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Science Advisory Report 2022/039

REDFISH (*SEBASTES MENTELLA* AND *SEBASTES FASCIATUS*) STOCKS ASSESSMENT IN UNITS 1 AND 2 IN 2021

Image: Redfish (Sebastes spp.) Credit: Fisheries and Oceans Canada

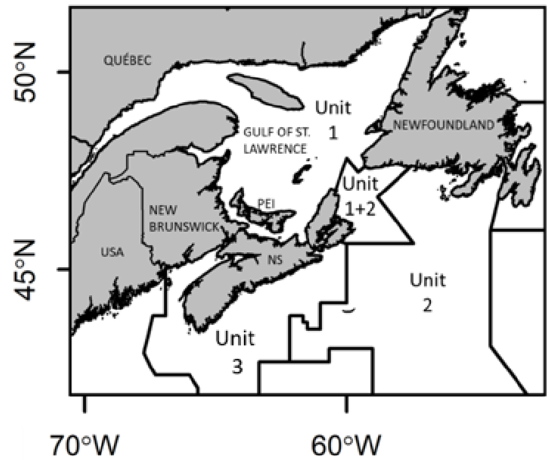

Figure 1. Units 1 and 2 Redfish stock management areas. The Unit 1+2 area, where Northwest Atlantic Fisheries Organization (NAFO) Subdivisions 3Pn and 4Vn are located, indicates the seasonal common area (January to May, Unit 1 and June to December, Unit 2).

Context

*The Redfish fisheries in Unit 1 and Unit 2 harvest two Redfish species, the Deepwater Redfish (*Sebastes mentella*) and Acadian Redfish (*Sebastes fasciatus*), each considered a single stock. Combined annual landings for both stocks dropped from over 100,000 t in the 1970s to less than 12,000 t as of 1995. Management measures have been applied to promote stocks recovery. Since 1995, the Redfish fishery in Unit 1 has been under a moratorium, with a 2,000 t/year index fishery authorized since 1999. An experimental fishery was additionally established in Unit 1 in 2018-19, with an initial quota of 2,500 t which has increased annually to reach 5,463 t in 2021-2022. There has been no moratorium on the commercial fishery in Unit 2, where the total allowable catch has been 8,500 t/year since 2006.*

Strong cohorts in 2011, 2012 and 2013 have recruited to the stocks and resulted in a significant increase in Redfish biomass in Units 1 and 2 since 2016. Genetic analyses indicated these cohorts were dominated by S. mentella *of the Gulf of St. Lawrence ecotype. In 2019, a limit reference point (LRP) and a proposed upper stock reference point (USR) were empirically derived for each stock based on the biomass time series from the research survey in Unit 1, which covers historical periods of contrasting abundance.*

*This Science Advisory Report is from the February 21-24 and March 16, 2022 zonal advisory meetings on the Assessment of Redfish Stocks (*S. mentella *and* S. fasciatus*) in Units 1 and 2 in 2021. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada Science Advisory Schedule] as they become available.*

September 2022

SUMMARY

- Redfish landings in 2020-21 were 1,130 t in Unit 1 (20% of the combined quota in the experimental and index fisheries) and 5,787 t in Unit 2 (68% of the TAC).
- Large numbers of regulatory-sized fish between 22 to 26 cm in length have entered the fishery in Unit 1 (since 2018) and Unit 2 (since 2019).
- Annual landed bycatch is a low proportion of total landings in Redfish fisheries. Bycatch includes commercial species and species of conservation concern. The impact of bycatch in Redfish fisheries has not been evaluated for all species.
- Fishing deeper than 300 m can reduce catches of *S. fasciatus* in all fishing areas except the Laurentian Fan, and reduce catches of under-sized (< 22 cm) Redfish.
- Simulations of bias in the species identification process and available genetic information on the relative abundance of the two species suggest the biomass of *S. fasciatus* in research surveys may currently be overestimated.
- The Unit 1 (2021) total estimated survey biomass for *S. mentella* (2,805 kt (2,133-3,549 95% CI)) remained among the highest values in the time series beginning in 1984, while *S. fasciatus* (420 kt (118-722 95% CI)) was at the highest value recorded.
- The Unit 2 (2018 – most recent calibrated survey) total estimated biomass for *S. mentella* (805 kt (607-1089 kt 95% CI)) was the highest value recorded in the time series beginning in 2000, while *S. fasciatus* (101 kt (0-352 kt 95% CI)) was below the series mean.
- Fish larger than the minimum regulatory size (22 cm) accounted for a large fraction of total survey biomass in Unit 1 in 2021 (93% for *S. mentella* and 85% for *S. fasciatus*) and 89% of the total survey biomass of both species in Unit 2 in 2018.
- Individuals from the strong 2011-2013 cohorts of *S. mentella* and *S. fasciatus* currently exhibit a reduced growth potential and are maturing at smaller sizes than previously observed strong cohorts.
- The empirical limit reference point (LRP) for each stock was updated based on current maturity information used to estimate spawning stock biomass from 2011 onwards. The revised LRPs are 44 kt for *S. mentella* and 30 kt for *S. fasciatus*.
- In 2021, the spawning stock biomass of *S. mentella* would be in the Healthy Zone based on the proposed upper stock reference (USR). The magnitude of the increase in spawning stock biomass of *S. fasciatus* is uncertain, but evidence indicates the stock is at least above the LRP.
- Short-term prospects for Redfish stocks in Units 1 and 2 are generally positive. High biomass of *S. mentella* allows for increased harvests, while caution is warranted for *S. fasciatus* and bycatch species.

BACKGROUND

Species biology

Units 1 and 2 Redfish inhabit cold waters along the slopes of banks and deep channels at depths ranging from 100 to 700 m. *Sebastes mentella* is typically found in deeper waters than *S. fasciatus*. In the Gulf of St. Lawrence (GSL) and Laurentian Channel, *S. mentella* is found primarily in the main channels at depths ranging from 200 to 400 m. In contrast, *S. fasciatus* is present mainly at depths less than 300 m, along the slopes of channels and on the banks, except in the Laurentian Fan, where it inhabits deeper waters. Adult Redfish are demersal and mainly reside near the bottom but are known to undertake vertical feeding migrations at night to follow their prey as they migrate.

Redfish are slow growing, long lived and ovoviviparous. Copulation occurs in the fall, most likely between September and December, and the females carry developing embryos until they are extruded in spring at the larval stage when they are able to swim. Larval extrusion occurs from April to July, depending on the species and area. Copulation and larval extrusion do not necessarily occur in the same locations. In the GSL, *S. mentella* releases its larvae approximately three to four weeks earlier than *S. fasciatus*. The larvae develop in surface waters and juveniles gradually migrate to greater depths as they grow.

Stock structure based on genomics

Genomic analyses of samples collected from 2001 to 2015 confirmed a pronounced genetic distinction between *S. mentella* and *S. fasciatus*, despite their morphological similarity (Benestan et al. 2021). A single ecotype of *S. mentella* (the Gulf ecotype) was identified in Units 1 and 2. Individuals of this ecotype were also encountered in the Labrador Sea and northeastern Newfoundland Shelf. 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. Three populations of *S. fasciatus* were identified in Units 1 and 2. Two of the three *S. fasciatus* populations were also encountered in southern Labrador Sea and northeastern Newfoundland Shelf. 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 ecotype and population does not always correspond to fishery management units.

Species identification

Redfish species are morphologically very similar and difficult to distinguish. A meristic trait, the soft anal fin ray (AFR) count, has been used to distinguish *S. mentella* and *S. fasciatus* in catch samples from scientific surveys in Unit 1 (since 1984) and Unit 2 (since 2000), as well as the index and experimental fisheries in Unit 1 and the commercial fishery in Unit 2 (since 2018). This information is used to inform species-specific stock assessment since 2010.

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 how it can affect the perception of stock status for *S. mentella* and *S. fasciatus* in Units 1 and 2, remains a research priority.

Recruitment events

In the Northwest Atlantic, annual recruitment in Redfish populations are characterized by sporadic strong recruitment events. Based on genetic evidence, there was a strong cohort of *S. mentella* around 1980 in Units 1 and 2, which subsequently greatly contributed to the fishery. Strong cohorts of *S. fasciatus* were observed in 1974, 1985, 1988 and 2003, and were mainly associated with Unit 1. Those year-classes of *S. fasciatus* decreased rapidly within a few years without significantly recruiting to the adult stock and fishery.

