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 2024/031

Quebec Region

Potential Removals of Redfish (*Sebastes mentella* and *S. fasciatus*) in Unit 1

Caroline Senay and Daniel Duplisea

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

May 2024

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 978-0-660-71577-3 Cat. No. Fs70-5/2024-031E-PDF

Senay, C. and Duplisea, D. 2024. Potential Removals of Redfish (*Sebastes mentella* and *S. fasciatus)* in Unit 1. DFO Can. Sci. Advis. Sec. Res. Doc. 2024/031. iv + 11 p.

Aussi disponible en français :

*Senay, C. et Duplisea, D. 2024. Potentiels de capture de sébastes (*Sebastes mentella *et* S. fasciatus*) dans l'unité 1. Secr. can. des avis sci. du MPO. Doc. de rech. 2024/031. iv + 12 p.*

TABLE OF CONTENTS

ABSTRACT

Redfish biomass in Unit 1 increased significantly in the past decade, as supported by the strong cohorts of 2011-2013. Since then, no important recruitment has been observed in the Gulf of St. Lawrence. The growth rate of the 2011-2013 cohorts has been low since 2021. The goal of the present document is to determine a range of potential removals for Unit 1 Redfish. To do so, 17 estimation methods of natural mortality rate based on temperature and/or life history traits were applied to Unit 1 Redfish stocks. To determine a range of potential removals consistent with a precautionary target using natural mortality in the estimation of fishing pressure, natural mortality rates were halved and multiplied by species-specific estimates of biomass for fish larger than 22 cm. Given that extreme values of natural mortality are the most unlikely, a realistic range of potential removals was determined between the 25th and 75th percentiles of these estimates, corresponding to 88 and 318 kt for *S. mentella*. *S. mentella* will very likely remain in the healthy zone in 2024 given this range of removals for the 2024-2025 fishing season. Considering the uncertainty over the status of the *S. fasciatus* stock in Unit 1 and the assumptions underlying the proposed approach, a range of potential removals could not be determined with certainty. The available evidence suggests that fishing deeper than 300 m would target the more abundant species, *S. mentella,* and reduce catches of undersized Redfish. Taking into account the low recruitment and growth observed in recent years, and even in the absence of fishing, Redfish biomass is expected to decrease in upcoming years, mainly due to natural mortality.

INTRODUCTION

The Unit 1 corresponds to the Northwest Atlantic Fisheries Organization (NAFO) Divisions 4RST and 3Pn4Vn from January to May. Two Redfish species are present in Unit 1, namely the Deepwater Redfish (*Sebastes mentella*) and the Acadian Redfish (*S. fasciatus*). Occasionally, Golden Redfish (*S. norvegicus*) are also observed, but they are uncommon in the region 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.

Redfish recruitment success is highly variable and sporadic, with large year classes observed at irregular intervals. The 1980 cohort was the last important cohort in Unit 1 prior to the arrival of the strong cohorts born in 2011, 2012, and 2013. These cohorts were dominated by *S. mentella*. Since then, the biomass increased to unprecedented levels and a large proportion has now reached the minimum regulatory size of 22 cm. The goal of the present document is to propose a range of potential removals for the 2024-2025 fishing season in Unit 1, that is unlikely to pose a conservation risk. The proposed approach is meant to be used in the short-term. Details on Redfish biology can be found in Senay et al. (2023).

DATA

The analyses presented in this document use Redfish biomass estimates and length frequency from the northern Gulf of St. Lawrence (nGSL) DFO survey (Senay et al. 2023). During the nGSL DFO survey, soft anal fin ray counts (AFR) are recorded, which permits post-hoc attribution of Redfish catches into *S. mentella* and *S. fasciatus* (Senay et al. 2022). A range of natural mortality rates (M) was derived from available information on specific life history traits, such as longevity, growth curve parameters (k and t_0), maximum length (L_{inf}), age-at-maturity (A_{50}), as well as water temperature.

Due to operational issues with the CCGS *John Cabot* in August 2023, the time at sea for the nGSL DFO survey was reduced by a third and the study area could not be fully covered. Consequently, two sectors were not sampled, namely the Strait of Belle Isle and the St. Lawrence Estuary west of Pointe-des-Monts. Additionally, sampling coverage was reduced in coastal areas. However, Redfish habitats were prioritized and well covered, especially for *S. mentella*. When strata were not sampled by a minimum of two successful tows in any given year, a multiplicative model was used to estimate the catch rates in number and weight for that stratum and year, using data from the current year and the previous three years (Bourdages et al. 2023).

When comparing the nGSL DFO survey to other surveys, the normalized relative biomass estimate was similar to the nGSL Sentinel bottom trawl survey, with the 2023 estimate remaining among the highest values of the time series. However, the southern Gulf of St Lawrence (sGSL) survey biomass estimate decreased in 2023 to values comparable to the late 1980s, 2019, and 2020. The heterogeneous distribution of Redfish, living in large schools, can generate important spatiotemporal variations and large confidence intervals. Overall, we have sufficient confidence in the nGSL survey to provide an advice for the 2024-2025 fishing season (Figure 1).

