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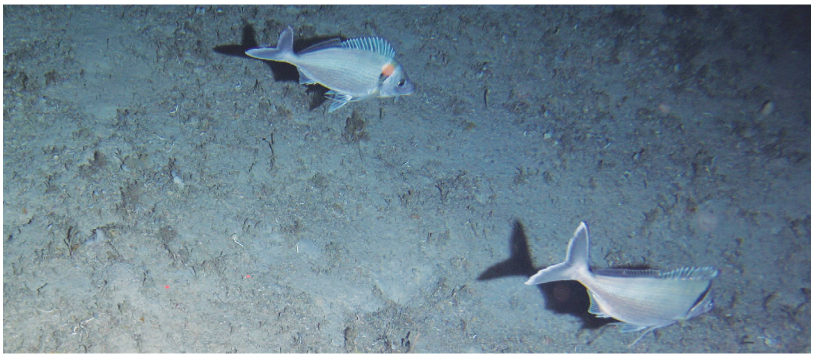
Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2020 and 2021



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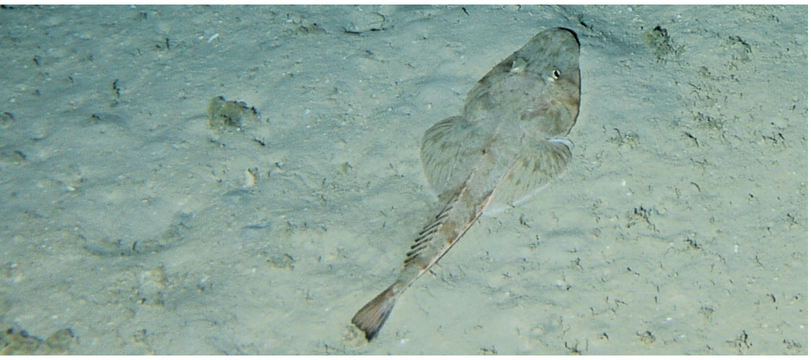

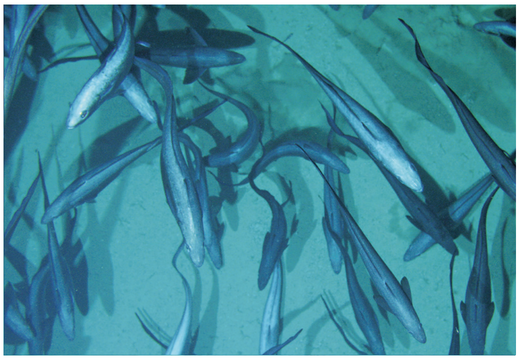

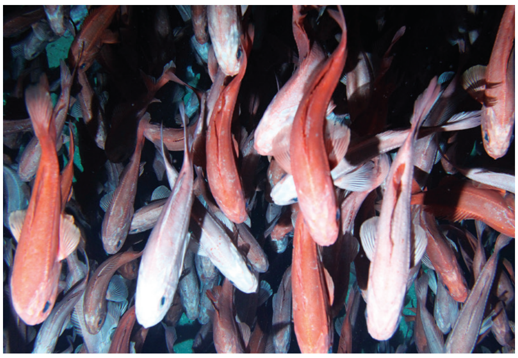

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All authors wish to thank the science, management and industry members of the south east, GAB and shark resource assessment groups for their contributions to the work presented in this report. Authors also acknowledge support from Fish Ageing Services (for fish ageing data) and AFMA (for the on-board and port length-frequencies, and in particular John Garvey, for the log book data). Toni Cracknell is greatly thanked for her assistance with the production of this report.

Cover photographs

Front cover, jackass morwong, orange roughy, blue grenadier, and flathead.

Report structure

Part 1 of this report describes the Tier 1 assessments of 2021. Part 2 describes the Tier 4 and Tier 5 assessments, catch rate standardisations and other work contributing to the assessment and management of SESSF stocks in 2021.

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2020 and 2021

Part 1: 2021

G.N. Tuck
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Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2021

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6. Blue Grenadier (*Macruronus novaezelandiae*) stock assessment based on data up to 2020

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6.1 Executive Summary

This document presents the agreed base case for an updated quantitative Tier 1 assessment of Blue Grenadier (*Macruronus novaezelandiae*) for presentation at the SERAG3 meeting in 2021. The last full assessment was conducted in 2018 (Castillo-Jordán and Tuck, 2018b). The preliminary base case was presented at SERAG2 (October 2021; Tuck and Bessell-Browne, 2021) and the 2018 assessment was updated by the inclusion of data up to the end of 2020, which entails an additional three years of catch, discard, CPUE, length and age data and ageing error updates. The development of, and results from, the preliminary base case for Blue Grenadier through the sequential updating of recent data in the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.30, Methot and Wetzel (2013)) is described in Tuck and Bessell-Browne (2021) and is not repeated here. This document describes the agreed base case from SERAG2 which differs from the preliminary base case through the inclusion of estimation of both female and male natural mortality, and no longer including the FIS survey results.

Results of the base case show reasonably good fits to the length-composition data, conditional age at length, egg and acoustic surveys and discard mass. 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. More recent catch rates fit reasonably well, including the recent marked increase in catch rate in 2019 and 2020.

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 very little recruitment between these years. However, recent recruitments are more stable, as was first observed in the 2018 assessment. The trajectories of spawning biomass show increases and decreases in spawning biomass as strong cohorts move into and out of the spawning population.

For the base case model, the estimated virgin female spawning biomass (SSB_0) is 37,445 tonnes and the projected 2022 spawning stock biomass will be 155% of SSB_0 (projected assuming 2020 catches in 2021), compared to 122% for 2019 in the 2018 assessment. The 2022 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 23,777 t, with 245 t estimated discards (23,532 t retained). The long-term RBC is 7,100 t, with 183 t discards.

6.2 Introduction

An integrated analysis model, implemented in the generalized stock assessment software package, Stock Synthesis (SS) (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 2020 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. 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 fit separately with a common selectivity curve by fleet.

The assessment model presented in 2011 (Tuck and Whitten, 2011; Tuck, 2011) was the first for Blue Grenadier to be implemented using Stock Synthesis (SS). The 2013 assessment updated this assessment using SS-V3.22a (Tuck, 2013), and the last full assessment was in 2018 (Castillo-Jordán and Tuck, 2018b), using 3.30.12.00-safe. The preliminary base case presented to SERAG in October 2021 (Tuck and Bessell-Browne, 2021) illustrated the changes that have occurred since 2018 through changes to software, assessment practices and new data (bridging). The bridging analysis 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 et al., 2021) and is not reproduced here. This document updates the assessment presented in 2018 and the preliminary assessment presented at SERAG in October 2021 (Tuck and Bessell-Browne, 2021).

6.3 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 four years for males and five years for females (length-at-50% maturity for females is 57 cm and 64 cm 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 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 gonadosomatic 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. There are two defined fleets: the spawning (SESSF Zone 40, months June, July and August) and non-spawning fisheries (all other months and zones).

6.4 Data

The assessment has been updated since the previous assessment (Castillo-Jordán and Tuck, 2018) by including recent length-composition and conditional age-at-length data from the spawning and non-spawning fisheries; updated standardized CPUE series (Sporcic, 2021), 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 (Figure 6.1). The agreed base case no longer includes the FIS abundance estimates from the non-spawning area, as SERAG2 did not believe the series (FIS1-3) was indexing either the spawning or non-spawning biomass; extremely large inter- annual fluctuations in survey biomass are evident. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec), as in previous models.