Recent DFO research surveys have observed the three most abundant Redfish cohorts ever observed in Unit 1: the 2011, 2012, and 2013 cohorts. Genetic analyses performed on the 2011 cohort have indicated that 91% of juvenile fish collected in 2013 in Unit 1 were *S. mentella* from the GSL ecotype, suggesting that they should remain in the area and contribute to the recovery of *S. mentella*. No similar analyses have been performed for Unit 2.

Ecosystem

Temperatures in the deep waters of the Laurentian channel have been rising for over a decade. These waters result from the mixing of cold Labrador current water and warm Gulf Stream water. There is currently a higher proportion of warm, oxygen-poor Gulf Stream water in the deep water layer entering the GSL. In Unit 1, new series record highs (since 1915) were set in 2020 at depths of 200, 250, and 300 m, at 5.7°C, 6.6°C, and 6.8°C respectively, on average corresponding to an increase of 1-1.5°C relative to the series mean. Bottom area covered by waters warmer than 6°C was at a record high in the Northwest GSL, the Northeast GSL, and in Centre and Cabot Strait, and some 7–8°C areas appeared for the first time in the Northeast GSL (Galbraith et al. 2021). In Unit 2, the warming trend is also clearly visible for the bottom temperature in recent years, with the five warmest years in this time series (1970-2021) occurring since 2015 (2015, 2016, 2018, 2020, and 2021).

The GSL ecosystem was dominated by groundfish during the 1990s and subsequently dominated by mid-trophic level invertebrates and forage species. Increases in Redfish have caused the ecosystem to shift back to one dominated by groundfish. In 2021, *Sebastes* spp. represented the most common taxon, accounting for 82% of the sampled biomass during the DFO survey in Unit 1, as compared to 15% between 1995 and 2012 (Figure 2). This increase of Redfish biomass, now estimated at 3.2 million tonnes, has important repercussions on other species, through predation and competitive interactions. No similar analyses have been performed for Unit 2.

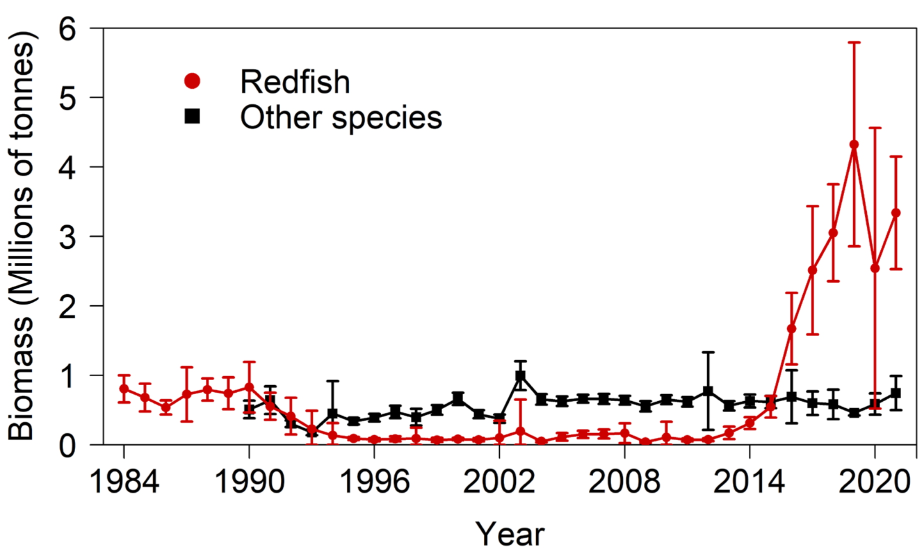

Figure 2. Trawlable biomass (millions of tonnes, with 95% confidence intervals) of Redfish spp. (red circles) and all other species (black squares) sampled in the Unit 1 DFO survey from 1984 to 2021.

The summer diet of Redfish in Unit 1 varies according to fish size (Figure 3). Redfish smaller than 25 cm consume mostly zooplankton. Once Redfish reach 25 cm, fish and shrimp (mainly Pink Glass Shrimp, *Pasiphaea multidentata*, and Northern Shrimp, *Pandalus borealis*) become more prominent in the diet. There are concerns that predation by Redfish may be contributing to the decline in Northern Shrimp abundance in the GSL. Stomach contents examination suggest that the predation pressure by Redfish on Northern Shrimp has increased substantially in the past five years, and the situation is not expected to change in the near future. However, the impact of this phenomenon may be lessened if the spatial overlap between these species diminishes due to the expected migration of Redfish as adults to depths of over 300 m. No diet samples are available for Unit 2.

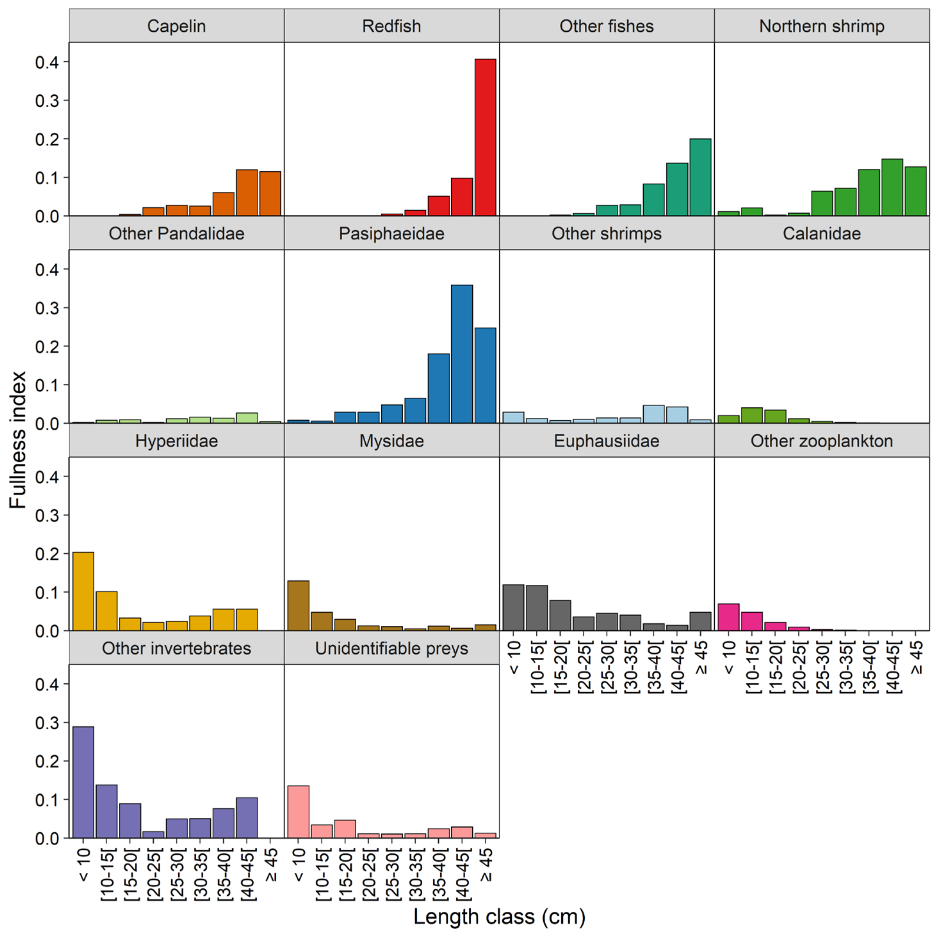

Figure 3. Average Redfish stomachs partial fullness index according to length class, and prey taxonomic group (1993-2021).

ASSESSMENT

Fishery

In the late 1950s, a directed fishery for Redfish was developed in the GSL and the Laurentian Channel. In 1993, Redfish management units were redefined to better align with available knowledge on the biology of the stocks. The resulting management units are Unit 1, which includes Divisions 4RST and Subdivisions 3Pn4Vn from January to May; Unit 2, which includes

Subdivisions 3Ps4Vs, Subdivisions 4Wfgj, and Subdivisions 3Pn4Vn from June to December; and Unit 3 which includes Subdivisions 4WdehklX (Figure 1). The latter is not being considered the same stock as Units 1 and 2.

In 1993, total allowable catches (TAC) for Redfish were set at 60,000 t in Unit 1 and 28,000 t in Unit 2. Following reductions in stock abundance, a moratorium was implemented in 1995 in Unit 1 while commercial fishing continued in Unit 2. A 2,000 t/year quota for an index fishery in Unit 1 was established in 1999. The TAC in Unit 2 has steadily declined since 1993, and a TAC of 8,500 t/year for the commercial fishery in Unit 2 has been in place since 2006.