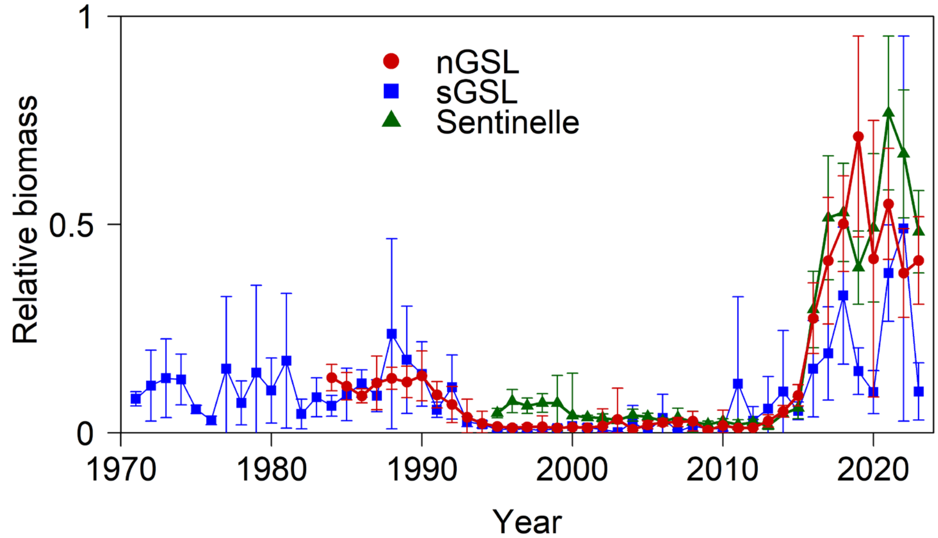

Figure 1. Comparison of relative indices of Redfish biomass in the time series (with 95% confidence intervals) derived from the DFO research survey in the nGSL (red line with circles) and sGSL (blue line with squares), and the nGSL Sentinel bottom trawl survey (green line with triangles).

In the nGSL DFO survey, biomass estimates of *S. mentella* and *S. fasciatus* declined sharply from the late 1980s to 1994 (Figure 2). Subsequently, Redfish biomass remained low and stable until the 2010s. The 2011–2013 cohorts, mainly dominated by the 2011 year class, started being caught in the survey in 2013. The biomass of small individuals (< 22 cm, minimum regulatory size) increased as they were growing, until 2018 when it started decreasing as they reached the size of 22 cm. The geometric mean of the 2022 and 2023 biomasses for *S. mentella* and *S. fasciatus* larger than 22 cm were 2,152 kt and 150 kt. A decline has been observed for *S. mentella* over the last four years, and over the last two years for *S. fasciatus*. However, these values still remain among the highest of the time series. In 2021-2023, the biomass of *S. mentella* larger than 25 cm was at the highest values of the time series, while it was close to the series average for *S. fasciatus*.