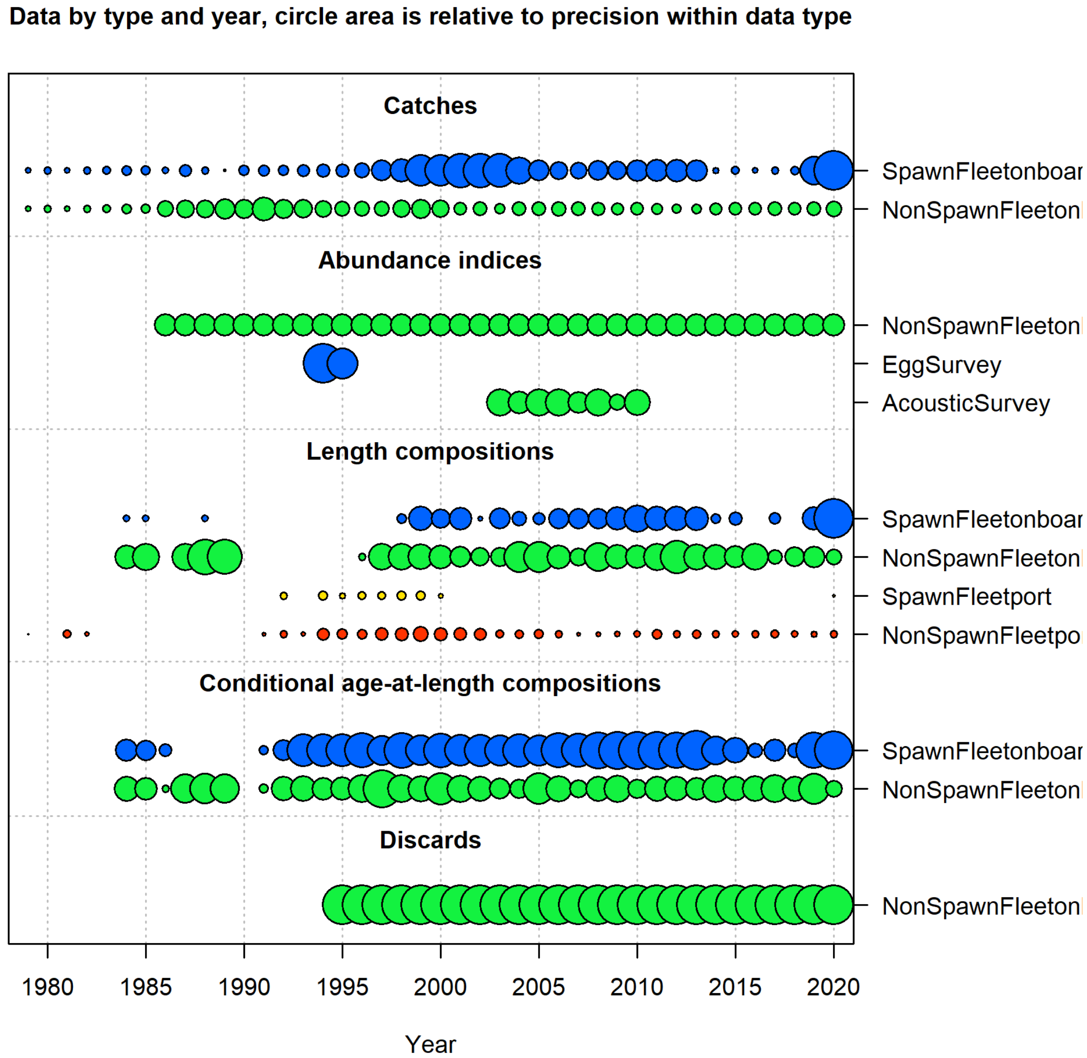


Figure 6.1. A summary of the input data for the base case Blue Grenadier assessment.

6.4.1 *Catch data*

6.4.1.1 Landings

The landings from the logbook data were used to apportion catches to the spawning and non-spawning fisheries (Table 6.1). 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 6.2 lists the annual catches used in the assessment and the annual TAC (Figure 6.2). The annual logbook catches by sub-fishery and the adjustments made to determine the catches used in the assessment are shown in Table 6.1. No state catches are included and are assumed negligible or included in the historical values.

6.4.1.2 Discards

Discard rates were estimated from onboard 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 rates are then scaled up to discard mass. 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). Tier 1 stock assessments implemented in Stock Synthesis estimate discards within the assessment by fitting to discard proportions or mass calculated by fleet. Discard proportions are estimated for a population (stock) by fleet, year, zone and season (usually a quarter) and then scaled to landed (CDR) catch to obtain estimates by population, fleet and year (Klaer 2018). The discard proportion is estimated as the sum of the discarded catch divided by the sum of discarded catch and the landed catch (Klaer 2018; Method 1). The previous assessment used Method 2, where the discard proportion was estimated as the average of the proportion discarded in each shot (Klaer 2018). However, Method 2 does not scale the mean discard proportion by shot weight and it is therefore sensitive to the discarding practices from shots with small catches and, as such, may not be representative of the overall fishery. At its August 2020 Data Meeting SESSFRAG endorsed the use of Method 1 to estimate discard proportions for Tier 1 assessments from 2020 onwards. 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. 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 6.2. The discard data were assumed to have standard error (on the log-scale) of 0.3. As with previous assessments, only discards from the non-spawning fishery are considered.

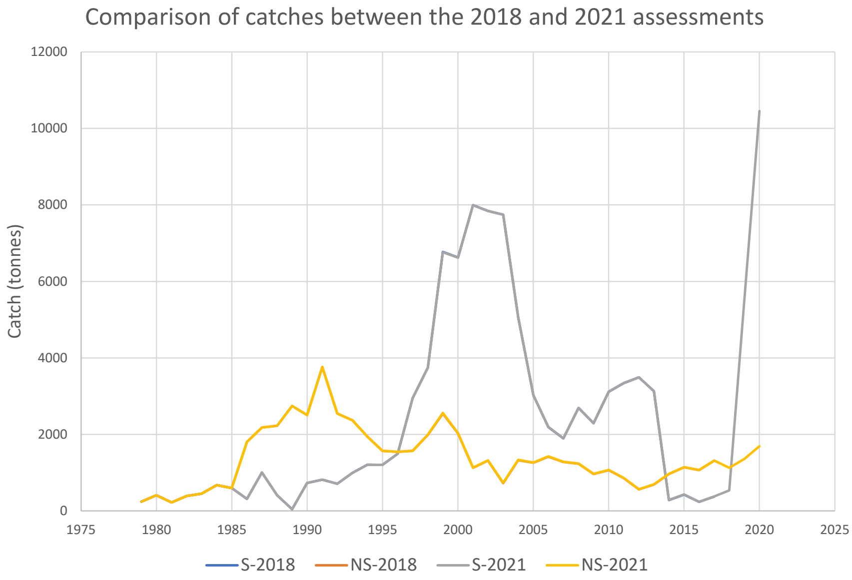


Figure 6.2. A comparison of total annual catches from the 2018 base case assessment and the updated catch used in the 2021 assessment for the spawning (S) and non-spawning (NS) fisheries.

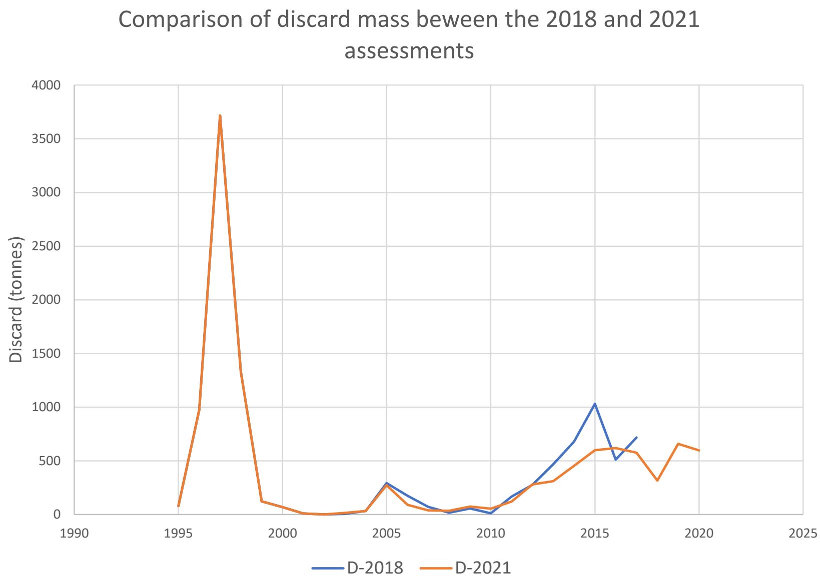


Figure 6.3. A comparison of total annual estimated discard mass from the 2018 base case assessment and the updated catch used in the 2021 assessment for the non-spawning fishery.

Table 6.1. 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 / logbook	Catch for assessment	
	Spawning	Non-		Spawnin	Non-	Spawning	Non-	Total		Spawning	Non-
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	1459	5733	1	1	2739	1459	4198	1.37	3740	1993
1999	5460	2068	9324	1	1	5460	2068	7528	1.24	6762	2562
2000	5735	1761	8655	1	1	5735	1761	7496	1.15	6622	2033
2001	7309	1034	9128	1	1	7309	1034	8343	1.09	7997	1131
2002	6825	1151	9165	1	1	6825	1151	7976	1.15	7843	1322
2003	7239	687	8480	1	1	7239	687	7926	1.07	7746	735
2004	4647	1225	6401	1	1	4647	1225	5872	1.09	5066	1336
2005	2880	1204	4293	1	1	2880	1204	4085	1.05	3027	1266
2006	2058	1339	3625	1	1	2058	1339	3397	1.07	2196	1429
2007	1815	1232	3184	1	1	1815	1232	3048	1.04	1896	1287
2008	2838	1307	3938	1	1	2838	1307	4145	0.95	2696	1242

2009	2723	1151	3269	1	1	2723	1151	3874	0.84	2298	971
2010	3384	1162	4195	1	1	3384	1162	4545	0.92	3123	1072
2011	3554	917	4207	1	1	3554	917	4471	0.94	3345	863
2012	3838	624	4063	1	1	3838	624	4461	0.91	3495	568
2013	3443	764	3828	1	1	3443	764	4207	0.91	3133	695
2014	279	935	1258	1	1	279	935	1215	1.04	289	969
2015	401	1061	1578	1	1	401	1061	1462	1.08	433	1146
2016	217	978	1311	1	1	217	978	1195	1.10	238	1073
2017	362	1261	1698	1	1	362	1261	1623	1.05	379	1319
2018	508	1067	1665	1	1	508	1067	1575	1.06	537	1128
2019	5799	1424	6914	1	1	5799	1424	7224	0.96	5551	1363
2020	9146	1482	12151	1	1	9146	1482	10628	1.14	10457	1694

Table 6.2. 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, 2021) 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] From 2008/09, the TACs cover the fishing year 1 May to 30 April. In the table below, 2008 refers to 2008/09. * This is an estimate of retained catch equal to the 2020 catch.