With the arrival of three strong cohorts, an experimental fishery was established in Unit 1 with an additional quota 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 round. The objectives of the experimental fishery are: 1) to target *S. mentella*, which are currently more abundant than *S. fasciatus*; 2) to investigate ways to limit bycatch of other species and undersized Redfish; and 3) to better understand the spatio-temporal distribution of Redfish and bycatch species.

Current Redfish conservation measures applicable to all fisheries include a protocol to protect small fish (< 22 cm), 100% dockside monitoring, mandatory hail reports upon departure and arrival, imposition of a level of coverage by at-sea observers, and a bycatch protocol. Additionally, there are closure periods and spatial management measures to reduce incidental bycatch and fishing impacts on the seabed, and protect sensitive species, habitats and Redfish reproduction.

Landings in Unit 1 and Unit 2

The Redfish fishery has been characterized by two periods of high landings: the first in the 1970s where the landings reached more than 130,000 t, and the second in the early 1990s where the landings were close to 100,000 t (Figure 4).

In Unit 1, from 1965 to 1976, annual landings averaged 79,000 t, peaking at 136,000 t in 1973. From 1987 to 1992, average annual landings were 59,000 t. In 1995, a moratorium was imposed on the Redfish fishery due to low stock abundance and poor recruitment. Since then, landings in Unit 1 have remained below the TACs. Between 1999 and 2005, average annual landings from the index fishery and bycatch in other fisheries reached 1,054 t in Unit 1. On average from 2010 to 2017, 470 t of Redfish were caught annually. Subsequently, landings increased to in average 1,090 t since 2018. The additional experimental quota resulted in a small increase in preliminary estimates of landings in 2020 (1,130 t) and 2021 (1,068 t).

In Unit 2, from 1960 to 1968, catches averaged about 20,000 t and increased to a time series high of 58,200 t in 1971, primarily due to increased landings from non-Canadian fleets. Since the declaration of the 200-mile Economic Exclusive Zone in 1977, landings have been primarily associated to Canadian fleets. Landings declined to 8,100 t in 1984 and then increased to over 27,000 t in 1993. Subsequently, an overall declining trend occurred and landings have remained well below the TAC. From 2018 to 2020, landings were 4,031 t, 5,423 t, and 5,787 t, respectively. The increase in catches in the late 1980s and early 1990s was driven primarily by depletion of other groundfish resources and increased interest in Redfish.

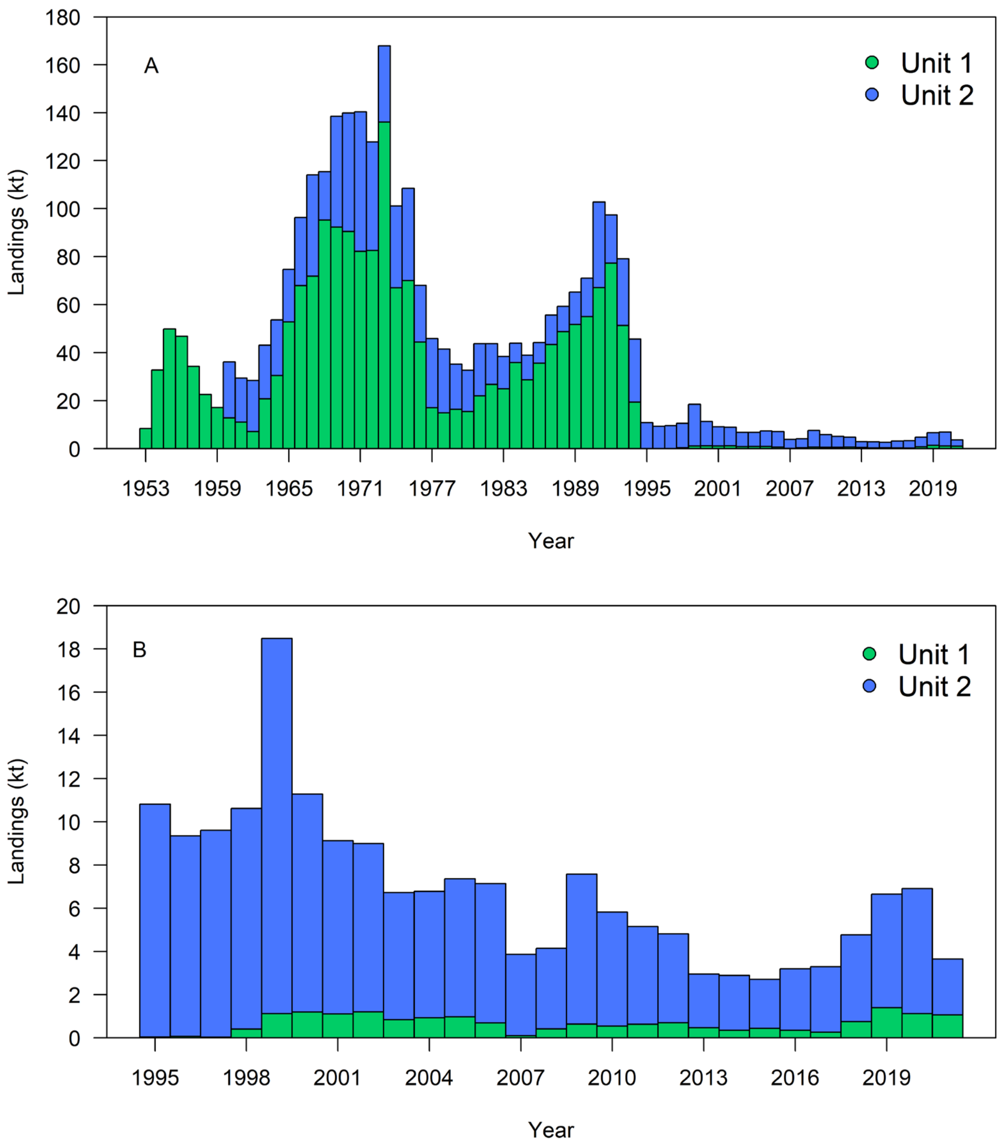

Figure 4. Fishery annual Redfish landings (in kilotonnes) in Unit 1 and 2 from 1953 to 2021 (A) and from 1995-2021 (B). Unit 2 landings were available starting in 1960. Data include fisheries directed to all species. No Redfish-directed fishery took place from 1995 to 1997 in Unit 1. 2020 and 2021 values are preliminary.

Length frequency of fisheries catches in Unit 1 and Unit 2

From 1981 to 1988, commercial catch length frequencies in Unit 1 indicated that catches primarily consisted of Redfish born in the early 1970s (Figure 5). It appears that the 1980 cohort began to recruit to the fishery in 1987 and remained in catches for many years. From 1988 to 2008, catches predominantly consisted of Redfish born in the early 1980s. From 1999 to 2016, most Redfish caught were larger than 30 cm. Redfish larger than 30 cm were less frequent from 2017 to 2021, while catches were dominated by the 2011-2013 cohorts. Large numbers of fish between 22 to 26 cm in length have entered the fishery in Unit 1 (since 2018) and Unit 2 (since 2019).

