-	-	↑

Figure 20. Summary of the influence of gear, depth, season, and geographic areas on Redfish and bycatch CPUE quantified by generalized linear models. The directionality of significant drivers are indicated by arrows, where an increase in probability of occurrence and CPUE is illustrated by an upward arrow and a decrease by a downward arrow. Desirable effects (increase in Redfish probability of occurrence and CPUE, and decrease in bycatch probability of occurrence and CPUE) are in green and disadvantageous effects in red.

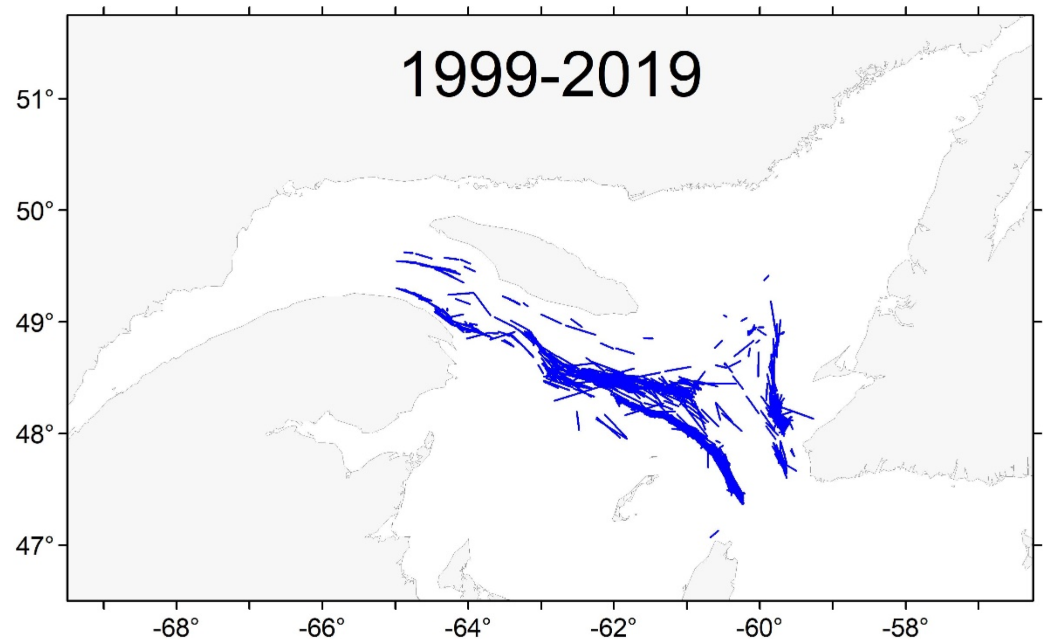


Figure 21. Start and end position of 1,731 retained tows sampled by at-sea observers in Unit 1 between June and October from 1999 to 2019. 2018 and 2019 values are preliminary.

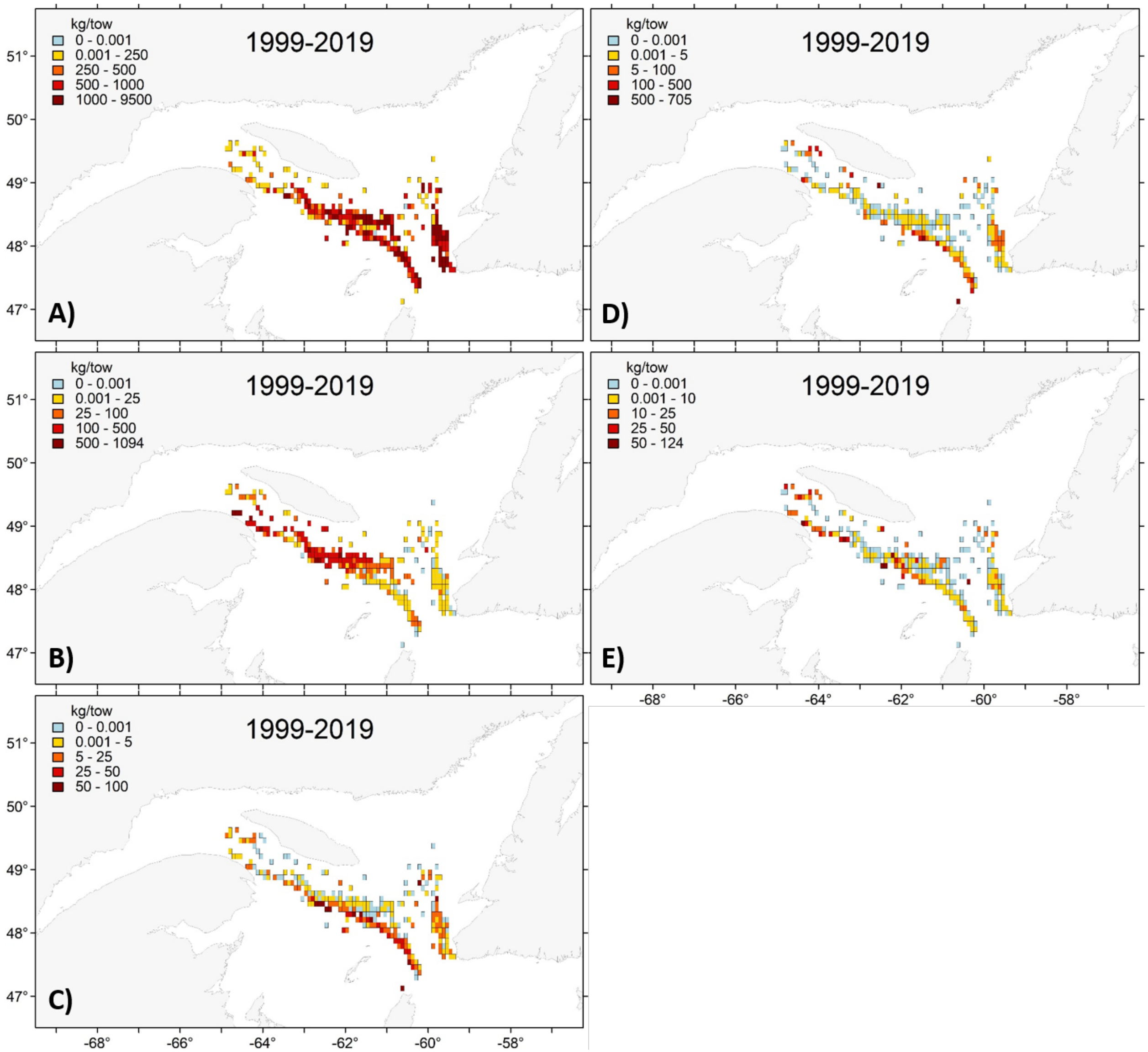


Figure 22. Catch rate (kg/tow) spatial distribution of Redfish (A), Greenland Halibut (B), White Hake (C), Atlantic Cod (D), and Atlantic Halibut (E) based on at-sea observer data in the Redfish directed fishery from 1999-2019. 2018 and 2019 values are preliminary.

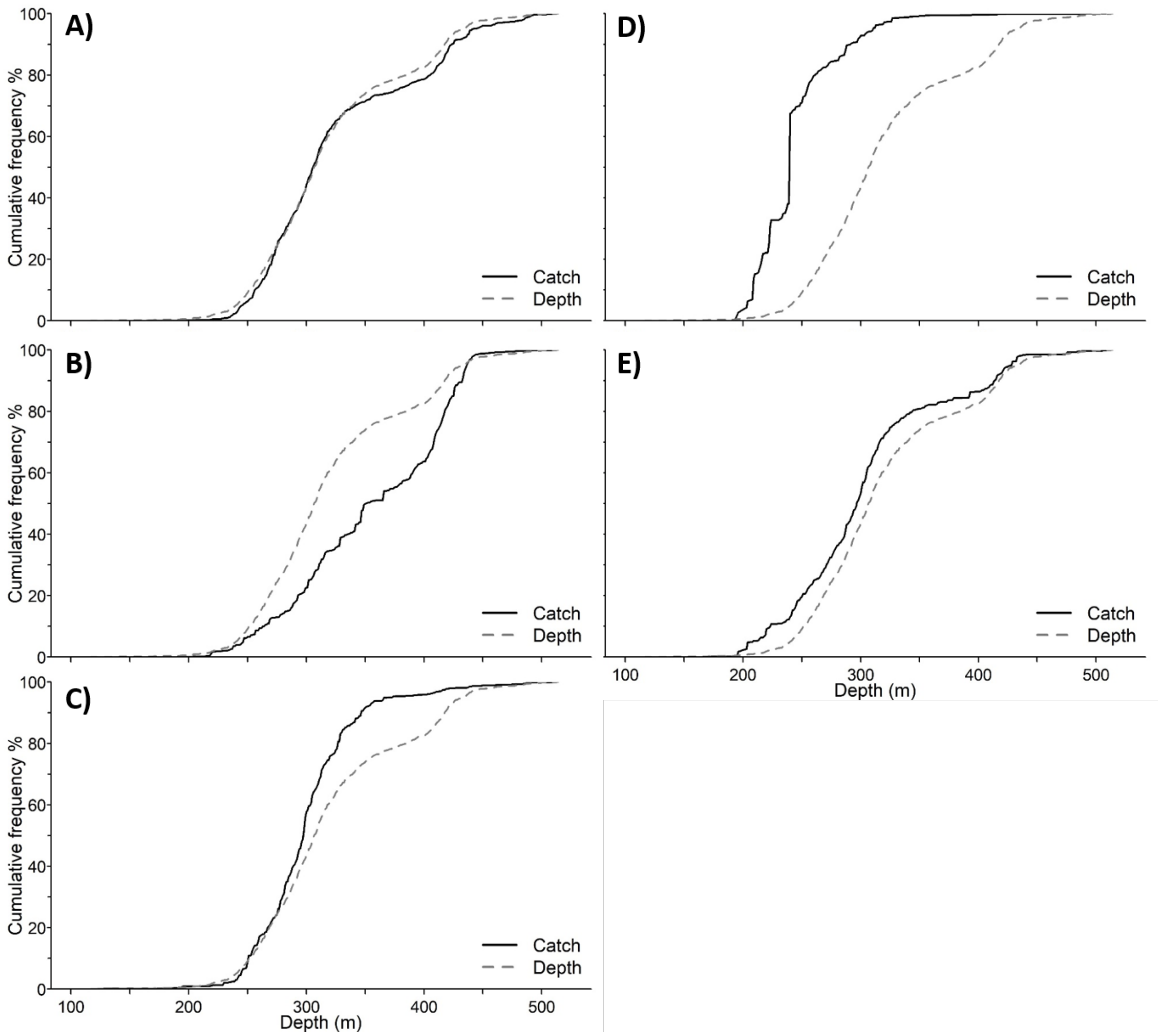


Figure 23. Cumulative frequency distribution (%) of Redfish (A), Greenland Halibut (B), White Hake (C), Atlantic Cod (D), and Atlantic Halibut (E) catch rate as a function of depth based on retained at-sea observer data in Redfish directed fishery from 1999-2019. The dashed curves represent the depth distribution for all the sets done over that time period. 2018 and 2019 values are preliminary.

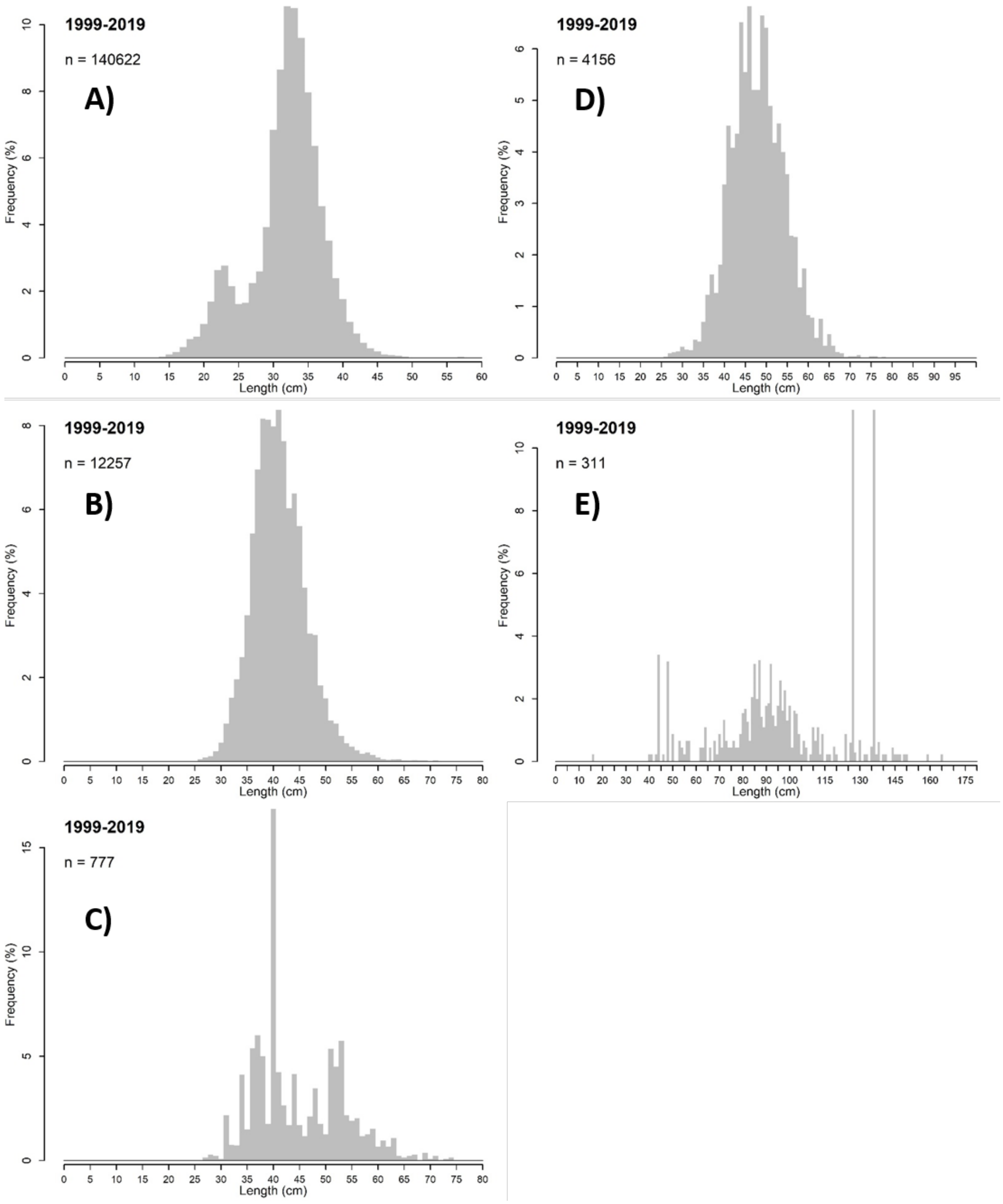


Figure 24. Length frequency distribution (%) of Redfish (A), Greenland Halibut (B), White Hake (C), Atlantic Cod (D), and Atlantic Halibut (E) based on retained at-sea observer data in Redfish directed fishery from 1999-2019. Numbers of fish measured are indicated (n). 2018 and 2019 values are preliminary.

