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Blue grenadier (*Macruronus novaezelandiae*) stock assessment based on data up to 2017 base case

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Contents

Figures

Tables

Acknowledgments

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Executive summary

This document presents the base case for an updated quantitative Tier 1 assessment of blue grenadier (*Macruronus novaezelandiae*) for presentation at the second SERAG meeting in 2018. The last full assessment was conducted during 2013 (Tuck, 2013). Relative to the 2013 assessment, the base case is updated by the inclusion of data to the end of 2017, which entails an additional five years of catch, discard, CPUE, length-composition and conditional age-at-age data and ageing error. This document describes the agreed base case from the September 2018 SERAG meeting and sensitivities to the base case.

The base case specifications agreed by the SlopeRAG in 2013 were generally maintained in the preliminary and the final base case presented here. The main differences are: separating length-composition into onboard- and port- collected components, assigning stage-1 weights to length-compositions by shots (onboard) and trips (port); and using the latest methods for assigning final weights to the various data sources and the extent of variation in recruitment. Differences between the preliminary base case (presented to the SERAG in September 2018) and the final base case include (a) the addition of the FIS abundance data for the non-Spawning area (and not the spawning area index), (b) the removal of discard lengths that were not believed to be representative from three early years and (c) the final assessment does not estimate recruitment for the last three years (instead of the last two years).

The estimated time series of recruitment under the base-case parameter set shows the typical episodic nature of blue grenadier recruitment, with strong year-classes in 1979, the mid-1980s, 1994, and 2003, with relatively low recruitment between these years. However, recent estimated recruitments are more stable than has been observed before. The trajectories of spawning biomass show increases and decreases in spawning biomass as strong cohorts move into and out of the spawning population. Results show reasonably good fits to the length-composition data, implied age compositions, egg survey and acoustic survey. The fit to the discard mass has improved compared to the 2013 assessment result. As has been noted in previous blue grenadier assessments, the fit to the standardized non-spawning catch-rate index is generally poor; the model is unable to fit to the high early catch rates and over-estimates catch rates during the early 2000s.

The estimated virgin female spawning biomass (B_o) from the base case assessment is 53,909t tonnes (SD 7,652t) and the projected 2019 spawning stock biomass will be 122% (SD 25.7%) of virgin female spawning biomass. Sensitivities are provided to test the influence of natural mortality estimation for males, excluding the port data, and removal of the CPUE index and cohort dependent growth, as was requested at the September 2018 SERAG meeting. Standard sensitivities are included to check how well the model fits if key parameters values are varied.

1 Introduction

An integrated analysis model, implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Methot, 2011; Methot and Wetzel, 2013), was applied to the stock of blue grenadier in the Southern and Eastern Scalefish and Shark Fishery (SESSF), with data updated by the inclusion of data up to the end of the 2017 calendar year (length-composition and conditional age-at-length data; age reading-error matrices, standardized catch rate series; landings and discard catch weight) and information from acoustic surveys of spawning biomass (series from 2003-2010, pertaining to total spawning biomass), with an assumption of 2-times turnover on the spawning ground (Russell and Smith, 2006; Punt et al., 2015). The base-case egg survey estimates of female (only) spawning biomass for 1994 and 1995 are included, as is the FIS abundance series from the non-spawning area. The model fits directly to length-composition data (by sex where possible) and conditional age-at-length data by fleet. Retained length-composition data from port and onboard samples are separated (a change from the last assessment following current protocols).

The assessment model presented in 2011 (Tuck, Whitten and Punt 2011; Tuck 2011) was the first for blue grenadier to be implemented using SS. The 2013 assessment updated this assessment using SS-V3.22a (Tuck, 2013). Considerable changes to both the software and the tuning methods have occurred since the last assessment five years ago. As such, changes to key model outputs, such as the estimates of depletion and of the trajectory of spawning biomass, should be expected. The preliminary base case presented to SERAG in September 2018 (Castillo-Jordan and Tuck, 2018) illustrated the changes that have occurred since 2013 through changes to software, assessment practices and new data (bridging). Castillo-Jordan and Tuck (2018) also provided likelihood profiles of natural mortality, steepness and R0. The bridging analysis and likelihood profiles are not repeated here.

The use of SS allows for multiple fishing fleets, and can fit simultaneously to several data sources and types of information. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, is outlined fully in the SS user manual (Methot, 2005; 2011; Methot et al. 2018) and is not reproduced here. This document updates the assessment presented in 2013 and the preliminary assessment presented at SERAG in September 2018 (Castillo-Jordan and Tuck, 2018).

2 The fishery

Blue grenadier are found from New South Wales around southern Australia to Western Australia, including the coast of Tasmania. Blue grenadier is a moderately long-lived species with a maximum age of about 25 years. Age at maturity is approximately 4 years for males and 5 years for females (length-at-50% maturity for females is 57cm and 64cm respectively) based upon 32,000 blue grenadier sampled between February 1999 and October 2001 (Russell and Smith, 2006). There is also evidence that availability to the gear on the spawning ground differs by sex, with a higher proportion of small males being caught than females. This is most likely due to the arrival of males on the spawning ground at a smaller size (and younger age) than females. This was also noted by Russell and Smith (2006) who state that “young males entered the fishery one year earlier than females” and is consistent with information for hoki (the same species) from New Zealand (Annala et al., 2003). Large fish arrive earlier in the spawning season than small fish. Spawning occurs predominantly off western Tasmania in winter (the peak spawning period based upon mean gonad somatic index (GSI) calculated by month was estimated to be between June and August according to Russell and Smith (2006)). There is some evidence that a high proportion of fish remain spawning in September. Variations in spawning period noted by Gunn et al. (1989) may occur due to inter-annual differences in the development of coastal current patterns around Tasmania. Adults disperse following the spawning season and while fish are found throughout the south east region during the non-spawning season, their range is not well defined. Spawning fish have been caught off the east coast of Australia, and larvae from a likely eastern spawning area have been described by Bruce et al. (2001).

Blue grenadier are caught by demersal trawling. The global agreed TAC for the 2017/18 fishing season was 8,810 tonnes. The annual TACs are show in Table 2. There are two defined sub-fisheries: the spawning (Zone 40, months June, July and August) and non-spawning fisheries (all other months and zones).

3 Data

The assessment has been updated since the previous assessment (Tuck, 2013) by including recent length-composition and conditional age-at-length data from the spawning and non-spawning fisheries; updated standardized CPUE series (Sporcic and Haddon, 2018), the total mass landed and discarded, and updated age-reading error matrices. Acoustic estimates of spawning biomass (2003-2010) and estimates of the female spawning biomass in 1994 and 1995 from egg surveys (Bulman et al., 1999) are included, as is the FIS abundance estimates from the non-spawning area. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec), as in previous models.

3.1 Catch data

3.1.1 Landings

The landings from the logbook data were used to apportion catches to the spawning and non-spawning fisheries (Table 1). The logbook landings have been adjusted upwards to match the CDR totals to take account of differences between logbook and landings data (multiple of 1.4 for the non-spawning fishery, based on 40% conversion from headed and gutted to whole, since 1986 and up to and including 1997 (reliable CDR data were available from 1998); 1.2 for the spawning fishery from 1986 up to and including 1996 (when factory vessels entered the spawning fishery) (D. Smith, pers. comm.). As stated by Thomson and He (2001), the factor is lower for the spawning fleet than the non-spawning fleet because some fish in the spawning fishery, landed headed and gutted, were recorded as being landed whole. These factors were chosen by the Blue Grenadier Assessment Group (BGAG) (Chesson and Staples (1995), as cited by Punt (1998)). The adjusted logbook catches were then scaled up to the SEF2 data (CDR). As historical CDR data were only available from 1992, the average scaling factor from 1992 to 1996 (1.07) was used to scale the data for years between 1986 and 1991. Note that in years 2008 to 2013 logbook data were greater than landings from the CDR. In these cases, the tonnage from the CDR was used as the total catch (AFMA, pers. comm. 2011). Table 2 lists the annual catches used in the assessment and the annual TAC. The annual logbook catches by sub-fishery and the adjustments made to determine the catches used in the assessment are shown in Table 1.

3.1.2 Discards

Discard rates were estimated from on-board data which gives the weight of the retained and discarded component of those shots that were monitored (Thomson and Klaer, 2011, Burch et al 2018). The discard values from 1995 to 2002 are based on estimates calculated from ISMP data by MAFRI and reported in He et al (1999) and Tuck, Smith and Talman (2004). The MAFRI estimates of discards were made accounting for differences in sampling and discard rates according to the ISMP zones. As agreed by Slope RAG (2011), since 2003 discard rates are estimated using the methods described in Thomson and Klaer (2011). The Tier 1 discard estimates have been updated in 2018 to more closely match the discard calculations in Bergh et al (2008). These estimates use ratios of total discards to (retained + discard) catch on a per shot basis, rather than aggregated across a whole strata, which are then weighted up according to CDR landings within zone and season (N. Klaer, pers. comm.). Information in support of the historical values was not able to be obtained and further exploration of the methods and data used to estimate these values should be encouraged. The discard data are provided in Table 2. The discard data were assumed to have standard error (on the log-scale) of 0.3.

Discard rates for Tier 1 assessments are required by fishing fleet. This means that the discard estimates for TAC purposes used for Tier 3 and 4 assessments which are provided in the discard report (Burch et al, 2018) cannot be used in Tier 1 assessments. The discards from Burch et al. (2018) are produced using a set of rules to determine, for the entire quota fishery, whether sufficient data are available to make an annual fishery wide discard estimate. The discard rates calculated for and input to Tier 1 stock assessments are used to fit retention selectivity curves, so individual year values are not greatly influential on model estimated discard rates.

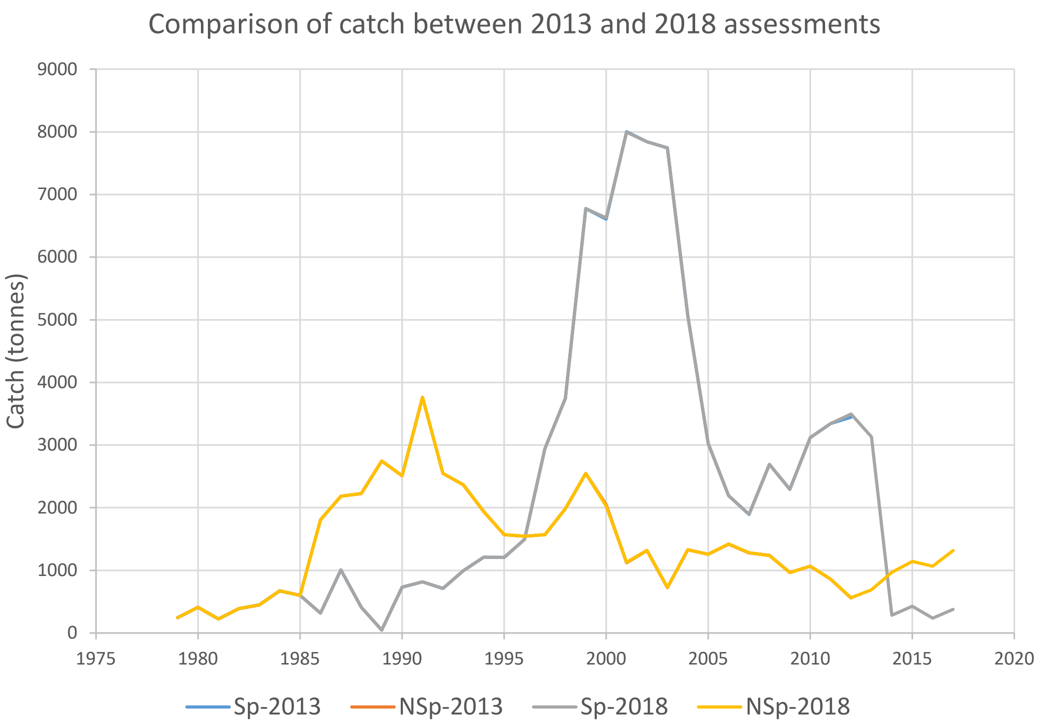


Figure 1. A comparison of total annual catches from the 2013 base case assessment and the updated catch used in the 2018 assessment for the spawning (Sp) and non-spawning (NSp) fisheries .

Table 1. Logbook and CDR landings for the spawning and non-spawning sub-fisheries by calendar year and adjustments made to account for logbooks being less than landings and incorrect reporting process code. Shaded CDR are historical landings values. [1] average of CDR/logbook ratio from 1992 to 1996.