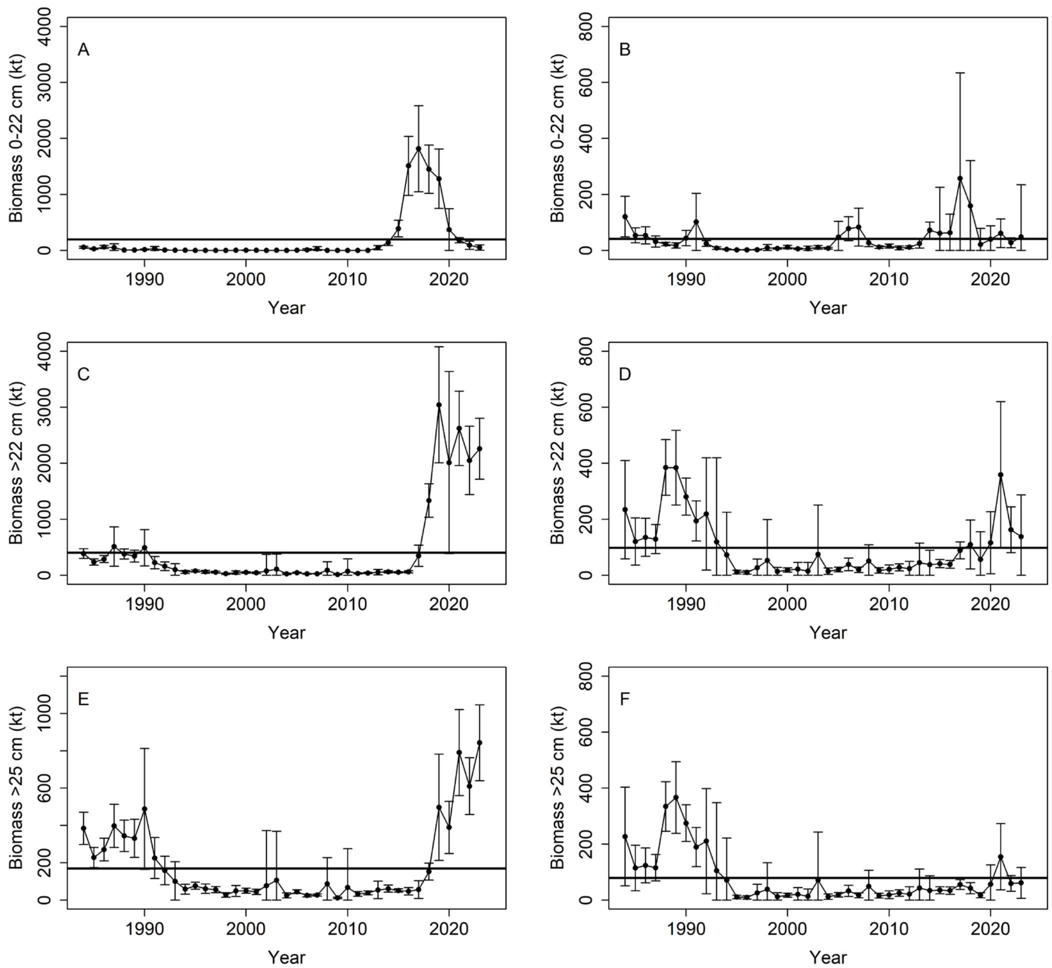

Figure 2. Minimum trawlable biomass in kilotonnes (kt, with 95% confidence intervals) of S. mentella (left column; panels A, C, and E) and S. fasciatus (right column; panels B, D, and F) in the nGSL DFO survey from 1984 to 2023, by length classes: 0–22 cm (A-B), > 22 cm (C-D), and > 25 cm (E-F). The solid lines represent the panel-specific mean for the 1984–2022 period. Note the different scales on the y-axis.

The Redfish cohorts of 2011, 2012 and 2013 are the largest ever observed in the survey. Since then, recruitment has remained at low levels based on the biomass of Redfish smaller than 11 cm (Figure 3).

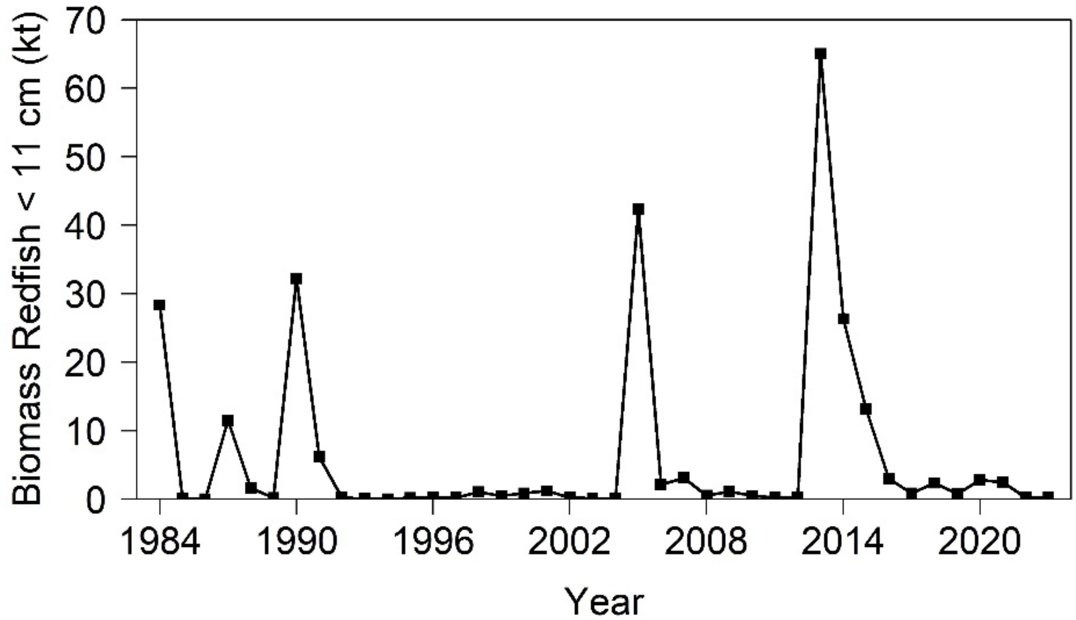

Figure 3. Minimum trawlable biomass in kilotons (kt) of Redfish smaller than 11 cm in the nGSL DFO survey from 1984 to 2023.