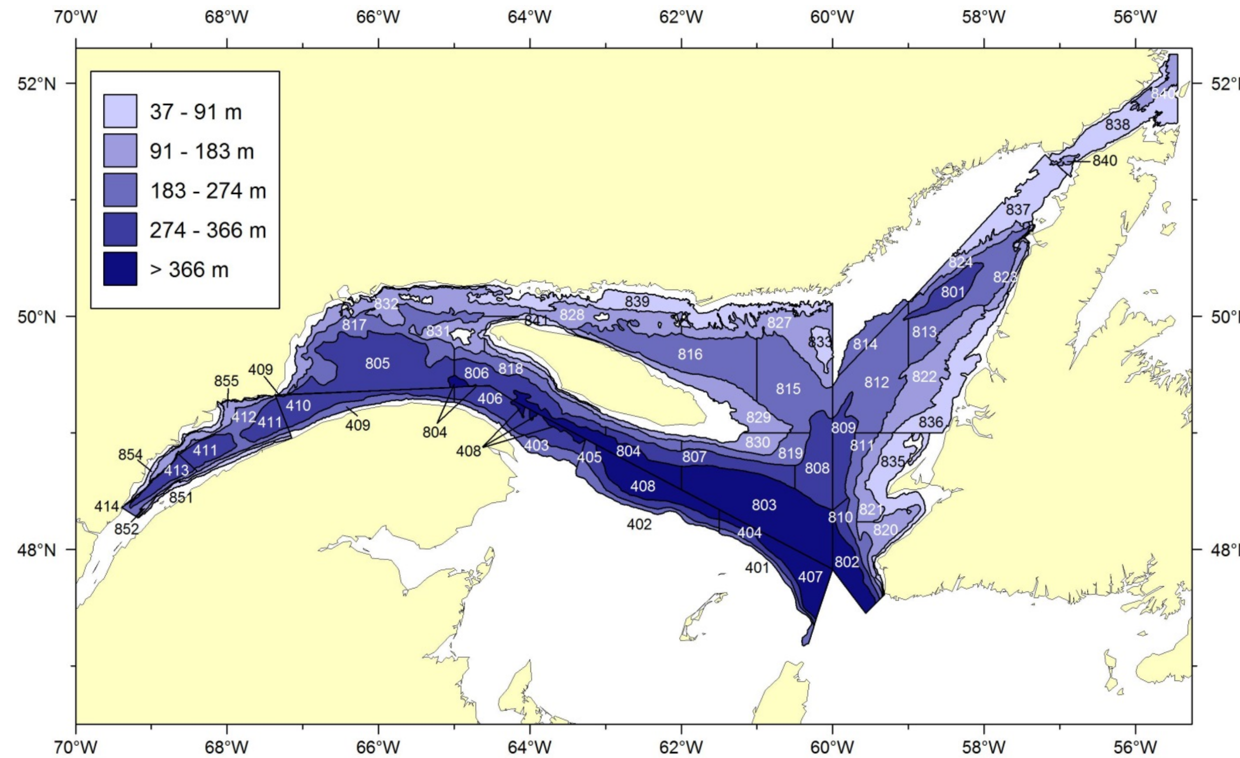


Figure 25. Stratification scheme used for the nGSL DFO survey.

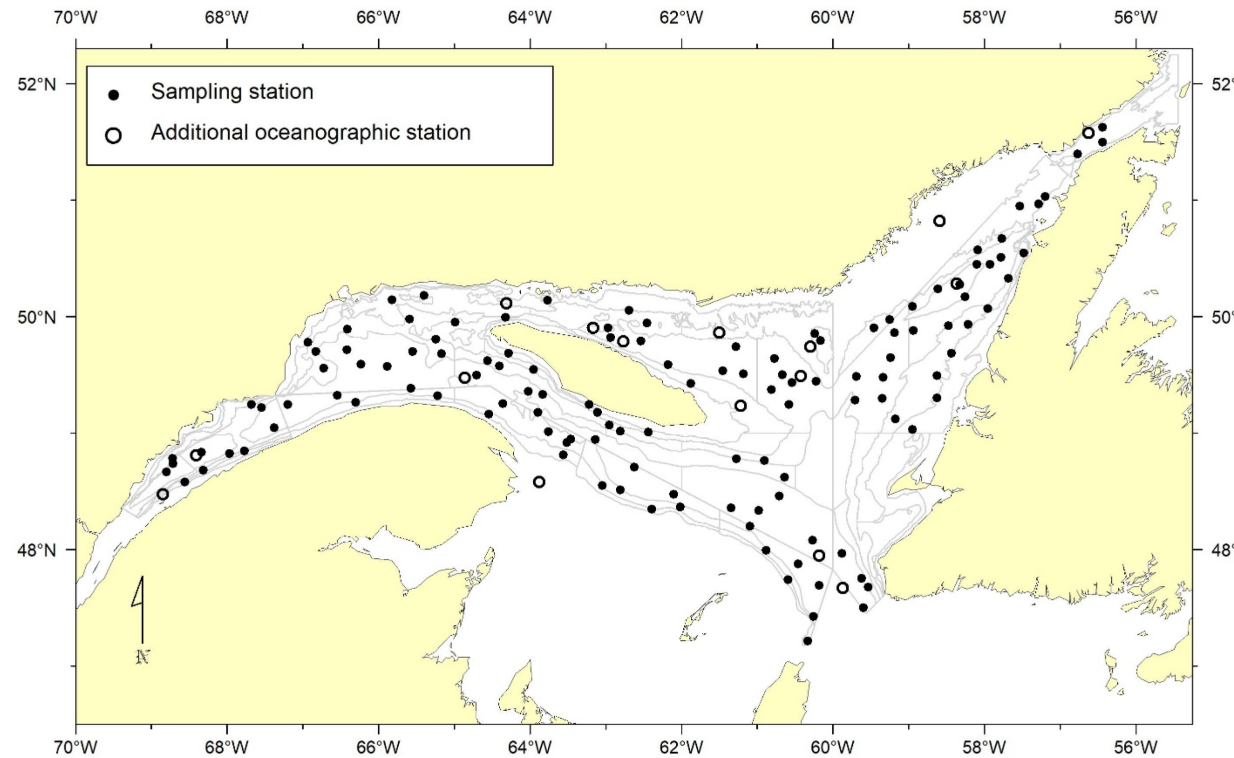


Figure 26. Locations of successful sampling stations and additional oceanographic stations for the nGSL DFO survey in August 2019.

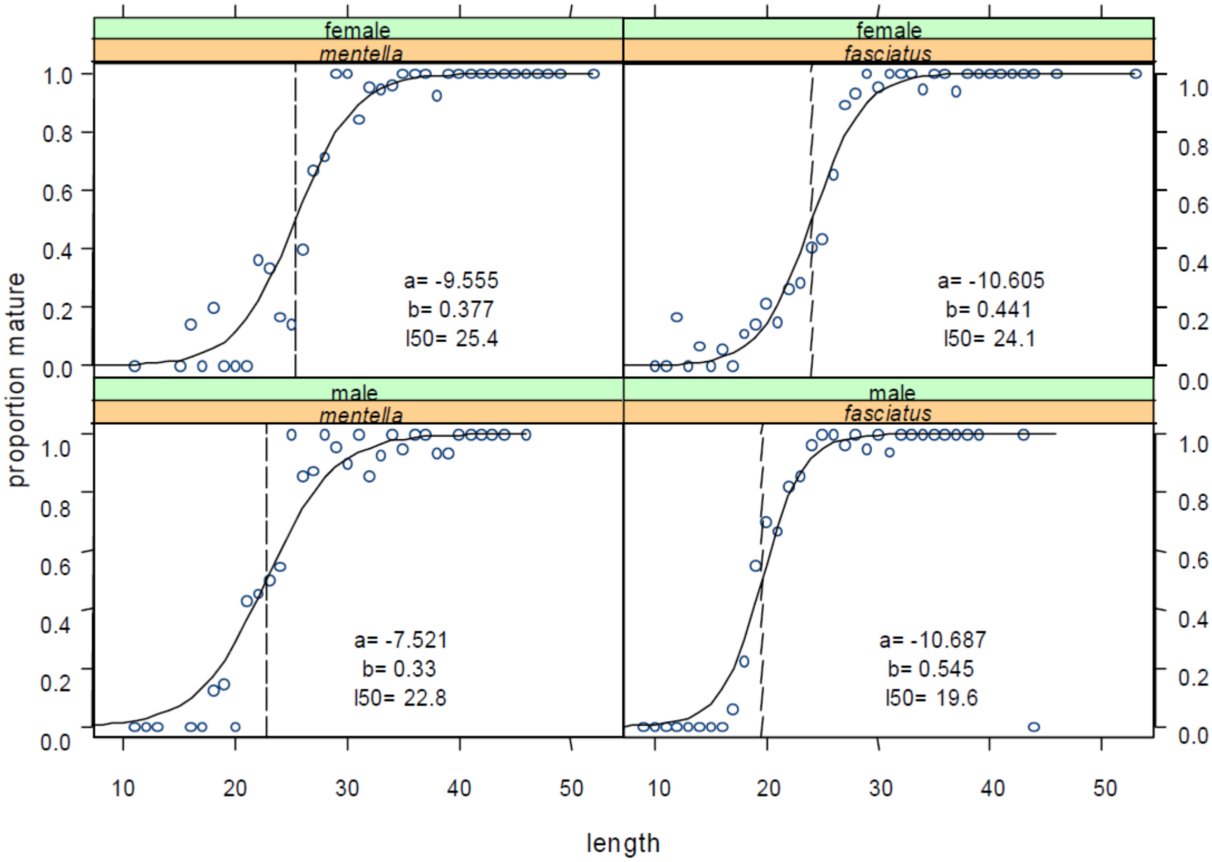
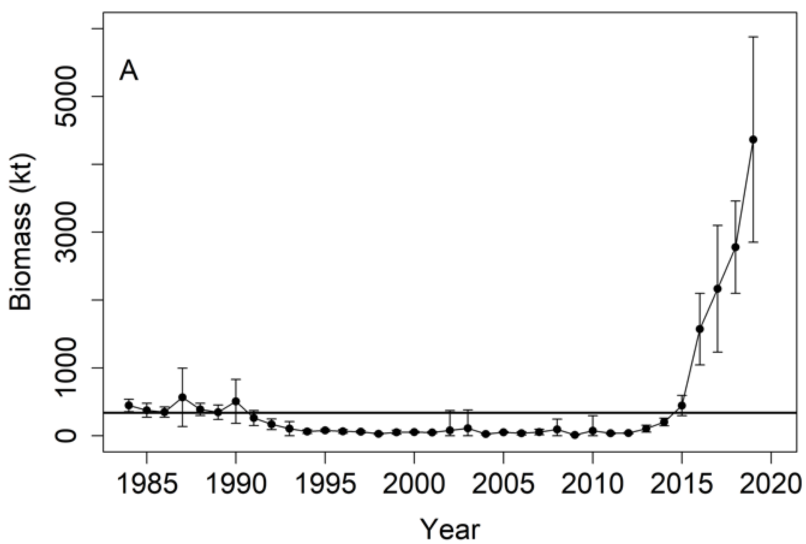


Figure 27. Redfish maturity ogive by species and sex from Gascon (2003). The proportion of mature individuals by length is illustrated by blue circles and the L50 are indicated.



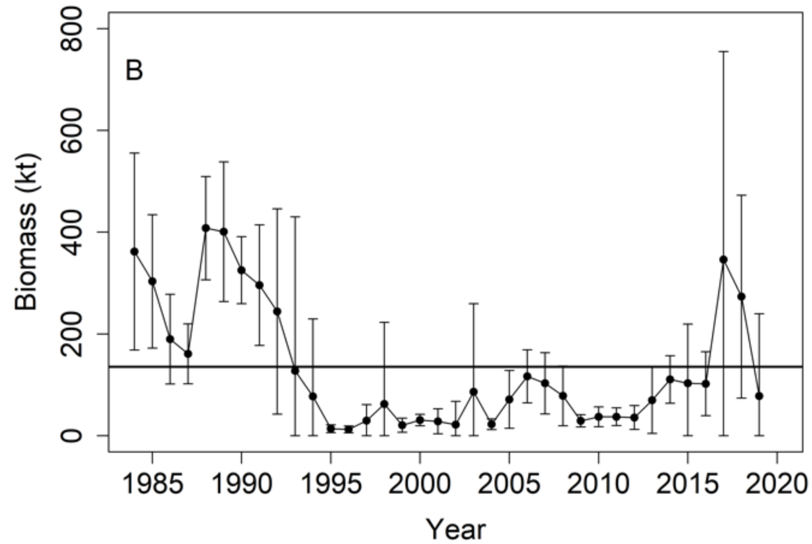


Figure 28. Minimum trawlable biomass in kilotonnes (kt) with 95% confidence intervals of S. mentella (A) and S. fasciatus (B) in the nGSL DFO survey from 1984 to 2019. The solid lines represent the 1984-2018 average. Note the different scales on the y-axis.

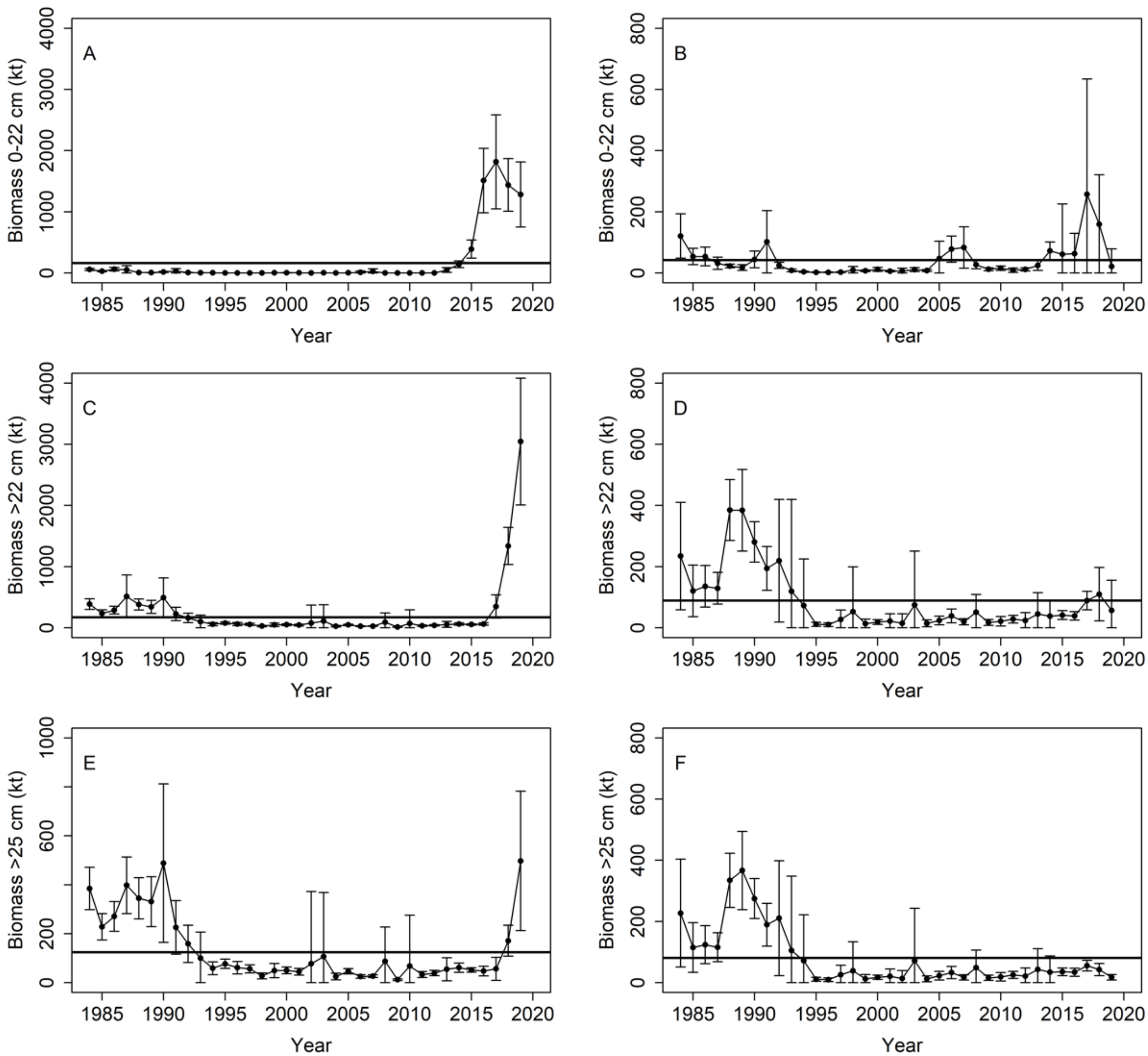


Figure 29. Trawlable biomass in kilotonnes (kt, with 95 % confidence intervals) of S. mentella (left column; panels A, C, and E) and S. fasciatus (right column; panels B, D, and F) in the nGSL DFO survey from 1984 to 2019, by length classes: 0-22 cm (A-B), > 22 cm (C-D), and > 25 cm (E-F). The solid lines represent the mean for the 1984-2018 period. Note the different scales on the y-axis.