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	1806			1.5312
1987	1006	2183			1.9494
1988	410	2228			2.1329
1989	46	2745			2.1313
1990	733	2508			2.1103
1991	819	3764			1.5098
1992	710	2549			1.2214
1993	994	2368			0.9287
1994	1211	1940		10000	0.8412
1995	1205	1570	80	10000	0.5802
1996	1496	1544	975	10000	0.5262
1997	2947	1569	3716	10000	0.5464
1998	3740	1993	1329	10000	0.8818
1999	6762	2562	123	10000	0.9257
2000	6622	2033	69	10000	0.6643
2001	7997	1131	10	10000	0.3828
2002	7843	1322	2	10000	0.3794
2003	7746	735	16	9000	0.3171
2004	5066	1336	35	7000	0.5326
2005	3027	1266	275	5000[1]	0.6428
2006	2196	1429	91	3730	0.8564
2007	1896	1287	40	4113[2]	0.7622
2008	2696	1242	36	4368[3]	0.8386
2009	2298	971	76	4700	0.7778
2010	3123	1072	56	4700	0.7805
2011	3345	863	123	4700	0.637
2012	3495	568	281	5208	0.508
2013	3133	695	311	5208	0.9059
2014	289	969	455	6800	1.092
2015	433	1146	601	8796	1.1867
2016	238	1073	619	8810	1
2017	379	1319	576	8765	1.1183
2018	537	1128	317	8810	0.899
2019	5551	1363	659	12183	1.1917
2020	10457	1694	598	12183	1.7107
2021	10457*	1694*			

6.4.2 *Catch rates*

Sporcic (2021) provides the updated standardised catch rate series for the non-spawning fishery of Blue Grenadier (Table 6.2; Figure 6.4). 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 0.252 (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.

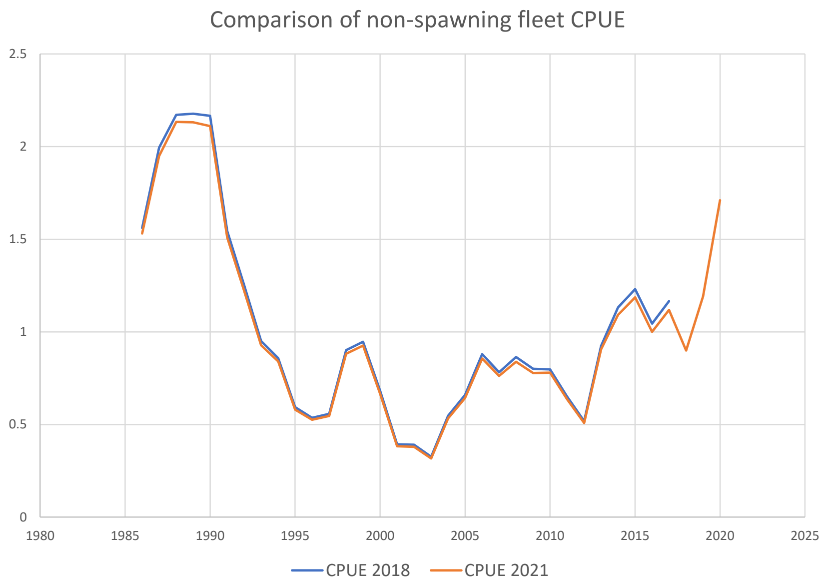


Figure 6.4. A comparison of the annual standardised catch rates series for Blue Grenadier between the 2018 and 2021 assessments.

6.4.3 *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 if available). Onboard and port length-compositions, when available, are used separately. Separating port and onboard lengths first occurred in the 2018 assessment. Prior to 2018, 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 6.3; Table 6.4).

Table 6.3. 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] these years of discard lengths were removed due to spurious numbers of large fish.

Year	Nfish	Fleet	Sex	Part	N
1984	1046	1	0	2	12
1985	1090[1]	1	0	2	12
1988	1133	1	0	2	12
1998	812	1	0	2	10
1998	1037	1	1	2	8
1998	469	1	2	2	8
1999	4147	1	1	2	79
1999	5929	1	2	2	79
2000	2672	1	1	2	48
2000	2956	1	2	2	46
2001	3620	1	1	2	67
2001	4256	1	2	2	67
2002	262	1	0	2	2
2002	444	1	1	2	3
2002	450	1	2	2	3
2003	2700	1	1	2	59
2003	2853	1	2	2	59
2004	1307	1	1	2	28
2004	1370	1	2	2	28
2005	198	1	1	2	20
2005	141	1	2	2	20
2006	3184	1	1	2	56
2006	3081	1	2	2	55
2007	2957	1	1	2	54
2007	1897	1	2	2	55
2008	3073	1	1	2	53
2008	2177	1	2	2	54
2009	3868	1	1	2	73
2009	3374	1	2	2	70
2010	2488	1	1	2	98
2010	1453	1	2	2	94
2011	4207	1	1	2	79
2011	3266	1	2	2	77
2012	3939	1	1	2	77
2012	3060	1	2	2	82
2013	1	1	0	2	1
2013	4443	1	1	2	76
2013	3892	1	2	2	76
2014	592	1	0	2	7
2014	229	1	1	2	9
2014	179	1	2	2	9
2015	715	1	0	2	11

2015	723	1	1	2	18
2015	862	1	2	2	18
2017	777	1	0	2	12
2017	131	1	1	2	11
2017	193	1	2	2	11
2018	10	1	0	2	1
2019	57	1	0	2	19
2019	3389	1	1	2	72
2019	4324	1	2	2	72
2020	8	1	0	2	6
2020	6776	1	1	2	204
2020	8774	1	2	2	201

Year	Nfish	Fleet	Sex	Part	N
1984	1935	2	0	2	75
1985	1829	2	0	2	99
1987	4063	2	0	2	100
1988	6660	2	0	2	164
1989	2424	2	0	2	160
1996	829	2	0	2	8
1997	3367	2	0	2	32
1998	8290	2	0	2	73
1999	8768	2	0	2	79
2000	9362	2	0	2	73
2001	6309	2	0	2	57
2002	5329	2	0	2	47
2003	2754	2	0	2	50
2004	7586	2	0	2	104
2005	5754	2	0	2	76
2006	6549	2	0	2	68
2007	1109	2	0	2	44
2008	2624	2	0	2	91
2009	2100	2	0	2	79
2010	2562	2	0	2	71
2011	1755	2	0	2	70
2012	3087	2	0	2	97
2013	1841	2	0	2	48
2014	2631	2	0	2	67
2015	1555	2	0	2	45
2016	3960	2	0	2	68
2017	1236	2	0	2	18
2018	1585	2	0	2	38
2019	2579	2	0	2	53
2020	1261	2	0	2	33

Year	Nfish	Fleet	Sex	Part	N
1992[2]	159	2	0	1	3
1993[2]	1532	2	0	1	12
1994[2]	2366	2	0	1	27
1995[2]	6651	2	0	1	61
1996[2]	5999	2	0	1	50
1997	6967	2	0	1	62
1998	2212	2	0	1	20
1999	940	2	0	1	7
2000	132	2	0	1	3
2003	11	2	0	1	6
2004	1078	2	0	1	22
2005	5299	2	0	1	48
2006	1225	2	0	1	8
2007	16	2	0	1	2
2008	219	2	0	1	18
2009	97	2	0	1	6
2010	16	2	0	1	2
2011	792	2	0	1	30
2012	1327	2	0	1	49
2013	1455	2	0	1	41
2014	873	2	0	1	17
2015	500	2	0	1	18
2016	1360	2	0	1	28
2017	531	2	0	1	9
2018	682	2	0	1	13
2019	151	2	0	1	8
2020	32	2	0	1	5
1992	774	3	0	2	6
1994	1038	3	0	2	9
1995	465	3	0	2	4
1996	927	3	0	2	7
1997	851	3	0	2	7
1998	1648	3	0	2	9
1999	1079	3	0	2	9
2000	360	3	0	2	3
2014	82	3	0	2	1
2016	74	3	0	2	1
2020	100	3	0	2	1

Year	Nfish	Fleet	Sex	Part	N
1979	164	4	0	2	2
1980	40	4	0	2	1
1981	1425	4	0	2	36
1982	478	4	0	2	12
1991	927	4	0	2	10
1992	3832	4	0	2	31
1993	1810	4	0	2	12
1994	8624	4	0	2	79
1995	7055	4	0	2	62
1996	5505	4	0	2	51
1997	11844	4	0	2	85
1998	16234	4	0	2	100
1999	13898	4	0	2	119
2000	13728	4	0	2	95
2001	12000	4	0	2	88
2002	9416	4	0	2	77
2003	5037	4	0	2	38
2004	4440	4	0	2	43
2005	6310	4	0	2	48
2006	3019	4	0	2	31
2007	979	4	0	2	9
2008	1955	4	0	2	16
2009	1080	4	0	2	19
2010	833	4	0	2	26
2011	1925	4	0	2	54
2012	1331	4	0	2	33
2013	1744	4	0	2	43
2014	1611	4	0	2	30
2015	2048	4	0	2	25
2016	1887	4	0	2	29
2017	2061	4	0	2	35
2018	1943	4	0	2	27
2019	1222	4	0	2	22
2020	1864	4	0	2	32

Table 6.4. Number of age-length otolith samples by fleet included in the base case assessment.

