Fisheries and Oceans Canada
Pêches et Océans Canada

Ecosystems and Oceans Science
Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2023/036

Quebec Region

Unit 1 Redfish (*Sebastes mentella* and *S. fasciatus*) stock status in 2021

Caroline Senay, Shani Rousseau, Caroline Brûlé, Caroline Chavarria, Laurie Isabel, Geneviève J. Parent, Denis Chabot and Daniel Duplisea

Fisheries and Oceans Canada
Maurice Lamontagne Institute
850, route de la Mer Mont-Joli
Québec, G5H 3Z4

June 2023

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.

Published by:

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

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

ISSN 1919-5044
ISBN 978-0-660-48889-9 Cat. No. Fs70-5/2023-036E-PDF

Correct citation for this publication:

Senay, C., Rousseau, S., Brûlé, C., Chavarria, C., Isabel, L., Parent, G.J., Chabot, D., and Duplisea, D. 2023. Unit 1 Redfish (*Sebastes mentella* and *S. fasciatus*) stock status in 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/036. xi + 125.

Aussi disponible en français :

*Senay, C., Rousseau, S., Brûlé, C., Chavarria, C., Isabel, L., Parent, G.J., Chabot, D., et Duplisea, D. 2023. État des stocks des sébastes (*Sebastes mentella *et* S. fasciatus*) de l'unité 1 en 2021. Secr. can. des avis sci. du MPO. Doc. de rech. 2023/036. xii + 130 p.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The Redfish fisheries in Unit 1 target two species, *Sebastes mentella* and *S. fasciatus*. Unit 1 includes Northwest Atlantic Fisheries Organization (NAFO) Divisions 4RST and from January to May Subdivisions 3Pn4Vn. Unit 2 includes Subdivisions 3Ps4V4Wfgj, and from June to December Subdivisions 3Pn4Vn. Although considered the same stocks as Unit 1, Unit 2 is not presented in this document.

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 in Unit 1. 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.

In 2018, an experimental fishery was established with an additional allocation of 2,500 t for 2018–2019, 3,950 t for 2019–2020, 3,681 t for 2020–2021, and 5,463 t for 2021–2022, which can be harvested all year. The objectives of the experimental fishery were to target *S. mentella,* which is more abundant than *S. fasciatus*, to investigate ways to limit bycatch and the harvesting of undersize Redfish, and to better understand the spatiotemporal distribution of Redfish and bycatch species.

According to surveys conducted in Unit 1, 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 northern Gulf of St. Lawrence (nGSL). The minimum trawlable biomass of both species combined is among the highest values of the time series and was estimated at 3.2 million t in 2021 with a modal size of 24 cm, slightly over the regulatory minimum size of 22 cm.

In support of the Redfish stock assessments (*S. mentella* and *S. fasciatus*) of Units 1 and 2 in 2022, this document describes the data and methods used to analyse the status of the stocks found in Unit 1.

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 they are rare in the region (Nozères et al. 2010) and are not being 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 GSL and neighbouring 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 and Laurentian channel was marked by three intense exploitation episodes (1954–1956, 1965–1976, and 1987–1992). The first total allowable catch (TAC) for Redfish, set according to the 1993 management plan, was 60,000 tonnes (t) in Unit 1. 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 index fishery TAC has been maintained at 2,000 t. Presently, Redfish conservation measures for the fishery in Unit 1 include implementation of a protocol for protecting small fish (<22 cm), 100% dockside monitoring of landings, mandatory hail reports upon departures and arrivals, imposition of a level of coverage (10–25%) by at-sea observers (ASO) 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) to avoid Greenland Halibut (*Reinhardtius hippoglossoides*) bycatch and an area has also been closed in NAFO Division 4T since August 2009 (Figure 2).

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 GSL 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. Following a Management Strategy Evaluation (DFO 2018, Licandeo et al. 2020, McAllister et al. 2021), the 2018 Stock Assessment, and the Advisory

Committee, an experimental fishery was established with an additional allocation of 2,500 t for 2018–2019, 3,950 t for 2019–2020, 3,681 t for 2020–2021, and 5,463 t for 2021–2022, which can be harvested year-round. The objectives of the experimental fishery are 1) to target *S. mentella*, more abundant than *S. fasciatus*; 2) to investigate ways to limit bycatch of other species and of undersized Redfish; 3) to better understand the spatiotemporal distribution of Redfish and bycatch species.

Based on the 2021 DFO survey in Unit 1, the minimum trawlable biomass of both species combined is among the highest values of the time series and was estimated at 3.2 million t with a modal size of 24 cm, slightly over the regulatory minimum size of 22 cm. This increase was mostly due to *S. mentella.* The stock assessment peer review meeting of Units 1 and 2 Redfish (*S. mentella* and *S. fasciatus*) took place in February 21–24nd and March 16th 2022. This research document supports the most recent Science advisory report for Unit 1 (DFO 2022), which falls under the responsibility of the Science Branch of DFO Quebec Region. The previous research document on this topic was published in 2021 (Senay et al. 2021).

BACKGROUND

STOCK DEFINITION AND SPECIES IDENTIFICATION USING GENETICS AND GENOMICS

In the last two decades, analyses of population genetics highlighted reproductively isolated entities in Redfish. Genetic or genomic markers allowed for species identification at the individual level using either microsatellites or single-nucleotide polymorphisms (SNPs). A subset of 13 microsatellite markers suggested seven to eight different genetic groups or biological units along the Canadian coast, four of these located 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. A first group was detected in Units 1 and 2, and was characterized by introgression from *S. mentella*. A second genetic group was identified in Units 1 and 2 and in the Scotian shelf. A third genetic group was identified in the eastern inlet of the Bonne Bay fjord, on the west coast of Newfoundland.

Recently, the use of thousands of genomic markers confirmed some genetic groups identified with microsatellites and described new ones (Benestan et al. 2021). 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 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 SNPs markers confirmed the pronounced genetic distinction between *S. mentella* and *S. fasciatus*, which is typical of interspecific differentiation. This new method also identified high genetic differentiation between three genetic groups of *S. mentella*. The term “ecotype” was used to describe these genetically well-differentiated groups due to their habitat specificity, as opposed to populations that are less differentiated. 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 m and 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 the only one 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* were also 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 widespread population (red), and the Bonne Bay population (green).

Population genomics results also showed that Unit 1 was not isolated demographically from 2G3K 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. Sample sizes in the Laurentian Fan were not sufficient to confirm or refute previous conclusions about a distinct population of *S. fasciatus* in that area. In conclusion, locations of specific ecotypes and populations do not always correspond to fishery management units.

SPECIES IDENTIFICATION IN RESEARCH SURVEYS AND IN THE FISHERY

Redfish species are morphologically very similar and often not distinguished in both scientific surveys and fisheries, thus quotas are not species-specific even if conservation objectives are. Many studies have focused on finding morphological and genetic features to allow species identification (Gascon 2003). Three different methods were traditionally used to distinguish the two species in the Northwest Atlantic: the genotype at the malate dehydrogenase locus (*MDH-A**), the extrinsic gas bladder muscle passage pattern (EGM), and the number of soft rays on the anal fin (AFR). 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 (Gascon 2003). 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).

Starting in 2010, AFR count has been used in the Redfish stock assessment in Units 1 and 2 to describe trends for each species separately (DFO 2010). Since 2018, AFR has also been collected in the fishery to determine catch species composition (Senay et al. 2022). The distribution of AFR numbers is species-specific, but there is an overlap for *S. mentella* and *S. fasciatus.*

The proportion of every number of AFR 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 (Table 1), 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 (Senay et al. 2022).

The AFR count method is practical and useful, but not without error or potential bias. Simulations revealed a likely bias in estimates of species composition in catch samples dominated by one species (Senay et al. 2022). The available evidence suggests a dominance of *S. mentella* in survey samples from both Units since 2016, which results in the potential for overestimating the biomass of *S. fasciatus* in the surveys and in the fishery catches. Quantifying and propagating uncertainty in species identification and determining how it can affect the perception of stock status for *S. mentella* and *S. fasciatus* in Units 1 and 2 remain a research priority.

DISTRIBUTION AND HABITAT

In the northwest Atlantic, Redfish inhabit cold waters along the slopes of banks and deep channels at depths ranging from 100 m 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 m 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 conduct diel vertical migrations, leaving the sea floor at night to follow their prey migrating in the upper layers of the water column. 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.

RECRUITMENT

Redfish are characterized by significant variability in recruitment, especially for *S. mentella*. The main abundant cohorts in Unit 1 were born in 1946, 1956–1958, 1970, 1980, 1985, 1988, 2003, and 2011–2013. Other cohorts, the 1985, 1988, and 2003 year classes, were very abundant at ages 2 to 4 in research survey data, but were not subsequently detected and never considerably contributed to the fishery (Licandeo et al. 2020). 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 suggest that *S. fasciatus* may use the GSL as a nursery. This should not be the case for the 2011–2013 cohorts given that genetic analyses indicated that 91% of sampled Redfish were *S. mentella* with the GSL signature, suggesting that these Redfish will remain in the area and should promote the recovery of *S. mentella* in Unit 1.

Different factors may be linked to successful recruitment events, one of them being the timing of larvae extrusion and the bloom of their prey. Redfish larvae feed mainly on immature copepod, *Calanus finmarchicus* (Runge and de Lafontaine 1996, Burns et al. 2020). Larvae growth was faster, and metamorphosis occurred earlier in 1980, when there was a close match between Redfish larval extrusion and *C. finmarchicus* reproduction, compared to 1981 when *C. finmarchicus* reproduction occurred seven weeks earlier (Anderson 1994). More recently, it has been suggested that Redfish larvae that fed on a diet comprised of *C. finmarchicus* nauplii were in better condition and grew faster than those that fed on other prey items (e.g., *C. finmarchicus* eggs). Warming GSL waters have shifted the phenology of commonly consumed prey taxa earlier in the season, which may increase the overlap between Redfish and nauplii prey that drives fast growth, survival, and potentially recruitment success (Burns et al. 2021). Hence, the production of an abundant year class may depend on a close co-occurrence between the predator and its prey.

ECOSYSTEM

DFO annually assesses the physical oceanographic conditions prevailing in the GSL with the Atlantic Zone Monitoring Program (AZMP). Conditions encountered in the northern Gulf of St. Lawrence (nGSL) in recent years were generally warmer than historical averages. Deep-water temperatures have been increasing overall in the Gulf since 2009, with inward advection from Cabot Strait. Gulf-wide average temperature at 150 m was lower than the 2015 record highs but above normal at 3.7 °C (±1.6 standard deviation [SD]). New series record highs (since 1915) were set at 200, 250 and 300 m, at 5.7 °C (+1.2 °C, ± 1.9 SD), 6.6 °C (+1.1 °C, ±2.5 SD) and 6.8 °C (+1.1 °C, ±2.7 SD), respectively. Bottom area covered by waters warmer than 6 °C was at a record high in the Northwest Gulf, the Northeast Gulf, and in Centre Gulf and Cabot Strait, and some 7–8 °C habitat appeared for the first time in the Northeast Gulf (Galbraith et al. 2021).

The GSL ecosystem is composed of a diverse fish community whose components abundances vary over time and space. Many species can interact with Redfish as prey (e.g., Northern Shrimp, *Pandalus borealis*), competitors (e.g., Greenland Halibut), predators (e.g., Atlantic Halibut, *Hippoglossus hippoglossus*) or by being caught as bycatch (e.g., Atlantic Cod). A brief description of these stocks are presented. The Northern Shrimp stocks in the Estuary and GSL have been in the healthy zone for several years, but are declining since 2010 (DFO 2020). The indicators for the Greenland Halibut stock in 4RST generally showed a downward trajectory from the end of the 2000s to 2019. These indices increased slightly between 2019 and 2020 to levels well below the peaks of the 2000s (DFO 2021a). There are moderate evidence and high consistency that the Atlantic Halibut status of the stock in 4RST was at a historically high level in 2020 (DFO 2021b). The Atlantic Cod stock in the Southern GSL (4T) is at very low abundance and under moratorium since 2009 (DFO 2019), whereas the nGSL (3Pn, 4RS) Atlantic Cod stock is also low and has been declining (Brassard et al. 2020, DFO 2021c).

COMMERCIAL FISHERY

LANDINGS DESCRIPTION

Landings are 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 a 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 GSL 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. From 1953 to 1990 (prior to the 1995 moratorium), landings originated mainly from NAFO Divisions 4RS.

Between 1999 and 2005, most of the fishing effort was located in Divisions 4RT, along the slopes of the Laurentian Channel and north of the Cabot Strait. In addition to these fishing sites, effort was also directed in Division 4S of the Laurentian Channel. Since 2006, the majority of the fishery effort was concentrated in Division 4T, except for 2019 and 2020 when landings in Division 4R were the highest (Figure 4 and Table 2). TACs in Unit 1 are not fully harvested. On average from 2010 to 2017, 470 t of Redfish were caught annually. Subsequently, landings increased to an average of 1,090 t since 2018.

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 was caught in June and July during the index fishery. Since the experimental fishery is allowed all year round, a greater proportion of the fishery happens from October to December.

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. In average, since 2018, 5% of landings were attributed to midwater trawls. The miscellaneous category mainly corresponded to unspecified dredge in 2021.

From 1985 to 1994, approximately 80% of the catches were made using large vessels over 100 feet in length (Figure 7). After the moratorium and the beginning of the index fishery, vessels between 65 feet to 100 feet have generated most of the landings. During this period, vessels less than 65 feet appeared in Unit 1.

LENGTH FREQUENCY IN UNIT 1

Fisheries catch length frequencies were quantified by combining data from ASO and port sampling (Figure 8). From 2010 to 2021, 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). Since 1999, 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. From 1999 to 2016, most Redfish caught were larger than 30 cm. Redfish larger than 30 cm were less frequent from 2017 to 2021. However, length frequencies are indicating that Redfish from the 2011–2013 cohorts are slowly growing (Figures 8 and 9).

CATCH PER UNIT EFFORT (CPUE) IN UNIT 1

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 activities 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, Quebec, Maritimes, and Newfoundland), and vessel 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 (1981–2021). Standardized CPUEs started increasing in 2018 reaching the highest value of the time series in 2021 (Figure 10). Generally, since 2016 the effort is decreasing, while catches are increasing since 2017, except in 2021 (Figure 11).

Since the experimental fishery, which started during the 2018 fishing season, there is a great variability in terms of seasons and gears being explored, some of them not being recorded in (e.g., escapement grids, T90 mesh, French rigging) limiting data that can be included for standardization. Thus, in 2020 and 2021, a small number of activities could be comparable to the index fishery, 41 and 19 respectively. For comparison, in average 120 activities were used from 2010 to 2019. Therefore, the interpretation of the standardized CPUE index in recent years is limited and should be done with caution.

BYCATCH IN UNIT 1

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 94% of the reported Redfish catches from 2010 to 2021 came from the directed Redfish fisheries conducted in Unit 1 (index and experimental fishery combined). Fisheries targeting Greenland Halibut and Atlantic Cod were responsible for 4% and 1% 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 2010 (Figure 13). The most common bycatch were Greenland Halibut, White Hake (*Urophycis tenuis*, designed as endangered in 4T), Atlantic Halibut, and Atlantic Cod (3Pn4RS and 4T stocks are both in the Critical zone, Figure 14). In recent years, catches of Greenland Halibut decreased while catches of Atlantic Halibut increased.

Juvenile Redfish are often caught as bycatch and discarded in the Northern Shrimp fishery, a commercially important resource, 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 2021 (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 is used to estimate exploitation rates on fish of those lengths (see section 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 2020 and 2021, 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 m to 20 cm (Figure 17). Starting in 2013, juveniles from the 2011–2013 cohorts started to be captured in the fishery and the survey. 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, has been below the average from 2015 to 2019, and was over the average in 2020 and 2021. This increase was mostly caused by the decrease in Redfish biomass less than 20 cm.

From 1999 to 2021, 2,057 sampled tows by the ASO program were retained based on the index fishery from 1999 to 2017, and both the index and experimental fisheries from 2018 to 2021

(Figure 19). The most frequent bycatch species were White Hake (caught in 60% of fishing activities directed to Redfish), Greenland Halibut (54%), Witch Flounder (*Glyptocephalus cynoglossus*, 46%), Atlantic Cod (43%) and Atlantic Halibut (37%, Table 3). Between 72 and 99% of those species catches were landed. For each bycatch species, catches represented less than 2% of Redfish catches (Table 3). Some variations were observed both temporally across time periods and spatially across NAFO Divisions.

The spatial distribution of Redfish catch and other species bycatch rates in the Redfish directed fishery for different time periods from 1999 to 2021 was mapped to identify locations to minimize bycatch in the Redfish directed fishery (Figure 20). Unfortunately, in the most recent time period, no specific location seemed to provide high Redfish catches while minimizing all other species. For instance, high Redfish catches were observed in 3Pn4Vn, while they were low for Atlantic Cod and high for White Hake.

Specific depths may also be prescribed to target and avoid certain species in summer. For instance, White Hake and Atlantic Cod are caught at a shallower depth than Redfish (Figure 21 and Table 4). ASO also measured fish length in the Redfish directed fishery. From 1999 to 2021, Redfish measured from 15 cm to 50 cm, and two modes were observed, one around 22 cm and a second around 33 cm. Greenland Halibut ranged from 25 cm to 65 cm (mode = 40 cm), White Hake from 25 cm to 75 cm, Atlantic Cod from 25 cm to 80 cm (mode = 46 cm), and Atlantic Halibut from 15 cm to 165 cm (Figure 22).

In 2021, the impact of an expending Redfish fishery on the southern Gulf of St. Lawrence (sGSL) White Hake Designable Unit (DU) designed as *endangered* by the COSEWIC has been assessed. The sGSL White Hake population was projected forward 25 years assuming that productivity would remain at recent levels. Spawning stock biomass (SSB) was estimated to decline by 38.7% with no catch and by 39.3% with annual bycatch of 20 t, the recent level. With annual bycatch of 150 t to 350 t, SSB was estimated to decline by 43% to 48%. With bycatch of 500 t to 1,500 t, SSB declined by 53% to 70%, respectively (DFO 2021d, Rolland et al. 2022).

RESEARCH SURVEYS

DFO RESEARCH SURVEYS IN UNIT 1

Since 1984, DFO has conducted an annual 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. 2022, Figure 23). 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 2021. This nGSL DFO survey uses a stratified random sampling design. Since 2008, the study area is divided into 56 strata (Figure 23) of which 52 have typically been sampled every year. Strata were defined based on depth, NAFO Divisions, and substrate type. For this survey, an initial annual allocation of 200 trawling stations is allocated proportionately to strata surface area, with a minimum of two stations per stratum. The positions of the stations are 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 weight 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. (2022).

In 2020, due to the context of the COVID -19 pandemic, the number of days at sea and the number of scientists on board the ship had to be reduced. The survey successfully carried out 147 trawl stations (52 in 4R, 62 in 4S and 33 in 4T, Bourdages et al. 2021). Eleven strata were not sampled with a minimum of two stations. These partially or uncovered strata were distributed throughout the study area and not located in a particular sector (Figure 24).

In 2021, 149 fishing stations were successfully completed (41 in 4R, 69 in 4S and 39 in 4T, Bourdages et al. 2022). The limited number of stations completed was due to the fact that the ship had to go to the wharf three times for medical or mechanical reasons. A lot of effort was made to cover the entire study area. Six strata were not sampled with a minimum of two stations, two of which were not visited. These partially or uncovered strata were distributed throughout the study area and were not located in a particular sector (Figure 24).

In such cases, a multiplicative model of the form:

$$\log(\text{catch rate} + 0.01) \sim \text{stratum} + \text{year}$$

was used to estimate their catch rate indices. This model provided a predicted value for strata with fewer than two tows based on the data of the current year and the previous three years, or from the current year and the three adjacent years for missing strata in the first three years of the series.

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

REPRODUCTION AND MATURITY DETERMINATION IN UNITS 1 AND 2

Redfish are ovoviviparous, meaning they fertilize internally, resulting in lecithotrophic larvae feeding exclusively on the yolk of the egg. Copulation would take place in fall, probably between September and December. Spermatozoa would be maintained in a state of physiological dormancy inside females until their ovaries mature in February to March (Hamon 1972). Larval extrusion would occur from April to July, depending on the area and species (Ni and Templeman 1985). Absolute fecundity would range from 3,330 to 107,000 larvae per female, increasing with female length (Gascon 2003). Mating and larval extrusion would not necessarily occur in the same locations and time for both species. In the GSL, *S. mentella* would release its larvae approximately three to four weeks earlier than *S. fasciatus*. Larvae would develop in surface waters and juveniles would gradually migrate deeper as they grow. Larvae would generally be found in the water surface layers and their growth would be optimal at temperatures between 4 °C and 11 °C. Redfish would be located in the Cabot Strait area in winter and return to the GSL in spring. This migration out of the GSL could start as early as November (Atkinson and Power 1991, Morin et al. 1994, Power 2003).

At each station during DFO surveys, a sample of Redfish is measured, sexed, and species identification is based on the number of soft AFR. The proportion of mature individuals, representing SSB by species and sex, is then determined from the sample and extrapolated to the entire catch.

In earlier years, the length at maturity relationships presented in Gascon (2003) were used 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 passage pattern. Maturity stage was determined using macroscopic appearance. The proportion mature as a function of length was modelled using a logistic curve. For mature females of both species, the shortest length at maturity was around 23–24 cm. In general, males reached sexual maturity one to two years before females. Ages (A_{50}) and lengths (L_{50}) at 50% maturity occurred at nine years and 22.8 cm for males, ten years and 25.4 cm for females *S. mentella*, and at seven years and 19.6 cm for males, and nine years and 24.1 cm for females *S. fasciatus* (Figure 25).

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

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

The constants are from 1984 to 2010:

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

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

In 2018 and 2019, 757 specimens of Redfish were collected in Units 1 and 2. Each was measured, genetically identified to species, and classified as immature or mature using gonad histology and macroscopic appearance. The revised species and sex-specific maturity ogives based on histological information are shown in Figure 26. These suggested a reduction in L_{50} values relative to maturity ogives based on earlier data from the 1990s (Gascon 2003). To ensure that this apparent reduction in size at maturity was not caused by methodological differences, the reduction in L_{50} values was further investigated based on data from macroscopic gonad examination available by sex for the two species combined for both the earlier (1996–1998) and current (2018–2019) periods. To do so, 2,583 immature and 6,868 mature females, as well as 2,312 immature and 6,039 mature males were included for the 1996–1998 period, while 98 immature and 251 mature females, as well as 79 immature and 278 mature males were included for the 2018–2019 period. This confirmed a reduction in L_{50} for male Redfish (from 21.7 cm to 18.1 cm) and female Redfish (from 23.6 cm to 19.2 cm) in the GSL between 1996–1998 and 2018–2019 (Figure 27). Note that the revised maturity ogives based on histological information are considered the best available science and most appropriate to inform stock status evaluation, as opposed to the ones based on macroscopic appearance, and were applied starting in 2011 to estimate SSB.

Based on these new ogives, the constants are from 2011 to present:

S. fasciatus	female	a = -12.200	b = 0.750	L_{50} = 16.3 cm
S. fasciatus	male	a = -15.445	b = 0.971	L_{50} = 16.0 cm
S. mentella	female	a = -18.374	b = 1.070	L_{50} = 17.2 cm
S. mentella	male	a = -18.701	b = 1.042	L_{50} = 18.0 cm

SURVEY INDICES AND LENGTH FREQUENCIES IN UNIT 1

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 until the 2010s (Figure 29 and Table 5). 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. The biomass of small individuals increased as they were growing, until 2018 when it started decreasing as they reached the size of 22 cm (Figure 29 A and B).

In 2021, the biomass of both Redfish species combined decreased by 27% over the 2019 estimate, but was still among the highest values of the time series that started in 1984 evaluated at 3,225,000 t at this time (Table 5). The biomass of the two species combined accounted for 82% of the biomass of all captured organisms in the survey (e.g., invertebrates, pelagic fish, demersal fish and groundfish), while it averaged 15% between 1995 and 2012 (Figure 30). *S. mentella* constituted alone 70% of the catches made during the survey, indicating that they actually dominate the ecosystem of the bottom of the GSL.

Total minimum trawlable biomass was estimated to be 2,805,000 t for *S. mentella*, one of the highest values ever observed, even if a decrease of 35% was observed between 2019 and 2021. Total minimum trawlable biomass of *S. fasciatus* was estimated to be 420,000 t, suggesting an important increase from 2019 to 2021 to values comparable to the highest one of the series (Figure 28).

Minimum trawlable biomass of Redfish greater than 22 cm in length began to increase in 2017. In 2021, it was estimated to be 2,622,000 t for *S. mentella*, which is among the highest of the series (Figure 29 C). Minimum trawlable biomass was estimated to be 359,000 t for *S. fasciatus*, indicating an increase to a value comparable to the highest one of the series (Figure 29 D).

Biomass of *S. mentella* greater than 25 cm in length increased from 497,000 t in 2019 to a record high of 790,000 t in 2021, whereas biomass of *S. fasciatus* increased from 18,000 t in 2019 to 155,000 t in 2021 (Figure 29 E and F, and Table 5).

Overall, 7% of *S. mentella* biomass was under 22 cm, 65% between 22 cm and 25 cm, and 28% over 25 cm. For *S. fasciatus*, 15% of the biomass was under 22 cm, 48% between 22 cm and 25 cm, and 37% over 25 cm (Figure 31). In the summer 2021, Redfish modal length was 24 cm for both species (Figure 32).

In 2010, the COSEWIC designated the GSL and Laurentian Channel 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 2021 was several folds higher than those levels (Figure 33 A). 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, before an increase in 2020 and 2021 suggest that it would be premature for COSEWIC to revisit the status of the DU until the trend stabilizes (Figure 33 B) and that uncertainties in species identification are better accounted for.

NEW COHORT SPECIES COMPOSITION AND MAGNITUDE IN UNIT 1

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 age 1+ and 2+.

A qPCR assay to discriminate *S. mentella* and *S. fasciatus* using the second intron of the nuclear S7 ribosomal gene was designed. DNA was extracted using QuickExtract™ DNA Extraction Solution (Lucigen). A specific region of 58–67 nucleotides in the targeted gene was then amplified using an AriaMx Real-Time PCR System (Agilent technologies™, G8830A). qPCR products were Sanger sequenced to confirm species identification. We then genotyped with the qPCR assay 247 reference fish sampled across the Northwestern Atlantic. DNA extract from tissues of all 247 fish were previously genotyped using 24,603 SNPs and classified as *S. mentella* or *S. fasciatus* using Admixture as described in Benestan et al. (2021). We estimated accurate identification with the qPCR assay based on SNPs species identification. Species identification using the qPCR assay was accurate for 96% of the 247 specimens tested. DNA extraction and qPCR based species identification for all the juveniles for 2019–2021 were processed as indicated in this section.

During the 2019–2021 surveys, 2,086 individuals from the 2017–2020 cohorts, ranging in length from 73 mm to 116 mm were collected (Table 6). The number of locations with juvenile samples varied between 21, 23 and 18 for 2019, 2020 and 2021 respectively, for a total of 62 locations (individual tow). Following genetic analyses, 364 individuals were identified as *S. mentella* and 161 individuals as *S. fasciatus* for 2019. For 2020, 532 individuals were identified as *S. mentella* and 134 as *S. fasciatus*. As for 2021, 729 individuals were identified as *S. mentella* and 166 as *S. fasciatus*. In 2019, sample size for each of the 21 locations were 25 individuals, and depth ranged from 125 m to 354 m, with a mean of 219 m. In 2020, sample size for the 23 locations ranged from 25 to 55 individuals with a mean of 29, while depth ranged from 146 m to 342 m with a mean of 248 m. Finally, in 2021, sample size for the 18 locations ranged from 24 to 100, with a mean of 50, while depth ranged from 104 m to 426 m with a mean of 245 m. Respectively for 2019, 2020 and 2021, Redfish fork lengths ranged from 73 mm to 116 mm, with a mean of 92 mm, 87 mm to 106 mm with a mean of 93 mm, and 78 mm to 91 mm with a mean of 84 mm. Most locations were largely dominated by one species. Figure 34 shows the geographical position of all 62 locations in the GSL overlaid with the species composition in a pie chart, where depth is indicated. The relationship between species composition and depth was also illustrated in Figure 35. Both a spatial gradient (Figure 34) and a depth gradient (Figure 35) were apparent, where *S. mentella* was mainly observed west from 60° W and at greater depth than *S. fasciatus,* which was mostly collected on the west coast of Newfoundland at depth lower than 175 m. In 2019, *S. fasciatus* was also present northwest from Anticosti. Based on the nGSL DFO survey, the 2019, 2020, and 2021 biomass of Redfish less than 11 cm was respectively 1.3%, 4.4%, and 3.8% of the maximum value observed in 2013, when the 2011–2013 cohort started to be captured in the survey (Figure 36).

SPATIAL DISTRIBUTION IN UNIT 1

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 37 to 40). 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 38 and 40). Starting in 2013, density of immature *S. mentella* has increased in the Esquiman, Anticosti, and Laurentian Channels, and the southwestern edge of Cabot Strait (Figures 38 and 39). In the 2018–2021 period, the density of immatures decreased, while density of matures *S. mentella* increased to unprecedented levels. Immatures *S. fasciatus* have also shown an increase in density albeit less so than in *S. mentella* (Figures 39 and 40).

The biomass and median length of Redfish catches (both species combined) from 2017 to 2021 are shown in Figure 41. The largest catches in biomass were obtained in deep channels south of Anticosti and in Esquiman Channel. In 2017, 92% of catch median lengths were below 22 cm. In 2021, it was reduced to 37% and these catches corresponded to small values of biomass. In addition, 58% of catch median lengths were between 22 cm and 25 cm and corresponded to large values of biomass.

Stratified cumulative frequency distributions of catches (Perry and Smith 1994) indicated that between 2017 and 2021, *S. mentella* were preferentially located at depths greater than 200 m, at temperatures between 5 °C and 7 °C, and at levels of dissolved oxygen between 50 µmol/kg to 150°µmol/kg (Figure 42). On the other hand, most *S. fasciatus* were caught preferentially at shallower depths between 100 m and 300 m, at temperature between 2°C and 7 °C, and at levels of dissolved oxygen between 75 µmol/kg and 200 µmol/kg (Figure 43). When considering size classes, *S. mentella* larger than 25 cm were found deeper than smaller individuals, whereas this difference of distribution is not observed for *S. fasciatus,* where the curve for 0 cm to 22 cm fish is close to the one of 22–25 cm and larger than 25 cm in shallower and deeper habitats, respectively (Figure 44).

SGSL AND SENTINEL SURVEYS IN UNIT 1

The sGSL survey consists of a stratified random groundfish bottom trawl survey conducted annually in September since 1971 in Division 4T (Figure 45). 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, vessels, and 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 biomass 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, which was followed by a rapid increase in biomass (Figure 46). All three indices have decreased in 2019–2020, before increasing again in 2021 to values among the highest of the time series.

GROWTH PROJECTION BASED ON NGSL SURVEY IN UNIT 1

Redfish are known to be slow-growing and long-lived species. Redfish could easily reach 40 years and could exceed 75 years of age, at which point they could measure about 42 cm. Previously, it has been shown that, on average, Redfish would take seven to eight years to reach minimum regulatory size (22 cm). Growth of *S. mentella* would be faster than *S. fasciatus*, although this difference in growth rates would only become evident after the age of ten. In both species, females would grow faster than males after their first ten years of life (Gascon 2003).

The current assessment is not based on a population model, which makes projection of year class strength into the future difficult. Nevertheless, projections of abundance and biomass of different size classes in different years were provided in previous stocks assessments (Brassard et al. 2017, Senay et al. 2019, Senay et al. 2021). These projections were based on a von Bertalanffy growth curve that was developed for *S. mentella*. 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, $L_{infinity}$ (L_{inf}), between 42 cm and 50 cm. 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. In the past few years, estimated modal size for recent cohorts have deviated from this growth curve and are below the length predicted by it. Other curves were explored by using the same approach but different data and constraints (Figure 47 and Table 7).

When using 1980 and/or 2011 cohorts modes with a L_{inf} constraint of 42–50 cm, similar curves were obtained, all being above the recent observed modes. When no L_{inf} constraint was used, the curves developed with the 1980, as well as the 1980 and 2011 cohorts, were also suggesting a higher growth than what is presently observed. The best fit to the observed recent modes was obtained with the 2011 cohorts and by using no L_{inf} constraint. This curve suggested a L_{inf} of 28 cm. The model fit is simply a function of the observed modes for the 2011 cohort which are all smaller than 28 cm and don't cover ages older than 10 years. These results suggest that Redfish from the strong 2011–2013 cohorts are currently growing slower and may reach smaller sizes compared to Redfish from the 1980 cohort. This could be explained by an earlier maturation, density-dependent and/or environmental effects in the context of presently low exploitation rates.

Cadigan and Campana (2017) used a hierarchical random effects growth model that includes between-individual variation to estimate growth for 10 Redfish stocks in the Northwest Atlantic. This study concluded that *S. mentella* usually grow to larger sizes than *S. fasciatus*, that females of both these species grow to larger sizes than males and it found little evidence of a change in growth rates over time. Growth and metabolism gene expression have been linked to temperature and explained spatial individual variations in the GSL and could provide insight on the growth pattern if used as a monitoring tool (Martinez-Silva et al. 2022). That said, information presently available does not allow for determining what L_{inf} could be for the 2011–2013 cohorts. Therefore, no projection is provided in the current stock assessment.

EMPIRICAL REFERENCE POINTS FOR UNITS 1 AND 2 STOCKS

The biomass that produces maximum sustainable yield (B_{msy}) is unknown for both Redfish species and the concept of B_{msy} may not apply for species producing such sporadic recruitment. Indeed, Units 1 and 2 Redfish do not display conventional stock-recruitment dynamics and the concept of recruitment over-fishing is difficult to apply. Throughout the stock's history, periods of high Redfish biomass have been sustained by a small number of large recruitment events. Redfish have recovered from low levels of SSB. However there are SSB levels from which recovery will be unlikely or impossible.

In 2020, a Limit Reference Point (LRP) was empirically estimated as the smallest SSB from which there has been a recovery (B_{rec}) for *S. mentella*, or in the case of *S. fasciatus*, the SSB that produced recruitment that would allow recovery if those recruits were to not emigrate from the ecosystem. B_{rec} has been deemed an acceptable basis for the LRP for species with sporadic recruitment dynamics. For both stocks, B_{rec} was empirically estimated as the geometric mean of the 2010–2012 SSB in the Unit 1 survey, i.e. the SSB which produced the 2011–2013 cohorts. The resulting LRP is based on a recent period of low SSB occurring in warm and apparently favorable environmental conditions that may not be unusual in the future.

An Upper Stock Reference (USR) point was similarly proposed for each stock based on SSB information from the DFO research survey in Unit 1. A period of relatively high SSB and landings was considered: 1984–1990 for *S. mentella* and 1984–1992 for *S. fasciatus*. The proposed USRs were empirically estimated as 80% of the SSB geometric mean during these periods. While not founded in recruitment-overfishing concepts, the proposed USRs provide a defensible baseline for what has previously been considered a “healthy” stock.

In 2022, the LRPs were adjusted based on new maturity ogive for the 2011–2013 cohorts implemented from 2011 onwards to estimate the SSB in both stocks (Figure 48). This adjustment corresponded to a 1 kt increase in the LRP for *S. mentella* (from 43 kt to 44 kt) and a 5 kt increase in the LRP for *S. fasciatus* (from 25 kt to 30 kt). The proposed USRs remained unchanged, at 265 kt and 168 kt for *S. mentella* and *S. fasciatus*, respectively.

According to the adjusted LRPs and proposed USRs, the status of the *S. mentella* stock in Units 1 and 2 in 2021 is in the Healthy Zone of the Precautionary Approach (PA, Figure 48A). The status of the *S. fasciatus* stock relative to the PA is unknown. The magnitude of the increase in SSB for *S. fasciatus* in 2021 is uncertain, owing to evidence suggesting it may currently be overestimated. The available information indicates the stock is at least above the LRP (Figure 48B).

Note that the proposed reference points will need to be revised as soon as reliable information on the recruitment and dynamics of Redfish stocks in both Unit 1 and Unit 2 is available.

DEVELOPMENT OF AN ACOUSTIC INDEX IN UNIT 1

Bottom trawl surveys effectively sample several meters above the sea bed, yet the vessel’s scientific echosounder frequently detected backscatter much higher in the water column, indicating that the bottom-trawl index may underestimate total biomass. This situation could potentially create hyperstability, as surveyed biomass may not necessarily be proportional to stock biomass, and catchability of the bottom-trawl net may significantly change with stock biomass for semi-pelagic species. For instance, when biomass is high and Redfish are distributed over a wider section of the water column, a lower proportion of Redfish may be found over the bottom trawl surveyed area, and overall catchability may be low. However as stock biomass decreases, a larger proportion of Redfish may be found near the bottom, where bottom trawl survey remain efficient, and catchability is comparatively high, causing the indices to remain unchanged. Under such a scenario, bottom-trawl based indices could fail to detect any sign of population decrease, leading to poor management advice.

The development of Redfish acoustic indices could provide a complementary method of quantifying stock status to inform management decisions for a large-scale commercial fishery. In this report, we present biomass estimates obtained from an analysis of the acoustic data collected during DFO’s annual bottom trawl survey in 2019 and 2020.

DATA COLLECTION AND STUDY AREA

Trawl and acoustic data collected in 2019 and 2020 as part of the DFO research survey in Unit 1 were used. The survey was conducted from August 14th to September 4th in 2019 and from August 13th to September 4th in 2020. In 2019, 128 fishing stations were successfully completed (Figure 49), distributed in 47 strata. In 2020, 55 strata containing 147 stations were sampled (Figure 50).

The vessel was equipped with a hull-mounted, split-beam SIMRAD EK60 echosounder operating at four frequencies (38, 70, 120 and 200 kHz). Calibration was conducted prior to each survey using tungsten carbide and copper spheres following methods outlined in Demer et al. (2015). The power output was 2000 W, 750 W, 250 W and 150 W at 38 kHz, 70 kHz, 120 kHz and 200 kHz, respectively. Transmitted pulse duration was 1.024 ms and ping rate was set to 1 second. Data from the 200 kHz transducer was not used in this analysis. Bottom depth at our sampling locations sometimes reached up to 550 m, and the signal-to-noise ratio was too low for proper detection at this high frequency. The 38 kHz frequency was used for biomass estimates.

ACOUSTIC DATA PROCESSING

The analyses were conducted in Echoview 11 (Myriax Pty, Ltd., Hobart, Tasmania, Australia) and the R software for statistical computing (version 4.0.2, R Core Team 2020) with RStudio (version 1.3.1056, RStudio Team 2020). Background noise was removed following the method by De Robertis and Higginbottom (2007). A signal-to-noise ratio of 10 dB was used. The background noise algorithm (Echoview) was applied to the data after impulse and attenuation noise were removed. Following De Robertis and Higginbottom (2007), we used a 40 pings and 10 m averaging cells. The maximum noise was set to -165 dB at all frequencies and was determined empirically.

Impulse noise, likely caused by interference with other instruments onboard the ship, was removed following the method described in Ryan et al. (2015). Areas of impulse noise were replaced by the mean of the surrounding cells.

An attenuated acoustic signal can result from the presence of air bubbles underneath the hull and the transducer. The attenuated pings were corrected following the method described in Ryan et al. (2015). Areas of attenuation were replaced by the 50th percentile for biomass estimates unless the area was too large (10 pings and more). In this case, the pings were removed from the analysis.

The loss of biomass resulting from the acoustic dead zone was corrected following the method by Kloser (1996). The acoustic bottom was estimated from the sounder detected bottom with a backstep of 0.5 m. The true bottom was a smoothed version of the maximum volume backscattering strength (S_v) bottom line algorithm implemented in Echoview and was thresholded to the maximum theoretical offset relative to the acoustic bottom. This offset was calculated following Ona and Mitson (1996) using the 3 dB half beam angle at 38 kHz ($\theta_{3\,dB}$) and a 500 m maximum depth (d):

$$h_{dz} = 2404\left[\frac{d\,tan^4\left(\theta_{3dB}\frac{\pi}{180}\right)}{\theta_{3dB}^2}\right] + \frac{c\tau}{4} \qquad (1)$$

c is the sound speed (m/s) and τ the pulse duration (s). This resulted in a maximum offset of 1.7 m, to which we added the 0.5 m backstep for a resulting maximum acoustic dead zone thickness of 2.2 m. The maximum dead zone thickness was thus rounded to 2.0 m.

The volume backscattering located inside the dead zone was replaced by the average volume backscattering in the two meters above the dead zone.

Each echogram was visually scrutinized to remove unwanted signals such as instruments in water or noise that was not successfully removed by the previously described data cleaning protocol.

The S_v data at 38 kHz was thresholded to -70 dB to remove unwanted signals from organisms other than fish.

Analysis regions were selected as periods of 15-minutes corresponding to the time interval when the trawl was expected to be on the seafloor. A time correction was applied to account for the distance between the trawl and the echosounder, using the vessel speed, bottom depth and warp length.

MULTI-FREQUENCY ANALYSIS

Multi-frequency analysis was conducted on the 38, 70 and 120 kHz frequencies. It was used to determine dB differencing thresholds to apply to the acoustic data in order to exclude non-Redfish signal.

This analysis was conducted on the acoustic data that temporally matched tows containing more than 90% Redfish in biomass and for which the acoustic data quality was good. Data in the 20 m above the acoustic bottom were used. This depth interval was chosen as a compromise between 1) focusing on the depth at which trawl samples were collected (5 m above bottom), providing direct validation of the acoustic data, and 2) obtaining enough acoustic data samples for statistical purposes. A similar analysis was also conducted on the 10 m above bottom and lead to similar results.

The mean volume S_v (S_v = 10 $\log_{10}(s_v)$, dB re 1 m^{-1}) was calculated in the linear domain over a grid cell of 25 m GPS distance in the horizontal and 2 m in the vertical at each frequency. Frequencies of 38 kHz, 70 kHz and 120 kHz were then subtracted from one another to investigate the frequency response of Redfish aggregations. The acoustic dead zone was excluded from the multi-frequency analysis as it would only replicate data. All pings where attenuated signal was present were also removed for this analysis.

BIOMASS ESTIMATION

The area density of fish aggregations (ind. km^{-2}) was calculated as follows (MacLennan et al. 2002):

$$\rho = \frac{NASC}{4\pi(1.852^2)\,10^{\frac{TS}{10}}} \qquad (2)$$

Where NASC is the Nautical Area Scattering Coefficient (m^2 nmi^{-2}) of the Redfish aggregation:

$$NASC = s_a\, 4\pi(1852^2) \qquad (3)$$

The 1852 value represents the conversion from meters to nautical miles. The echo integration of the fish aggregations were exported from Echoview as NASC. s_a is the area backscattering coefficient (m^2 m^{-2}) and is obtained from the vertical integration of S_v, the volume backscattering coefficient (m^{-1}). The dead zone area was included in the calculation of biomass. Data above 100 m were excluded from the Redfish biomass estimates since this area is outside the known ecological range of this species.

The mean target strength (TS = $10\log_{10}(\sigma_{bs})$, dB re 1 m^2) for each two-year combination was derived from a TS to length relationship for each fish species, available from the literature (Table 8). Biomass density of Redfish (kg/km^2) was obtained by multiplying ρ by mean weight. Mean weight was estimated from a weight-to-length relationship obtained from the bottom trawl data and was calculated for each year.

When multiple species were present in the echo integration, the proportion of the echo corresponding to one species was calculated as follow:

$$NASC_i = \frac{w_i 10^{\frac{TS_i}{10}}}{\sum_j \left[w_j 10^{\frac{TS_j}{10}} \right]} NASC_{tot} \qquad (4)$$

Where $NASC_i$, TS_i and w_i represent the nautical area scattering coefficient, target strength, and proportion relative to total catch of species *i*, respectively, and *j* represents all species present in the tow. Benthic flatfishes and skates were removed from the analysis as they would not be detected using the echosounder due to the presence of the acoustic dead zone.

In 2019 and 2020, excluding the species mentioned above, three species contributed 99% of the total biomass in survey catches: Atlantic Herring (*Clupea harengus*), Atlantic Cod and Redfish. Thus only those species were considered in the estimation of acoustic biomass. Redfish contributed 97% and 92% of the total biomass in 2019 and 2020, respectively.

Acoustic biomass was estimated using two different methods. In the first method (hereafter named method 1), the S_v data was exported as NASC, and a portion was assigned to Redfish following the species proportion found in the corresponding trawl data, following equation 4. Biomass was then calculated from this fraction of the total NASC. In the second method (hereafter named method 2), an upper and lower threshold was applied to the echogram of $S_{v\ 38\ kHz}$—$S_{v\ 70\ kHz}$ (hereafter $\Delta MVBS_{38\text{-}70\ kHz}$), and data not included within these thresholds were excluded from the S_v data before the remaining signal was exported as NASC. The thresholds were determined from the 5^{th} and 95^{th} percentiles of the multi-frequency analysis. Here, NASC was not partitioned according to trawl composition, because it is expected that the application of the thresholds effectively removed most non-Redfish signal.