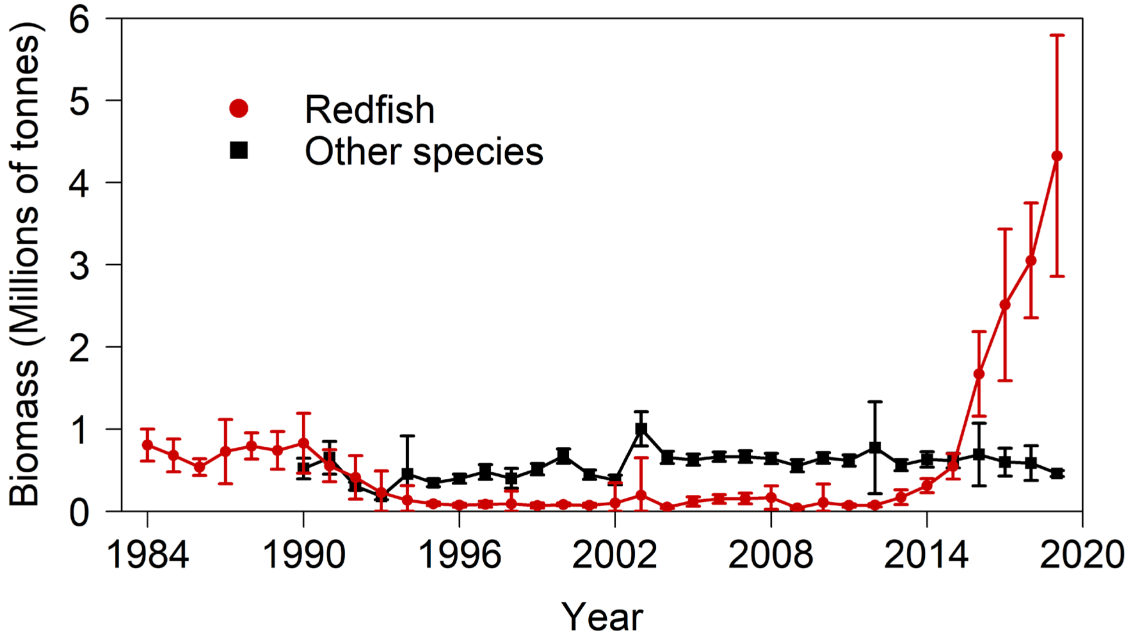


Figure 30. Trawlable biomass (millions of tonnes, with 95% confidence intervals) of Redfish spp. (red circles) and all other species (black squares) sampled in the nGSL DFO survey from 1984 to 2019.

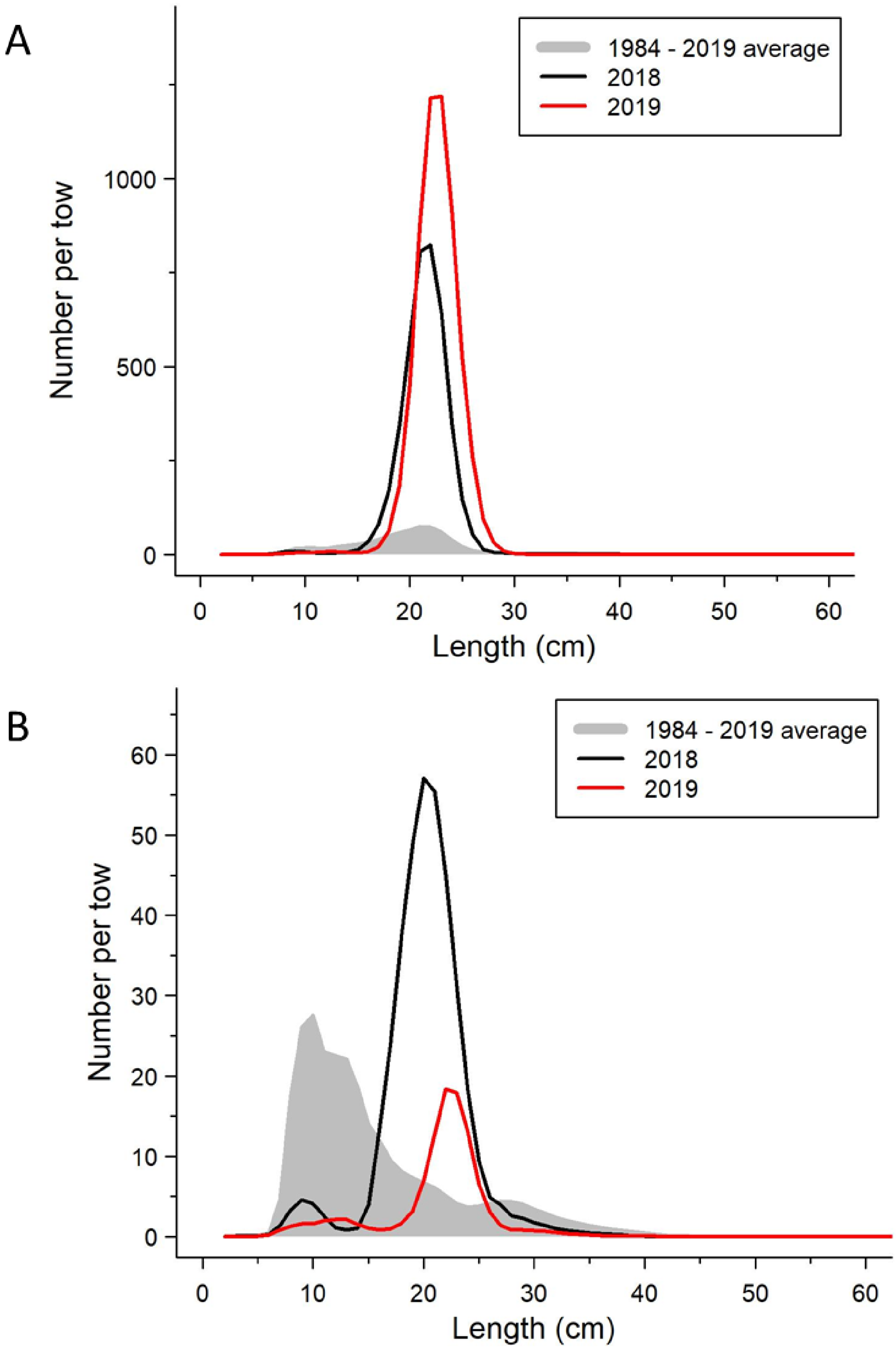


Figure 31. S. mentella (A) and S. fasciatus (B) length frequency in the nGSL DFO research surveys for 2018, 2019, and the 1984 to 2019 average. Note the different scales on the y-axis.

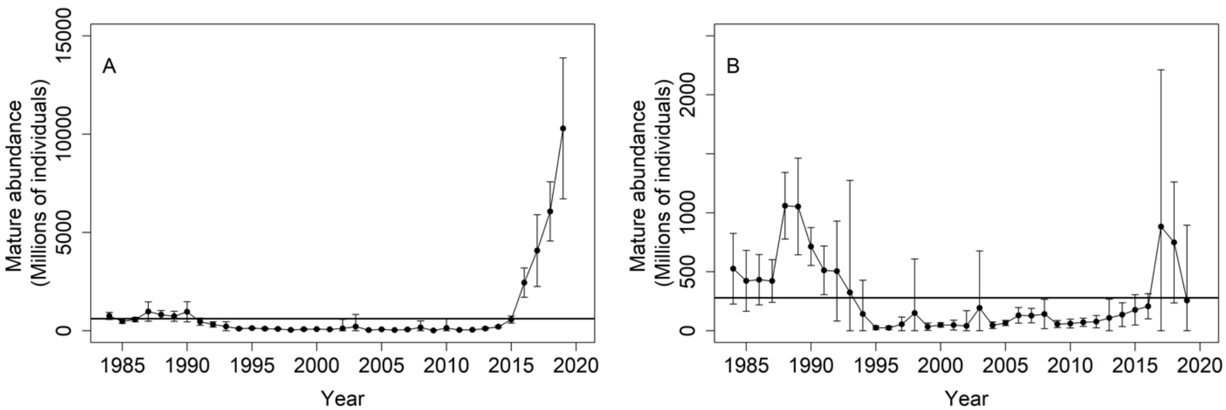


Figure 32. Trawlable mature fish abundance (millions of individuals, with 95% confidence intervals) of S. mentella (A) and S. fasciatus (B) in the nGSL DFO survey from 1984 to 2019. The solid lines represent the 1984-2018 average. Note the different scales on the y-axis.

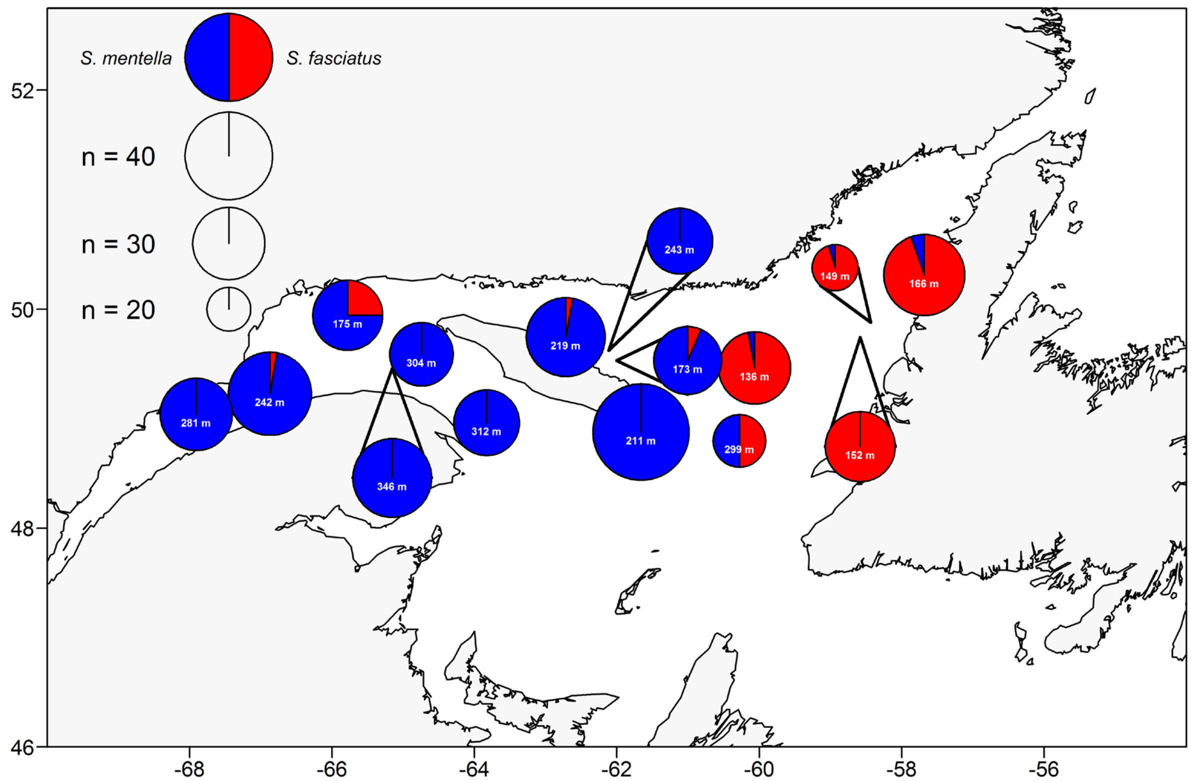


Figure 33. Map showing species composition (%) between S. mentella in blue and S. fasciatus in red and location of genotyped juveniles sampled during the 2018 nGSL DFO survey. Size of the pie charts is relative to sample size and depth (m) is indicated in the circle.

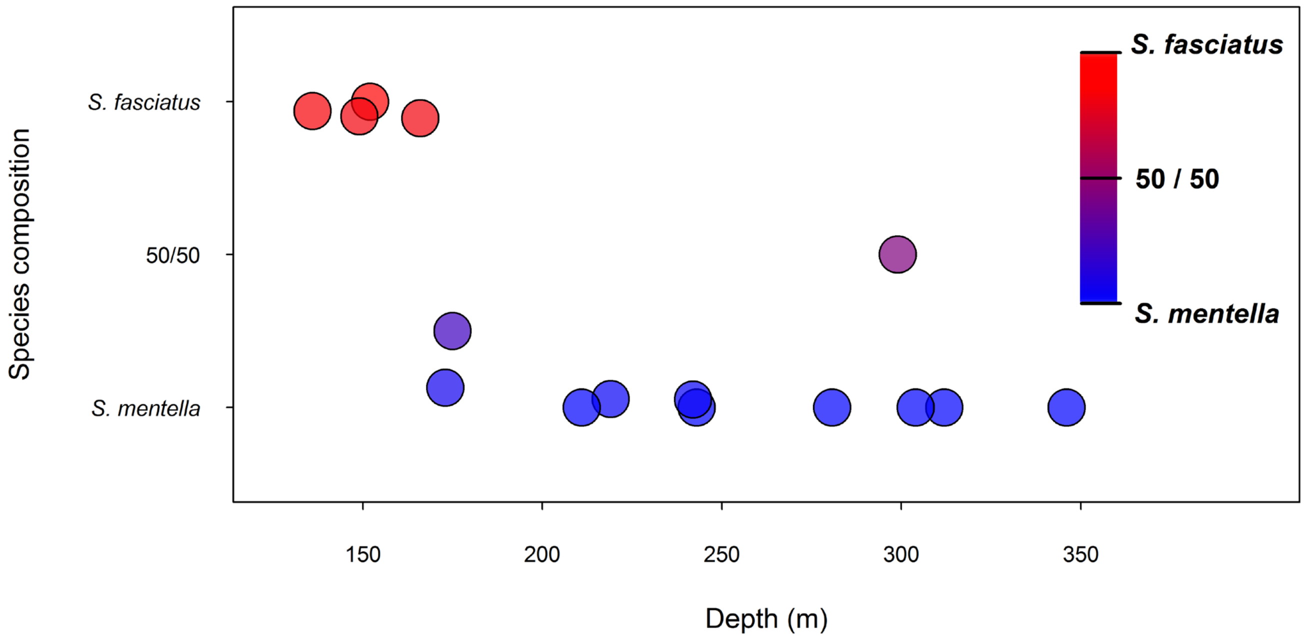


Figure 34. Relationship between species composition (%) and depth (m) according to the genotyped juveniles from the 15 locations sampled in 2018, where S. fasciatus is illustrated in red and S. mentella in blue.

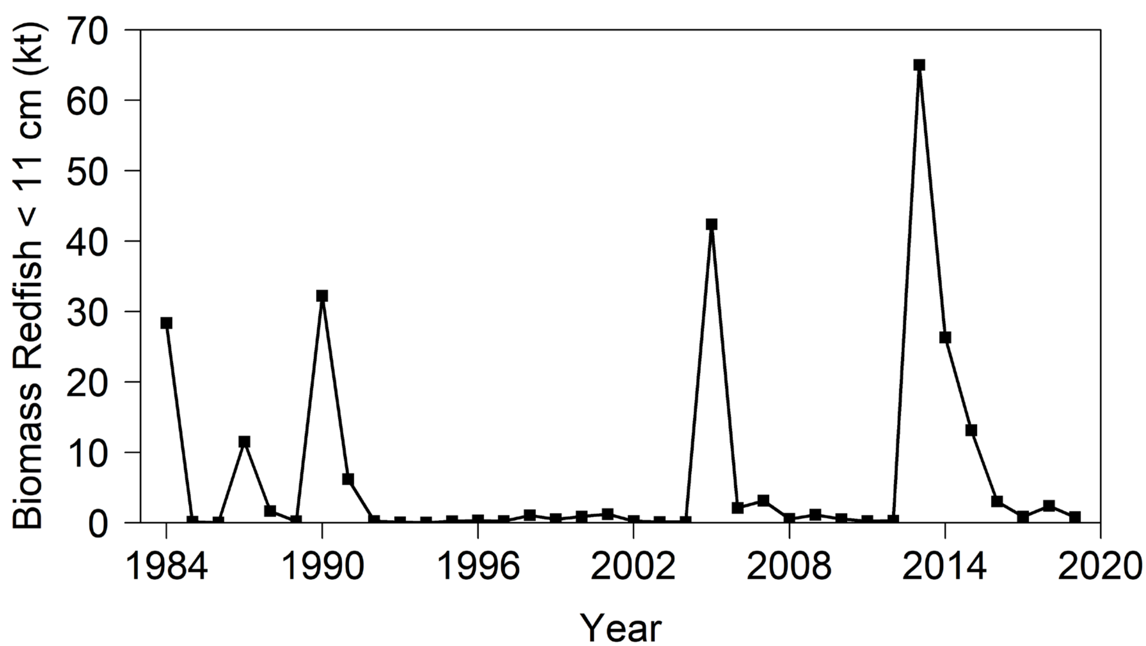


Figure 35. Minimum trawlable biomass in kilotonnes (kt) of Redfish of less than 11 cm in the nGSL DFO survey from 1984 to 2019.