Year	Logbook		CDR	H&G Multiplier		Adjusted Logbook			CDR /	Catch for assessment	
	Spawning	Non-		Spawning	Non-spawning	Spawning	Non-spawning	Total	logbook	Spawning	Non-spawning
1979	245	245		1	1	245	245	490	1.00	245	245
1980	410	410		1	1	410	410	820	1.00	410	410
1981	225	225		1	1	225	225	450	1.00	225	225
1982	390	390		1	1	390	390	780	1.00	390	390
1983	450	450		1	1	450	450	900	1.00	450	450
1984	675	675		1	1	675	675	1350	1.00	675	675
1985	600	600		1	1	600	600	1200	1.00	600	600
1986	246	1204		1.2	1.4	295	1685	1981	1.07	317	1806
1987	782	1455		1.2	1.4	939	2036	2975	1.07	1006	2183
1988	319	1485		1.2	1.4	383	2079	2461	1.07	410	2228
1989	36	1829		1.2	1.4	43	2560	2604	1.07	46	2745
1990	570	1671		1.2	1.4	684	2340	3023	1.07	733	2508
1991	637	2508		1.2	1.4	764	3511	4275	1.07[1]	819	3764
1992	509	1565	3259	1.2	1.4	610	2191	2802	1.16	710	2549
1993	812	1659	3362	1.2	1.4	975	2323	3298	1.02	994	2368
1994	974	1338	3151	1.2	1.4	1169	1873	3042	1.04	1211	1940
1995	911	1017	2775	1.2	1.4	1093	1424	2517	1.10	1205	1570
1996	1200	1061	3040	1.2	1.4	1439	1485	2925	1.04	1496	1544
1997	2623	997	4516	1	1.4	2623	1396	4019	1.12	2947	1569
1998	2739	1452	5733	1	1	2739	1452	4191	1.37	3746	1986
1999	5460	2054	9324	1	1	5460	2054	7514	1.24	6775	2549
2000	5735	1755	8655	1	1	5735	1755	7490	1.16	6627	2028
2001	7309	1032	9124	1	1	7309	1032	8340	1.09	7995	1129
2002	6825	1148	9161	1	1	6825	1148	7973	1.15	7842	1319
2003	7239	679	8471	1	1	7239	679	7918	1.07	7745	726
2004	4647	1219	6392	1	1	4647	1219	5865	1.09	5064	1328
2005	2880	1199	4283	1	1	2880	1199	4079	1.05	3024	1259
2006	2058	1332	3614	1	1	2058	1332	3390	1.07	2193	1420
2007	1815	1228	3176	1	1	1815	1228	3044	1.04	1894	1282
2008	2838	1304	3931	1	1	2838	1304	4141	0.95	2693	1237
2009	2723	1145	3259	1	1	2723	1145	3868	0.84	2295	965
2010	3384	1158	4185	1	1	3384	1158	4541	0.92	3118	1067
2011	3554	914	4201	1	1	3554	914	4467	0.94	3342	859
2012	3838	620	4060	1	1	3838	620	4458	0.91	3495	565

2013	3443	759	3821	1	1	3443	759	4201	0.91	3131	690
2014	271	928	1251	1	1	271	928	1200	1.04	283	968
2015	393	1054	1570	1	1	393	1054	1447	1.08	426	1144
2016	216	968	1305	1	1	216	968	1184	1.10	238	1068
2017	354	1237	1693	1	1	354	1237	1591	1.06	376	1316

Table 2. Landed and discarded catches for the spawning and non-spawning sub-fisheries by calendar year. These estimates have been scaled up to the landings data. Standardised CPUE (Sporcic and Haddon, 2018) for the non-spawning sub-fisheries by calendar year are shown, along with the TAC. [1] a voluntary industry reduction to 4,200 t was implemented in 2005. [2] This was a 16 month TAC. [3] The TACs cover the fishing year 1 May to 30 April. In the table below, 2008 refers to 2008/09. [4] This is an estimate of retained catch based on the 2017/2018 TAC and relative split of catch between the spawning and non-spawning fisheries of 2017.

Year	Spawning (t)	Non-spawning (t)	Discards (t)	TAC	CPUE
1979	245	245			
1980	410	410			
1981	225	225			
1982	390	390			
1983	450	450			
1984	675	675			
1985	600	600			
1986	317	1807			1.5611
1987	1006	2183			1.994
1988	410	2228			2.1709
1989	46	2745			2.1776
1990	733	2508			2.166
1991	819	3764			1.545
1992	710	2549			1.252
1993	994	2368			0.9511
1994	1211	1940		10000	0.8586
1995	1205	1570	80	10000	0.5937
1996	1496	1544	975	10000	0.5361
1997	2947	1569	3716	10000	0.5574
1998	3746	1986	1329	10000	0.901
1999	6775	2549	123	10000	0.9466
2000	6627	2028	69	10000	0.6815
2001	7995	1129	10	10000	0.3927
2002	7842	1319	2	10000	0.391
2003	7745	726	8	9000	0.3258
2004	5064	1328	34	7000	0.5474
2005	3024	1259	294	5000[1]	0.6594
2006	2193	1420	175	3730	0.8803
2007	1894	1282	72	4113[2]	0.782
2008	2693	1237	18	4368[3]	0.8643
2009	2295	965	57	4700[3]	0.8004
2010	3118	1067	13	4700[3]	0.7975
2011	3342	859	169	4700[3]	0.6511
2012	3495	565	277	5208[3]	0.5187
2013	3131	690	469	5208[3]	0.9243
2014	283	968	680	6800[3]	1.1316
2015	426	1144	1032	8796[3]	1.2303
2016	238	1068	512	8810[3]	1.0448
2017	376	1316	718	8765[3]	1.1656
2018	378[4]	1323[4]		8810[3]	

3.2 Catch rates

Sporcic and Haddon (2018) provide the updated standardised catch rate series for the non-spawning fishery of blue grenadier (Table 2; Figure 2). The catch rate generally follows the fluctuations of stock size driven by large, but sporadic, recruitments. The standard deviation of log-CPUE is assumed to be 0.25 (value equal to the standard error from a loess fit), but an extra variance component is estimated for the CPUE index during the tuning process.

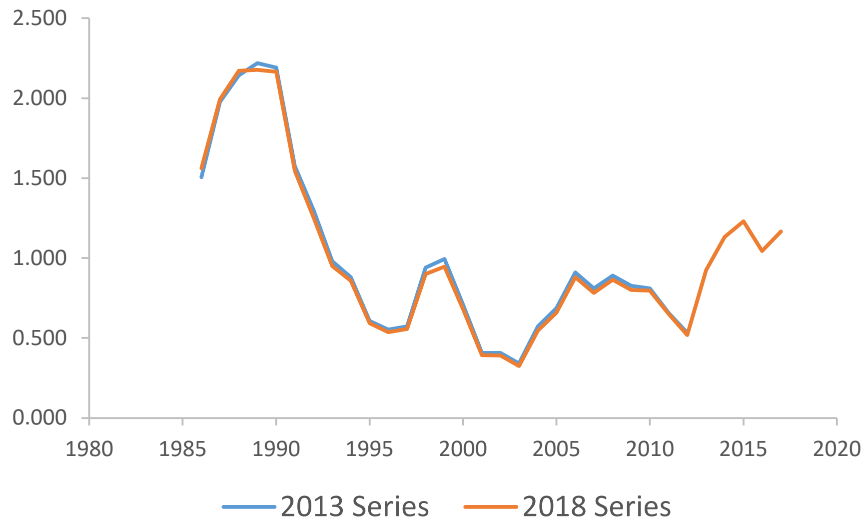


Figure 2. A comparison of the annual catch rates series for blue grenadier between the 2013 assessment (2013 Series) and 2018 (2018 Series).

3.3 Length-composition and age data

Length and age data are included in the assessment as length-composition data and conditional age-at-length data by fleet and sex (the latter when available). Age-composition data are included in diagnostic plots, but are not used directly when estimating the parameters of the population dynamics model. On-board and port length-compositions, when available, are used separately. This is a change in data protocol from the last assessment, where lengths from port and onboard measurements were combined. Prior to 2013, only port samples had been used to create the length-compositions. Plots of the observed length and age data are shown in later figures, with the corresponding model predicted values.

There had to be at least 100 measured fish for a retained and/or discard onboard and port length-composition data to be included in the assessment. For onboard samples, numbers of shots were used as the sampling unit (i.e. the stage-1 weights; Francis, 2011), with a cap of 200. For port samples, numbers of trips were used as the sampling unit, with a cap of 100. The number of fish measured is not used as the sample size because the appropriate sample size for length-composition data is probably more closely related to the number of shots (onboard) or trips (port) sampled, rather than the number of fish measured (Table 3).

Table 3. The years for which length data were available for the sub-fleets (spawning onboard = 1; spawning port = 3; non-spawning onboard = 2; non-spawning port = 4), sex (0 = no gender specified; female =1; male =2), partition (part: discard = 1; retained = 2). N is the number of shots (onboard) or trips (port). Red length data were excluded due to low sample sizes. [1] the average number of fish from years 1984 and 1988. [2] as no shot data were available, these estimates were based upon the average number of fish per shot for un-sexed fish for Fleet 1 (84.4). [3] the average number of fish from years 1984 and 1987-89. [4] as no shot data were available, these estimates were based upon the average number of fish per shot for Fleet 2 (40.7). [5] the average of 1980s samples, as no fish numbers or shot data were available. [6] these years of discard lengths were removed due to spurious numbers of large fish.

Year	Nfish	Fleet	Sex	Part	N
1984	1,046	1	0	2	12[2]
1985	1,090[1]	1	0	2	12[2]
1988	1,133	1	0	2	12[2]
1998	1,948	1	0	2	29
1999	4,147	1	1	2	49
1999	5,929	1	2	2	70
2000	2,672	1	1	2	32
2000	2,956	1	2	2	35
2001	3,620	1	1	2	43
2001	4,256	1	2	2	50
2002	760	1	0	2	3
2003	2,700	1	1	2	32
2003	2,853	1	2	2	34
2004	1,307	1	1	2	15
2004	1,370	1	2	2	16
2005	198	1	1	2	2
2005	141	1	2	2	2
2006	3,184	1	1	2	38
2006	3,081	1	2	2	36
2007	2,957	1	1	2	35
2007	1,897	1	2	2	22
2008	3,073	1	1	2	36
2008	2,177	1	2	2	26
2009	3,868	1	1	2	46
2009	3,374	1	2	2	40
2010	2,488	1	1	2	29
2010	1,453	1	2	2	17
2011	4,207	1	1	2	50
2011	3,266	1	2	2	39
2012	3,939	1	1	2	47
2012	3,060	1	2	2	36
2013	6,371	1	0	2	76
2014	927	1	0	2	27
2015	1,861	1	0	2	19
2017	1,020	1	0	2	16

Year	Nfish	Fleet	Sex	Part	N
1993[6]	207	2	0	1	2
1995[6]	2,216	2	0	1	21
1996[6]	5,225	2	0	1	73
1997	6,504	2	0	1	159
1998	2,212	2	0	1	97
1999	940	2	0	1	45
2000	132	2	0	1	4
2004	1,077	2	0	1	21
2005	5,139	2	0	1	51
2006	1,225	2	0	1	81
2007	16	2	0	1	3
2008	106	2	0	1	17
2009	97	2	0	1	10
2010	16	2	0	1	2
2011	792	2	0	1	47
2012	1,261	2	0	1	80
2013	1,450	2	0	1	119
2014	864	2	0	1	57
2015	500	2	0	1	51
2016	1,323	2	0	1	100
2017	531	2	0	1	12
1981	NA	2	0	2	100[5]
1982	NA	2	0	2	100[5]
1984	3,035	2	0	2	75[4]
1985	4,046[3]	2	0	2	99[4]
1987	4,063	2	0	2	100[4]
1988	6,660	2	0	2	164[4]
1989	2,424	2	0	2	60[4]
1996	829	2	0	2	40
1997	2,501	2	0	2	128
1998	7,771	2	0	2	146
1999	8,768	2	0	2	117
2000	8,036	2	0	2	65
2001	6,293	2	0	2	48
2002	5,325	2	0	2	43
2003	2,558	2	0	2	27
2004	5,499	2	0	2	46
2005	5,698	2	0	2	62
2006	6,098	2	0	2	117
2007	219	2	0	2	14
2008	575	2	0	2	29
2009	1,944	2	0	2	80
2010	1,801	2	0	2	45
2011	1,643	2	0	2	84
2012	1,707	2	0	2	85
2013	1,785	2	0	2	125
2014	1,358	2	0	2	72
2015	1,525	2	0	2	79
2016	2,822	2	0	2	121
2017	951	2	0	2	17