Total biomass was calculated following the method used in Bourdages et al. (2021) and Senay et al. (2021), with the exception that strata with missing stations were excluded instead of replaced by the mean of the two previous years, and that strata containing only one station were considered as good strata.

RESULTS

The multi-frequency analysis applied to the 2019 and 2020 acoustic data showed that in both years,90% of the signal corresponding to $\Delta MVBS_{38\text{-}70\ kHz}$ and $\Delta MVBS_{38\text{-}120\ kHz}$ was between 0 dB and 7 dB, and 90% of the signal corresponding to $\Delta MVBS_{70\text{-}120\ kHz}$ was between -3 dB and 3 dB (Figures 51 and 52). Thus, we used a threshold of 0 dB to 7 dB applied to ΔMVBS at 38 kHz and 70 kHz to calculate biomass using method 2. Although we could have applied all three thresholds to improve chances of excluding non-Redfish signal, here we selected one threshold in order to increase computing speed.

Both the acoustic and the trawl data suggest a decrease in biomass in 2020 compared to 2019. The trawl data suggest a decrease of 36%, while the acoustic data suggests a decrease of 42% when using method 1 and 43% when using method 2.

In 2019, the total estimated Redfish biomass was 3,965,121 t. This estimate excludes strata where no station was surveyed that year. The biomass estimated from the acoustic data was 3,535,255 t using method 1 and 3,222,669 t using method 2. In comparison, Senay et al. (2021) estimated a minimum trawlable biomass based on the bottom trawl of 4,443,000 t from the same survey, using a calculation method that used the two previous years to replace missing strata.

That year, the most important difference in biomass observed between methods 1 and 2 was found at stations located at the mouth of the Laurentian Channel near Cabot Strait (stations 3, 5, 7, 8, 10 and 11, Figures 53 and 54). The difference was caused by the presence of a strong acoustic signal in the pelagic zone between 260 m and the seafloor. At shallower depth, this signal was much stronger at 38 kHz than at 70 kHz, and as a result was excluded from the acoustic biomass derived from method 2. On the other hand, because Redfish contributed more than 80% of the trawl biomass at these stations, most of this signal was included in the acoustic biomass calculation using method 1. It is unclear what organism was responsible for this signal. Trawl data suggested the presence of Longfin Hake (*Phycis chesteri*) at these stations, but more data on the acoustic frequency response of this species is required to draw any conclusion. Catch biomass was lower than acoustic biomass at these stations. Catch biomass was generally higher than acoustic biomass in Esquiman channel.

In 2020, the total Redfish biomass was 2,539,377 t. The biomass estimated from the acoustic data was 2,055,056 t using method 1 and 1,841,237 t using method 2. In comparison, an estimated minimum trawlable biomass based on bottom trawl of 2,542,321 t was obtained from the same survey, using a calculation method that used the two previous years to replace missing strata.

Differences in biomass density were observed between methods 1 and 2, but they were not specific to a geographical area like those observed in 2019 (Figures 55 and 56). Higher acoustic biomass estimates were sometimes found in the Laurentian and Anticosti channels (apart from station 170, where the opposite is found), while higher trawl biomass estimates were often found in Esquiman channel.

At station 170, the trawl caught a Redfish biomass density of 949,146 kg/km^2. This corresponds to 26% of the entire biomass caught by the trawl in 2020 (this station was removed from Figure 56 to better show the remaining data). A corresponding biomass of 162,229 kg/km^2 and 152,685 kg/km^2 were estimated from the acoustic data with methods 1 and 2, respectively. At this station, a strong acoustic signal was observed in the first few meters above the acoustic bottom, thus it is likely that a large portion of the biomass caught by the trawl was located in the acoustic dead zone (Figure 57).

The vertical distribution of Redfish was variable between years and geographical locations (Figure 58). However, the acoustic signal summed over all stations suggests that the abundance of Redfish was concentrated at the seafloor in 2019, while in 2020 a greater proportion was found between 10 m to 20 m away from the seafloor (Figure 59). The acoustic signal located between 0 m and 20 m above the seafloor was responsible for 36% of the total decrease in NASC between 2019 and 2020.

DISCUSSION

Combining acoustic and trawl surveys could offer an improved and complementary view of Redfish biomass in the GSL, and help address uncertainties associated with each method. For instance, the acoustic biomass estimated through method 1 makes the assumption that the species composition found in the trawl is representative of that found in the entire water column. This is unlikely the case given the known depth dependency of fish distribution. This may present a challenge when a large portion of the biomass is found above the depths available to the bottom trawl. The main uncertainty associated with method 2 is that many swim-bladder fish have a similar multi-frequency acoustic response. For example, Atlantic Cod, Atlantic Herring and Capelin (*Mallotus villosus*), all present in the study area, likely overlap with Redfish in their frequency response. Extending the multi-frequency analysis to other swim-bladder fish species would help define the uncertainties linked to this overlap. Including additional variables such as aggregation size and shape, temperature and salinity may also improve classification. Both acoustic methods are limited by the fact that a portion of the Redfish biomass is likely found in the acoustic dead zone, which in this study covers a vertical extent of up to two metres but varies with depth and bathymetry.

The bottom trawl is limited by its vertical extent above the seafloor. The acoustic data showed that signal matching Redfish acoustic signature can be found at depths as shallow as 80 m above the seafloor. The effective fishing height for this survey is unknown, but it likely misses part of the shallower aggregations. In addition, several studies suggest that trawl catchability may vary with fish density (Godo et al. 1999, O'Driscoll et al. 2002, Kotwicki et al. 2018). This factor may also lead to hyperstability in the abundance index, although this has not been investigated. Acoustic data is independent from density and may therefore be used to evaluate density-related catchability of Redfish in the trawl samples. Furthermore, a validated acoustic classification method would allow to extend the analysis to the entire survey, including transit periods, thereby improving spatial coverage.

Kotwicki et al. (2018) propose a method for combining bottom trawl and acoustic surveys that use environmental variables to predict the vertical overlap between the two types of surveys. They found that near-bottom light level and bottom depth were the most important factors in predicting the overlap for Walleye Pollock (*Gadus chalcogrammus*). Fish length was also important. Combining acoustic and trawl surveys likely produces a more reliable index of abundance and results in less inter-annual variability (Kotwicki et al. 2018). However, this approach requires a good understanding of the target species' biology in order to model its interaction with environmental variables, as these parameters are required to predict the vertical overlap.

DIET BASED ON UNIT 1 SURVEY

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. 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 among 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 dataset. 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, *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 *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 MC_i of all the taxa found gives 100%. This implies interdependence between the MC_i 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 M_{tot} 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:

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

$$TFI_j = \sum_{i=1}^{I} PFI_{ij} \tag{6}$$

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

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 constant 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 *PFI* 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}):

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

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 60). 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 taxon 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:

$$CTFI_i = \frac{PFI_i}{TFI_{tot}} \cdot 100 \tag{9}$$

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

$$F_{occ} = \frac{N_i}{N} \cdot 100 \tag{10}$$

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. Preys 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 2015–2021 periods. We based the consumption estimates on *Q/B* ratios provided by ecosystem models available from other studies for the nGSL, where *Q* is thetotal 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 2015–2021 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 focused on the 2006–2010 period, so the *Q/B* ratio used for the 2015–2021 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-dependent 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:

$$Q_k = B_k \cdot {}^{Q}/_{B} \tag{11}$$

Q_k represents the total annual consumption per square 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 year from each period (1990s, 2015–2018 and 2019–2021). Consumption of Northern 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:

$$Q_k = Q_k \cdot MC_k \begin{cases} 0 \; if \; sample \; size < 20 \; stomachs \\ \qquad\qquad else \; MC_k \end{cases} \tag{12}$$

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

$$Q = \sum_{k=1}^{K} Q_k \tag{13}$$

Redfish were targeted for stomach samples for twelve years over the period 1993–2021, excluding 2000 to 2014, from which 8,491 stomachs were analyzed in the laboratory (Figure 61). The geographic coverage of stomach samples is depicted in Figure 62 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 24 cm (Table 9). With the recent strong cohorts, the mean and median lengths of Redfish from which stomachs were collected in the 2015–2021 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 (1.5 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 nineteen taxa were found in the stomach contents of the 8,491 Redfish used in the analysis (Tables 9 and 10), of which almost half were zooplankton taxa. The group of prey contributing the most to *TFI* in Redfish is zooplankton (35%), 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 analyzed, *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 12% of stomachs. The Pink Glass Shrimp (*Pasiphaea multidentata*) was the most important taxon in Redfish diet, all prey combined, contributing to 13% of the total food intake (Table 10, F_{occ} of 6%). Northern Shrimp (F_{occ} of 2.6%) was second in importance among the 119 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 4% of analyzed Redfish stomachs contained fish prey, accounting for 13.5% 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 63 and 64). 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 63). In order to avoid excessively large tables, three length groups were created to summarize these results in Table 11: < 20, [20–30], and ≥ 30 cm.

Small Redfish (< 20 cm) are mainly zooplanktivorous (55% 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 9% of small Redfish food intake. Fish contribution to small Redfish diet is almost nil (*CTFI* of 0.7%) 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 22 times 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 119 taxa recorded in the 8,491 stomachs can be summarized in 14 groups shown in Figure 65. 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 2015–2021 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 2015–2021 period, mainly as a result of cannibalism (Figure 66 and Table 12).

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 67). Smaller specimens from the recent period had a lower feeding intensity than their counterparts from the 1990s, which could be attributable to intraspecies 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 68). Approximately 9,500 t of Northern Shrimp were estimated to have been consumed annually during the period 1997–1999, compared to 187,000 t for the 2019–2021 period, corresponding to a 20-fold increase. Northern Shrimp consumption roughly quintupled between 2017 and 2021, which reflecting the long-term growth of the 2011–2013.

SOURCES OF UNCERTAINTY

The prevailing sources of uncertainty in the assessment of Redfish stocks in Units 1 and 2 are stock structure assumptions (including species distribution and movements) and factors affecting the perception of stock status, namely species distinction (in research surveys and the fisheries), temporal changes in survey trawl catchability, and productivity dynamics (sporadic recruitment, and growth and maturity responses to changing environmental conditions). Another important source of uncertainty relates to fisheries bycatch and potential ecosystem effects from Redfish fisheries.

The development and application of effective and economical genetic procedures for Redfish species identification is key to minimizing uncertainty in biomass trajectories and the status of *S. mentella* and *S. fasciatus*. Until such procedures are available, ongoing training of ASO and port samplers to ensure reliable AFR counts is required. In addition, theoretical AFR distributions for each species need to be updated to minimize bias and improve accuracy in species distinction.

Continued development of Redfish acoustic biomass indices in Unit 1 and Unit 2 will serve to minimize potential bias arising from temporal changes in survey trawl catchability, and improve Redfish biomass and stock status evaluation.

The information available and used to inform the assessment of Redfish in Units 1 and 2 is mainly derived from spring and summer surveys. The DFO winter surveys planned for 2022–2024 in Unit 1 and part of Unit 2 will serve to augment knowledge and information on seasonal Redfish movements and winter diet, and on the distribution of co-occurring species and their potential availability/susceptibility to bycatch in Redfish fisheries during the winter.

Data acquisition and research efforts to improve the understanding of factors affecting bycatch composition and trends in Redfish fisheries is a high priority. This includes spatial and temporal changes in commercial effort and bycatch species distribution, vessel specifications and fishing gear configuration, and size and species selectivity.

Effects on ongoing environmental changes on Redfish productivity are mostly unknown. Empirical and statistical research initiatives aimed at understanding relationships between the observed increase in water temperature, decrease in dissolved O_2 and Redfish physiology (*e.g.,* metabolism, growth), demographic rates (*e.g.,* recruitment, mortality) and density-dependent processes, need to be maintained or initiated.

Continued data acquisition and validation in Unit 2 are required to further inform and optimize the PA framework for each stock (which is currently based on Unit 1 information only). This is highly desirable in the near-term to ensure the current PA is applicable to the entire stocks distribution area. A comparative survey in Unit 2 is also a high priority to ensure continuity in the survey biomass time series for the two stocks from 2020 onwards.

No assessment model is currently being used to determine quotas and exploitation rates. Some perspectives were provided in the Management Strategy Evaluation (DFO 2018) which suggested that Units 1 and 2 stocks could support together quotas around 40 kt to 60 kt by 2026. However, based on the Exceptional Circumstances Protocol and given the important changes in life-history traits (*e.g.,* growth and maturity) observed in the current evaluation, the conclusion of the Management Strategy Evaluation should be used with caution. If the development of new models were considered a priority, the involvement of managers and other stakeholders would be key for the implementation of any harvest control rule and other components of a PA (Deith et al. 2021).

CONCLUSION

Prospects for *S. mentella* in Unit 1 and Unit 2 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*. This increase of *S. mentella* biomass may have important repercussions on other species, through predation and competition interactions. Moreover, there are concerns about impacts of an expanded Redfish fishery on depleted bycatch species. Contemporary fishery dependent (ASO sampling) and research data (winter surveys) are required to refine the scientific advice on bycatch, particularly as regards vulnerable species.

Full implementation of the PA will require the definition of a fishing limit reference and harvest control rules. When doing so, 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.

REFERENCES CITED

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

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

Benestan, L., Rougemont, Q., Senay, C., Normandeau, E., Parent, E., Rideout, R., Bernatchez, L., Lambert, Y., Audet, C., and Parent, G.J. 2021. Population genomics and history of speciation reveal fishery management gaps in two related redfish species (*Sebastes mentella* and *Sebastes fasciatus*). Evol. Appl. 14(2), 588-606.

Benoît, H.P. 2006. Standardizing the southern Gulf of St. Lawrence bottom-trawl survey time series: Results of the 2004–2005 comparative fishing experiments and other recommendations for the analysis of the survey data. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/008: 80 p.

Benoît, H.P., and Swain, D.P. 2003. Accounting for length and depth-dependent diet variation in catchability of fish and invertebrates in an annual bottom-trawl survey. ICES J. Mar. Sci. 60, 1298-1317.

Bernier, B., and Chabot, D. 2013. Évaluation de l'état du stock de flétan du Groenland (*Reinhardtius hippoglosoides*) du golfe du Saint-Laurent (4RST) en 2010 et description de son régime alimentaire. Secr. can. de consult. sci. du MPO. Doc. de rech. 2012/140. viii + 85 p.

Bourdages, H., and Marquis, M.-C. 2019. Assessment of northern shrimp stocks in the Estuary and Gulf of St. Lawrence in 2017: commercial fishery data. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/056. iv + 99 p.

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

Bourdages, H., Brassard, C., Desgagnés, M., Galbraith, P., Gauthier, J., Isabel, L. and Senay, C. 2021. Preliminary results from the ecosystemic survey in August 2020 in the Estuary and northern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/054. iv + 93 p.

Bourdages, H., Brassard, C., Chamberland, J.-M., Desgagnés, M., Galbraith, P., Isabel, L. and Senay, C. 2022. Preliminary results from the ecosystemic survey in August 2021 in the Estuary and northern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/011. iv + 95 p.

Bowering, W.R., and Lilly, G.R. 1992. Greenland halibut (*Reinhardtius hippoglossoides*) off Southern Labrador and Northeastern Newfoundland (Northwest Atlantic) feed primarily on capelin (*Mallotus villosus*). Neth. J. Sea Res. 29(1), 211-222.

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

Brassard, C., Lussier, J-F., Benoît, H, Way, M., and Collier, F. 2020. The status of the Northern Gulf of St. Lawrence (3Pn, 4RS) Atlantic cod (*Gadus morhua*) stock in 2018. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/075. xi + 128 p.

Burns, C.M., Lauzon, F., Plourde, S., Sirois, P., and Robert, D. 2020. Interannual variability of diet composition and prey preference of larval redfish (*Sebastes* spp.) in the Gulf of St. Lawrence. J. Plankton Res. 42(5), 581-594.

Burns, C. M., Pepin, P., Plourde, S., Veillet, G., Sirois, P., and Robert, D. 2021. Revealing the relationship between feeding and growth of larval redfish (*Sebastes* sp.) in the Gulf of St. Lawrence. ICES J. Mar. Sci. 78(10), 3757-3766.

Cadigan, N.G., and Campana, S.E. 2017. Hierarchical model-based estimation of population growth curves for redfish (*Sebastes mentella* and *Sebastes fasciatus*) off the Eastern coast of Canada. ICES J. Mar. Sci. 74(3), pp.687-697.

COSEWIC. 2010. COSEWIC assessment and status report on the Deepwater Redfish/Acadian Redfish complex *Sebastes mentella* and *Sebastes fasciatus*, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 80 pp.

Deith, M.C., Skerritt, D.J., Licandeo, R., Duplisea, D.E., Senay, C., Varkey, D.A., and McAllister, M.K. 2021. Lessons learned for collaborative approaches to management when faced with diverse stakeholder groups in a rebuilding fishery. Mar. Policy, 130, p.104555.

Demer, D.A., Berger, L., Bernasconi, M., Bethke, E., Boswell, K., Chu, D., Domokos, R., Dunford, A., Fassler, S., Gauthier, S., and Hufnagle, L.T. 2015. Calibration of acoustic instruments. ICES Coop. Res. Rep. No. 326. doi:10.17895/ices.pub.5494.

De Robertis, A., and Higginbotton, I. 2007. A post-processing technique for estimation of signal-to-noise ratio and removal of echosounder background noise. ICES J. Mar. Sci. 64, 1282–1291.

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

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

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

DFO. 2019. Assessment of Atlantic Cod (*Gadus morhua*) in the southern Gulf of St. Lawrence (NAFO Div. 4T-4Vn (Nov. – April)) to 2018. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/021.

DFO. 2020. Assessment of Northern Shrimp stocks in the Estuary and Gulf of St. Lawrence in 2019. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/010.

DFO. 2021a. Assessment of the Gulf of St. Lawrence (4RST) Greenland halibut stock in 2020. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/017.

DFO. 2021b. Stock Assessment of Gulf of St. Lawrence (4RST) Atlantic Halibut in 2020. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/034.

DFO. 2021c. Update of stock status indicators for northern Gulf of St. Lawrence (3Pn, 4RS) Atlantic Cod in 2020. DFO Can. Sci. Advis. Sec. Sci. Resp. 2021/006.

DFO. 2021d. Impact of an expanding Redfish (*Sebastes* spp.) fishery on southern Gulf of St. Lawrence White Hake (*Urophycis tenuis*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/033.

DFO. 2022. Redfish (*Sebastes mentella* and *Sebastes fasciatus*) Stocks Assessment in Units 1 and 2 in 2021. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/039.

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

Galbraith, P.S., Chassé, J., Shaw, J.-L., Dumas, J., Caverhill, C., Lefaivre, D., and Lafleur, C. 2021. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2020. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/045. iv + 81 p.

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

Gauthier, S., and Rose, G.A. 2002. *In situ* target strength studies on Atlantic redfish (*Sebastes spp.*). ICES J. Mar. Sci., 59, 805-815.

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

Godo, O.R., Walsh, S.J. and Engas, A. (1999). Investigating density-dependent catchability in bottom-trawl surveys. ICES J. Mar. Sci., 56, 292-298.

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

Hovde, S.C., Albert, O.T., and Nilssen, E.M. 2002. Spatial, seasonal and ontogenetic variation in diet of Northeast Arctic Greenland halibut (*Reinhardtius hippoglossoides*). ICES J. Mar. Sci. 59(2), 421-437.

Kloser, R.J. 1996. Improved precision of acoustic surveys of benthopelagic fish by means of a deep-towed transducer. ICES J. Mar. Sci. 53, 407-413.

Kotwicki, S., Ressler, P.H., Ianelli, J.N., Punt, A.E, and Horne, J.K. 2018. Combining data from bottom-trawl and acoustic-trawl surveys to estimate an index of abundance for semipelagic species. Can. J. Fish. Aquat. Sci., 75, 60-71.

Licandeo, R., Duplisea, D.E., Senay, C., Marentette, J.R., and McAllister, M.K. 2020. Management strategies for spasmodic stocks: a Canadian Atlantic redfish fishery case study. Can. J. Fish. Aquat. Sci. 77(4), 684-702.

MacLennan, D.N., Fernandes, P.G., and Dalen, J. 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES J. Mar. Sci. 59:365-369.

Martínez-Silva, M.A., Vagner, M., Senay, C., and Audet, C. 2022. Using gene expression to identify the most suitable environmental conditions for growth and metabolism of juvenile deepwater redfish (*Sebastes mentella*) in the Estuary and the Gulf of St. Lawrence. ICES J. Mar. Sci. 79(2), 382-393.

McAllister, M.K., Duplisea, D.E., Licandeo, R., Marentette, J.R., and Senay, C. 2021. Units 1 and 2 Redfish Management Strategy Evaluation. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/066. vi + 152 p.

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

Ni, I-H., and Templeman, W. 1985. Reproductive cycles of Redfishes (Sebastes) in Southern Newfoundland waters. J. Northw. Atl. Fish. Sci. 6, 57-63.

Nielsen, G.A. 1994. Comparison of the fishing efficiency of research vessels used in the southern Gulf of St. Lawrence groundfish surveys from 1971 to 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1952: 56 p.

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

O'Driscoll, R.L., Rose, G.A. and Anderson, J.T. (2002). Counting capelin: a comparison of acoustic density and trawl catchability. ICES J. Mar. Sci., 59, 1062-1071.

Ona, E. 2003. An expanded target-strength relationship for herring. ICES J. Mar. Sci., 60, 493-499.

Ona, E., and Mitson, R.B. 1996. Acoustic sampling and signal processing near the seabed: the deadzone revisited. ICES J. Mar. Sci. 53, 677-690.

Orr, D.C., and Bowering, W.R. 1997. A multivariate analysis of food and feeding trends among Greenland halibut (*Reinhardtius hippoglossoides*) sampled in Davis Strait, during 1986. ICES J. Mar. Sci. 54(5), 819-829.

Ouellette-Plante, J., Chabot, D., Nozères, C. and Bourdages, H. 2020. Diets of demersal fish from the CCGS Teleost ecosystemic surveys in the estuary and northern Gulf of St. Lawrence, August 2015-2017. Can. Tech. Rep. Fish. Aquat. Sci. 3383: v + 121 p.

Perry, R.I., and Smith, S.J. 1994. Identifying habitat associations of marine fishes using survey data: an application to the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 51(3), 589-602.

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

R Core Team. 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Rolland, N., McDermid, J.L., Swain, D.P., and Senay, C. 2022. Impact of an expanding Redfish (*Sebastes* spp.) fishery on southern Gulf of St. Lawrence White Hake (*Urophycis tenuis*). DFO Can. Sci. Advis. Sec. Res. Doc. 2022/005. viii + 69 p.

Rose, G.A., and Porter, D.R. 1996. Target-strength studies on Atlantic cod (*Gadus morhua*) in Newfoundland waters. ICES J. Mar. Sci., 53, 259-265.

RStudio Team. 2020. RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA.

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

Ryan, T.E., Downie, R.A., Kloser, R.J., and Keith, G. 2015. Reducing bias due to noise and attenuation in open-ocean echo integration data. ICES J. Mar. Sci., 72, 2482-2493.

Saha, A., Johansen, T., Hedeholm, R., Nielsen, E.E., Westgaard, J.I., Hauser, L., Planque, B., Cadrin, S.X., and Boje, J. 2017. Geographic extent of introgression in *Sebastes mentella* and its effect on genetic population structure. Evol. Appl. 10(1), 77-90.

Savard, L., Gauthier, J., Bourdages, H., and Desgagnés, M. 2013. Bycatch in the Estuary and Gulf of St. Lawrence Northern shrimp fishery. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/151. ii+ 56 p.

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

Savoie, L. 2016. Indices of abundance to 2014 for six groundfish species based on the September research vessel and August sentinel vessel bottom-trawl surveys in the southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/085. v + 52 p.

Senay, C., Gauthier, J., Bourdages, H., Brassard, C., Duplisea, D., and Ouellette-Plante, J. 2019. Redfish (*Sebastes mentella* and *S. fasciatus*) stocks status in Unit 1 in 2017. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/002. viii + 61 p.

Senay, C., Ouellette-Plante, J., Bourdages, H., Bermingham, T., Gauthier, J., Parent, G., Chabot, D., and Duplisea, D. 2021. Unit 1 Redfish (*Sebastes mentella* and *S. fasciatus*) stock status in 2019 and updated information on population structure, biology, ecology, and current fishery closures. DFO Can. Sci. Advis. Sec. Res. Doc. 2021/015. xi + 119 p.

Senay, C., Bermingham, T., Parent, G.J., Benoît, H. P., Parent, E., Bourret, A. 2022. Identifying two Redfish species, *Sebastes mentella* and *S. fasciatus*, in fishery and survey catches using anal fin ray count in Units 1 and 2. Can. Tech. Rep. Fish. Aquat. Sci. 3445.

Swain, D.P., Nielsen, G.A., and McKay, D.E. 1995. Incorporating depth-dependent differences in fishing efficiency among vessels in the research survey time series for Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. Can. MS Rep. Fish. Aquat. Sci. 2317, 20.

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

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

TABLES

Table 1. Number of individuals (occurrence) assigned to S. mentella, S. fasciatus or heterozygotes by 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	0.0000	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	0.0000

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	1,160	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	0.0000

Table 2. Annual landings (t) per NAFO Division or Subdivision and total allowable catches (TAC) per management cycle of Sebastes spp. *in Unit 1 from 1953 to 2021. Data include fisheries directed to all species. No Redfish directed fishery took place from 1995 to 1997. 2020 and 2021 values are preliminary.*

Year	Landings (t)						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 (t) 4R	4S	4T	3Pn Jan.–May	4Vn Jan.–May	Total	TAC
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 [a]	9,410	13,824	3,222	63	212	26,731	31,000
1983 [a]	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	10,445	5,755	67,123	57,000
1992	30,088	11,193	8,198	13,901	13,946	77,326	57,000
1993 [b]	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 [c]	27	8	13	0	2	50	0
1996	28	3	41	1	0	74	0
1997	6	10	20	0	1	38	0
1998 [d]	127	77	200	0	5	409	1,000
1999	589	63	456	10	3	1123	2,000
2000	794	53	258	85	3	1192	2,000
2001	710	6	370	13	5	1105	2,000
2002	689	50	465	0	1	1205	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 (t)						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	30	34	113	89	0	265	2,000
2018 [e]	142	210	191	187	18	748	4,500
2019	648	142	245	160	207	1,403	5,950
2020, [f]	711	80	243	58	38	1,130	5,681
2021 [f]	377	68	623	0	0	1,068	7,463

[a] TAC changed during the year
[b] 1993: Beginning of Redfish management Unit 1
[c] 1995: Beginning of the moratorium
[d] 1998: Beginning of the index fishery
[e] 2018: Beginning of the experimental fishery
[f] Preliminary data

Table 3. Occurrence percentage (%), sampled biomass (kg), landed catches percentage (%), and percentage of each species biomass as a function Redfish biomass (%) based on at-sea observer data for the Redfish directed fishery from 1999 to 2021, by time period (1999–2004, 2005–2010, 2011–2016, and 2017–2021), as well as per NAFO division for the most recent time period. 2020 and 2021 values are preliminary.

Unit 1, 1999–2021

Name	Occurrence (%)	Biomass (kg)	Landed (%)	Bycatch / Redfish (%)
Redfish	98.81	3,993,798	99.87	100.00
White Hake	59.62	43,059	72.41	1.08
Greenland Halibut	53.47	84,030	99.05	2.10
Witch Flounder	45.52	22,852	84.23	0.57
Atlantic Cod	42.86	60,607	92.25	1.52
Atlantic Halibut	36.82	39,867	76.57	1,00
Thorny Skate	28.34	8,784	16.40	0.22
Skates	21.47	8,334	1.48	0.21
Monkfish	17.62	2,519	76.46	0.06
Norway King Crab	15.14	1,396	1.29	0.03
Black Dogfish	13.02	13,097	5.54	0.33
Pollock	12.15	5,706	63.74	0.14
Silver Hake	11.65	1,928	7.57	0.05
American Plaice	11.40	1,940	79.38	0.05

Unit 1, 1999–2004

Name	Occurrence (%)	Biomass (kg)	Landed (%)	Bycatch / Redfish (%)
Redfish	97.59	1,289,614	99.93	100.00
Greenland Halibut	57.83	29,239	99.55	2.27
White Hake	53.25	9,993	95.55	0.77
Atlantic Cod	35.06	13,044	100.00	1.01
Witch Flounder	31.33	1,171	98.72	0.09
Thorny Skate	31.08	1,971	1.12	0.15
Spiny Dogfish	23.01	3,634	0.17	0.28
Atlantic Argentine	18.43	7,719	87.85	0.60
Atlantic Halibut	15.66	2,726	94.97	0.21
Norway King Crab	13.37	327	0.00	0.03
Skates	13.25	1,357	0.37	0.11
Monkfish	12.65	484	73.76	0.04
Snow Crab (*C. opilio*)	11.69	302	0.99	0.02
Black Dogfish	11.08	2,924	24.79	0.23
American Plaice	10.72	433	100.00	0.03

Unit 1, 2005–2010

Name	Occurrence (%)	Biomass (kg)	Landed (%)	Bycatch / Redfish (%)
Redfish	99.18	368,212	99.85	100.00
Greenland Halibut	80.66	36,220	99.90	9.84
White Hake	50.82	7,125	79.90	1.94
Witch Flounder	41.36	1,190	99.33	0.32
Atlantic Cod	36.21	22,653	99.94	6.15
Thorny Skate	36.21	1,988	38.38	0.54
Atlantic Halibut	28.81	2,787	81.34	0.76
Skates	28.81	1,434	1.12	0.39
Monkfish	19.96	500	96.60	0.14
Norway King Crab	18.31	282	0.00	0.08
Anthozoan	16.87	220	0.00	0.06
Black Dogfish	13.79	4,360	0.00	1.18
Squids	12.14	200	14.50	0.05
American Plaice	11.11	172	100.00	0.05

Unit 1, 2011–2016

Name	Occurrence (%)	Biomass (kg)	Landed (%)	Bycatch / Redfish (%)
Redfish	99.32	216,127	99.16	100.00
Greenland Halibut	95.22	13,264	99.88	6.14
White Hake	80.55	5,622	70.19	2.60
Witch Flounder	69.62	1,104	95.83	0.51
Skates	54.27	3,097	2.07	1.43
Atlantic Halibut	48.81	3,101	75.85	1.43
Norway King Crab	45.39	671	2.68	0.31
Atlantic Cod	44.37	1,851	91.95	0.86
Monkfish	38.91	577	98.09	0.27
Thorny Skate	27.99	2,617	24.84	1.21
Black Dogfish	17.75	2,412	0.00	1.12
Common Grenadier	17.41	157	0.64	0.07
Rock Grenadier	14.68	76	0.00	0.04
American Plaice	11.60	87	95.40	0.04
Sea pen	11.26	405	0.00	0.19

Unit 1, 2017–2021

Name	Occurrence (%)	Biomass (kg)	Landed (%)	Bycatch / Redfish (%)
Redfish	99.40	2,119,845	99.90	100,00
White Hake	62.54	20,319	59.01	0.96
Atlantic Halibut	52.13	31,253	74.61	1.47
Witch Flounder	51.28	19,387	81.77	0.91
Atlantic Cod	50.77	23,059	80.33	1.09
Greenland Halibut	28.67	5,307	88.41	0.25
Silver Hake	23.72	1,608	7.84	0.08
Thorny Skate	23.21	2,208	0.27	0.10
Pollock	19.88	3,919	51.06	0.18
Skates	16.04	2,446	1.55	0.12
Argentine	15.36	2,449	0.00	0.12
Monkfish	14.85	958	54.28	0.05
Black Dogfish	12.88	3,401	0.00	0.16
Squid (*Teuthida*)	12.12	315	0.32	0.01
American Plaice	11.95	1,248	68.27	0.06

4R, 2017–2021

Name	Occurrence (%)	Biomass (kg)	Landed (%)	Bycatch / Redfish (%)
Redfish	99.36	1,124,572	99.93	100.00
White Hake	59.00	12,481	49.88	1.11
Atlantic Halibut	53.70	22,879	78.74	2.03
Atlantic Cod	50.80	10,969	80.92	0.98
Witch Flounder	50.80	15,543	80.15	1.38
Squid (*Teuthida*)	22.51	313	0.32	0.03
Silver Hake	22.19	755	5.43	0.07
Pollock	19.77	2,846	37.70	0.25
Skates	18.97	1,255	0.32	0.11
Monkfish	16.40	453	22.52	0.04
Thorny Skate	16.40	880	0.00	0.08
Argentine	14.63	569	0.00	0.05
Greenland Halibut	13.02	522	39.85	0.05
Atlantic Wolffish	12.06	448	0.00	0.04

4S, 2017–2021

Name	Occurrence (%)	Biomass (kg)	Landed (%)	Bycatch / Redfish (%)
Redfish	98.83	191,522	99.89	100.00
White Hake	63.74	845	73.14	0.44
Witch Flounder	63.16	794	81.11	0.41
Greenland Halibut	60.82	1,438	88.04	0.75
Atlantic Cod	57.89	2,627	96.46	1.37
Atlantic Halibut	57.31	3,452	68.37	1.80
Thorny Skate	42.11	628	0.00	0.33
American Plaice	33.33	106	93.40	0.06
Pollock	15.79	97	61.86	0.05
Silver Hake	13.45	75	0.00	0.04
Atlantic Herring	12.87	63	0.00	0.03

4T, 2017–2021

Name	Occurrence (%)	Biomass (kg)	Landed (%)	Bycatch / Redfish (%)
Redfish	100.00	170,468	99.61	100.00
White Hake	74.17	2,457	97.64	1.44
Greenland Halibut	74.17	2,791	97.49	1.64
Witch Flounder	47.50	1,098	91.26	0.64
Atlantic Halibut	45.00	1,533	81.87	0.90
Atlantic Cod	33.33	638	80.09	0.37
Thorny Skate	32.50	322	1.86	0.19
Monkfish	30.00	269	93.68	0.16
Northern Shortfin Squid (*I. illecebrosus*)	25.00	159	7.55	0.09
Silver Hake	23.33	211	10.43	0.12
American Plaice	21.67	172	98.26	0.10
Skates	20.83	353	9.63	0.21
Pollock	15.00	144	84.03	0.08
Scyphozoan (Jellyfish) (*Scyphozoa*)	14.17	71	0.00	0.04
Common Grenadier	10.00	35	0.00	0.02
Spotted Flounder	10.00	31	0.00	0.02

3Pn, 2017–2021

Name	Occurrence (%)	Biomass (kg)	Landed (%)	Bycatch / Redfish (%)
Redfish	99.52	440,254	99.93	100.00
Atlantic Cod	61.90	8,773	75.06	1.99
White Hake	60.48	3,589	50.24	0.82
Atlantic Halibut	42.86	2,035	20.25	0.46
Argentine	40.95	1,877	0.00	0.43
Silver Hake	40,00	560	10,00	0.13
Witch Flounder	34.29	395	53.42	0.09
Black Dogfish	31.90	641	0,00	0.15
Pollock	25.24	797	89.34	0.18
Thorny Skate	18.57	231	0.00	0.05
Skates	14.29	726	0.00	0.16
Lumpfish	12.86	68	0.00	0.02
Scyphozoan (Jellyfish) (*Scyphozoa*)	10.00	162	0.00	0.04

4Vn, 2017–2021

Name	Occurrence (%)	Biomass (kg)	Landed (%)	Bycatch / Redfish (%)
Redfish	100.00	192,983	99.97	100.00
Witch Flounder	100.00	1,543	99.74	0.80
Greenland Halibut	89.36	460	98.48	0.24
White Hake	85.11	945	100.00	0.49
Atlantic Halibut	72.34	1,331	95.94	0.69
Black Dogfish	61.70	539	0.00	0.28
Thorny Skate	42.55	147	0.00	0.08
Northern Shortfin Squid (*I. illecebrosus*)	36.17	71	0.00	0.04
Monkfish	34.04	122	100.00	0.06
Spiny Dogfish	31.91	242	0.00	0.13
Pollock	25.53	35	100.00	0.02
Skates	23.40	101	0.00	0.05
Norway King Crab	19.15	12	0.00	0.01
Atlantic Cod	17.02	18	100.00	0.01
Smooth Skate	17.02	84	0.00	0.04
Longfin Hake	17.02	32	21.88	0.02
Hakes	14.89	160	100.00	0.08
Barndoor Skate	12.77	85	0.00	0.04
Silver Hake	10.64	7	100.00	0.00

Table 4. 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 2021. 2020 and 2021 values are preliminary.

Percentile	Redfish	Greenland Halibut	White Hake	Atlantic Cod	Atlantic Halibut
p5	233	247	243	204	201
p10	246	263	251	209	204
p25	272	302	272	223	242
p50	298	350	297	240	282
p75	356	413	324	274	303
p90	422	433	357	301	393
p95	437	437	409	318	422

Table 5. Abundance (1,000,000 individuals, A) and biomass (1,000 t, B) indices in DFO research surveys from 1984 to 2021 for S. mentella, S. fasciatus, and Sebastes spp. *by length class.*

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	146	72	66	218	4,408	43	35	4,451	4,554	116	101	4,670
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	12,867	7,499	513	20,366	1,410	492	120	1,902	14,277	7,990	633	22,267
2019	11,312	17,251	1,982	28,562	245	279	50	524	11,557	17,529	2,033	29,086
2020	3,164	10,742	1,592	13,906	457	493	173	950	3,621	11,235	1,765	14,857
2021	1,941	12,918	3,088	14,859	644	1,599	517	2,243	2,584	14,518	3,605	17,102

B

Year	Biomass (1,000 tonnes)											
	S. mentella				*S. fasciatus*				*Sebastes* spp.			
	0–22 cm	> 22 cm	> 25 cm	Total	0–22 cm	> 22 cm	> 25 cm	Total	0–22 cm	> 22 cm	> 25 cm	Total
1984	57	388	385	445	121	234	227	355	178	622	612	800
1985	28	236	228	264	54	120	115	174	82	357	343	439
1986	61	288	271	349	54	136	124	189	115	423	395	538
1987	52	514	398	566	32	129	116	161	84	643	514	727
1988	8	382	345	389	23	385	334	408	31	767	679	797
1989	5	341	331	346	18	384	367	402	23	725	698	748
1990	15	492	488	507	44	281	275	325	59	773	763	832
1991	34	227	226	261	102	194	189	296	136	421	415	557
1992	8	162	158	170	25	219	211	244	33	381	369	414
1993	2	101	100	103	8	119	105	128	11	220	206	231
1994	2	59	59	61	4	73	72	77	6	132	131	138
1995	2	77	77	79	2	12	11	14	4	89	88	93
1996	2	62	61	64	2	10	10	12	4	72	71	76
1997	2	57	56	58	3	27	26	30	4	84	82	88
1998	2	28	28	30	10	53	39	62	12	81	67	92
1999	2	50	49	52	7	14	13	21	9	63	62	73
2000	4	51	50	55	12	19	18	31	16	70	68	85
2001	3	45	44	47	6	22	21	28	9	67	65	76
2002	2	78	77	80	7	15	14	22	8	93	91	102
2003	2	109	106	111	11	75	71	86	13	184	178	197
2004	1	25	25	27	8	15	12	22	9	40	37	49
2005	3	46	45	49	48	21	19	68	50	67	64	117
2006	10	25	25	36	78	39	33	117	88	64	58	152
2007	27	27	27	55	83	20	17	103	110	47	44	158
2008	1	91	87	92	27	51	49	78	28	142	136	170
2009	0	12	12	12	12	17	16	29	12	29	28	42
2010	1	72	68	73	15	21	19	37	17	93	87	110
2011	2	34	33	36	9	28	25	37	11	62	58	73
2012	1	40	39	40	12	24	22	36	12	64	60	76
2013	49	55	55	104	25	45	43	70	73	101	98	174
2014	141	62	61	203	72	38	34	111	214	100	96	314
2015	391	54	52	445	62	42	35	103	453	95	87	548
2016	1,510	61	47	1,572	63	39	34	102	1,574	100	81	1,674
2017	1,817	349	56	2,166	257	89	56	346	2,075	438	112	2,513
2018	1,450	1,334	153	2,784	159	110	43	269	1,609	1,444	195	3,053
2019	1,280	3,043	497	4,323	21	57	18	78	1,302	3,100	515	4,401
2020	372	2,013	389	2,384	40	116	57	156	412	2,129	446	2,540
2021	183	2,622	790	2,805	61	359	155	420	244	2,981	945	3,225

Table 6. Species composition, mean depth (m), number of genotyped Redfish (n), mean fork length (mm), and geographical coordinates for each location used in the genetic analysis of juveniles Redfish sampled in 2019–2021.

Year	*S. mentella* (%)	*S. fasciatus* (%)	Mean depth (m)	n	Mean length (mm)	Latitude	Longitude
2019	0	100	147	25	73	49.12	-59.17
2019	40	60	201	25	103	49.65	-59.24
2019	24	76	184	25	78	49.92	-58.47
2019	84	16	176	25	88	50.33	-57.68
2019	76	24	250	25	116	50.51	-57.78
2019	4	96	153	25	91	50.67	-57.77
2019	64	36	216	25	108	49.88	-58.94
2019	96	4	269	25	113	49.51	-61.18
2019	92	8	233	25	87	49.79	-62.54
2019	96	4	223	25	88	49.82	-62.94
2019	80	20	173	25	86	49.90	-62.97
2019	60	40	125	25	83	50.05	-62.69
2019	28	72	127	25	95	49.99	-64.32
2019	100	0	221	25	85	49.98	-65.59
2019	84	16	304	25	98	49.71	-66.41
2019	100	0	249	25	82	48.82	-67.97
2019	92	8	328	25	88	48.74	-68.71
2019	96	4	354	25	92	48.84	-68.34
2019	100	0	256	25	84	49.32	-65.22
2019	96	4	250	25	84	49.16	-64.54
2019	44	56	165	25	106	49.54	-63.95
2020	95	5	276	55	90	48.97	-64.15
2020	97	3	327	30	94	49.70	-65.77
2020	93	7	328	30	98	49.56	-66.26
2020	97	3	286	30	90	49.28	-66.49
2020	100	0	291	29	91	49.36	-66.73
2020	90	10	245	30	89	49.14	-66.79
2020	90	10	325	30	96	48.83	-68.07
2020	100	0	342	25	91	48.70	-68.75
2020	100	0	271	25	91	49.02	-67.99
2020	100	0	264	25	91	49.05	-67.82
2020	92	8	297	25	93	49.15	-67.52
2020	100	0	298	25	91	49.25	-67.44
2020	100	0	224	25	92	49.78	-66.86
2020	88	12	279	25	89	49.86	-66.01
2020	94	6	146	47	87	49.81	-63.10
2020	57	43	159	30	95	49.86	-61.42
2020	90	10	206	30	92	49.40	-59.95

Year	*S. mentella* (%)	*S. fasciatus* (%)	Mean depth (m)	n	Mean length (mm)	Latitude	Longitude
2020	32	68	178	25	96	49.80	-58.53
2020	92	8	247	25	94	50.46	-57.87
2020	52	48	162	25	89	50.49	-58.32
2020	32	68	203	25	100	49.67	-58.89
2020	4	96	176	25	104	49.50	-58.96
2020	0	100	178	25	106	49.40	-59.05
2021	98	2	426	50	82	48.58	-61.97
2021	2	98	113	45	78	48.16	-59.35
2021	0	100	104	50	79	48.32	-59.09
2021	14	86	163	50	85	49.88	-58.48
2021	96	4	245	50	91	49.95	-59.34
2021	96	4	275	50	91	49.67	-59.58
2021	97	3	192	100	81	49.64	-64.36
2021	97	3	393	30	84	49.39	-64.92
2021	96	4	331	24	80	49.77	-65.68
2021	98	2	272	49	83	48.32	-69.21
2021	96	4	261	49	85	49.16	-67.66
2021	98	2	276	49	86	49.51	-66.59
2021	98	2	213	49	83	49.68	-66.88
2021	100	0	220	50	85	49.86	-62.85
2021	90	10	142	50	82	49.70	-62.72
2021	98	2	260	50	84	49.72	-62.10
2021	88	12	260	50	83	49.62	-61.84
2021	96	4	265	50	81	49.58	-61.55

Table 7. Parameters of different von Bertalanffy growth curves based on length-at-age trends of the 1980 and/or 2011 cohorts estimated modal size, with our without a $L_{infinity}$ (L_{inf}) constraint between 42–50 cm, as well as how they are illustrated on Figure 47.

