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Assessment of 3LN redfish using the ASPIC model in 2022 (*Sebastes mentella* and *S. fasciatus*)

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Abstract:

There are two species of redfish in Divisions 3L and 3N, the deep-sea redfish (*Sebastes mentella*) and the Acadian redfish (*Sebastes fasciatus*) that have been commercially fished and reported collectively as redfish in fishery statistics. Both species, occurring on Div. 3LN and managed as a single stock, don't belong to isolated local populations but, on the contrary, are part of a large Northwest Atlantic complex ranging from the Gulf of Maine to south of Baffin Island. Lack of survey indices in recent years limits our understanding of stock status since 2019, but available data indicate that biomass is at or below the long-term mean. The stock appears to be above the interim limit reference point (B_{lim}). The previous assessment model (ASPIC) was rejected at the 2022 assessment. Continued mismatch between recent observed survey indices and the ASPIC model biomass estimates resulted in a lack of confidence in the model. Mean of the standardized survey biomass indices indicates that biomass has declined from timeseries highs in the mid-2010s to the long-term mean. Estimates from 2020 and 2021 should be treated with caution as only one of a potential four survey was completed in each year. In the absence of Canadian spring surveys in 2020 and 2021 proxy fishing mortality cannot be determined. However, it is unlikely that levels of fishing mortality have changed substantially. Recruitment of redfish between 15 and 20 cm has been below the long-term average since the mid-2010s across Canadian 3LN spring and autumn as well as EU-Spain 3L and 3N survey series.

Introduction

There are two species of the genus *Sebastes* with distribution overlapping in several areas of Northwest Atlantic, namely on the Gulf of St. Lawrence, Laurentian Channel, off Newfoundland and south of Labrador Sea: the deep sea redfish (*Sebastes mentella*), with a maximum abundance at depths greater than 350m, and Acadian redfish (*Sebastes fasciatus*), preferring shallower waters of less than 300m (DFO, 2008). They have been commercially fished on the slopes of the Grand Bank, both on Div. 3LN (north-south east) and Div. 3O (south-west).

Due to their external resemblance *S. mentella* and *S. fasciatus* are commonly designated as beaked redfish. Beaked redfish are viviparous, long living and slow growing. Both species have pelagic and demersal concentrations, as well as a long larval periods prior to settlement. Their external characteristics are very similar, making them difficult to distinguish. Therefore, they are reported collectively as "redfish" in the commercial fishery statistics. *S. mentella* and *S. fasciatus* are also treated as a single species in the Div. 3LN surveys carried out by Canada, Russia and more recently by EU-Spain.



Neither redfish species occurring in Div. 3LN belong to isolated local populations, but are part of a large Northwest Atlantic complex ranging from the Gulf of Maine to south of Baffin Island. The Gulf of St. Lawrence (GSL)- Laurentian Channel (Units 1 and 2) are sometimes used as a nursery area for *S. mentella* and *S. fasciatus* populations within NAFO Divisions 3LNO (Senay et al., 2021).

Commercial Fishery

Nominal catches and TAC's

Between 1959 and 1960, reported catches dropped from 44 600 to 26 600 t, oscillating over the next 25 years (1960-1985) around an average level about 21 000 t. Catches increased to a 79 000 t high in 1987, and declined steadily to a 450 t minimum reached in 1996. The NAFO Fisheries Commission (FC) implemented a moratorium on directed fishing for this stock in 1998. Catches were primarily bycatch and remained at relatively low levels (450-3 000 t) until 2009. In June 2009 the Scientific Council confirmed the upward trend of the stock as shown by spring and autumn surveys (NAFO, 2009). The Fisheries Commission endorsed the Scientific Council recommendations to reopen the fishery from 2011 onwards and catches steadily increased to 13 050t in 2019, the highest level recorded since 1993 (Table 1, Figure 1).

Landings from 2011-2016 were taken from the NAFO STATLANT 21 database. Landings in 2017 were estimated with the CDAG method, and the CESAG method has provided the catch estimates since 2018.

The perception of the recent stock status, with biomass above B_{msy} and fishing mortality below F_{MSY} , justified the adoption of a Risk-Based Management Strategy (MS) in 2014 for redfish in Divisions 3LN (Ávila de Melo et al., 2014). This MS was designed to reach an annual landings value of 18 100 t by 2019-2020 through a constant, stepwise biannual catch increase.

Description of the fishery

In the early 1980's the former USSR, Cuba, and Canada were the primary fleets directing for redfish in Div. 3LN. The rapid expansion of the fishery was due to the entry of EU-Portugal in 1986 and South Korea in 1987, along with various re-flagged fleets. In the early 1990's Russia and the Baltic mid-water trawlers, together with South Korea and Portuguese bottom trawlers, were still responsible for the bulk of fishing effort.

Rapid declines in catch rates resulted in the withdrawal of South Korea from the redfish fishery and the reductions of efforts by other fleets.. Since 1994, most of the redfish catches in NAFO Divisions 3L and 3N have been taken as by-catch in the Greenland halibut fishery primarily undertaken by EU-Portugal and EU-Spain bottom trawl fleets.

Since the lifting of the commercial fishing moratorium in 2010, Canada, Russia and EU-Portugal have been the primary fleets in this fishery.

Commercial CPUE

During the 1997 assessment (Power, 1997) catch/effort data for Div. 3L and Div. 3N from 1959 to 1995 were analyzed with a multiplicative model (Gavaris, 1980), in order to derive a catch rate series for each division standardized for country-gear-tonnage class, NAFO division, month, and amount of by-catch associated with each observation. The CPUE series shows much within year variability over time, with no statistical difference between the catch rates for most of the years. The 1997 assessment considered that catch rate indices for Div. 3L and Div. 3N were not reflective of year-to-year changes in population abundance, but they may be indicative of trends over longer periods of time.

Previous ASPIC assessments recovered the predicted effort series in fishing hours for Div. 3L and Div. 3N from the 1997 multivariate analysis, in order to derive a single annual catch rate for Div. 3LN. For each year of the 1959-1994 interval, this standardized catch rate is given by the ratio between the sum of Div. 3L and Div. 3N STATLANT catch (thousand tons) and the sum of Div. 3L and Div. 3N predicted effort (fishing hours). The

catch rate series for Div. 3LN is presented in Table 2 and Figure 2. Catch rate for Div. 3LN increased during the early part of the time series, 1959-1967, after which it oscillated around the average until beginning to decline after 1987. In the final years of this CPUE series, 1990-1994, catch rates were stable at a minimum level. It should be noted that the 3LN catch rate series are presented without associated errors, since error estimates are for Divisions 3L and 3N separately.

Commercial length frequencies

Most of the commercial length sampling data available for the 3LN beaked redfish since 1990 comes from the Portuguese fisheries, with some data available from Spanish and Estonian fisheries since 2002 and 2008, respectively (Figure 3). Commercial length frequency data has largely been absent from the Canadian fishery since 1991, with only sporadic sampling of often small sized fish. Previous assessments have calculated commercial catch at length utilizing primarily the data collected in the Portuguese fishery. This assessment does not calculate catch at length, but rather displays the distribution of available commercial length frequencies, since the exact catch at length values could not be replicated. As this assessment model does not incorporate commercial catch at length, lack of catch at length should not impact the assessment or perception of this stock.

Research Surveys

From 1978 until 1990, several stratified-random bottom trawl surveys have been conducted by Canada in various years and seasons in Div. 3L. However, Canadian stratified-random surveys have covered the entire stock area only since 1991. No survey was carried out on Div. 3N in spring 2006 and autumn 2014. In the spring of 2017, there were problems with 3L survey coverage and none of the redfish 3L strata were sampled (Rideout and Ings, 2020; Rideout 2020). No spring survey was completed in 2020 and 2021, nor was an autumn survey completed in 2021. Canadian data collected using the Engel trawl (prior to 1996) has been converted to Campelen trawl equivalents.

Russian stratified-random bottom trawl surveys in NAFO Divs. 3LMNO occurred from 1983 to 1994. In 1992, redfish indices from the 1984-1991 surveys were revised (Power and Vaskov, 1992). Since 2008, the Russian survey series has been incorporated into the input framework of the 3LN redfish ASPIC assessment (Ávila de Melo et al., 2008). Between 1992 and 1994 the coverage of NAFO Subarea 3 by the Russian bottom trawl series became irregular and was discontinued in 1995.

In 1995, EU-Spain started a new stratified-random bottom trawl spring (May-June) survey in the NAFO Regulatory Area of Divs. 3NO. All strata within the NRA were covered every year following the standard stratification (Doubleday, 1981). Early surveys were completed to a depth of 732m, and were extended to 1464 m in 1998 (González et al., 2020). In 2003, this survey was extended northwards to include strata in Div. 3L, but it has only been since 2006 that an adequate coverage of 3L has been accomplished for this survey (Román et al., 2020).

Further details on the two Canadian survey series, as well as on the Russian series and the two Spanish surveys can be found in previous assessments (Ávila de Melo et al., 2014) as well as Rideout et al. (2022) and Garrido et al. (2022).

Survey biomass and female spawning biomass

Spring and autumn female spawning survey biomass (SSB) by division has historically been estimated using female maturity at length vectors for each NAFO Division applied to abundance at length estimates. This mature abundance was then converted to biomass estimates using previously estimated length-weight relationships (Power 2001; Ávila de Melo et al., 2005) using data collected on board of the Canadian 3LN autumn surveys, 1997-2004 (Power, pers. comm., 2005). Large scale changes in length at 50% (L50) maturity have been observed in this stock since L50 was last investigated (Power 2004), and as such, previous estimates of SSB may be inaccurate. Bootstrapped estimates of L50 from the Canadian autumn survey are

shown in Figure 4 along with previous estimates of L50. Further work is needed to refine and validate these changes in SSB, therefore data related to SSB has been removed from this assessment until additional work can be completed. SSB is not used to assess stock status of 3LN redfish, therefore this should have minimal impact on the assessment of this stock.