Year	Nfish	Fleet	Sex	Part	N
1992	774	3	0	2	6
1994	1,038	3	0	2	9
1995	465	3	0	2	4
1996	927	3	0	2	7
1997	851	3	0	2	7
1998	1,648	3	0	2	9
1999	1,079	3	0	2	9
2000	339	3	0	2	2
2014	82	3	0	2	1
2016	74	3	0	2	1
1991	927	4	0	2	10
1992	3,832	4	0	2	31
1993	1,487	4	0	2	10
1994	8,604	4	0	2	78
1995	6,938	4	0	2	61
1996	5,397	4	0	2	51
1997	11,191	4	0	2	85
1998	16,234	4	0	2	100
1999	13,286	4	0	2	100
2000	13,613	4	0	2	91
2001	11,959	4	0	2	87
2002	9,416	4	0	2	77
2003	5,023	4	0	2	37
2004	4,392	4	0	2	41
2005	6,310	4	0	2	48
2006	2,874	4	0	2	30
2007	809	4	0	2	7
2008	1,320	4	0	2	11
2009	1,035	4	0	2	18
2010	698	4	0	2	25
2011	1,678	4	0	2	54
2012	999	4	0	2	29
2013	1,457	4	0	2	35
2014	1,611	4	0	2	30
2015	1,799	4	0	2	24
2016	1,790	4	0	2	27
2017	1,808	4	0	2	27

3.4 Acoustic survey estimates

Estimates of spawning biomass for 2003-2010 are provided in Ryan and Kloser (2012). There are no acoustic estimates since 2010. Table 4 shows the estimates of spawning biomass with their corresponding CV's used in the assessment. Sampling cv's less than 0.3 were increased to 0.3 to account for process error. Low sampling cvs (of 0.19 for example) were considered too low for an acoustic survey and a minimum of 0.3 should be used to reflect the total uncertainty (D. Smith, pers comm., Tuck et al., 2004; Slope RAG 2011). Of 22 acoustic cv's used for hoki in New Zealand, none are lower than 0.3 (Francis, 2009). It is assumed that the spawning ground experiences a turnover rate of 2 (i.e. for the model applied here, the spawning biomass estimates are doubled) (Russell and

Smith, 2006; Punt et al., 2015). The acoustic survey selectivity is matched to the maturity ogive, as it is assumed the acoustic survey observes mature fish on the spawning ground.

Table 4. The estimated biomass (tonnes) of blue grenadier on the spawning grounds in years 2003 to 2010 (Ryan and Kloser, 2012).

	2003	2004	2005	2006	2007	2008	2009	2010
biomass (t)	24,690	16,295	18,852	42,882	56,330	24,450	24,787	20,622
c.v. for assessment model	0.30	0.46	0.30	0.30	0.52	0.30	1	0.33
Sampling cv	0.16	0.46	0.14	0.14	0.52	0.22	1	0.33

3.5 Egg survey estimates

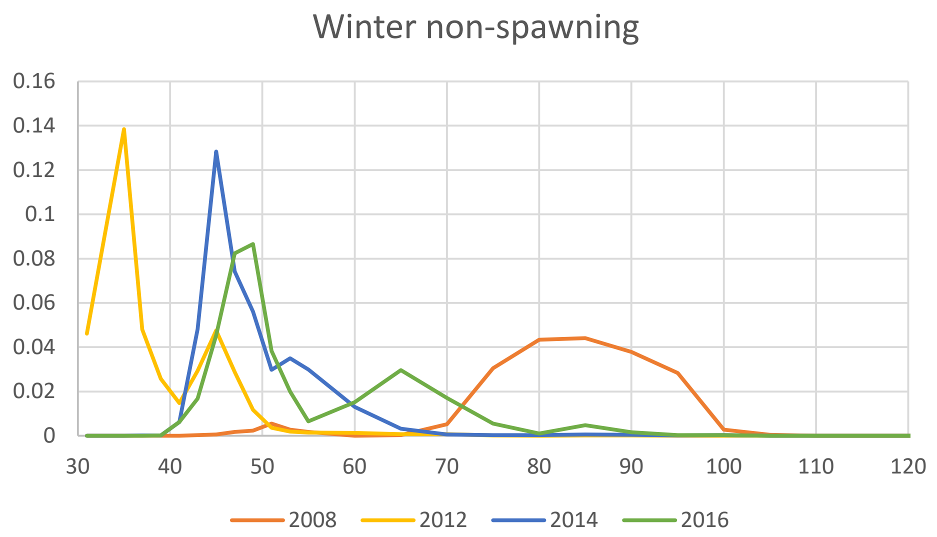
Egg survey estimates of female spawning biomass are available for 1994 and 1995 (Bulman et al., 1999). The egg-estimates (CV) for 1994 and 1995 respectively are: 57,772 (0.18) and 41,409 (0.29) tonnes. For the analysis considered here, the base-case egg estimates were used.

3.6 The Fishery Independent Survey (FIS)

Abundance indices for blue grenadier for the FIS surveys conducted between 2008 and 2016 are provided in Table 5 (Knuckey et al., 2017; J. Day, pers comm.). The length-composition data from the FIS are shown in Figure 3. In the base case the FIS selectivity is mirrored to the non-spawning trawl fleet selectivity. Ideally the lengths would be used to independently estimate a FIS selectivity due to potential differences between survey selectivity and the non-spawning fleet selectivity. However, until there is an agreed set of weighted lengths, the length data have not been included in the base case model, and should be considered as a sensitivity in subsequent reports.

Table 5. FIS-derived abundance indices for blue grenadier with corresponding coefficient of variation (CV).

	2008	2010	2012	2014	2016
Blue grenadier (all)	15.83	3.38	10.75	19.65	58.20
CV	0.30	0.28	0.23	0.21	0.23
Spawning	65.06	17.97	15.12	44.52	211.29
CV	0.59	0.35	0.34	0.32	0.26
Non-spawning	30.26	9.25	10.57	50.26	10.39
CV	0.57	2.31	0.93	2.19	0.34



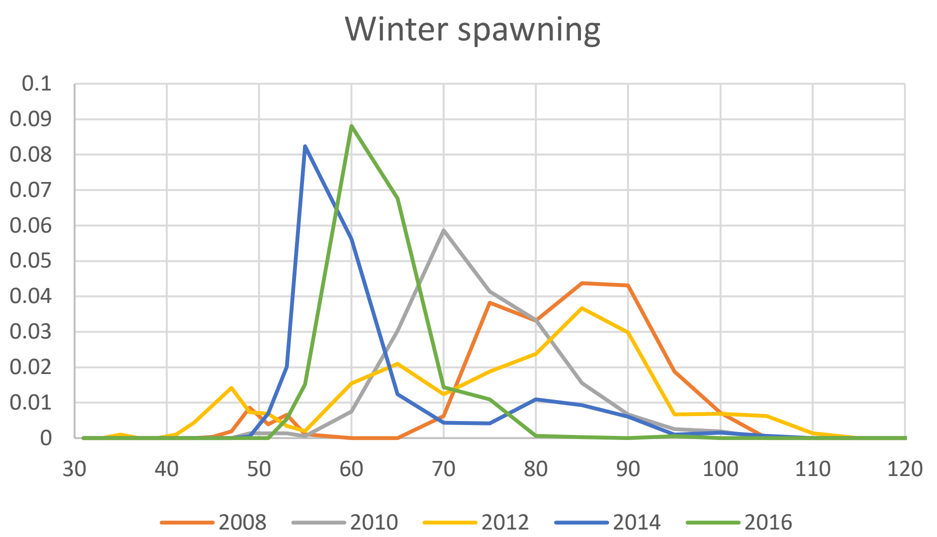


Figure 3. The length-compositions for blue grenadier from the FIS from the winter non-spawning (top) and spawning area (bottom) surveys.

3.7 Biological parameters and stock structure assumptions

The assessment assumes that the proportion of females that spawn in each year is 0.84 and a length at 50% maturity of 63.7cm for females (Russel and Smith, 2006). The female maturity ogive is shown in Figure 4.

The length weight-relationship for males and females was estimated from spawning fishery data over years 1999 to 2008 (Figure 4). Natural mortality for females is estimated when fitting the model and male natural mortality is assumed to be 20% greater than the value for females based upon assumptions made for hoki in New Zealand (McAllister et al., 1994). A sensitivity is conducted where male natural mortality is estimated, in line with current practice for hoki.

Francis (2009) reviews the values of steepness used in New Zealand hoki assessments, where a value of *h*=0.9 had been used since 1994. This value of steepness was derived from work of Punt et al. (1994) using 45 stocks of gadiform species (0.9 is the median). Following an analysis of the profile likelihood, the effect of steepness on the 2007 assessment and additional information of Myers et al. (1999; 2002) beyond that used by Punt et al. (1994), Francis (2009) concludes that steepness should be reduced to *h*=0.75. This value of steepness was assumed in the previous blue grenadier assessments in 2011 and 2013 (Tuck, 2011; 2013) and in this assessment.

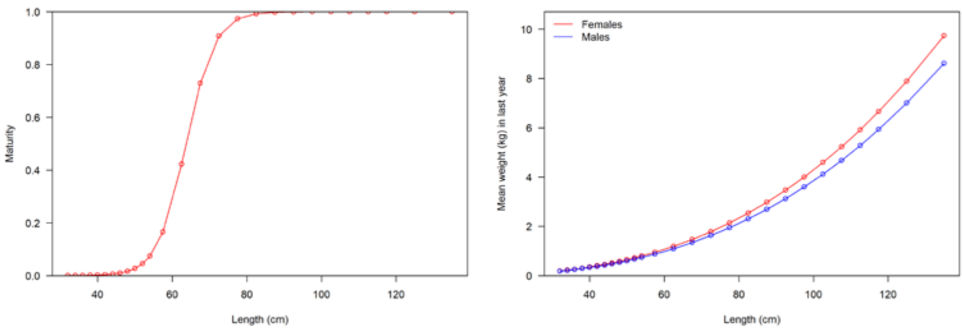


Figure 4. The maturity ogive by length for female blue grenadier (parameters from Russell and Smith (2006)) and the length-weight relationship for males and females.

3.8 Age-reading error

Updated standard deviations for aging error by reader (A and B) have been estimated, producing the age-reading error matrix of Table 6 (A. Punt, pers. comm.). Reader A applied to years 1991-93 and 2007-17, and reader B to years 1984-90 and 1994-2006.

Table 6. The standard deviation of age reading error.

	St Dev	
Age	A	B
0	0.223	0.282
1	0.223	0.282
2	0.266	0.299
3	0.301	0.318
4	0.331	0.338
5	0.357	0.359
6	0.378	0.383
7	0.396	0.408
8	0.412	0.435
9	0.424	0.464
10	0.435	0.495
11	0.444	0.529
12	0.452	0.565
13	0.459	0.604
14	0.464	0.646
15	0.469	0.692
16	0.473	0.741
17	0.476	0.793
18	0.479	0.850
19	0.481	0.911
20	0.483	0.976

4 Analytic approach

The 2018 base case assessment of blue grenadier uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.30.12.00-safe, NOAA 2018). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment relationship (*h*), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, acoustic, FIS and egg surveys, discard mass, discard and retained catch length-compositions, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

This assessment follows the agreements made at the 2013 meetings of Slope RAG, and the 2018 meeting of SERAG. These were: include gender-specific selectivity for the spawning fishery, estimate natural mortality for females, use historical discard tonnages estimated by MAFRI, include cohort-dependent growth, set steepness at 0.75, use the non-spawning area of FIS abundances estimates, and separate port and onboard lengths.

The base–case model includes the following key features:

(a) Two sub-fisheries are included in the model – the spawning sub-fishery that operates during winter (June – August inclusive) off western Tasmania (zone 40), and the non-spawning sub-fishery that operates during other times of the year and in other areas throughout the year.
(b) The selectivity pattern was assumed to be length-specific, logistic and time-invariant for the spawning fleet and dome-shaped for the non-spawning fleet. The parameters of the selectivity function for each fleet were estimated within the assessment.
(c) The inclusion of the FIS is considered for the first time for the non-spawning area, and the selectivity mirrors the corresponding non-spawning fleet (Fleet 2).
(d) Blue grenadier consists of a single stock within the area of the fishery.
(e) The model accounts for males and females separately (growth, natural mortality, age at first breeding).
(f) The population was at its unfished biomass with the corresponding equilibrium (unfished) age-structure at the start of 1960.
(g) The CVs of the CPUE indices were initially set at a value equal to the standard error from a loess fit (0.25; Sporcic and Haddon, 2018), before being re-tuned to the model-estimated standard errors within SS. The acoustic estimates were tuned through the estimation of an extra variance component that is added to the model input standard errors. This is done within SS.
(h) Discard tonnage was estimated through the assignment of a retention function for the non-spawning fleet. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. In addition, the discard length data from 1993, 1995 and 1996 were removed for the 2018 base case as recommended by SERAG (September, 2018) due to the existence of unusually large fish in the length distribution which is likely to be misreporting.