Data	L_{inf} constraint	$L_{infinity}$	k	t_0	Curve
1980	42–50 cm	42	0.086	-1.57	Black
2011	42–50 cm	42	0.079	-1.81	Blue
1980 and 2011	42–50 cm	42	0.085	-1.52	Orange
1980	Unconstrained	37	0.153	0.07	Black dotted
2011	Unconstrained	28	0.200	-0.17	Blue dotted
1980 and 2011	Unconstrained	37	0.132	-0.24	Orange dotted

Table 8. TS-to-length relationships used for each species considered in the acoustic analysis.

Species	Equation	Reference
Atlantic Herring	TS = 20 log10(L) - 67.3	Ona (2003)
Atlantic Cod	TS = 20 log10(L) - 66.0	Rose and Porter (1996)
Redfish	TS = 20 log10(L) - 68.7	Gauthier and Rose (2002)

Table 9. Summary 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	2015–2021	< 20	[20–30[	≥ 30	
TFI		0.63	0.41	0.54	0.26	0.65	0.50
Nb. of stomachs		3,321	5,170	3,375	2,397	2,719	8,491
Nb. of empty stomachs		1,894	2,050	1,420	1,193	1,331	3,944
% of empty stomachs		57.0	39.7	42.1	49.8	49.0	46.4
Fork length (mm)	Mean	270.2	223.4	146.7	244.9	356.7	241.7
	Median	298	215	152	240	351	230
	Min	40	42	40	200	300	40
	Max	515	501	199	299	515	515
Total stomach contents (g)	Mean	4.44	1.50	0.27	0.87	6.80	2.42
	Median	1.30	0.12	0.09	0.13	2.77	0.22
	Min	0.001	0.001	0.001	0.001	0.001	0.001
	Max	133.800	88.325	6.455	19.771	133.800	133.800
Nb. of taxa observed	Fishes	13	18	4	11	21	23
	Shrimps	9	12	10	7	10	14
	Zooplanktons	31	54	49	38	33	57
	Other invertebrates	8	19	15	6	13	23
	Unidentifiable preys	2	2	2	2	2	2
	Total	63	105	80	64	79	119

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	CTFI Rank
Bony fish	*Actinopterygii*	<1	1.01	<0.01	0.57	30
Atlantic Herring	*Clupea harengus*	<1	<0.01	<0.01	<0.01	98
Capelin	*Mallotus villosus*	<1	8.46	0.03	5.06	7
Lanternfish	*Myctophidae*	<1	0.18	<0.01	0.08	46
Kroyer's lanternfish	*Notoscopelus kroyeri*	<1	0.46	<0.01	0.15	37
Barracudinas	*Paralepis* sp.	<1	0.06	<0.01	0.03	58
White Barracudina	*Arctozenus risso*	<1	2.39	<0.01	1.07	25
Slender Snipe Eel	*Nemichthys scolopaceus*	<1	0.18	<0.01	0.08	44
Threespine Stickleback	*Gasterosteus aculeatus*	<1	0.02	<0.01	0.02	65
Cods	*Gadus* sp.	<1	<0.01	<0.01	<0.01	83
Longfin Hake	*Phycis chesteri*	<1	0.19	<0.01	0.09	43
Marlin-Spike	*Nezumia bairdii*	<1	0.15	<0.01	0.08	45
Shannies	*Lumpenus* sp.	<1	0.02	<0.01	0.01	70
Slender Eelblenny	*Lumpenus fabricii*	<1	<0.01	<0.01	<0.01	86
Daubed Shanny	*Leptoclinus maculatus*	<1	0.02	<0.01	0.02	61
Eelpout	*Zoarcidae*	<1	<0.01	<0.01	<0.01	95
Atlantic Soft Pout	*Melanostigma atlanticum*	<1	0.25	<0.01	0.14	38
Redfish	*Sebastes* spp.	<1	7.12	0.02	3.11	11
Flatfish	Pleuronectiformes	<1	0.05	<0.01	0.02	69
Digested roundfish	-	<1	1.45	<0.01	0.82	27
Fish (spawn) egg	-	<1	0.06	<0.01	0.02	62
Digested fish	-	1.5	3.88	0.01	2.12	16
Fishes, total	**-**	**3.8**	**26**	**0.07**	**13.55**	-
Digested shrimp	-	3.4	4.41	0.02	3.35	9
Glass shrimp	*Pasiphaeidae*	<1	0.81	<0.01	0.40	31
Glass shrimp	*Pasiphaea* sp.	<1	0.51	<0.01	0.28	33
Pink Glass Shrimp	*Pasiphaea multidentata*	6.2	22.05	0.06	12.90	1
Shrimp	*Hippolytidae*	<1	<0.01	<0.01	0.02	66
Arctic Eualid	*Eualus fabricii*	<1	<0.01	<0.01	0.04	55
Greenland Shrimp	*Eualus macilentus*	<1	0.02	<0.01	0.05	50
Gaimard's Eualid	*Eualus gaimardii gaimardii*	<1	<0.01	<0.01	0.10	40
Parrot Shrimp	*Spirontocaris spinus*	<1	<0.01	<0.01	0.04	54
Boreal Red Shrimps	*Pandalus* sp.	<1	1.71	<0.01	1.13	24

Prey Common name	Latin name	F_{occ}	MC	PFI	CTFI	
					Value	Rank
Northern Shrimp	*Pandalus borealis*	2.6	14.49	0.05	9.13	2
Striped Pink Shrimp	*Pandalus montagui*	<1	0.66	<0.01	0.97	26
Sevenline Shrimp	*Sabinea septemcarinata*	<1	0.03	<0.01	0.05	52
Norwegian Shrimp	*Pontophilus norvegicus*	<1	<0.01	<0.01	<0.01	89
Shrimps, total	**-**	**12**	**44.71**	**0.14**	**28.46**	**-**
Calanoid Copepod	*Calanoida*	8.5	0.44	0.01	2.66	12
Calanoid Copepod	*Calanus* sp.	5.3	0.40	0.01	2.05	17
Calanoid Copepod	*Calanus finmarchicus*	<1	<0.01	<0.01	<0.01	77
Calanoid Copepod	*Calanus hyperboreus*	7.8	0.43	<0.01	1.17	21
Calanoid Copepod	*Calanus glacialis*	<1	<0.01	<0.01	<0.01	119
Calanoid Copepod	*Tortanus discaudatus*	<1	<0.01	<0.01	<0.01	106
Calanoid Copepod	*Scolecithricella* sp.	<1	<0.01	<0.01	<0.01	116
Calanoid Copepod	*Calanus finn*. + *glacialis*	<1	0.02	<0.01	0.17	36
Calanoid Copepod	*Bradyidius similis*	<1	<0.01	<0.01	0.03	60
Calanoid Copepod	*Temora longicornis*	<1	<0.01	<0.01	<0.01	107
Calanoid Copepod	*Chiridius gracilis*	<1	<0.01	<0.01	<0.01	108
Calanoid Copepod	*Aetideidae*	<1	<0.01	<0.01	0.08	47
Calanoid Copepod	*Euchaeta* sp.	<1	<0.01	<0.01	<0.01	111
Calanoid Copepod	*Paraeuchaeta norvegica*	2.9	0.06	<0.01	0.17	35
Calanoid Copepod	*Metridinidae*	<1	<0.01	<0.01	0.01	74
Calanoid Copepod	*Metridia* sp.	1.6	0.03	<0.01	0.30	32
Calanoid Copepod	*Metridia longa*	<1	<0.01	<0.01	<0.01	85
Calanoid Copepod	*Metridia lucens*	<1	<0.01	<0.01	0.01	72
Hyperiid	*Hyperiidea*	<1	<0.01	<0.01	<0.01	105
Hyperiid	*Hyperiidae*	2.4	2.37	<0.01	1.88	18
Hyperiid	*Themisto* sp.	6.2	0.84	0.01	2.58	14
Hyperiid	*Themisto abyssorum*	3.1	0.53	<0.01	1.21	20
Hyperiid	*Themisto compressa*	3.6	1.01	0.01	2.65	13
Hyperiid	*Hyperoche medusarum*	<1	<0.01	<0.01	<0.01	118
Hyperiid	*Themisto libellula*	2.2	2.30	0.01	2.43	15
Hyperiid	*Hyperia* sp.	<1	<0.01	<0.01	0.01	71
Hyperiid	*Hyperia galba*	<1	<0.01	<0.01	<0.01	78
Hyperiid	*Scina borealis*	<1	<0.01	<0.01	0.04	56
Gammarid	*Gammaridea*	<1	<0.01	<0.01	0.03	59

Prey Common name	Latin name	F_{occ}	MC	PFI	CTFI	
					Value	Rank
Gammarid	*Byblis* sp.	<1	<0.01	<0.01	<0.01	75
Gammarid	*Rhachotropis aculeata*	<1	<0.01	<0.01	<0.01	93
Gammarid	*Melita* sp.	<1	<0.01	<0.01	<0.01	94
Gammarid	*Maera loveni*	<1	<0.01	<0.01	<0.01	84
Gammarid	*Lysianassidae*	<1	<0.01	<0.01	<0.01	76
Gammarid	*Tmetonyx cicada*	<1	<0.01	<0.01	<0.01	96
Gammarid	*Hippomedon* sp.	<1	<0.01	<0.01	<0.01	103
Gammarid	*Neohela monstrosa*	<1	0.02	<0.01	0.09	42
Gammarid	*Monoculodes* sp.	<1	<0.01	<0.01	<0.01	97
Gammarid	*Harpinia* sp.	<1	<0.01	<0.01	<0.01	100
Mysid	*Mysida*	<1	<0.01	<0.01	<0.01	101
Mysid	*Mysidae*	<1	0.32	<0.01	0.68	28
Mysid	*Boreomysis* sp.	3.6	0.98	0.02	3.19	10
Mysid	*Boreomysis tridens*	<1	0.02	<0.01	0.05	51
Mysid	*Boreomysis arctica*	1.2	0.39	<0.01	1.15	22
Mysid	*Erythrops* sp.	<1	<0.01	<0.01	<0.01	82
Mysid	*Erythrops erythrophthalma*	<1	<0.01	<0.01	<0.01	80
Mysid	*Pseudomma* sp.	<1	<0.01	<0.01	0.02	63
Mysid	*Pseudomma roseum*	<1	<0.01	<0.01	0.02	68
Mysid	*Mysis* sp.	<1	0.01	<0.01	0.10	41
Mysid	*Mysis mixta*	<1	<0.01	<0.01	<0.01	81
Mysid	*Stilomysis* sp.	<1	<0.01	<0.01	<0.01	87
Euphausiid	*Euphausiacea*	<1	<0.01	<0.01	<0.01	79
Euphausiid	*Euphausiidae*	2.7	1.41	0.02	3.64	8
Northern krill	*Meganyctiphanes norvegica*	4.3	3.47	0.03	5.81	6
Euphausiid	*Thysanoessa* sp.	<1	0.42	<0.01	1.74	19
Euphausiid	*Thysanoessa inermis*	<1	<0.01	<0.01	0.03	57
Arctic krill	*Thysanoessa raschii*	<1	0.12	<0.01	0.63	29
Zooplankton, total	**-**	**34**	**15.64**	**0.17**	**34.72**	-
Invertebrate	*Invertebrata*	<1	<0.01	<0.01	<0.01	109
Anemone	*Metridiidae*	<1	<0.01	<0.01	0.02	64
Arrow worm	*Parasagitta elegans*	<1	<0.01	<0.01	<0.01	117
Mollusc	*Mollusca*	<1	<0.01	<0.01	<0.01	112
Gastropod	*Gastropoda*	<1	<0.01	<0.01	<0.01	110

Prey Common name	Latin name	F_{occ}	MC	PFI	CTFI	
					Value	Rank
Shelled sea butterfly	*Limacina* sp.	<1	<0.01	<0.01	<0.01	102
Dipperclam	*Cuspidaria* sp.	<1	<0.01	<0.01	<0.01	90
Bobtail	*Rossia* sp.	<1	0.07	<0.01	0.05	48
Polychaete	*Polychaeta*	<1	<0.01	<0.01	<0.01	91
Sea mouse	*Aphrodita hastata*	<1	<0.01	<0.01	0.05	53
Crustacean	*Crustacea*	13.8	4.18	0.04	8.26	3
Ostracod	*Ostracoda*	<1	<0.01	<0.01	<0.01	88
Copepod	*Copepoda*	3.2	0.20	<0.01	1.15	23
Crustacean	*Malacostraca*	<1	0.01	<0.01	0.20	34
Cumacean	*Cumacea*	<1	<0.01	<0.01	0.05	49
Isopod	*Isopoda*	<1	<0.01	<0.01	<0.01	115
Isopod	*Syscenus infelix*	<1	0.02	<0.01	0.01	73
Amphipod	*Amphipoda*	2	5.87	0.03	6.99	4
Crab	*Brachyura*	<1	<0.01	<0.01	<0.01	104
Snow crab	*Chionoecetes opilio*	<1	<0.01	<0.01	<0.01	113
Lyre crab	*Hyas* sp.	<1	<0.01	<0.01	<0.01	114
Invertebrate egg	-	<1	<0.01	<0.01	<0.01	99
Digested invertebrates	-	<1	0.08	<0.01	0.11	39
Other invertebrates, total	**-**	**19**	**10.44**	**0.08**	**16.92**	-
Invertebrates, total	**-**	**50.4**	**70.79**	**0.40**	**80.09**	-
Unidentified digested material	-	4.9	3.21	0.03	6.36	5
Unidentified egg	-	<1	<0.01	<0.01	<0.01	92
Unidentifiable preys, total	**-**	**4.9**	**3.21**	**0.03**	**6.37**	-
Total	**-**	**-**	**100**	**0.50**	**100**	-

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

Prey	F_{occc}				MC				CTFI			
	< 20	**[20–30[**	**≥ 30**	**Total**	**< 20**	**[20–30[**	**≥ 30**	**Total**	**< 20**	**[20–30[**	**≥30**	**Total**
Bony fish (*Actinopterygii*)	<1	<1	<1	<1	<0.01	0.85	1.08	1.01	<0.01	0.65	1.14	0.57
Atlantic Herring (*Clupea harengus*)	-	<1	-	<1	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Capelin (*Mallotus villosus*)	<1	<1	1.6	<1	1.09	9.17	8.78	8.46	0.42	9.27	8.41	5.06
Lanternfish (*Myctophidae*)	-	-	<1	<1	-	-	0.21	0.18	-	-	0.19	0.08
Kroyer's Lanternfish (*Notoscopelus kroyeri*)	-	-	<1	<1	-	-	0.53	0.46	-	-	0.37	0.15
Barracudinas (*Paralepis* sp.)	-	-	<1	<1	-	-	0.07	0.06	-	-	0.07	0.03
White Barracudina (*Arctozenus risso*)	-	<1	<1	<1	-	1.34	2.64	2.39	-	1.12	2.17	1.07
Slender Snipe Eel (*Nemichthys scolopaceus*)	-	-	<1	<1	-	-	0.21	0.18	-	-	0.20	0.08
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	-	-	0.22	0.19	-	-	0.21	0.09
Marlin-Spike (*Nezumia bairdii*)	-	<1	<1	<1	-	0.11	0.17	0.15	-	0.07	0.17	0.08
Shannies (*Lumpenus* sp.)	-	-	<1	<1	-	-	0.02	0.02	-	-	0.03	0.01
Slender Eelblenny (*Lumpenus fabricii*)	-	<1	-	<1	-	0.04	-	<0.01	-	0.03	-	<0.01
Daubed Shanny (*Leptoclinus maculatus*)	-	<1	<1	<1	-	0.19	<0.01	0.02	-	0.14	0.01	0.02
Eelpout (Zoarcidae (*Zoarcidae*)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Atlantic Soft Pout (*Melanostigma atlanticum*)	-	<1	<1	<1	-	0.32	0.26	0.25	-	0.29	0.24	0.14
Redfish (*Sebastes* spp.)	-	<1	1.4	<1	-	1.05	8.19	7.12	-	0.84	7.17	3.11
Flatfish (Pleuronectiformes)	-	-	<1	<1	-	-	0.05	0.05	-	-	0.04	0.02
Digested roundfish	<1	<1	1.2	<1	<0.01	0.62	1.62	1.45	<0.01	0.49	1.80	0.82
Fish (spawn) egg	-	-	<1	<1	-	-	0.07	0.06	-	-	0.06	0.02
Digested fish	<1	<1	3.5	1.5	0.42	2.87	4.18	3.88	0.27	3.12	3.69	2.12
Fishes, total	**<1**	**2.3**	**9.4**	**3.8**	**1.51**	**16.56**	**28.39**	**26.00**	**0.69**	**16.03**	**26.08**	**13.54**
Digested shrimp	1.1	1.8	7.6	3.4	1.71	4.43	4.55	4.41	1.73	4.38	4.67	3.35
Glass shrimp (*Pasiphaeidae*)	-	-	<1	<1	-	-	0.94	0.81	-	-	0.95	0.40

Prey	F_{occ}				MC				CTFI			
	< 20	[20–30[	≥ 30	Total	< 20	[20–30[	≥ 30	Total	< 20	[20–30[	≥30	Total
Glass shrimp (*Pasiphaea* sp.)	-	<1	<1	<1	-	0.43	0.55	0.51	-	0.31	0.55	0.28
Pink Glass Shrimp (*Pasiphaea multidentata*)	<1	2.8	15.8	6.2	5.99	14.00	23.83	22.05	3.42	13.86	22.46	12.90
Shrimp (*Hippolytidae*)	<1	-	-	<1	0.05	-	-	<0.01	0.05	-	-	0.02
Arctic Eualid (*Eualus fabricii*)	<1	-	-	<1	0.06	-	-	<0.01	0.10	-	-	0.04
Greenland Shrimp (*Eualus macilentus*)	<1	-	<1	<1	0.12	-	0.02	0.02	0.09	-	0.03	0.05
Gaimard's Eualid (*Eualus gaimardii gaimardii*)	<1	-	-	<1	0.19	-	-	<0.01	0.23	-	-	0.10
Parrot Shrimp (*Spirontocaris spinus*)	<1	-	-	<1	0.09	-	-	<0.01	0.10	-	-	0.04
Boreal red shrimps (*Pandalus* sp.)	<1	<1	1.6	<1	0.36	1.80	1.77	1.71	0.43	1.44	1.75	1.13
Northern Shrimp (*Pandalus borealis*)	<1	1.4	6.5	2.6	1.28	13.68	15.30	14.49	1.84	11.73	15.83	9.13
Striped Pink Shrimp (*Pandalus montagui*)	<1	<1	<1	<1	1.79	0.96	0.56	0.66	1.09	0.97	0.83	0.97
Sevenline Shrimp (*Sabinea septemcarinata*)	-	<1	<1	<1	-	0.11	0.03	0.03	-	0.22	0.04	0.05
Norwegian Shrimp (*Pontophilus norvegicus*)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Shrimps, total	**2.6**	**6.5**	**28.6**	**12.0**	**11.65**	**35.41**	**47.57**	**44.71**	**9.08**	**32.91**	**47.12**	**28.46**
Calanoid copepod (*Calanoida*)	11.4	12.8	1.2	8.5	4.79	1.65	0.06	0.44	5.26	2.19	0.10	2.66
Calanoid copepod (*Calanus* sp.)	8.4	5.5	1.2	5.3	6.10	0.77	0.05	0.40	4.27	1.08	0.06	2.05
Calanoid Copepod (*Calanus finmarchicus*)	<1	-	<1	<1	0.02	-	<0.01	<0.01	0.02	-	<0.01	<0.01
Calanoid Copepod (*Calanus hyperboreus*)	6.5	14.6	3.5	7.8	2.40	1.91	0.15	0.43	1.67	2.36	0.22	1.17
Calanoid Copepod (*Calanus glacialis*)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Calanoid Copepod (*Tortanus discaudatus*)	-	<1	-	<1	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Calanoid copepod (*Scolecithricella* sp.)	-	<1	-	<1	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Calanoid copepod (*Calanus finn. + glacialis*)	<1	<1	<1	<1	0.17	0.15	<0.01	0.02	0.31	0.23	<0.01	0.17
Calanoid Copepod (*Bradyidius similis*)	<1	<1	-	<1	0.03	<0.01	-	<0.01	0.06	<0.01	-	0.03
Calanoid Copepod (*Temora longicornis*)	<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	0.05	0.03	-	<0.01	0.16	0.05	-	0.08
Calanoid copepod (*Euchaeta* sp.)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01

Prey	F_{occ}				MC				CTFI			
	< 20	[20–30[	≥ 30	Total	< 20	[20–30[	≥ 30	Total	< 20	[20–30[	≥30	Total
Calanoid Copepod (*Paraeuchaeta norvegica*)	2.6	4.8	1.6	2.9	0.31	0.29	0.02	0.06	0.24	0.39	0.03	0.17
Calanoid copepod (*Metridinidae*)	<1	<1	-	<1	0.03	<0.01	-	<0.01	0.02	<0.01	-	0.01
Calanoid copepod (*Metridia* sp.)	3.4	<1	<1	1.6	0.60	0.01	<0.01	0.03	0.69	0.02	<0.01	0.30
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
Hyperiid (*Hyperiidea*)	-	<1	-	<1	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Hyperiid (*Hyperiidae*)	2	<1	4.3	2.4	1.46	1.14	2.56	2.37	1.51	0.93	2.60	1.88
Hyperiid (*Themisto* sp.)	7.7	5.5	5	6.2	3.12	2.13	0.57	0.84	4.49	2.24	0.71	2.58
Hyperiid (*Themisto abyssorum*)	2.2	2.5	4.9	3.1	1.43	1.31	0.39	0.53	1.82	1.18	0.59	1.21
Hyperiid (*Themisto compressa*)	3.3	2.2	5.2	3.6	3.77	1.03	0.86	1.01	4.74	0.96	1.07	2.65
Hyperiid (*Hyperoche medusarum*)	-	-	<1	<1	-	-	<0.01	<0.01	-	-	<0.01	<0.01
Hyperiid (*Themisto libellula*)	1.1	1.7	4	2.2	1.79	2.54	2.31	2.3	2.18	3.41	2.34	2.43
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	0.09	<0.01	<0.01	<0.01	0.09	<0.01	<0.01	0.04
Gammarid (*Gammaridea*)	<1	<1	<1	<1	0.02	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	0.03
Gammarid (*Byblis* sp.)	<1	-	-	<1	0.02	-	-	<0.01	0.02	-	-	<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	0.02	0.01	-	<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	-	<1	0.30	0.02	-	0.02	0.18	0.05	-	0.09
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

Prey	F_{occ}				MC				CTFI			
	< 20	[20–30[	≥ 30	Total	< 20	[20–30[	≥ 30	Total	< 20	[20–30[	≥30	Total
Mysid (*Mysida*)	<1	<1	-	<1	<0.01	<0.01	-	<0.01	<0.01	<0.01	-	<0.01
Mysid (*Mysidae*)	1.4	<1	<1	<1	1.61	0.34	0.25	0.32	1.19	0.45	0.24	0.68
Mysid (*Boreomysis* sp.)	3.7	2.6	4.3	3.6	4.48	2.30	0.64	0.98	5.73	2.71	0.72	3.19
Mysid (*Boreomysis tridens*)	<1	<1	<1	<1	0.17	0.01	<0.01	0.02	0.10	0.02	<0.01	0.05
Mysid (*Boreomysis arctica*)	1.2	1.3	<1	1.2	1.34	1.01	0.26	0.39	1.96	1.29	0.27	1.15
Mysid (*Erythrops* sp.)	<1	<1	<1	<1	<0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
Mysid (*Erythrops erythrophthalma*)	<1	-	<1	<1	<0.01	-	<0.01	<0.01	0.01	-	<0.01	<0.01
Mysid (*Pseudomma* sp.)	<1	-	-	<1	0.02	-	-	<0.01	0.05	-	-	0.02
Mysid (*Pseudomma roseum*)	<1	-	-	<1	0.04	-	-	<0.01	0.04	-	-	0.02
Mysid (*Mysis* sp.)	<1	<1	<1	<1	0.08	0.09	<0.01	0.01	0.19	0.09	<0.01	0.1
Mysid (*Mysis mixta*)	<1	-	-	<1	0.03	-	-	<0.01	0.01	-	-	<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	0.04	<0.01	<0.01
Euphausiid (*Euphausiidae*)	3.3	2	2.4	2.7	6.23	4.65	0.78	1.41	6.15	4.43	0.73	3.64
Northern Krill (*Meganyctiphanes norvegica*)	3	4.6	5.8	4.3	8.88	7.57	2.72	3.47	7.22	8.30	3.47	5.81
Euphausiid (*Thysanoessa* sp.)	<1	1	<1	<1	3.78	1.69	0.09	0.42	3.32	1.63	0.14	1.74
Euphausiid (*Thysanoessa inermis*)	<1	<1	<1	<1	0.06	<0.01	<0.01	<0.01	0.06	<0.01	<0.01	0.03
Arctic Krill (*Thysanoessa raschii*)	<1	<1	<1	<1	0.82	0.70	0.01	0.12	1.08	0.99	0.02	0.63
Zooplankton, total	**40.6**	**36.3**	**23.7**	**34.0**	**54.19**	**31.44**	**11.76**	**15.64**	**55.05**	**35.11**	**13.35**	**34.72**
Invertebrate (*Invertebrata*)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Anemone (*Metridiidae*)	<1	-	-	<1	0.01	-	-	<0.01	0.05	-	-	0.02
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

Prey	F_{occ}				MC				CTFI			
	< 20	[20–30[	≥ 30	Total	< 20	[20–30[	≥ 30	Total	< 20	[20–30[	≥30	Total
Bobtail (*Rossia* sp.)	-	-	<1	<1	-	-	0.08	0.07	-	-	0.13	0.05
Polychaete (*Polychaeta*)	<1	-	<1	<1	<0.01	-	<0.01	<0.01	<0.01	-	<0.01	<0.01
Sea mouse (*Aphrodita hastata*)	<1	-	-	<1	0.08	-	-	<0.01	0.10	-	-	0.05
Crustacean (*Crustacea*)	18.3	11.3	10.6	13.9	14.81	5.16	3.48	4.18	13.51	5.74	3.69	8.27
Ostracod (*Ostracoda*)	<1	-	-	<1	<0.01	-	-	<0.01	<0.01	-	-	<0.01
Copepod (*Copepoda*)	4.3	3.8	1.3	3.2	1.97	0.63	0.06	0.20	2.30	0.76	0.09	1.15
Crustacean (*Malacostraca*)	<1	-	<1	<1	0.18	-	<0.01	0.01	0.46	-	<0.01	0.20
Cumacean (*Cumacea*)	1.1	<1	<1	<1	0.07	<0.01	<0.01	<0.01	0.12	<0.01	<0.01	0.05
Isopod (*Isopoda*)	-	<1	-	<1	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Isopod (*Syscenus infelix*)	-	-	<1	<1	-	-	0.02	0.02	-	-	0.03	0.01
Amphipod (*Amphipoda*)	1.5	1.3	3.2	2	5.63	6.82	5.77	5.87	8.09	5.14	6.48	6.99
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	0.18	-	0.08	0.08	0.17	-	0.09	0.11
Other invertebrates, total	**24.6**	**15.7**	**14.9**	**19**	**22.94**	**12.62**	**9.51**	**10.44**	**24.82**	**11.65**	**10.52**	**16.92**
Invertebrates, total	**54.9**	**48.1**	**46.8**	**50.4**	**88.78**	**79.47**	**68.84**	**70.79**	**88.95**	**79.67**	**70.99**	**80.09**
Unidentified digested material	5.4	3.8	5.1	4.9	9.70	3.97	2.77	3.21	10.36	4.30	2.93	6.36
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	**5.5**	**3.8**	**5.1**	**4.9**	**9.71**	**3.97**	**2.77**	**3.21**	**10.36**	**4.30**	**2.93**	**6.37**
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.

Prey	F_{occ}			MC			CTFI		
	1990s	2015–21	Total	1990s	2015–21	Total	1990s	2015–21	Total
Bony fish (*Actinopterygii*)	<1	-	<1	1.75	-	1.01	1.15	-	0.57
Atlantic Herring (*Clupea harengus*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Capelin (*Mallotus villosus*)	<1	<1	<1	11.48	4.36	8.46	5.79	4.34	5.06
Lanternfish (*Myctophidae*)	-	<1	<1	-	0.43	0.18	-	0.16	0.08
Kroyer's Lanternfish (*Notoscopelus kroyeri*)	-	<1	<1	-	1.07	0.46	-	0.31	0.15
Barracudinas (*Paralepis* sp.)	<1	-	<1	0.11	-	0.06	0.06	-	0.03
White Barracudina (*Arctozenus risso*)	<1	<1	<1	0.56	4.88	2.39	0.22	1.91	1.07
Slender Snipe Eel (*Nemichthys scolopaceus*)	-	<1	<1	-	0.42	0.18	-	0.17	0.08
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	-	0.19	0.17	-	0.09
Marlin-Spike (*Nezumia bairdii*)	<1	<1	<1	0.04	0.31	0.15	0.03	0.13	0.08
Shannies (*Lumpenus* sp.)	-	<1	<1	-	0.04	0.02	-	0.03	0.01
Slender Eelblenny (*Lumpenus fabricii*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Daubed Shanny (*Leptoclinus maculatus*)	-	<1	<1	-	0.06	0.02	-	0.05	0.02
Eelpout (*Zoarcidae*)	<1	-	<1	<0.01	-	<0.01	<0.01	-	<0.01
Atlantic Soft Pout (*Melanostigma atlanticum*)	<1	<1	<1	0.24	0.27	0.25	0.12	0.16	0.14
Redfish (*Sebastes* spp.)	<1	<1	<1	0.59	15.97	7.12	0.26	5.91	3.11
Flatfish (Pleuronectiformes)	-	<1	<1	-	0.11	0.05	-	0.03	0.02
Digested Roundfish	<1	<1	<1	0.89	2.20	1.45	0.51	1.12	0.82
Fish (spawn) egg	<1	<1	<1	<0.01	0.13	0.06	<0.01	0.05	0.02
Digested fish	1.8	1.2	1.5	4.96	2.42	3.88	2.72	1.52	2.12
Fishes, total	**4.2**	**3.5**	**3.8**	**20.99**	**32.78**	**26.00**	**11.09**	**15.95**	**13.54**
Digested shrimp (*Dendrobranchiata / Caridea*)	5.2	2.2	3.4	6.48	1.59	4.41	5.12	1.61	3.35
Glass shrimp (*Pasiphaeidae*)	<1	-	<1	1.40	-	0.81	0.80	-	0.40

Prey	F_{occ} 1990s	F_{occ} 2015–21	F_{occ} Total	MC 1990s	MC 2015–21	MC Total	CTFI 1990s	CTFI 2015–21	CTFI Total
Glass shrimp (*Pasiphaea* sp.)	<1	<1	<1	0.88	0.01	0.51	0.55	<0.01	0.28
Pink Glass Shrimp (*Pasiphaea multidentata*)	7.1	5.6	6.2	19.11	26.04	22.05	11.64	14.14	12.9
Shrimp (*Hippolytidae*)	-	<1	<1	-	<0.01	<0.01	-	0.04	0.02
Arctic Eualid (*Eualus fabricii*)	-	<1	<1	-	<0.01	<0.01	-	0.08	0.04
Greenland Shrimp (*Eualus macilentus*)	<1	<1	<1	0.03	0.01	0.02	0.02	0.08	0.05
Gaimard's Eualid (*Eualus gaimardii gaimardii*)	-	<1	<1	-	0.02	<0.01	-	0.20	0.10
Parrot Shrimp (*Spirontocaris spinus*)	-	<1	<1	-	0.01	<0.01	-	0.09	0.04
Boreal red shrimps (*Pandalus* sp.)	<1	<1	<1	2.19	1.05	1.71	1.30	0.96	1.13
Northern Shrimp (*Pandalus borealis*)	3.2	2.2	2.6	13.06	16.42	14.49	8.34	9.91	9.13
Striped Pink Shrimp (*Pandalus montagui*)	<1	<1	<1	0.55	0.80	0.66	0.97	0.96	0.97
Sevenline Shrimp (*Sabinea septemcarinata*)	-	<1	<1	-	0.08	0.03	-	0.10	0.05
Norwegian Shrimp (*Pontophilus norvegicus*)	<1	-	<1	0.01	-	<0.01	<0.01	-	<0.01
Shrimp, total	**15.0**	**10.1**	**12.0**	**43.72**	**46.05**	**44.71**	**28.76**	**28.17**	**28.46**
Calanoid Copepod (*Calanoida*)	<1	13.6	8.5	0.06	0.95	0.44	0.28	5.00	2.66
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
Hyperiid (*Hyperiidea*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Hyperiid (*Hyperiidae*)	5.4	<1	2.4	4.11	0.01	2.37	3.67	0.12	1.88
Hyperiids (*Themisto* sp.)	3	8.3	6.2	0.44	1.37	0.84	1.17	3.96	2.58
Hyperiid (*Themisto abyssorum*)	4.1	2.5	3.1	0.77	0.21	0.53	1.99	0.45	1.21
Hyperiid (*Themisto compressa*)	3.6	3.6	3.6	0.98	1.05	1.01	1.93	3.36	2.65
Hyperiid (*Hyperoche medusarum*)	<1	-	<1	<0.01	-	<0.01	<0.01	-	<0.01
Hyperiid (*Themisto libellula*)	3.3	1.5	2.2	3.02	1.34	2.3	2.89	1.97	2.43
Hyperiid (*Hyperia* sp.)	-	<1	<1	-	<0.01	<0.01	-	0.02	0.01
Hyperiid (*Hyperia galba*)	-	<1	<1	-	0.01	<0.01	-	0.01	<0.01
Hyperiid (*Scina borealis*)	<1	<1	<1	<0.01	0.01	<0.01	<0.01	0.08	0.04

Prey	F_{occ} 1990s	F_{occ} 2015–21	F_{occ} Total	MC 1990s	MC 2015–21	MC Total	CTFI 1990s	CTFI 2015–21	CTFI Total
Gammarid (*Gammaridea*)	<1	<1	<1	<0.01	<0.01	<0.01	<0.01	0.05	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	-	0.02	<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	0.03	0.02	0.03	0.14	0.09
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	0.56	<0.01	0.32	1.36	0.03	0.68
Mysid (*Boreomysis* sp.)	3.5	3.7	3.6	1.04	0.90	0.98	4.44	1.97	3.19
Mysid (*Boreomysis tridens*)	<1	<1	<1	0.02	<0.01	0.02	0.07	0.02	0.05
Mysid (*Boreomysis arctica*)	<1	1.5	1.2	0.34	0.45	0.39	0.42	1.87	1.15
Mysid (*Erythrops* sp.)	-	<1	<1	-	<0.01	<0.01	-	0.01	<0.01
Mysid (*Erythrops erythrophthalma*)	-	<1	<1	-	<0.01	<0.01	-	0.01	<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	-	0.03	0.01	-	0.19	0.10
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	0.01	<0.01
Euphausiid (*Euphausiidae*)	2.1	3	2.7	1.38	1.46	1.41	2.62	4.64	3.64
Northern Krill (*Meganyctiphanes norvegica*)	3.2	5.1	4.3	1.51	6.13	3.47	2.57	9.01	5.81

Prey	F_{occ}			MC			CTFI		
	1990s	2015–21	Total	1990s	2015–21	Total	1990s	2015–21	Total
Euphausiid (*Thysanoessa* sp.)	-	1.1	<1	-	0.99	0.42	-	3.46	1.74
Euphausiid (*Thysanoessa inermis*)	<1	<1	<1	<0.01	0.02	<0.01	<0.01	0.06	0.03
Arctic Krill (*Thysanoessa raschii*)	<1	<1	<1	<0.01	0.28	0.12	<0.01	1.24	0.63
Zooplankton, total	**20.1**	**42.9**	**34.0**	**14.53**	**17.13**	**15.64**	**24.35**	**44.90**	**34.72**
Invertebrate (*Invertebrata*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Anemone (*Metridiidae*)	-	<1	<1	-	<0.01	<0.01	-	0.04	0.02
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	-	0.16	0.07	-	0.11	0.05
Polychaete (*Polychaeta*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Sea mouse (*Aphrodita hastata*)	-	<1	<1	-	<0.01	<0.01	-	0.09	0.05
Crustacean (*Crustacea*)	10.4	16.1	13.9	5.58	2.28	4.18	8.60	7.94	8.27
Ostracod (*Ostracoda*)	-	<1	<1	-	<0.01	<0.01	-	<0.01	<0.01
Copepod (*Copepoda*)	2.8	3.5	3.2	0.22	0.19	0.20	1.48	0.83	1.15
Crustacean (*Malacostraca*)	<1	-	<1	0.02	-	0.01	0.41	-	0.20
Cumacean (*Cumacea*)	-	<1	<1	-	<0.01	<0.01	-	0.11	0.05
Isopod (*Isopoda*)	<1	-	<1	<0.01	-	<0.01	<0.01	-	<0.01
Isopod (*Syscenus infelix*)	-	<1	<1	-	0.05	0.02	-	0.02	0.01
Amphipod (*Amphipoda*)	4.2	<1	2	10.18	0.02	5.87	13.88	0.21	6.99
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

Prey	F_{occ} 1990s	F_{occ} 2015–21	F_{occ} Total	MC 1990s	MC 2015–21	MC Total	CTFI 1990s	CTFI 2015–21	CTFI Total
Digested invertebrates	<1	<1	<1	0.11	0.03	0.08	0.18	0.04	0.11
Other invertebrates, total	**16.9**	**20.3**	**19.0**	**16.13**	**2.75**	**10.44**	**24.56**	**9.40**	**16.92**
Invertebrates, total	**38.4**	**58.1**	**50.4**	**74.38**	**65.93**	**70.79**	**77.67**	**82.48**	**80.09**
Unidentified digested material	6.5	3.8	4.9	4.63	1.29	3.21	11.24	1.57	6.36
Unidentified egg	<1	<1	<1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Unidentifiable preys, total	**6.5**	**3.8**	**4.9**	**4.63**	**1.30**	**3.21**	**11.24**	**1.57**	**6.37**
Total	**-**	**-**	**-**	**100**	**100**	**100**	**100**	**100**	**100**

FIGURES

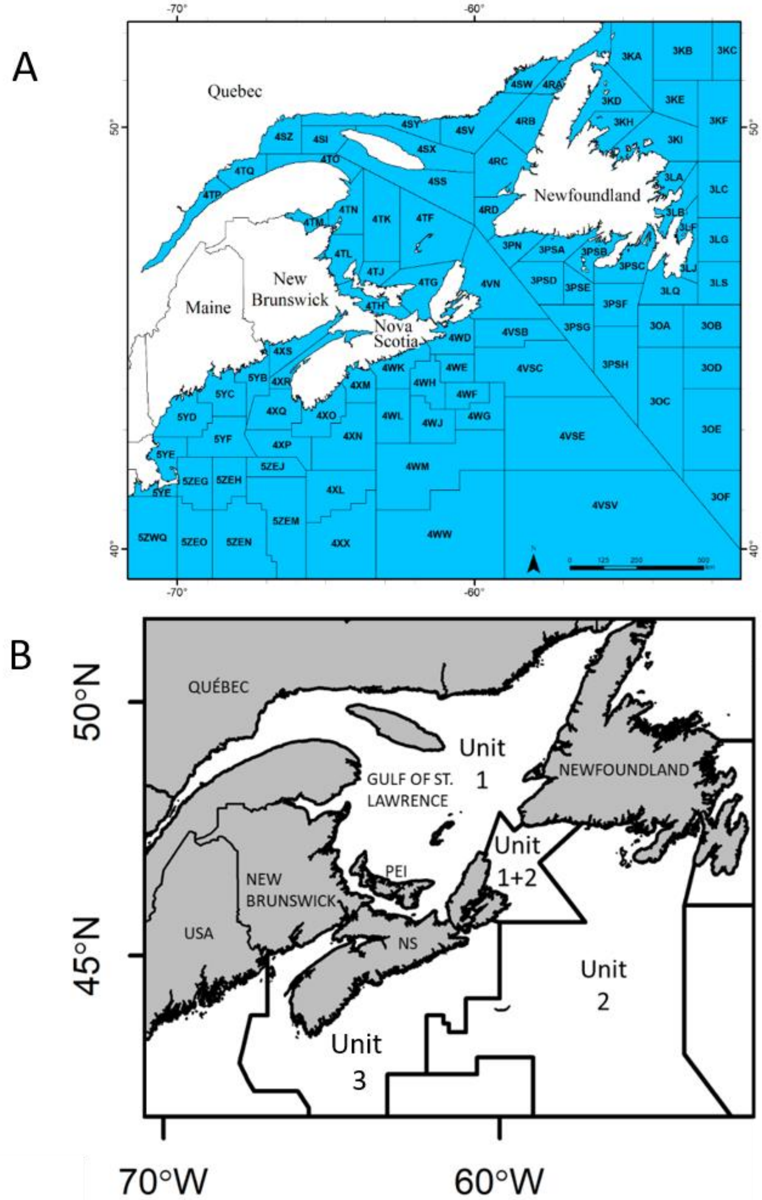

Figure 1. Northwest Atlantic Fishery Organization (NAFO) Divisions and Subdivisions (A), and management Units 1, 2, and 3 (B). PEI = Prince Edward Island, NS = Nova Scotia, USA = United States of America.

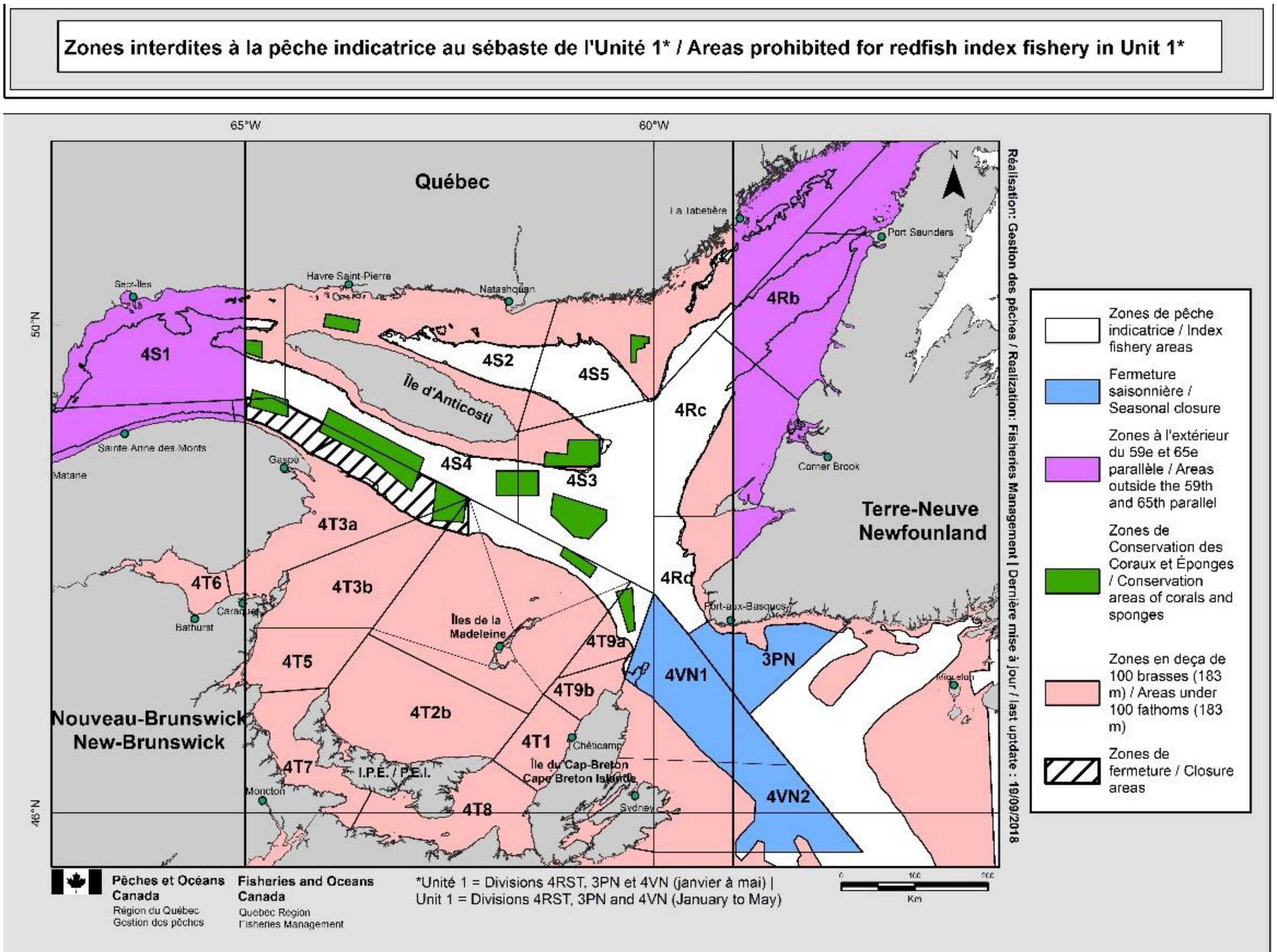

Figure 2. Closure areas pertaining to the Redfish index fishery. PEI = Prince Edward Island.