GROWTH CURVE OF DIFFERENT COHORTS

Redfish are slow-growing and long-lived species. Projections of growth for the 2011-2013 cohorts were provided in previous stock assessments (Senay et al. 2023). Growth parameters were estimated based on modal estimates of length for the 1980 *S. mentella* cohort and subjected to a constraint on L_{inf}, between 42 cm and 50 cm. Estimated modal size for recent cohorts have deviated from this growth curve, with the modal size remaining at 24 cm since 2021 (Figure 4). Other curves were explored by using the same approach but with different data and constraints (Figure 4 and Table 1).

When using the modal lengths of the 1980 and/or 2011-2013 cohorts with a L_{inf} constraint of 42–50 cm, similar curves were obtained, all suggesting higher growth than observed in recent modes (Figure 4). Similarly, when no L_{inf} constraint was used on the 1980 cohort, and the combined 1980 and 2011-2013 cohorts, the curves suggested a higher growth than what is presently observed. The best fit to the observed recent modes was obtained with the 2011-2013 cohorts without L_{inf} constraint. This curve suggested a L_{inf} of 27 cm (Table 1). These results indicate that Redfish from the strong 2011–2013 cohorts are currently growing slower and are expected to reach smaller sizes compared to Redfish from the 1980 cohort. Generally, this could be explained by a maturation at smaller size, density-dependence, and/or environmental effects in the context of presently low exploitation rates.

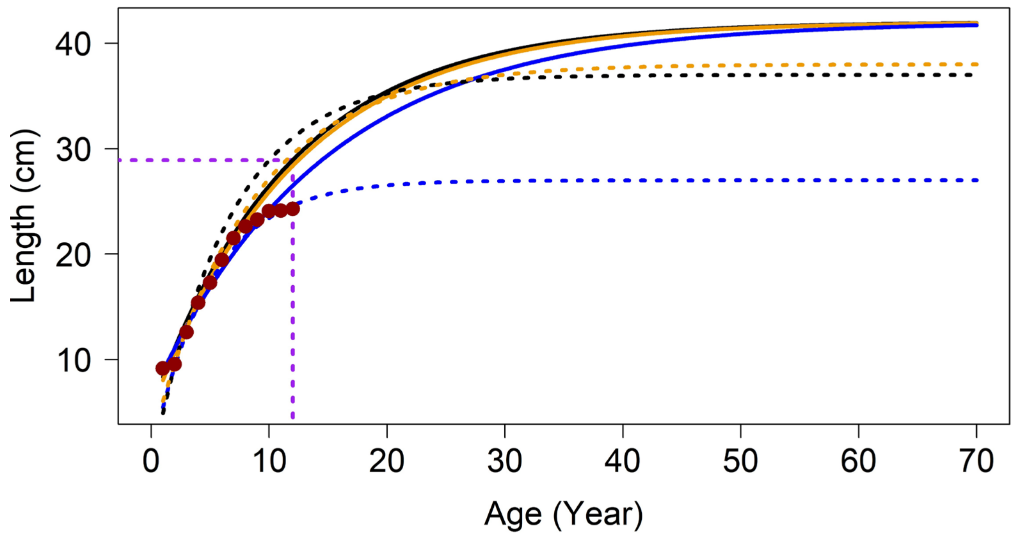

Figure 4. von Bertalanffy growth curves for Redfish parameterized based on length-at-age data. The black lines correspond to curves developed for the 1980 cohort, the blue lines for the 2011-2013 cohorts, and the orange lines for both 1980 and 2011-2013 cohorts. Solid lines assume a L_{inf} constraint between 42–50 cm and dotted lines assume no constraint on L_{inf}. The dotted purple lines show that a 12 years old individual (2011 cohort in 2023) should measure 28.9 cm based on the 1980 cohort constrained growth curve. The red dots indicate the observed annual modal sizes of the 2011-2013 cohorts since 2012.

Table 1. Parameters of different von Bertalanffy growth curves based on length-at-age trends of the 1980 and/or 2011-2013 cohorts modal size, with or without a constraint on L_{inf} between 42–50 cm, as well as how they are illustrated in Figure 4. The curve with the best fit for the 2011-2013 cohorts is in bold.

Data	L_{inf} constraint	L_{inf}	k	t_0	Curve
1980	42-50 cm	42	0.086	-1.570	Black
2011-2013	42-50 cm	42	0.069	-2.437	Blue
1980 and 2011-2013	42-50 cm	42	0.083	-1.561	Orange
1980	Unconstrained	37	0.153	0.070	Black dotted
2011-2013	**Unconstrained**	**27**	**0.200**	**-0.129**	**Blue dotted**
1980 and 2011-2013	Unconstrained	38	0.120	-0.447	Orange dotted

POTENTIAL REMOVALS

A range of potential removals for Unit 1 Redfish 2024-2025 fishing season was determined based on the first rule of thumb of Froese et al. (2016). This work suggests taking less than nature by ensuring that the fishing mortality rate (F) is lower than the M, where $F \sim 0.5 * M$ may be a precautionary target when stock size is above half of their natural level and composed of matured individuals. Other studies have supported that this range of F should be prudent (Patterson 1992, Zhou et al. 2012). This approach is applied to Unit 1 Redfish, however the proposed approach in this document is meant to be used in the short-term (< 5 years).