(i) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for female M is estimated within the assessment. Following previous assessments, male natural mortality is assumed be 20% greater than that of females. A sensitivity was considered where both male and female M are estimated.
(j) Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the base-case analysis is set to 0.75. Deviations from the average recruitment at a given spawning biomass (recruitment residuals) are estimated for 1974 to 2014. Deviations are not estimated before 1974 or after 2014 because there are insufficient data to permit reliable estimation of recruitment residuals outside of this time period.
(k) The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is set to 1.0, reflecting the large variation in recruitment observed for blue grenadier. The magnitude of bias-correction depends on the precision of the estimate of recruitment and time-dependent bias-correction factors were estimated following the approach of Taylor and Methot (2011).
(l) The population plus-group is modelled at age 20 years. The maximum age for age observations was 15 years, reflecting that used in previous assessments.
(m) Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with the parameters of the growth function being estimated separately for females and males inside the assessment model. Growth is also assumed to vary through time and to be cohort (year class) specific. Evidence for time-varying and cohort specific growth in blue grenadier has been accumulating over several decades (see Punt and Smith 2001; Whitten et al., 2013). The 2018 base-case model treats conditional age-at-length information as data (i.e. to incorporate error), and predicts the expected length-at-age for each year. This is achieved by estimating the parameters of a von Bertalanffy growth function where the expected annual growth increment is based on the von Bertalanffy growth function but with a growth rate parameter that is determined by an expected value and a cohort-specific deviation. Cohort-specific deviations from average growth are estimated in the base case model for year classes 1978 to 2014.
(n) Retained and discarded onboard length sample sizes were capped at 200 and a minimum of 100 fish measured was required for length-composition data to be included in the assessment. For port samples, numbers of trips were used as the sampling unit, with a cap of 100. The number of fish measured is not used as the sample size because the appropriate sample size for length-composition data is probably more closely related to the number of shots (onboard) or trips (port) sampled, rather than the number of fish measured (Table 3).

The values assumed for some of the parameters of the preliminary base case model are shown in Table 7.

Table 7. Parameter values assumed for some of the non-estimated parameters of the base-case model (BC).

Parameter	Description	BC
M_f	Natural mortality for females	Estimated
M_m	Natural mortality for males	1.2* M_f
σ_r	Initial CV for the recruitment residuals	1.0
σ_g	Input standard deviation for the cohort growth deviations	0.1
h	“steepness” of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	15 years
μ	fraction of mature population that spawn each year	0.84
aa	Female allometric length-weight equations	0.01502 g^{-1}.cm
bb	Female allometric length-weight equations	2.728
aa	Male allometric length-weight equations	0.0168 g^{-1}.cm
bb	Male allometric length-weight equations	2.680
l_m	Female length at 50% maturity	63.7cm
l_s	Parameter defining the slope of the maturity ogive	-0.261

4.1.1 Tuning method

Iterative rescaling (reweighting) of input CVs or input sample sizes is a repeatable method to ensure that the expected variation of the different data streams is comparable to what is input (Pacific Fishery Management Council, 2018). Sampling standard deviations/ CVs and stage-1 effective sample sizes for most of the data (CPUE, survey indices, composition data) used in fisheries assessments underestimate their true error by only reflecting measurement or estimation error and not including process (or model) error.

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated within the model. In SS3.30 there is an automatic adjustment made to survey CVs (CPUE). The steps are:

1. set the standard error for the log of relative abundance indices (CPUE, acoustic abundance survey, or FIS) to their estimated standard errors for each survey or for CPUE (and FIS values) to the standard deviation of a loess curve fitted to the logs of the original data (which will provide a more realistic estimate compared to that obtained from the original statistical analysis). SS3.30 then re-balances the relative abundance variances appropriately.
2. The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is set to 1.0, reflecting the large variation in recruitment observed for blue grenadier. The magnitude of bias-correction depends on the precision of the estimate of recruitment and time-dependent bias-correction factors were estimated following the approach of Taylor and Methot (2011).

An automated tuning procedure was used for the remaining adjustments. For the conditional age-at-length and length-composition data:

3. multiply the stage-1 sample sizes for for the conditional age-at-length data by the sample size multipliers using the approach of Punt (2017).

4. similarly multiply the initial samples sizes by the sample size multipliers for the length-composition data using the ‘Francis method’ (Francis, 2011).
5. repeat steps 2 and 3, until all are converged and stable (proposed changes are < 1 – 2%).

This procedure may change in the future after further investigations, but this approach constitutes current best practice.

5 Calculating the RBC

The SESSF Harvest Strategy Framework (HSF) was developed during 2005 (Smith et al., 2008) and has been used as a basis for providing advice on TACs in the SESSF quota management system for fishing years 2006–2018. The HSF uses harvest control rules to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system. Each stock is assigned to one of five Tier levels depending on the basis used for assessing stock status or exploitation level for that stock. Blue grenadier is assessed as a Tier 1 stock as it has an agreed quantitative stock assessment.

The Tier 1 harvest control rule specifies a target and a limit biomass reference point, as well as a target fishing mortality rate. Since 2005 various values have been used for the target and the breakpoint in the rule. Currently, the 20:40:40 (Blim:Bmsy:Ftarg) form of the rule will be used up to where fishing mortality reaches F48. Once this point is reached, the fishing mortality is set at F48. Day (2008) has determined that for most SESSF stocks where the proxy values of B40 and B48 are used for BMSY and BMEY this form of the rule is equivalent to a 20:35:48 strategy.

This document reports RBCs calculated under the 20:35:48 strategy.

6 Sensitivity tests and alternative models

A number of tests were used to examine the sensitivity of the results of the model to some of the assumptions and data inputs:

1. Estimation of *M* for males.
2. Exclusion of the non-spawning CPUE series.
3. Exclusion of cohort dependent growth.
4. Exclusion of the port length data.
5. Exclusion of the FIS abundance series
6. h = 0.9 (0.75 in the base case)
7. $M = 1.2\ M_{est}\ yr^{-1}$, where M_{est} is the estimated value for female natural mortality (0.174) in the base case
8. $M = 0.8\ M_{est}\ yr^{-1}$
9. Double and halve the weighting on the length composition data.
10. Double and halve the weighting on the age-at-length data.
11. $\sigma_r = 0.8$
12. $\sigma_r = 1.2$

The results of the sensitivity tests are summarized by the following quantities:

1. SB_0 the average equilibrium female spawning biomass.
2. SB_{2019} the female spawning biomass at the start of 2019.
3. SB_{2019}/SB_0 the depletion level at the start of 2019, i.e. the 2019 spawning biomass expressed as a fraction of the unexploited spawning biomass.
4. *2019 RBC* - the 2019 RBC, calculated using the 20:35:48 harvest rule.
5. *Long-term RBC* - the long-term RBC calculated using the 20:35:48 harvest rule.

7 Results and discussion

7.1 The base case stock assessment

7.1.1 Parameter estimates

Figure A.2 shows how the expected mean length-at-age values change over time for the base case model. The ridges reflect the impact of some cohorts growing faster or slower than average. This figure also shows the expected mean length-at-age values for the end-year of the model. The impact of slower than average growth is visible by the decrease in expected size of 9 and 18 yo fish, corresponding to the larger than average recruitments in years 2003 and 1994 respectively. Natural mortality for females was estimated to be M_f =0.174 and males therefore was M_m =0.204.

The selectivity for the spawning and non-spawning fisheries and the retention function for the non-spawning fishery are shown in Figure A.5. Selectivity is assumed to be time-invariant, sex-specific and logistic for the spawning fleet and dome-shaped for the non-spawning fleet. Note that the estimated female length-specific selectivity for the spawning ground shows an ascending limb that includes much larger fish than the maturity ogive estimated by Russell and Smith (2006), which has an estimate of 50% maturity of 63.7cm. This result implies that, to a large extent, small mature females do not appear to be evident on the spawning ground. Russell and Smith (2006) present length frequencies during their study of blue grenadier reproductive biology showing that very few female fish less than 60cm were caught (also see Figure 4). However those that were caught were included in the study and a proportion of these fish were shown to be mature.

7.1.2 Fits to the data

Figure A.4 shows the model fit to the non-spawning catch rate series. The model fits intersect most of the 95% confidence intervals for the data, indicating that adjustments to the CV for the indices performed as expected. As has been seen in all previous assessment models for blue grenadier, the model is not able to fit the rise in catch rate following the large recruitment of the mid-1990s. The fit to the discard mass is able to replicate the increase in discarding through the late 1990s and mid 2000s, however the magnitude is under-estimated (as has been the case with previous assessments). Alternative models that time-blocked discarding, re-weighting discard CVs and including a discard fleet have all been unsuccessful in improving the fit to the discard and CPUE data. Further consideration should be perhaps be given to the GLM model structure used in the standardisation of CPUE. Fits to the biomass estimates from the acoustic surveys and egg surveys were reasonable. The predicted biomass trajectory intersects all of the 95% confidence intervals.

The model is able to replicate the length composition and implied age-composition data well (Figures A.6 – A.17). Predicted age-compositions are able to track the strong cohorts typical of blue grenadier as they move through both the non-spawning fishery and the spawning fishery. Length composition data are also well estimated by the model.

7.2 Assessment outcomes

The estimated time series of recruitment under the base-case parameter set shows the typical episodic nature of blue grenadier recruitment, with strong year-classes in 1979, the mid-1980s, 1994, 2003, and from 2010 to 2014 (Figure 5). The magnitude of the recruitment of 2010 is consistent with the estimation in the previous assessment (Tuck, 2013) and is well estimated according to the current model results. As with the 2010 recruitment in Tuck (2013), the magnitude of the recent recruitment estimates will be better determined in the next assessment as they move well into the available stock of the fishery.

The trajectories of spawning biomass and spawning biomass relative to the un-exploited level are shown in Figure 5. This shows the increases and decreases in spawning biomass as the strong cohorts move into and out of the spawning population. The estimated virgin female biomass is 53,909 tonnes (compared to 36,815 t in the 2013 assessment). In the 2018 assessment, the estimated spawning biomass in 2019 which is used in the harvest control rule, is approximately 122% *SBo* (compared to 94% *SBo* in the 2013 assessment).

The optimistic outlook from this assessment is largely being driven by the addition of 5 further years of data and the substantial estimates of recruitment since 2010. While a promising sign for the fishery, some caution should be exercised with regard to these recruitment estimates and its implication on future stock status, until clear further indications of its existence (and magnitude) are evident in future years' data. But note that the recruitment estimates do appear to be well estimated (Figure A.3; top right).

For the base case model the 2019 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 13,260t. The long-term retained catch is 4,899t. The retained portion of the RBC for 2019 is estimated to be 12,671t (Table 8).