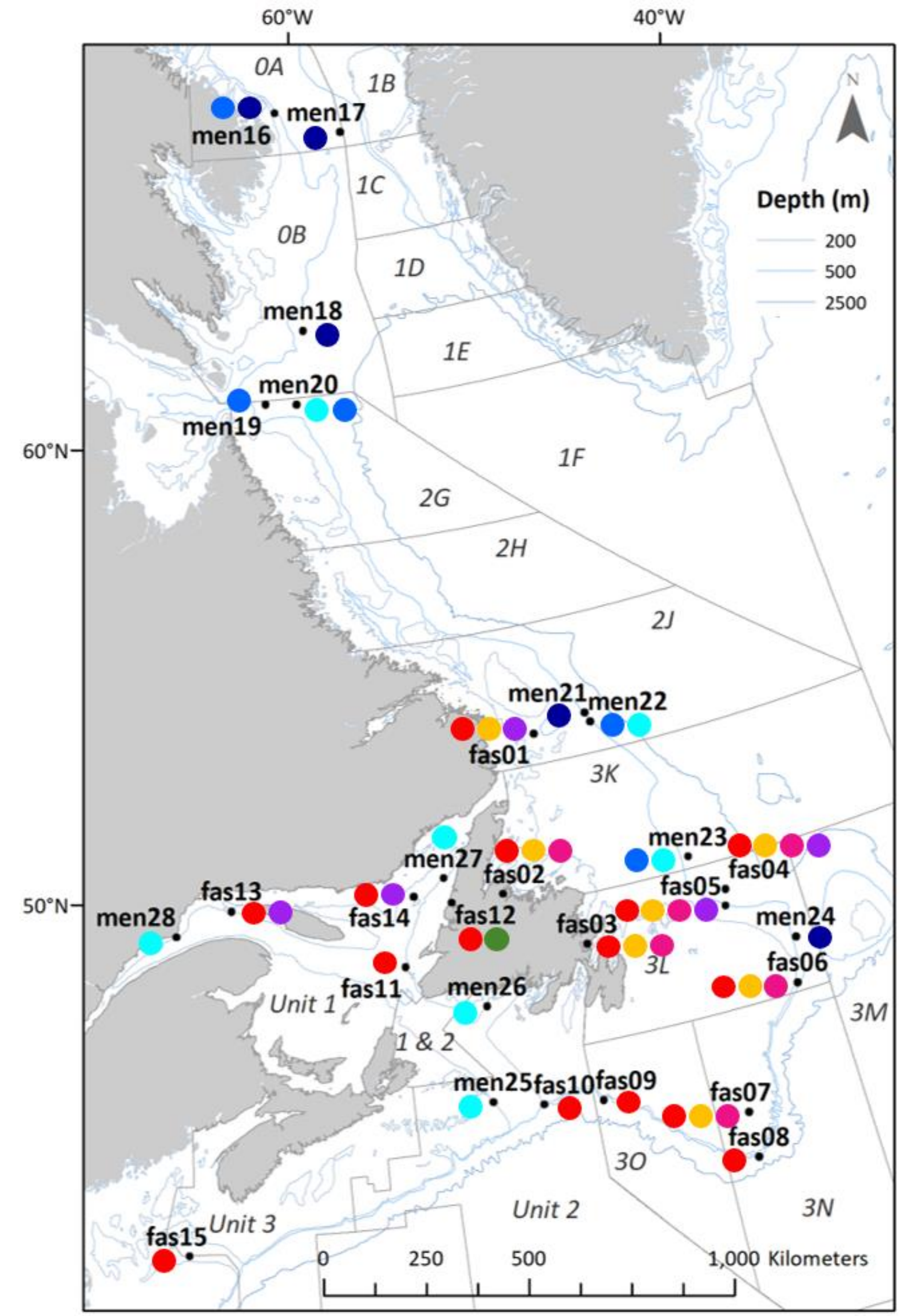

Figure 3. Map of the 28 locations (black points) sampled from 2001 to 2015 in the Northwest Atlantic. The colored points next to each sampling point indicate the presence of genetic clusters. A genetic cluster was indicated as present if one individual showed at least 50% associated ancestry in the sampling 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.*

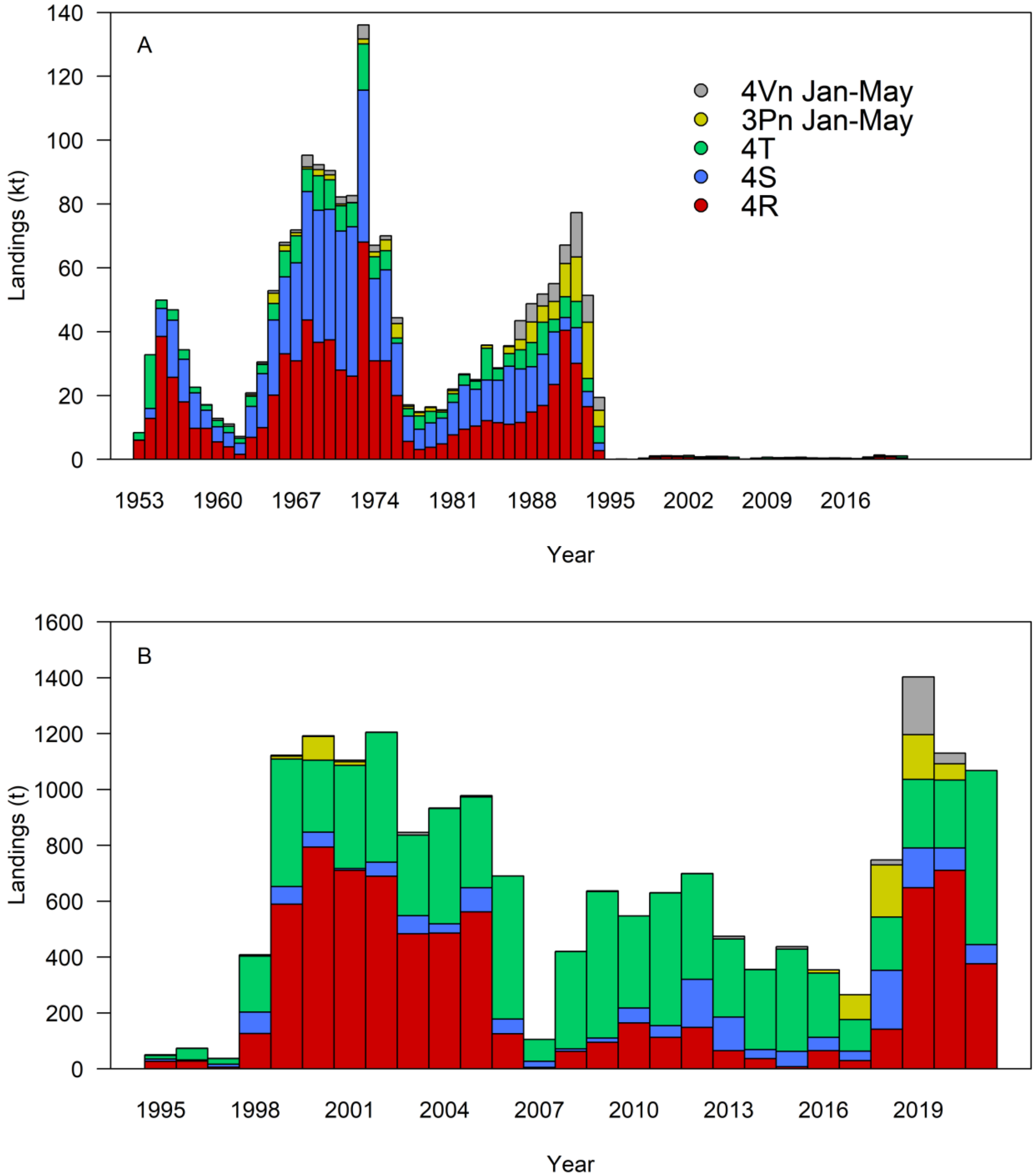

Figure 4. Commercial fishery annual Redfish landings in Unit 1 per NAFO Division or Subdivision from 1953 to 2021 (A, thousands of t (kt)) and from 1995-2021 (B, t). Data include fisheries directed to all species. No Redfish directed fishery took place from 1995 to 1997. 2020 and 2021 values are preliminary.

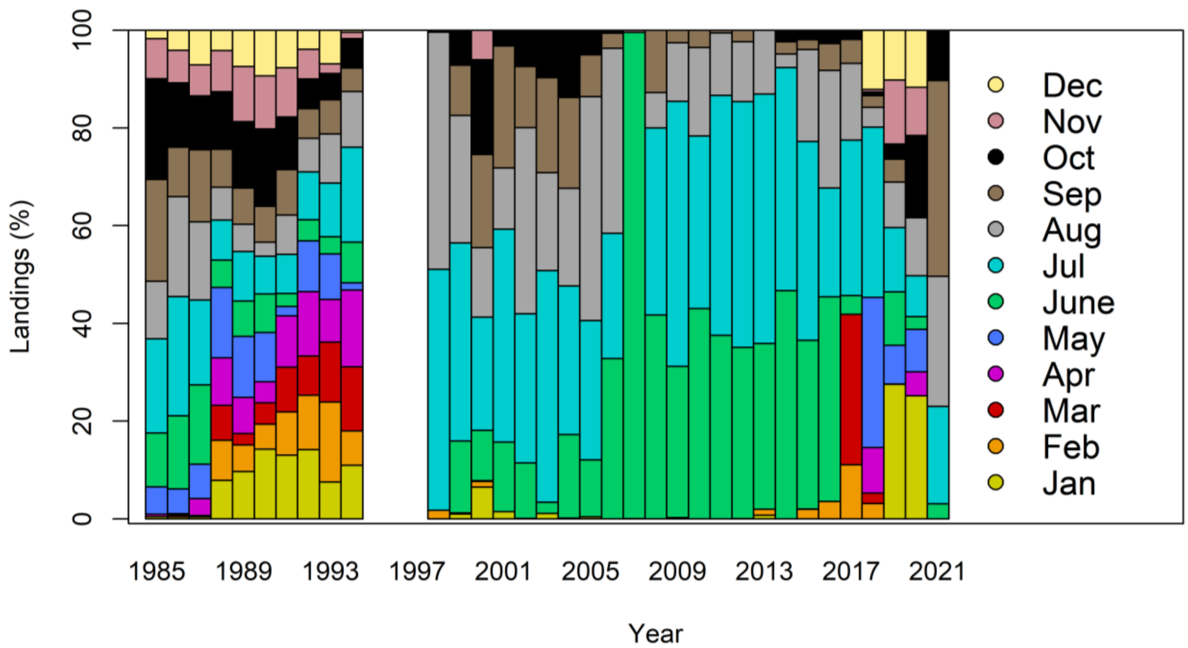

Figure 5. Redfish annual landings (biomass percentage) by month in Unit 1 from 1985 to 2021. Data include only Redfish directed fishery. No Redfish directed fishery took place from 1995 to 1997. 2020 and 2021 values are preliminary.

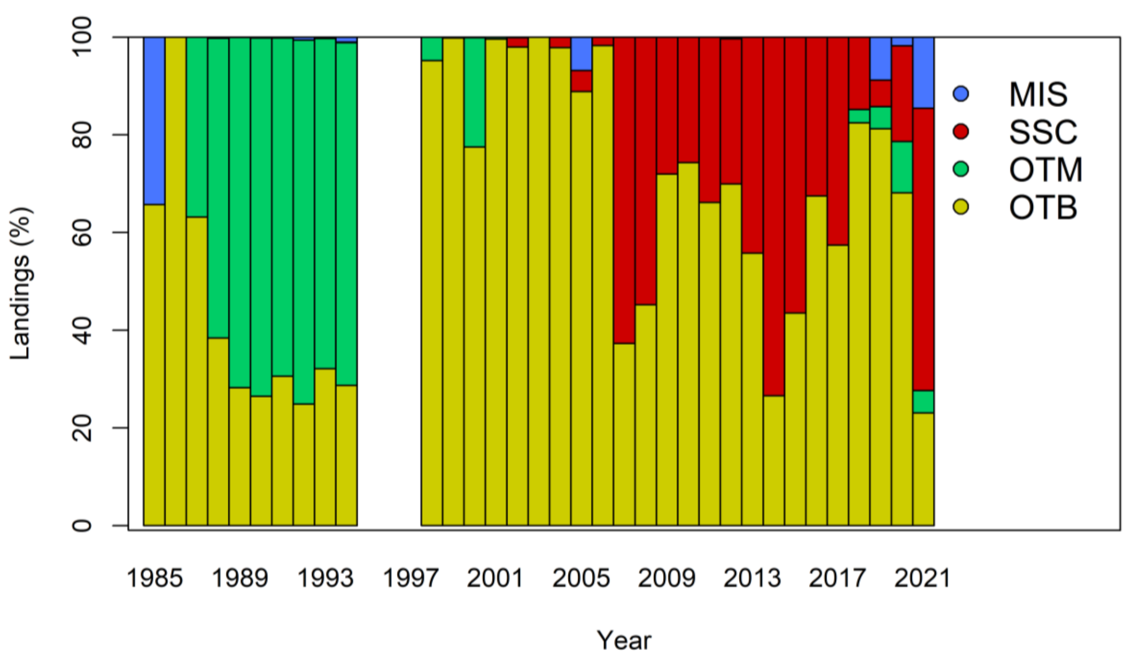

Figure 6. Redfish annual landings (biomass percentage) by gear in Unit 1 from 1985 to 2021. Data include only the Redfish directed fishery. No Redfish directed fishery took place from 1995 to 1997. 2020 and 2021 values are preliminary. OTB: bottom trawl, OTM: midwater trawl, SSC: Scottish seine, and MIS: miscellaneous.

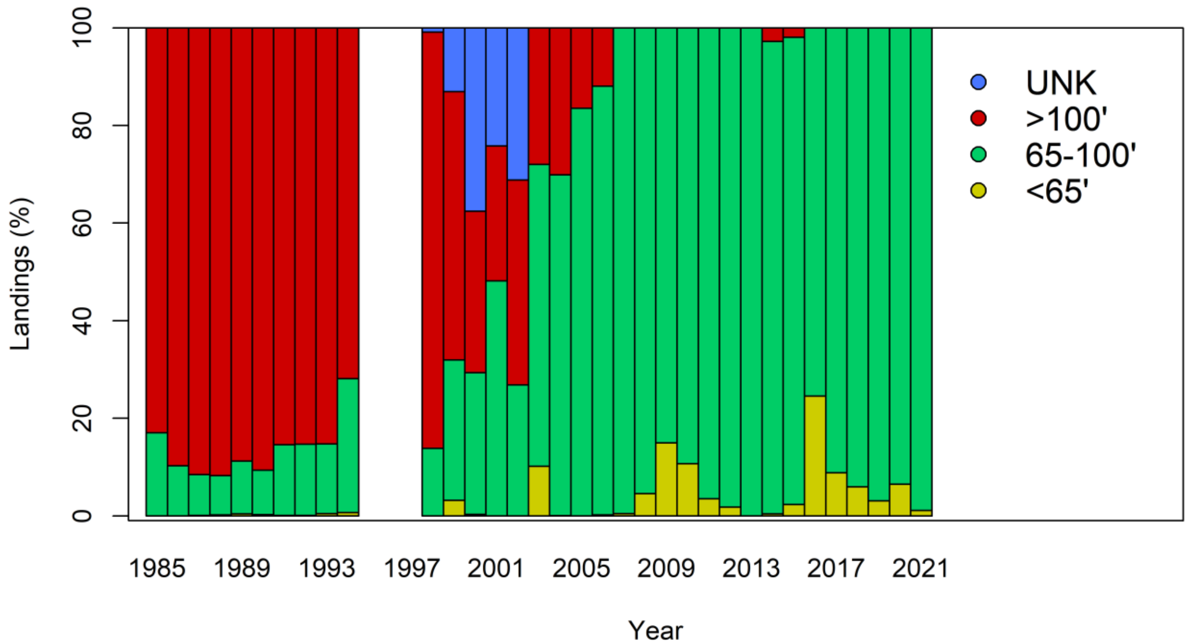

Figure 7. Redfish annual landings (biomass percentage) by boat size (feet) in Unit 1 from 1985 to 2021. Data include only the Redfish directed fishery. No Redfish directed fishery took place from 1995 to 1997. 2020 and 2021 values are preliminary. UNK: unknown.

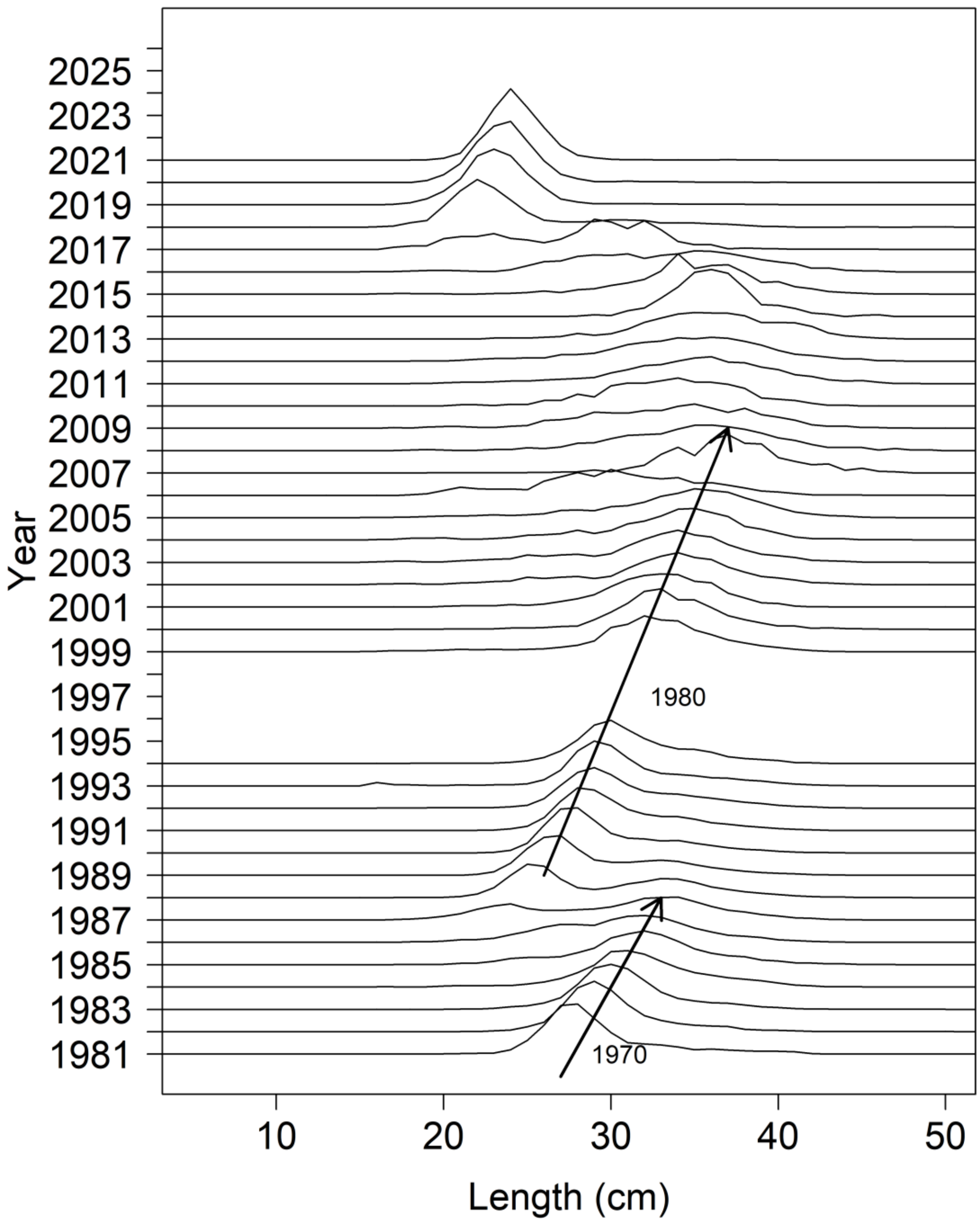

Figure 8. Commercial catch length frequency in percentage in Unit 1 from 1981 to 2021 based on at-sea-observer and port sampler data. No Redfish directed fishery took place from 1995 to 1997. The arrows indicate growth trajectories of the 1970 and 1980 cohorts. 2020 and 2021 values are preliminary.

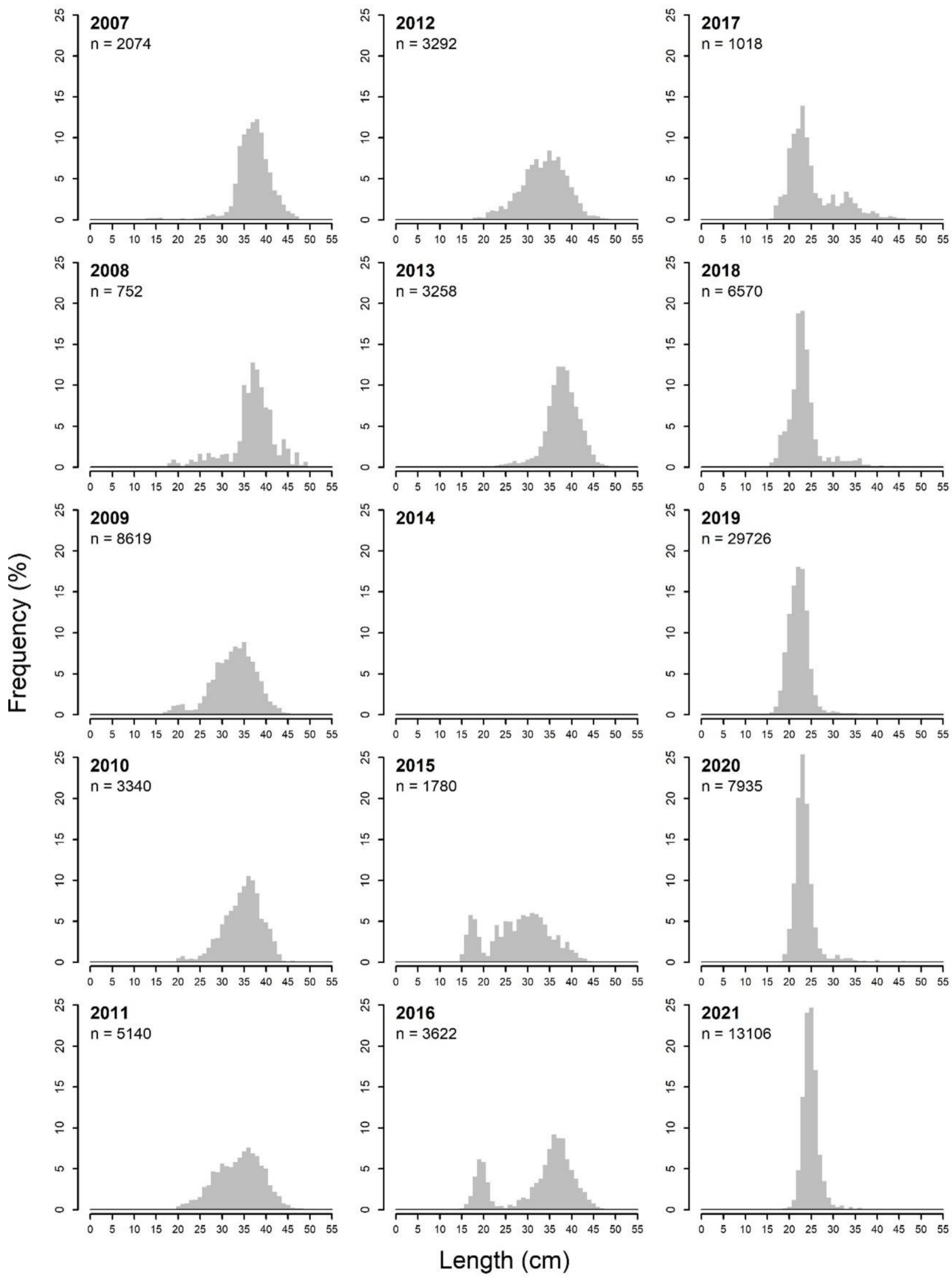

Figure 9. Redfish length frequency (%) in Unit 1 from 2007 to 2021 based on at-sea-observer data. Numbers of fish measured are indicated (n). No fish were sampled in 2014. 2020 and 2021 values are preliminary.

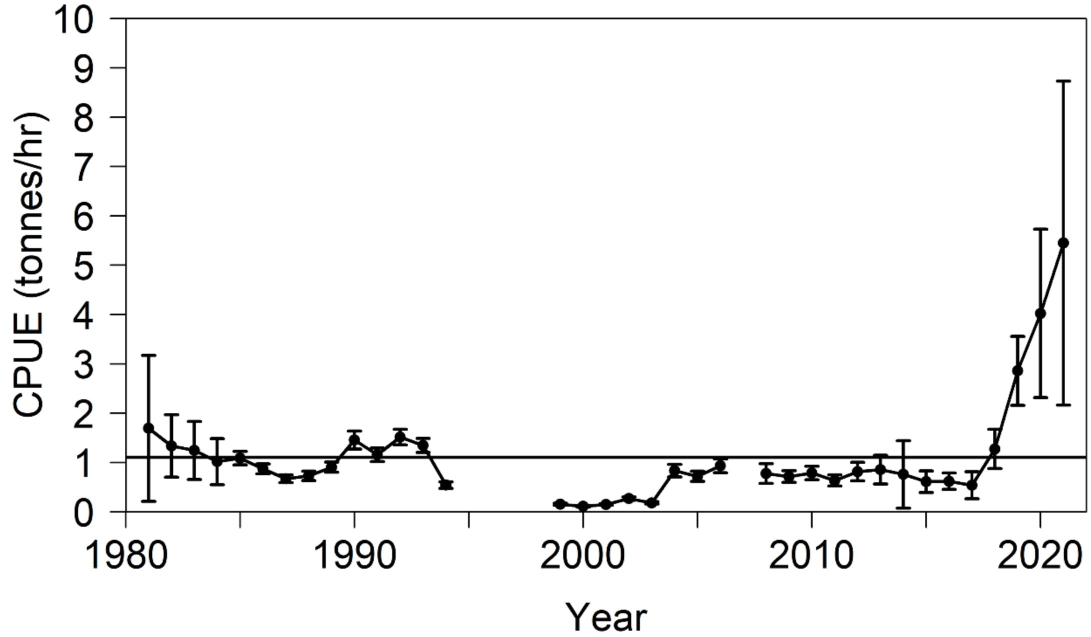

Figure 10. Standardized bottom trawl catch-per-unit-effort (CPUE with 95% confidence intervals) in the Unit 1 commercial fishery between May and October (1981–1994), index fishery (1999–2006 and 2008–2021), and experimental fishery (2018–2021). 2007 is not presented given the very limited fishing activities. The solid line represents the series average. 2020 and 2021 values are preliminary.

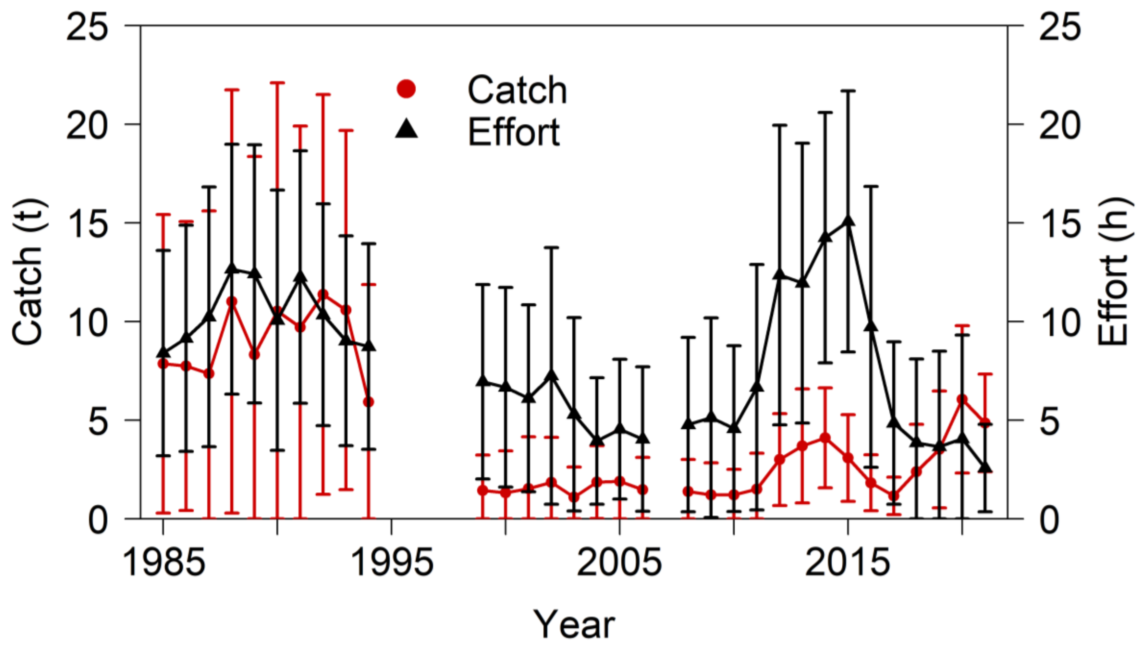

Figure 11. Average catch (red circles) and effort (black triangles) in the Redfish fishery between May and October (1985–1994), index fishery (1999–2006 and 2008–2021), and experimental fishery (2018–2021). Error bars represent standard deviation. 2020 and 2021 values are preliminary.

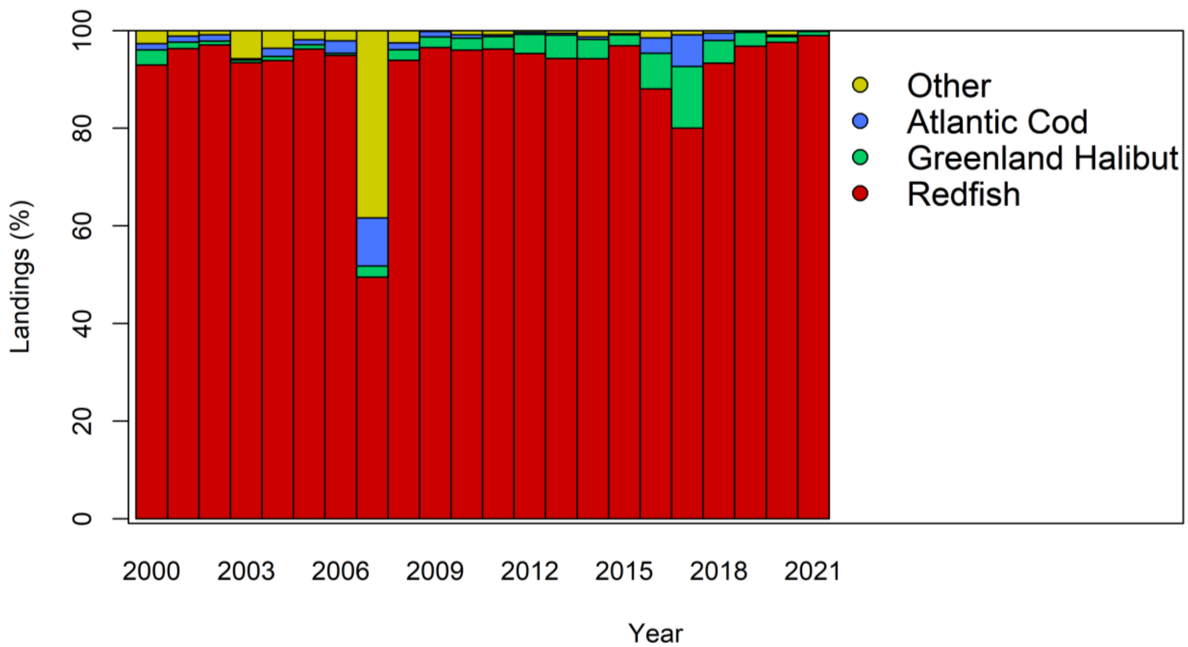

Figure 12. Redfish annual landings (biomass percentage) in Unit 1 as a function of targeted species by the fishery from 2000 to 2021. 2020 and 2021 values are preliminary.

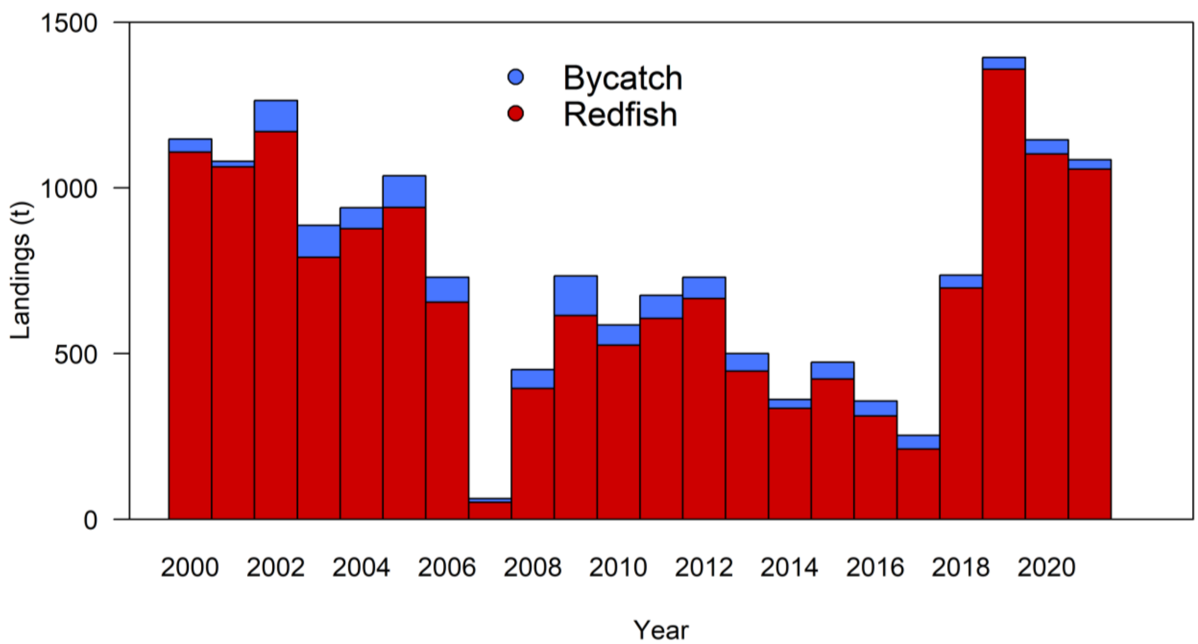

Figure 13. Annual landings of Redfish and bycatch (t) in the Redfish directed fishery in Unit 1 from 2000 to 2021. 2020 and 2021 values are preliminary.

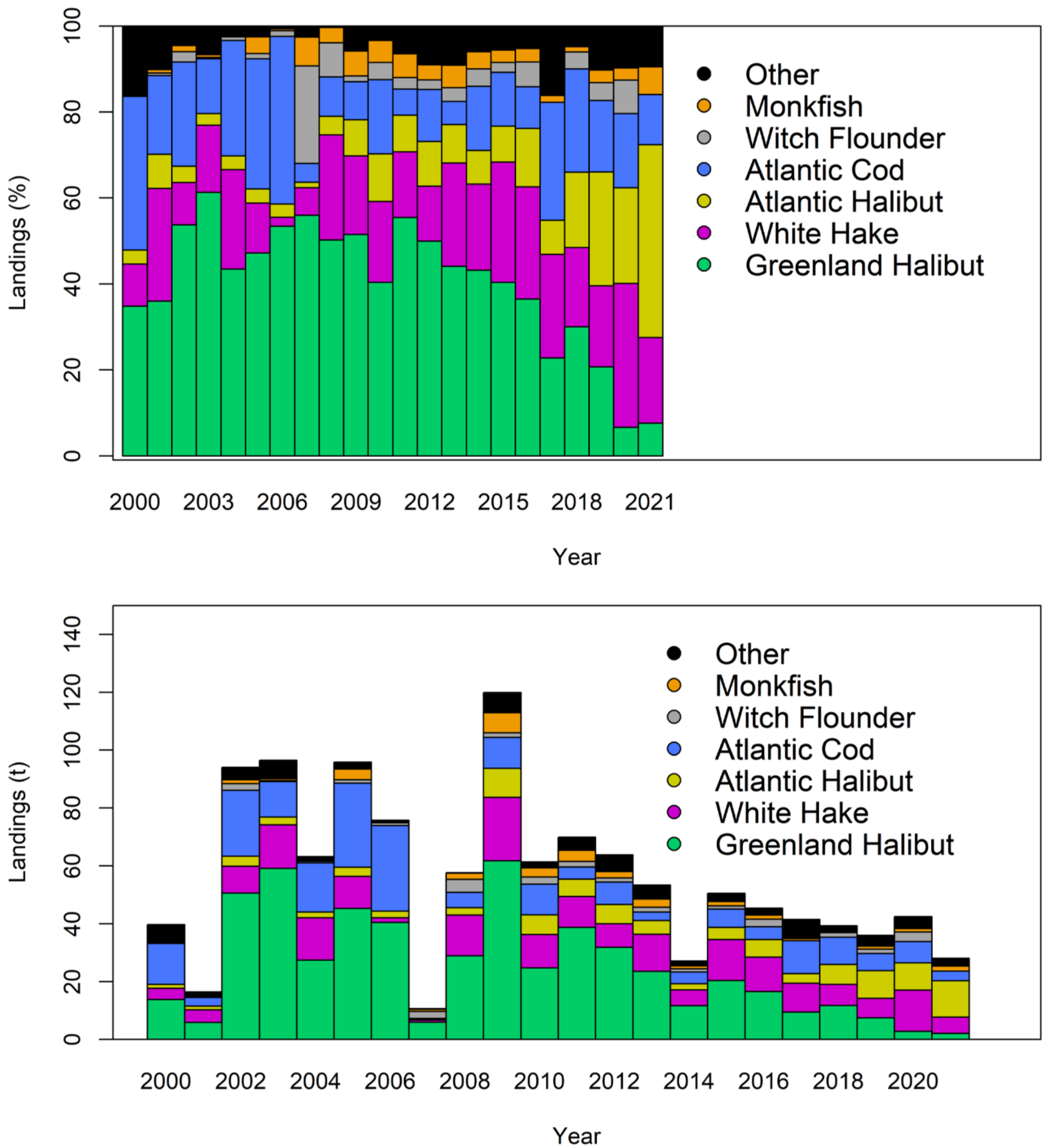

Figure 14. Annual bycatch landings (biomass percentage and tonnes) by species captured in the Redfish directed fishery in Unit 1 from 2000 to 2021. 2020 and 2021 values are preliminary.

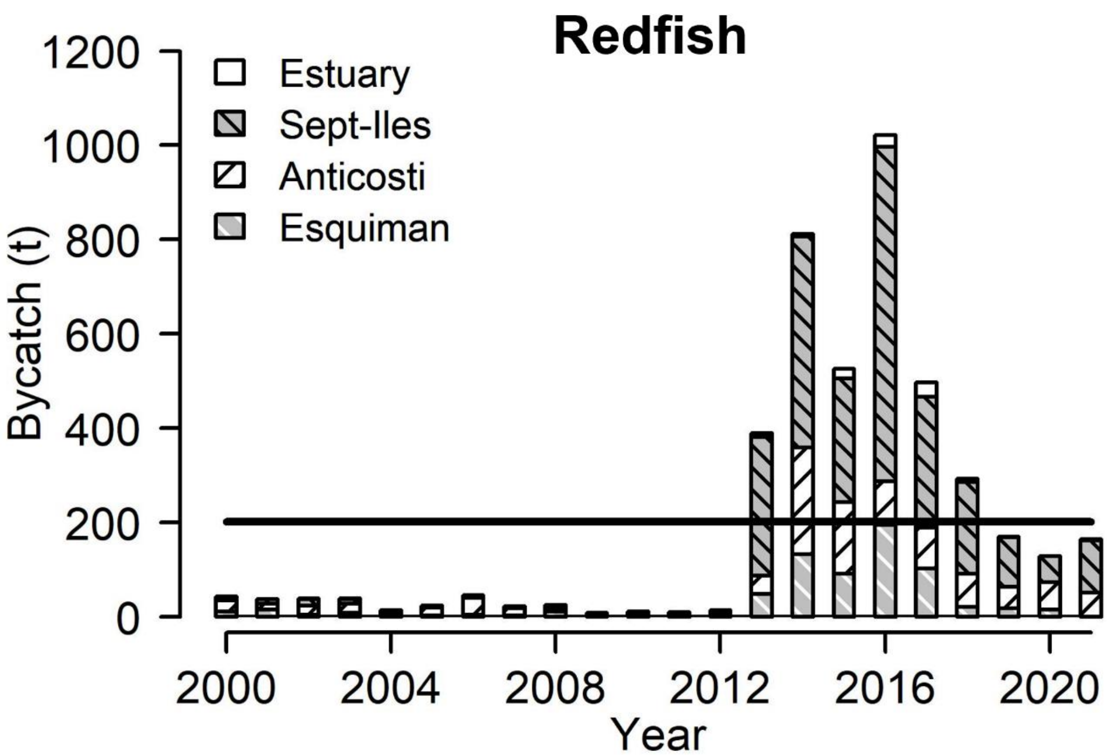

Figure 15. Annual estimated Redfish bycatch (t) in the Northern Shrimp fishery by shrimp fishing areas based on at-sea observer data. The solid horizontal line represents the 2000–2019 average. 2020 and 2021 values are preliminary.

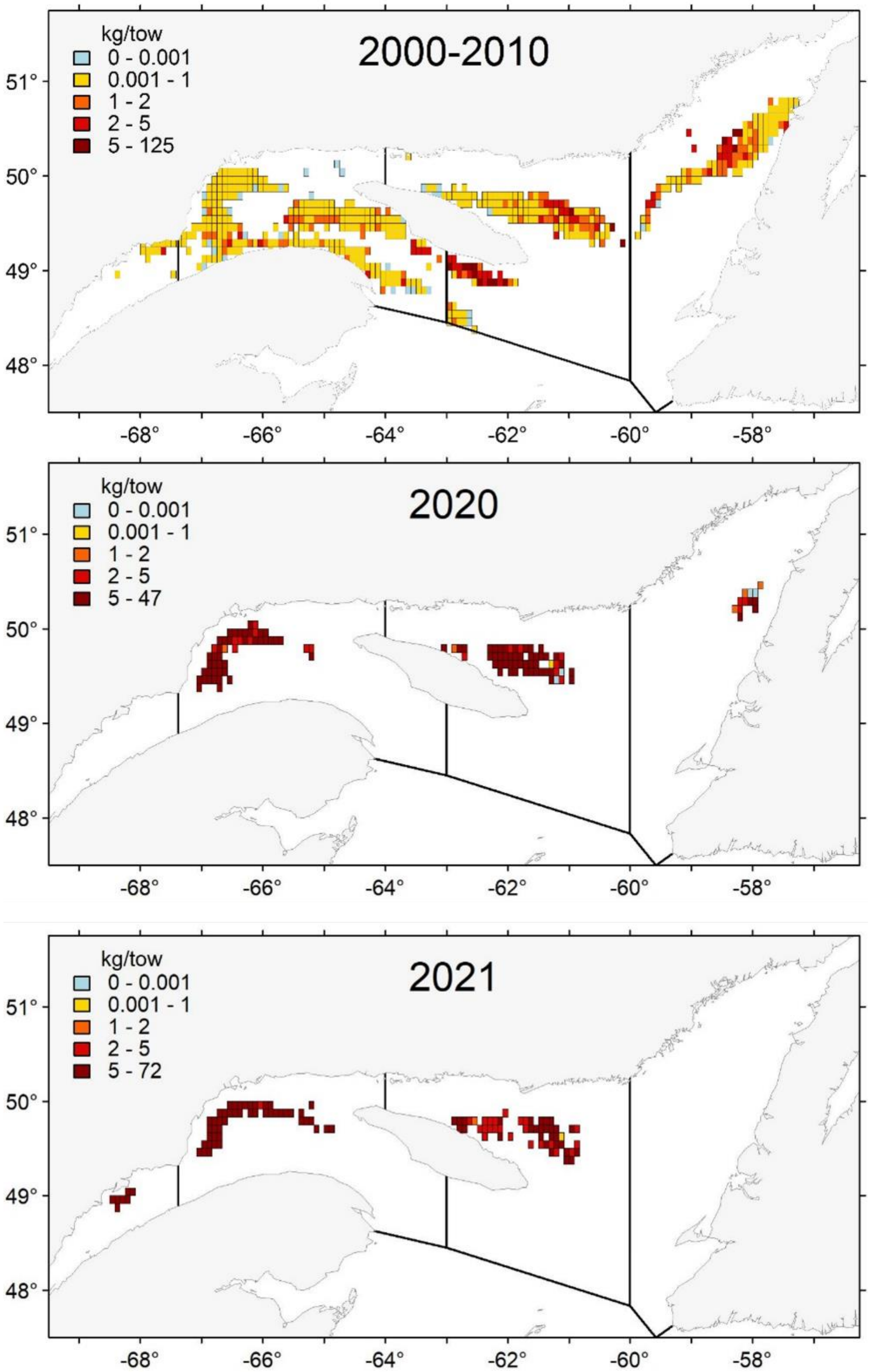

Figure 16. Redfish bycatch rate (kg/tow) distribution in the Northern Shrimp fishery from 2000–2010, 2020, and 2021. 2020 and 2021 values are preliminary.