This assessment uses the Canadian spring 3LN, Canadian autumn 3LN, EU-Spain 3N, and EU-Spain 3L surveys as an index of stock status. Historic surveys (3L Russian survey, 3L winter survey, and 3L summer survey) were not used this assessment. All survey biomass indices from stratified-random bottom trawl surveys used in the 2022 assessment are presented in Table 3. In an effort to facilitate comparisons and enhance the detection of trends in stock dynamics, the survey biomass series used in the assessment framework were standardized to zero mean and unit standard deviation (Figure 5).

From the late 1970s to the beginning of the 1990s, Canadian survey indices in Div. 3L and Russian bottom trawl survey indices in Div. 3LN suggest that stock size suffered a substantial reduction (Ávila de Melo et al, 2020). Redfish bottom biomass from surveys in Div. 3LN remained well below average level over the 1990's and early 2000's (Figure 5). By the mid-2000s, most indices began to show increases with each index peaking in the mid-2010s. Since the mid-2010s, there have been some conflicting signals between survey indices, the cause of which are still uncertain but may be related to the movement of fish within the stock area.

Survey abundance at length

Spring and autumn Canadian Div. 3LN survey as well as EU-Spain 3L and 3N survey abundance at length are presented in Tables 4, 5, 6, and 7 respective length frequencies in Figure 6.

During the first half of the 1990's, the stock was composed of primarily fish smaller than 25 cm, with very few larger fish present, although these data are converted from Engel units to Campelen units and there are some concerns about the accuracy of conversion factors at smaller sizes. Through the mid-2000s, the movement of cohorts through the stock was apparent, as modal lengths increased until 2008. In 2008, a pulse of <20cm redfish appeared in the autumn survey and could be tracked through the population via increases in modal size until 2017. Since 2017, few and small pulses of <15cm redfish have been observed and the modal size has stagnated at around 24 cm. This stock currently thought to be comprised primarily of larger, reproductive size fish with few recruits and pre-recruits being observed (Figure 3 and Figure 6).

Recruitment

Recruitment in this stock, as with most redfish stocks, is sporadic. This assessment examined the abundance of redfish between 15 and 20 cm as a recruitment index as well as the abundance of redfish less than 15 cm as a pre-recruitment index. Recruitment of redfish between 15 and 20 cm has been below the long-term average since the mid-2010s (Figure 7). The recruitment index appears to show better consistency between available surveys than the previous index (Figure 7 & Figure 8). Recruitment of redfish <15cm show less consistency between surveys, with multiple spikes in abundance occurring in different years and very little evidence of pre-recruits in the EU-Spain 3N survey since 2009 (Figure 8).

There is recent evidence of very small redfish (<10 cm) in the Canadian Fall 3LN and Spain 3L indices during 2015, 2016, and 2019, although this has not translated into increased abundance of larger fish in recent years.

ASPIC assessment suite

Brief history and background for the pre-fixed MSY option

Previously a non-equilibrium surplus production model (ASPIC; Prager, 1994) had been used to assess the status of this stock. The ASPIC model is a non-equilibrium implementation of Schaefer's production model.

Until 2012, the model was fitted to a series of Canadian, Russian, and Spanish surveys as outlined in Ávila de Melo and Alpoim (2010). However, the fit of the model to these survey indices has been increasingly poor in recent years. The framework completed in 2012 concluded the 3N Spanish survey and several interannual biomass variations within the both Canadian survey series should be excluded (Ávila de Melo et al., 2012).

The 2014 assessment (Ávila de Melo et al., 2014) re-examined the model and indices used in an effort to determine an inclusive approach that would incorporate most, if not all, the survey points available while also providing reliable results of key parameters that were consistent with the current and historical understanding of this stock. A total of five (5) frameworks were explored prior to the 2014 assessment, with two (2) of the those frameworks incorporating a fixed maximum sustainable yield (MSY) of 21 000 t. This MSY proxy was selected as it is the average level of sustained catch for a period (1960-1985) when the stock was thought to have experienced relative stability, as suggested by the STATLANT CPUE series and historic surveys.

The 2014 exploratory analysis concluded that the best framework to undertake the 3LN redfish assessment incorporated a fixed MSY (21 000 t) at the average of the 1960-1985 landings. This framework also retained the negatively correlated STATLANT CPUE series (Ávila de Melo et al., 2014). In 2016, further exploratory analysis allowed the inclusion of the 3L Spanish survey, which has allowed the inclusion of all survey series in Divisions 3LN as inputs in this assessment model. In 2022, the ASPIC model was rejected (discussed below).

Assessment results

The previous assessment model (ASPIC) was rejected at the 2022 assessment. Continued mismatch between recent observed survey indices and the ASPIC model biomass estimates resulted in a lack of confidence in the model. The ASPIC model has continued to show patterning in residuals of input series (Figure 9) and the use of a fixed MSY approach has resulted in an value of r that is considered too high for this species (>0.2). Simulations of a suite of MSY levels, including a freely estimated MSY, were undertaken but resulted in either a K or an r value that was considered unrealistically high (Figure 10 and Table 8).

Mean of the standardized survey biomass indices indicates that biomass has declined from timeseries highs in the mid-2010s to the long-term mean. Estimates from 2020 and 2021 should be treated with caution as only one of a potential four survey was completed in each year.

Rejection of the assessment model and lack of the Canadian spring survey estimates in recent years precludes the calculation of the usual proxy fishing mortality index, but it is reasonable to expect that levels of fishing mortality have not changed substantially. From 2010 to 2016 this proxy of fishing mortality was at a level close to zero, then increased in 2018 and 2019 (no survey spring data available for 3L 2006 or 2017 and 3LN 2020-2021).

Stock/fishing mortality trajectory within a Precautionary Approach framework

Prior reference points were dependent on the ASPIC model fit and outputs. Upon rejection of the assessment model, and until the MSE process is completed, an interim limit reference point (LRP) was adopted using the average of the mean standardized biomass of the Canadian spring and autumn 3LN and EU-Spain 3N surveys ($B_{lim}=B_{rec}$) from the period 1991-2005. This period was chosen as it represented a time when stock biomass recovered from a prolonged low level. The EU-Spain 3L survey was not included in the calculation of this interim LRP as it does not begin until 2006. Previous assessment updates (between full assessments) have used landings/Canadian 3LN spring survey biomass as a proxy for fishing mortality. In the absence of Canadian spring surveys in 2020 and 2021, the current proxy fishing mortality could not be determined. However, it is unlikely that levels of fishing mortality have changed substantially from estimates in 2020 (Figure 11).

Conclusion

Rejection of the assessment model and lack of the Canadian spring survey estimates in recent years precludes the calculation of the usual proxy fishing mortality index, but it is not expected that levels of fishing mortality have changed substantially from estimates in 2020. Recruitment of redfish between 15 and 20 cm has been below the long-term average since the mid-2010s across Canadian 3LN spring and autumn as well as EU-Spain 3N survey series. Lack of survey indices in recent years limits our understanding of stock status since 2019, but available data indicate that biomass is at or below the long-term mean. The stock appears to be above the interim limit reference point (B_{lim}).

Acknowledgements

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Tables

Table 1. Summary of catch and total allowable catch (TAC)'s of redfish in Div. 3LN. Landings from 2017 are estimated from CDAG (COM-SC CESAG-WP 18-01). Landings from 2018 onwards are estimated using CESAG. Otherwise landings are from STATLANT 21A.

Year	3L	3N	Total	TAC
1959	34107	10478	44585	--
1960	10015	16547	26562	--
1961	8349	14826	23175	--
1962	3425	18009	21439 ^a	--
1963	8191	12906	27362 ^a	--
1964	3898	4206	10261 ^a	--
1965	18772	4694	23466	--
1966	6927	10047	16974	--
1967	7684	19504	27188	--
1968	2378	15265	17660 ^a	--
1969	2344	22356	24750 ^a	--
1970	1029	13359	14419 ^a	--
1971	10043	24310	34370 ^a	--
1972	3095	25838	28933	--
1973	4709	28588	33297	--
1974	11419	10867	22286	28000
1975	3838	14033	17871	20000
1976	15971	4541	20513	20000
1977	13452	3064	16516	16000
1978	6318	5725	12043	16000
1979	5584	8483	14067	18000
1980	4367	11663	16030	25000
1981	9407	14873	24280	25000
1982	7870	13677	21547	25000
1983	8657	11090	19747	25000
1984	2696	12065	14761	25000
1985	3677	16880	20557	25000
1986	27833	14972	42805	25000
1987	30342	40949	79031 ^b	25000
1988	22317	23049	53266 ^b	25000
1989	18947	12902	33649 ^b	25000
1990	15538	9217	29105 ^b	25000
1991	8892	12723	25815 ^b	14000
1992	4630	10153	27283 ^b	14000
1993	5897	9077	21308 ^b	14000
1994	379	2274	5741 ^{bc}	14000
1995	292	1697	1989 ^{bc}	14000

Year	3L	3N	Total	TAC
1996	112	339	451	11000
1997	151	479	630	11000
1998	494	405	899	0
1999	518	1318	2318 ^b	0
2000	657	819	3141 ^{bc}	0
2001	653	245	1442 ^b	0
2002	651	327	1216 ^b	0
2003	584	751	1334	0
2004	401	236	637	0
2005	581	78	659	0
2006	53	444	496	0
2007	118	1546	1664	0
2008	220	377	597	0
2009	57	994	1051	0
2010	260	3688	4120	3500
2011	2418	1254	3672	6000
2012	2781	1535	4316	6000
2013	4446	1786	6232	6500
2014	4245	1450	5695	6500
2015	8620	1320	9940	10400
2016	6652	1805	8457	10400
2017	7790	4026	11815	14200
2018	7300	3979	11279	14200
2019	6357	6693	13050	18100
2020	4806	6285	11091	18100
2021	4228	5944	10172	18100

^aIncludes catch that could not be identified by division

^bIncludes estimates of unreported catches

^cCatch could not be precisely estimate due to discrepancies in figures from available sources: average of the range of the different catch estimates

Table 2. Redfish STATLANT catch and predicted effort for Div. 3L and Div. 3N, 1959-1994 (Power,1997). Standardized catch rate for Div. 3LN, 1959-1994. Highlighted values were corrected in the 2022 ASPIC formulation.