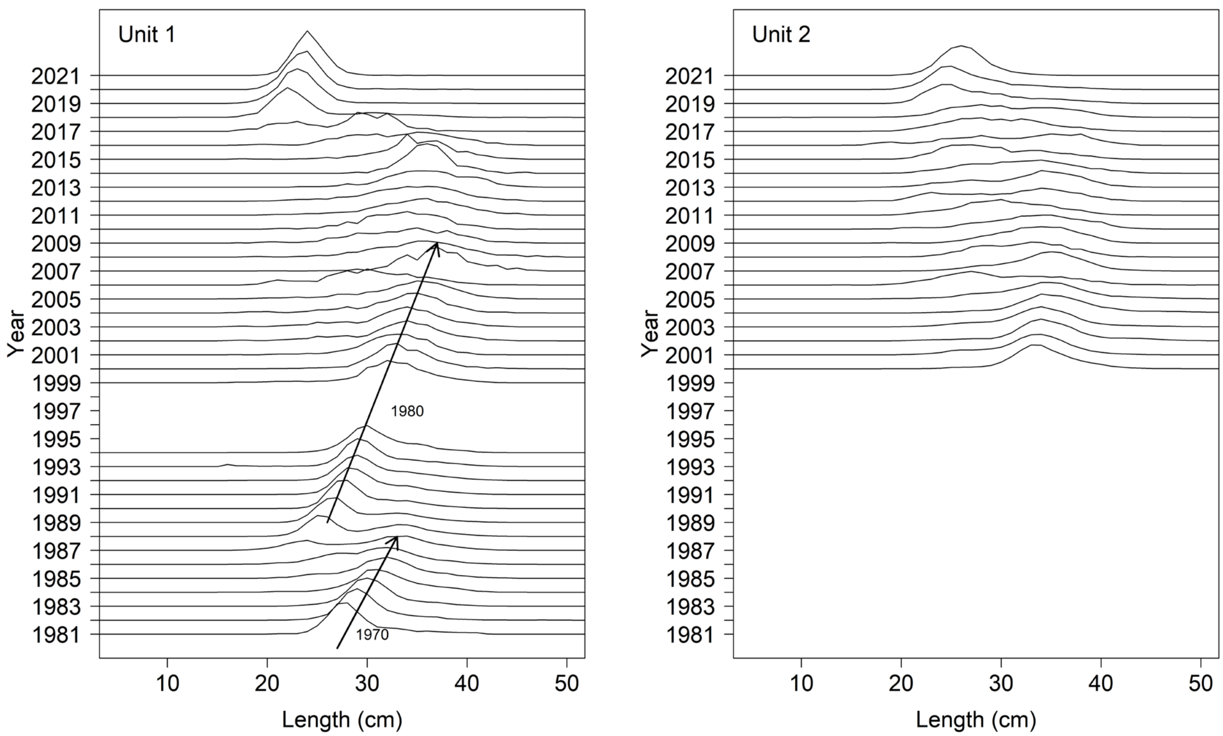

Figure 5. Fisheries catch length frequencies in percentage in Unit 1 from 1981 and Unit 2 from 2000. No Redfish directed fishery took place from 1995 to 1997 in Unit 1. The arrows indicate growth trajectories of the 1970 and 1980 cohorts. 2020 and 2021 values are preliminary.

Bycatch in Unit 1 and Unit 2

Redfish captured in groundfish-directed fisheries must be landed and are therefore monitored in the dockside monitoring program. Since 2000, annual landed bycatch is a low proportion (<10%) of total landings in Redfish fisheries (Figure 6). Bycatch includes commercial species and species of conservation concern. The impact of bycatch in Redfish fisheries has not been evaluated for all species.

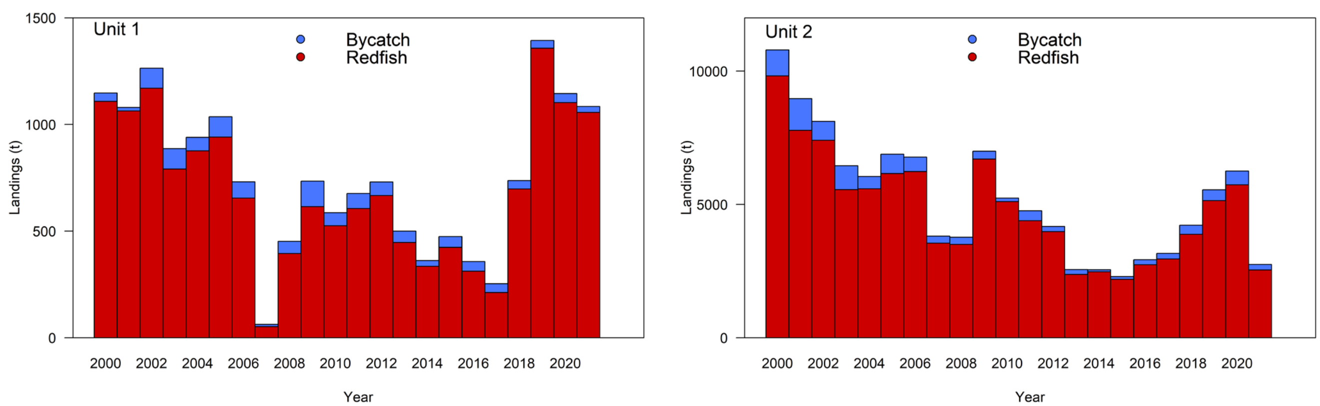

Figure 6. Declared landings (tonnes) of Redfish and bycatch species in the directed Redfish fishery in Unit 1 and 2 from 2000 to 2021.

Research Surveys

A DFO bottom-trawl research survey has taken place annually in August in Unit 1 since 1984.

A biennial industry-led bottom-trawl research survey has been undertaken by the *Atlantic Groundfish Council (AGC; formerly the Groundfish Enterprise Allocation Council)* since 2000 in Unit 2. Indices of biomass and abundance are available by Redfish species from 2000-2018 (excluding 2014 which is assessed as *Sebastes* spp.). A survey was undertaken in 2020, however full survey results are not available due to a vessel change and lack of comparative fishing experiments. Comparative fishing is expected to be carried out in the future to ensure the two vessel series can be merged into one.

Biomass indices and length composition in Unit 1

Survey biomass indices for *S. mentella* and *S. fasciatus* declined sharply from the late 1980s to 1994 (Figure 7), and remained stable low for all size class until 2015 (Figure 8). The new cohorts (2011-2013) dominated by the one of 2011 composed primarily of *S. mentella*, started being caught in the survey in 2013. These juveniles were largely dominated by *S. mentella*, with the genetic signature of the GSL ecotype.

In 2021, total survey biomass was estimated at 2,805,000 t for *S. mentella*, one of the highest values ever observed. Total survey biomass of *S. fasciatus* was estimated at 420,000 t, corresponding to the highest value since 1984 and indicating an important increase from 2019 (Figure 7).

The biomass of Redfish greater than 22 cm in length, corresponding to minimum regulatory size, began to increase in 2017 and reached 2,622,000 t for *S. mentella* in 2021 (93% of total survey biomass) and 359,000 t for *S. fasciatus* (85% of total). Biomass of *S. mentella* greater than 25 cm in length, corresponding to marketable size for many stakeholders, 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 8). In the summer 2021, Redfish modal size was 24 cm for both species (Figure 9).

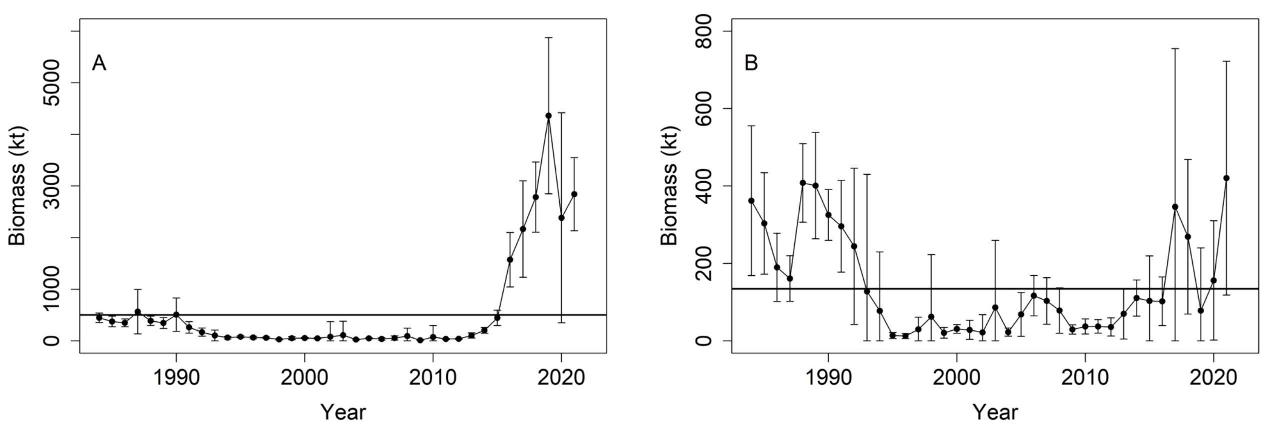

Figure 7. Minimum trawlable biomass in kilotonnes (kt, with 95% confidence intervals) of S. mentella (A) and S. fasciatus (B) in the Unit 1 DFO survey from 1984 to 2021. The solid lines represent the 1984-2020 average.