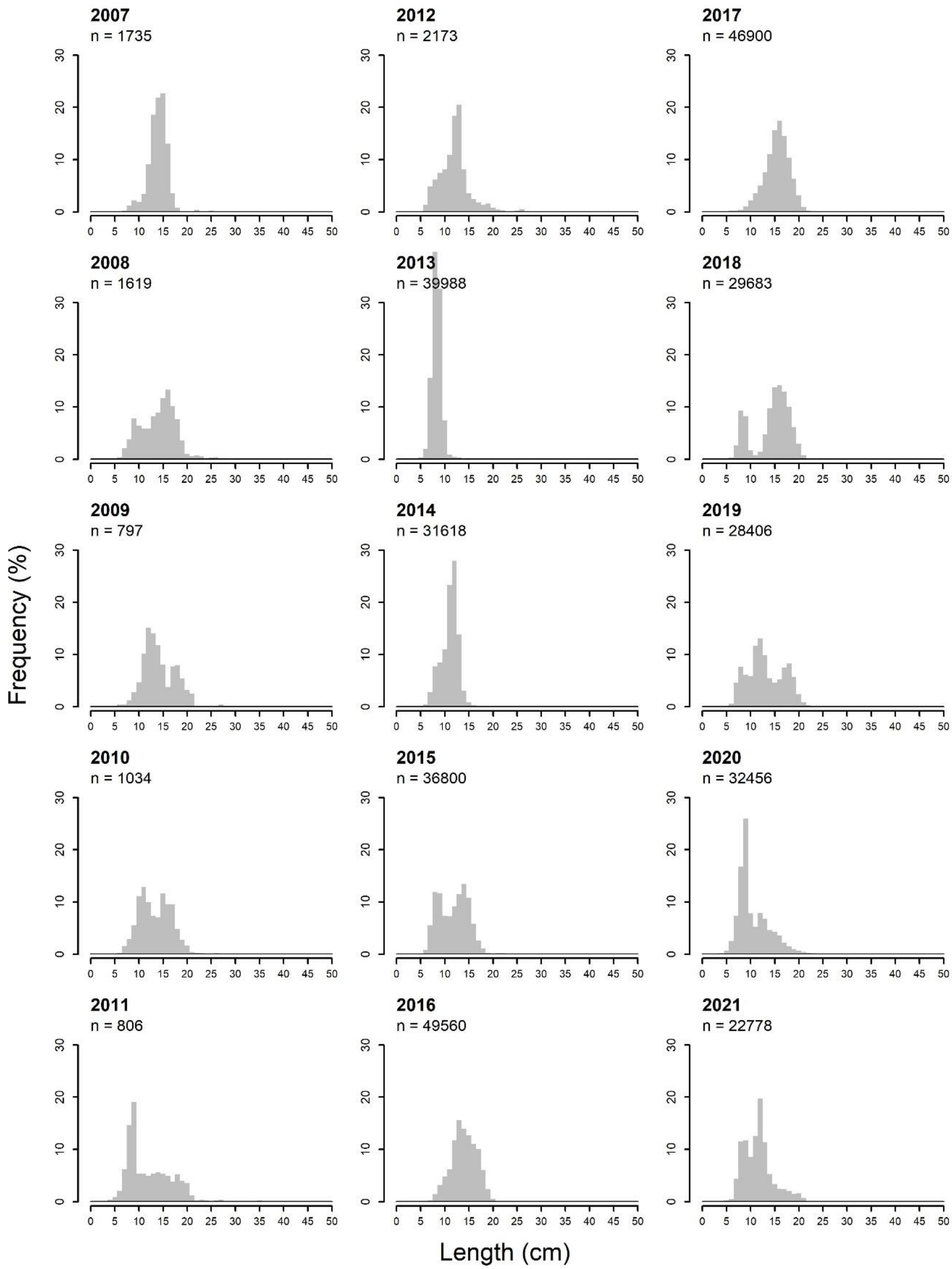

Figure 17. Length frequency of Redfish caught as bycatch in the Northern Shrimp fishery from 2007 to 2021. The numbers of fish measured are indicated (n). 2020 and 2021 values are preliminary.

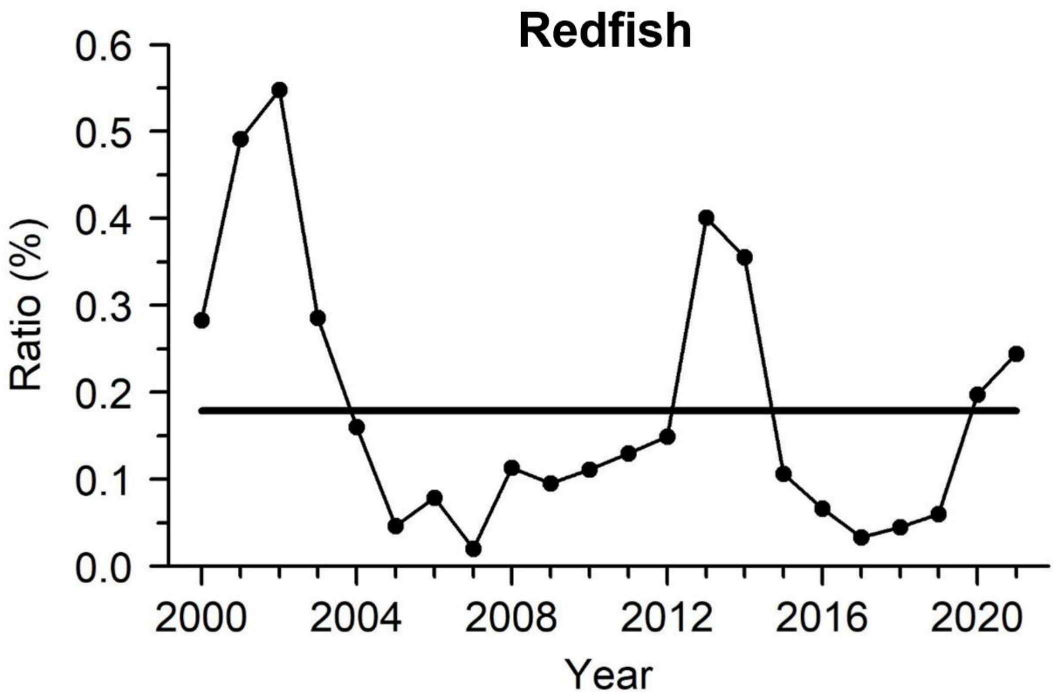

Figure 18. Ratio (%) between the quantity of Redfish caught as bycatch in the Northern Shrimp fishery and research survey minimum trawlable biomass of Redfish smaller than 20 cm from 2000 to 2021. Solid line indicates the average for the years 2000–2019. 2020 and 2021 values are preliminary.

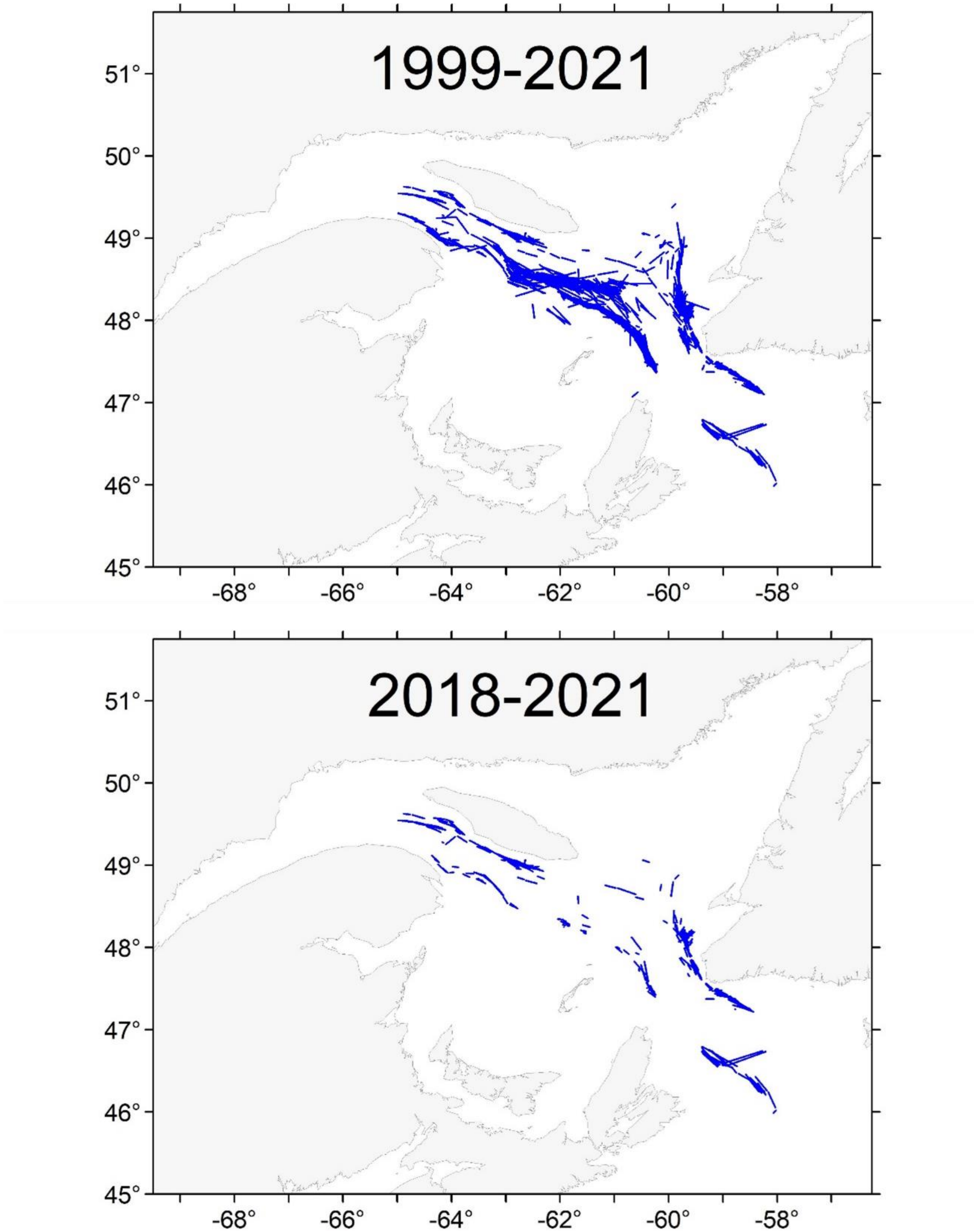

Figure 19. Start and end position of tows sampled by at-sea observers in Unit from 1999 to 2021 (2,057 tows, upper panel) and from 2018 to 2021 (590 tows, lower panel). Data include the index fishery from 1999 to 2017, and both the index and experimental fisheries from 2018–2021. 2020 and 2021 values are preliminary.

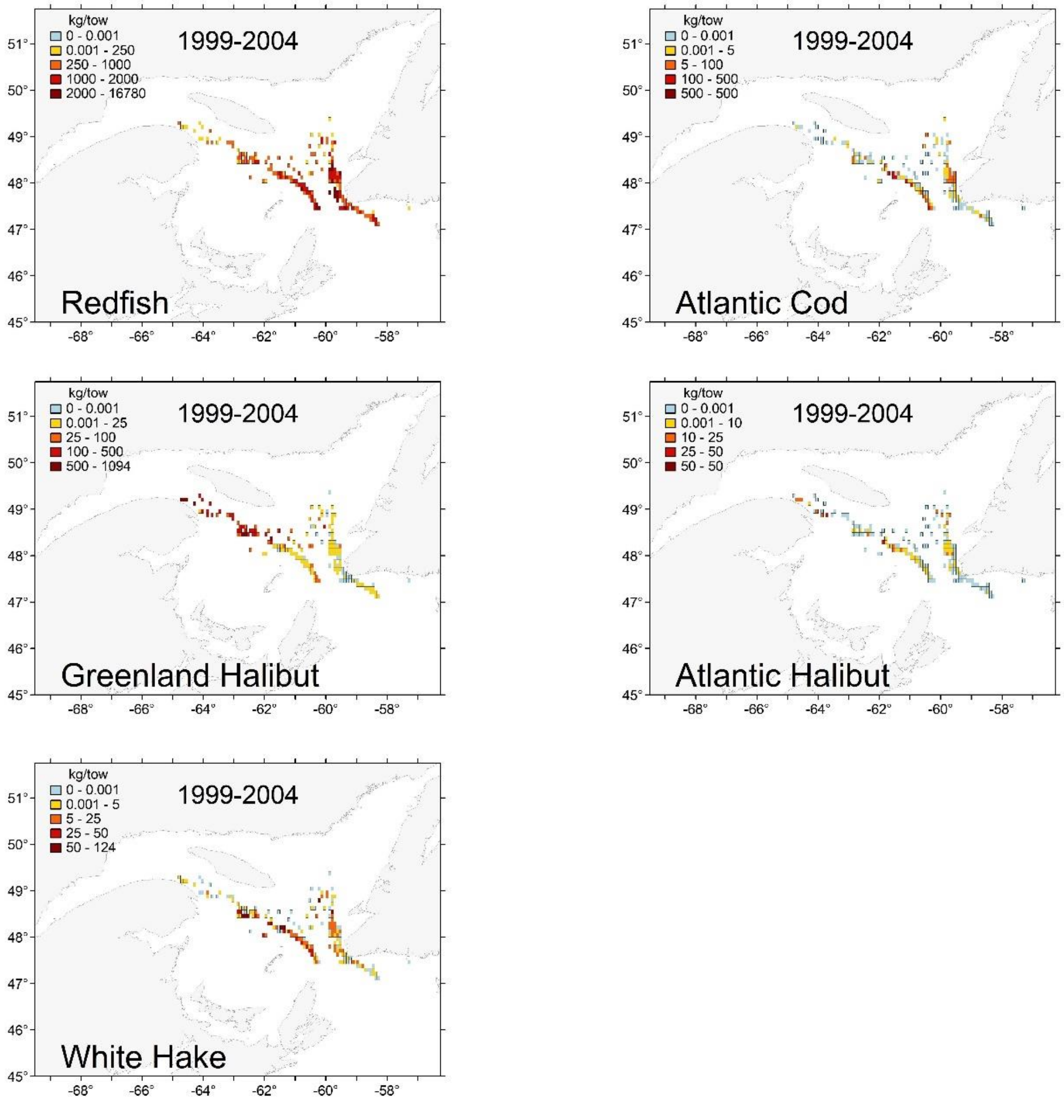

Figure 20. Catch rate (kg/tow) spatial distribution of Redfish, Greenland Halibut, White Hake, Atlantic Cod, and Atlantic Halibut based on at-sea observer data in the Redfish directed fishery for different time periods: 1999–2004, 2005–2010, 2011–2016, and 2017–2021. 2020 and 2021 values are preliminary.

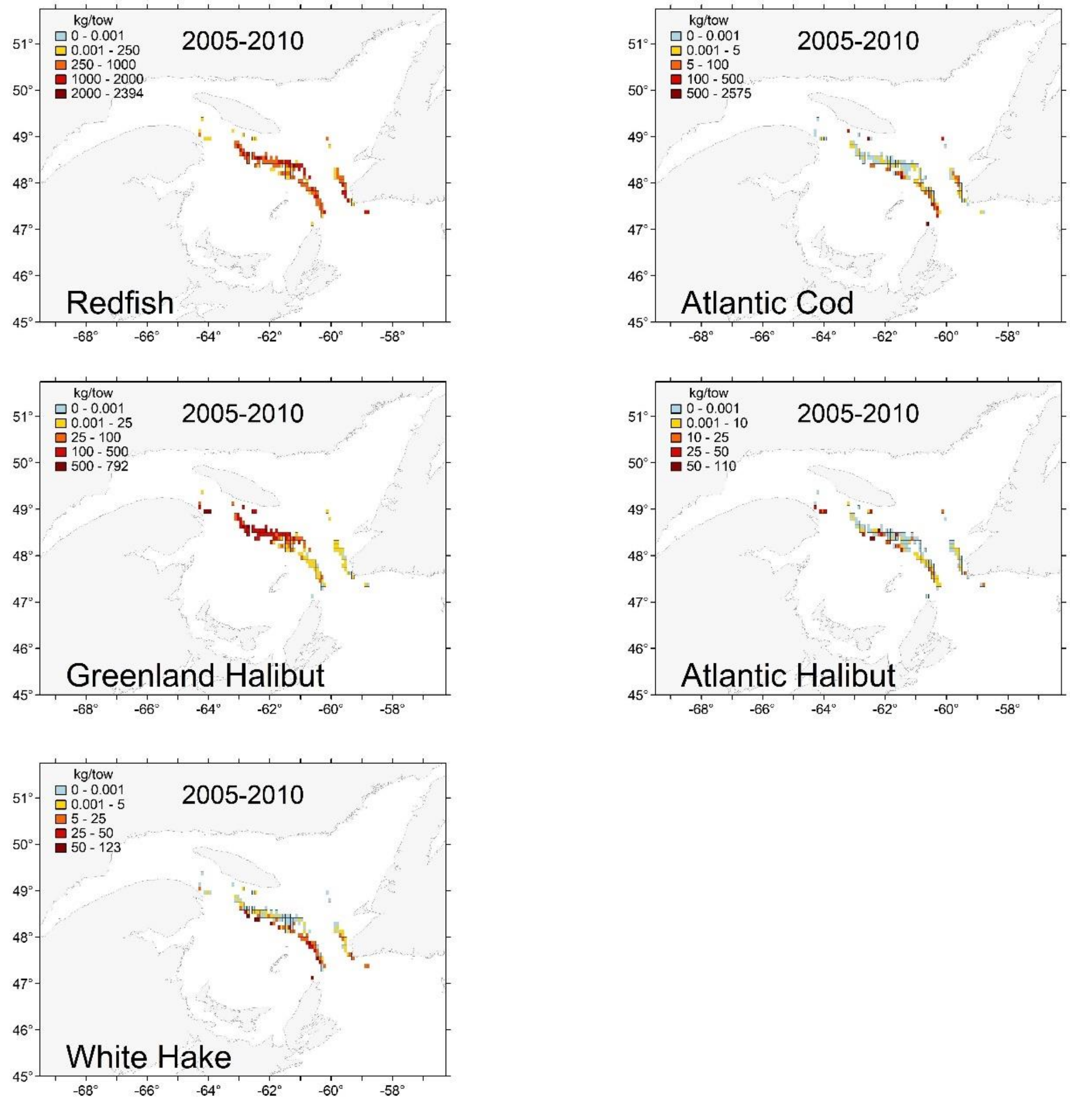

Figure 20. Continued

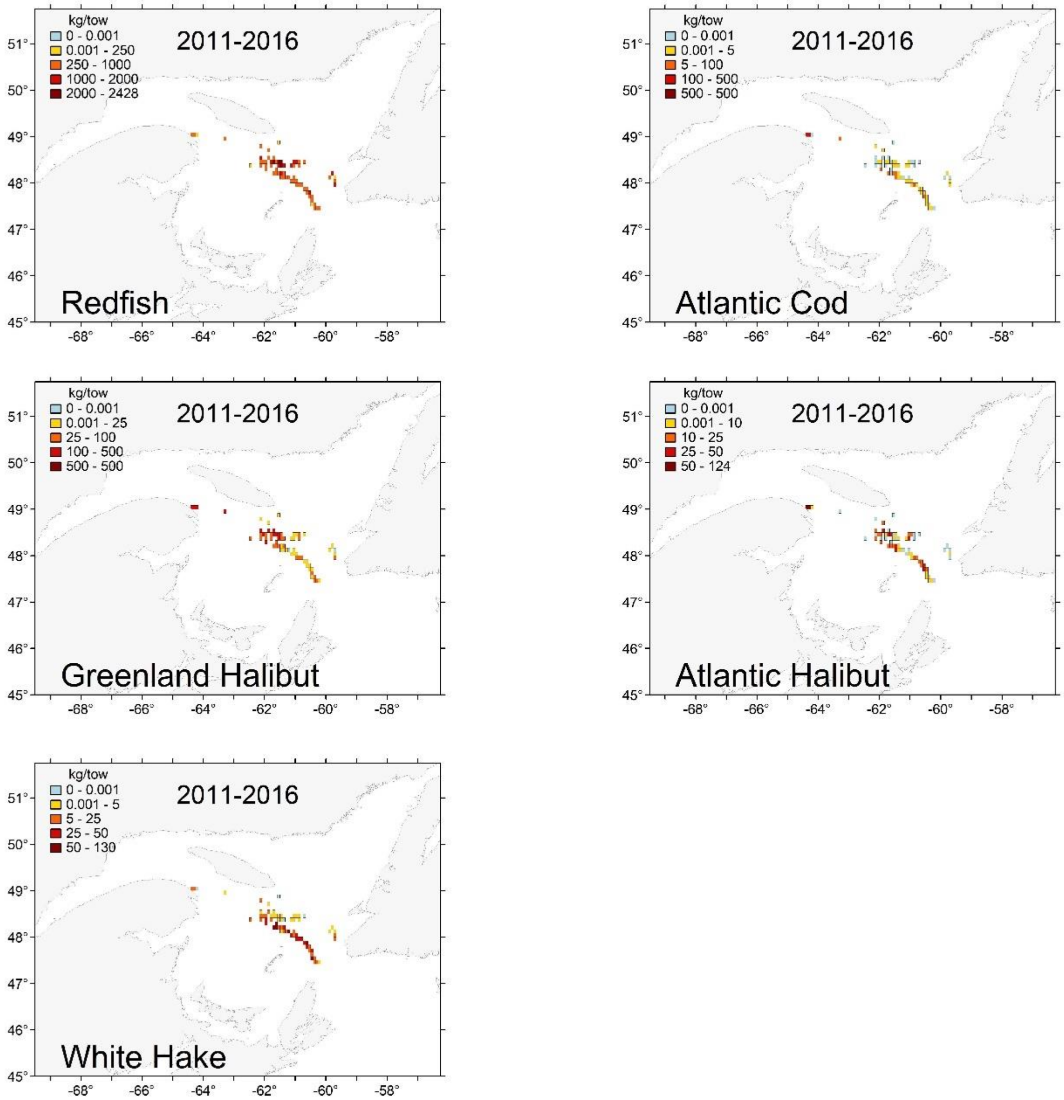

Figure 20. Continued

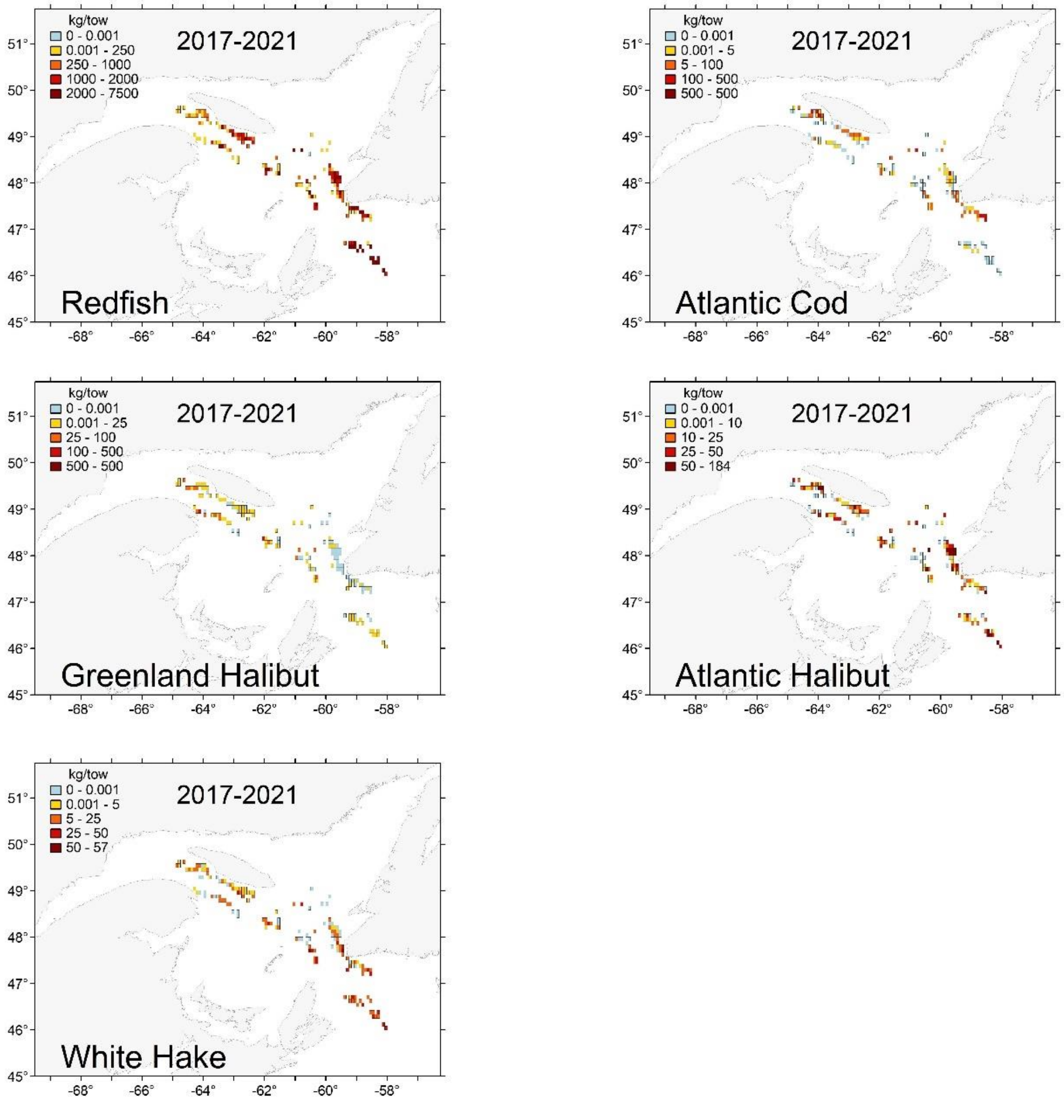

Figure 20. Continued

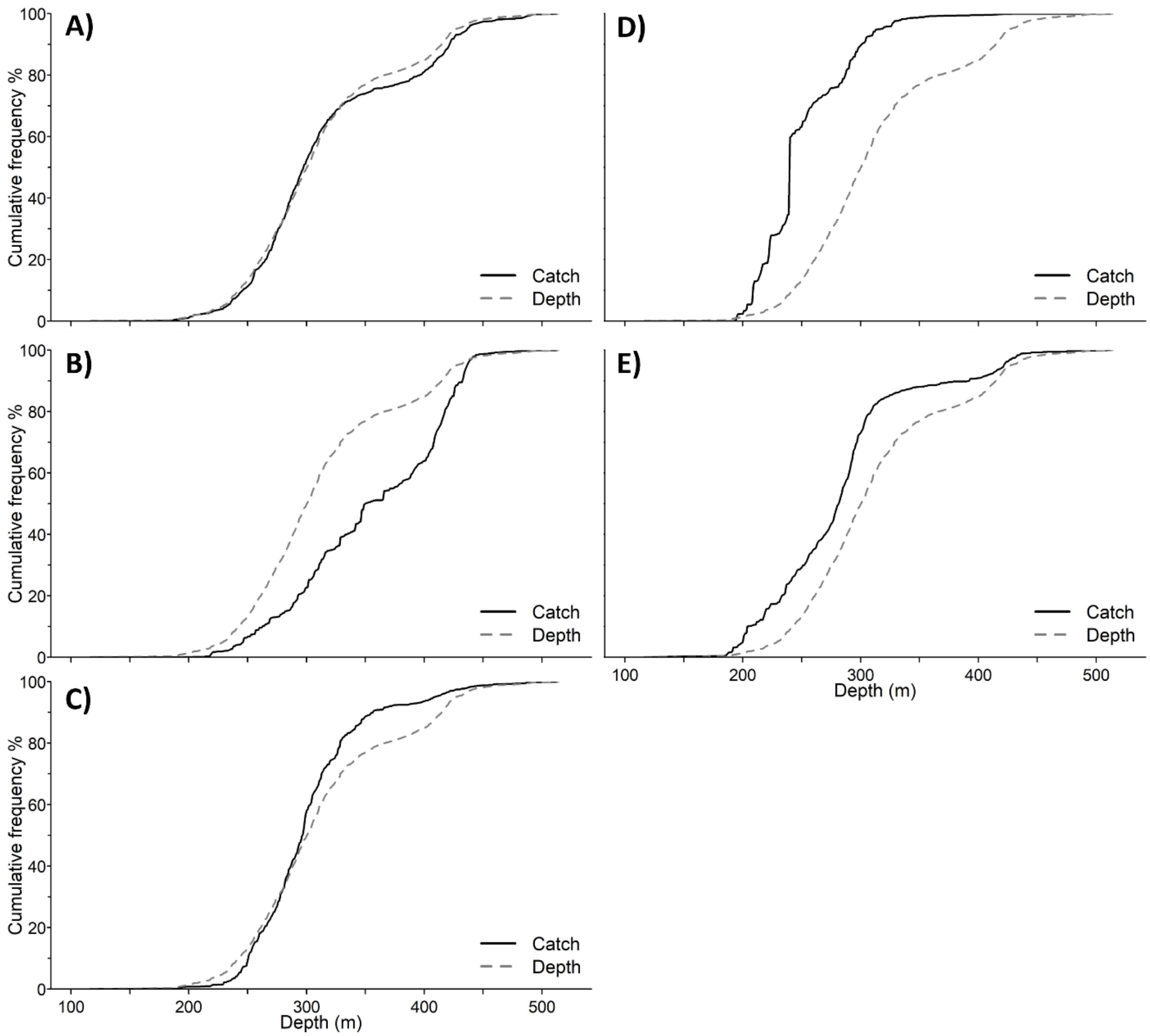

Figure 21. Cumulative frequency distribution (%) of Redfish (A), Greenland Halibut (B), White Hake (C), Atlantic Cod (D), and Atlantic Halibut (E) catch rate as a function of depth based on retained at-sea observer data in Redfish directed fishery from 1999–2021. The dashed curves represent the depth distribution for all the sets done over that time period. 2020 and 2021 values are preliminary.

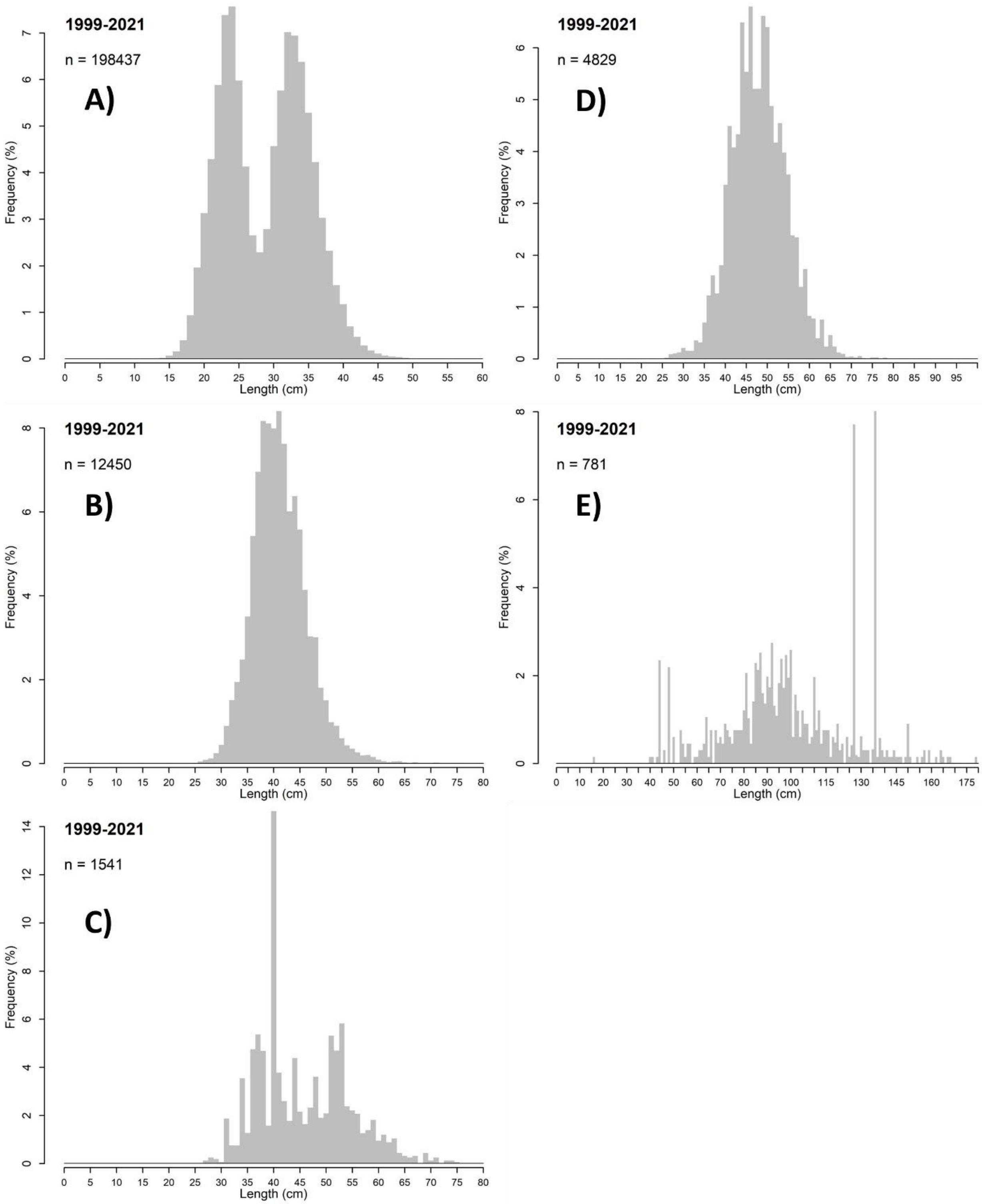

Figure 22. Length frequency distribution (%) of Redfish (A), Greenland Halibut (B), White Hake (C), Atlantic Cod (D), and Atlantic Halibut (E) based on retained at-sea observer data in Redfish directed fishery from 1999–2021. Numbers of fish measured are indicated (n). 2020 and 2021 values are preliminary.

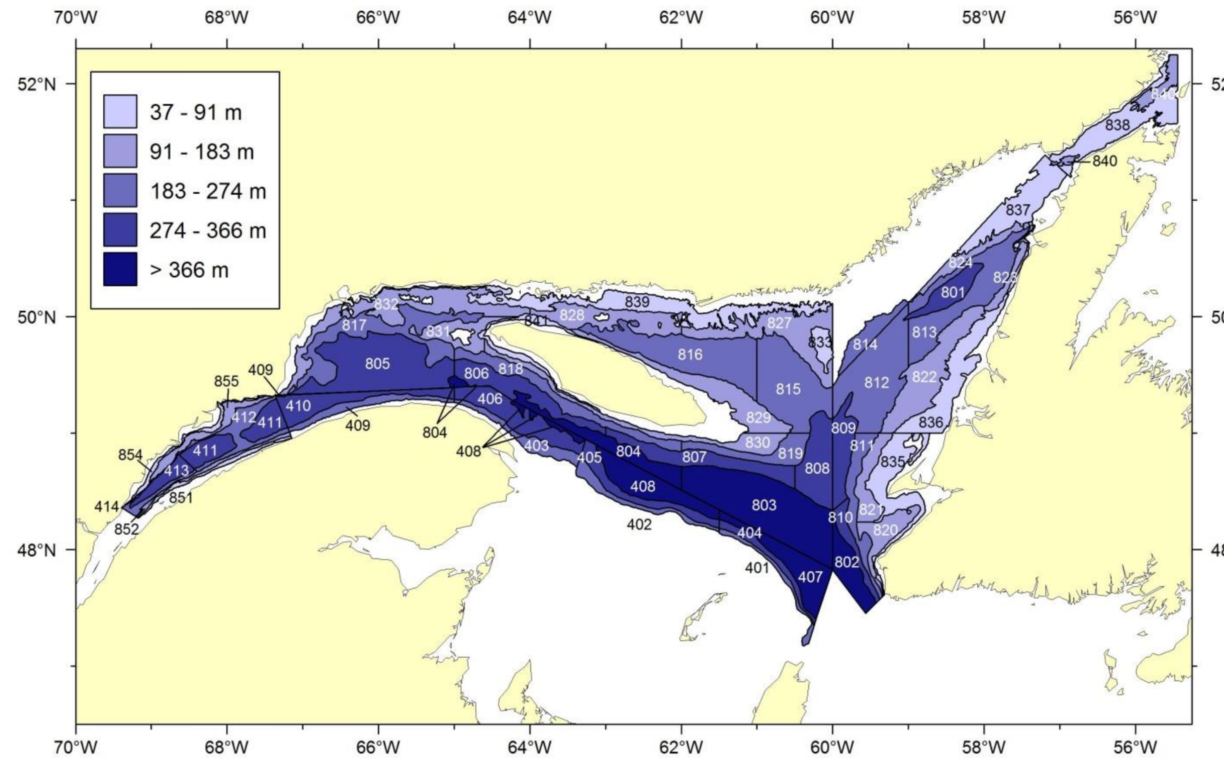

Figure 23. Stratification scheme used for the nGSL DFO survey.

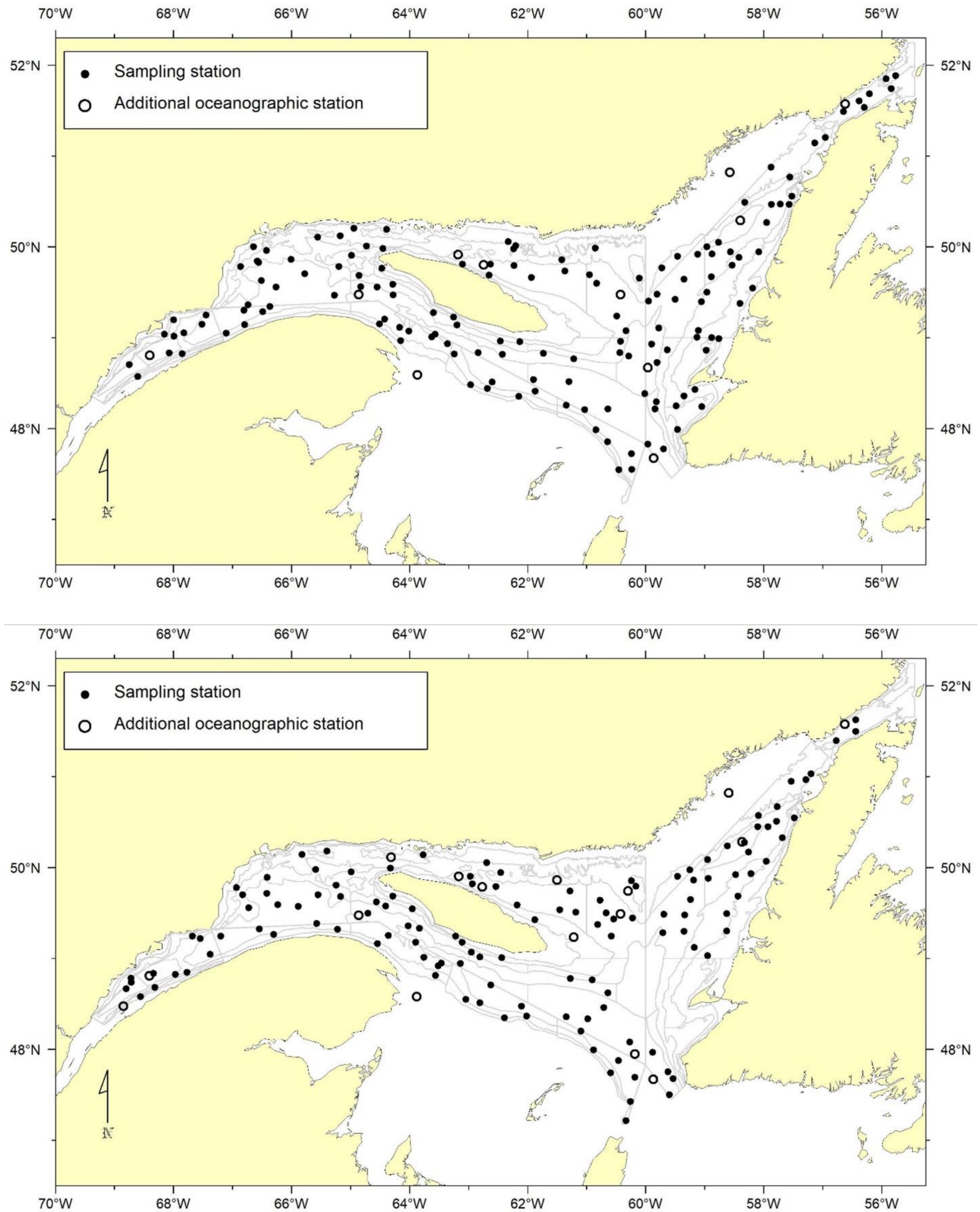

Figure 24. Locations of successful sampling stations and additional oceanographic stations for the nGSL DFO survey in August 2020 (upper panel) and 2021 (lower panel).

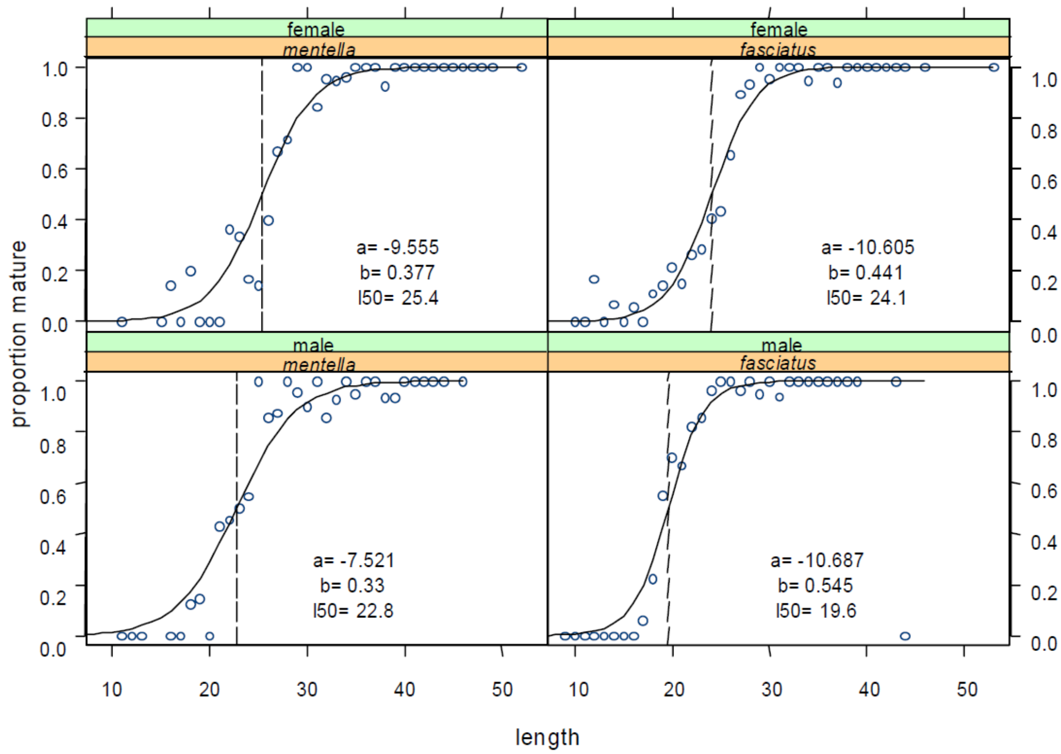

Figure 25. Redfish maturity ogive by species and sex from Gascon (2003). The proportion of mature individuals by length is illustrated by blue circles and the L_{50} are indicated.