Year	3L		3N		3LN		CPUE Annual
	STATLANT Catch	Predicted Effort	STATLANT Catch	Predicted Effort	STATLANT Catch	Predicted Effort	
1959	34107	22604	10478	8659	44585	31263	1.426
1960	10015	5690	16547	10892	26562	16582	1.602
1961	8349	3610	14826	10049	23175	13659	1.697
1962	3425	2049	18009	11090	21434	13139	1.631
1963	8191	3973	12906	8958	21097	12931	1.632
1964	3898	1491	4206	2981	8104	4472	1.812
1965	18772	8190	4694	2551	23466	10741	2.185
1966	6927	4615	10047	4915	16974	9530	1.781
1967	7684	3793	19504	10569	27188	14362	1.893
1968	2378	1446	15265	17684	17643	19130	0.922
1969	2344	1354	22356	17109	24700	18463	1.338
1970	1029	499	13359	10026	14388	10525	1.367
1971	10043	5207	24310	20320	34353	25527	1.346
1972	3095	1877	25838	18982	28933	20859	1.387
1973	4709	2078	28588	18186	33297	20264	1.643
1974	11419	11907	10867	5374	22286	17281	1.290
1975	3838	2443	14033	8265	17871	10708	1.669
1976	15971	11335	4541	4537	20512	15872	1.292
1977	13452	10461	3064	2738	16516	13199	1.251
1978	6318	5961	5725	4925	12043	10886	1.106
1979	5584	3517	8483	6176	14067	9693	1.451
1980	4367	2873	11663	6229	16030	9102	1.761
1981	9407	6020	14873	9216	24280	15236	1.594
1982	7870	4812	13677	8160	21547	12972	1.661
1983	8657	4960	11090	7734	19747	12694	1.556
1984	2696	1804	12065	12263	14761	14067	1.049
1985	3677	2104	16880	16858	20557	18962	1.084
1986	27833	15247	14972	15057	42805	30304	1.413
1987	34212	22369	44819	29517	79031	51886	1.374
1988	26267	19629	26999	24453	53266	44082	1.029
1989	19847	10567	13802	14884	33649	25451	1.251
1990	17713	16774	11392	18513	29105	35287	0.702
1991	8892	12329	12723	20052	25820	32381	0.668
1992	4630	2452	10153	13755	27280	16207	1.018
1993	5897	1576	9077	17116	21310	18692	0.801
1994	379	410	2274	2900	5741	3310	0.810

Table 3. Survey biomass ('000 t) from stratified bottom trawl surveys on Div. 3L and Div.3N included in the 2022 assessment.

Year	3LN Spring	3LN Autumn	3L Spanish	3N Spanish
1991	10.6	37.9		
1992	10.1	136.4		
1993	22.6	19.2		
1994	4.2	31.8		
1995	5.9	90.7		46.1
1996	22.8	16.0		6.6
1997	14.9	70.7		4.8
1998	59.4	112.2		22.5
1999	61.5	72.0		46.5
2000	87.8	100.5		68.9
2001	41.6	132.6		53.9
2002	31.0	50.1		7.6
2003	27.7	71.9		11.0
2004	79.6	49.9		27.0
2005	66.5	58.6		146.9
2006		91.9	70.1	87.8
2007	218.8	124.8	31.4	87.6
2008	144.0	198.5	75.6	68.1
2009	183.4	246.7	103.7	735.7
2010	165.3	461.5	266.8	359.5
2011	173.7	562.3	170.6	418.3
2012	322.0	596.0	481.5	265.2
2013	271.5	288.8	235.2	429.5
2014	271.8		216.4	178.1
2015	480.6	425.9	130.4	523.5
2016	654.2	215.2	98.8	117.3
2017		192.0	56.6	265.9
2018	106.0	191.4	40.4	292.8
2019	136.5	285.9	54.0	174.6
2020		199.3		
2021				73.2

Table 4. Abundance at length for Canadian 3LN spring survey 2008-2022 (thousands). Lengths have been trimmed to 45 cm and less as very few fish are caught at lengths greater than 45 cm. Note surveys were not conducted in 2020 or 2021.

Length	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	0	0	0	0	0	0	25	0	19	0	0	0	--	--
5	423	44	257	0	0	145	183	0	331	0	0	34	--	--
6	1958	472	134	562	40	699	1349	946	1247	121	1756	106	--	--
7	2945	979	563	782	1052	1771	968	8495	2957	728	3736	583	--	--
8	3128	958	928	851	1038	1100	826	5173	13159	2416	6084	1493	--	--
9	3389	375	1365	1079	1590	1790	1038	673	19021	1924	4463	2779	--	--
10	4266	991	2462	1348	1917	1902	1265	249	6234	749	932	2273	--	--
11	5323	1690	2903	2472	2176	2218	1376	812	2529	164	889	4603	--	--
12	2430	3647	2873	1703	2858	1754	1609	1127	1195	38	1887	5982	--	--
13	1288	16091	2262	2462	2582	2292	1707	614	469	44	3590	4640	--	--
14	5395	12648	4900	3563	3653	1805	1526	333	563	8	6104	4713	--	--
15	3837	11255	8525	4481	6003	4328	1148	285	1693	256	8358	3480	--	--
16	15873	75227	14350	8917	9628	2460	1437	928	1116	1217	3902	3851	--	--
17	45717	19768 4	26141	17787	52508	3940	4386	125	2833	96	3349	4710	--	--
18	77466	32543 2	10892 3	56815	96675	12318	9408	13442	2199	1453	1713	4481	--	--
19	50559	31028 5	21928 1	11571 3	19472 7	20107	63950	81530	2881	17647	2203	3106	--	--
20	48020	16436 0	23458 9	14482 2	28968 4	10382 3	18796 0	38873 1	9036	37321	7698	6152	--	--
21	49080	92562	17864 6	22198 0	39807 0	21062 7	32375 6	67222 8	24063	11282 7	23474	28368	--	--
22	78864	60971	74444	12809 0	31598 1	23794 4	34020 6	73482 0	57931	12947 8	51105	60633	--	--
23	88837	65885	72509	85376	19075 9	18222 1	24630 3	47978 0	90420	94527	86567	11770 4	--	--



Length	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
24	87289	76920	66497	62257	14034 2	14793 5	17623 7	29125 2	85381	58411	80265	10014 0	--	--
25	61333	55772	60999	46547	94274	11479 2	78040	10756 5	75114	34479	65984	79850	--	--
26	54232	30399	38289	44960	63503	62527	62658	41932	91633	20914	51852	48836	--	--
27	34940	17043	18644	37757	45175	45086	33587	24505	94094	14252	33932	35069	--	--
28	28219	14165	18909	32307	32817	40858	24589	23672	13625 9	10129	20531	27791	--	--
29	19453	13070	11301	24988	33678	28453	15447	15086	15504 0	6475	12477	20242	--	--
30	12305	8666	10694	16754	26255	25852	11804	23282	14300 8	5864	9464	13082	--	--
31	10568	6011	4700	10144	18316	15526	9536	17647	15664 1	2859	7073	10796	--	--
32	7018	4105	4099	8776	14819	14995	7282	16680	10768 3	1202	5151	7797	--	--
33	7751	3441	2913	4916	5041	9918	4665	13283	10891 7	835	3635	9366	--	--
34	4320	2327	2574	2995	4692	9072	4323	11633	71847	838	2508	10128	--	--
35	1850	1600	1811	1661	1756	10037	3832	6785	75696	431	1146	3780	--	--
36	1354	836	1031	1361	1267	5807	3448	4791	52143	244	1044	3749	--	--
37	776	314	389	792	966	3553	1380	1913	50187	136	767	2130	--	--
38	388	231	204	854	544	1832	769	1486	21874	231	390	1965	--	--
39	323	87	28	229	898	1418	205	657	3972	42	158	674	--	--
40	193	53	60	72	166	1282	174	199	8477	11	168	637	--	--
41	0	30	0	120	79	865	11	81	5888	13	74	168	--	--
42	53	45	0	0	15	1632	1256	29	2803	7	23	93	--	--
43	0	0	70	0	47	460	0	552	149	0	12	0	--	--
44	61	0	0	0	95	11	0	12	0	0	0	0	--	--
45	0	0	0	86	0	427	0	0	3050	0	0	0	--	--

Table 5. Abundance at length for Canadian 3LN autumn survey 2008-2022 (thousands). Lengths have been trimmed to 45 cm and less as very few fish are caught at lengths greater than 45 cm. Note survey was not conducted in 2021 and is considered incomplete in 2014.