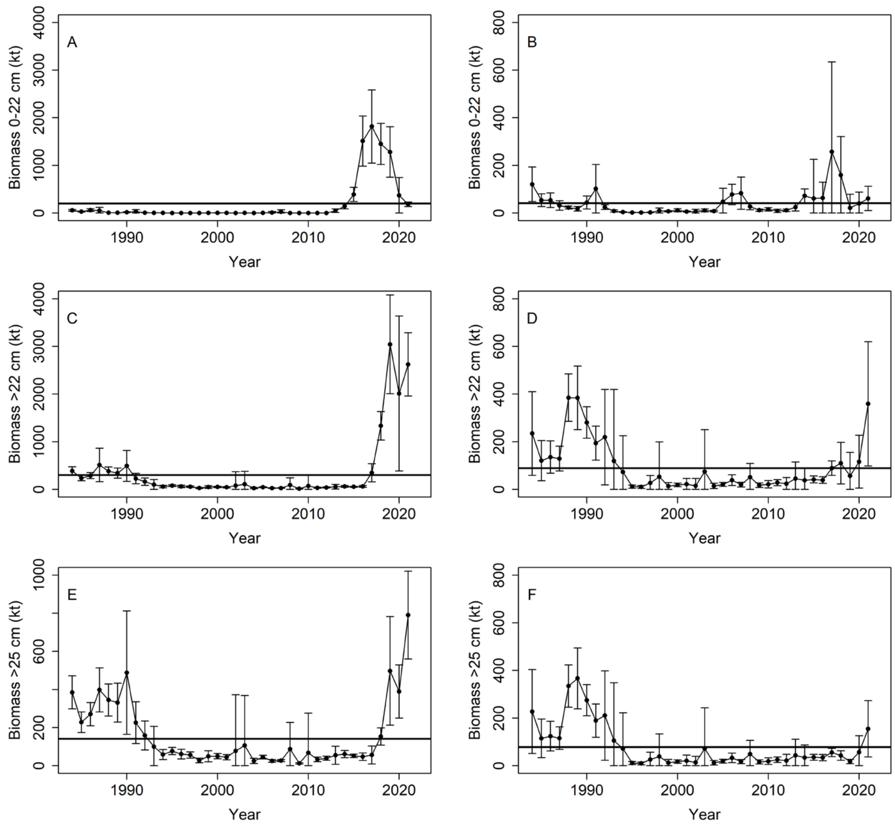

Figure 8. Trawlable biomass in kilotonnes (kt, with 95% confidence intervals) of S. mentella on the left side (A, C, and E) and S. fasciatus on the right side (B, D, and F) in the Unit 1 DFO survey from 1984 to 2021, by size classes: 0-22 cm (A-B), > 22 cm (C-D), and > 25 cm (E-F). The solid lines represent the mean for the 1984-2020 period.

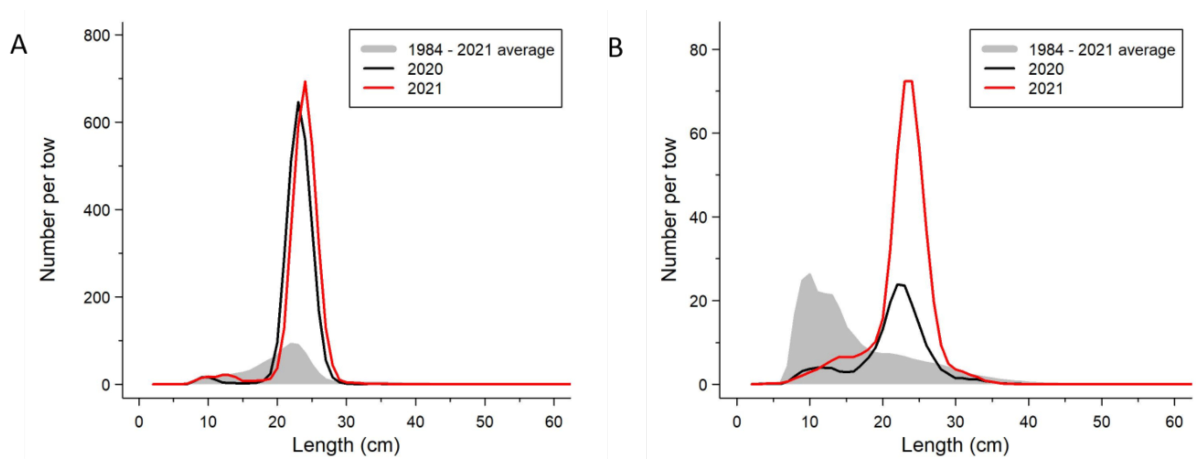

Figure 9. S. mentella (A) and S. fasciatus (B) length frequency in the Unit 1 DFO research survey for 2020, 2021, and the 1984 to 2021 average frequency.

Biomass indices and length composition in Unit 2

Due to issues surrounding the validation of anal fin ray counts in 2014 and 2020, data for the two species are combined for these survey years (Figure 10). Additionally, the 2020 data point is not yet calibrated to the rest of the series and is therefore not directly comparable.

The biomass indices of *Sebastes* spp. in Unit 2 showed an increase in biomass from 2016 (547 kt) to 2018 (905 kt) (Figure 10). This trend was driven by *S. mentella*, where an important increase in biomass from 2016 (280 kt) to 2018 (805 kt) was observed. *S. fasciatus*, however, declined from 2016 (267 kt) to 2018 (101 kt) (Figure 10). This decrease may be the result of interannual variation between survey years.

In 2018, the survey biomass for fish greater than 22 cm in length was estimated to be 719,725 t for *S. mentella*, which is the highest of the series (Figure 11). Minimum trawlable biomass was estimated to be 89,211 t for *S. fasciatus*, indicating a decrease relative to 2016.

Biomass of *S. mentella* greater than 25 cm in length increased from 68,508 t in 2016 to a record high of 353,901 t in 2018, whereas biomass of *S. fasciatus* decreased from 118,120 t in 2016 to 49,267 t in 2018 (Figure 11). The magnitude of this decline in *S. fasciatus* remains uncertain and should be interpreted with caution. Modal size of Redfish in the Unit 2 survey was 24 cm in 2018, about 5 cm larger than the 2016 survey (Figure 12) and larger than the long-term average.

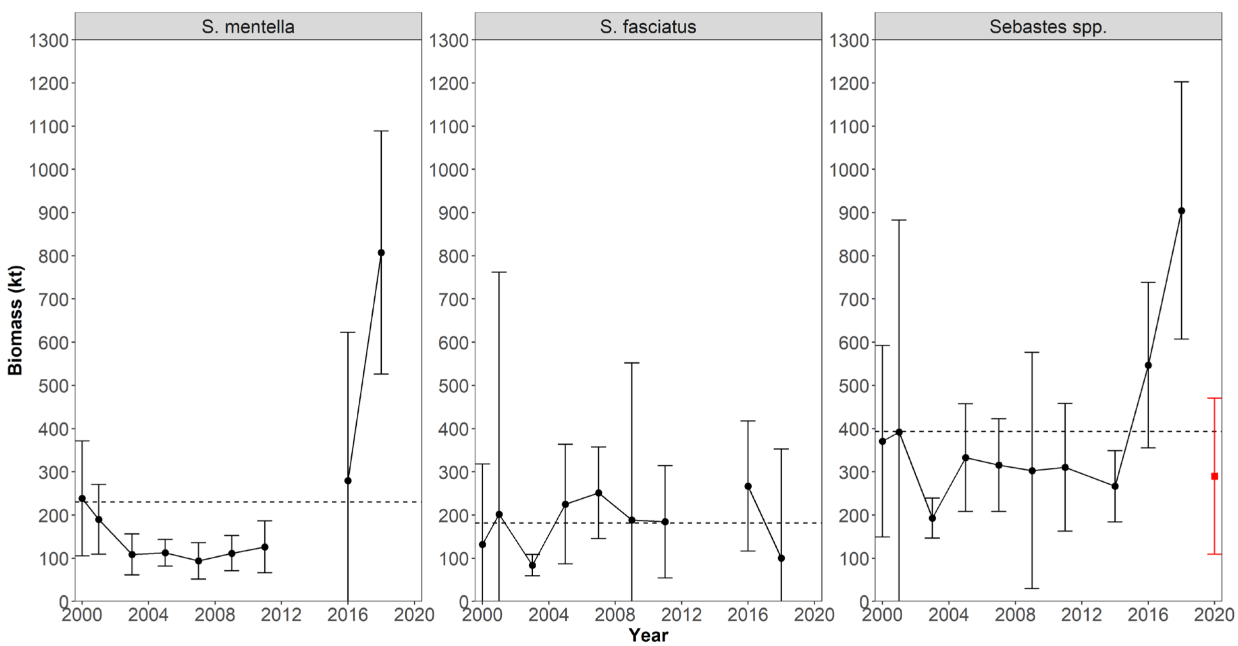

Figure 10. Minimum trawlable biomass in kilotonnes (kt) with 95% confidence intervals of S. mentella and S. fasciatus in the Unit 2 survey from 2000 to 2018. The red square and error bars represent an unconverted 2020 survey point. The 2020 point should not be interpreted in the context of the overall timeseries. The dashed lines represent the average.