Estimates of Redfish *M* were derived from available temperature and life history traits information using a tool developed by the National Oceanic and Atmospheric Administration (NOAA, Cope and Hamel 2022). A temperature of 7°C (Galbraith et al. 2023), a longevity of 65 years (Campana et al. 1990), and growth parameters for the 2011-2013 cohorts (Table 1, L_{inf} = 27 cm, k = 0.200 y^{-1}, and t_0 = - 0.129 y) were used as input, together with the average length-at-maturity recently updated for *S. mentella* and *S. fasciatus* from Unit 1 and 2 (Senay et al. 2023, Brûlé et al. 2024) and corresponding age-at-maturity based on the aforementioned growth curve. All outputs were set to describe fish over 12 years old and 22 cm in length (minimum regulatory size). Seventeen different methods using different input information were applied to obtain 17 estimates of *M* for each species (Table 2). For both species, the median values of *M* across methods were 0.275, and included extreme values above 0.4 and below 0.01.

Extremes values of *M* seemed improbable, but were still reported and used to determine the complete range of potential removals with all 17 *M* estimates available in Cope and Hamel (2022). Some of these methods have been shown to be more or less appropriate for Redfish stocks in other areas (Sullivan et al. 2022). The two lowest values of *M* were derived from longevity, k and t_0, while the highest value was derived from L_{inf} and k. The large differences in the estimates may be due to departures from generalized life history relationships. Some *Sebastes* species tend to grow to near L_{inf} quickly relative to their lifespans, and therefore, the standard cross-taxa relationship between k and *M* may be biased for some species like *Sebastes* (Beverton 1992). Longevity is often considered the most informative input to estimate *M* (Cope and Hamel 2022). However, no update of longevity for the 2011-2013 Redfish cohorts in the nGSL is yet available. Longevity is expected to be lower given other changes in life history traits, namely the growth parameters and length-at-maturity. Lower longevity would increase natural mortality and potential removals. Höffle and Planque (2023) estimated 48 different values of *M* for *S. mentella* in the Norwegian and Barents Seas which were similarly highly variable, ranging from 0.01 to 0.32 across the population. They subsequently selected a subset of realistic estimates based on expert knowledge and values distribution. In the absence of recent information on Redfish longevity in Unit 1, and considering that limited information is currently available to inform the selection of specific *M* estimation methods over others, all 17 estimates of *M* were considered to derive potential removals for the 2024-2025 fishing season, and values corresponding to the 25^{th} and 75^{th} percentiles were retained as a realistic range.

Table 2. Values of annual M derived for 17 methods based on temperature and life history traits for S. mentella and S. fasciatus (Cope and Hamel 2022).

Method	Input	*S. mentella*	*S. fasciatus*
FishLife	species names	0.078	0.139
Then_nls	longevity	0.107	0.107
Then_lm	longevity	0.082	0.082
Hamel_Amax	longevity	0.083	0.083
Chen-Wat	age, k, t_0	0.219	0.219
ZM_AC_pel	longevity, k, t_0	0.012	0.012
ZM_AC_dem	longevity, k, t_0	0.002	0.002
Then_VBGF	L_{inf}, k	0.428	0.428
Hamel_k	k	0.310	0.310
Jensen_k 1	k	0.300	0.300
Jensen_k 2	k	0.320	0.320
Gislason	L_{inf}, k, length	0.275	0.275
Charnov	L_{inf}, k, length	0.272	0.272
Pauly_lt	L_{inf}, k, temperature	0.338	0.338
Roff	k, age-at-maturity	0.333	0.421
Jensen_Amat	age-at-maturity	0.320	0.372
Ri_Ef_Amat	k, age-at-maturity	0.307	0.361

Consistent with the precautionary target described above ($F \sim 0.5 * M$), all M estimates were halved and multiplied by the biomass of fish larger than 22 cm (minimum regulatory size) to determine a range of potential removals. To cope with annual variations in biomass estimates, the geometric mean of the last two years was calculated and used (2,152 kt for *S. mentella* and 150 kt for *S. fasciatus*). Potential removals were thus estimated as follow:

$$\text{Potential removal} = \text{Biomass} * (1 - \exp(-M * 0.5))$$

This provided a range of annual potential removals of 2 to 414 kt, with a median of 276 kt for *S. mentella*. For *S. fasciatus*, potential removals varied from 0.14 to 29 kt, with a median of 19 kt (Figure 5). Given that extreme values of M are the most unlikely, a realistic range of potential removals for the 2024-2025 fishing season was defined between the 25th and 75th percentiles of these estimates, corresponding to 88 and 318 kt for *S. mentella* and 8 and 23 kt for *S. fasciatus*. *S. mentella* will very likely remain in the healthy zone in 2024 with this range of removals. Given the uncertainty over the status of the *S. fasciatus* stock, and the assumptions underlying the proposed method (namely the appropriateness of the precautionary target, 0.5 * *M*, requiring stock biomass to be above half of its natural, unfished level), a range of potential removals could not be determined with certainty. A cautious approach is recommended for *S. fasciatus* given the large difference in biomass between the two species.