Length	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
3	0	0	0	0	0	0	--	0	0	0	0	0	29	--
4	0	0	0	0	0	0	--	0	127	0	0	0	0	--
5	34	97	1380	50	268	418	--	712	421	1577	154	0	409	--
6	671	614	1107	320	1407	4542	--	2832	736	15752	499	236	525	--
7	2467	320	1407	732	924	2910	--	35134	500	18605	3653	743	1054	--
8	2948	864	3380	876	2330	4872	--	86936	6969	2498	6104	903	4214	--
9	2722	3450	3790	2884	6978	5703	--	33862	22011	1709	6283	1910	22154	--
10	4224	9938	4674	2270	9923	5434	--	5654	50151	4011	4356	3121	81839	--
11	5839	5207	6604	1847	8541	8458	--	2409	12039	12382	2125	2681	47604	--
12	5073	4026	7941	1927	6511	12924	--	1685	7327	19336	4473	2577	13993	--
13	27461	9471	10308	3247	5476	12046	--	1763	2496	20204	6067	3516	2699	--
14	29034	20335	11146	4192	6380	14943	--	2357	858	19109	8423	4242	2821	--
15	24076	17753	8573	8266	5242	18131	--	2474	1070	9797	7350	9176	1896	--
16	11702 3	35716	12966	14612	3164	10243	--	2477	1358	7002	9499	14909	3920	--
17	22995 6	13876 1	18482	46430	9774	19629	--	3824	1070	6679	8101	45437	5018	--
18	22268 7	39698 3	77804	10365 7	24091	38675	--	5006	1507	3379	6155	57444	8169	--
19	14282 4	42153 3	26915 3	43256 0	11673 8	86347	--	27584	3038	7596	2410	61536	9856	--
20	80869	27979 5	45946 2	99692 5	31539 0	10275 1	--	92418	16748	16291	6431	38644	11986	--
21	66510	13885 4	49999 5	11982 27	66490 6	27680 3	--	28732 1	72436	42545	23753	64850	33489	--
22	56622	67339	30348 0	58704 7	65314 6	44896 2	--	51904 3	15812 5	77531	10385 2	13705 9	69967	--
23	89498	53181	26146 9	30078 6	50147 8	31443 1	--	45369 9	20656 0	94752	17505 9	23624 4	94541	--
24	80569	65255	26074 8	12670 9	31484 9	19235 0	--	35147 4	15328 9	80650	18887 8	22877 3	93346	--

Length	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
25	66378	46817	16544 7	97725	20372 0	12290 7	--	21966 9	87763	60725	12056 5	20097 8	99125	--
26	49936	39921	12085 6	82801	15217 7	72775	--	11331 4	65125	54045	99623	12517 9	69923	--
27	48816	34945	95152	49337	13513 3	36871	--	93978	26168	43722	64324	89264	65288	--
28	37458	24853	72531	35080	76041	28034	--	66287	14923	31508	32833	54122	49338	--
29	21735	24361	37998	30900	67573	17921	--	45312	13548	22839	18904	22567	37118	--
30	18380	14244	26795	35536	46126	14967	--	33830	11434	18163	11769	17528	27109	--
31	11861	10905	15931	17230	29845	10468	--	35103	12143	18193	10713	12977	17761	--
32	6799	7950	14872	11681	28060	8997	--	8146	12385	13255	8035	8734	12783	--
33	6388	6666	9282	4847	18837	7509	--	8690	12602	18244	4640	5940	10324	--
34	5259	3633	5884	2154	7513	3350	--	3807	17742	14247	4148	3698	9165	--
35	2384	2543	1891	1868	4536	2520	--	2404	14477	9729	2622	2629	7604	--
36	969	2198	2311	1327	2703	2153	--	2168	16953	7528	1356	3668	7982	--
37	777	1764	1316	812	5542	722	--	676	7122	6774	1236	2475	4677	--
38	649	703	1359	145	5697	440	--	446	6651	5298	535	2507	6222	--
39	0	289	369	132	1947	169	--	352	4179	2845	368	1901	2373	--
40	387	248	386	0	958	530	--	355	1810	1327	558	943	1658	--
41	0	130	218	0	1506	0	--	63	557	914	88	509	1143	--
42	261	510	194	0	622	0	--	44	53	223	86	204	623	--
43	0	92	0	49	578	0	--	0	663	243	161	130	386	--
44	0	0	0	0	523	0	--	274	212	155	0	110	0	--
45	134	46	83	0	361	0	--	0	71	23	35	11	310	--

Table 6. Abundance at length for EU-Spain 3L spring survey 2008-2022 (thousands). Lengths have been trimmed to 45 cm and less as very few fish are caught at lengths greater than 45 cm. Note surveys were not conducted in 2020 or 2021.

Length	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	96	6	25	110	12	49	211	98	6	103	80	74	--	--
6	1730	159	478	146	733	1010	1320	5415	218	226	1065	212	--	--
7	3127	615	1098	2742	5732	1869	1331	31537	1845	241	3501	716	--	--
8	3698	1405	1512	2731	6340	2655	1542	15384	13526	331	8869	3058	--	--
9	6589	2750	1180	906	3055	2657	2239	1943	27009	1240	4544	3931	--	--
10	14741	2009	988	1229	5551	3245	3102	1654	17152	7079	1148	5491	--	--
11	20112	1639	1292	1711	5560	3069	2648	2458	5379	18194	1135	6348	--	--
12	11066	2331	1169	1381	6700	2924	2124	3436	1560	22158	3334	7273	--	--
13	2943	2976	1014	1509	3119	2797	2566	3197	804	13677	7038	4555	--	--
14	3438	2201	1079	1595	3301	3511	1973	3585	515	6734	12465	3689	--	--
15	3704	3606	6058	1567	1459	4349	1206	5163	970	2264	18111	6987	--	--
16	8071	8299	14920	4505	3143	5317	2715	3826	718	1081	13748	18447	--	--
17	14647	29255	22892	6350	6710	5368	4135	2866	1210	962	7282	27667	--	--
18	24467	76206	77248	14090	29721	5315	5842	4010	1338	1018	2999	29963	--	--
19	42823	69501	22686 8	33310	89901	12241	12908	6694	1871	1630	2564	14834	--	--
20	53606	60316	35825 9	61708	22088 5	51832	24487	16234	3417	2496	3333	7849	--	--
21	41845	51175	28789 5	81324	34965 0	10299 8	39141	22809	7950	3620	3551	5736	--	--
22	47593	57031	21540 2	68997	47584 0	14108 7	69887	45739	15037	4464	3876	5609	--	--
23	38662	70905	11748 4	59786	45645 7	17057 9	12040 9	64558	23806	9834	3565	5355	--	--
24	35586	50491	61201	70164	32860 5	15804 7	11332 7	72336	30642	15749	5641	7004	--	--
25	23398	42968	49159	62479	19545 5	11616 8	10426 7	60022	33103	14828	6787	8091	--	--

Length	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
26	19507	31628	50446	50204	11333 1	78312	10112 3	47952	33469	18912	9472	9961	--	--
27	15325	21353	26662	44902	77545	48893	66267	35228	28604	19733	11949	12326	--	--
28	14500	9139	23902	40773	39846	33171	47176	27149	25155	14103	12234	11255	--	--
29	11104	5231	21194	33877	35294	27117	43315	22779	19094	12027	9119	11309	--	--
30	6584	4801	6012	22911	25058	21801	26470	16325	14245	8617	5788	8516	--	--
31	5293	2510	5754	22694	19745	17979	20574	9920	8581	8776	4715	7545	--	--
32	3164	2235	4628	11197	10443	8915	13920	8605	7106	7531	3235	5758	--	--
33	1870	1518	3273	5423	7970	5758	8732	7821	10708	6800	3546	4750	--	--
34	1082	1413	2266	6321	3143	5790	5951	6544	6714	5989	3773	3665	--	--
35	1271	909	1611	3643	2385	2245	3894	3847	7873	4019	4243	3309	--	--
36	421	784	1126	2381	1650	1654	2225	3229	6264	4013	2091	2897	--	--
37	277	348	747	1024	519	1612	2328	1766	6308	2243	1699	2001	--	--
38	136	61	663	422	468	804	1726	1333	3463	1464	972	2320	--	--
39	69	40	527	52	1095	405	474	318	1206	669	693	606	--	--
40	79	195	248	13	239	74	206	40	653	379	603	316	--	--
41	0	178	270	20	50	56	74	27	731	317	105	192	--	--
42	45	15	702	0	7	260	64	5	204	32	171	153	--	--
43	28	5	248	9	0	265	0	0	280	0	74	34	--	--
44	0	162	48	0	0	333	0	0	180	47	0	0	--	--
45	0	5	6	0	5	751	45	27	180	0	0	278	--	--

Table 7. Abundance at length for EU-Spain 3N spring survey 2008-2022 (thousands). Lengths have been trimmed to 45 cm and less as very few fish are caught at lengths greater than 45 cm. Note survey was not conducted in 2020.

Length	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
3	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	48	31	106	0	0	0	17	146	44	444	21	77	--	0
6	308	73	77	43	--	141	6	4131	6	277	160	50	--	129
7	238	42	12	111	0	146	6	3534	53	925	516	60	--	714
8	108	6	0	65	5	49	0	619	20	31	556	77	--	412
9	103	560	12	50	10	0	4	6	6	311	232	57	--	210
10	76	2996	0	59	0	0	0	33	963	39	54	55	--	425
11	362	9944	12	74	5	16	13	85	0	2640	47	26	--	775
12	213	5990	12	72	0	0	9	30	0	881	94	194	--	1840
13	1314	20874	6	1493	38	0	4	33	1961	14	76	2518	--	703
14	3683	21182	44	3604	180	0	0	12	14	5228	90	3712	--	461
15	14506	57442	106	8191	1288	16	0	18	0	1749	1005	6013	--	538
16	67404	16330 7	16415	22671	3167	344	446	12	21	1762	168	5951	--	296
17	83227	60800 5	77475	67666	8176	1386	3370	114	27	1785	131	3612	--	433
18	56242	12074 25	33636 2	21437 0	31635	22268	13286	26698	2002	1952	1351	2381	--	1484
19	30080	11371 83	56174 2	70354 4	17683 0	13300 0	41972	72959	6807	13296	4624	2789	--	2531
20	17970	49461 4	53777 1	95995 0	46688 4	50546 3	12970 7	30844 2	34566	55182	20517	2989	--	5079
21	18334	20040 8	28014 8	74030 5	43276 3	99300 1	21718 2	68648 1	13735 9	17406 3	90391	15475	--	9175
22	23940	18341 7	16576 4	24904 2	26580 3	64257 1	19812 3	71967 6	16361 7	32270 3	28317 9	53316	--	29562
23	33212	19742 6	12729 1	98668	11928 9	34581 9	15515 1	41482 0	12181 6	30439 0	36893 6	99718	--	47948
24	39471	17699 4	12304 8	68170	72983	12673 6	92005	31935 9	80610	22572 5	29023 5	10224 5	--	49678