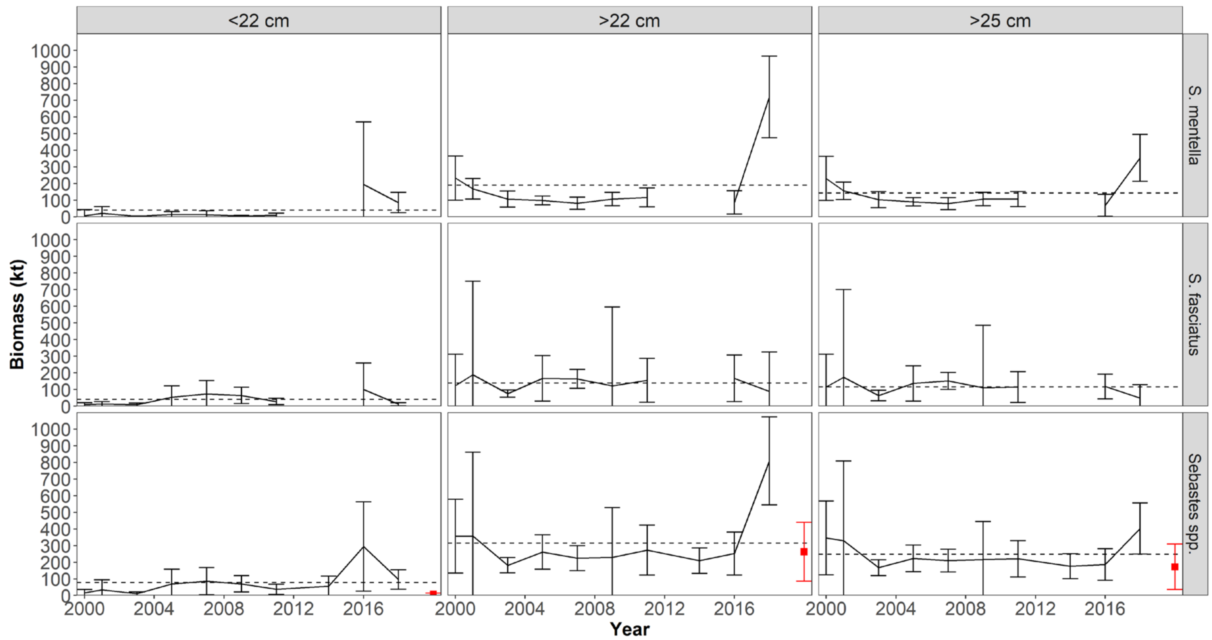

Figure 11. Trawlable biomass in kilotonnes (kt, with 95% confidence intervals) of S. mentella, S. fasciatus, and Sebastes spp. in the Unit 2 survey from 2000 to 2020, by length classes: 0-22 cm, >22 cm, and > 25 cm. The 2020 point should not be interpreted in the context of the overall timeseries. The dashed lines represent the average.

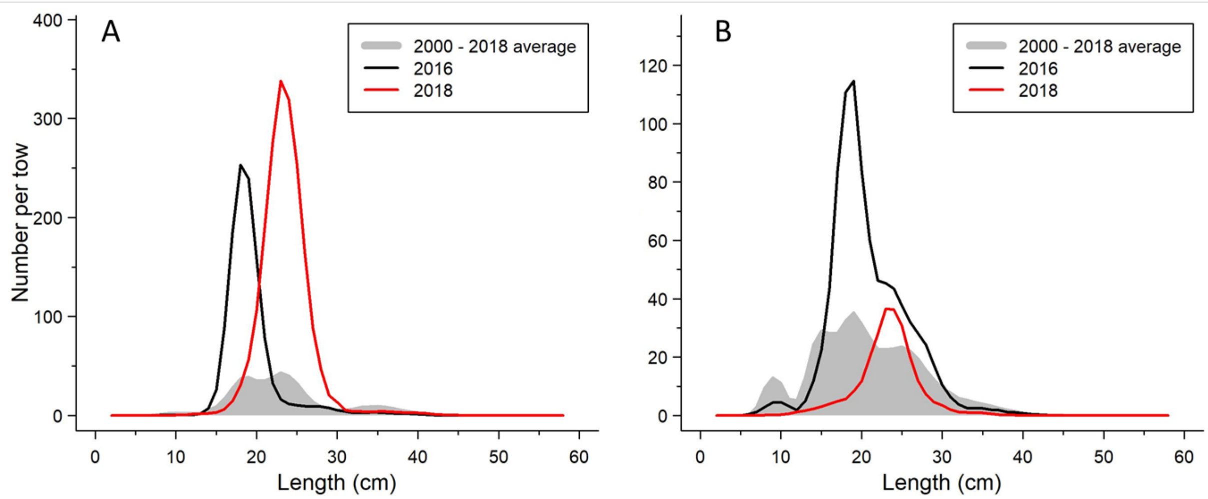

Figure 12. S. mentella (A) and S. fasciatus (B) length frequency in the Unit 2 surveys for 2016 and 2018. Note the different scales on the y-axis.

Spatial distribution in Unit 1 and Unit 2

Stratified cumulative frequency distributions of Redfish catches according to depth in 2017-2021 are presented for both stocks (Figure 13). Despite some degree of overlap in the depth distribution between the two species, *S. mentella* from all sizes are generally found deeper than *S. fasciatus*. Larger-sized (> 25 cm) *S. mentella* are found deeper than smaller individuals, while the depth distributions of *S. fasciatus* size classes generally overlap. Fishing deeper than 300 m could reduce catches of *S. fasciatus* in all fishing areas except the Laurentian Fan, and reduce catches of under-sized (< 22 cm) Redfish.

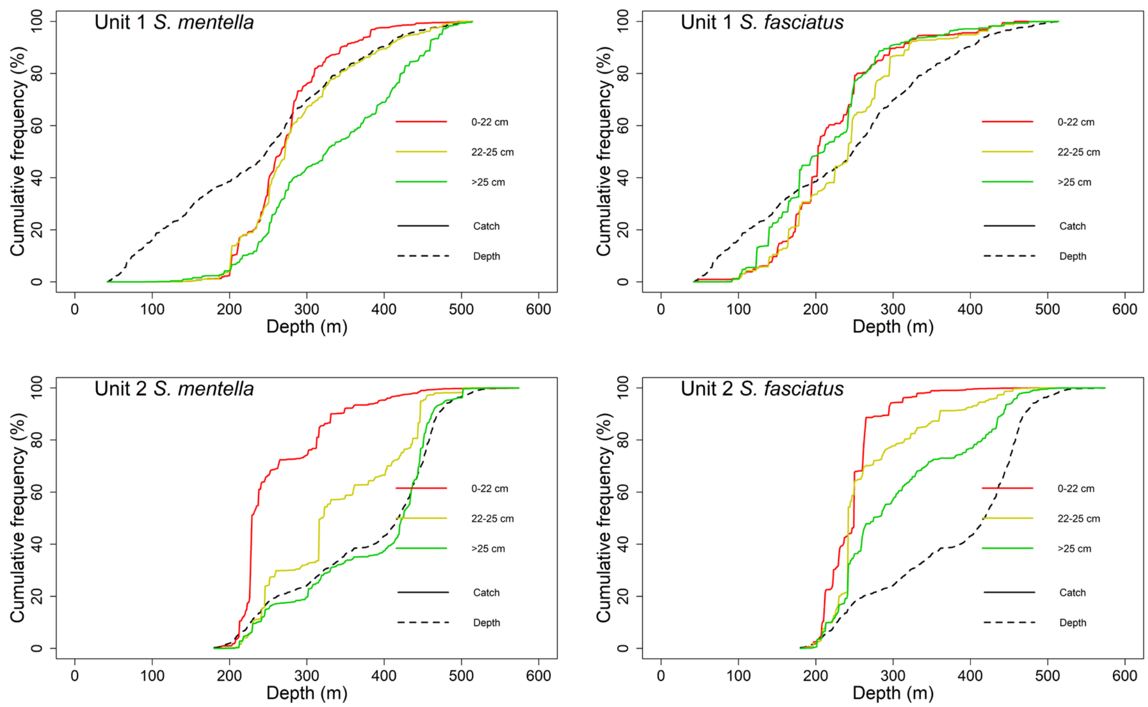

Figure 13. Stratified cumulative frequency of S. mentella (left panels) and S. fasciatus (right panels) in research surveys in Unit 1 (top panels) and Unit 2 without the Laurentian fan (bottom panels) from 2017-2021. The solid and dotted lines represent the cumulative frequency of catches and survey 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.

Life History Traits

Individuals from the strong 2011-2013 cohorts of *S. mentella* and *S. fasciatus* are currently maturing at smaller sizes and exhibit a reduced growth potential than previously observed strong cohorts.