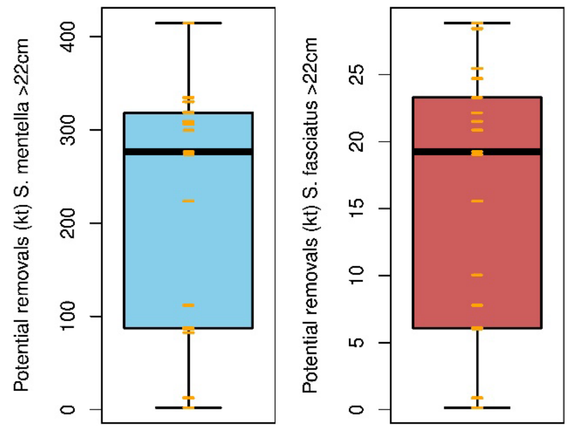

Figure 5. Boxplots representing annual potential removals for the 2024-2025 fishing season in kilotons (kt) for S. mentella (left panel) and S. fasciatus (right panel). The different values derived from various estimates of M are indicated by yellow horizontal lines. The blue and red boxes are delimited by the 25th and 75th percentiles and could be used as an acceptable range of potential removals. Note the different scales on the y-axis.

The available evidence suggests that fishing in deeper areas would target the more abundant species, *S. mentella,* and larger individuals, while fishing in shallower areas would target *S. fasciatus*. Typically in Unit 1, *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 (Senay et al*.* 2023, Figure 6).

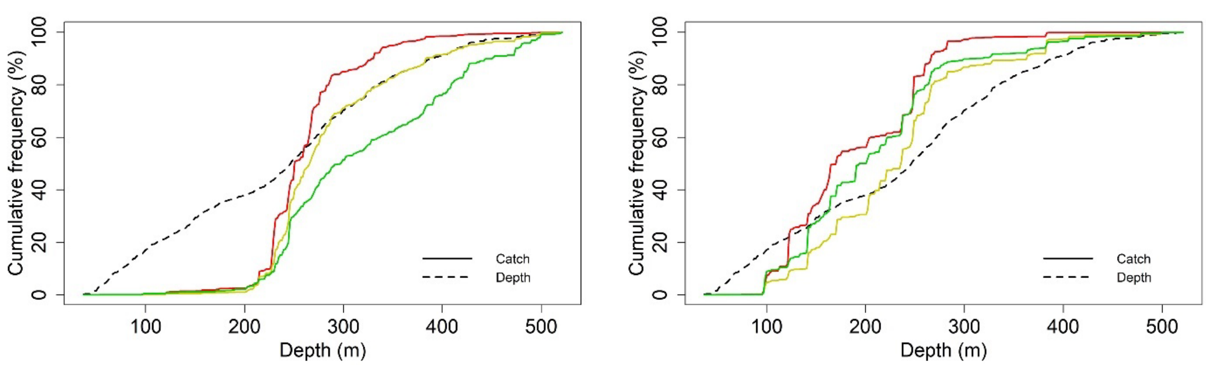

Figure 6. Stratified cumulative frequency of S. mentella (left panel) and S. fasciatus (right panel) in the nGSL DFO survey from 2019–2023. The solid and dotted lines represent the cumulative frequency of catches and survey stations, respectively, according to depth (m) and by length classes, 0-22 cm in red, 22–25 cm in yellow, and ≥ 25 cm in green.

The estimated range of potential removals for *S. mentella* could be used in the short-term. Given that potential removals are based on current estimates of biomass, the first year of fishing would correspond to the largest removals in the absence of new production (recruitment and growth). Potential removals would have to be updated every year with the updated biomass of fish larger than 22 cm. If some new production happens, it would be considered when determining subsequent potential removals.

DEPLETION RATE

The biomass depletion rate was determined assuming that no new production (no recruitment and no growth) occurs after 2023, and that emigration or immigration of Redfish in Unit 1 do not occur. This is not a realistic situation, nevertheless it shows how long the 2011-2013 cohorts could be expected to contribute to a fishery.