Length	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
25	31110	15861 3	99445	36061	40757	49414	49404	15572 2	47953	17325 6	19324 8	11165 5	--	35918
26	28244	12154 2	69478	29917	28252	37105	25975	11497 7	27574	84336	14832 3	11227 6	--	30903
27	13210	48882	42887	16279	28422	20272	17943	68643	17303	29486	71351	95609	--	31689
28	8718	41712	28098	18482	25716	13449	14454	33588	8809	19160	36080	62802	--	25879
29	6383	28296	17602	9628	20166	8535	9565	33164	7637	7718	18760	33719	--	13288
30	3222	17748	12544	8066	12944	10574	8102	25776	4282	5169	12459	15826	--	7917
31	2310	8549	10487	4284	9502	8825	6344	15067	3270	2416	7868	14347	--	4987
32	2237	3533	6824	2956	4252	3381	4348	12159	2418	1426	5164	7303	--	2895
33	2120	2899	4100	970	2393	2321	2213	6194	943	886	4317	3356	--	1141
34	1782	2541	3558	1234	3370	1759	1135	3847	825	687	1721	223	--	925
35	1174	1698	2571	519	456	1264	639	1414	267	271	817	216	--	448
36	512	1501	1537	494	1389	4203	666	1244	362	269	400	179	--	346
37	477	3386	742	492	1020	352	335	900	71	155	506	249	--	86
38	254	249	683	239	501	320	173	762	121	228	245	188	--	112
39	131	123	478	121	285	189	86	516	65	90	162	121	--	68
40	119	66	265	112	105	72	76	272	96	69	22	112	--	72
41	41	33	521	7	53	100	30	226	45	55	27	107	--	60
42	42	48	173	28	6	78	21	112	10	45	3	52	--	33
43	21	72	20	3	7	37	4	3	14	10	0	40	--	17
44	16	37	153	0	0	0	0	45	0	3	0	7	--	9
45	0	0	11	6	0	3	0	0	0	5	0	4	--	0

Table 8. Parameter estimates from various ASPIC explorations with fixed and freely estimated MSY values.

MSY	Bmsy	K	r	MSY Option
21000	183820	367641	0.228	21000t
13000	243829	487657	0.107	13000t
17000	215470	430939	0.158	17000t
10800	256072	512143	0.084	10800t
9000	264947	529893	0.068	9000t
5000	289443	578886	0.035	5000t
31681	266443	532885	0.238	Freely estimated



Figures

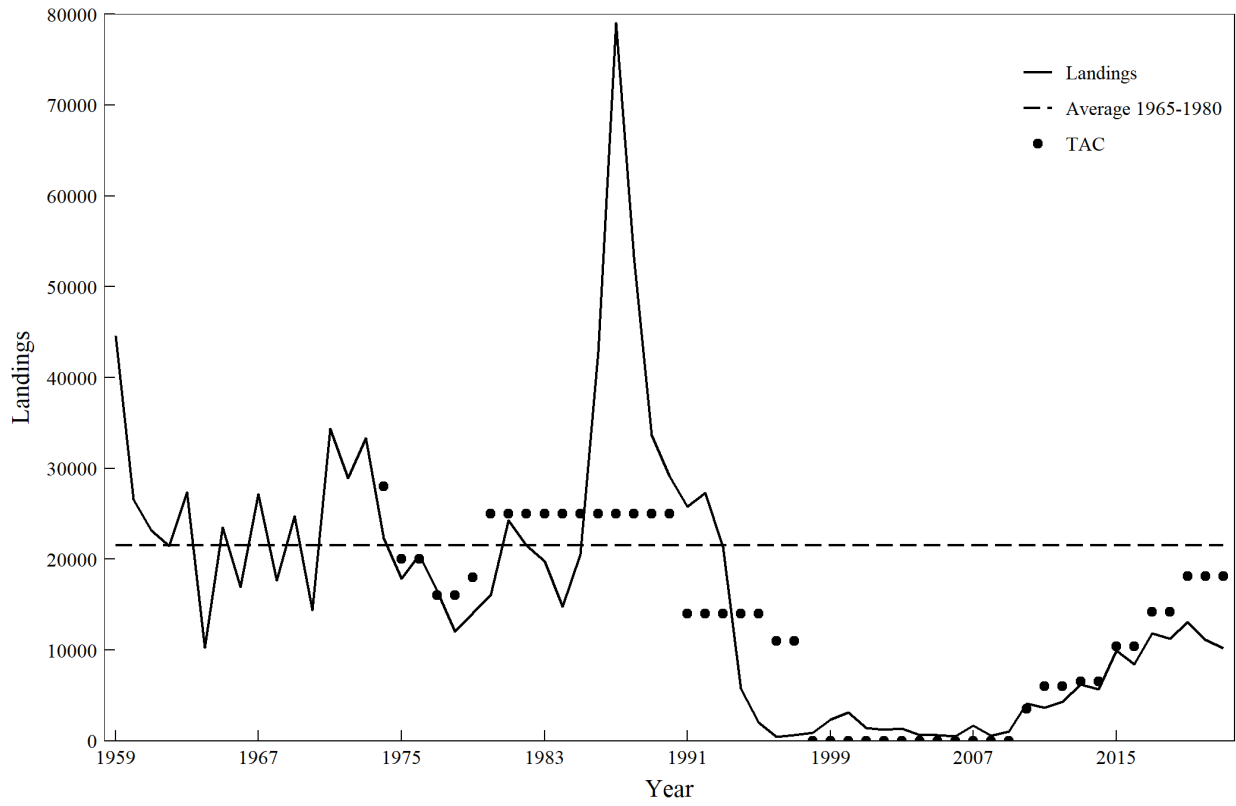


Figure 1. Landings of 3LN redfish since 1959.

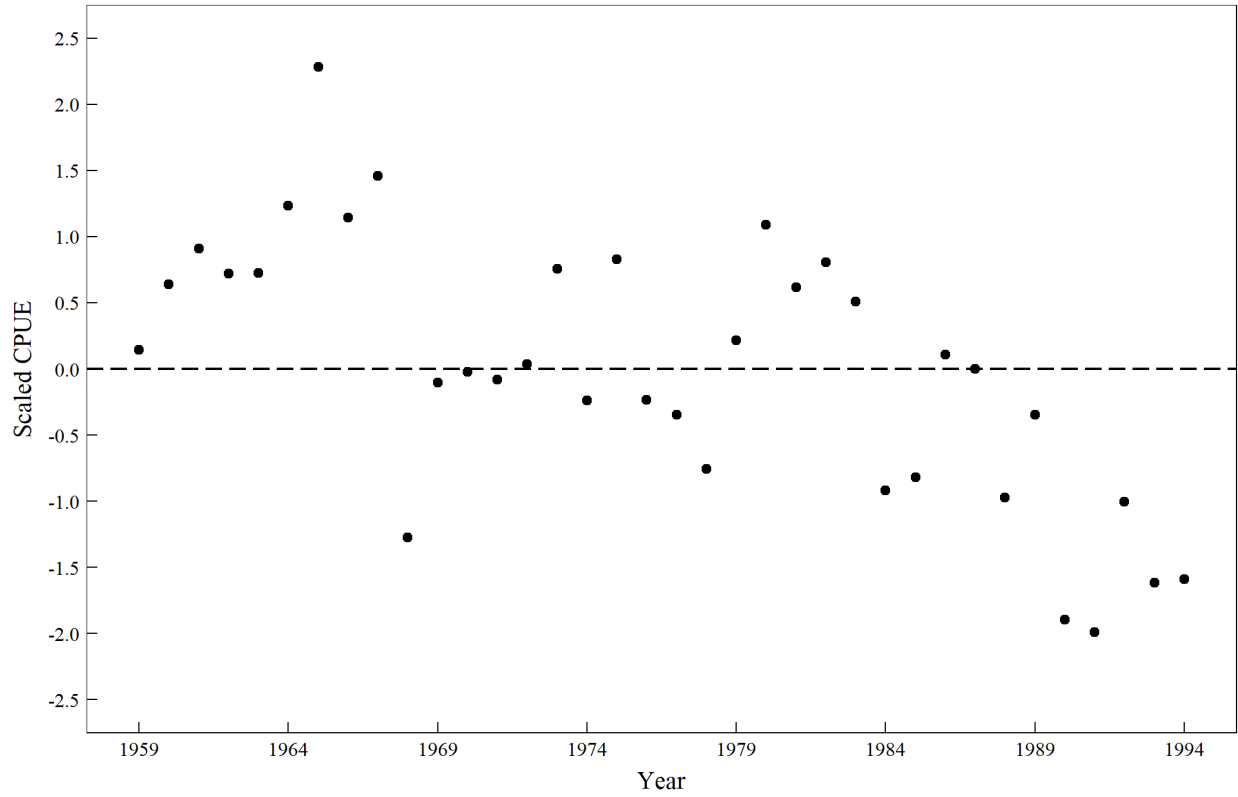


Figure 2. CPUE index of 3LN redfish from 1959-1994 standardized to zero mean and unit standard deviation in the figure.