In 2018 and 2019, 757 specimens of redfish were collected in Units 1 and 2. Each were 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 showed in Figure 14. 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 (1996-98) and current (2018-19) 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 1996-98 and 2018-19 (Figure 15). 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.

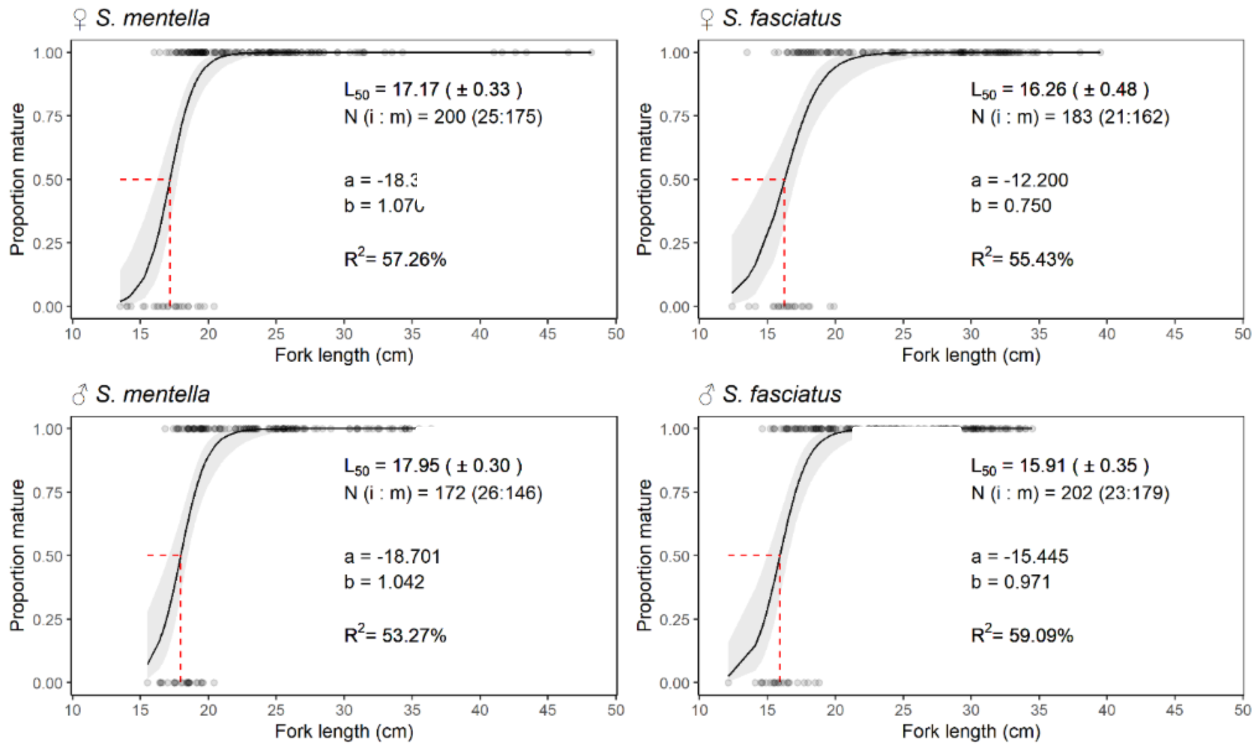

Figure 14. Maturity ogives based on histology as a function of fork length (cm) for each combination of species and sex (female in top panels and males in bottom panels). L_{50} (± standard error), sample size (N) of immature (i) and mature (m) individuals, as well as a and b parameters in each panel. The red dotted lines correspond to L_{50}, and the shaded areas to 95% confidence interval.

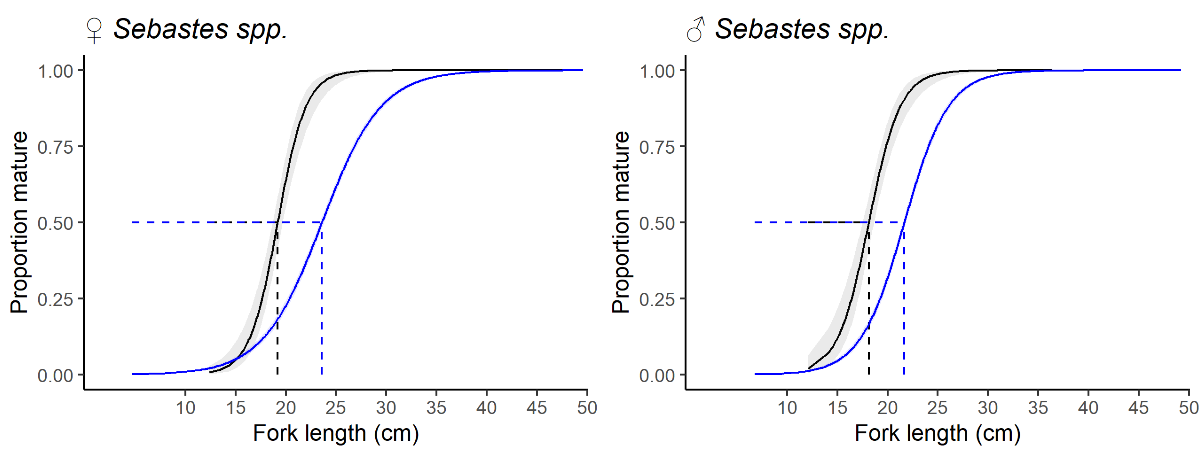

Figure 15. Comparison of maturity ogives based on macroscopic gonad appearance categories following a visual chart used in the 1990s to contrast L_{50} between1996–1998 (in blue) and 2018–2019 (in black). Females are in the left panel and males in the right panel. The dotted lines correspond to L_{50}, and the shaded areas to 95% confidence interval.

Applying the von Bertalanffy growth curve for Redfish, determined based on length at age data for the 1980 cohort, a 10 year-old Redfish from the 2011 cohort should have measured 26.5 cm in 2021 (Figure 16). Releasing the constraint on maximum size (Linf) of 42-50 cm imposed by this growth function and using data from the recent cohorts, reduced the maximum size value for the 2011 cohort to approximately 28 cm. 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.

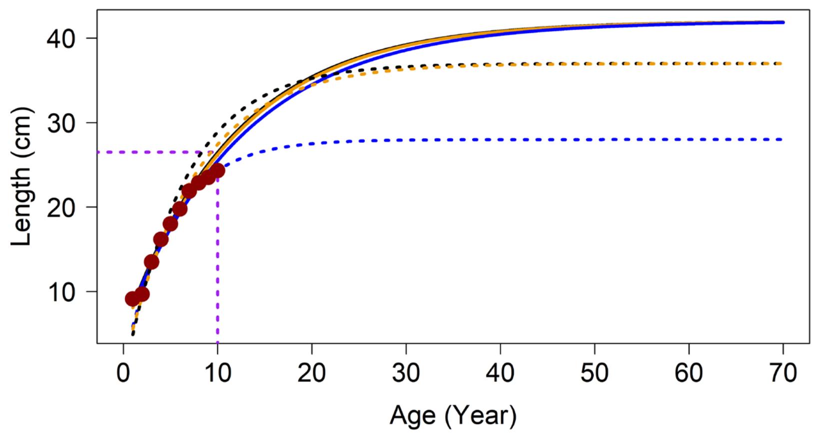

Figure 16. von Bertalanffy growth curves for Redfish parameterized based on length at age data. The black lines correspond to curves developed for the 1980 cohort, the blue lines for the 2011 cohort, and the orange lines to both 1980 and 2011 cohorts. Solid lines assume a maximum size (Linf) constraint between 42-50 cm, and dotted lines assume no constraint on Linf. 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.

REFERENCE POINTS AND CURRENT STATUS

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 spawning stock biomass (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 information for the 2011-2013 cohorts implemented from 2011 onwards to estimate the SSB in both stocks (Figure 17). 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 17 A). 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 17 B).

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.