First, the trajectories of the initial biomass (year 0 in Figure 7) of the 2011-2013 cohorts were subjected to the 17 different species-specific values of *M* without any removal from fishing. For *S. mentella* and *S. fasciatus*, respectively 12 and 13 scenarios out of 17 resulted in less than 10% of the initial biomass in 25 years or less. Within 15 years, initial biomass decreased to 10% in 6 and 9 scenarios out of 17 for *S. mentella* and *S. fasciatus*, respectively. For both species, the two lowest values of *M* provided unrealistic scenarios, where biomass stayed at high level for a period longer than Redfish longevity (> 100 years).

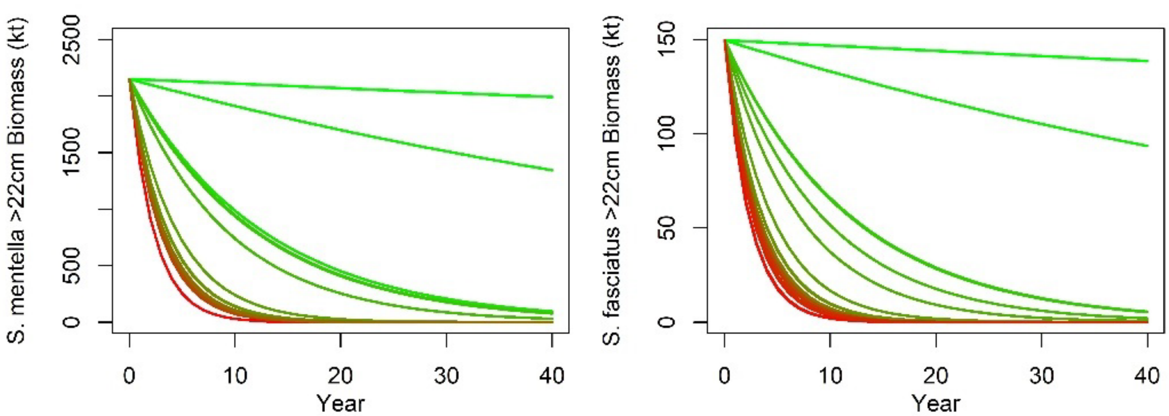

Figure 7. Impact of the 17 estimates of natural mortality rate (M) on the depletion of biomass for the 2011-2013 cohorts of S. mentella (left panel) and S. fasciatus (right panel). The depletion assumes no new production. Small to large values of M are illustrated in a green to red gradient.

To illustrate the biomass trajectories for the 2011-2013 cohorts under various *F*, *M* was set as the median value of the 17 *M* presented in Table 2 (0.275 for both species) and the 17 *M* were used to derive 17 *F* (*F* = 0.5 * *M*). The absence of fishing (*F* = 0), the 25th percentile of *F* (0.042 for both species), the median *F* (0.138 for both species), and the 75th percentile of *F* (0.160 for *S. mentella* and 0.169 for *S. fasciatus*) were contrasted (Figure 8). For both species, and in the absence of recruitment and growth, and emigration or immigration from Unit 1, the median and 75th percentile of *F* provided similar trajectories, with biomass decreasing to less than 10% of the initial biomass in 6 years, compared to 8 years with the 25th percentile of *F,* and 9 years without fishing. A decrease to 10% of initial biomass, corresponding to 215 kt for *S. mentella* and 15 kt for *S. fasciatus* would have different implications for each species relative to their precautionary approach.

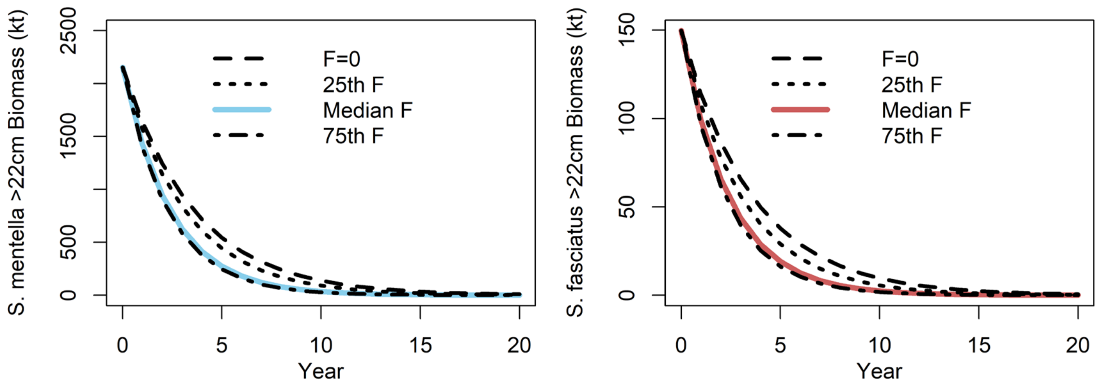

Figure 8. Impact of different fishing mortality (0, as well as 25th percentile, median, and 75th percentile of F) on the trajectories of 2011-2013 cohorts biomass for S. mentella (left panel) and S. fasciatus (right panel) without new production.