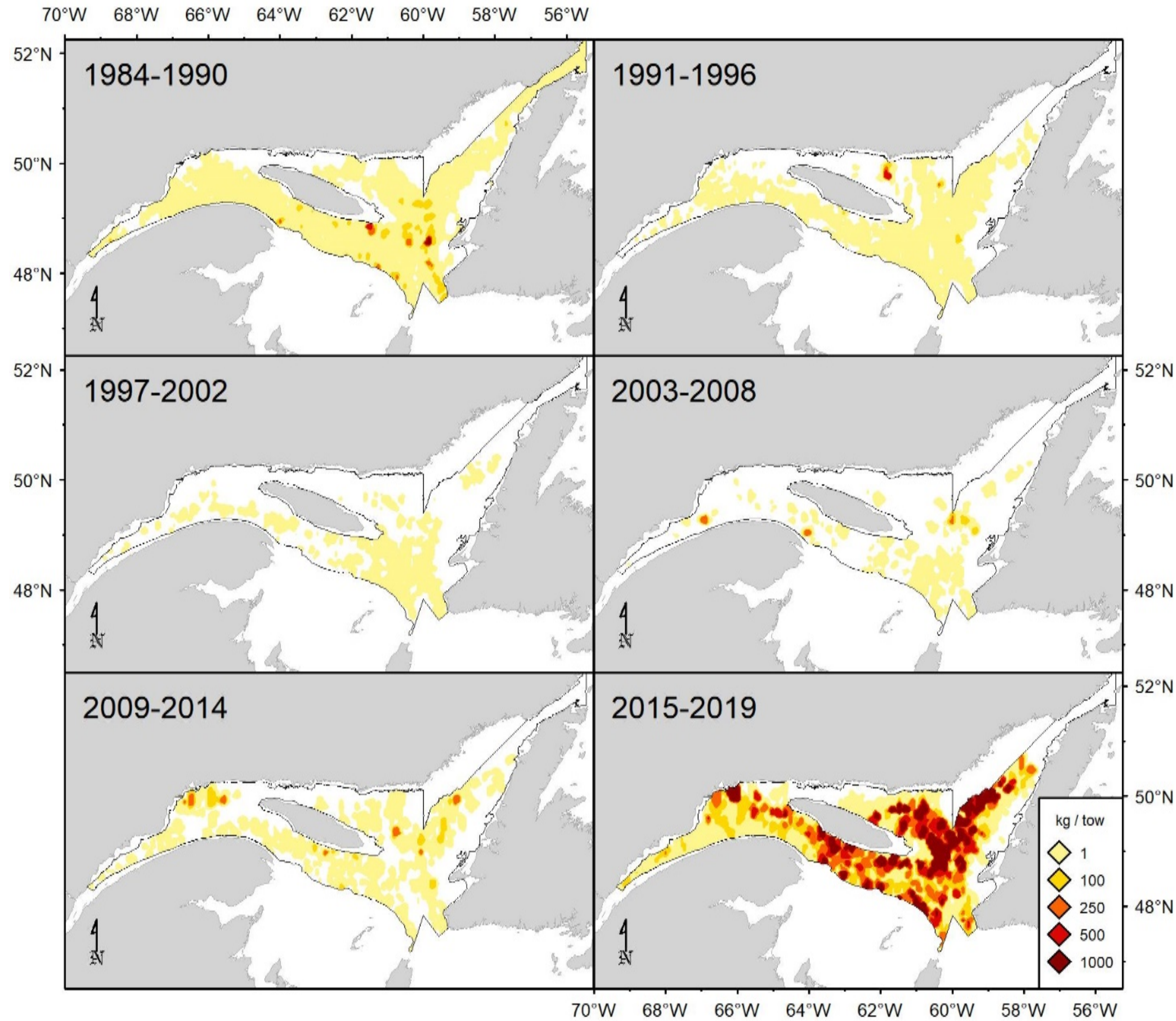


Figure 36. Catch rate distribution of immature S. mentella (kg/15-minute tow) in the nGSL DFO survey from 1984 to 2019.

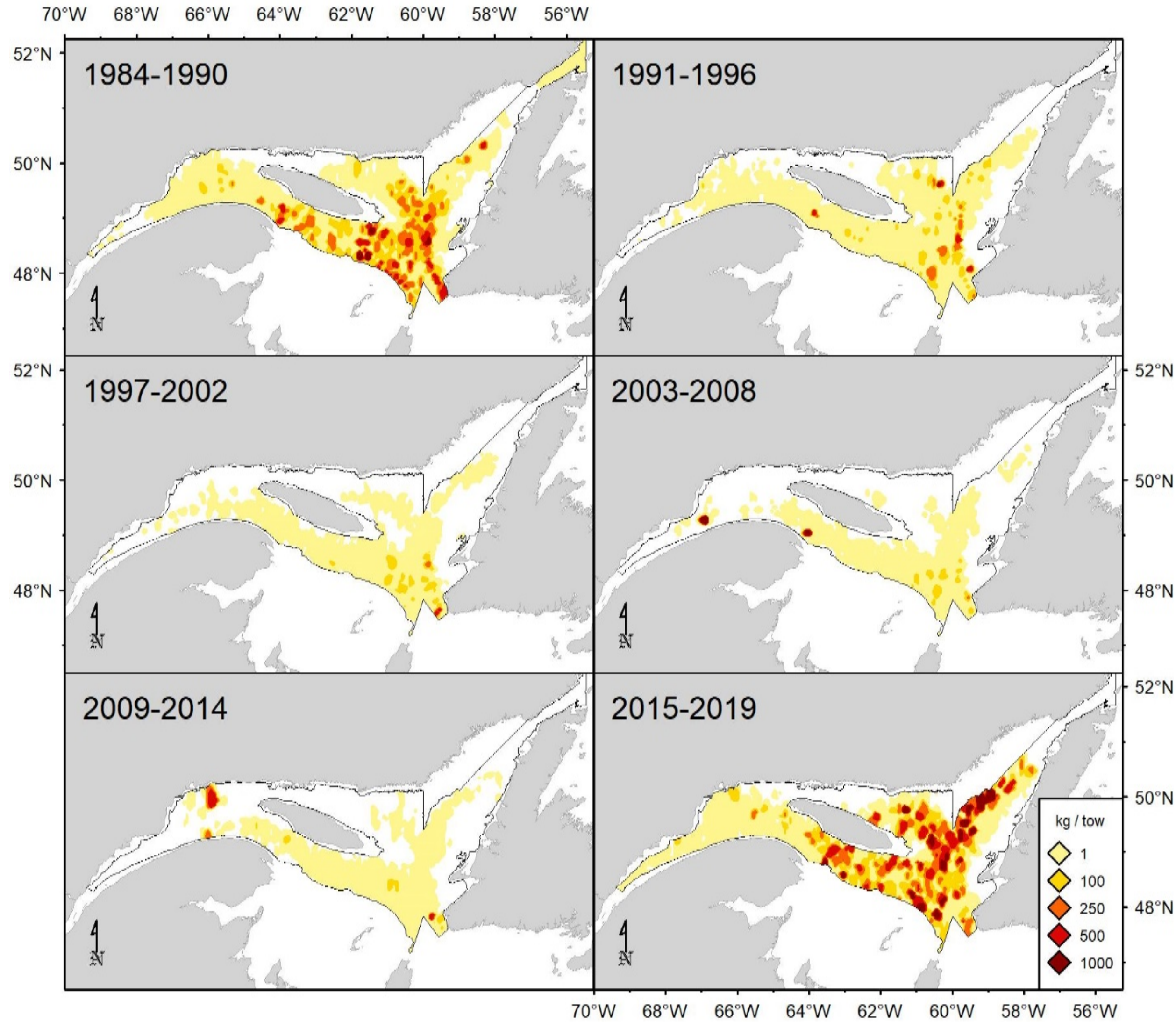


Figure 37. Catch rate distribution of mature S. mentella (kg/15-minute tow) (kg/15-minute tow) in the nGSL DFO survey from 1984 to 2019.

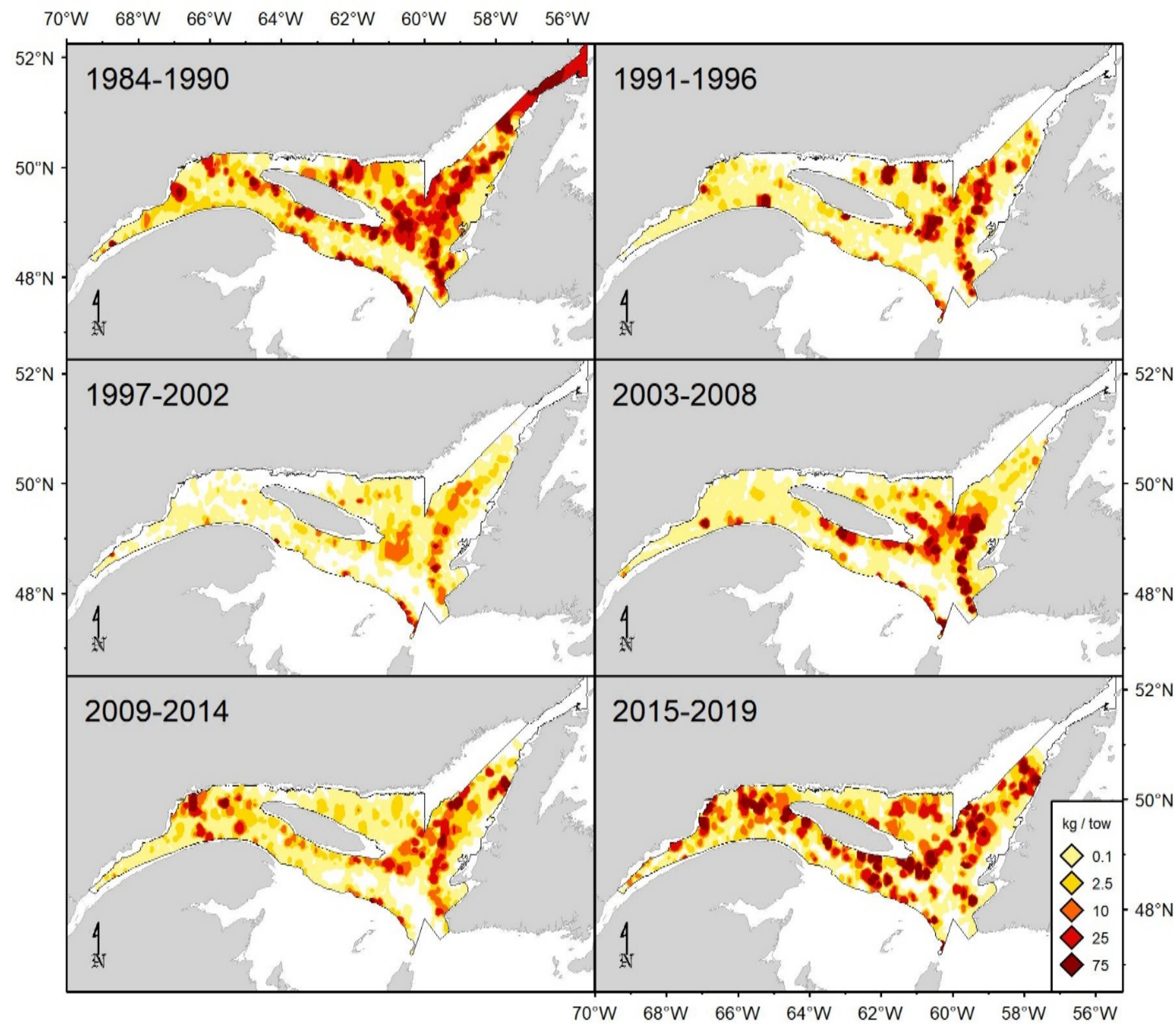


Figure 38. Catch rate distribution of immature S. fasciatus (kg/15-minute tow) in the nGSL DFO survey from 1984 to 2019.

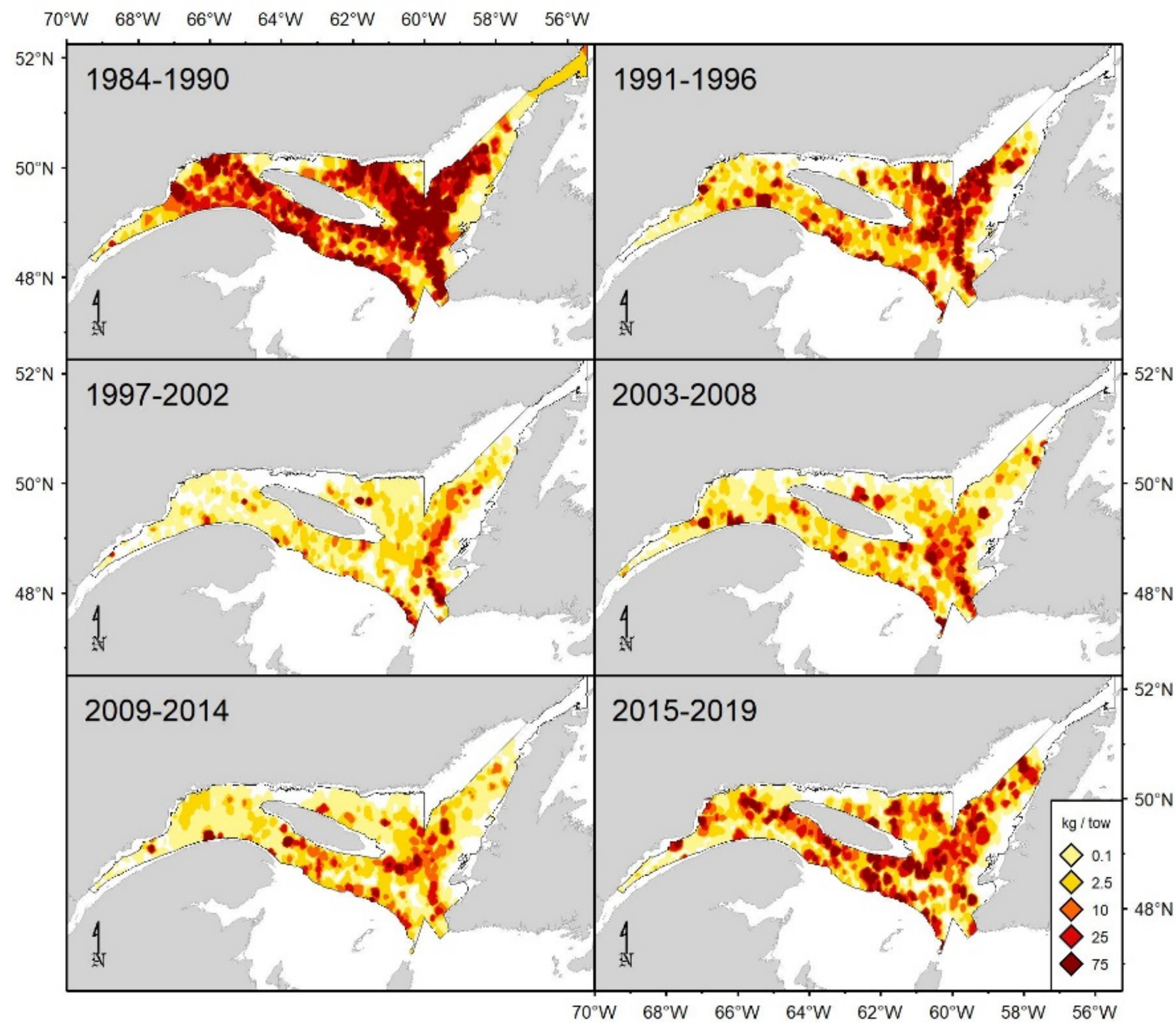


Figure 39. Catch rate distribution of mature S. fasciatus (kg/15-minute tow) in the nGSL DFO survey from 1984 to 2019.