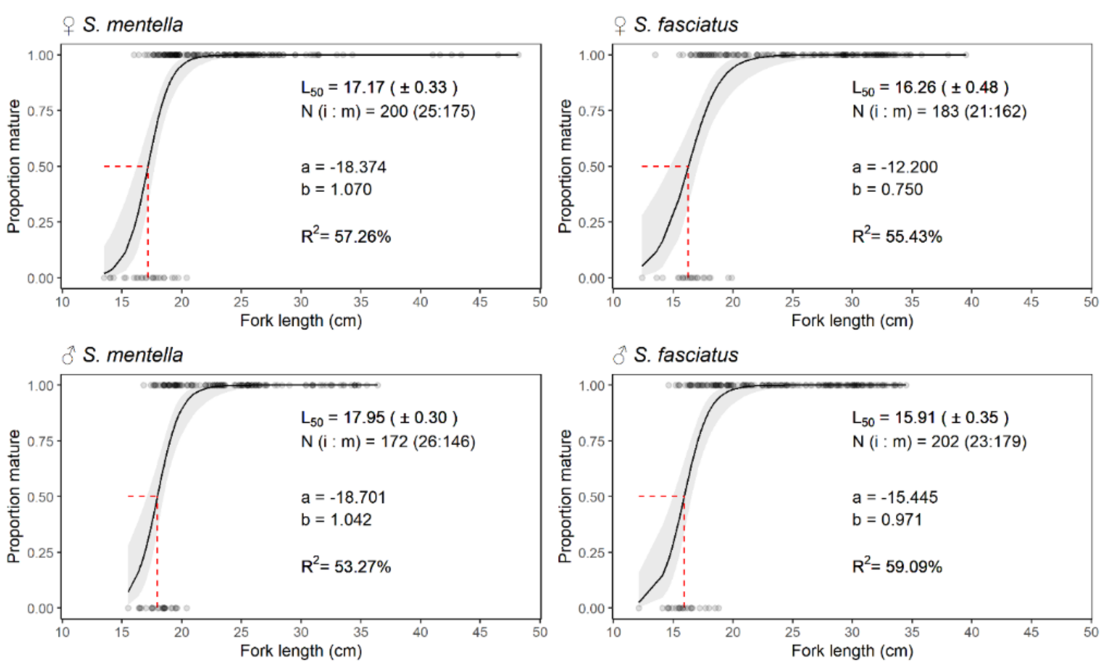

Figure 26. Maturity ogives based on histology as a function of fork length (cm) for each combination of species and sex (female in upper panels and males in lower panels). L_{50} (± standard error), sample size (N) of immature (i) and mature (m) individuals, as well as a and b parameters in each panel. The red dotted lines correspond to L_{50} and the shaded areas to 95% confidence interval.

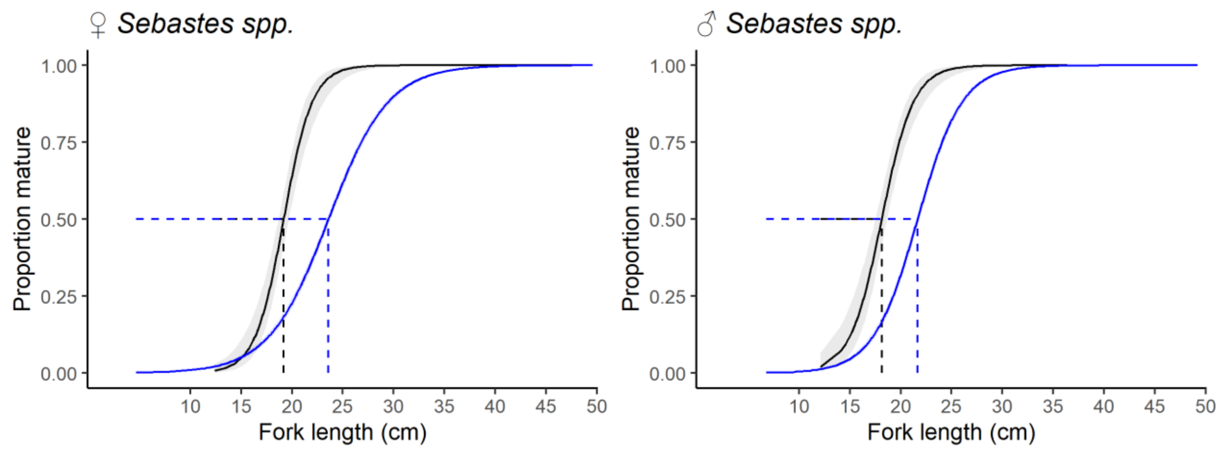

Figure 27. Comparison of maturity ogives based on macroscopic gonad appearance categories following a visual chart used in the 1990s to contrast L_{50} between1996–1998 (in blue) and 2018–2019 (in black). Females are in the left panel and males in the right panel. The dotted lines correspond to L_{50} and the shaded areas to 95% confidence interval.

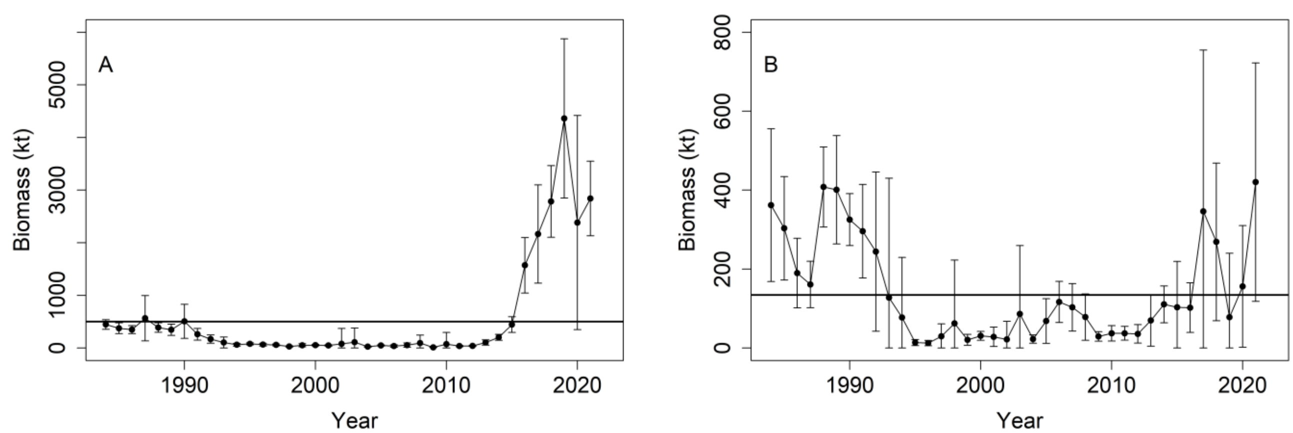

Figure 28. Minimum trawlable biomass in kilotonnes (kt) with 95% confidence intervals of S. mentella *(A) and* S. fasciatus *(B) in the nGSL DFO survey from 1984 to 2021. The solid lines represent the 1984–2020 average. Note the different scales on the y-axis.*

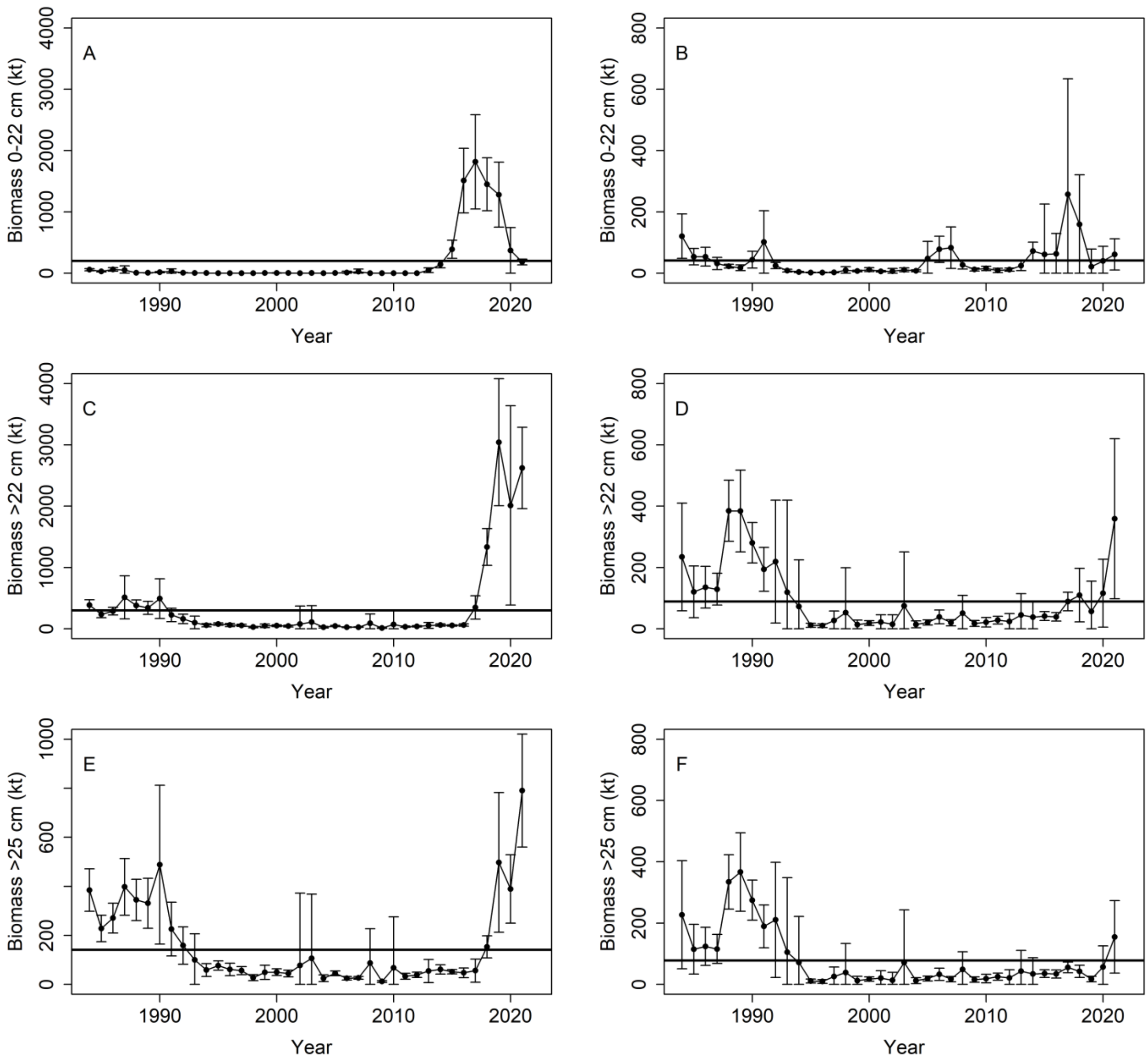

Figure 29. Trawlable biomass in kilotonnes (kt, with 95% confidence intervals) of S. mentella *(left column; panels A, C, and E) and* S. fasciatus *(right column; panels B, D, and F) in the nGSL DFO survey from 1984 to 2021, by length classes: 0–22 cm (A-B), > 22 cm (C-D), and > 25 cm (E-F). The solid lines represent the mean for the 1984–2020 period. Note the different scales on the y-axis.*

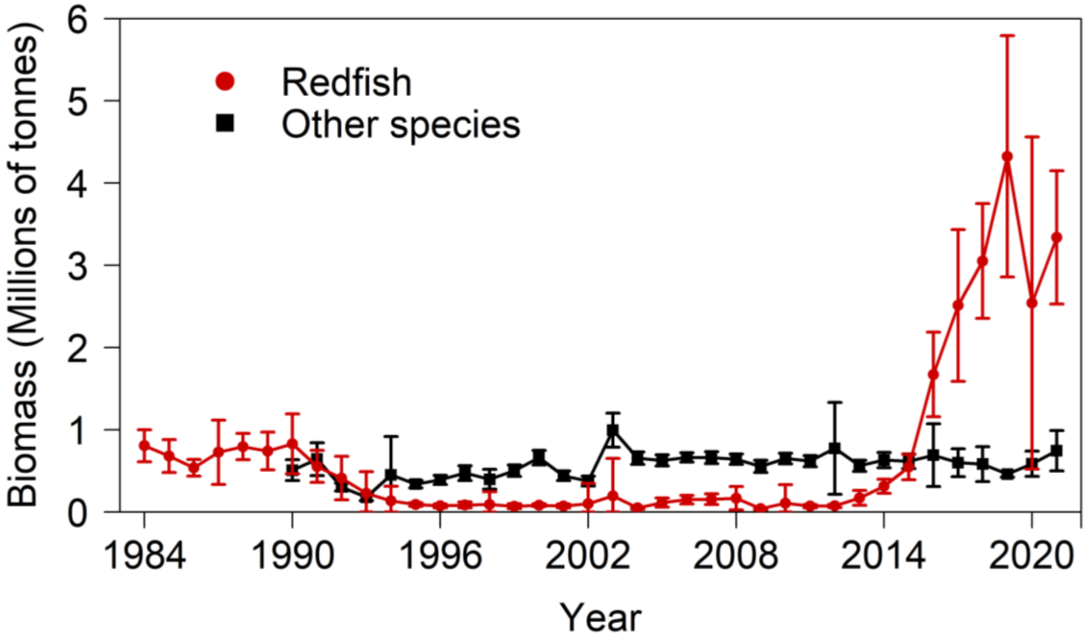

Figure 30. Trawlable biomass (millions of tonnes, with 95% confidence intervals) of Redfish spp. *(red circles) and all other species (black squares) sampled in the nGSL DFO survey from 1984 to 2021.*

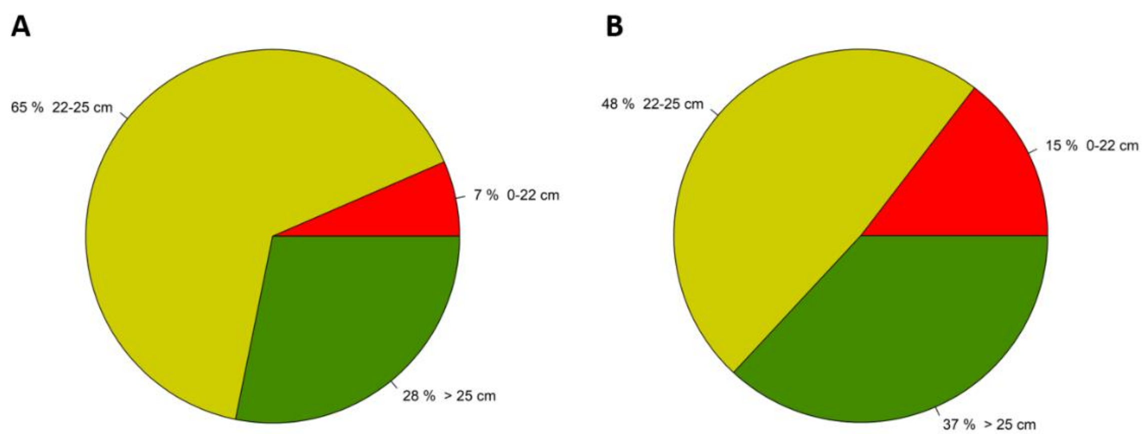

Figure 31. Percentage of trawlable biomass of S. mentella *(A) and* S. fasciatus *(B) in the nGSL DFO survey in 2021 by length classes, 0–22 cm in red, 22–25 cm in yellow, and larger than 25 cm in green.*

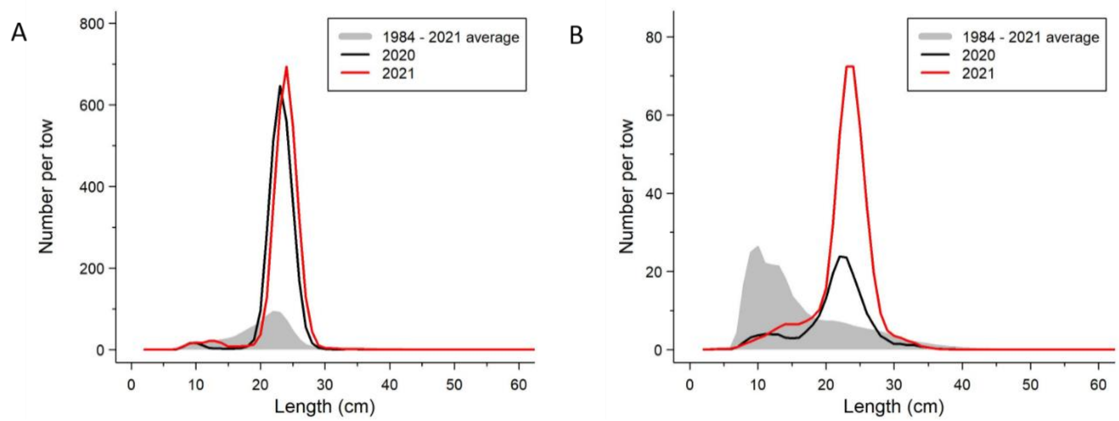

Figure 32. S. mentella *(A) and* S. fasciatus *(B) length frequency in the nGSL DFO research surveys for 2020, 2021, and the 1984 to 2021 average. Note the different scales on the y-axis.*

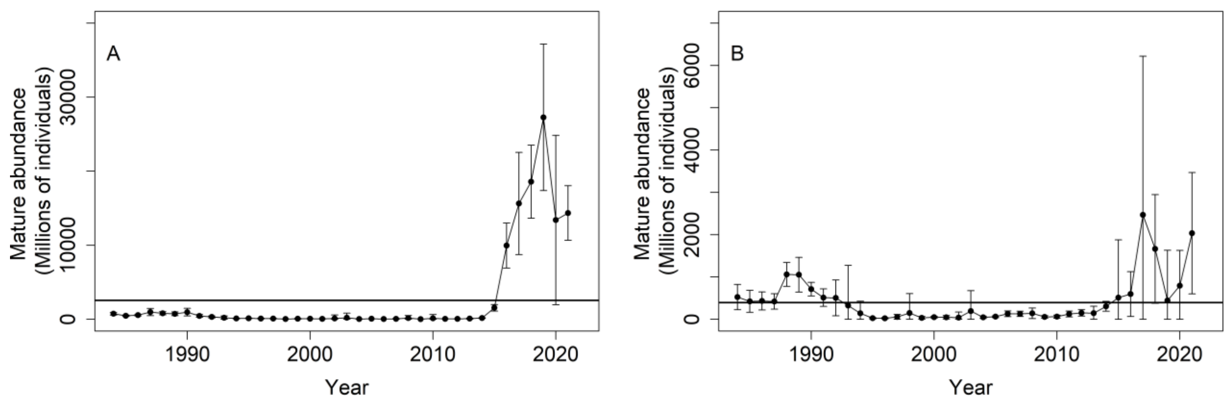

Figure 33. Trawlable mature fish abundance (millions of individuals, with 95% confidence intervals) of S. mentella *(A) and* S. fasciatus *(B) in the nGSL DFO survey from 1984 to 2021. The solid lines represent the 1984–2020 average. Note the different scales on the y-axis.*

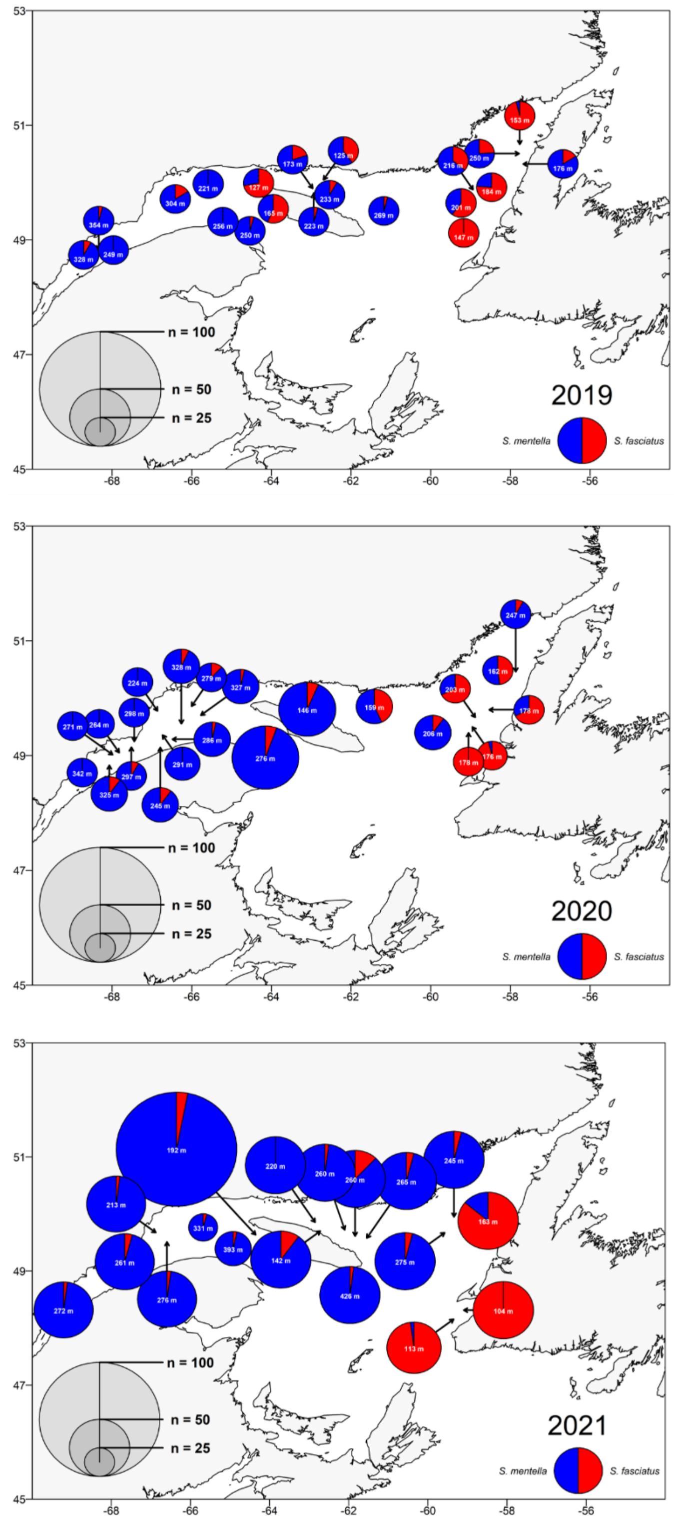

Figure 34. Map showing species composition (%) between S. mentella *in blue and* S. fasciatus *in red and location of genotyped juveniles sampled during the 2019–2021 nGSL DFO survey. Size of the pie charts is relative to sample size and depth (m) is indicated in the circle.*

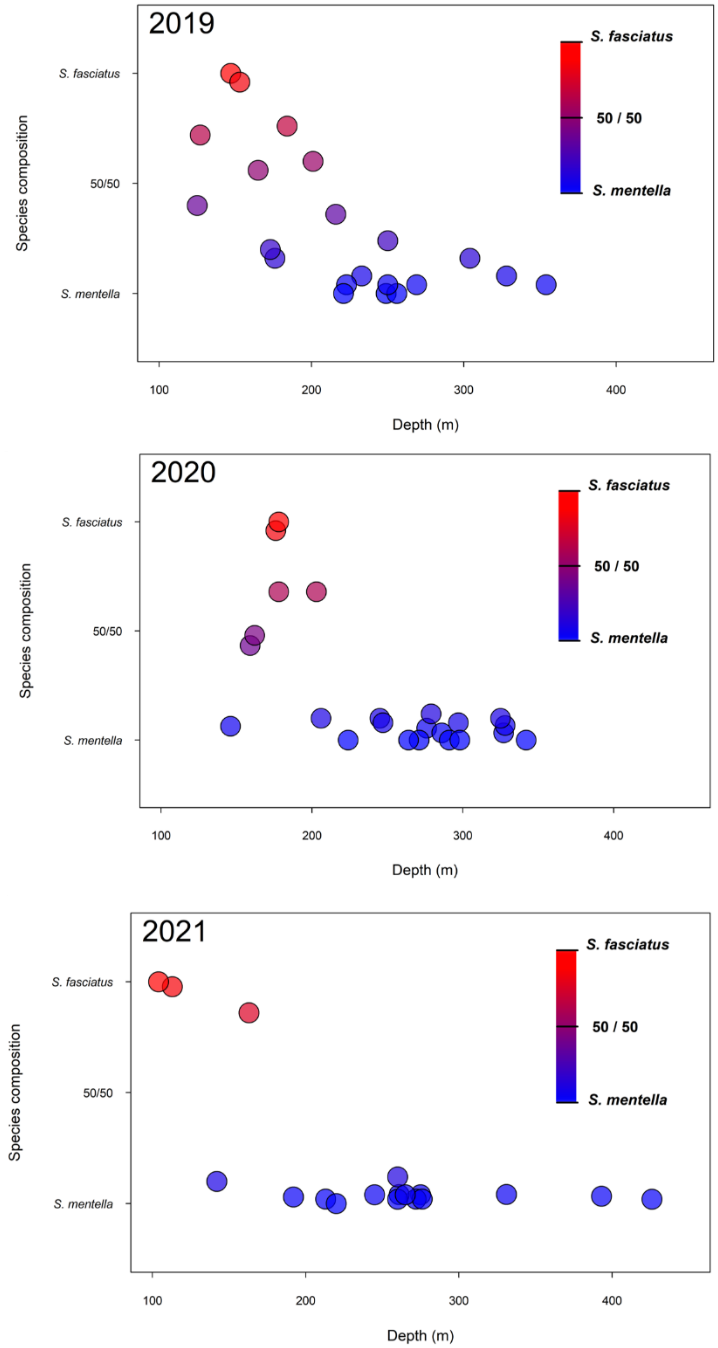

Figure 35. Relationship between species composition (%) and depth (m) according to the genotyped juveniles from the locations sampled in 2019, 2020 and 2021, where 100% S. fasciatus *is illustrated in red and 100%* S. mentella *in blue.*

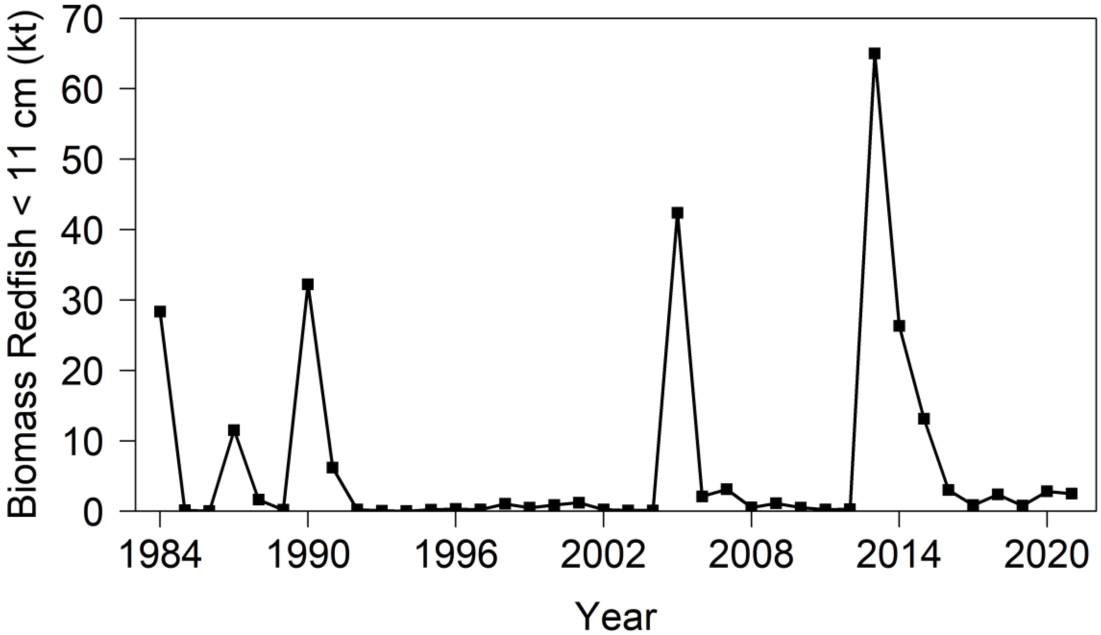

Figure 36. Minimum trawlable biomass in kilotonnes (kt) of Redfish of less than 11 cm in the nGSL DFO survey from 1984 to 2021.

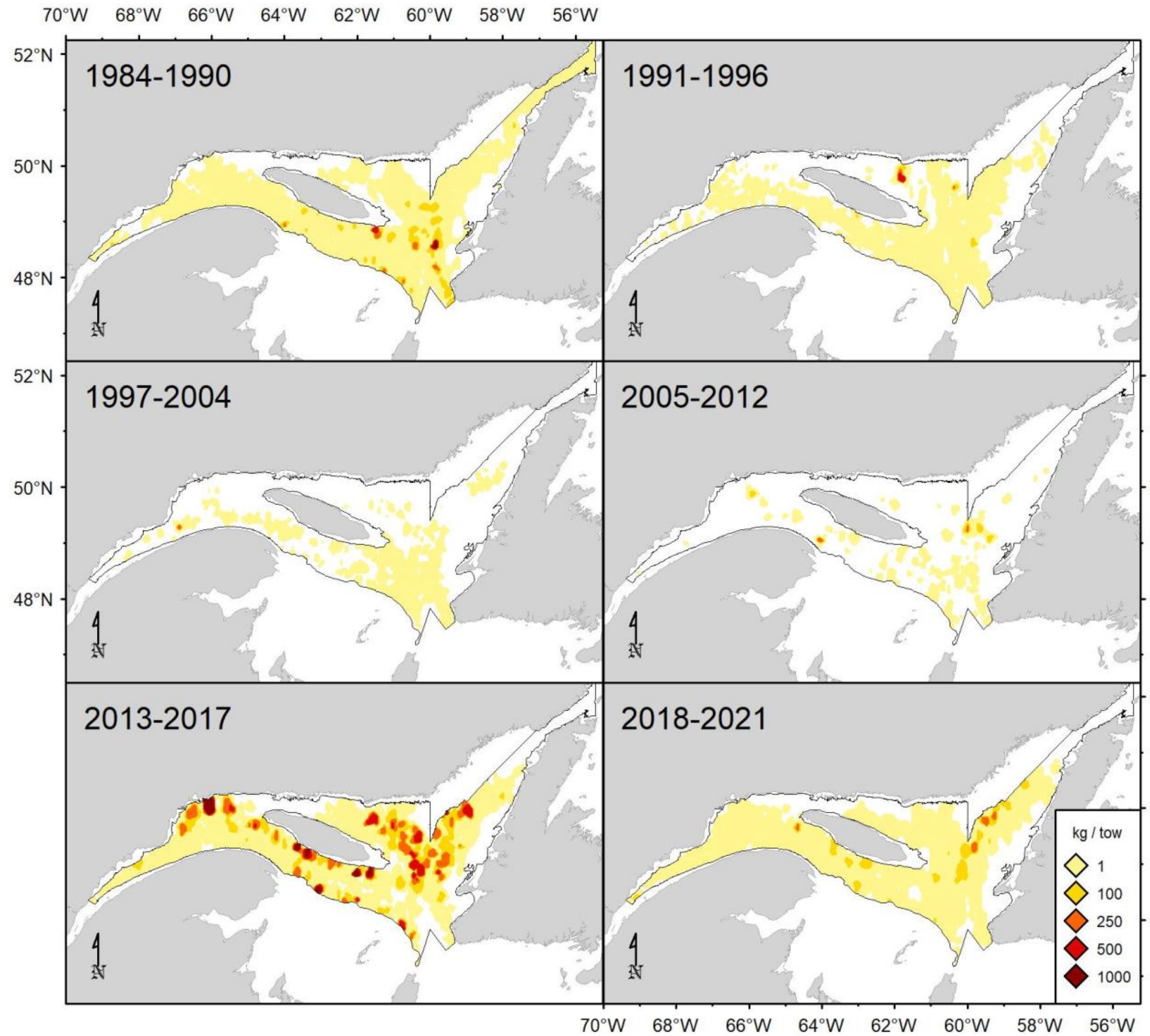

Figure 37. Catch rate distribution of immature S. mentella *Ia (kg/15-minute tow) in the nGSL DFO survey from 1984 to 2021.*

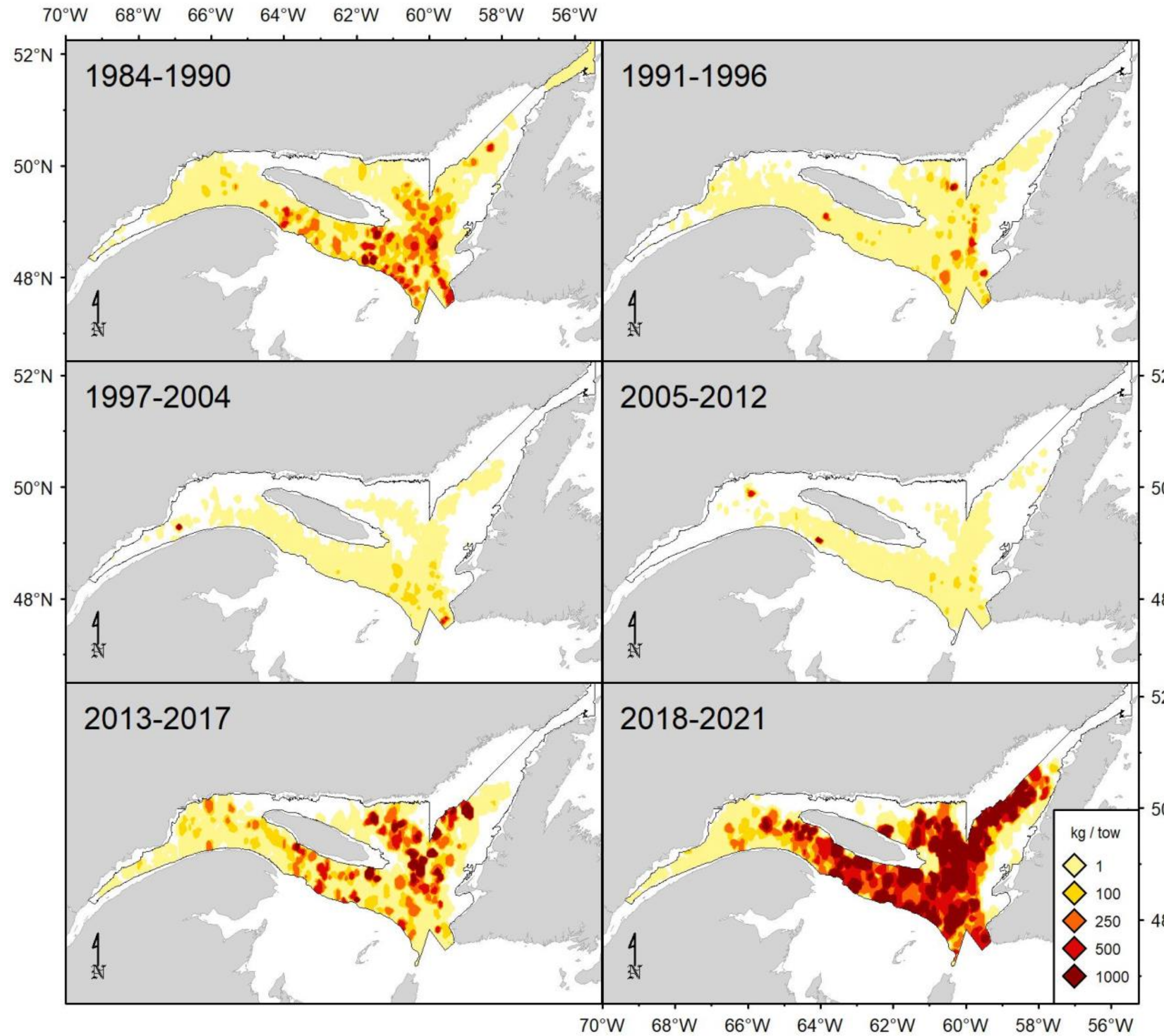

Figure 38. Catch rate distribution of mature S. mentella *(kg/15-minute tow) (kg/15-minute tow) in the nGSL DFO survey from 1984 to 2021.*

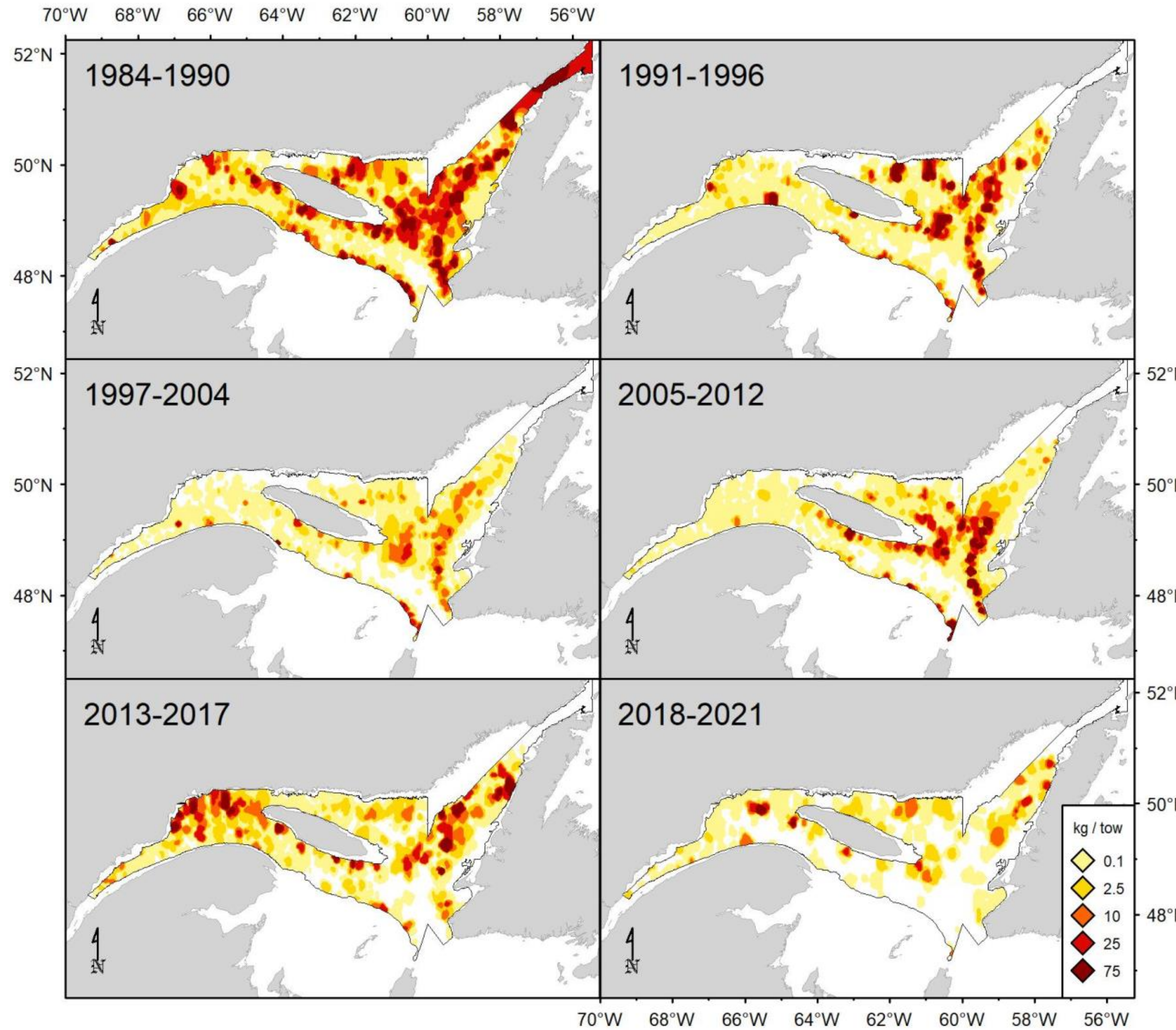

Figure 39. Catch rate distribution of immature S. fasciatus *(kg/15-minute tow) in the nGSL DFO survey from 1984 to 2021.*

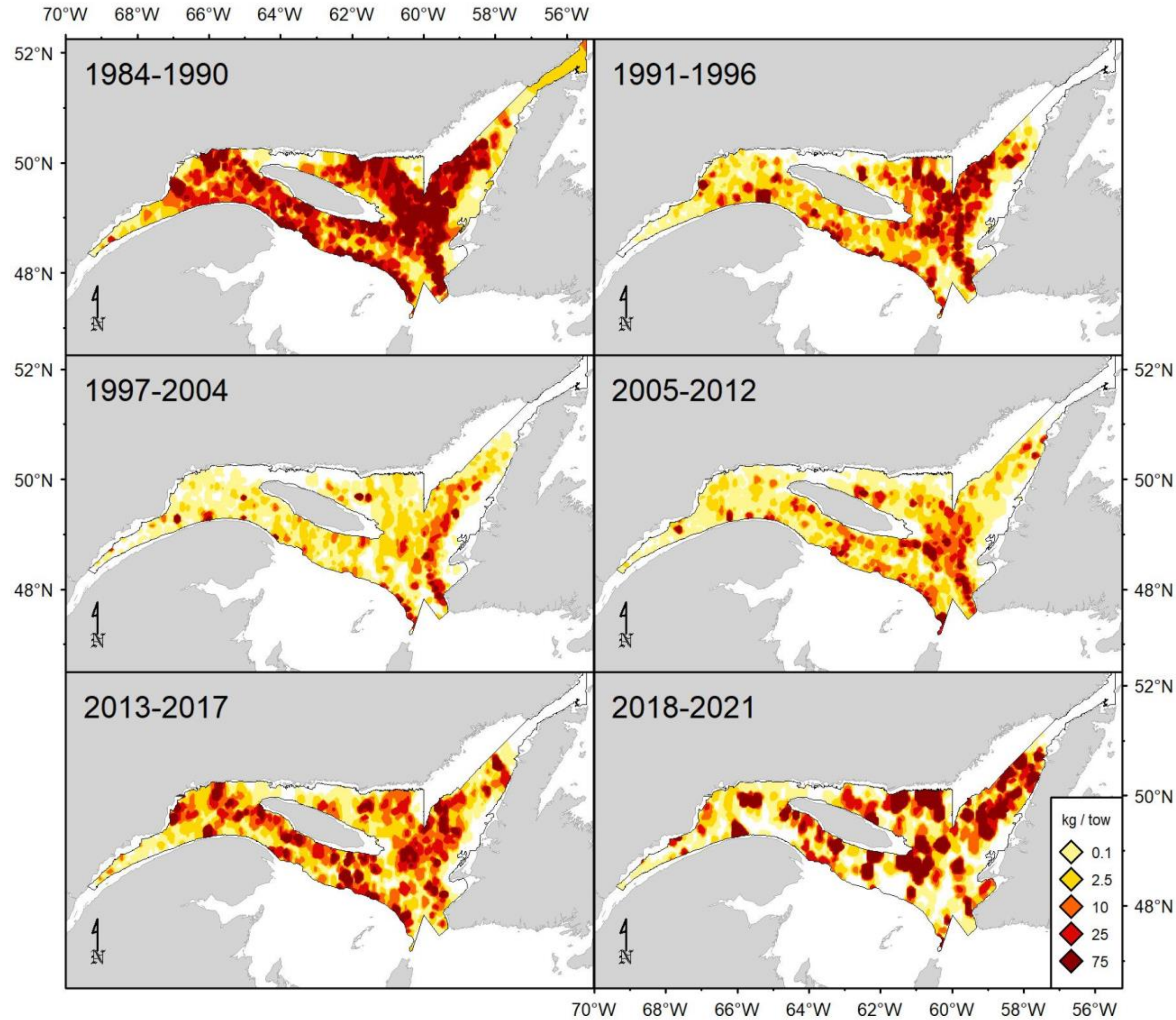

Figure 40. Catch rate distribution of mature S. fasciatus *(kg/15-minute tow) in the nGSL DFO survey from 1984 to 2021.*

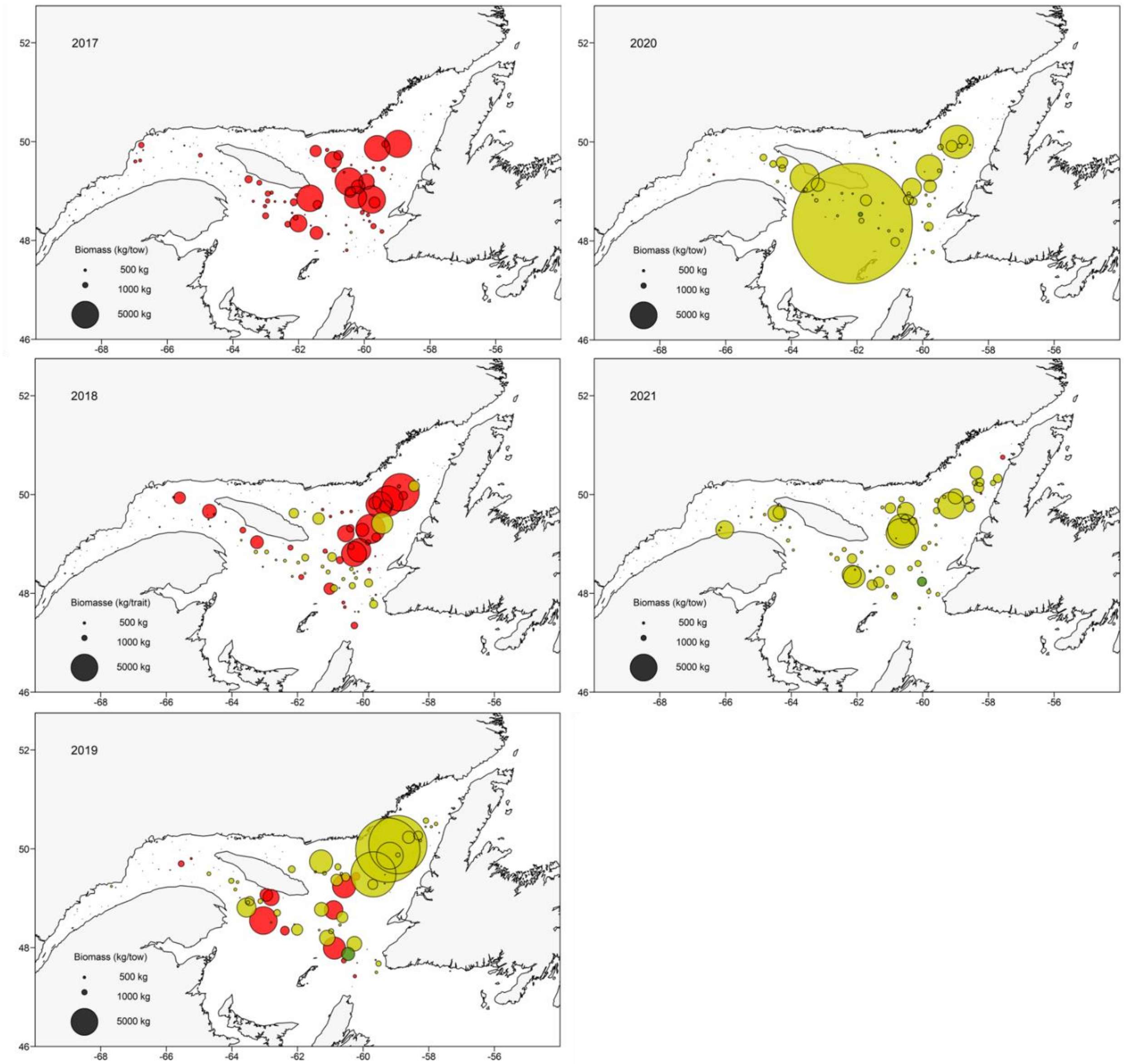

Figure 41. Catch rate distribution of Redfish (kg/15-minute tow) in the nGSL DFO survey from 2017 to 2021. Catch biomass is indicated by bubbles size and median Redfish length is indicated by colors, where a median smaller than 22 cm is illustrated in red, between 22 and 25 cm in yellow, and larger than 25 cm in green.