Year	Spawn	Non-spawn
1984	512	735
1985	432	603
1986	174	71
1987		1027
1988		1092
1989		1031
1990		
1991	93	100
1992	481	706
1993	1122	772
1994	1130	623
1995	1154	637
1996	1296	932
1997	932	1697
1998	1334	948
1999	992	802
2000	1247	1224
2001	1062	891
2002	1077	751
2003	1035	514
2004	1187	435
2005	1016	1185
2006	1313	816
2007	1205	396
2008	1437	753
2009	1545	907
2010	1530	451
2011	1515	763
2012	1391	715
2013	1655	621
2014	884	887
2015	696	723
2016	221	773
2017	537	928
2018	221	733
2019	1406	1119
2020	1579	344

6.4.4 *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 6.5 shows the estimates of spawning biomass with their corresponding CV's used in the assessment. Sampling CVs 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 CVs 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 two (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 6.5. 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
CV 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

6.4.5 *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.

6.4.6 *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 63.7 cm for females (Russel and Smith, 2006). The female maturity ogive is shown in Figure 6.4.

The length weight-relationship for males and females was estimated from spawning fishery data over years 1999 to 2008 (Figure 6.5). Natural mortality for females and males is estimated when fitting the model.

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 has been assumed in all Blue Grenadier assessments since 2011 and in this assessment.

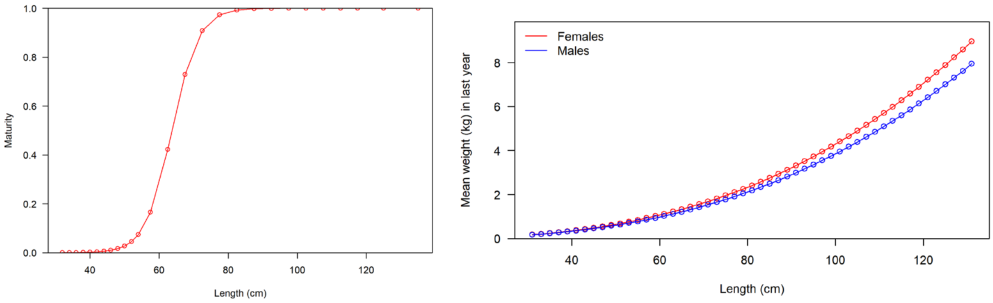


Figure 6.5. The maturity ogive by length for female Blue Grenadier (parameters from Russell and Smith (2006)) and the length-weight relationship for males and females.

6.4.7 *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 6.6 (A. Punt and P. Burch, pers. comm.). Reader A applied to years 1991-93 and 2007-20, and reader B to years 1984-90 and 1994-2006.

Table 6.6. The standard deviation of age reading error for readers A and B.

	St Dev	
Age	A	B
0	0.198	0.281
1	0.198	0.281
2	0.258	0.299
3	0.305	0.318
4	0.341	0.338
5	0.369	0.359
6	0.391	0.383
7	0.407	0.408
8	0.420	0.435
9	0.430	0.464
10	0.438	0.495
11	0.444	0.529
12	0.448	0.565
13	0.452	0.604
14	0.455	0.646
15	0.457	0.691
16	0.459	0.740
17	0.460	0.792
18	0.461	0.848
19	0.462	0.908
20	0.462	0.974

6.5 Analytical Approach

6.5.1 Model structure and parameters

The 2021 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 3.30.17.00, Methot et al. (2021)). 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 function (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, discard mass, discard and retained catch length-frequencies, 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.

Model data have been updated by the inclusion of data up to the 2020 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 two-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. 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.

The base–case model includes the following key features:

a) Blue grenadier consists of a single stock within the area of the fishery.

b) The model accounts for males and females separately (growth, natural mortality, age at first breeding).

c) The population was at its unfished biomass with the corresponding equilibrium (unfished) age-structure at the start of 1960.

d) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for female and male M is estimated within the assessment.

e) 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 2017. Deviations are not estimated before 1974 or after 2017 because there are insufficient data to permit reliable estimation of recruitment residuals outside of this time period.

f) The population plus-group is modelled at age 20 years. The maximum age for age observations is 20 years.

g) 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 Whitten et al., 2013). The 2021 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 2017.

h) Two fleets are included in the model – the spawning 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. GAB catches are not included.

i) Each 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.

j) The CVs of the CPUE indices were initially set at a value equal to the standard error from a loess fit (0.252; Sporcic, 2021), 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.

k) 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 prior to 1996 were removed as recommended by SERAG (September, 2018) due to the existence of unusually large fish in the length distribution which is likely to be misreporting.

l) 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.

The values assumed for fixed parameters of the preliminary base case model are shown in Table 6.7.

Table 6.7. Parameter values assumed for some of the non-estimated parameters of the base-case model

Parameter	Description	Value
M_f	Natural mortality for females	Estimated
M_m	Natural mortality for males	Estimated
h	"steepness" of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	20 years
μ	fraction of mature population that spawn each year	0.84
a_f	Female allometric length-weight equations	0.01502 g^{-1} cm
b_f	Female allometric length-weight equations	2.728
a_m	Male allometric length-weight equations	0.0168 g^{-1} cm
b_m	Male allometric length-weight equations	2.680
l_m	Female length at 50% maturity	63.7 cm
l_s	Parameter defining the slope of the maturity ogive	-0.261

6.5.2 *Tuning Method*

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams is comparable to what is input (Pacific Fishery Management Council, 2018). Most of the indices (CPUE, surveys and composition data) used in fisheries underestimate their true variance by only reporting measurement or estimation error and not including process 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 by the model. In SS-V3.30 it is possible to estimate an additional standard deviation parameter to add to the input CVs for the abundance indices (CPUE).

1. Set the standard error for the log of relative abundance indices (CPUE) to the standard deviation of a loess curve fitted to the original data - which will provide a more realistic estimate to that obtained from the original statistical analysis. SS-V3.30 then allows an estimate to be made for an additional adjustment to the relative abundance variances appropriately.

An automated iterative tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

2. Adjust the maximum bias adjustment and the start and finish bias adjustment ramps as predicted by SS-V3.30 at each step.

For the age and length composition data:

3. Multiply the stage-1 (initial) sample sizes 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 2–4, until all are converged and stable (with proposed changes < 1–2%).

This procedure constitutes current best practice for tuning assessments.

6.5.3 *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 2006–2020. 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 a Tier level 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. The 20:40:40 (B_{lim}:B_{MSY}:F_{targ}) form of the rule is used up to where fishing mortality reaches F_{48}. Once this point is reached, the fishing mortality is set at F_{48}. Day (2008) has determined that for most SESSF stocks where the proxy values of B_{40} and B_{48} are used for B_{MSY} and B_{MEY} this form of the rule is equivalent to a 20:35:48 strategy.

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

6.5.4 *Sensitivity tests*

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. h = 0.85, 0.65 (0.75 in the base case)
2. M_{fem} = 0.21, 0.25 (0.23 in the base case)
3. Double and halve the weighting on the length composition data.
4. Double and halve the weighting on the age-at-length data.
5. Double and halve the weighting on the index (survey) data.
6. σ_r = 0.6, 0.8 (0.7 in the base case)

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

1. SB_0 the average equilibrium female spawning biomass.
2. SB_{2022} the female spawning biomass at the start of 2022.
3. SB_{2022}/SB_0 the depletion level at the start of 2022, i.e. the 2022 spawning biomass expressed as a fraction of the unexploited spawning biomass.
4. *2022 RBC* - the 2022 RBC, calculated using the 20:35:48 harvest rule (presented for the agreed base case only).
5. *Long-term RBC* - the long-term RBC calculated using the 20:35:48 harvest rule (presented for the agreed base case only).

6.6 Results

6.6.1 The base-case analysis

6.6.1.1 Transition from the 2018 base case to the 2021 base case

The development of a preliminary base case, and a bridging analysis from the 2018 assessment (Castillo-Jordán and Tuck, 2018b), was presented at the October 2021 SERAG 2 meeting (Tuck and Bessell-Browne, 2021), including updating the version of Stock Synthesis and sequentially updating data. This bridging analysis is not repeated in this report.

6.6.1.2 Paramater estimates

Figure 6.6 shows how the expected mean length-at-age values change over time for the base case model. The ridges reflect the impact of the estimated cohort dependent growth with 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 say 10 year old fish in 2005, corresponding to the larger than average recruitment in 1994. Natural mortality for females was estimated to be $M_f = 0.23$ and males was $M_m = 0.24$.

The selectivity for the spawning and non-spawning fisheries and the retention function for the non-spawning fishery are shown in Figure 6.7. Selectivity is assumed to be time-invariant, sex-specific and logistic for the spawning fleet and dome-shaped for the non-spawning fleet.

The estimate of the parameter that defines the initial numbers (and biomass), ln*(R0)*, is 9.89 for the base case.