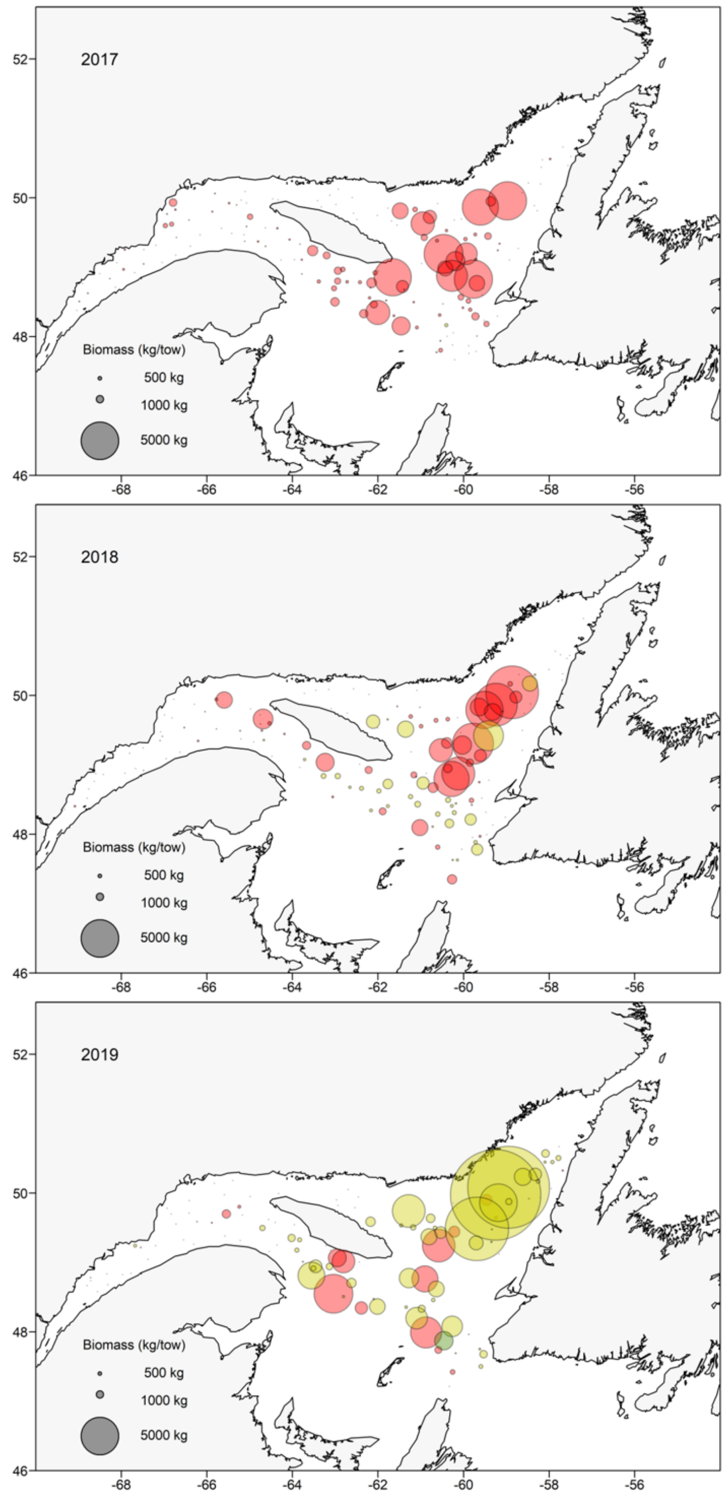


Figure 40. Catch rate distribution of Redfish (kg/15-minute tow) in the nGSL DFO survey from 2017 to 2019. Catch size is indicated by bubbles size and median Redfish length is indicated by colors, where a median smaller than 22 cm is illustrated in red, between 22 and 25 cm in yellow, and larger than 25 in green.

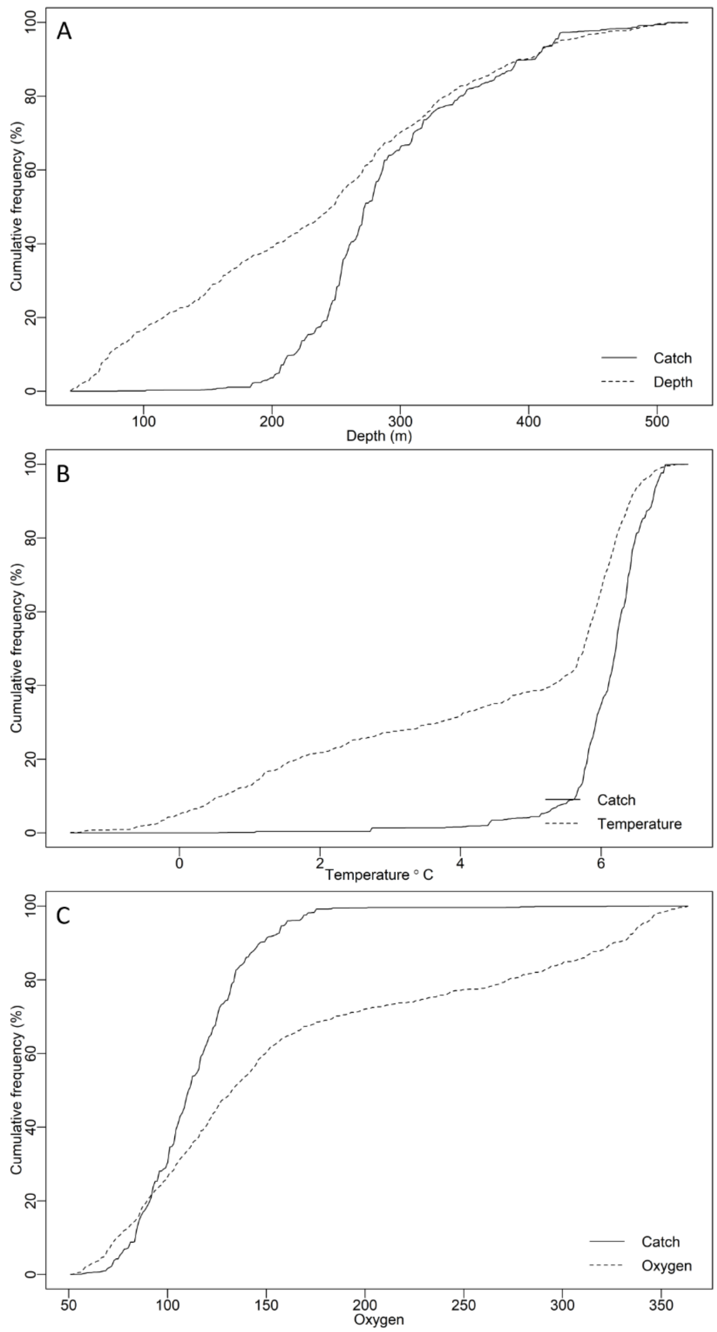


Figure 41. Stratified cumulative frequency of S. mentella in DFO survey from 2015-2019. The solid and dotted lines represent the cumulative frequency of catches and survey stations, respectively, according to depth (A, m), temperature (B, °C), and dissolved oxygen (C, μmol/kg).

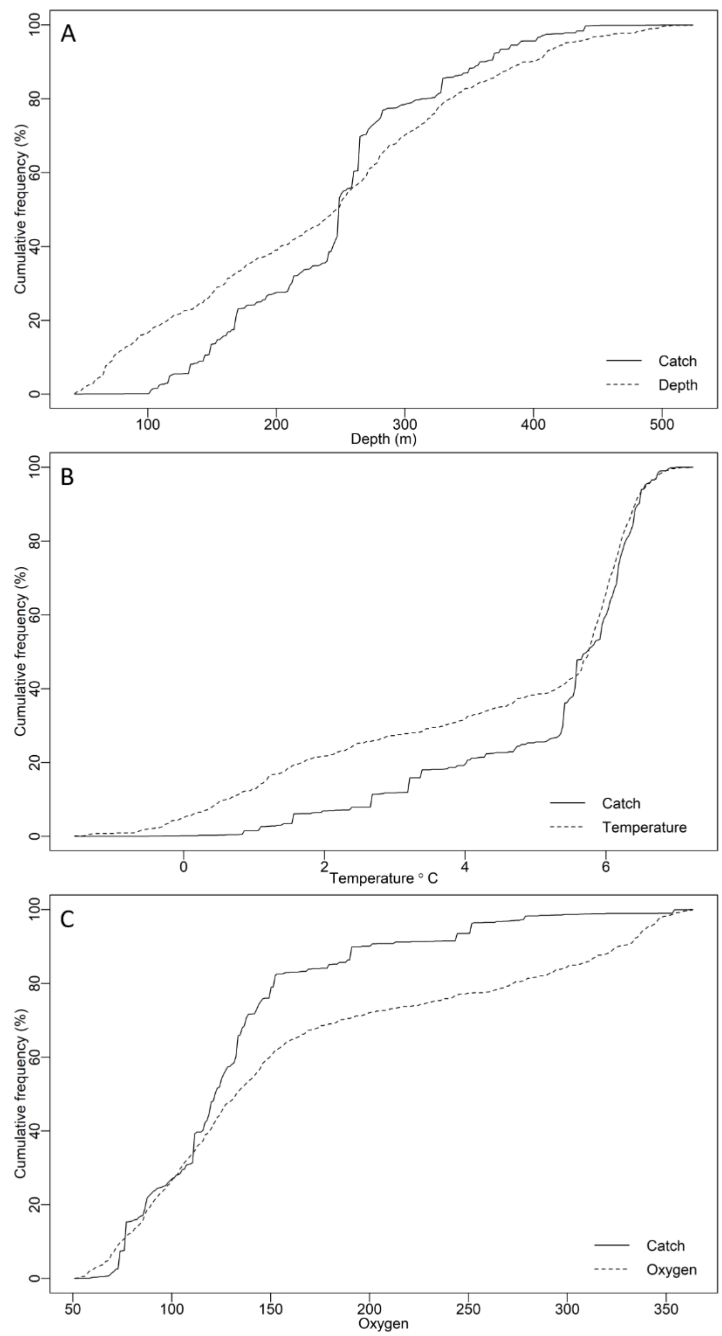


Figure 42. Stratified cumulative frequency of S. fasciatus in DFO survey from 2015-2019. The solid and dotted lines represent the cumulative frequency of catches and survey stations, respectively, according to depth (A, m), temperature (B, °C), and oxygen (C, μmol/kg).

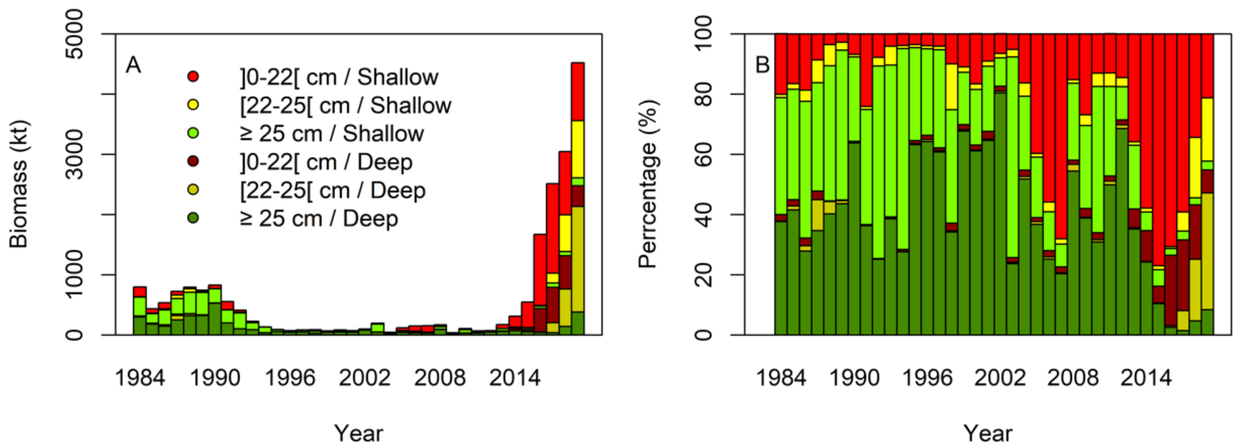


Figure 43. Redfish biomass in kilotonnes (kt) (A) and percentage (B) in the nGSL DFO survey (1984-2019) as a function of length classes ([0-22] cm, [22-25] cm, and ≥ 25 cm) and depth class areas ("Deep" or "Shallow"). Deep areas were defined as strata greater than 274 meters located between 59°W and 65°W (the area in which the index fishery takes place), while the "Shallow" areas constitute the rest of the study area.

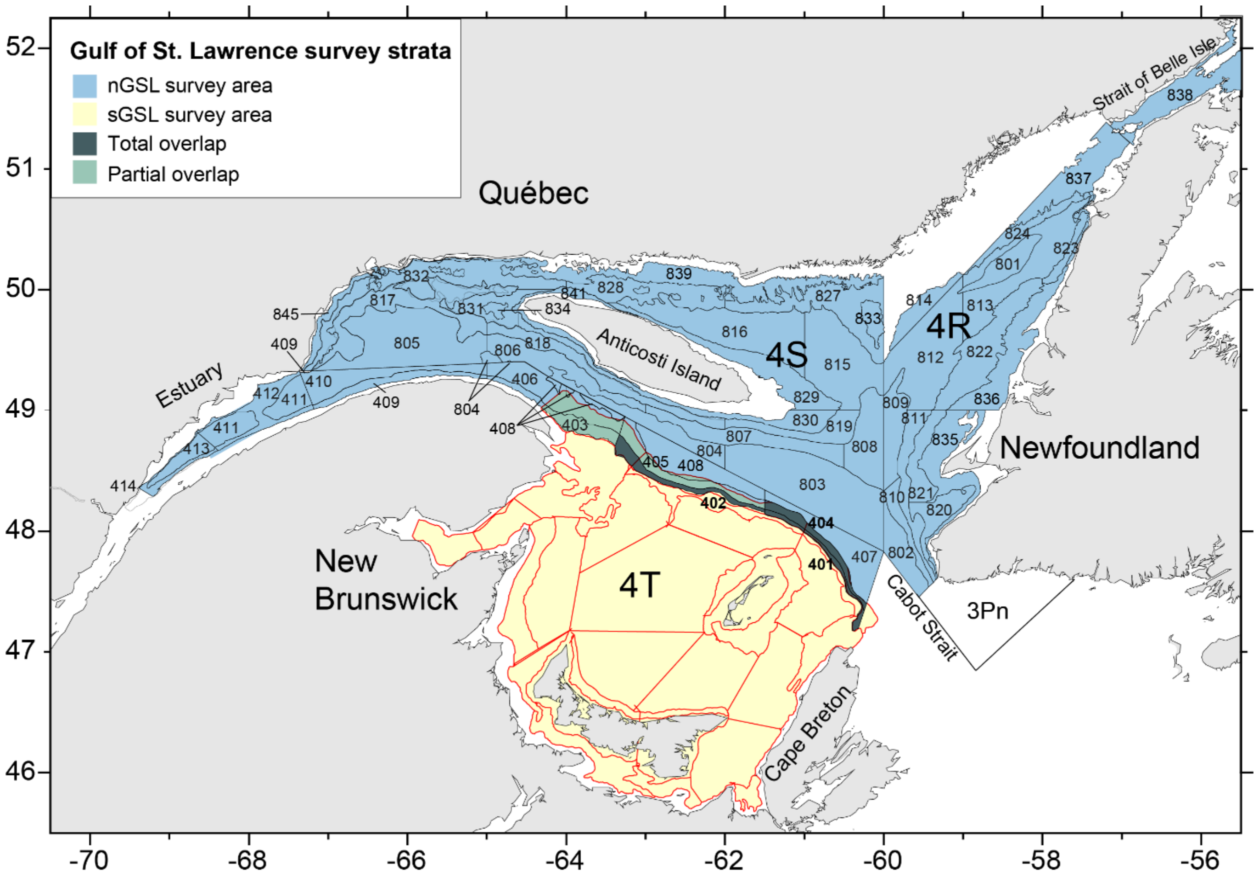


Figure 44. Map showing the area covered by the northern Gulf of St. Lawrence (nGSL) and the southern Gulf of St. Lawrence (sGSL) DFO surveys and their overlap.