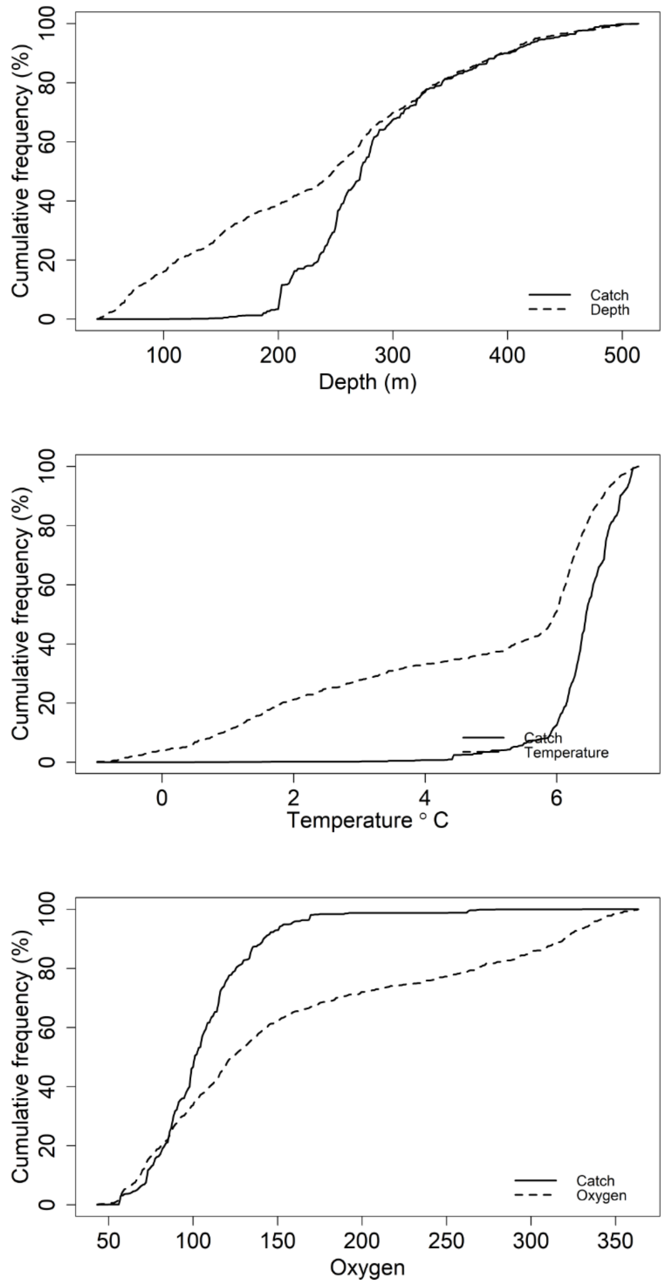

Figure 42. Stratified cumulative frequency of S. mentella in DFO survey from 2017–2021. The solid and dotted lines represent the cumulative frequency of catches and survey stations, respectively, according to depth (m), temperature (°C), and dissolved oxygen (µmol/kg).

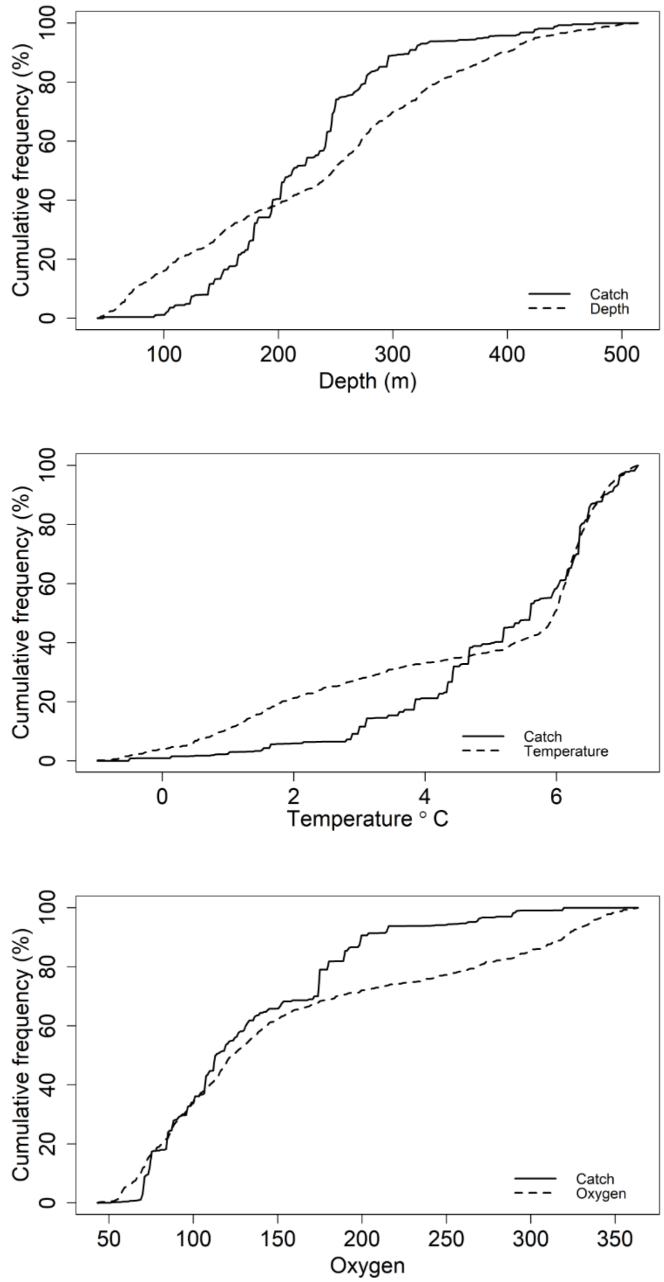

Figure 43. Stratified cumulative frequency of S. fasciatus in DFO survey from 2017–2021. The solid and dotted lines represent the cumulative frequency of catches and survey stations, respectively, according to depth (m), temperature (°C), and oxygen (µmol/kg).

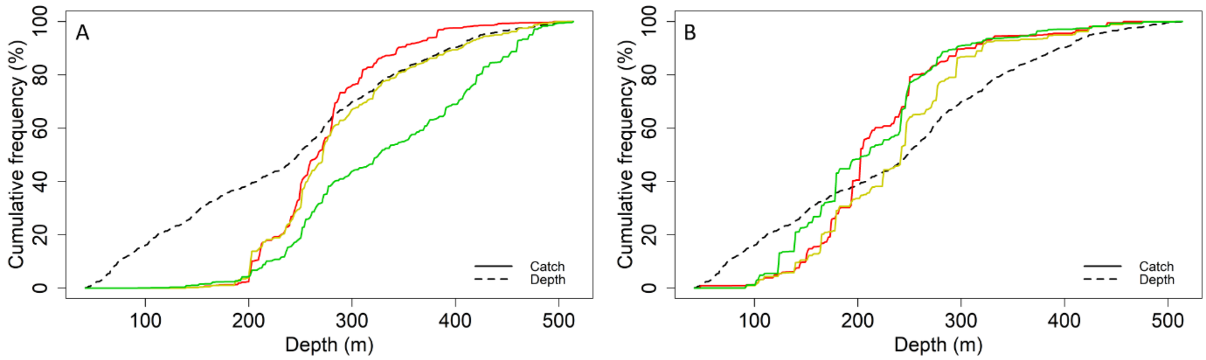

Figure 44. Stratified cumulative frequency of A) S. mentella *and B)* S. fasciatus *in DFO survey from 2017–2021. The solid and dotted lines represent the cumulative frequency of catches and survey stations, respectively, according to depth (m) and by length classes, 0-22 cm in red, 22–25 cm in yellow, and ≥ 25 cm in green.*

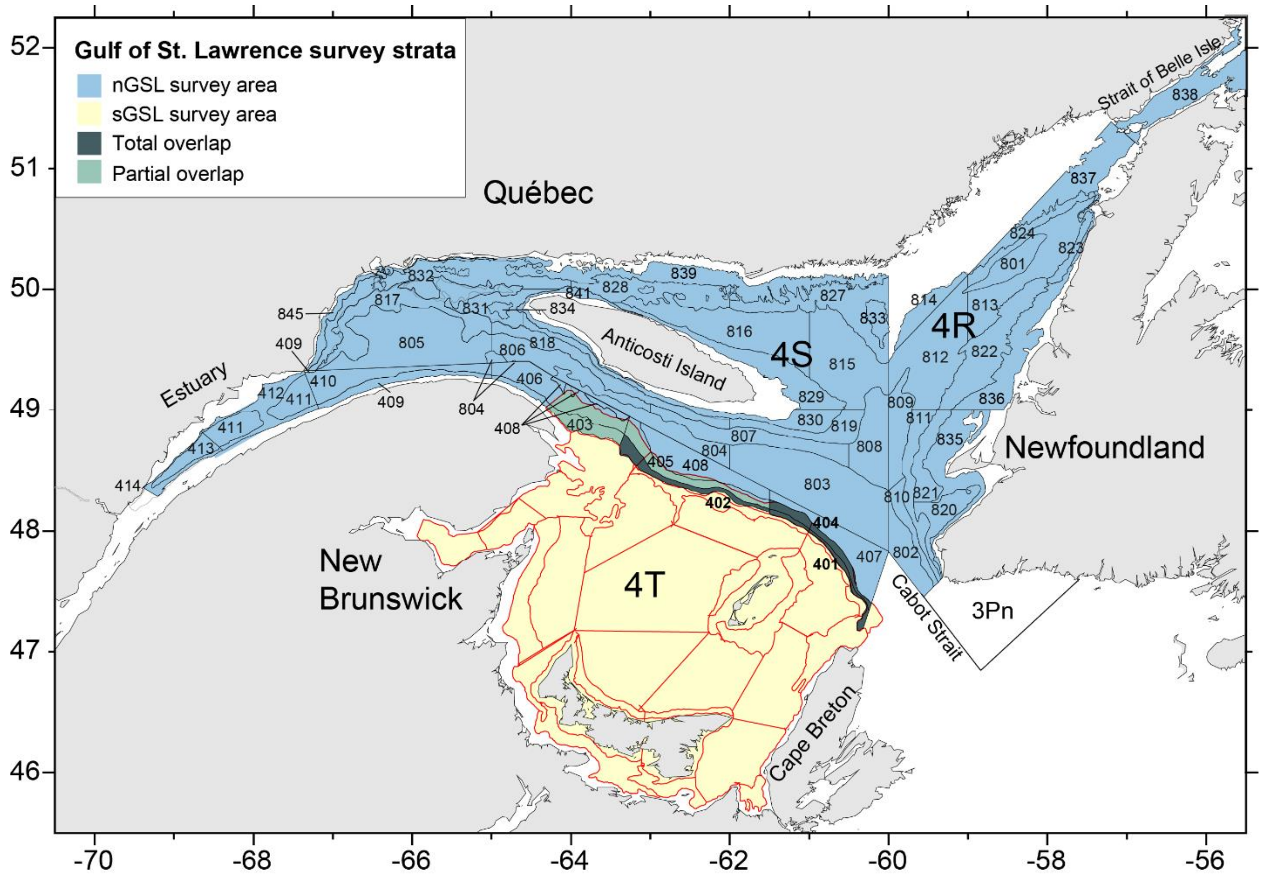

Figure 45. Map showing the area covered by the northern Gulf of St. Lawrence (nGSL) and the Southern Gulf of St. Lawrence (sGSL) DFO surveys and their overlap.

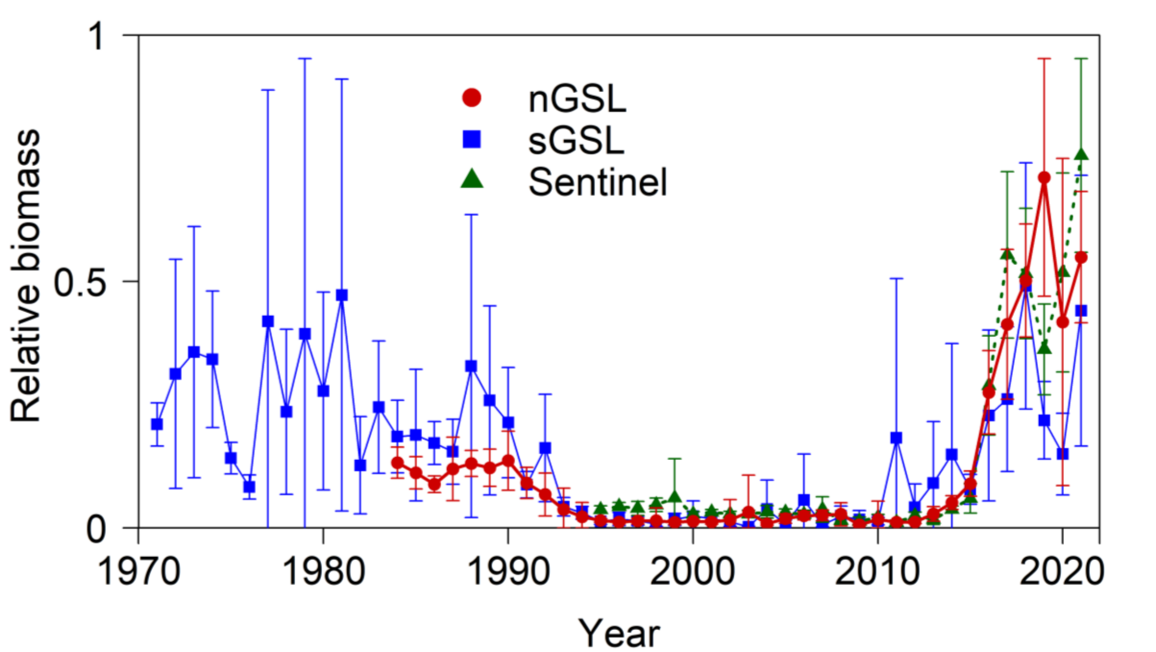

Figure 46. Comparison of DFO research surveys in the nGSL(red line with circles), sGSL (blue line with squares), and nGSL mobile sentinel (green line with triangles) surveys relative indices with 95% confidence intervals of Redfish biomass time series.

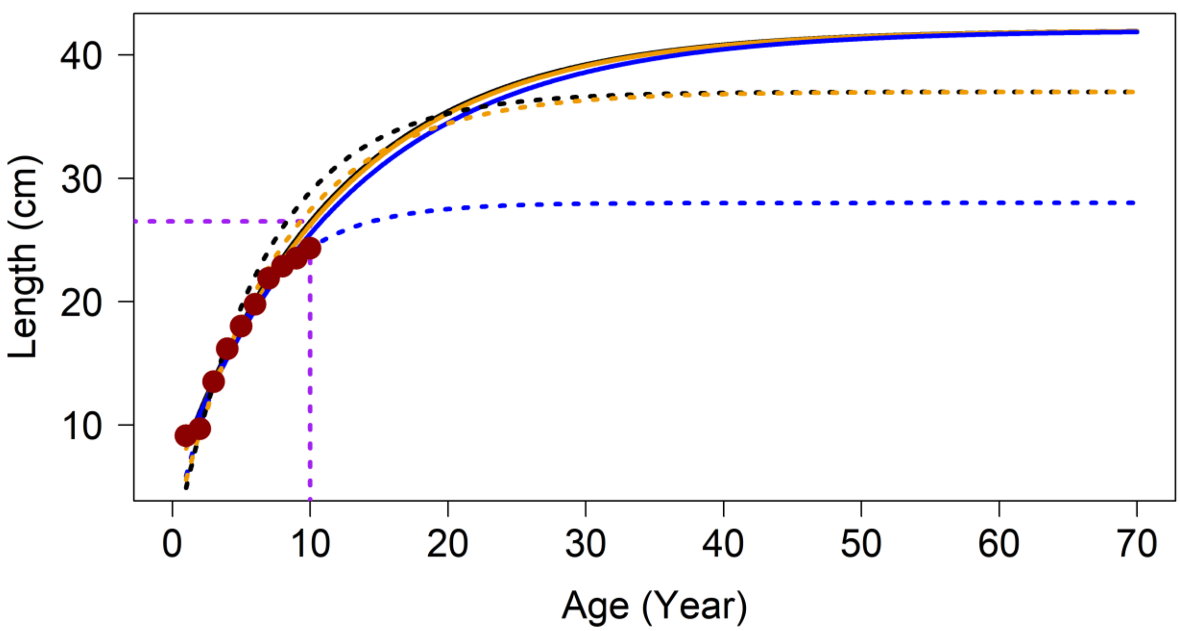

Figure 47. von Bertalanffy growth curves for Redfish parameterized based on length-at-age data. The black lines correspond to curves developed for the 1980 cohort, the blue lines for the 2011 cohort, and the orange lines to both 1980 and 2011 cohorts. Solid lines assume a maximum size (L_{inf}) constraint between 42–50 cm, and dotted lines assume no constraint on L_{inf}. The dotted purple lines show that a 10 years old individual should measure 26.5 cm based on the 1980 cohort constrained growth curve. The red dots indicate the observed modal size of the 2011 cohort in previous years.

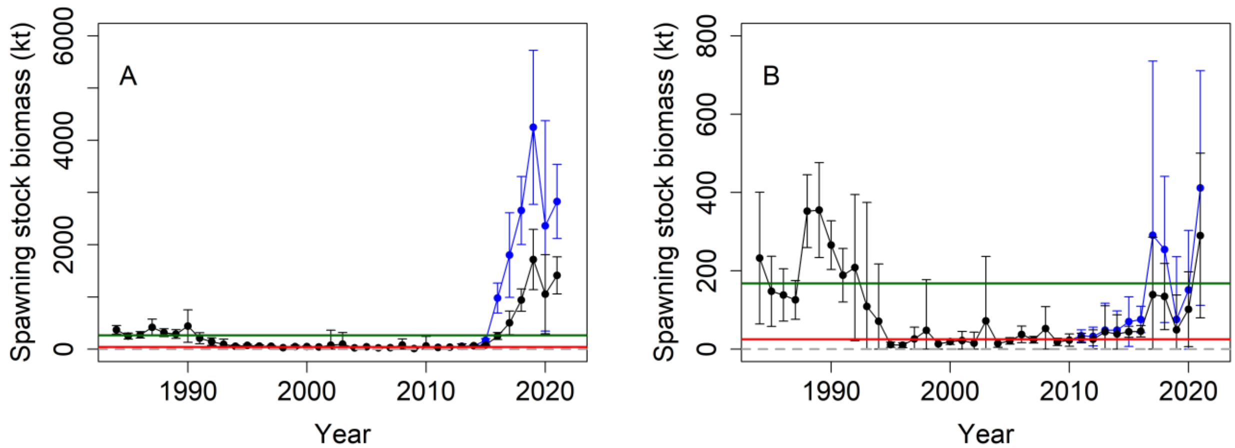

Figure 48. Spawning stock biomass (kilotonnes) in the nGSL DFO survey from 1984 to 2021 based on Gascon (2003) ogives (black) and with the new ogives starting in 2011 (blue) with 95% confidence intervals. The proposed Upper Stock Reference (green line) and Limit Reference Point (red line) for S. mentella (A) and S. fasciatus (B) are shown. The 0 y-axis value is indicated by a gray dashed line. Note the different scales on the y-axis.

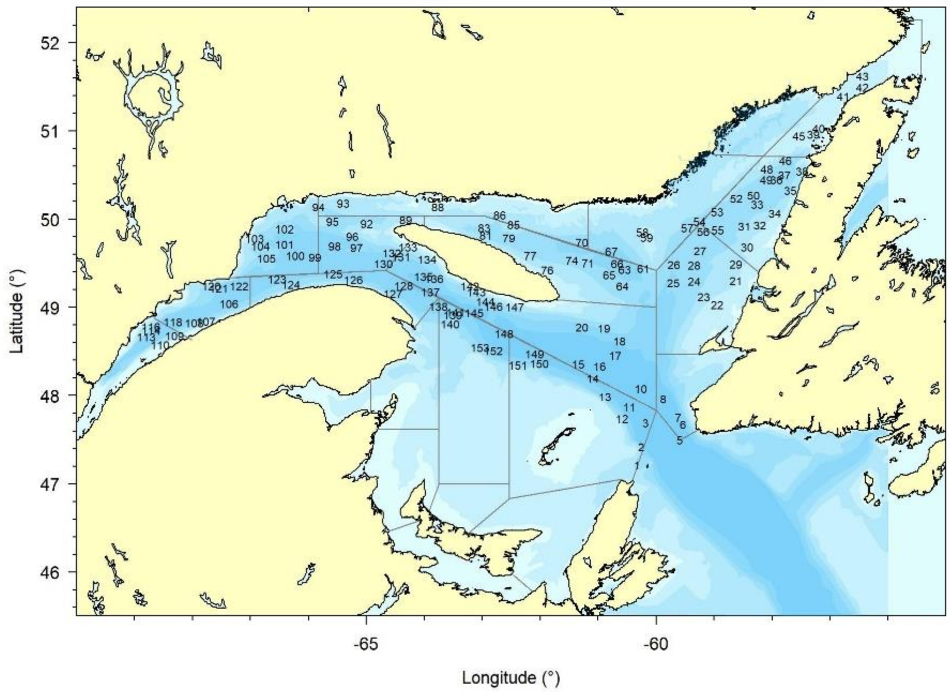

Figure 49. Stations sampled during the 2019 nGSL survey.

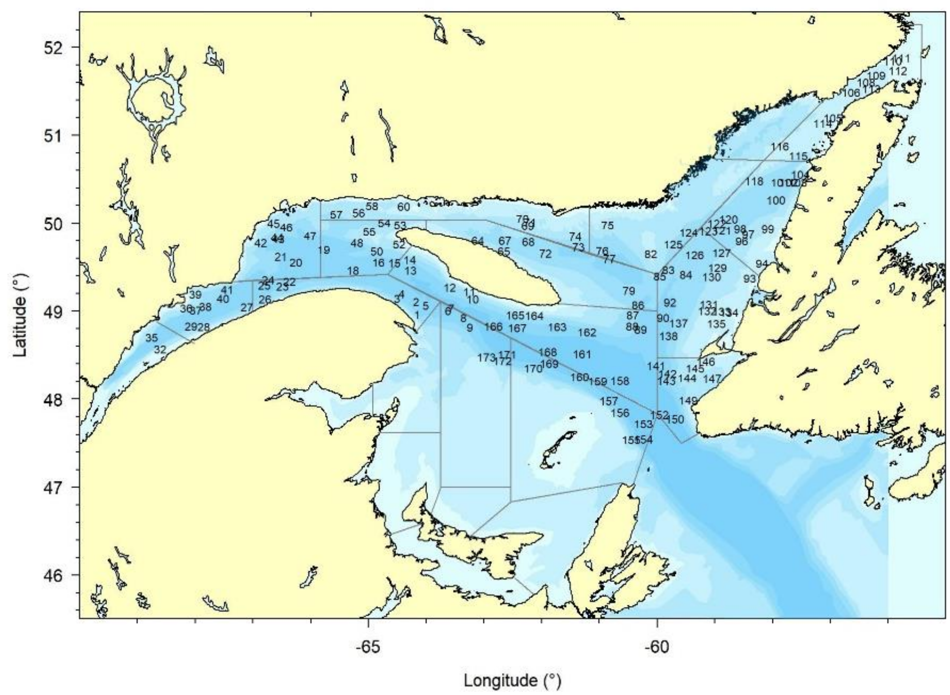

Figure 50. Stations sampled during the 2020 nGSL survey.

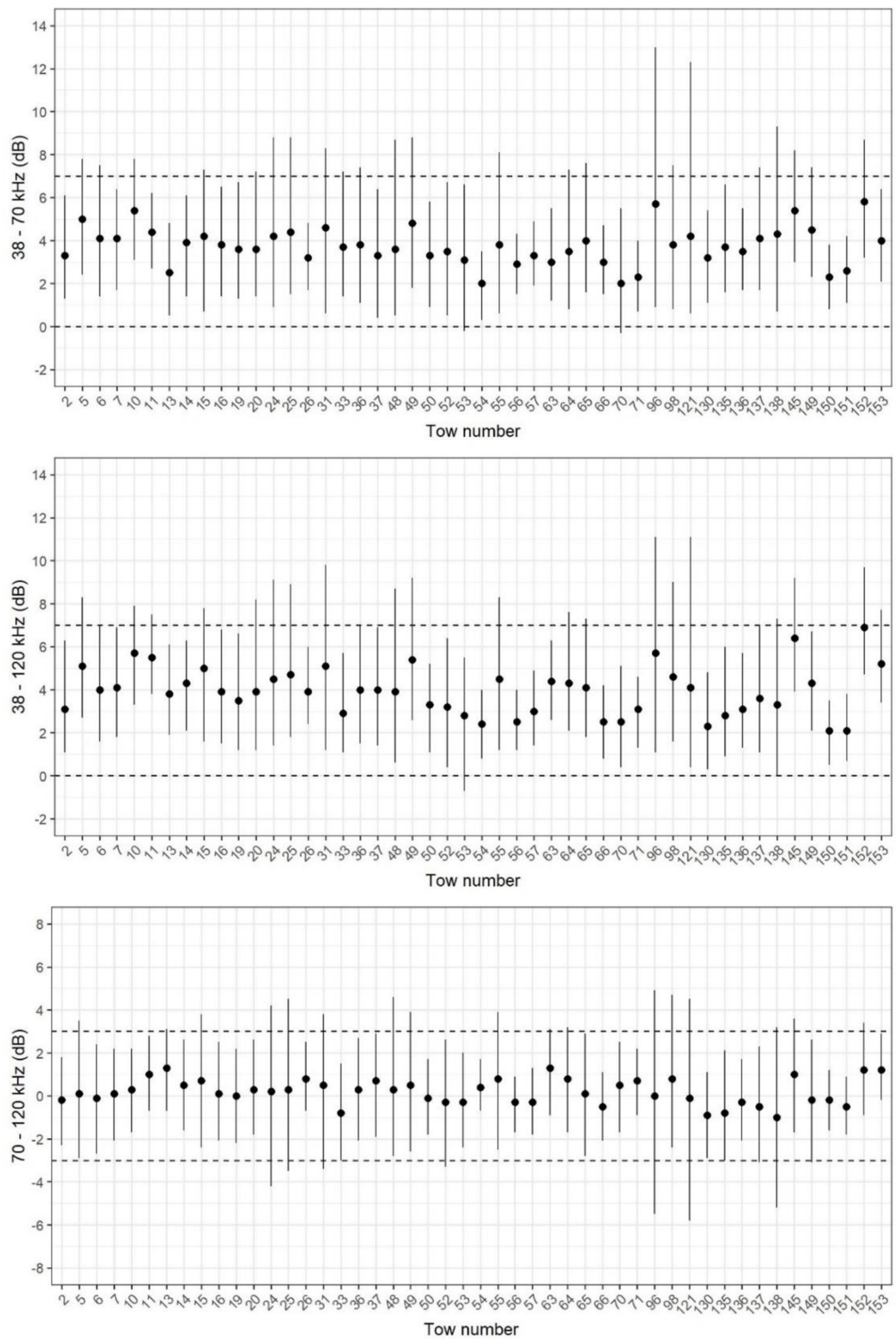

Figure 51. ∆MVBS in the 20 m above the seafloor at stations containing more than 90% Redfish biomass in 2019. Dotted lines represent the 0- and 7-dB thresholds in the upper and middle panels, and the -3- and 3-dB thresholds in the lower panel. Error bars correspond to twice the standard deviation.

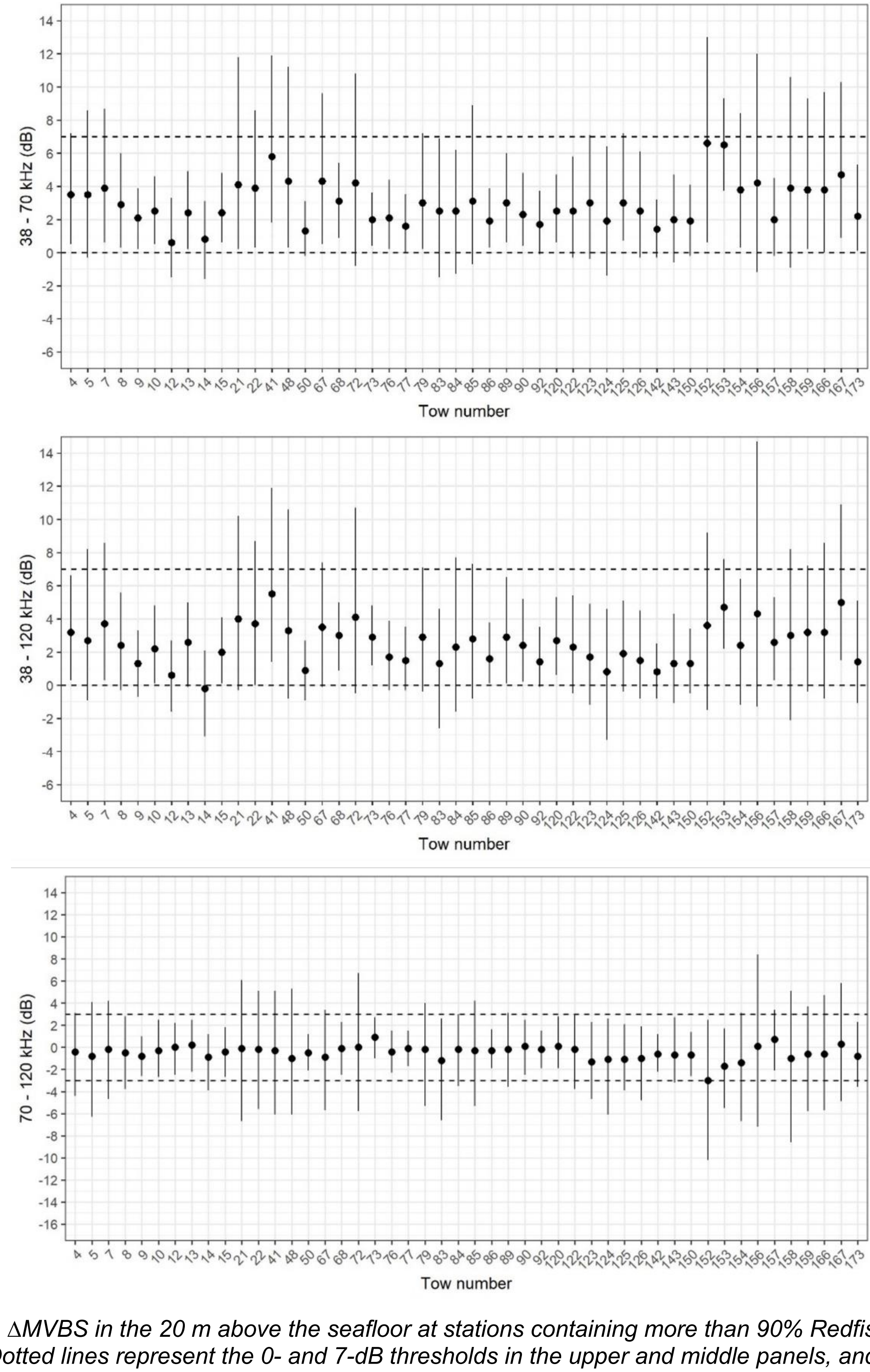

Figure 52. ∆MVBS in the 20 m above the seafloor at stations containing more than 90% Redfish biomass in 2020. Dotted lines represent the 0- and 7-dB thresholds in the upper and middle panels, and the -3- and 3-dB thresholds in the lower panel. Error bars correspond to twice the standard deviation.

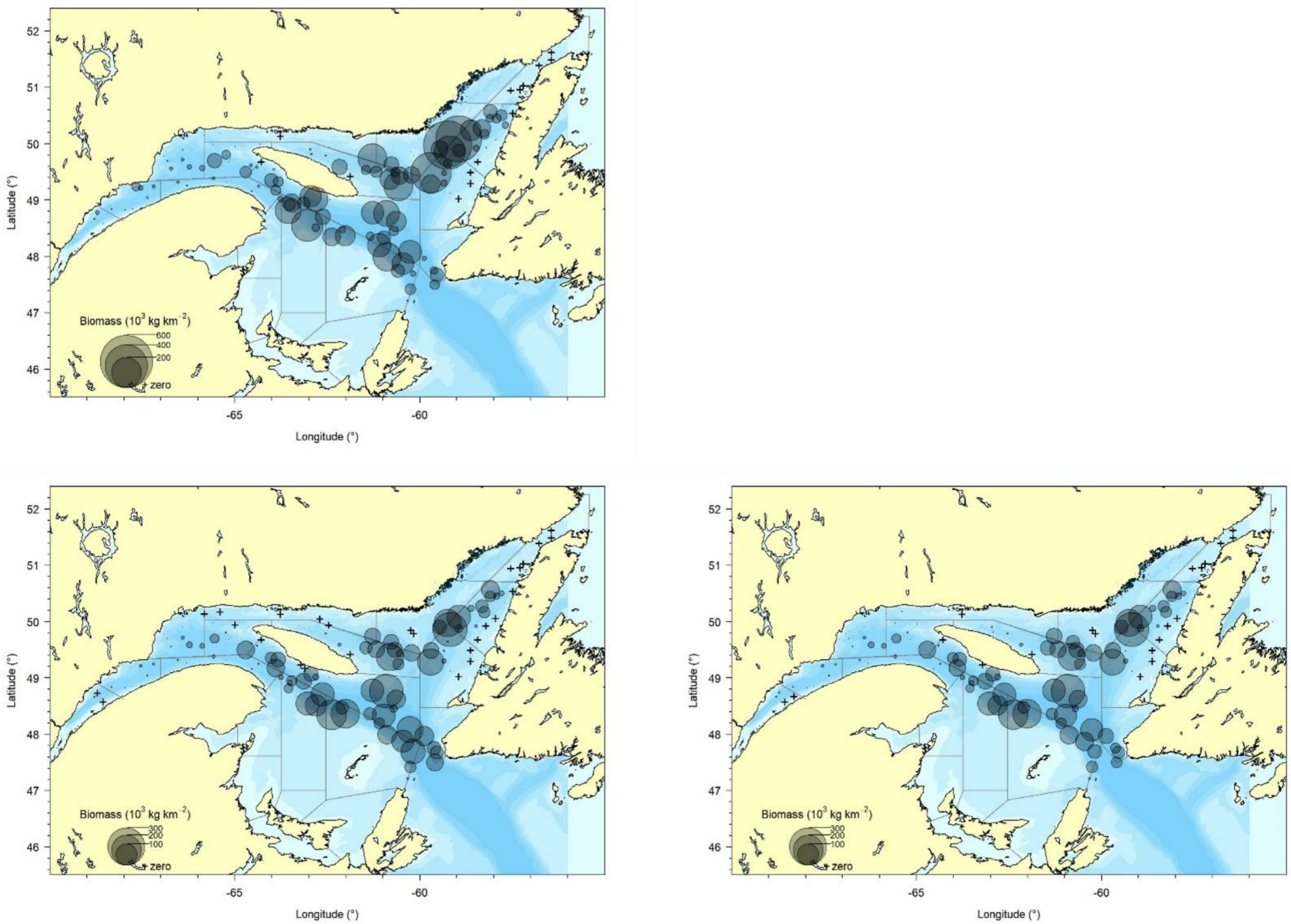

Figure 53. Biomass density at each station sampled in 2019. Upper left: catch data; lower left: acoustic data (method 1); lower right: acoustic data (method 2).

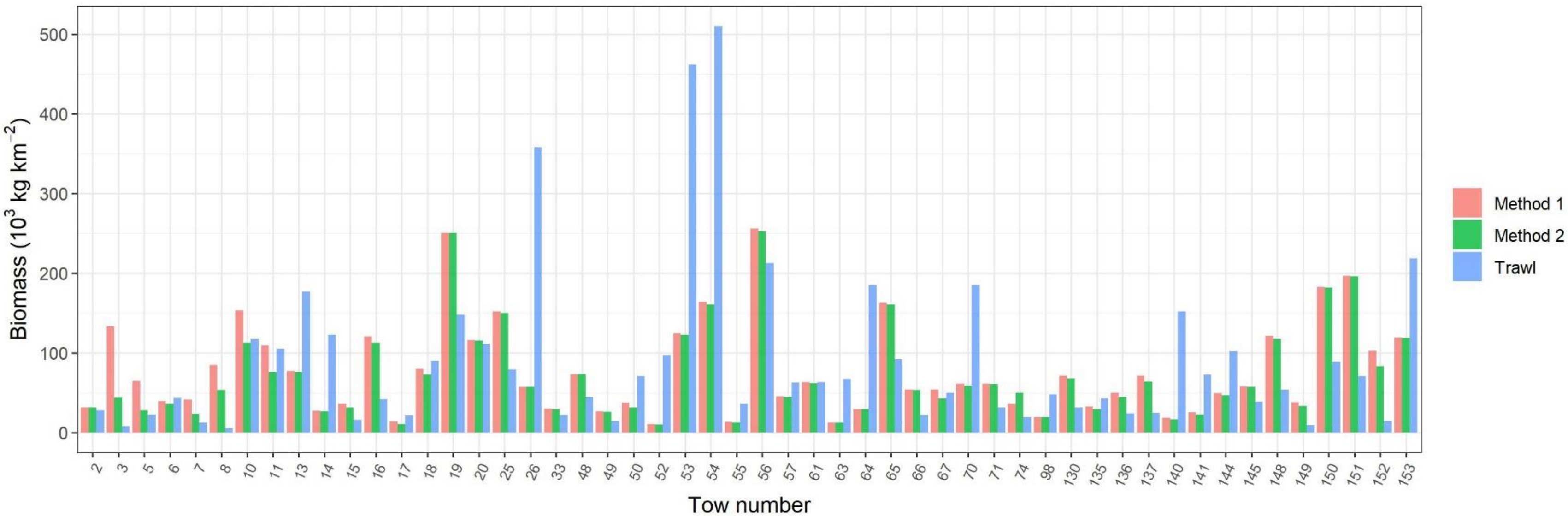

Figure 54. Biomass density per station estimated from the 2019 trawl and acoustic data. For clarity purposes, only stations where biomass for at least one method was greater than 10^3 kg km^{-2} are presented.

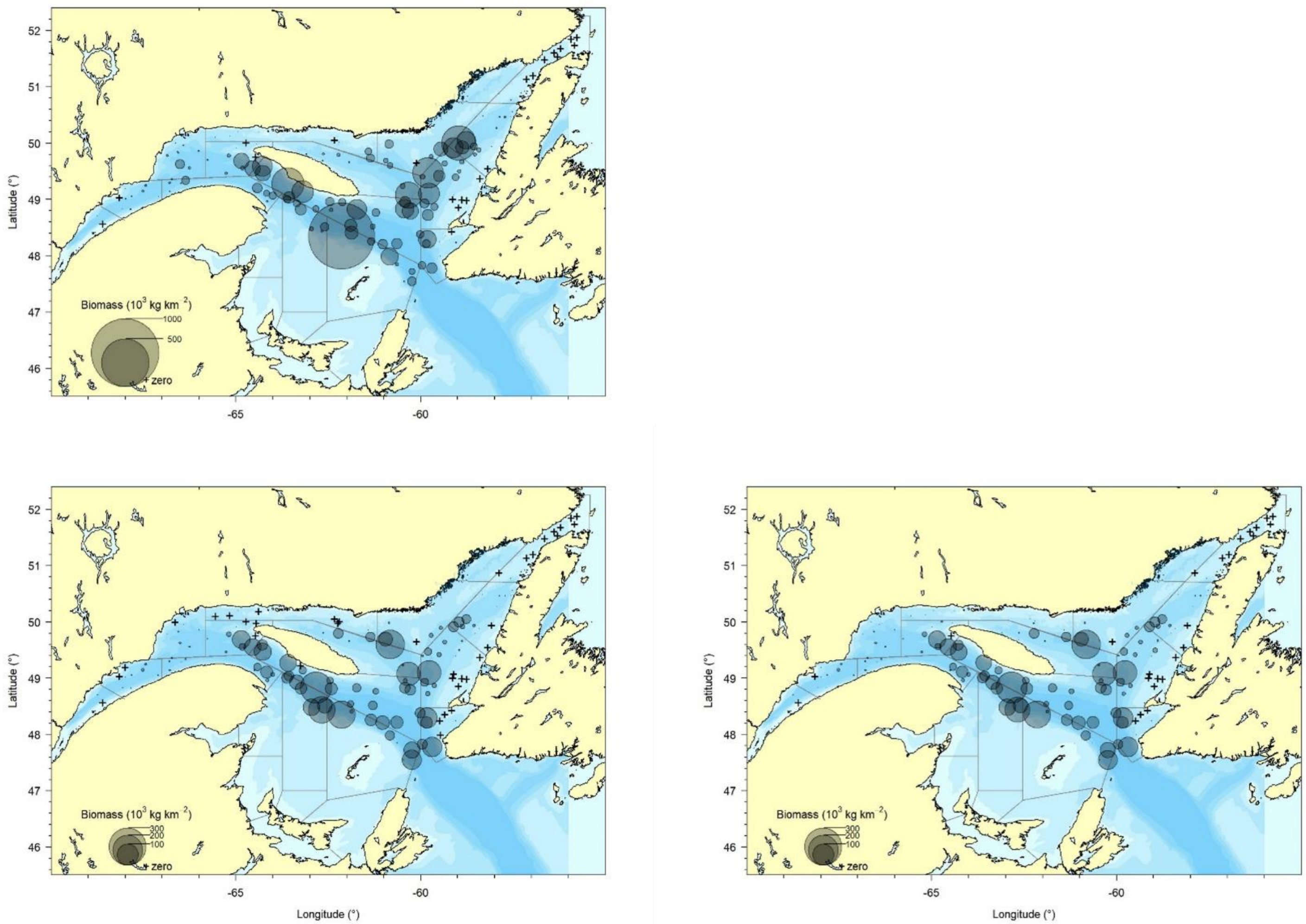

Figure 55. Biomass density at each station sampled in 2020. Upper left: catch data; lower left: acoustic data (method 1); lower right: acoustic data (method 2).