CONCLUSION

Given the low recruitment and growth observed in recent years, and even in the absence of fishing, Redfish biomass is expected to decrease in upcoming years. Nevertheless, the recent strong biomass increase may support higher catches over the short-term. A range of realistic potential removals varied between 88 and 318 kt, with a median of 276 kt for *S mentella* for the 2024-2025 fishing season. *S. mentella* will very likely remain in the healthy zone in 2024 given this range of removals. A cautious approach is recommended for *S. fasciatus* given the large difference in biomass between the two species. The available evidence suggests that fishing deeper than 300 m would target the more abundant species, *S. mentella,* and reduce catches of undersized Redfish.

Closely monitoring bycatch will be crucial during the expansion of the Redfish fishery. Contemporary fishery dependent (at-sea observer sampling) and research data (winter surveys) are required to refine the scientific evidence and advice on bycatch, particularly as regards to vulnerable species. On the other hand, a reduction in the biomass of Redfish in Unit 1 could be favourable to certain species whether prey or competitors. In Unit 1, high Redfish biomass has been identified as one of the potential causes of the decline of Northern Shrimp (*Pandalus borealis*), through increased predation pressure (DFO 2023a), and the decline in the condition of Greenland Halibut (*Reinhardtius hippoglossoides*, DFO 2024) and Atlantic Cod (*Gadus morhua*, DFO 2023b), through increased competition for food resources. Further research is needed to better understand the combined impacts of the increase in Redfish biomass, changes in environmental condition (warmer water temperature and low oxygen level), and fishing pressure on the ecosystem.

REFERENCES CITED

Beverton, R.J.H., 1992. Patterns of reproductive strategy parameters in some marine teleost fishes. J. Fish Bio. 41, 137-160.

Bourdages, H., Chamberland, J.-M., Desgagnés, M., Galbraith, P., Isabel, L., Ouellette-Plante, J., Roux, M.-J., and Senay, C. 2023. Preliminary results from the ecosystemic survey in August 2022 in the Estuary and northern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2023/074. iv + 100 p.

Brûlé, C., Benhalima, K., Roux, M-J., Parent, G.J, Chavarria, C, and Senay, C. 2024. Reduction in size-at-maturity in unprecedentedly strong cohorts of Redfish (*Sebastes mentella* and *S. fasciatus*) in the Gulf of St. Lawrence and Laurentian Channel. J. Fish Biol. In press.

Campana, S.E., Zwanenburg, K.C.T., and Smith, J.N., 1990. 210 Pb/ 226 Ra determination of longevity in redfish. Can. J. Fish. Aquat. Sci. 47(1), 163-165.

Cope, J.M., and Hamel, O.S. 2022. Upgrading from M version 0.2: An application-based method for practical estimation, evaluation and uncertainty characterization of natural mortality. Fisheries Research 256. .

DFO. 2023a. Review of the Precautionary Approach and Assessment of Northern Shrimp in the Estuary and Gulf of St. Lawrence in 2023. DFO Can. Sci. Advis. Sec. Sci. Resp. 2023/044.

DFO. 2023b. Assessment of the Northern Gulf of St. Lawrence (3Pn, 4RS) Atlantic Cod Stock in 2022. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2023/035.

DFO. 2024. Update of the Stock Status Indicator for Greenland Halibut in the Gulf of St. Lawrence (4RST) in 2023. DFO Can. Sci. Advis. Sec. Sci. Resp. 2024/002.

Froese, R., Winker, H., Gascuel, D., Sumaila, U.R., and Pauly, D. 2016. Minimizing the impact of fishing. Fish Fish. 17(3), 785-802.

Galbraith, P.S., Chassé, J., Shaw, J.-L., Dumas, J. Lefaivre, D., and Bourassa, M.-N. 2023. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2022. Can. Tech. Rep. Hydrogr. Ocean Sci. 354 : v + 88 p.

Höffle, H., and Planque, B. 2023. Natural mortality estimations for beaked redfish (*Sebastes mentella*)–a long-lived ovoviviparous species of the Northeast Arctic. Fish. Res. 260, 106581.

Patterson, K. 1992. Fisheries for small pelagic species: an empirical approach to management targets. Rev. Fish Biol. Fish. 2, 321-338.

Senay, C., Bermingham, T., Parent, G.J., Benoît, H.P., Parent, E., and 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.

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.

Sullivan, J.Y., Tribuzio, C.A., and Echave, K.B. 2022. A review of available life history data and updated estimates of natural mortality for several rockfish species In Alaska. NOAA Tech. Memo. NMFS-AFSC-443.

Zhou, S., Yin, S., Thorson, J.T., Smith, A.D., and Fuller, M. 2012. Linking fishing mortality reference points to life history traits: an empirical study. Can. J. Fish. Aquat. Sci., 69(8), 1292-1301.