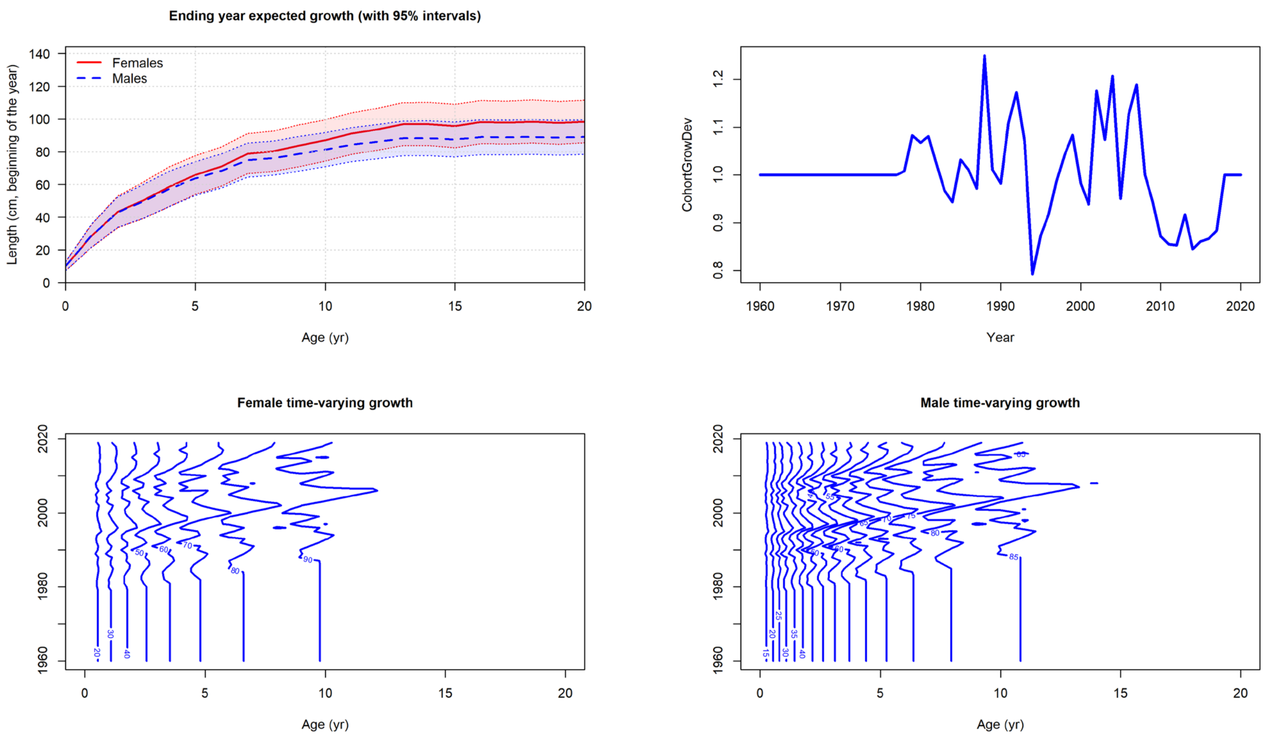


Figure 6.6. The estimate growth curve, with cohort dependent growth for Blue Grenadier.

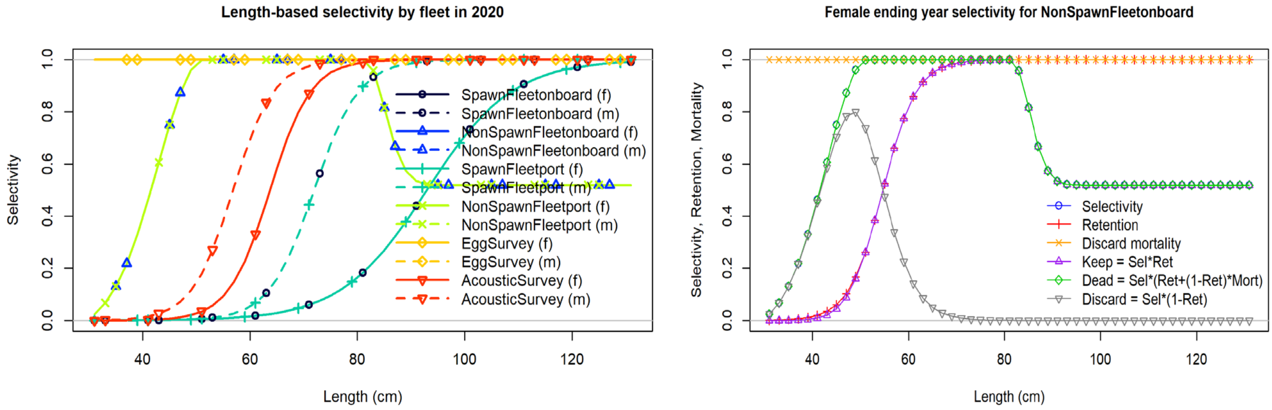


Figure 6.7. Estimated selectivity for the spawning and non-spawning fleets, port and onboard samples and for males (m) and females (f) and the estimated retention function for the non-spawning fleet.

6.6.1.3 Fits to the data

Figure 6.8 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 CVs 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. More recent increases in catch rate are estimated well. The fit to the discard mass is able to replicate the increase in discarding through the late 1990s, mid-2000s and since 2012, however the magnitude is under-estimated (as has been the case with previous assessments). In the past, alternative models that time-blocked discarding, re-weighted discard CVs and included a discard fleet have all been unsuccessful in improving the fit to the discard and CPUE data. Further consideration should 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 95% confidence intervals.

The base-case model fits to the aggregated retained and discarded length-frequency distributions well (Figure 6.9). Note that a single selectivity is estimated for the combined port and onboard fleets. The saw-tooth port lengths which occurs when lengths measured in dorsal standard length (DSL), with values across all length bins, are converted to standard (STD) length, resulting in some length bins with lower estimates and higher estimates in neighbouring bins in the new length composition. Length composition fits by year and fleet are in the Appendix.

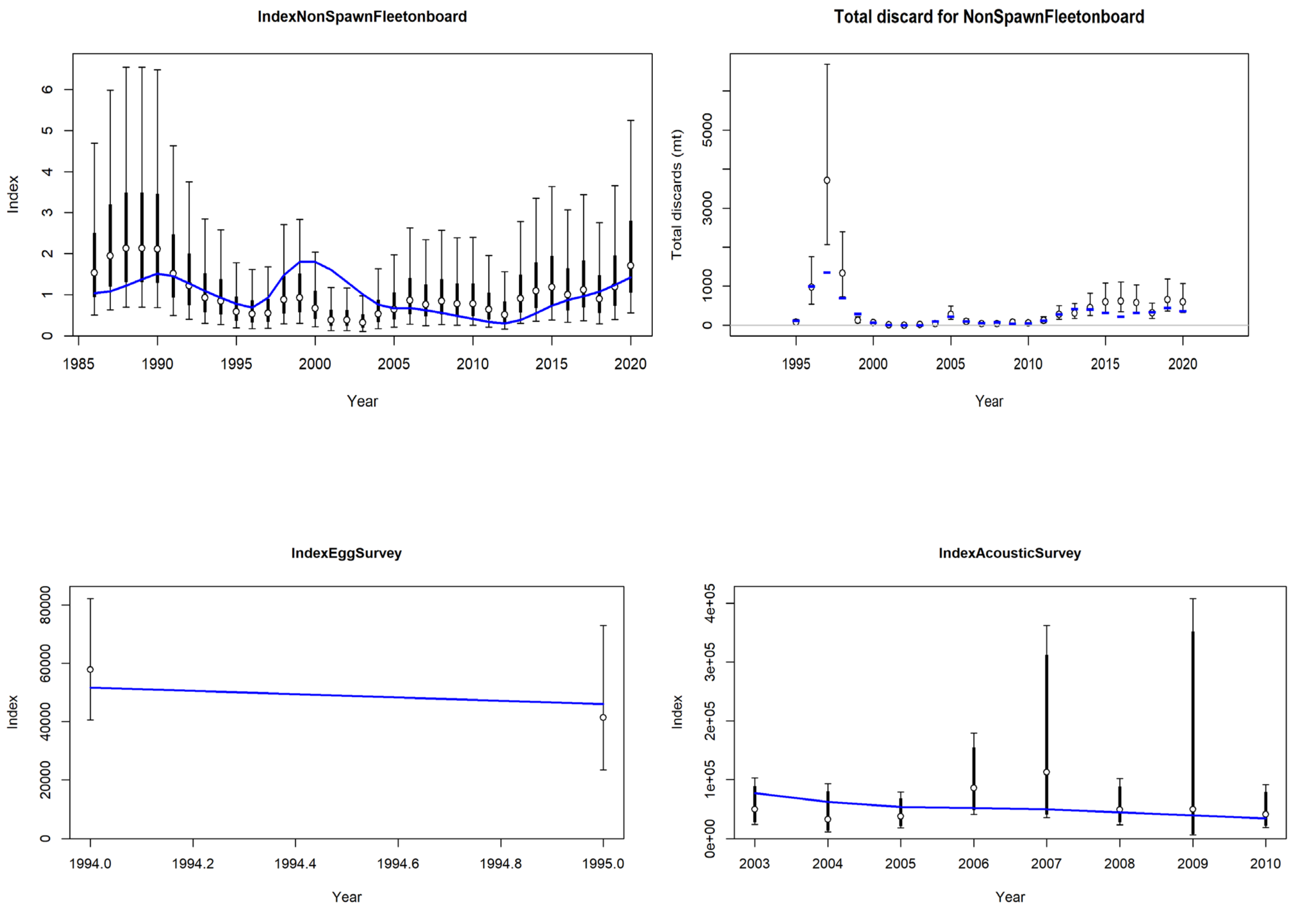


Figure 6.8. Fits to the non-spawning CPUE index, discard mass, egg survey and acoustic survey.