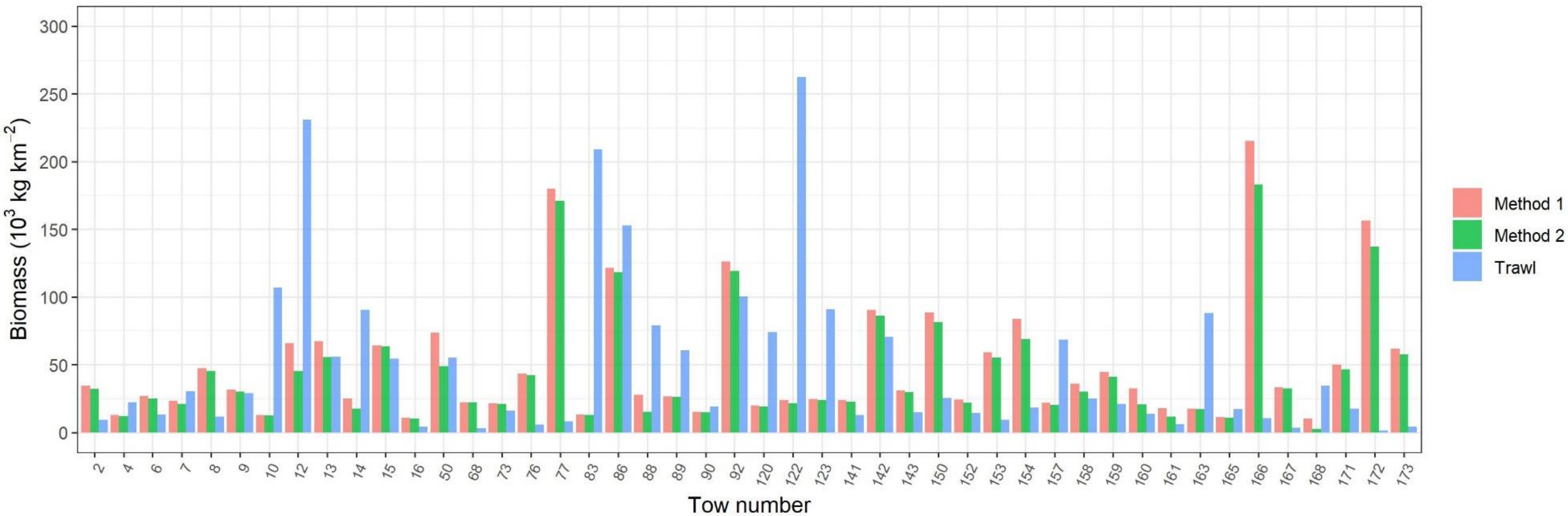

Figure 56. Biomass density per station estimated from the 2020 trawl and acoustic data. Station 170 not shown. For clarity purposes, only stations where biomass for at least one method was greater than 10^3 kg km^{-2} are presented.

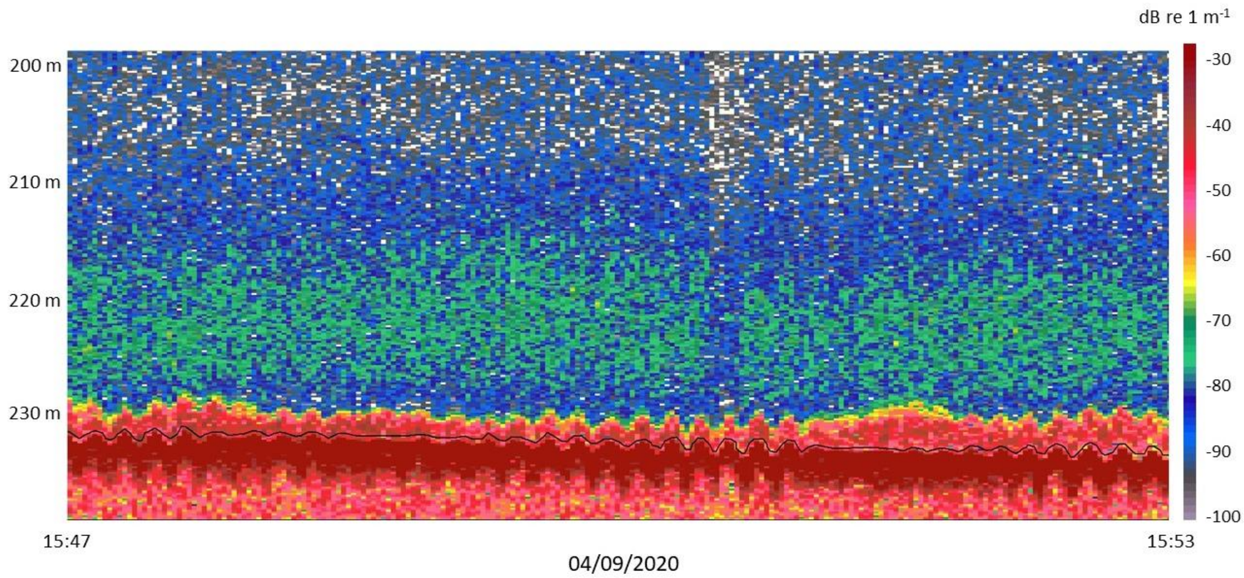

Figure 57. Volume backscattering strength echogram showing a strong acoustic layer near the bottom. Data collected on September 9 2020 at station 170. The acoustic bottom is defined as a black line.

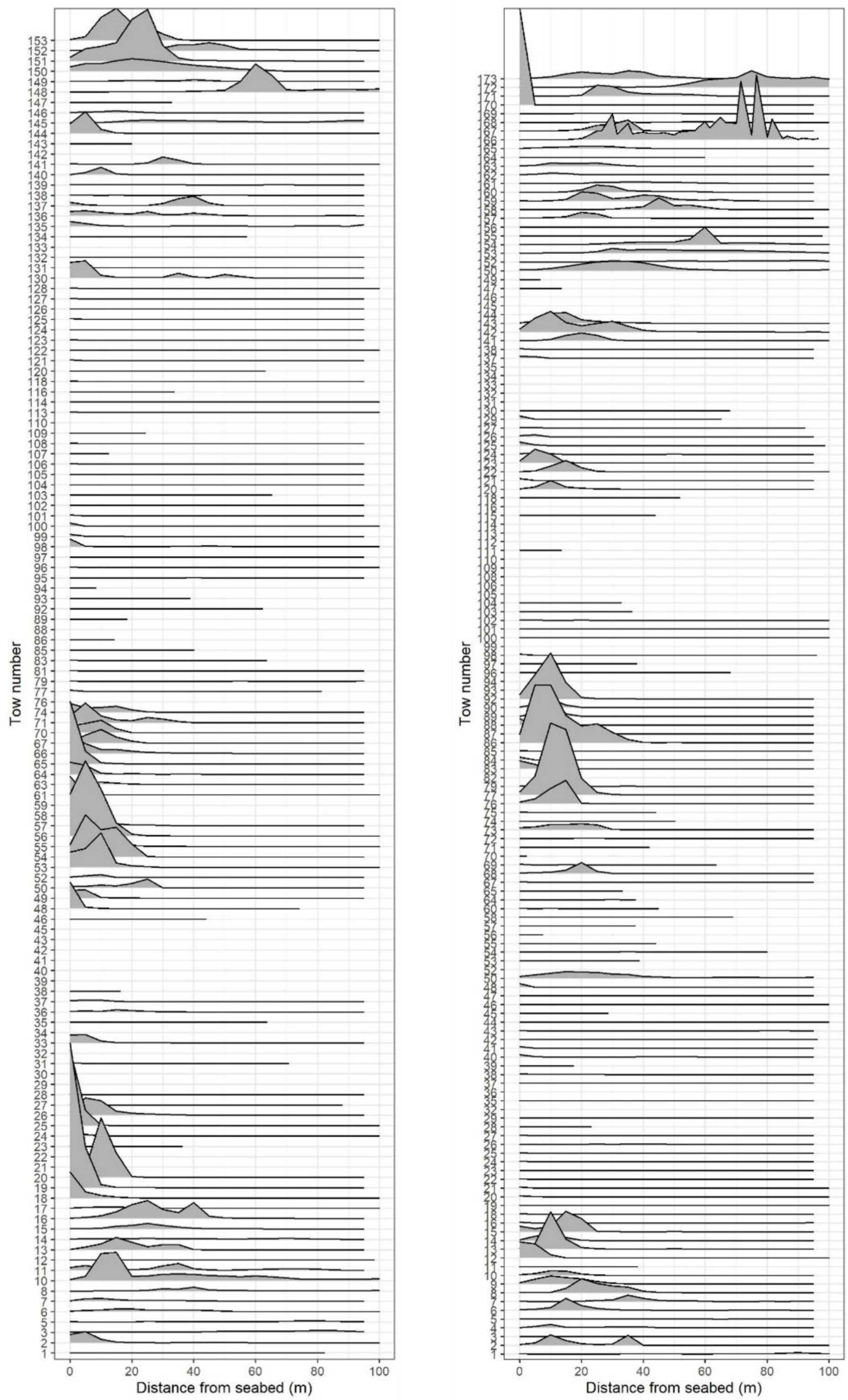

Figure 58. NASC (m^2 nmi^{-2}) per tow as a function of distance from seabed (m) in 2019 (left panel) and 2020 (right panel). Method 2 shown. Note that station numbers in 2019 and 2020 correspond to different geographical locations, and that vertical scale of NASC amplitude varies with year.

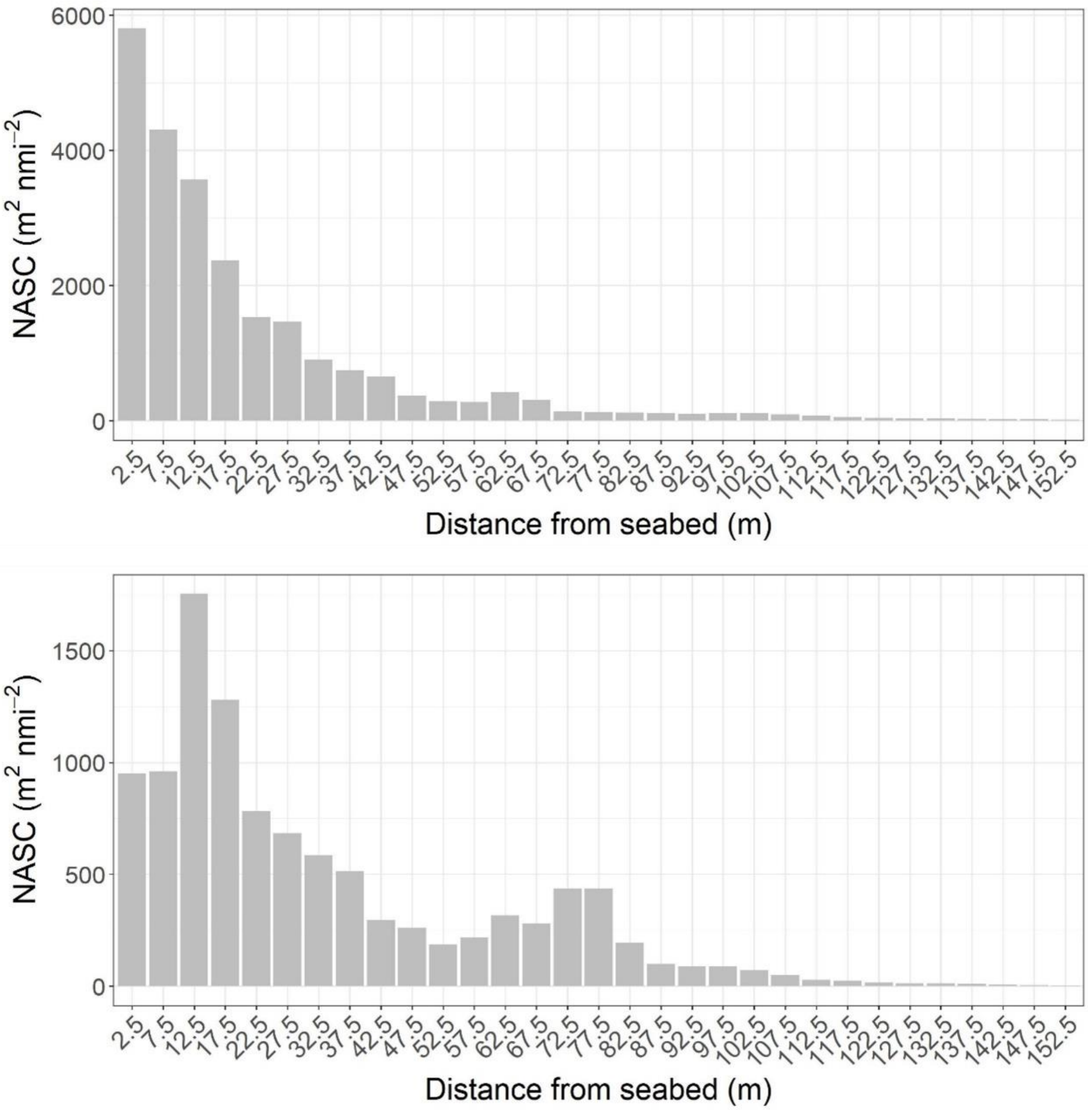

Figure 59. NASC (m^2 nmi^{-2}) summed over all stations as a function of distance from seabed (5 m increments) in 2019 (upper panel) and 2020 (lower panel). Method 2 is shown.

Figure 60. 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.

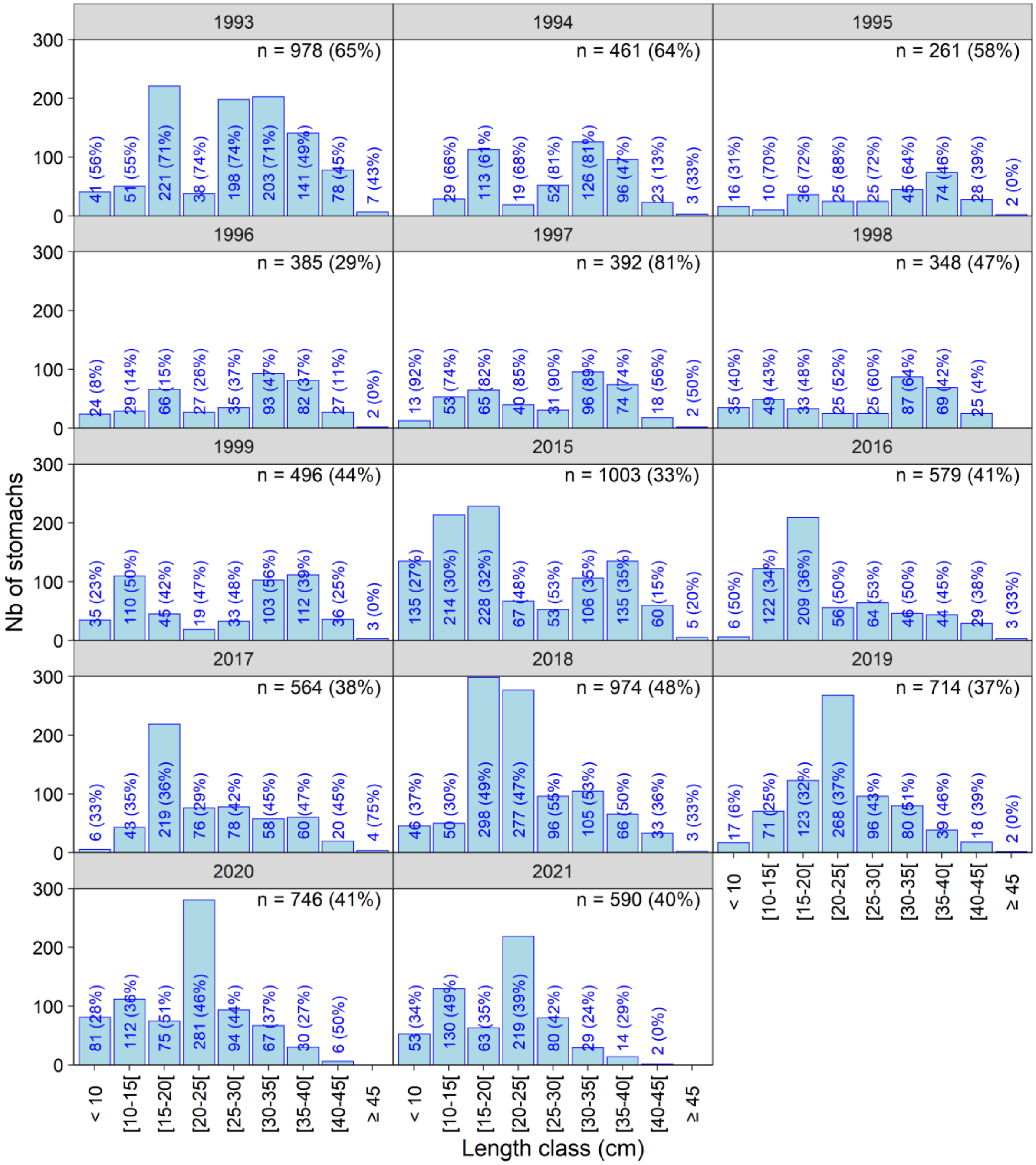

Figure 61. Number of Redfish stomachs, by year and length class. Values in parentheses are percentages of empty stomachs.

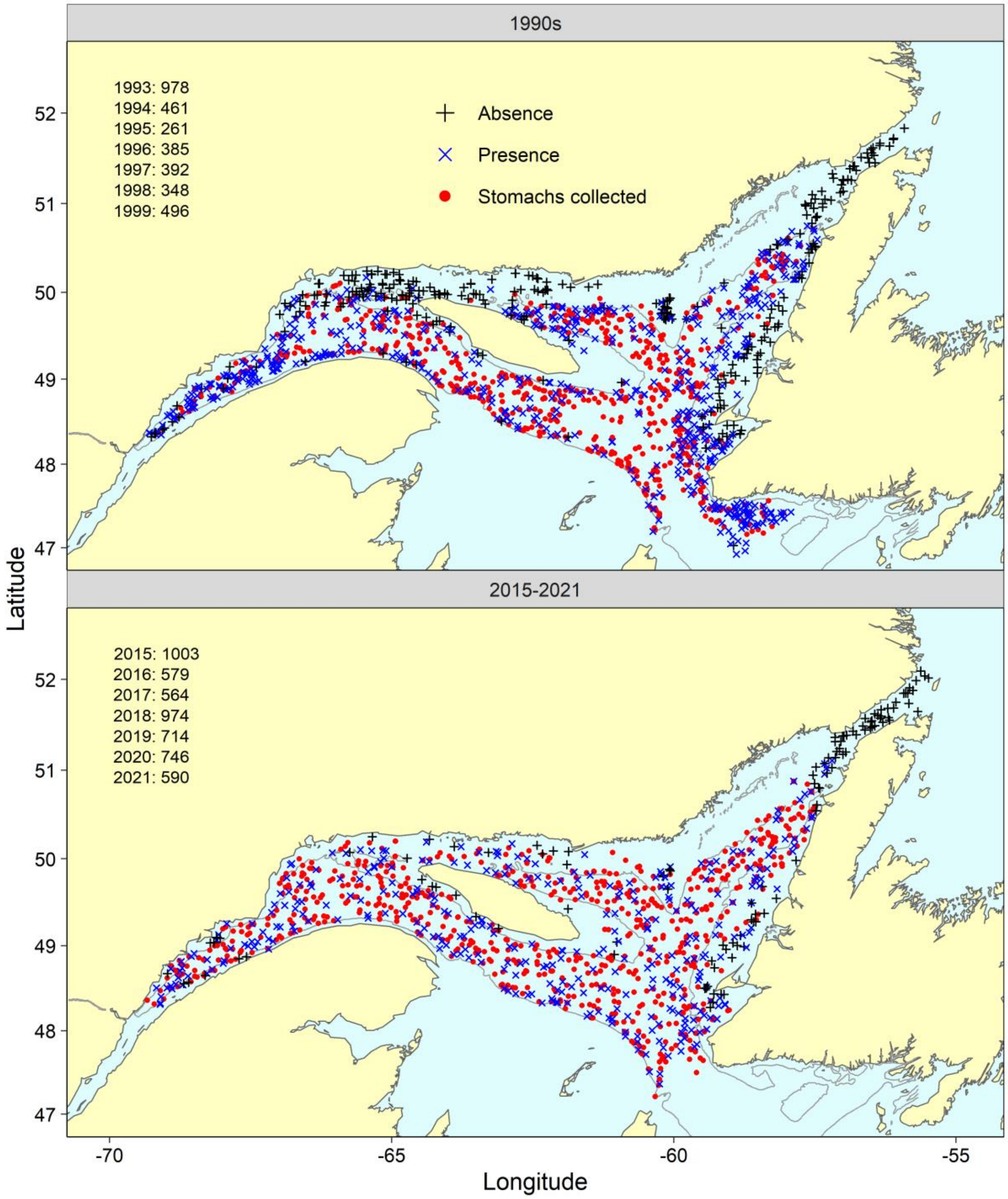

Figure 62. Origin of Redfish stomachs used in the analyses (in red), by sampling period. The black marks are set locations without Redfish in the capture. The blue marks are set locations with Redfish in the capture, but without any stomachs collected. Values in the upper left corner are the number of stomachs collected for each year.

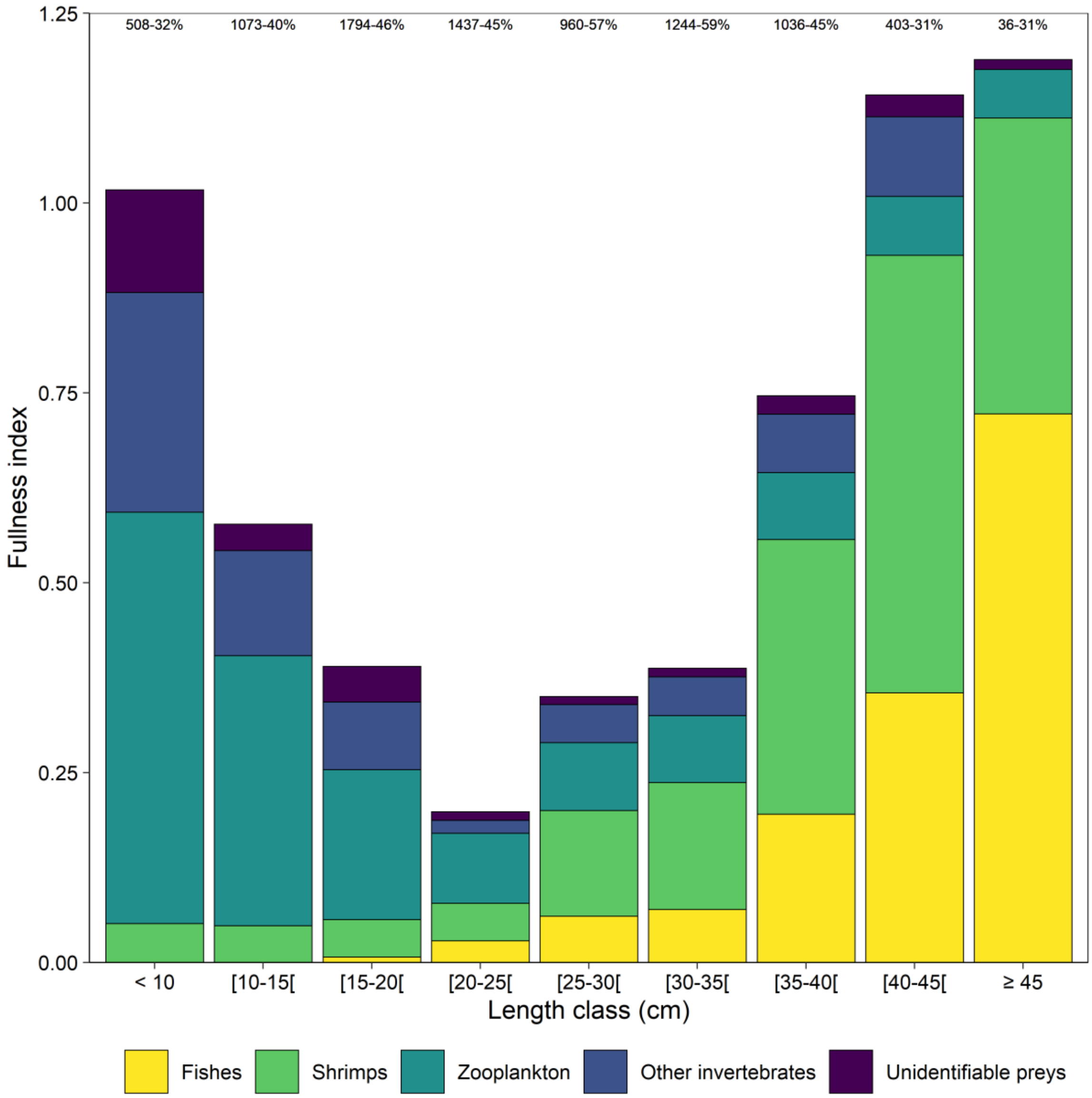

Figure 63. Redfish partial fullness index according to length class and type of prey, all years combined. The height of the columns corresponds to the total fullness index. The numbers above the columns correspond to the number of stomachs used for the analysis with the percentage of those being empty.

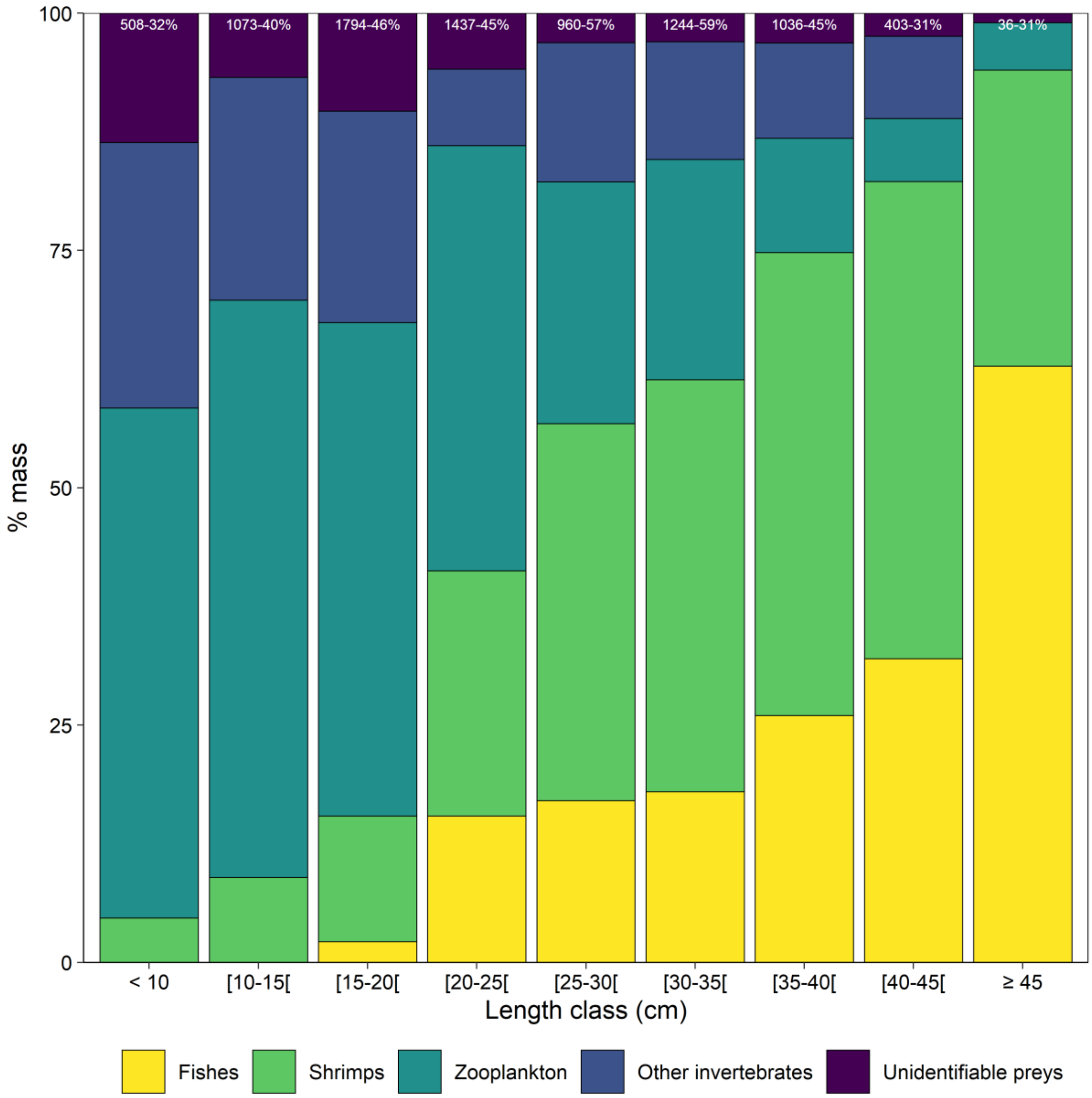

Figure 64. Redfish average mass contribution (MC, % mass) according to length class and type of prey, all years combined. The numbers above the columns correspond to the number of stomachs used for the analysis with the percentage of those being empty.

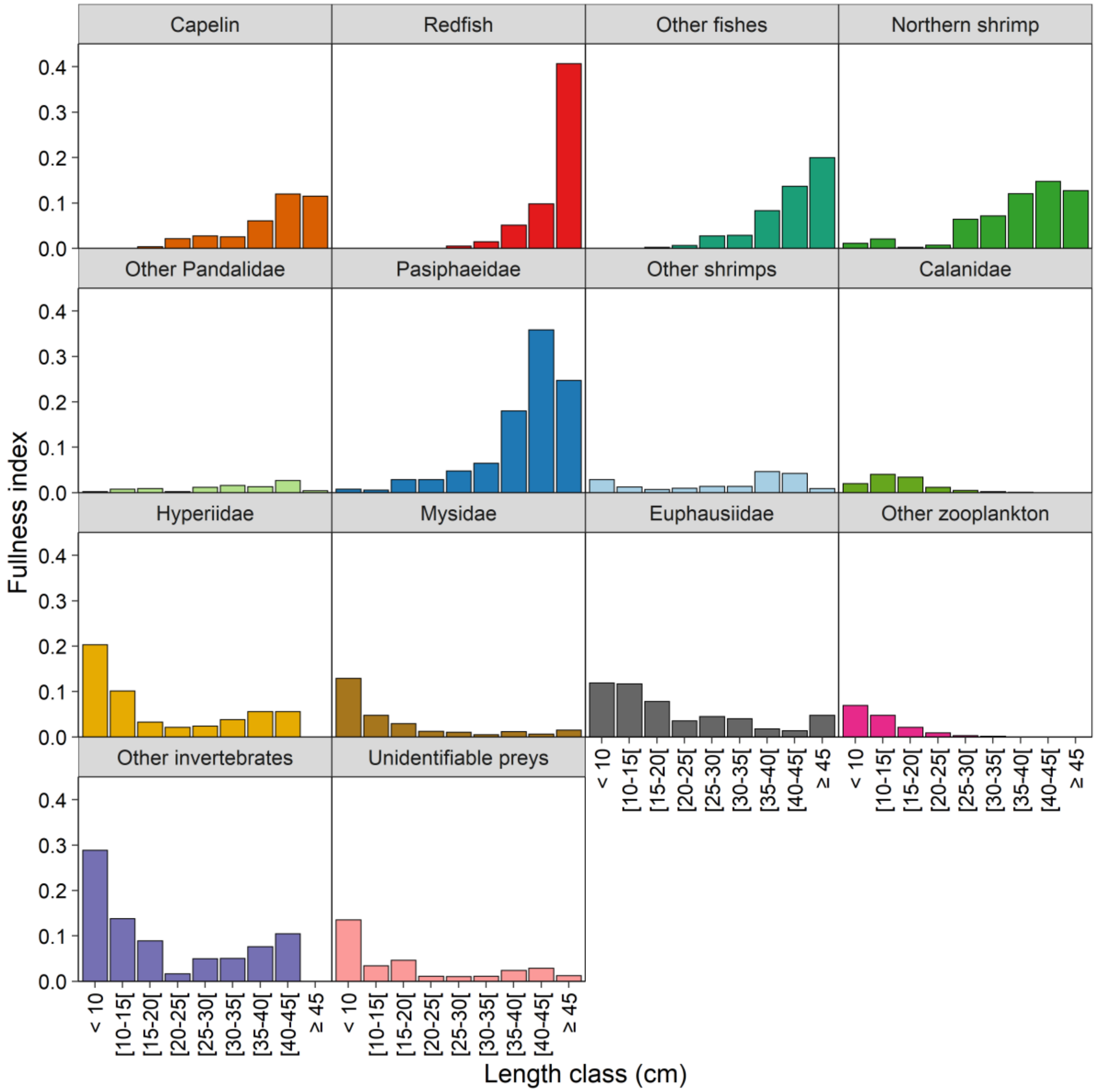

Figure 65. Redfish partial fullness index according to length class and taxonomic group, all years combined.

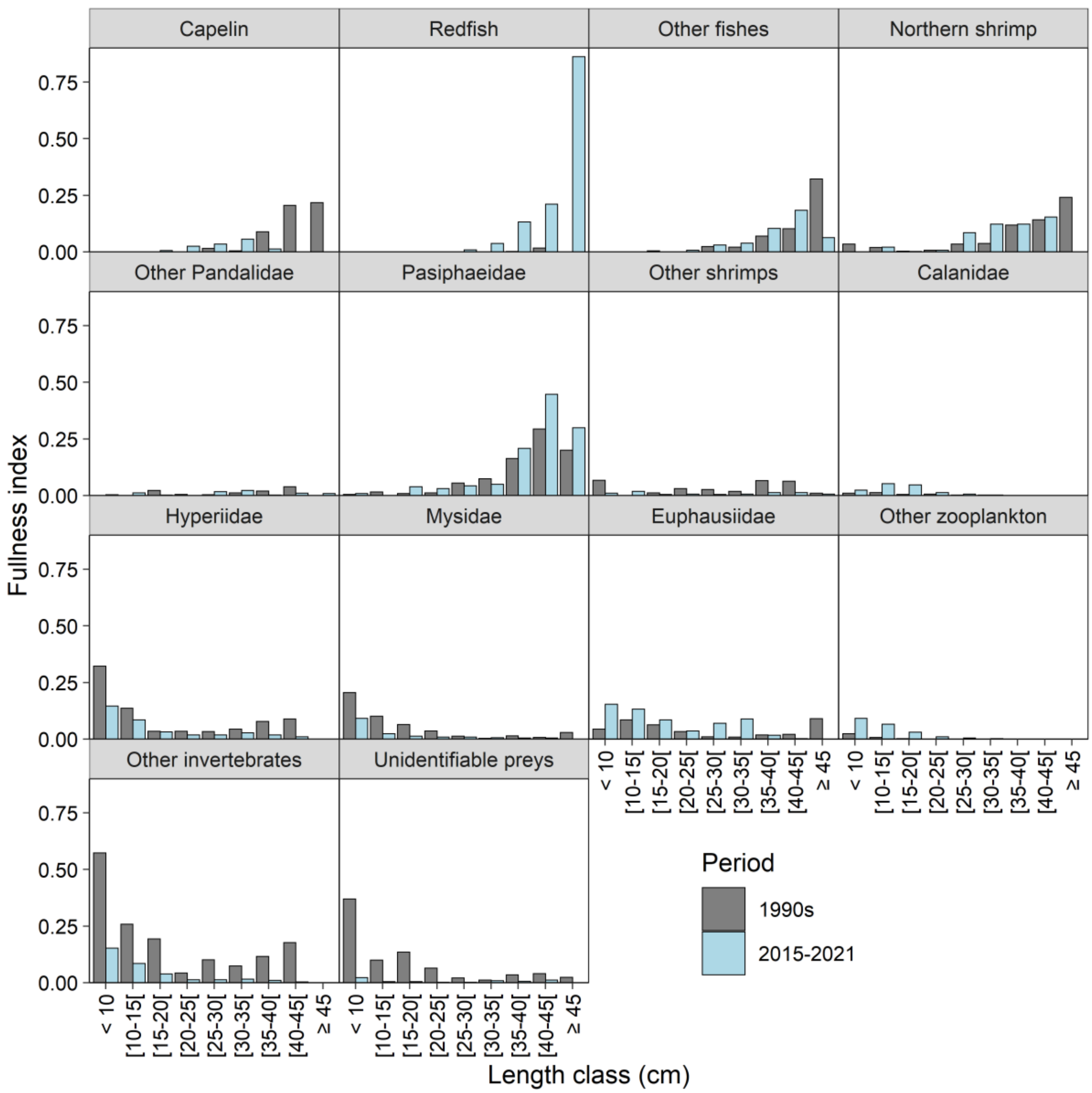

Figure 66. Redfish partial fullness index according to length class, period, and taxonomic group.

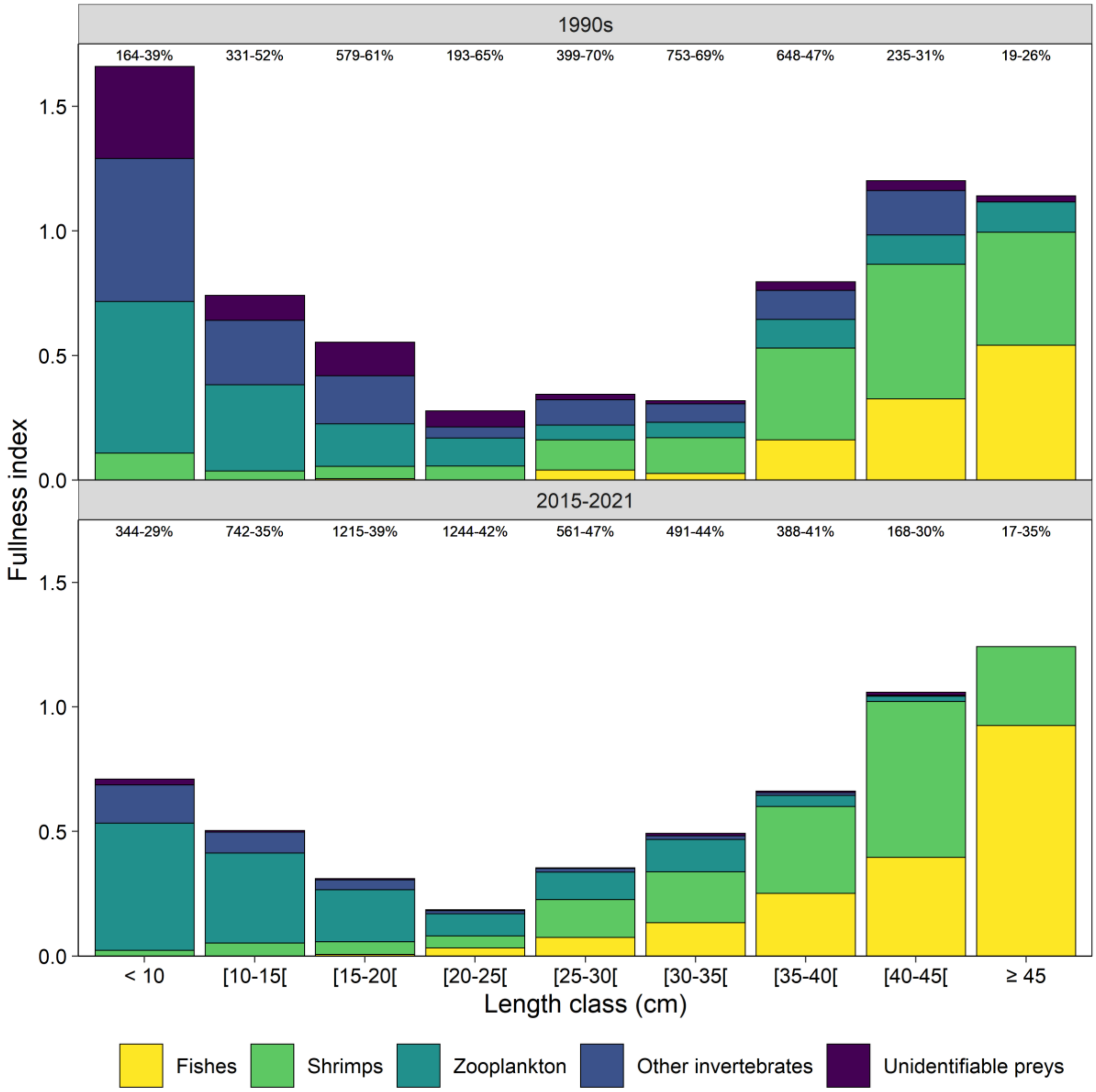

Figure 67. Redfish partial fullness index according to length class, period, and type of prey. The height of the columns corresponds to the total fullness index. The numbers above the columns correspond to the number of stomachs used for the analysis with the percentage of those being empty.

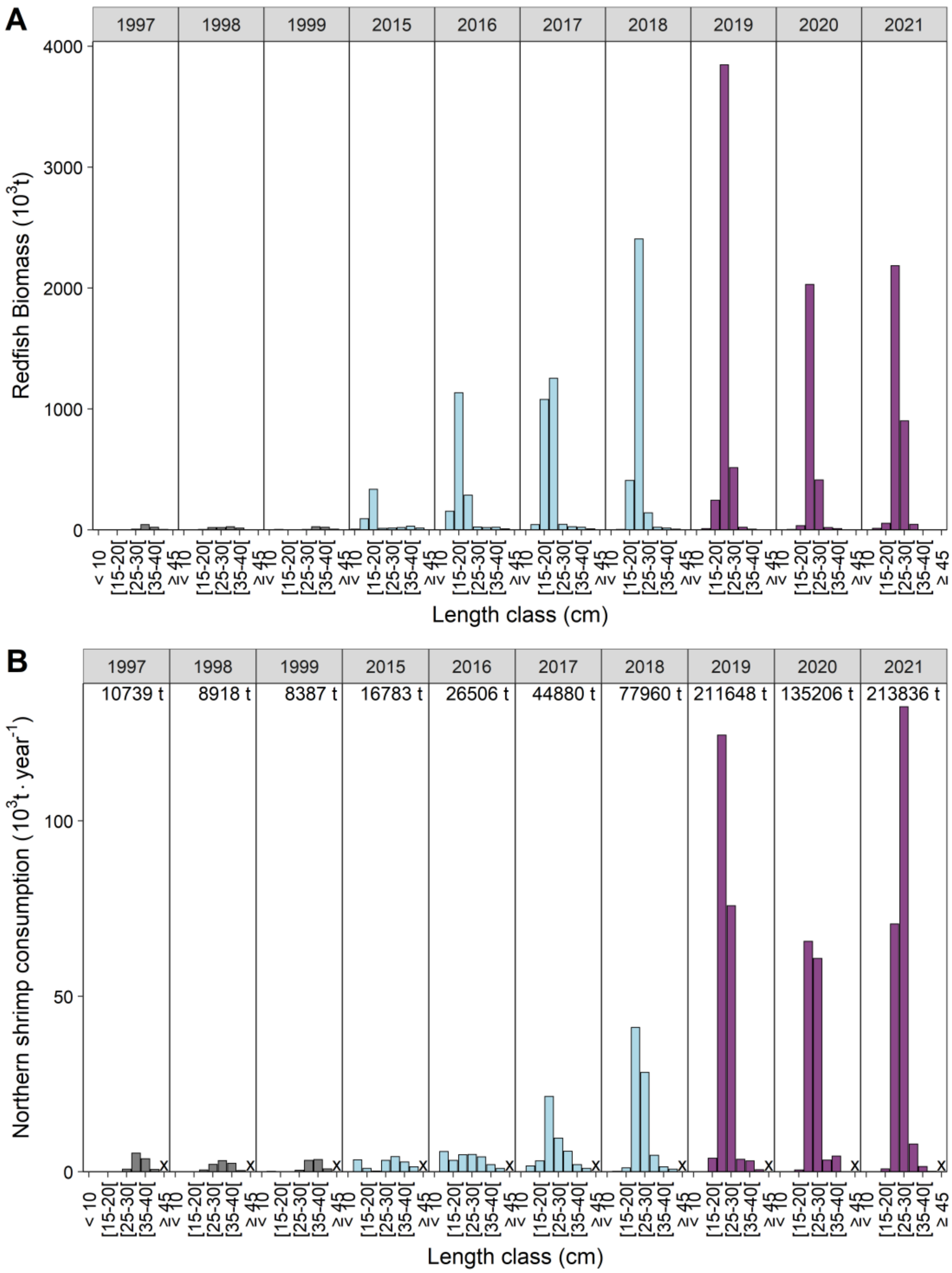

Figure 68. Estimated annual Redfish biomass (A) and Northern Shrimp consumption by Redfish (B) by length class for 1997–1999 and 2015–2021. The values provided in the upper part of the panels in B) are total estimated consumption for a given year. An "x" symbol denotes < 20 stomachs collected for a given 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 analyze 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)
}
```