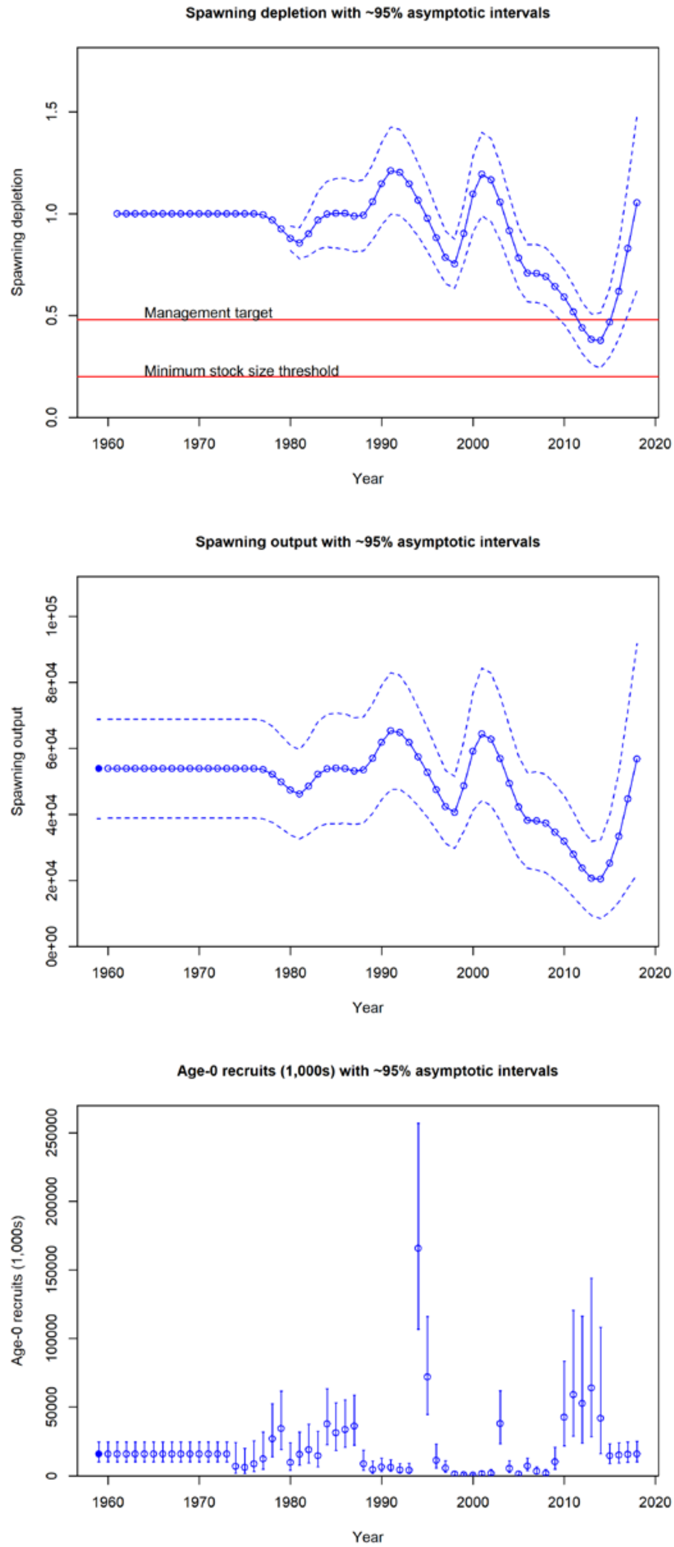


Figure 5. The estimated time-series of relative spawning biomass and annual recruitment for the 2018 base case assessment for blue grenadier.

Table 8. The estimated retained portion of the RBC and the RBC (that includes a model estimate of discarding) for blue grenadier under the base case model.

Year	Retained Catch	RBC
2019	12,671	13,260
2020	11,706	12,238
2021	10,529	11,052
2022	9,422	9,943
2023	8,493	9,012
2024	7,748	8,264
2025	7,159	7,672
2026	6,693	7,202
2027	6,321	6,827
2028	6,023	6,525
2029	5,782	6,281
2030	5,586	6,081
2031	5,425	5,918
2032	5,293	5,783
2033	5,184	5,671
2034	5,093	5,578
2035	5,017	5,500
2036	4,953	5,434
2037	4,899	5,378

7.2.1 Sensitivity tests

Results of the sensitivity tests are shown in Table 9 and 10, and Figure 6. Steepness is not well estimated as the model estimated spawning biomass does not decrease to low enough magnitudes to inform the estimation of this parameter (as confirmed by the likelihood profile conducted on steepness in Castillo-Jordan and Tuck, 2018). All model sensitivities show relative spawning biomass levels well above the target biomass level (48% SBo), except for a model where the non-spawning CPUE was excluded. This is not surprising, given the importance of the non-spawning CPUE in the catch trend. A model sensitivity with both female and male natural mortality (*Mmale*) estimated provided reasonable fits to the data (not shown), and predicted natural mortality values of M_f=0.154 y^{-1} and M_m=0.230y^{-1} (noting that the male natural mortality is estimated to be ~1.5 times that of females). The inclusion of estimated male natural mortality could be considered in the base case for this stock (see Figure A.19 for a comparison of the base case and *Mmale* model spawning biomass and recruitment time series).

Table 9. Summary of results for the base case model BC and sensitivity tests. ^This is the retained catch at 2037. The long term catch had not yet stabilised by year 2037. Ret C = retained catch. Ret C 2019-21 is the average 3-year retained catch. Ret C 2019-23 is the average 5-year retained catch. Note that the upper two models are tuned.

Model	SB0	SB_Curr	CurrDepl	2019 RBC	2019 Ret C	Ret C 2019-2021	Ret C 2019-2023	Ret C Long-term
Base Case Model (Mf=est=0.174, h=0.75)	53,909	65,993	1.22	13,260	12,271	11,635	10,564	^4,899
***M*male** (Mf=est=0.154,Mm=est=0.230)	57,647	62,027	1.08					
NoCPUE	27,536	656	0.02					
NoCGD	48,036	56,589	1.18					
NoPort data	54,668	67,942	1.24					
NoFIS	54,146	67,895	1.25					
h=0.90	52,581	64,403	1.22					
*M*f 20% more	59,815	85,121	1.42					
*M*f 20% less	47,831	45,210	0.95					
Halve weight on LF data	54,309	66,603	1.23					
Double weight on LF data	52,933	65,061	1.23					
Halve weight on Age data	57,021	67,820	1.19					
Double weight on Age data	51,259	65,464	1.28					
Sigma R 0.8	47,284	59,876	1.27					
Sigma R 1.2	64,337	69,950	1.09					

Table 10. Summary of likelihood components for the base-case BC and sensitivity tests. Likelihood components are unweighted, and sensitivities from the BC are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit. Note that the upper two models are tuned and so likelihoods are not comparable.

Model	TOTAL	Survey	Discard	Length comp	Age comp	Recruitment
Model BC (Mf=est=0.174, h=0.75)	773	-6	27	201	580	39
***M*male** (Mf=est=0.154,Mm=est=0.230)	3	1	0	4	-2	0
NoCPUE	-3	7	-9	2	-3	-2
NoCGD	267	1	36	85	75	2
NoPort data	-56	-1	-5	-45	-4	0
NoFIS	-1	-1	0	0	0	0
h=0.90	-1	0	0	0	0	0
*M*f 20% more	4	0	-1	4	1	0
*M*f 20% less	5	1	1	-1	4	0
Halve weight on LF data	10	-1	-13	31	-5	0
Double weight on LF data	11	0	25	-25	10	0
Halve weight on Age data	7	-1	-7	-6	23	-3
Double weight on Age data	5	1	4	10	-13	3
Sigma R 0.8	14	0	3	1	3	6
Sigma R 1.2	-7	0	-3	0	-2	-3

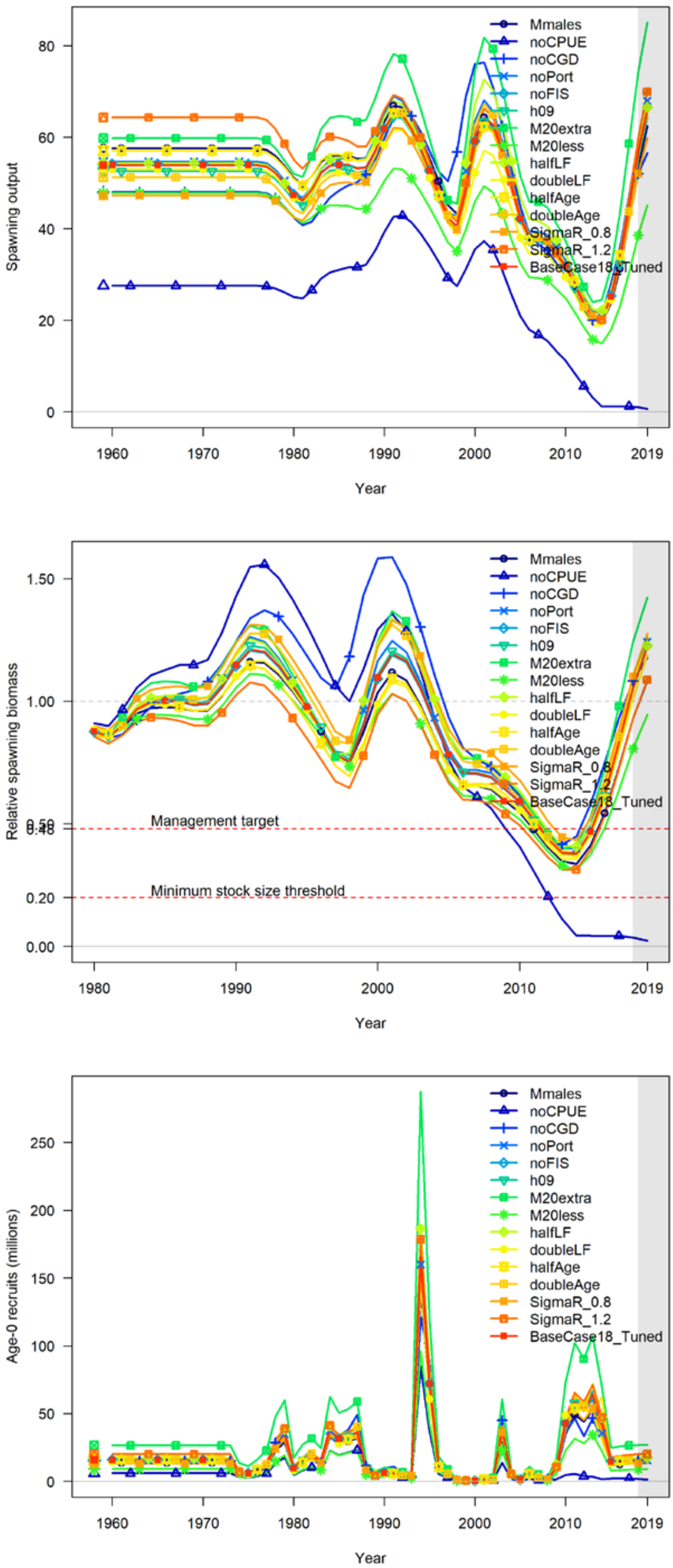


Figure 6. Comparison plot for the base case and sensitivities applied for the 2018 blue grenadier stock assessment for female spawning biomass (top), relative female spawning biomass (middle) and recruitment (bottom).

7.3 Further development

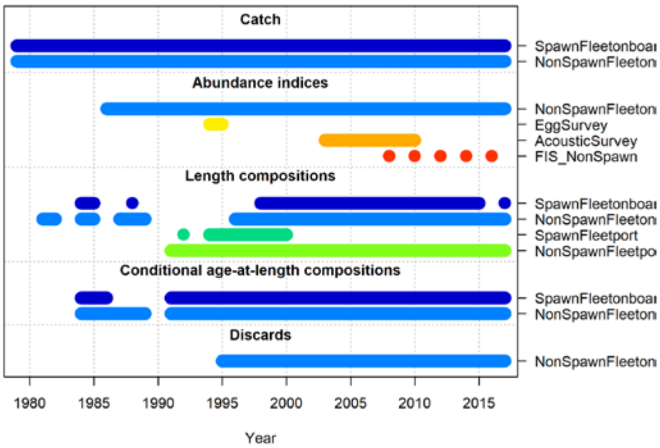
1) Explore the lack of fit to the catch rate series of the non-spawning fishery and whether the poor fit is a data issue or model structure issue.

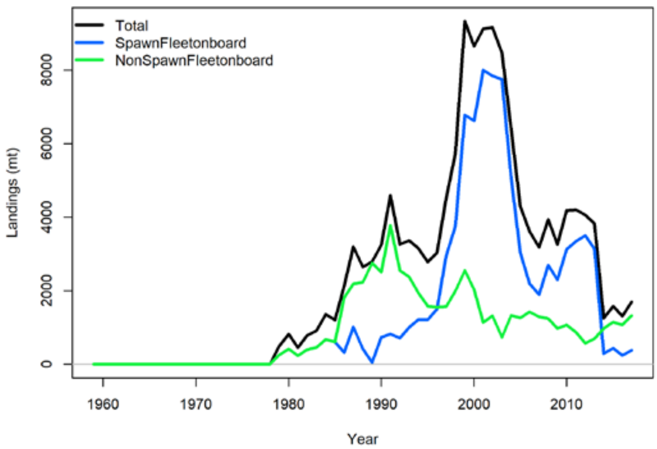
2) Explore the utility of having age-dependent and sex-specific estimates of natural mortality.

3) Include updated FIS estimates of abundance and corresponding length frequencies.