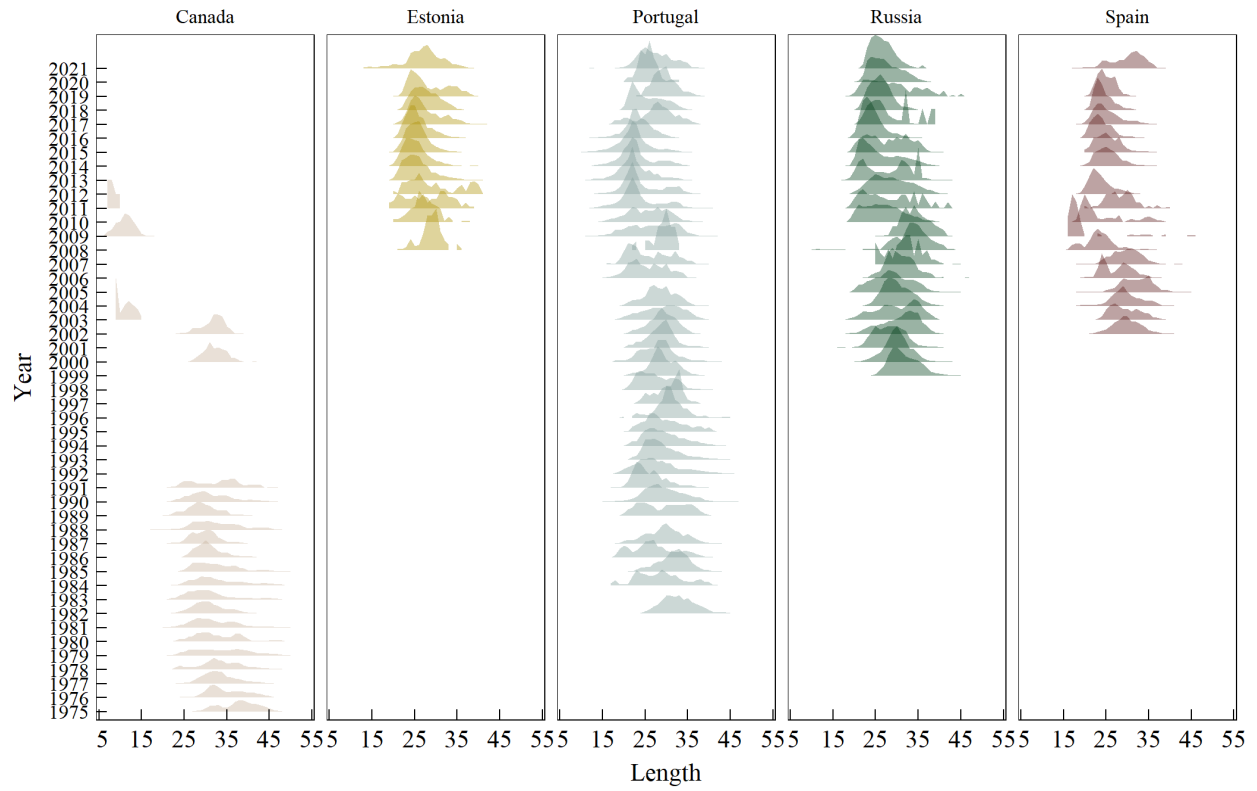


Figure 3. Commercial length frequencies of 3LN redfish.

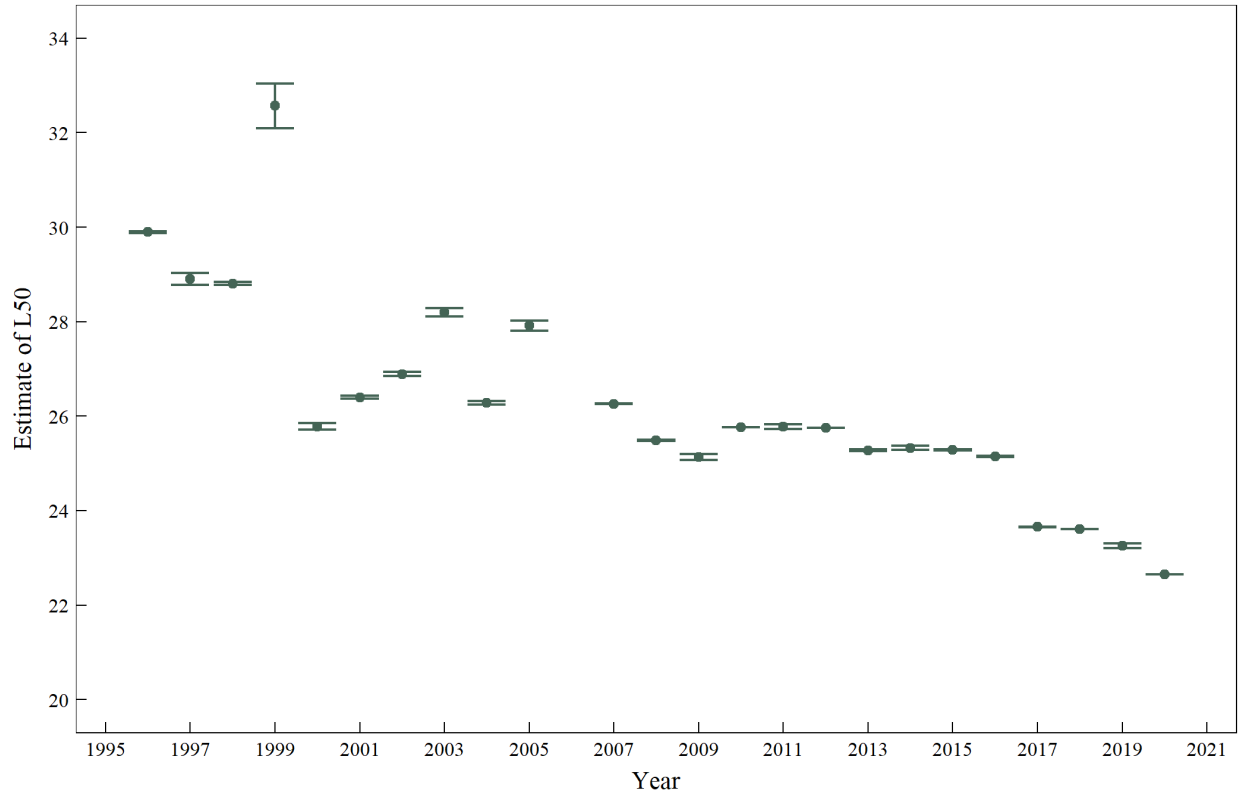


Figure 4. Current estimates of length at 50% maturity (L50) for female 3LN redfish. Point estimates and CI are estimated using a binomial GLM and bootstrapping.

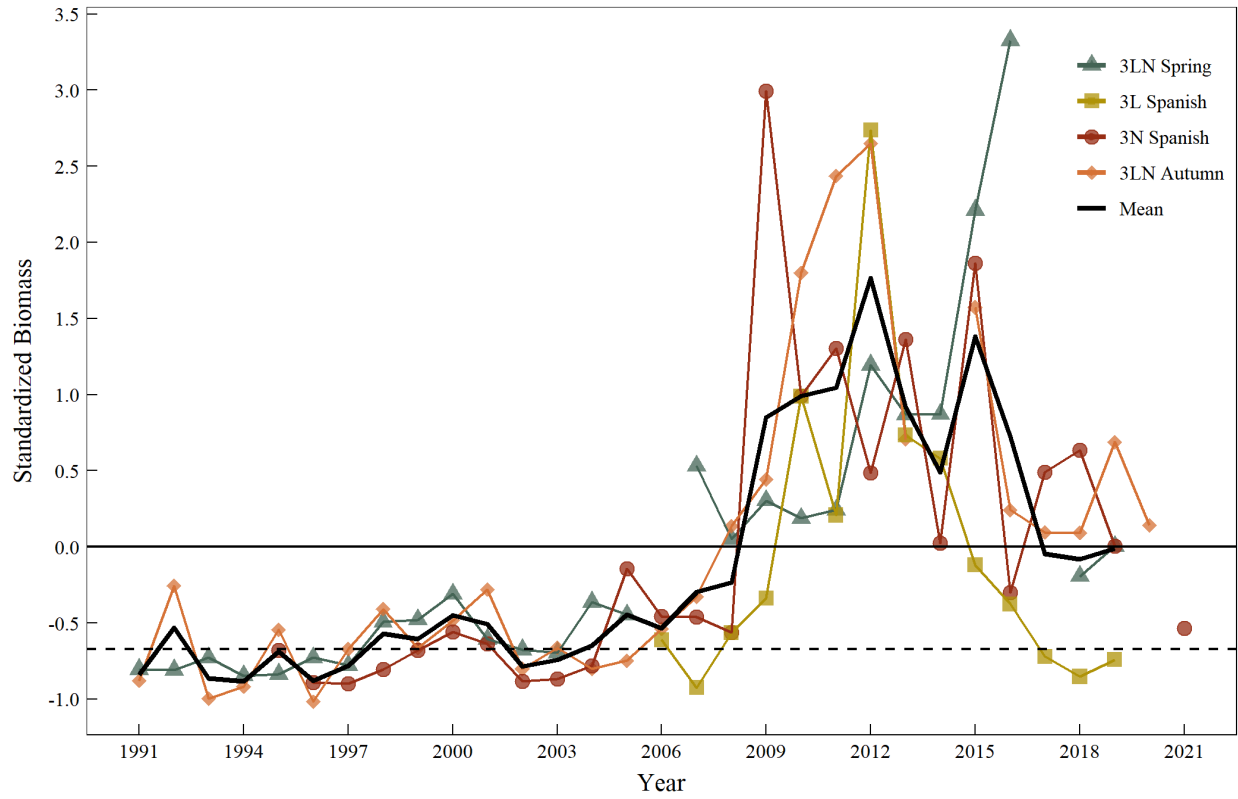


Figure 5. Standardized biomass of 3LN redfish from bottom trawl surveys. Solid black trendline represents the mean of the observed series in each year. Horizontal dashed line represents the average of the mean standardized survey biomass index from 1991-2005 (Brec).