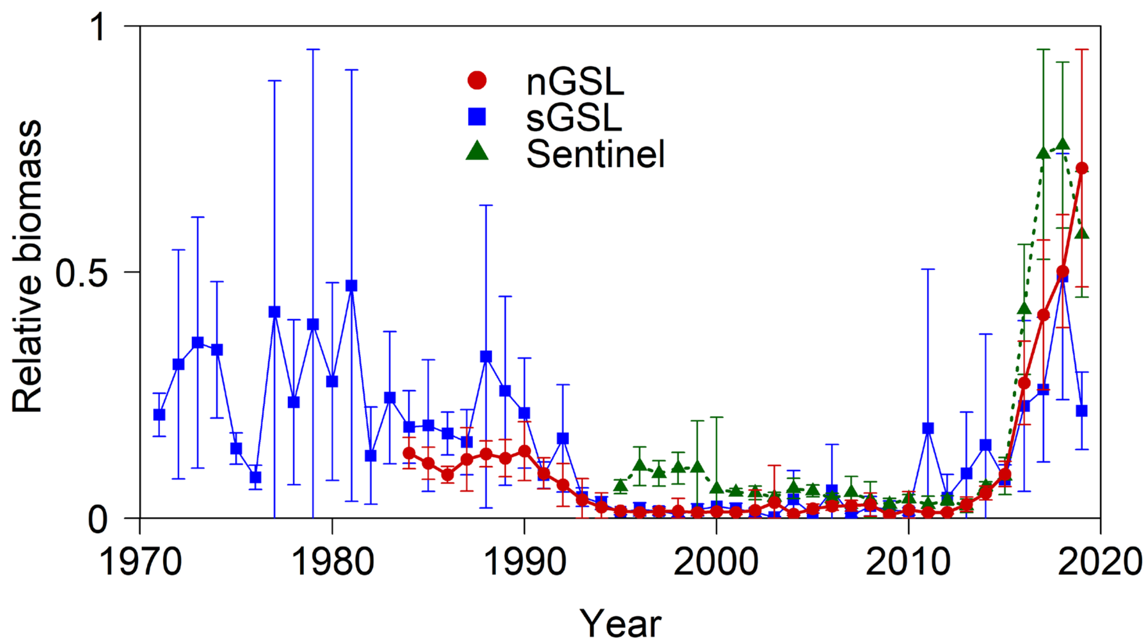


Figure 45. Comparison of DFO research surveys (nGSL, red line with circles), sGSL (blue line with squares), and mobile sentinel (green line with triangles) surveys relative indices with 95% confidence intervals of Redfish biomass time series.

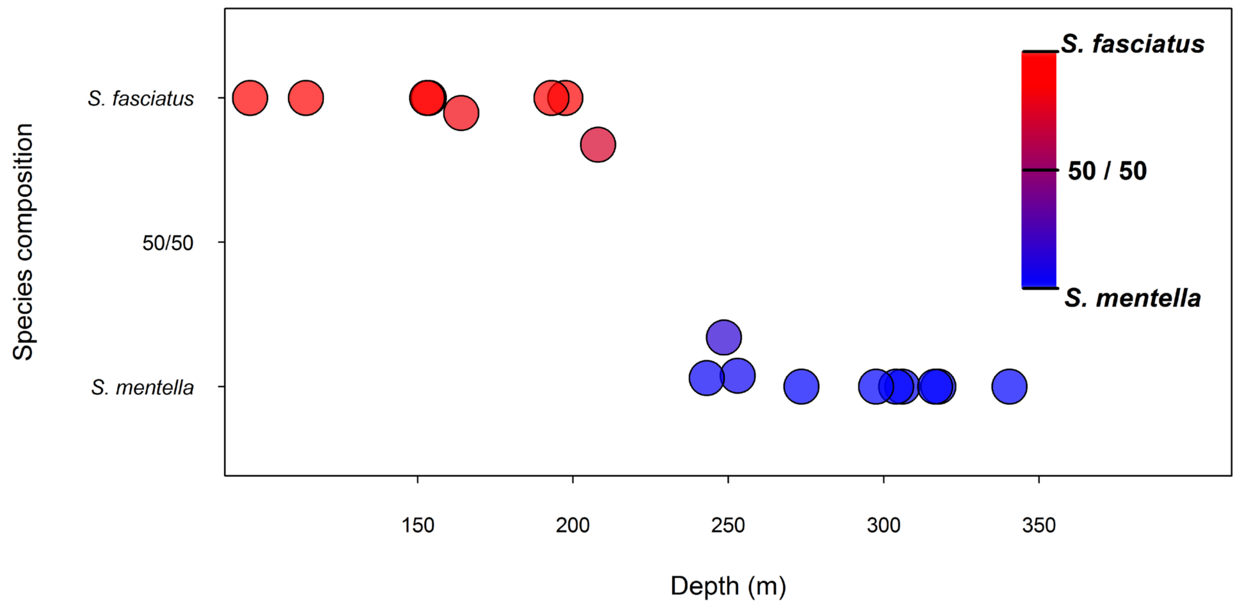


Figure 46. Relationship between species composition (%) and depth (m) according to the sGSL DFO survey in 2019, where S. fasciatus is illustrated in red and S. mentella in blue.

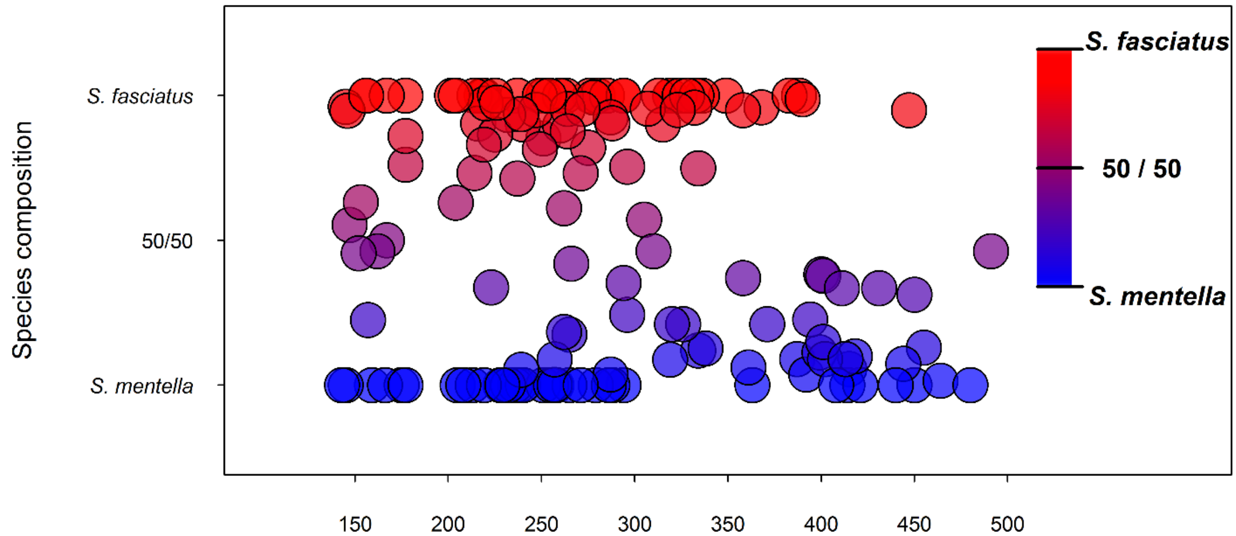


Figure 47. Relationship between species composition (%) and depth (m) according to mobile sentinel survey in 2019, where S. fasciatus is illustrated in red and S. mentella in blue.

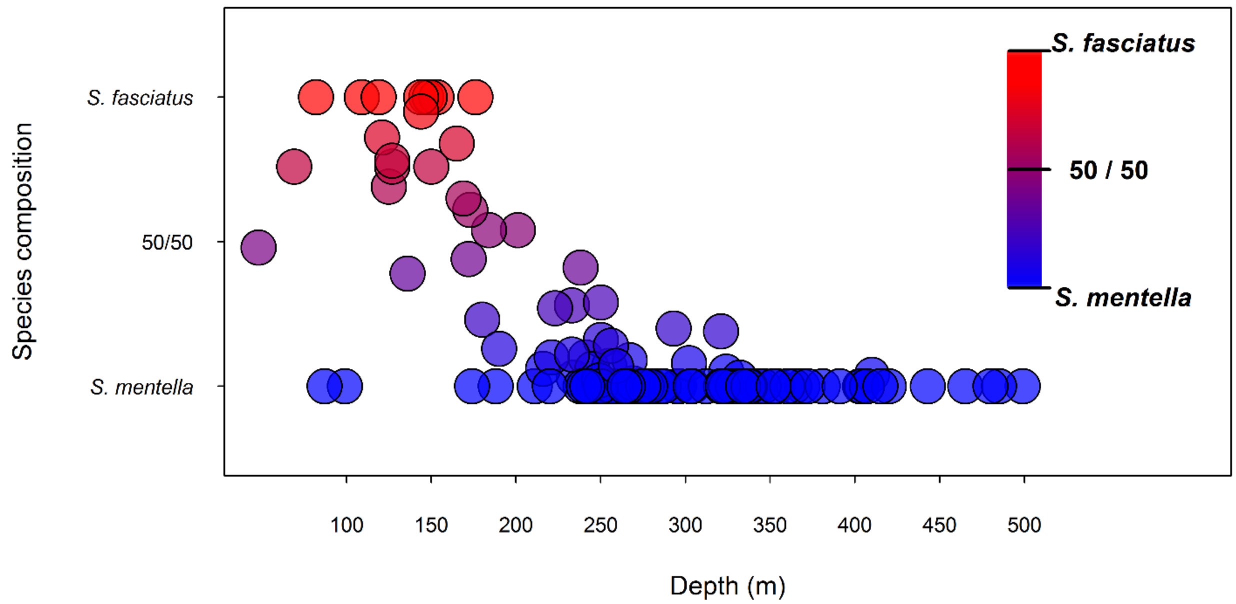


Figure 48. Relationship between species composition (%) and depth (m) according to nGSL DFO survey in 2019, where S. fasciatus is illustrated in red and S. mentella in blue.

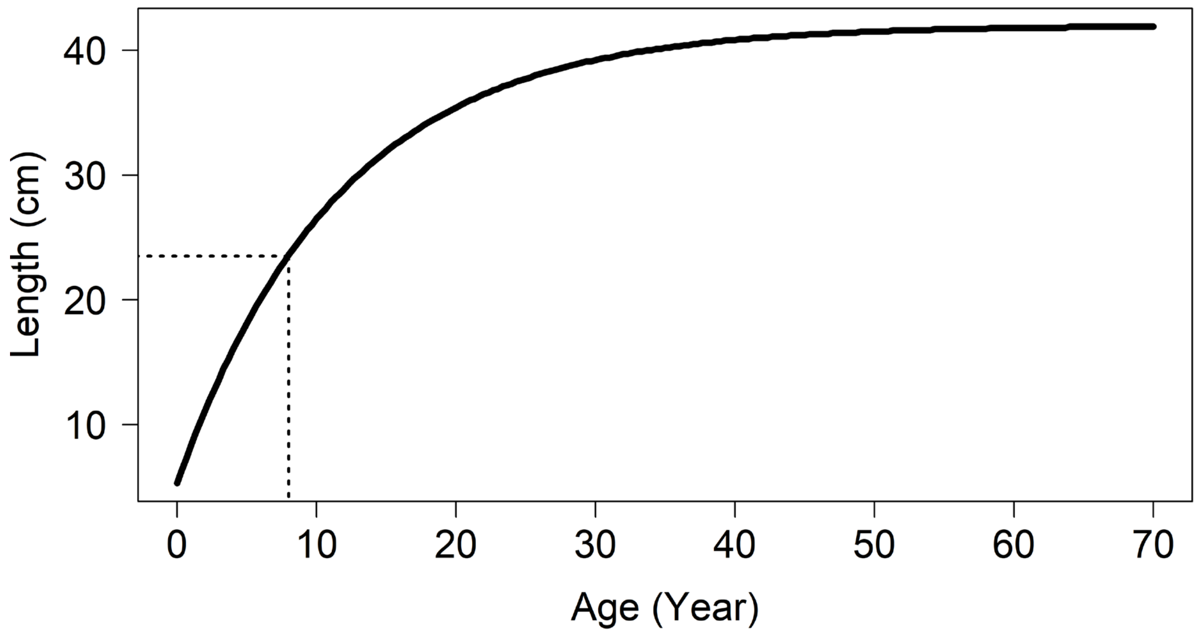


Figure 49. Von Bertalanffy growth curve for Redfish based on length at age trends for the 1980 cohort. The dotted lines indicate that a 8 years old individual should measure 23.5 cm (dotted line). The parameters for the curve are $L_{infinity}$ = 42 cm, k = 0.086, t_0 = -1.57.

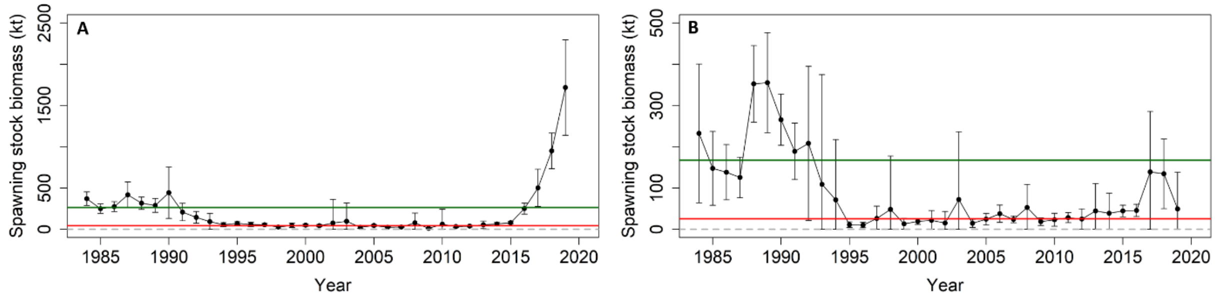


Figure 50. Spawning stock biomass (kilotonnes) in the nGSL DFO survey from 1984 to 2019 (black points with 95% confidence intervals), and the proposed Upper Stock Reference (green line) and Limit Reference Point (red line) for S. mentella (A) and S. fasciatus (B). The 0 y-axis value is indicated by a gray dashed line. Note the different scales on the y-axis.

Figure 51. Illustration of barotraumatic damages (stomach evaginated into mouth and eyes filled with gas) caused by the rapid ascent of Redfish from the bottom to water surface. This often leads to partial or complete regurgitation of stomach content.