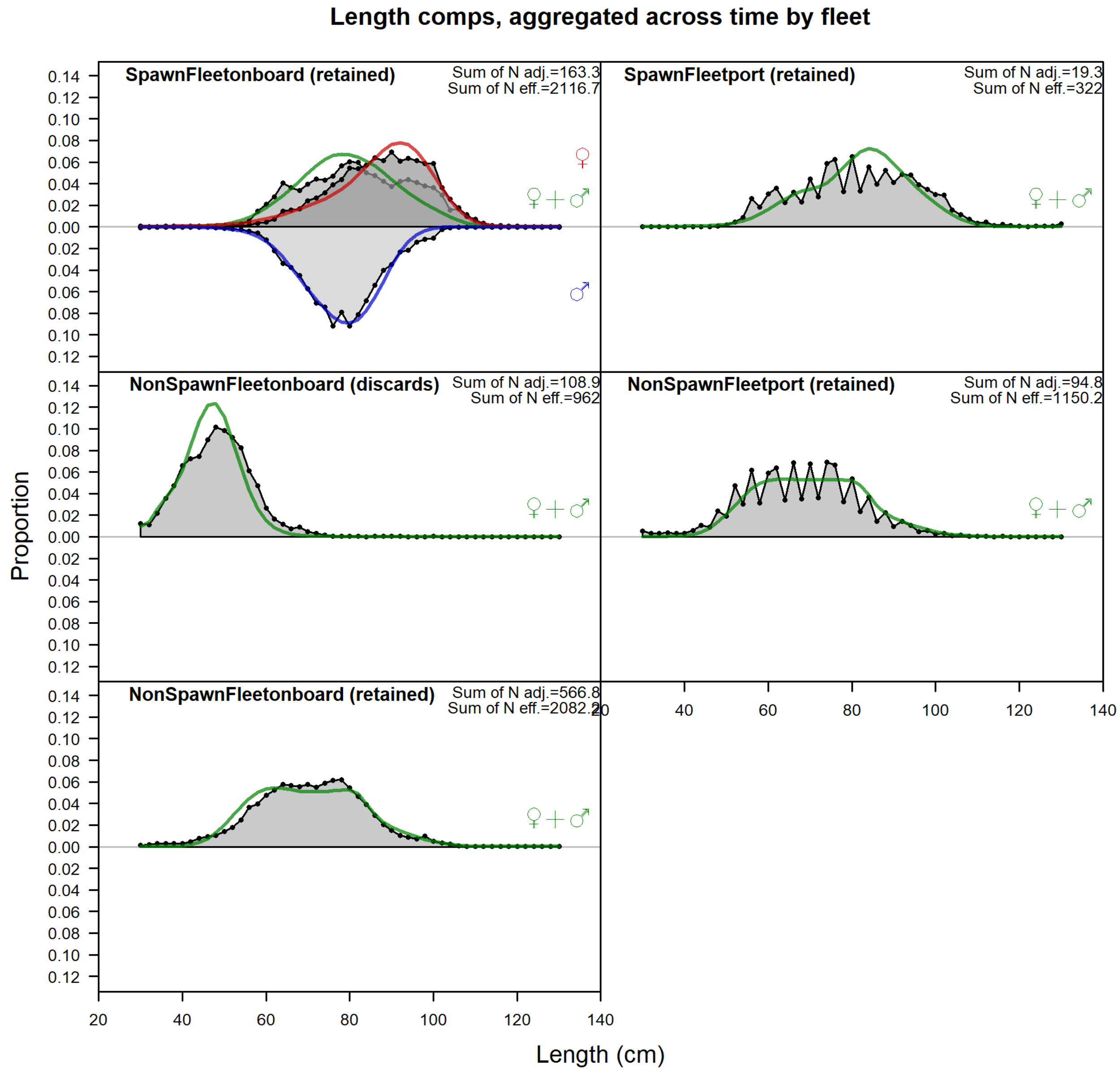


Figure 6.9. Length composition fits aggregated across years.

6.6.1.4 Assessment outcomes – base case

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 2017 (Figure 6.10). The trajectories of spawning biomass and spawning biomass relative to the un-exploited level are shown in Figure 6.10. This shows the increases and decreases in spawning biomass as the strong cohorts move into and out of the spawning population. Spawning biomass has varied considerably, with biomass below the target in 2013 and 2014, but nearly double virgin biomass in 1991, 2001 and 2021. Figure 6.11 shows various recruitment diagnostics and the annual recruitment deviations for the base case model. The figure showing recruitment deviations illustrates the historical episodic nature of recruitment, but also that the last eight estimates of recruitment are well above average. The Kobe plot in Figure 6.12 shows that the stock is well above virgin biomass levels, but also that there is considerable uncertainty regarding both relative fishing mortality and stock status.

The estimated virgin female biomass is 37,445 t (compared to 53,909 t in 2018 and 36,815 t in the 2013 assessments). Initial biomass is known to be sensitive in this model and often has varied betweem 35,000 t and 60,000 t (Figure 6.13; Castillo- Jordán and Tuck, 2018a). A likelihood profile on initial biomass illustrates this uncertainty (Section 5.2).

For the base case model, the projected 2022 spawning stock biomass will be 155% of virgin female spawning biomass (projected assuming 2020 catches in 2021), compared to 122% for 2019 in the 2018 assessment, and 94% for 2014 in the 2013 assessment. The 2022 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 23,777 t, with 245 t estimated discards (23,532 t retained). The long-term RBC is 7,100 t, with 183 t discards (Table 6.8).

Table 6.8. The estimated RBC (tonnes), retained portion of the RBC, estimated discards and relative stock status for Blue Grenadier under the base case model. The retained catch up to 2020 is the actual tonnage (and 2021 catches are projected assuming 2020 catches in 2021), and the RBC is the sum of retained and estimated discards. The grey shading for year 2022 is used for stock status and RBC determination.

Year	RBC	Retained	Discard	Status
2017	2026	1698	328	0.87
2018	2010	1665	345	0.98
2019	7370	6914	456	1.09
2020	12,513	12,151	362	1.23
2021	12,341	12,151	190	1.41
2022	23,777	23,532	245	1.55
2023	21,605	21,391	214	1.47
2024	18,712	18,504	207	1.31
2025	15,848	15,643	205	1.14
2026	13,480	13,277	203	0.97
2027	11,684	11,482	201	0.84
2028	10,380	10,181	199	0.74
2029	9,458	9,262	196	0.66
2030	8,816	8,623	194	0.61
2031	8,370	8,178	191	0.58
2032	8,055	7,866	189	0.55
2033	7,827	7,640	188	0.54
2034	7,658	7,472	187	0.52
2035	7,529	7,343	186	0.51
2036	7,429	7,244	185	0.51
2037	7,351	7,166	184	0.50
2038	7,289	7,105	184	0.50
2039	7,241	7,058	184	0.49
2040	7,204	7,020	183	0.49
2041	7,174	6,991	183	0.49
2042	7,151	6,968	183	0.49
2043	7,133	6,950	183	0.48
2044	7,118	6,936	183	0.48
2045	7,107	6,925	183	0.48