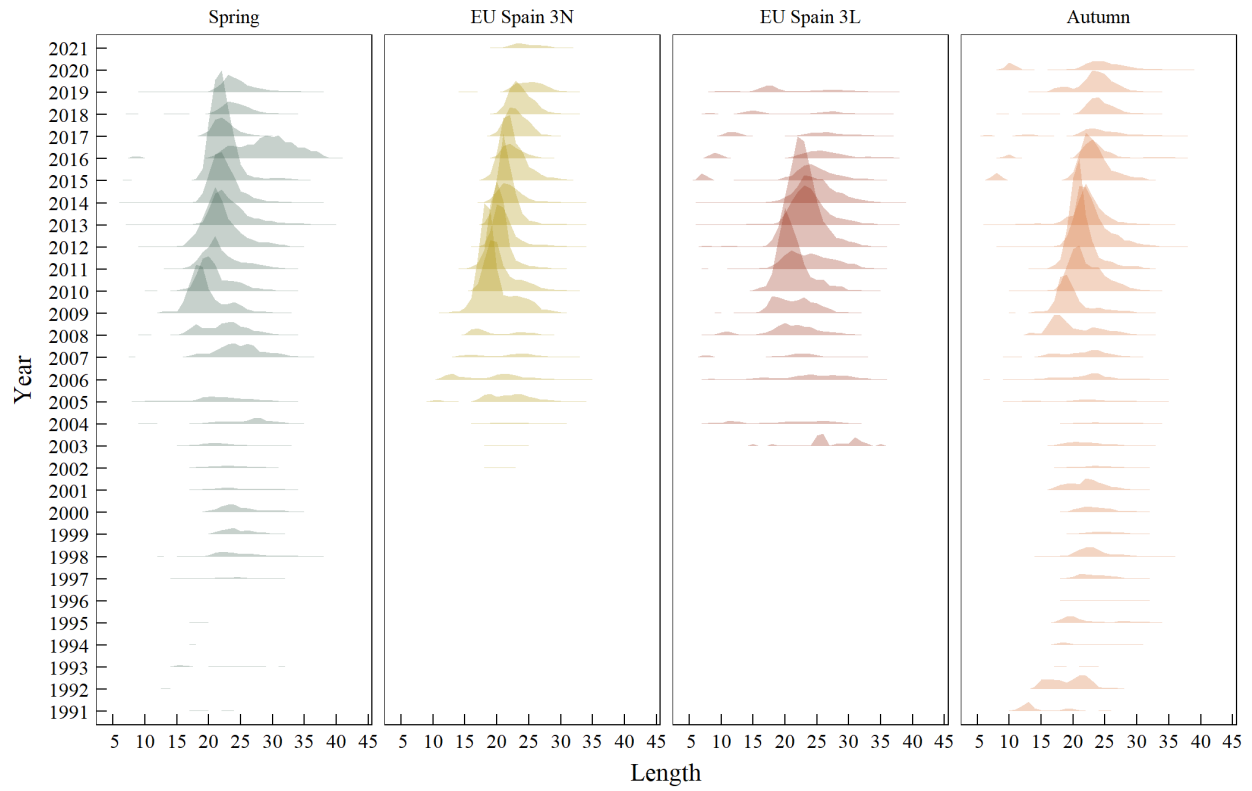


Figure 6. Survey length frequencies of 3LN redfish. Dashed lines represent average length of redfish in each survey across the tie series.

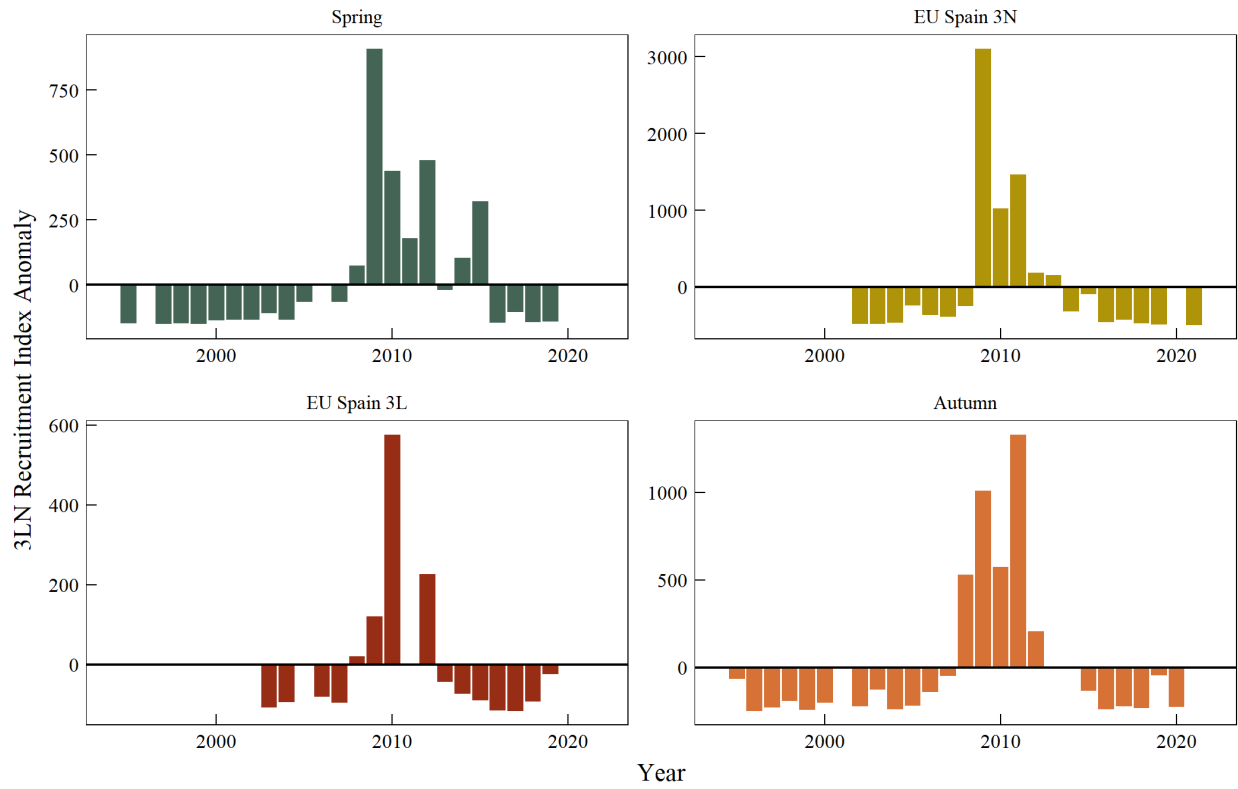


Figure 7. Recruitment index anomalies of 3LN redfish (15-20cm) from Canadian (DFO-NL) spring and autumn and EU-Spain 3L and 3N multispecies surveys.

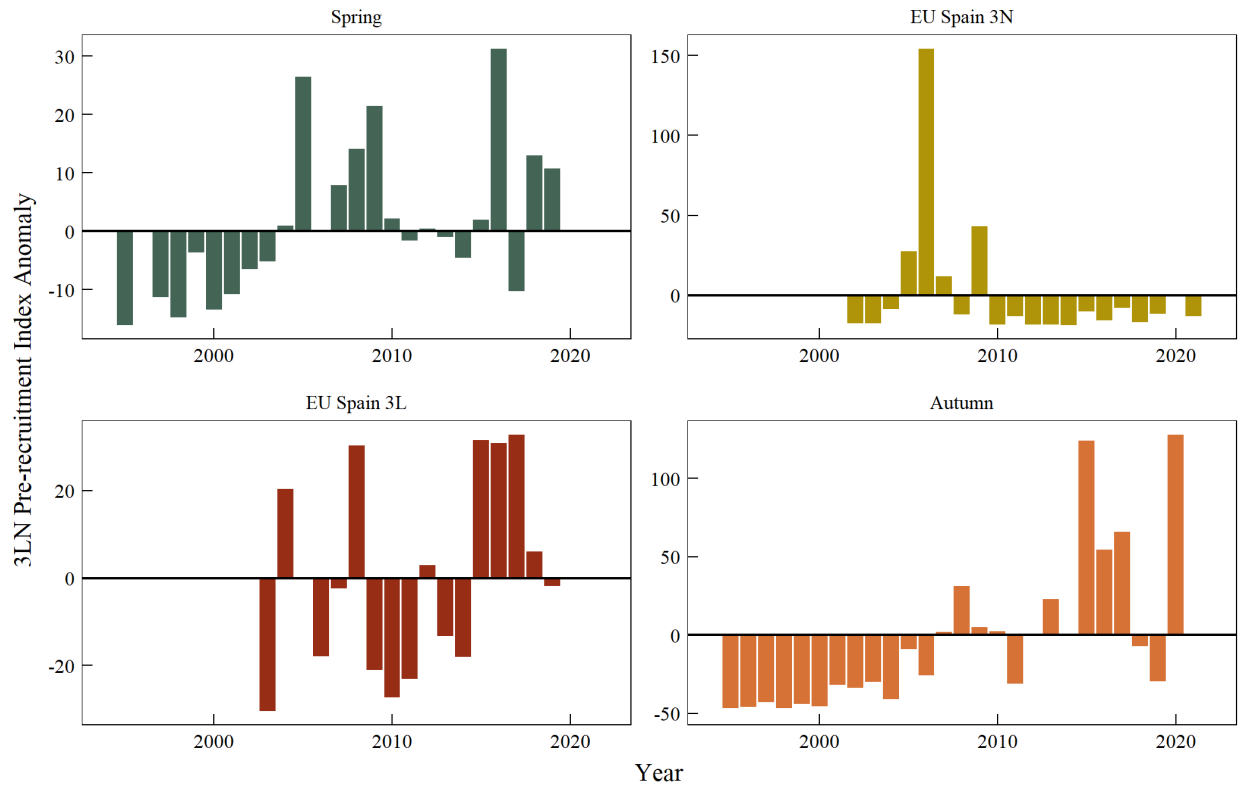


Figure 8. Pre-recruitment index anomalies of 3LN redfish (<15 cm) from Canadian (DFO-NL) spring and autumn and EU-Spain 3L and 3N multispecies surveys.