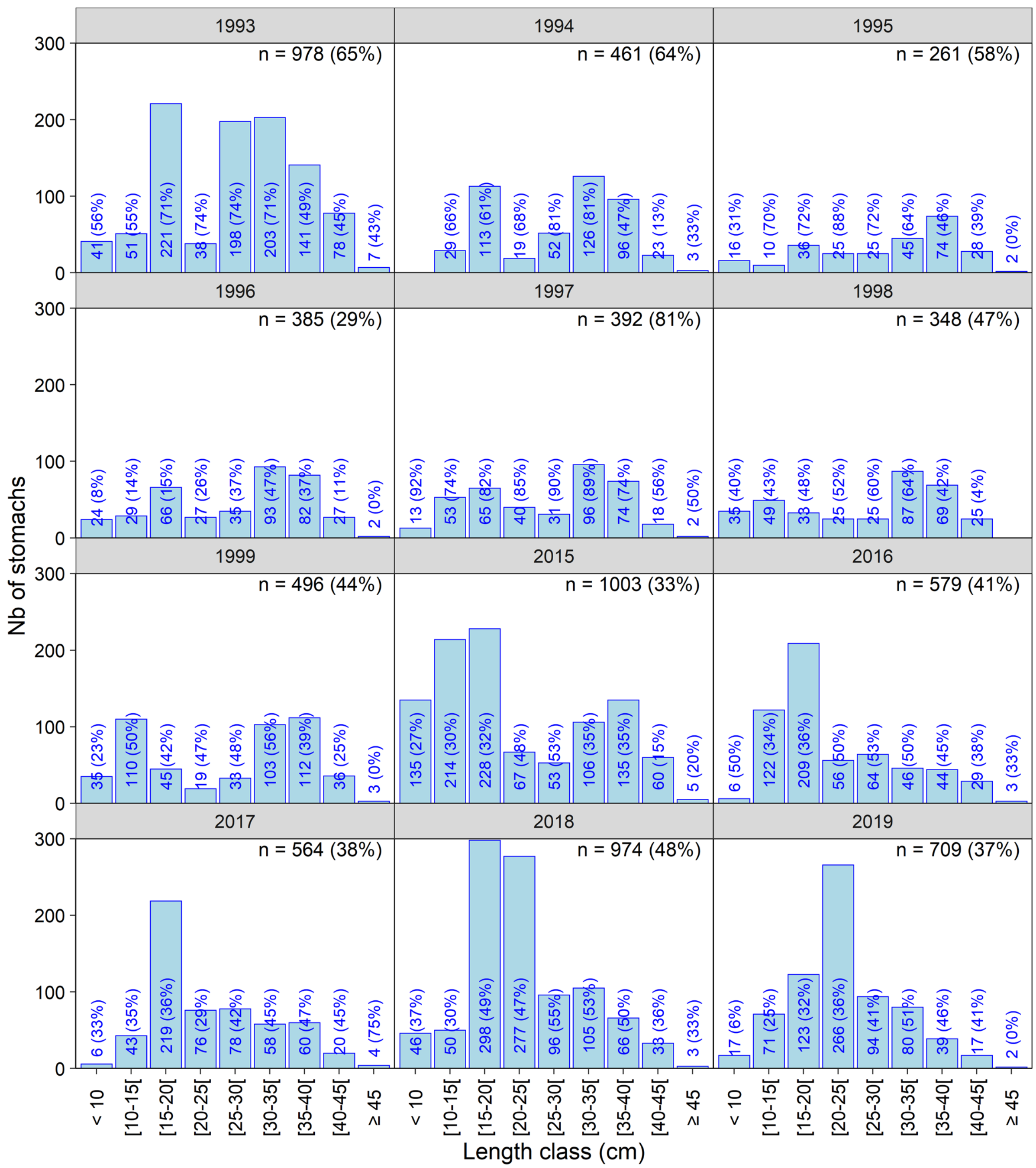


Figure 52. Number of Redfish stomachs, by year and length class. Values in parentheses are percentages of empty stomachs.

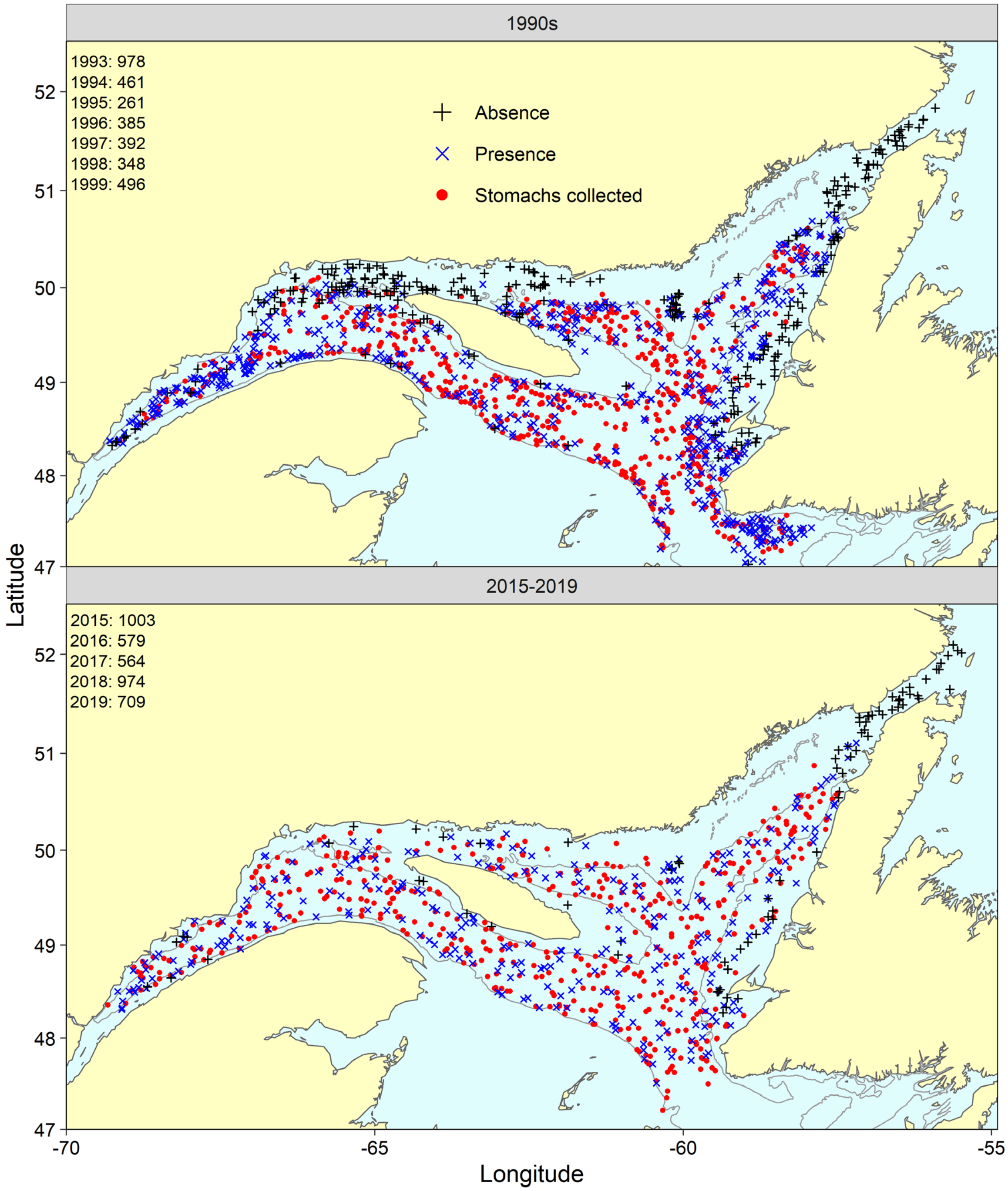


Figure 53. Origin of Redfish stomachs used in the analyses (in red), by sampling period. The black marks are set locations without Redfish in the capture. The blue marks are set locations with Redfish in the capture, but without any stomachs collected. Values in the upper left corner are the number of stomachs collected for each year.

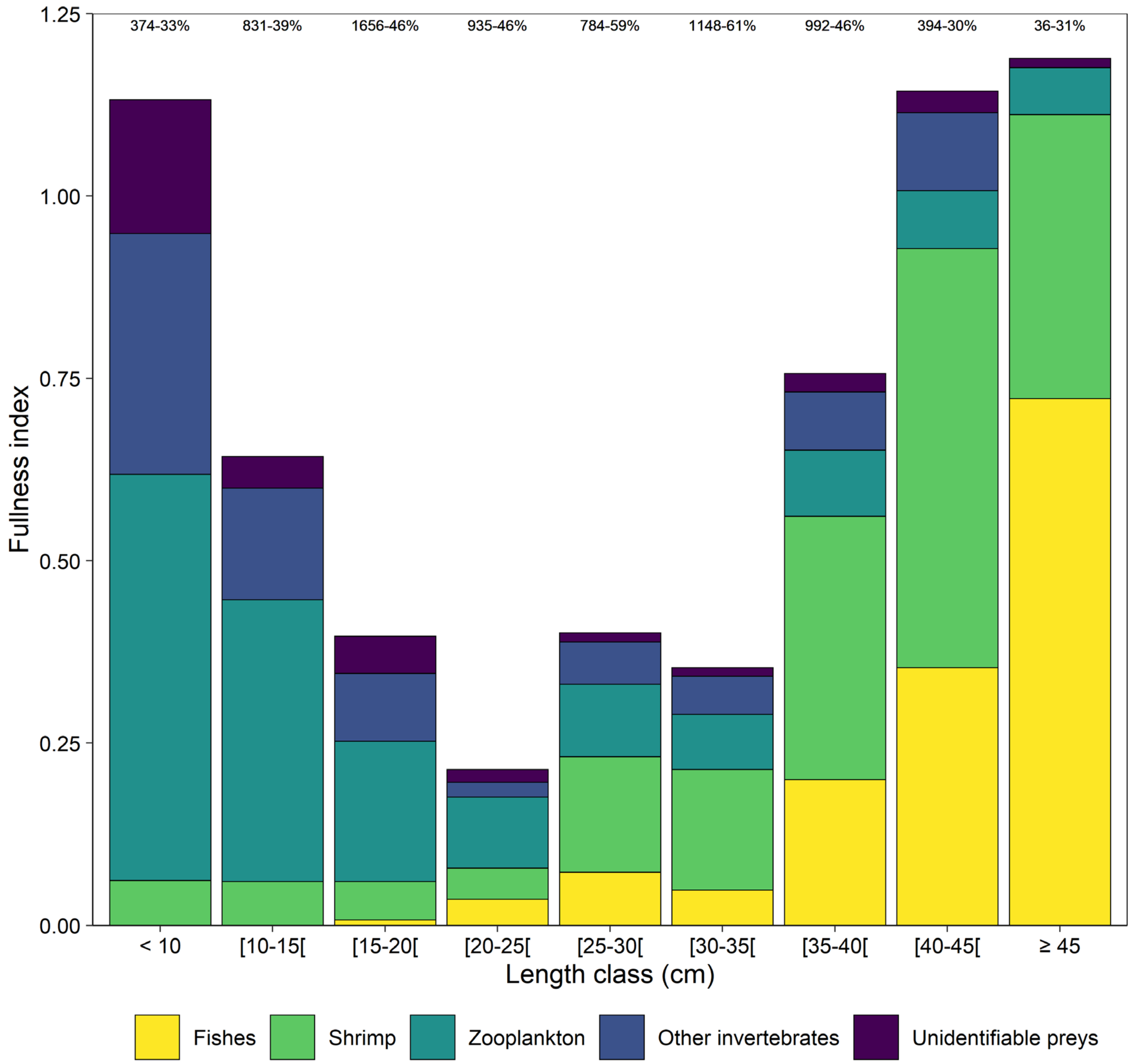


Figure 54. Redfish partial fullness index according to length class and type of prey, all years combined. The height of the columns corresponds to the total fullness index. The numbers above the columns correspond to the number of stomachs used for the analysis with the percentage of those being empty.

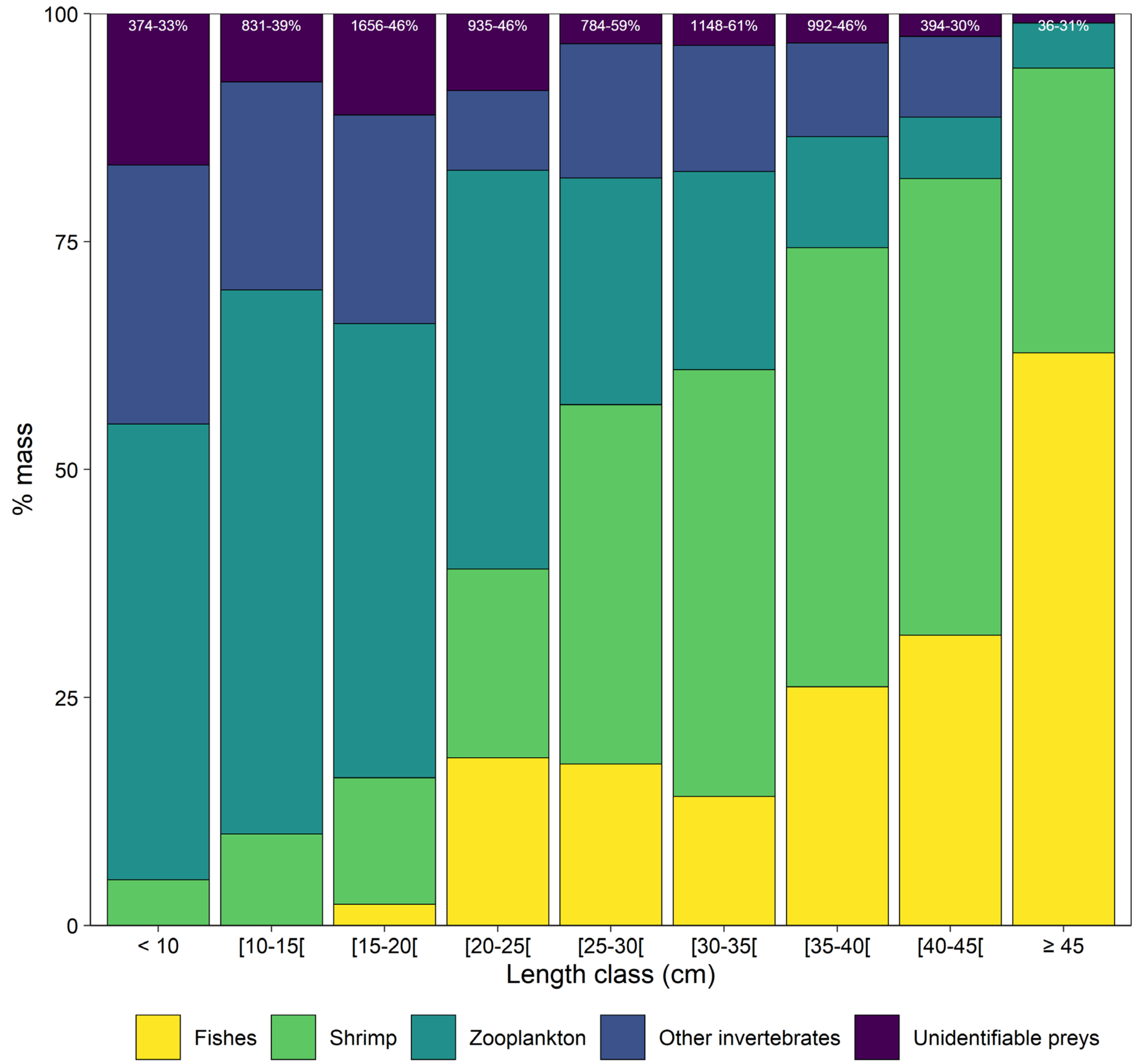


Figure 55. Redfish average mass contribution (MC, % mass) according to length class and type of prey, all years combined. The numbers above the columns correspond to the number of stomachs used for the analysis with the percentage of those being empty.