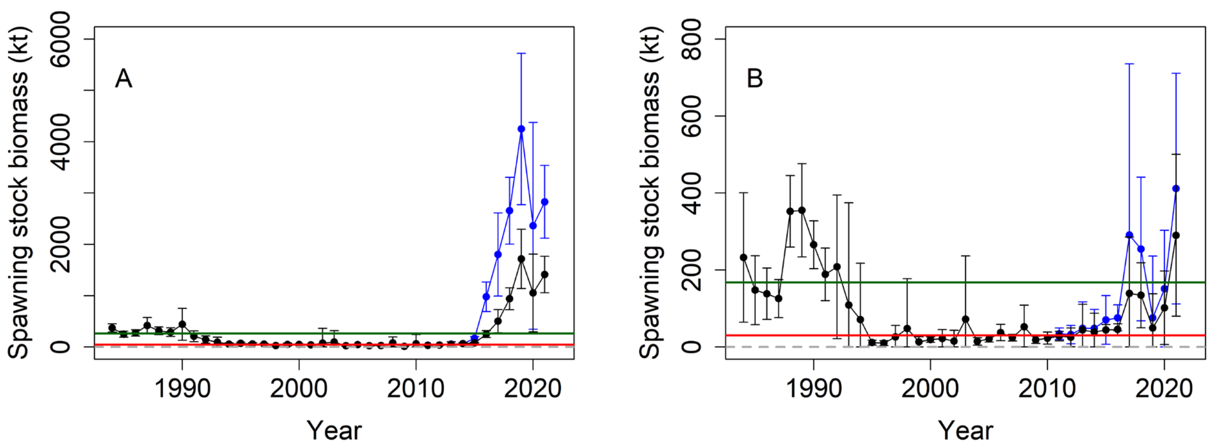

Figure 17. Spawning stock biomass (kilotonnes) in the nGSL DFO survey from 1984 to 2021 based on Gascon (2003) ogives (black) and with the new ogives starting in 2011 (blue) with 95% confidence intervals. The proposed Upper Stock Reference (green line) and Limit Reference Point (red line) for S. mentella (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.

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 at-sea observers 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 season.

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 and/or initiated.

Continued data acquisition and validation in Unit 2 is 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 40-60 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.

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* 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 (at-sea observer 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.

LIST OF MEETING PARTICIPANTS

Name	Affiliation	Feb. 21	Feb. 22	Feb. 23	Feb. 24	March 16
Aylward, Molly	PEIFA	x	-	-	-	-
Bayes, Shannon	Marine Institute, Memorial Univ.	x	-	-	x	-
Beaton, Eugene	Inverness South Fishermen's Ass.	-	-	-	x	x
Benoît, Hugues	DFO – Science	x	x	x	x	x
Bermingham, Tom	DFO – Science	x	x	x	x	x
Bernatchez, Claudio	ACPG	x	-	-	-	x
Boudreau, Mathieu	DFO – Science	x	x	x	x	-
Boudreau, Paul	Madelipêche	x	x	x	x	x
Bourdages, Hugo	DFO – Science	x	x	x	x	x
Bourdages, Yan	ACPG	x	x	x	x	-
Bottke, Lauren	DFO – Fisheries Management	x	x	x	x	x
Boussens-Dumon, Grégoire	UQAR		x	x	x	x
Brassard, Claude	DFO – Science	x	x	x	x	x
Brown-Vuillemin, Sarah	UQAR	-	-	x	-	-
Brûlé, Caroline	DFO – Science	x	x	x	x	x
Burns, Corinne	UQAR	x	x	x	x	x
Butler, Renae	Ass. of Seafood Producers	x	x	x	x	-
Byrne, Vanessa	Province – NL	x	x	x	x	x
Carruthers, Erin	FFAW	x	-	-	-	x
Chabot, Denis	DFO – Science	x	x	x	x	-
Chamberland, Jean-Martin	DFO – Science	x	x	x	x	-
Chlebak, Ryan	DFO – Science	-	-	-	x	-
Coussau, Lola	UQAR	x	-	x	-	-
Cyr, Charley	DFO – Science	x	x	x	x	x
Debertin, Allan	DFO – Science	-	x	x	x	-
Delaney, Paul	Madelipêche	-	x	x	x	x
D'entremont, Alain	Mersey Seafoods	x	x	x	x	-
Desgagnés, Mathieu	DFO – Science	x	x	x	x	-
Deslauriers, Marcelle	DFO – Fisheries Management	x	-	-	-	-
Dewland, Jennifer	PEIFA	x	x	x	x	x
Doherty, Penny	DFO – Fisheries Management	x	x	x	x	x
Dubé, Sonia	DFO – Science	x	x	x	x	x
Duplisea, Daniel	DFO – Science	x	x	x	x	x
Dwyer, Karen	DFO – Science	x	x	x	x	x
Dwyer, Shelley	DFO – Fisheries Management	x	x	-	x	x
Edgar, Leigh	DFO – Fisheries Management	x	-	-	-	-
Élément, Patrice	ACPG	x	-	x	x	x
Genge, Rendell	FFAW	x	x	x	x	-
Girard-Robert Mathilde	DFO – Science	-	x	x	x	-
Grelon, Damien	Merinov	x	x	x	x	-
Guitard, Joëlle	UQAR	x	-	x	x	-
Haché, Luc	Midshore Independant Groundfish Vessel Operators	x	x	x	-	-
Hébert, Denyse	DFO – Fisheries Management	x	-	-	-	
Hewitt, Michelle	Province – PEI	x	x	x	x	x
Isabel, Laurie	DFO – Science	x	x	x	x	x
Jubinville, Isabelle	Oceana	x	x	x	x	-
Juillet, Cédric	DFO – Science	x	-	-	-	-
Kumar, Rajeev	DFO – Science	x	-	x	-	-
Labbé-Giguère, Stéphanie	DFO – Fisheries Management	x	x	x	x	x
Lacasse, Olivia	DFO – Science	x	-	-	-	-
Lanteigne, Jean	ACAG	-	x	x	-	-
Lapierre, Daniel	DFO – Fisheries Management	x	x	x	-	x
Lavallée, Dean	Fisher LNS	-	x	-	-	-

Name	Affiliation	Feb. 21	Feb. 22	Feb. 23	Feb. 24	March 16
Leblanc, Léonard	GNSFPB	x	x	-	x	-
Leung, Christelle	DFO – Science	x	x	x	x	-
Lewis, Keith	DFO – Science	x	x	x	x	x
Loboda, Sarah	DFO – Science	x	-	-	-	-
MacPherson, Ian	PEIFA	x	-	-	x	-
Mallet, Pierre	DFO – Fisheries Management	x	x	x	x	x
Mccutcheon, Alexandre	DFO – Fisheries Management	x	-	-	-	-
Mugridge, Adam	Province – Nova Scotia	x	-	x	-	x
Mussells, Claire E.	DFO – Science	x	-	x	-	-
Nadeau, Paul	APBCN	x	-	-	x	x
Nozères, Claude	DFO – Science	x	x	x	-	-
Osborne, Derek	DFO – Science	-	x	-	-	x
Parent, Geneviève	DFO – Science	x	-	-	-	-
Patterson, Maryline	MAPAQ	x	-	-	x	x
Pelletier, Claude	Province – New Brunswick	x	x	x	x	x
Poissant, David	AGHAMM	x	-	x	x	-
Pond, Nancy	DFO – Fisheries Management	x	x	-	x	-
Rayner, Gemma	Oceans North	x	x	x	x	x
Rideout, Rick	DFO – Science	x	x	x	x	-
Robert, Dominique	ISMER/UQAR	x	x	x	-	-
Rogers, Bob	DFO – Science	x	x	x	x	x
Rolland, Nicolas	DFO – Science	x	x	x	x	-
Rousseau, Shani	DFO – Science	x	x	x	x	x
Roussel, Eda	FRAPP and ACAG	-	x	x	x	-
Roux, Marie-Julie	DFO – Science	x	x	x	x	x
Riley, Cyrena	DFO – Science	-	-	x	-	-
Senay, Caroline	DFO – Science	x	x	x	x	-
Small, Daniel	DFO – Science	x	x	x	x	-
Spingle, Jason	FFAW	x	x	x	x	x
Tamdrari, Hacène	DFO – Science	x	x	x	x	-
Thériault, Stéphane	ACPG	x	-	-	-	-
Varkey, Dyvia	DFO – Science	x	x	x	x	x
Vascotto, Kris	Atlantic Groundfish	x	x	x	x	x
Watts, Taylor	GNSFPB	x	x	x	-	x
Wheeland, Laura	DFO – Science	x	x	x	x	x
Winger, Paul	Memorial Univ.	x	-	x	-	x

SOURCES OF INFORMATION

This Science Advisory Report is from the zonal advisory meeting of February 21-24 and March 16, 2022 on the Assessment of Redfish Stocks (*Sebastes mentella* and *S. fasciatus*) in Units 1 and 2 in 2021. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada Science Advisory Schedule as they become available.

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.

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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.

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Center for Science Advice (CSA)
Quebec Region
Fisheries and Oceans Canada
Maurice Lamontagne Institute
850 route de la Mer
P.O. Box 1000
Mont-Joli (Quebec)
Canada G5H 3Z4

E-Mail: bras@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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