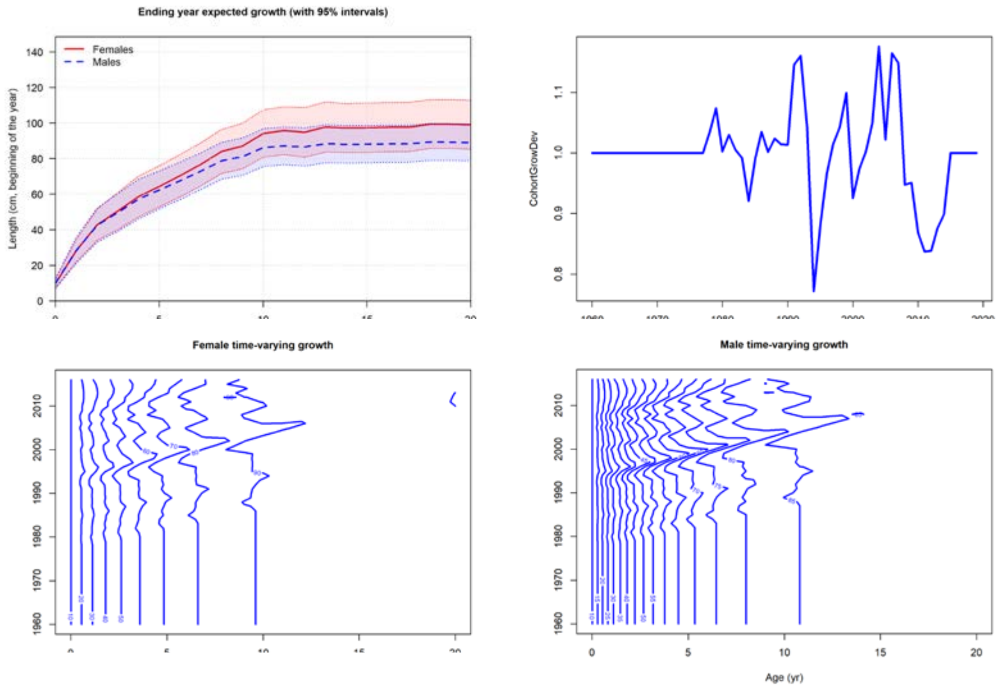
Appendix A

A.1 Base case diagnostics

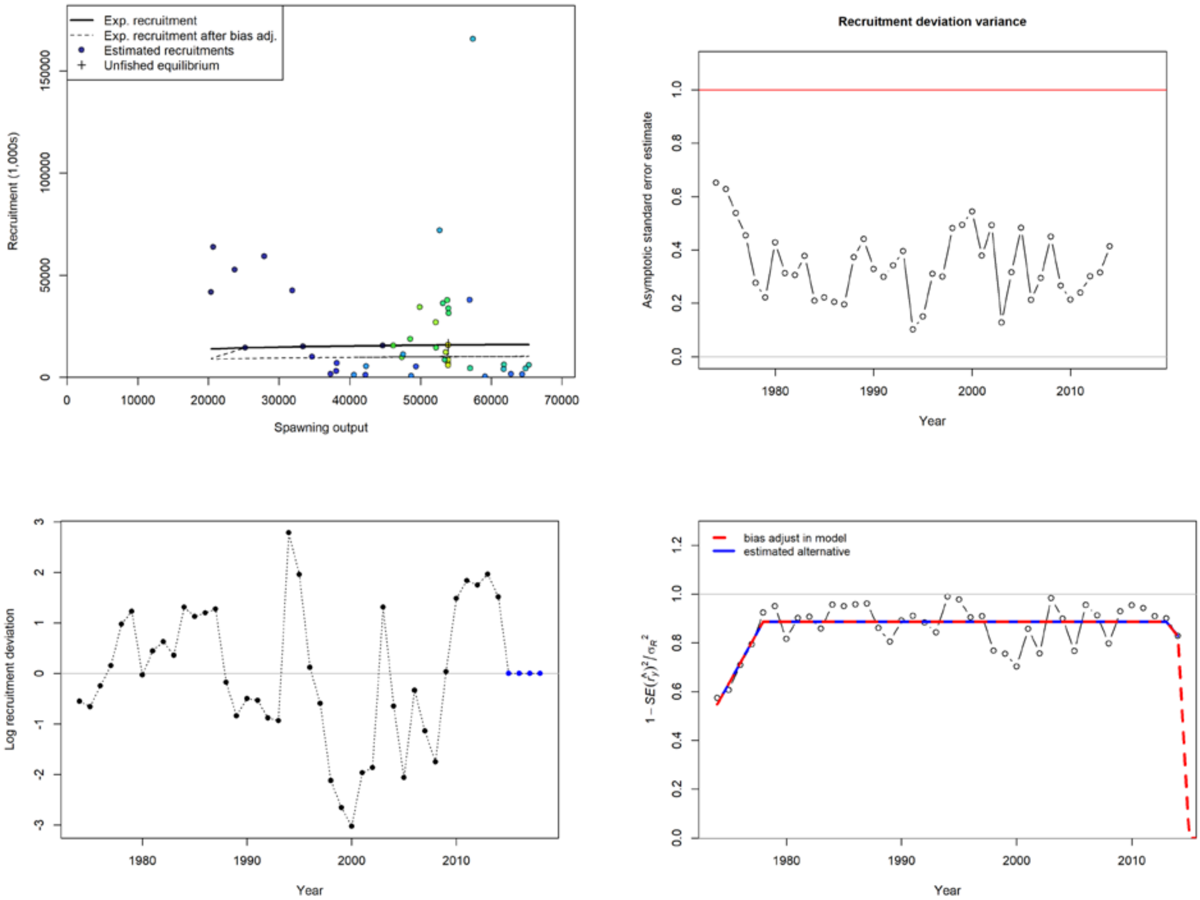




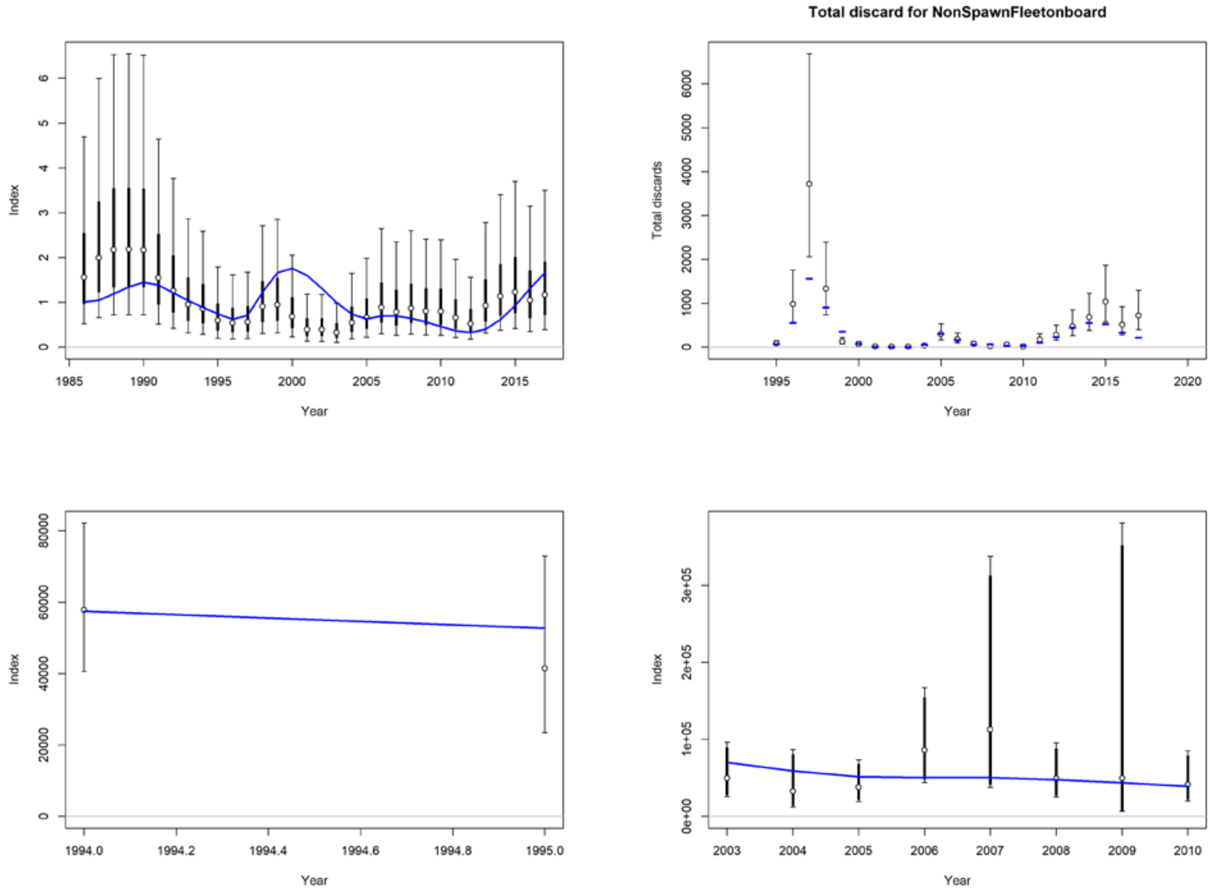
Apx Figure A.1 Summary of data sources and the catch time-series for the base case assessment.



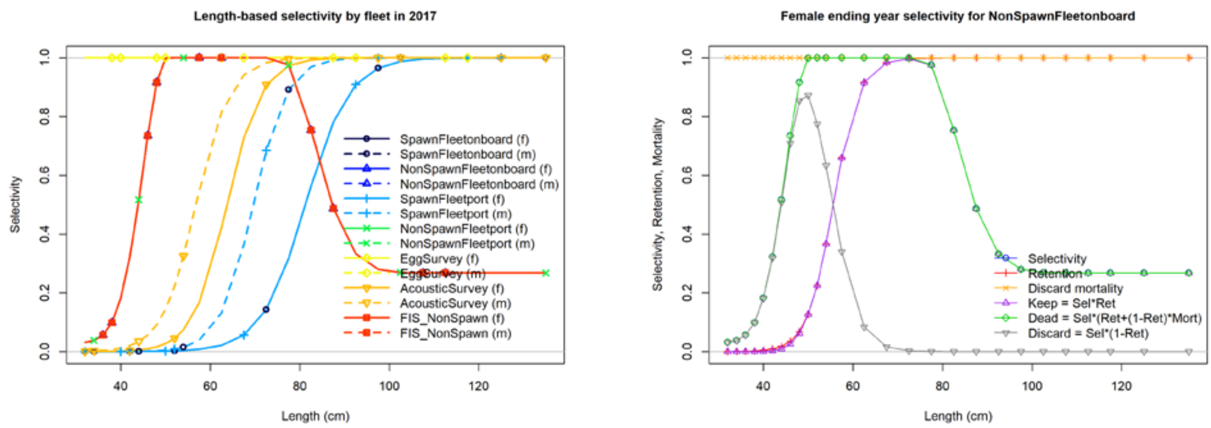
Apx Figure A.2 Growth for blue grenadier.



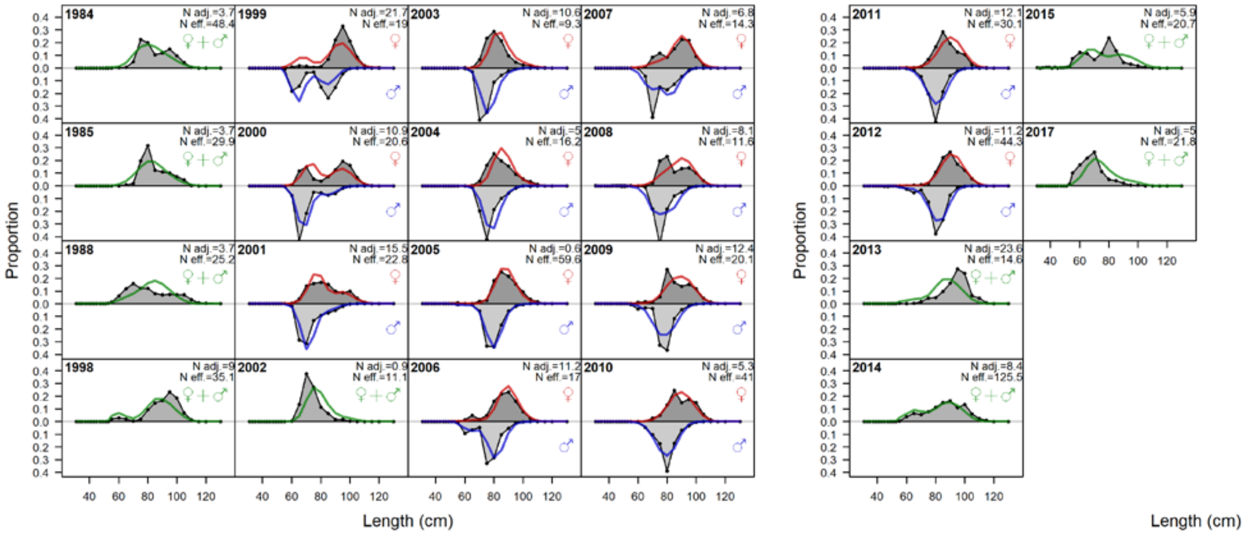
Apx Figure A.3 Time series showing the stock recruitment curve, recruitment deviations and recruitment deviation variance check for blue grenadier.