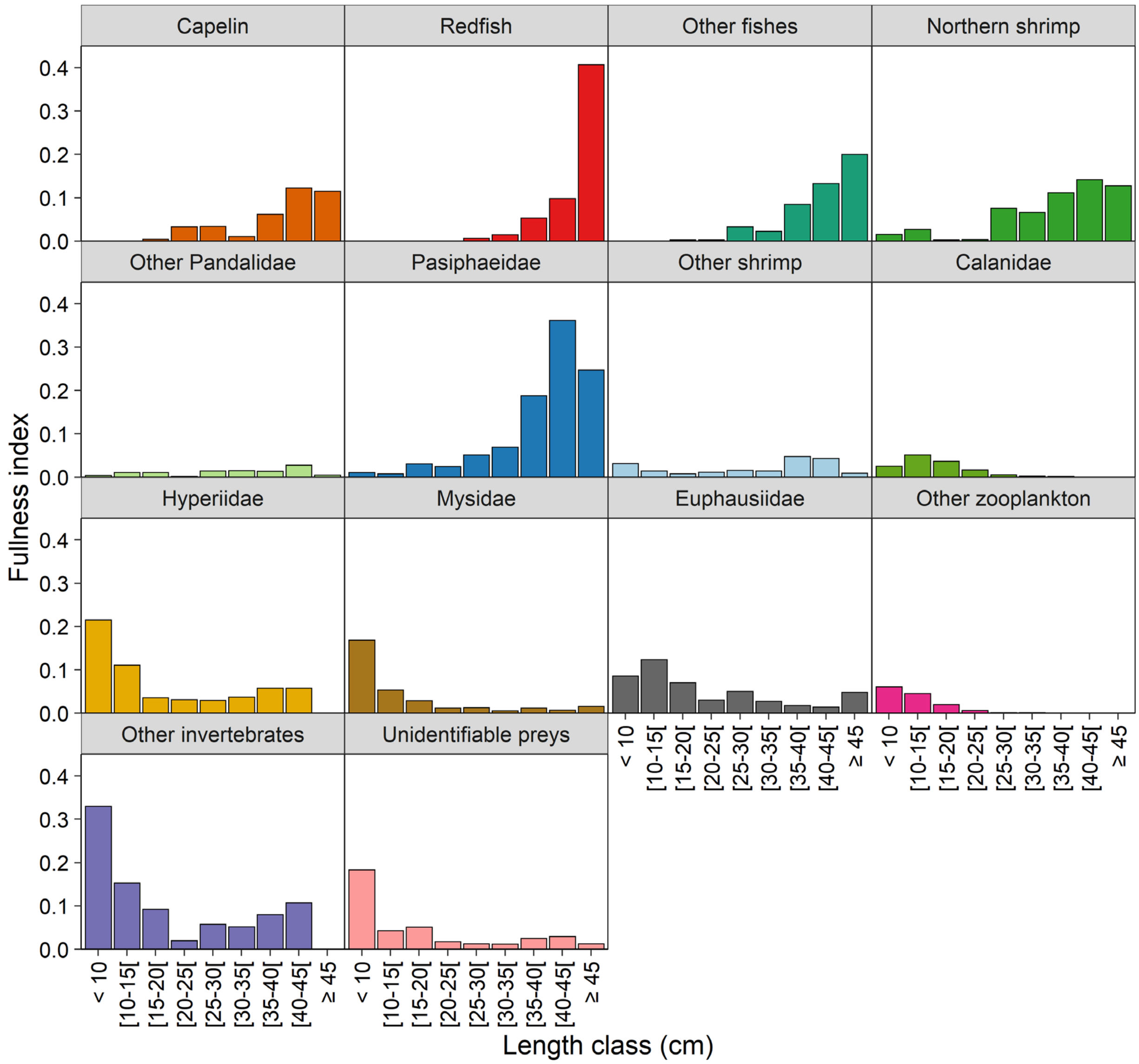


Figure 56. Redfish partial fullness index according to length class and taxonomic group, all years combined.

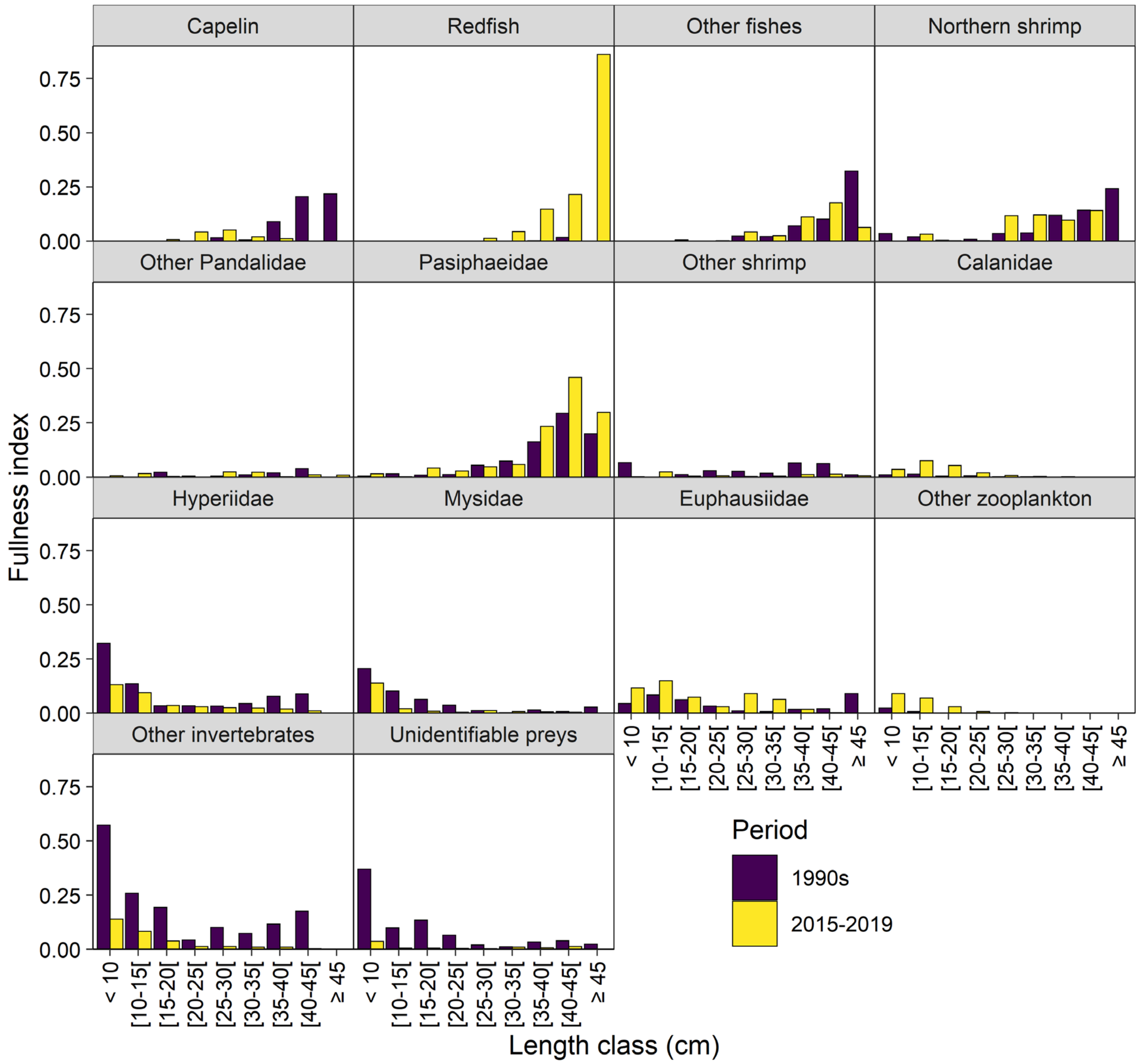


Figure 57. Redfish partial fullness index according to length class, period, and taxonomic group.

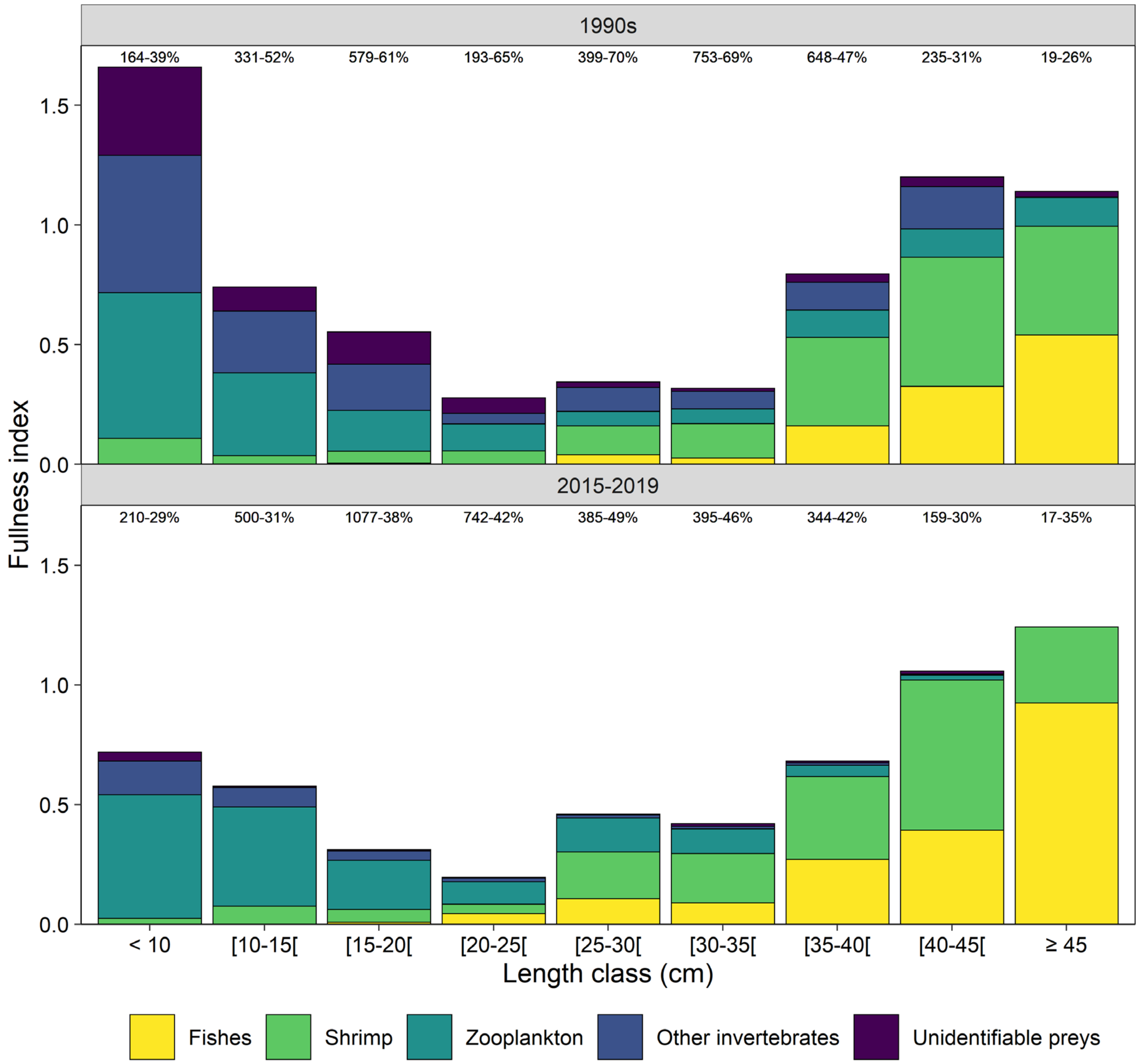


Figure 58. Redfish partial fullness index according to length class, period, and type of prey. The height of the columns corresponds to the total fullness index. The numbers above the columns correspond to the number of stomachs used for the analysis with the percentage of those being empty.

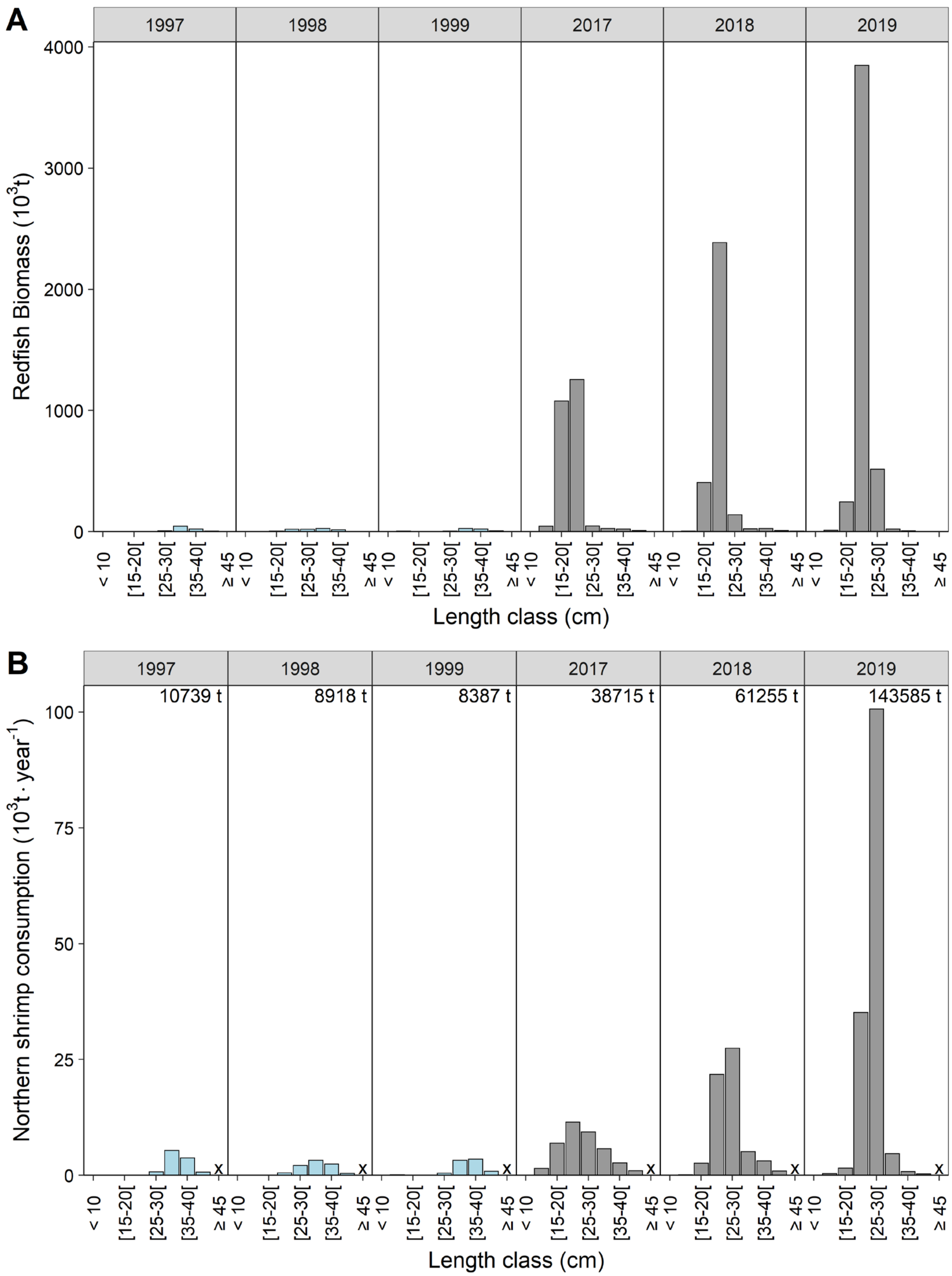


Figure 59. Estimated A) annual Redfish biomass and B) Northern Shrimp consumption by Redfish by length class for the last three years of the 1990s and the 2010s. The values provided in the upper part of the panels in B) are total estimated consumption for a given year. An "x" symbol denotes < 20 stomachs collected for a given length class. Estimating annual consumption for these length classes was identified as not representative due to small sample sizes.

APPENDIX

Appendix A : R code to estimate the proportion of *S. fasciatus* from a series of AFR count from catches in Units 1 or 2.

```
#Function to estimate species composition at the tow level
#Author : Adapted by Tom Bermingham from Hugo Bourdages
#arguments :

#afr     Vector of all the afr count to be evaluated for one tow. Possible value are integer ranging from 6 to 10
#unit    Use 1 to analyse afr from Unit 1, and 2 for Unit 2

sp_split <- function(afr, unit = 1){
if (unit != 1 & unit != 2) stop("Can only be used for catches of Units 1 or 2")
if (unit == 1) {
#expected frequency for both species in Unit 1
nbFasciatus<-function(x)   x*c(0.0078,0.6464,0.3349,0.0109,0.0000)
nbMentella<-function(x)   x*c(0.0010,0.1076,0.6870,0.2022,0.0022)
} else{
#...or Unit 2
nbFasciatus<-function(x)   x*c(0.0124,0.7592,0.216,0.0124,0.0000)
nbMentella<-function(x)   x*c(0.0016,0.0799,0.6166,0.2835,0.0184)
}
#remove NAs
afr <- afr[!is.na(afr)]
#create a vector of observed frequencies for 6,7,8,9, and 10 afr
Dat <- c(length(afr[which(afr==6)]), length(afr[which(afr==7)]), length(afr[which(afr==8)]), length(afr[which(afr==9)]), length(afr[which(afr==10)]))
#function to calculate de chi square value
Chi2<-function(prop,obs){
n<-sum(obs)
prop<-1/(1+exp(-prop))
est<-nbMentella(n*(1-prop))+nbFasciatus(n*prop)
sum((obs-est)^2/est)
}
#optimizing function to locate the minimum calculated by the chi square function and return proportion of S. fasciatus
```

```
Ajust<-function(vecteur){
res<-optimize(Chi2,c(-50,50),obs=vecteur)
prop<-1/(1+exp(-1*res$minimum))
}
#return rounded proportion of S. fasciatus in the catch
#proportion of S. mentella is 1 - proportion of S. fasciatus
PropFasc<- round(Ajust(Dat), digits = 4)
return(PropFasc)
}
```