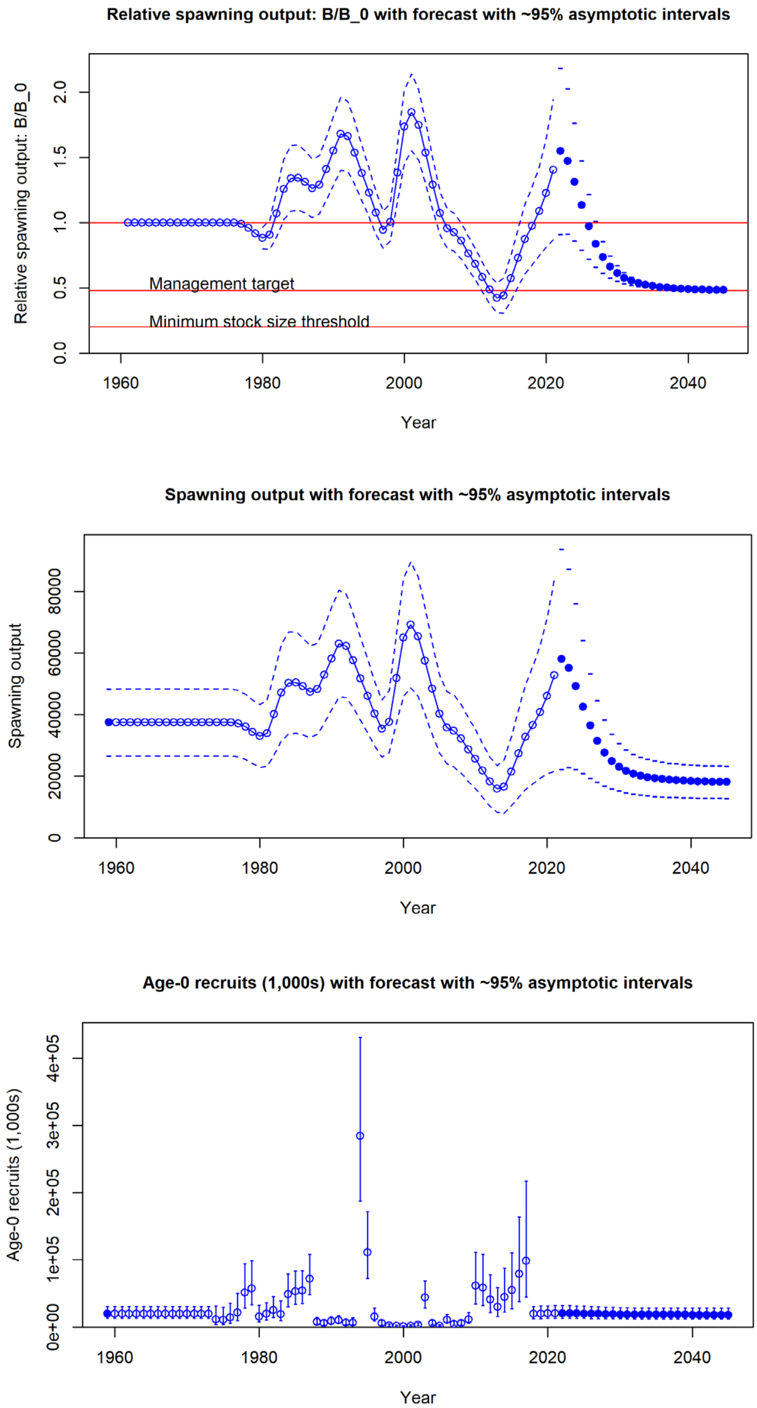


Figure 6.10. The estimated time-series of relative spawning biomass and annual recruitment for the 2021 base case assessment for Blue Grenadier.

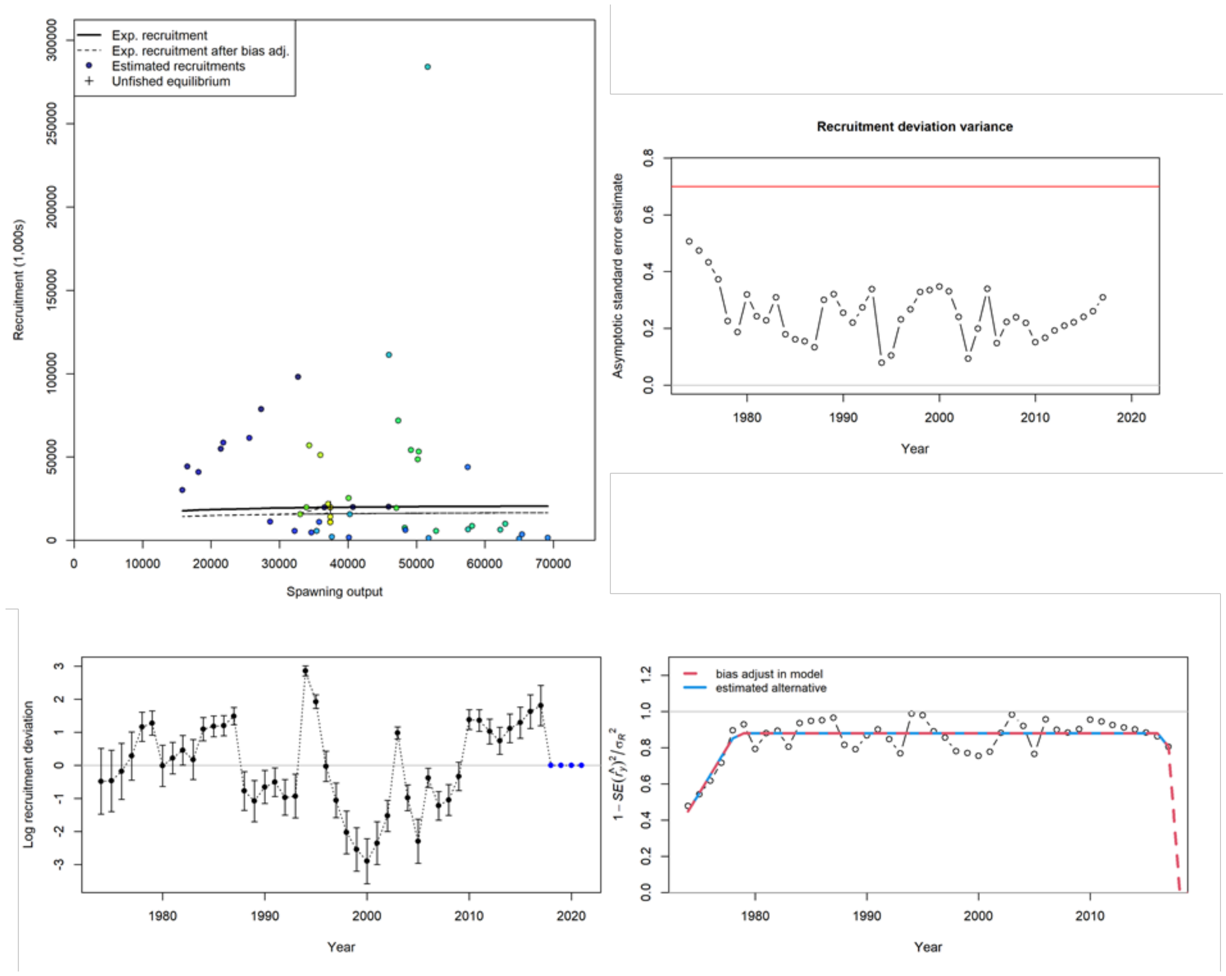


Figure 6.11. Time series showing the stock recruitment curve, recruitment deviations, recruitment deviation variance check and bias ramp for Blue Grenadier.

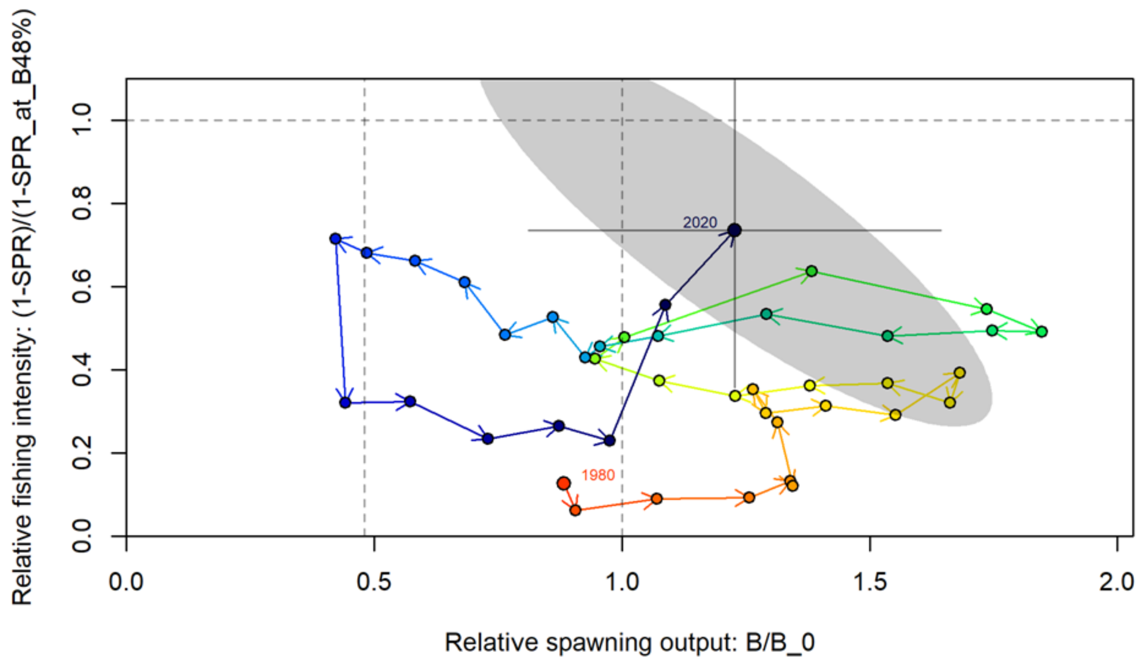


Figure 6.12. Kobe plot showing relative fishing mortality (y-axis) versus relative spawning biomass (x-axis).