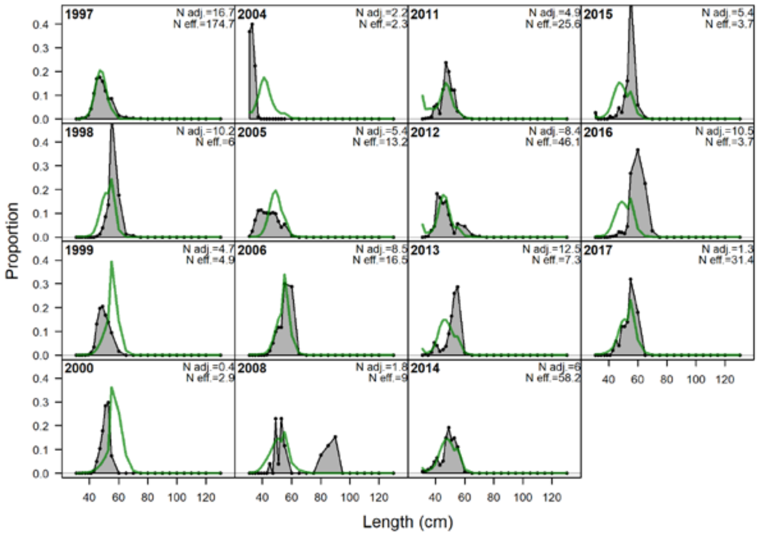
Apx Figure A.4 Fits to the non-spawning CPUE index, discard mass, egg survey and acoustic survey.



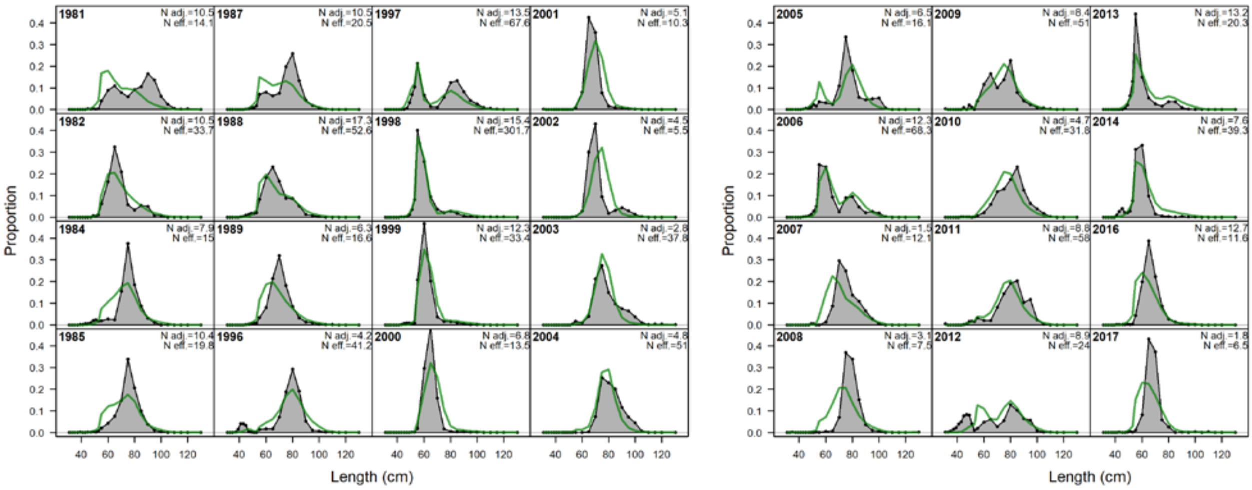
Apx Figure A.5 Estimated selectivity for the spawning and on-spawning fleets using port and onboard samples and for males (m) and females (f) and the retention function.



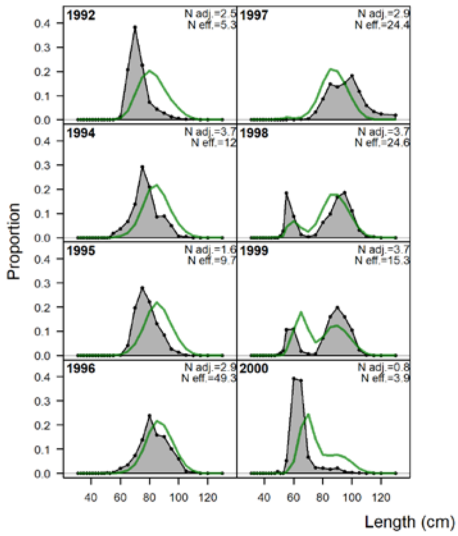
Apx Figure A.6 Length composition fits: spawning fleet onboard retained.



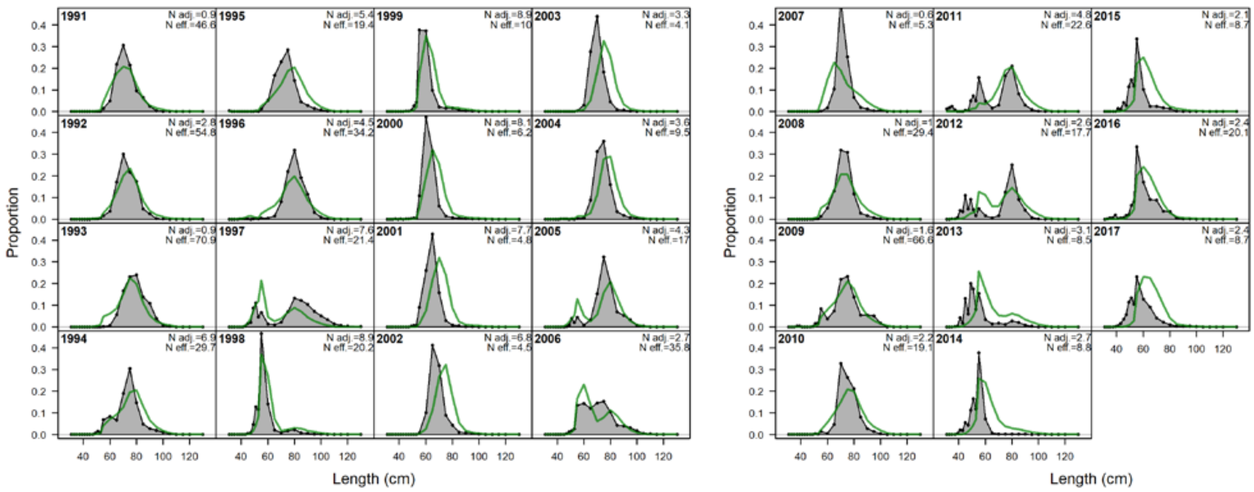
Apx Figure A.7 Length composition fits: onboard non-spawning fleet discard.



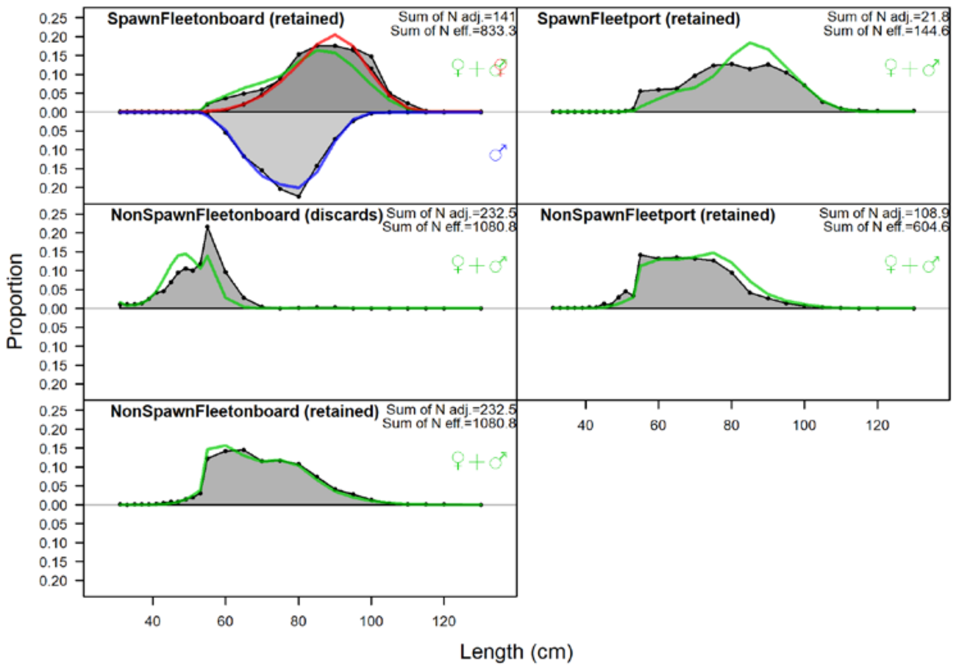
Apx Figure A.8 Length composition fits: onboard non-spawning fleet retained.



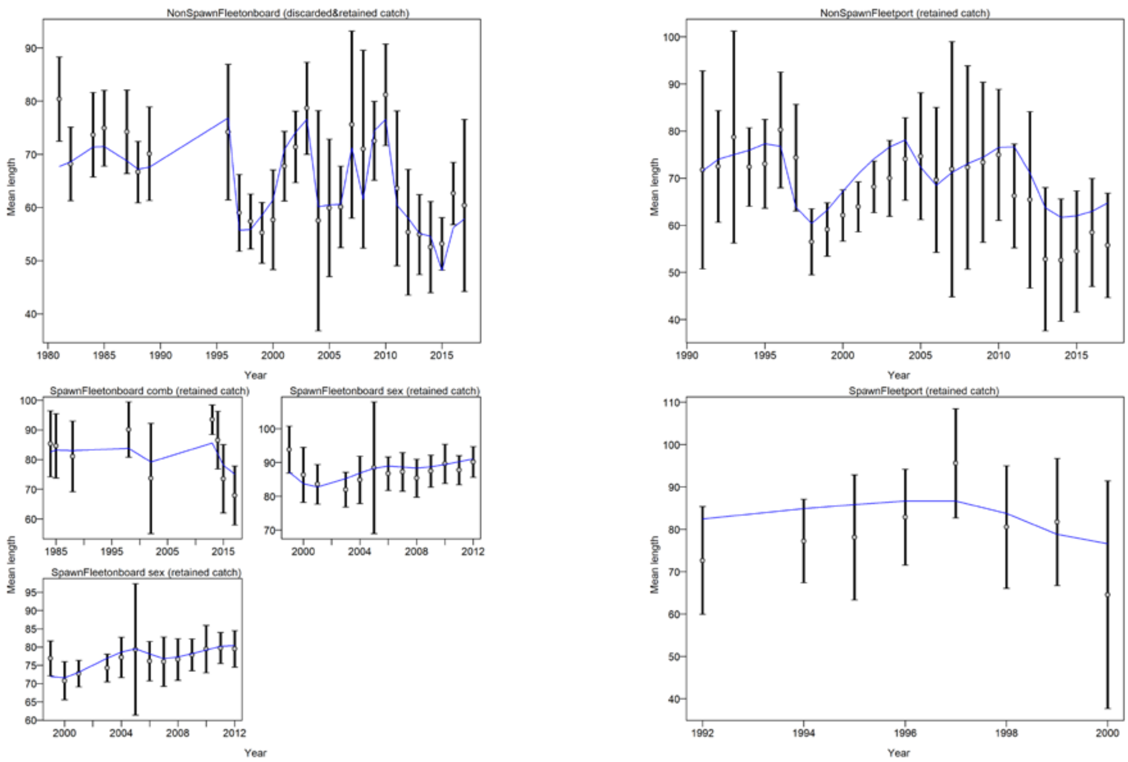
Apx Figure A.9 Length composition fits: port spawning fleet retained.