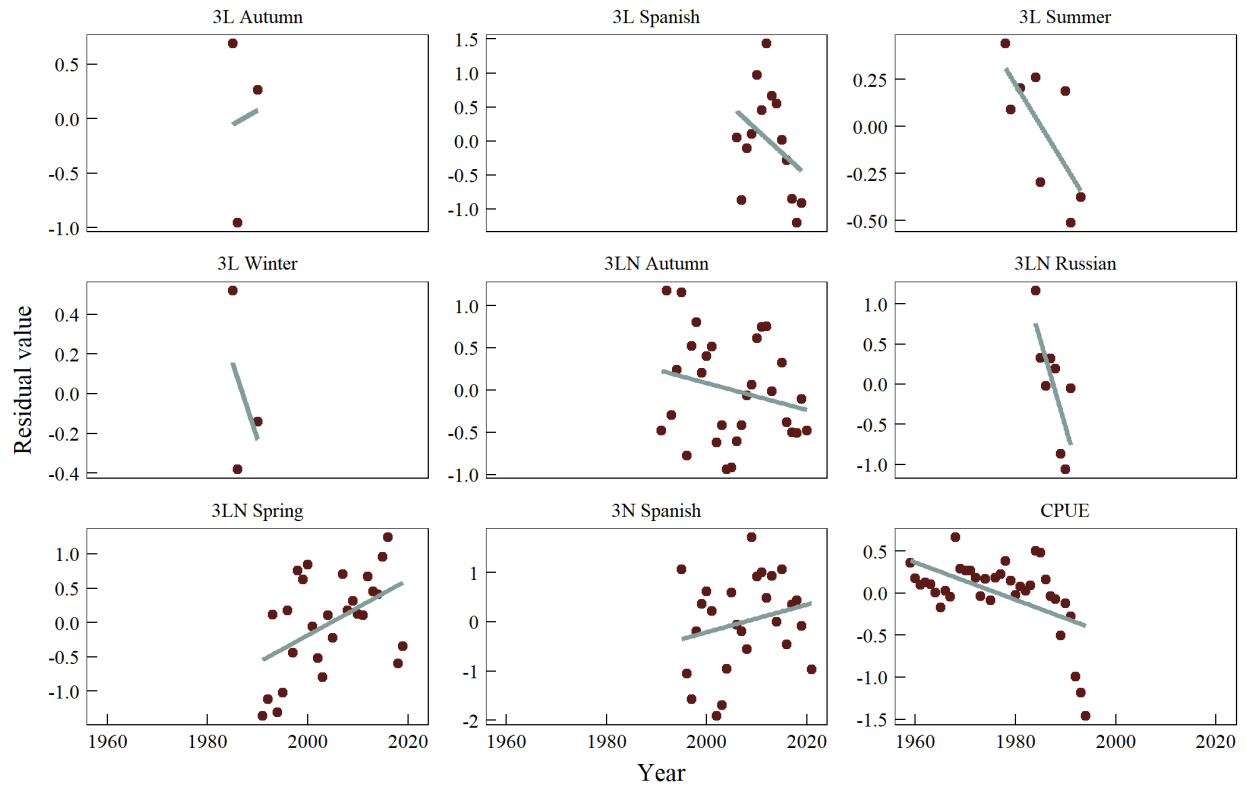


Figure 9. Residual patterns in input survey series of the ASPIC model. Points represent the difference between observed (input) and expected (modelled) values and the line represents a simple linear model showing the potential trend in residuals.

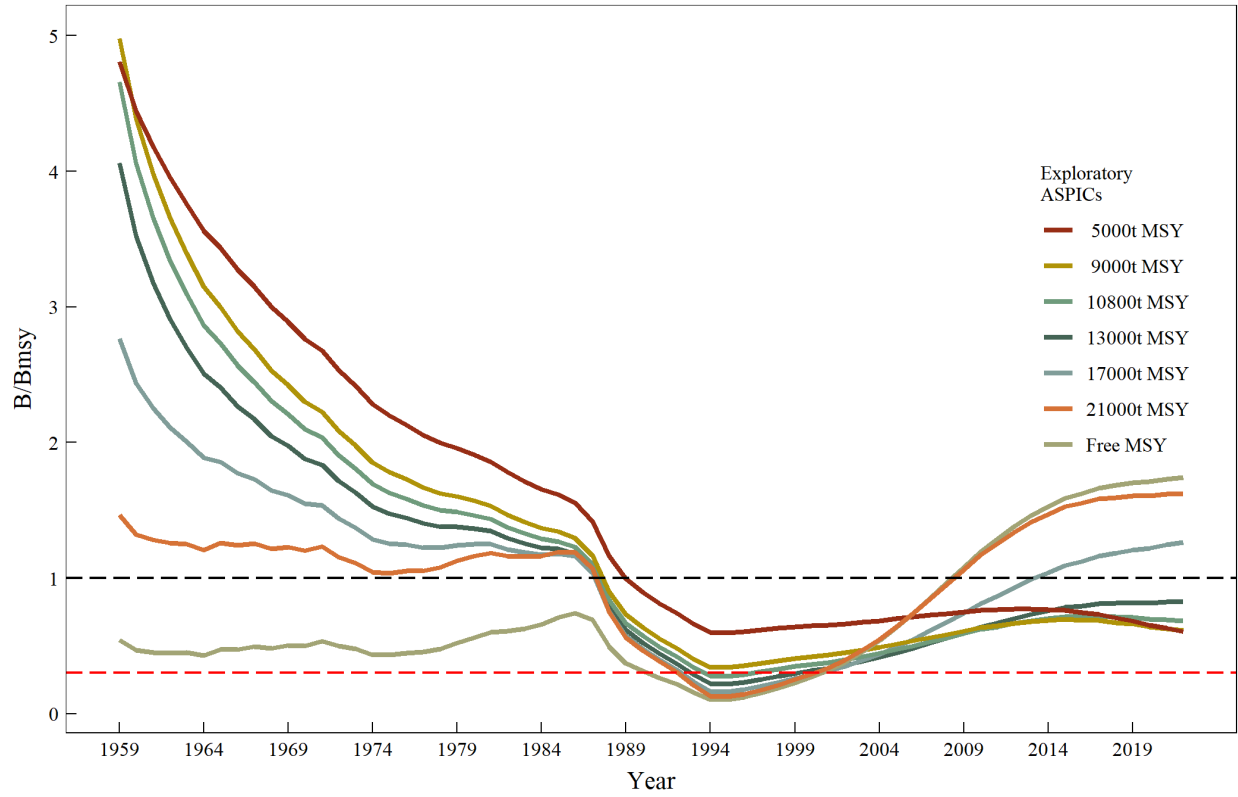


Figure 10. Biomass over B_{msy} trends for model runs of ASPIC with various MSY options. Dashed black line represents $B=B_{msy}$ and dashed red line represents 30% of B_{msy} (former B_{lim}).

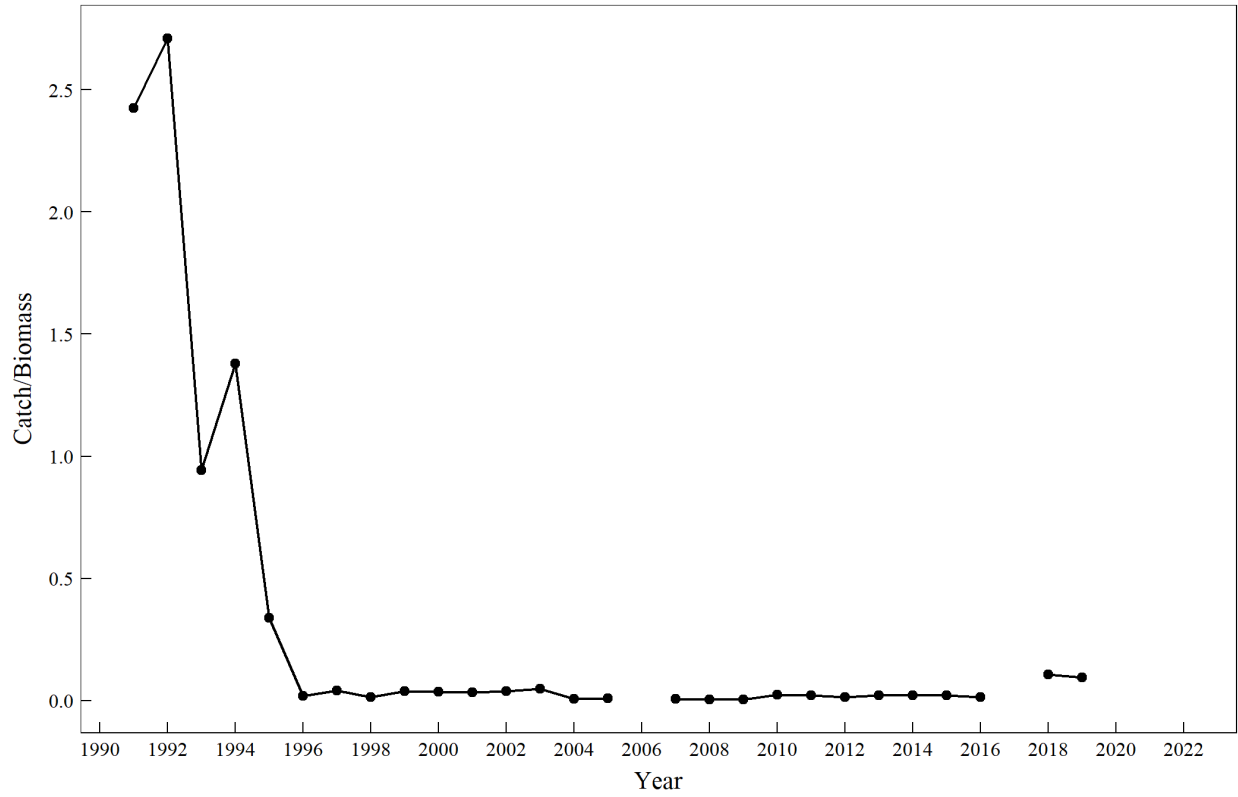


Figure 11. Redfish in Div. 3LN: C/B ratio using commercial catch and Canadian spring survey biomass (1991-2019). No Canadian spring survey data are available in 2020 or 2021.