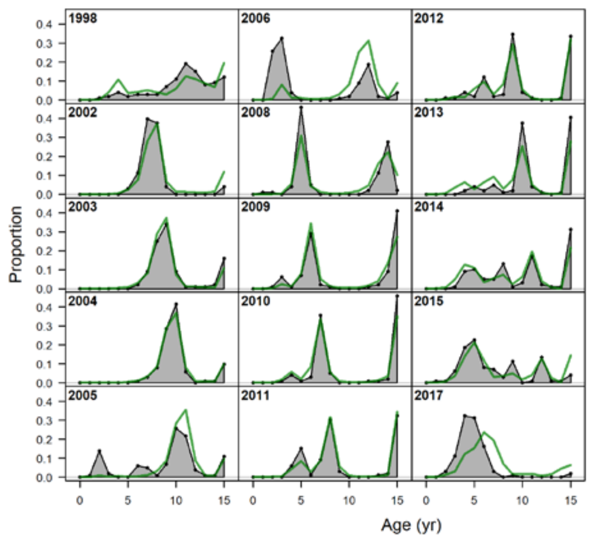
Apx Figure A.10 Length composition fits: port non-spawning fleet retained.



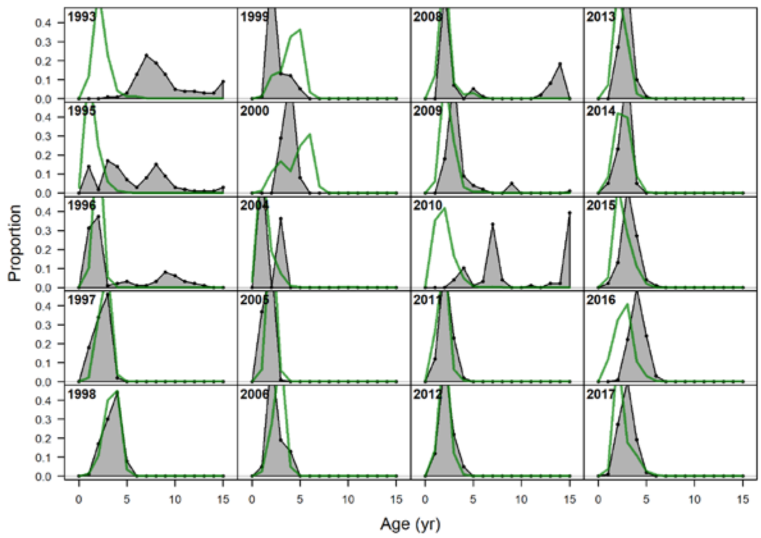
Apx Figure A.11 Length composition fits aggregated across years.



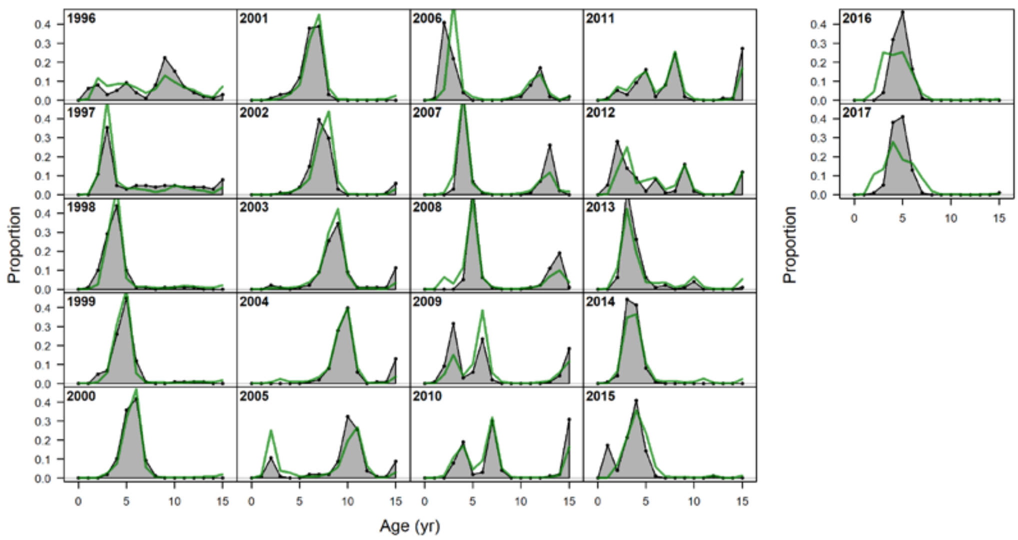
Apx Figure A.12 Length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.



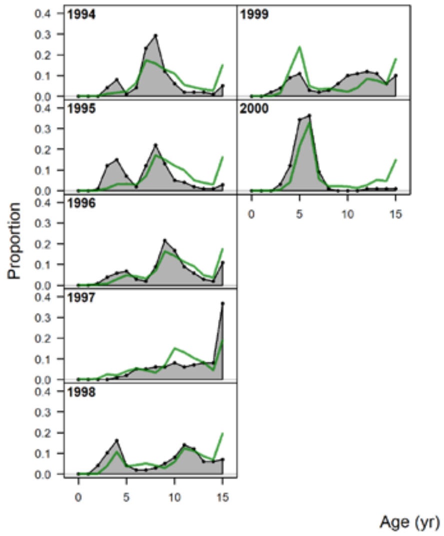
Apx Figure A.13 Age composition fits: spawning fleet onboard retained.



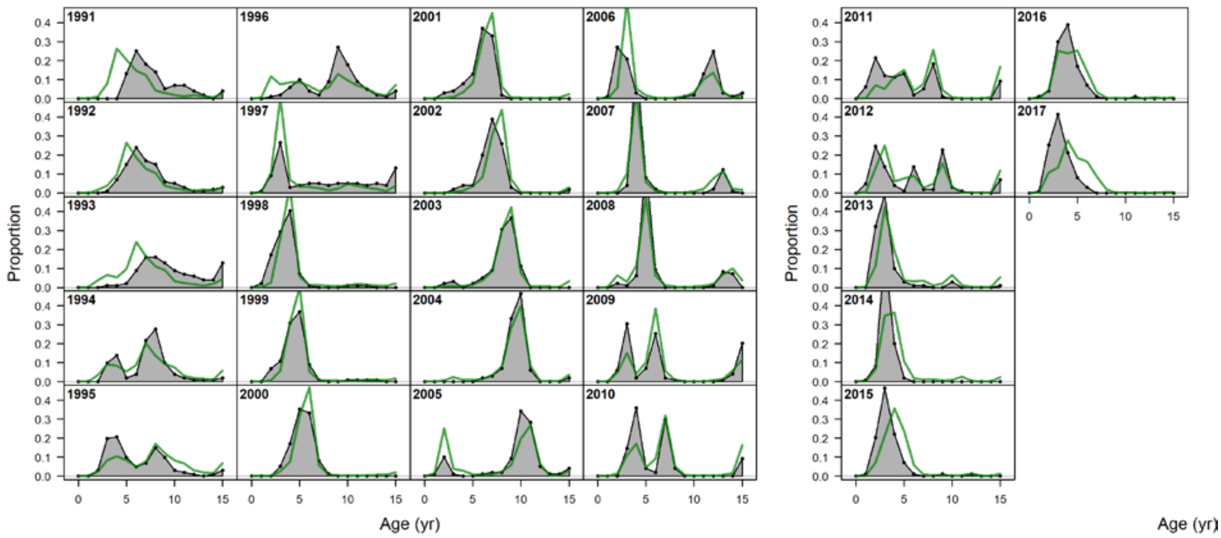
Apx Figure A.14 Age composition fits: non-spawning fleet onboard discard.



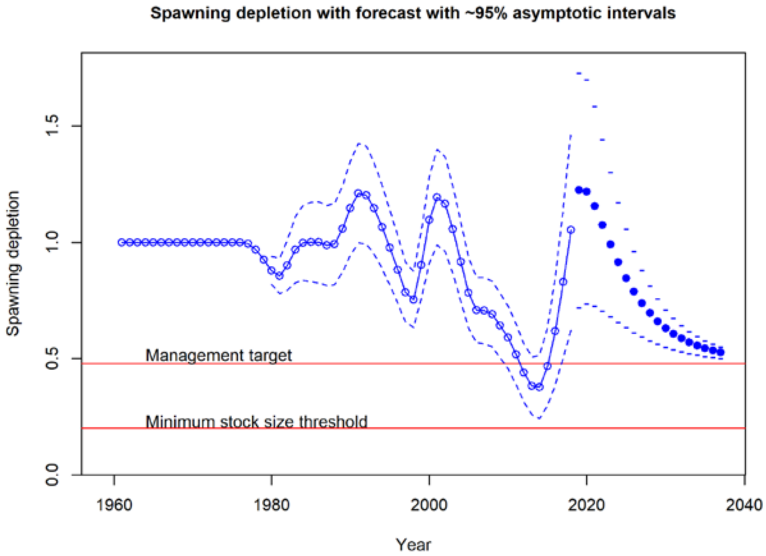
Apx Figure A.15 Age composition fits: non-spawning fleet onboard retained.



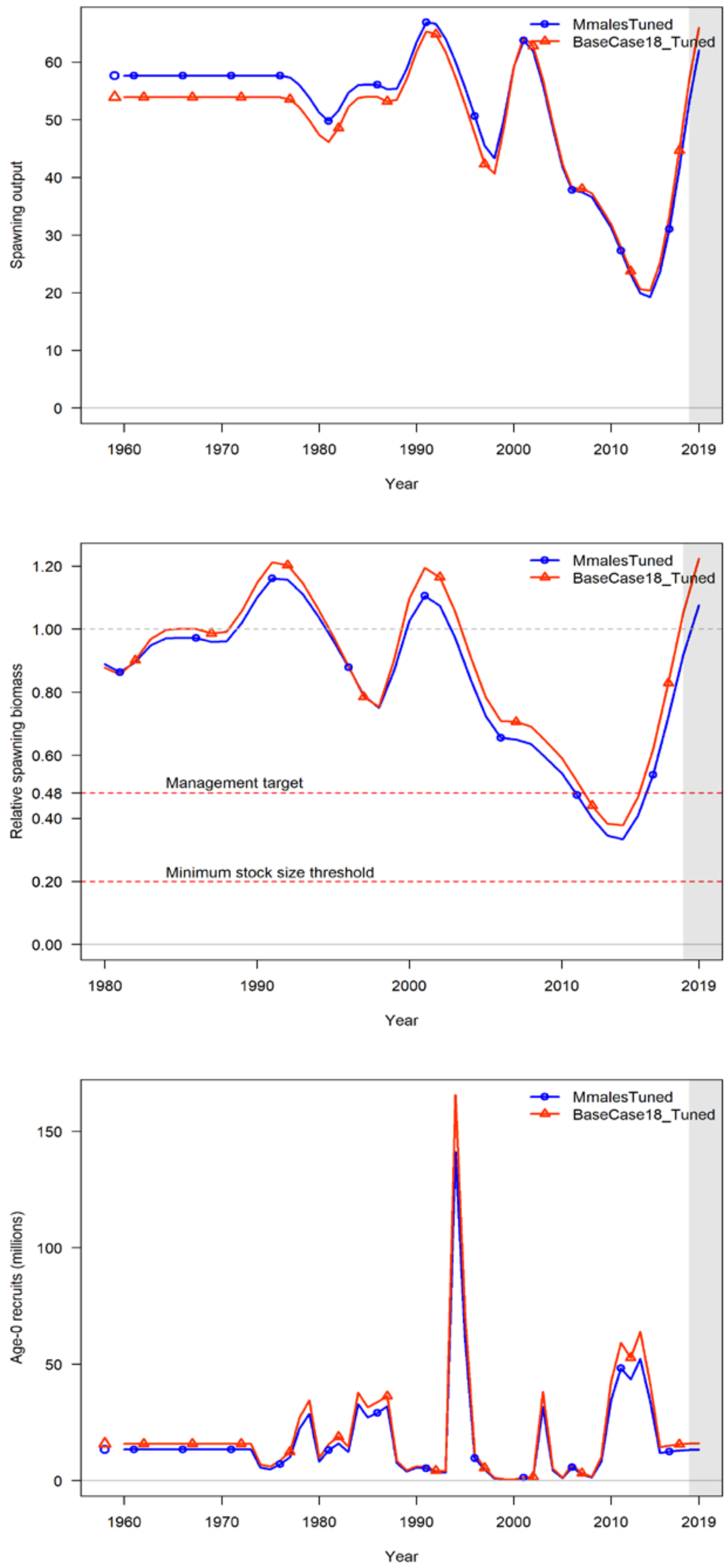
Apx Figure A.16 Age composition fits: spawning fleet port retained.



Apx Figure A.17 Age composition fits: non-spawning fleet port retained.



Apx Figure A.18 The time-series of relative female spawning biomass with a projection to 2037.



Apx Figure A.19 Comparison plot for the base case and *Mmales* sensitivity applied for the 2018 blue grenadier stock assessment for female spawning biomass (top), relative female spawning biomass (middle) and recruitment (bottom).

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