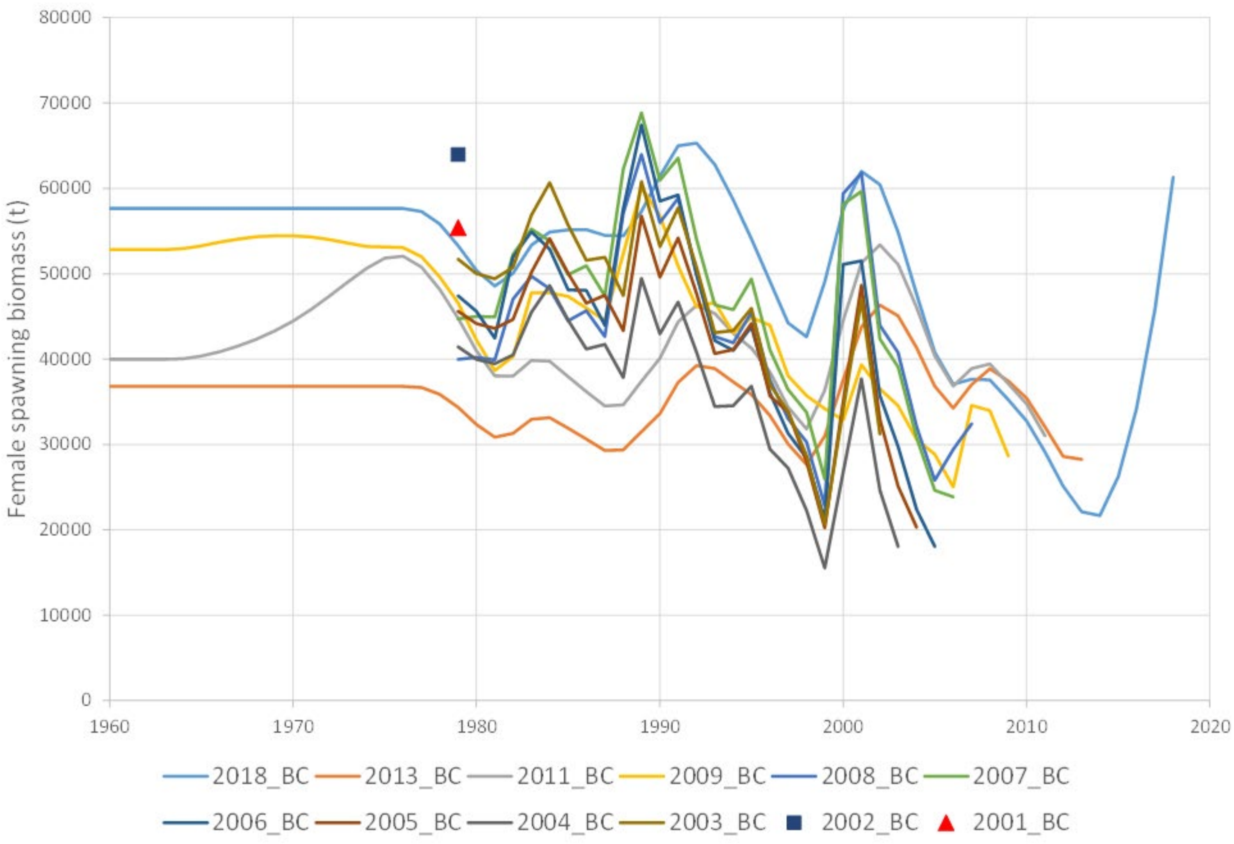


Figure 6.13. A retrospective of assessment outputs of female spawning biomass from each stock assessment from 2001 to 2018. Note that for 2001 and 2002 only values of biomass in 1979 were available (from Castillo-Jordán and Tuck, 2018a).

6.6.2 *Likelihood profiles*

As stated by Punt (2018), likelihood profiles are a standard component of the toolbox of applied statisticians. They are most often used to obtain a 95% confidence interval for a parameter of interest. Many stock assessments "fix" key parameters such as M and steepness based on *a priori* considerations. Likelihood profiles can be used to evaluate whether there is evidence in the data to support fixing a parameter at a chosen value. If the parameter is within the entire range of the 95% confidence interval, this provides no support in the data to change the fixed value. If the fixed value is outside the 95% confidence interval, it would be reasonable for a review panel to ask why the parameter was fixed and not estimated, and if the value is to be fixed, on what basis and why should what amounts to inconsistency with the data be ignored. Integrated stock assessments include multiple data sources (e.g., commonly catch-rates, length-compositions, and age-compositions) that may be in conflict, due for example to inconsistencies in sampling, but more commonly owing to incorrect assumptions (e.g., assuming that catch-rates are linearly related to abundance), i.e. model-misspecification. Likelihood profiles can be used as a diagnostic to identify these data conflicts (Punt, 2018).

Likelihood profiles for key parameters of interest such as female natural mortality (M_f), virgin spawning biomass and stock status are provided in Figure 6.14-Figure 6.16.

For Blue Grenadier, the likelihood profile for female natural mortality, M_f, is shown in Figure 6.14, with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This parameter is estimated in the model (M=0.23 yr^{-1}) and the likelihood profile suggests that it is reasonably well estimated, with a likely range between 0.21 and 0.26 yr^{-1}. The index and age data (suggest higher mortality) and the length data (suggest lower mortality) are in conflict. The non-spawning CPUE and to a lesser extent the egg survey data are driving the preference towards higher estimates of M_{f}, while there is little information in the Acoustic Survey data. All length data inputs are suggesting lower estimates of M_{f}, however, this is mostly driven by the spawning fleet onboard data. There is conflict in age data between the fleets, with the spawning fleet age data suggesting higher estimates of M_{f} are preferable, while the non-spawning fleet age data suggests lower estimates.

A likelihood profile for virgin spawning biomass (SSB_0) is shown in Figure 6.15, with the total likelihood shown in black and components of the total likelihood from different data sources shown in a range of colours. This likelihood profile suggests a range of plausible values for SSB_0 ranging between around 27,000 and 52,000 t with the most likely value at around 37,000 t. The components of the likelihood relating to the surveys suggest larger values of SSB_0 whereas the age data want lower values of SSB_0. Similarly, a likelihood profile on stock status (2020) suggests a broad range of plausible values, from approximately 0.8 to 1.7 (Figure 6.16). The index and age data suggest higher relative biomass whereas the length data suggest lower relative biomass.

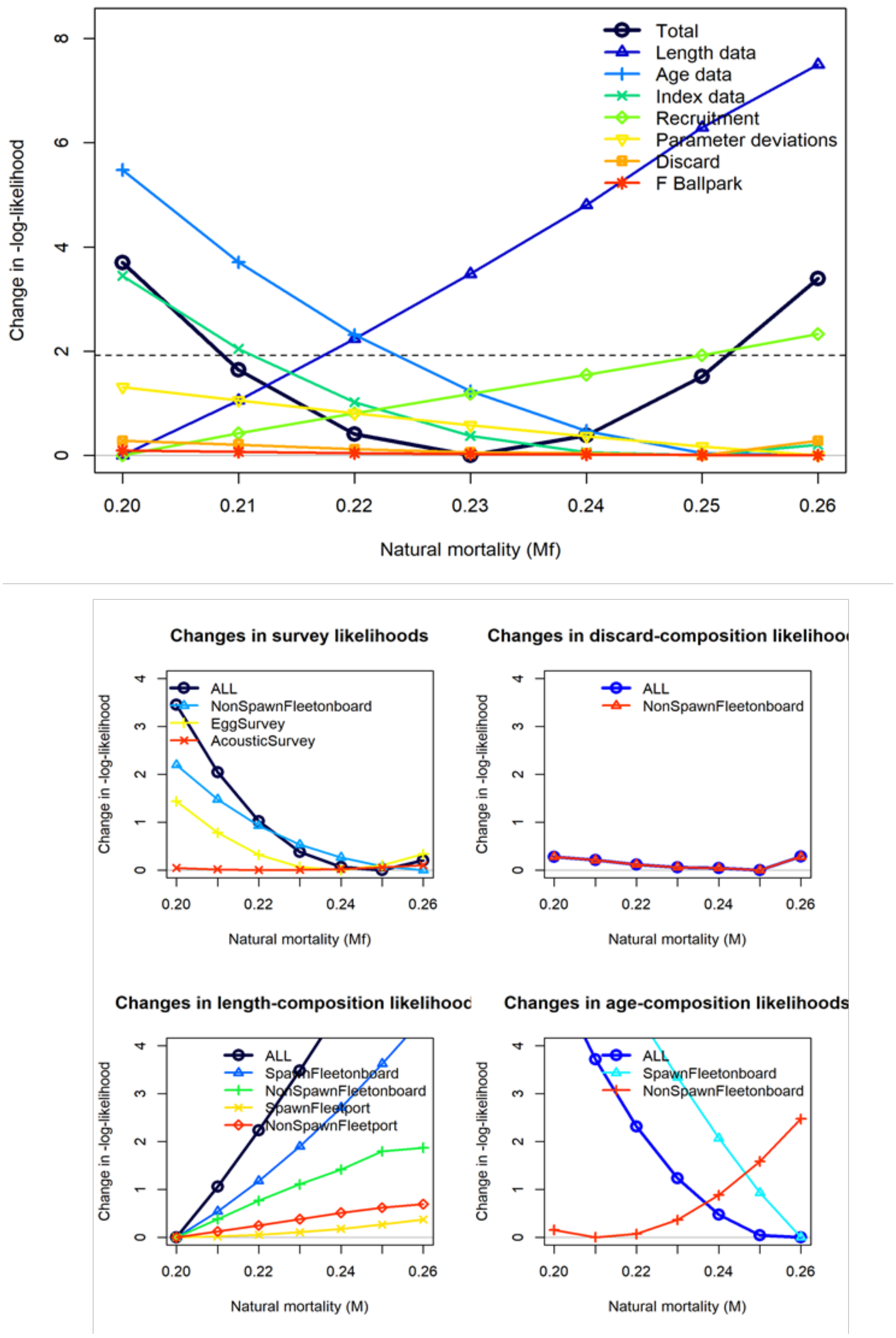
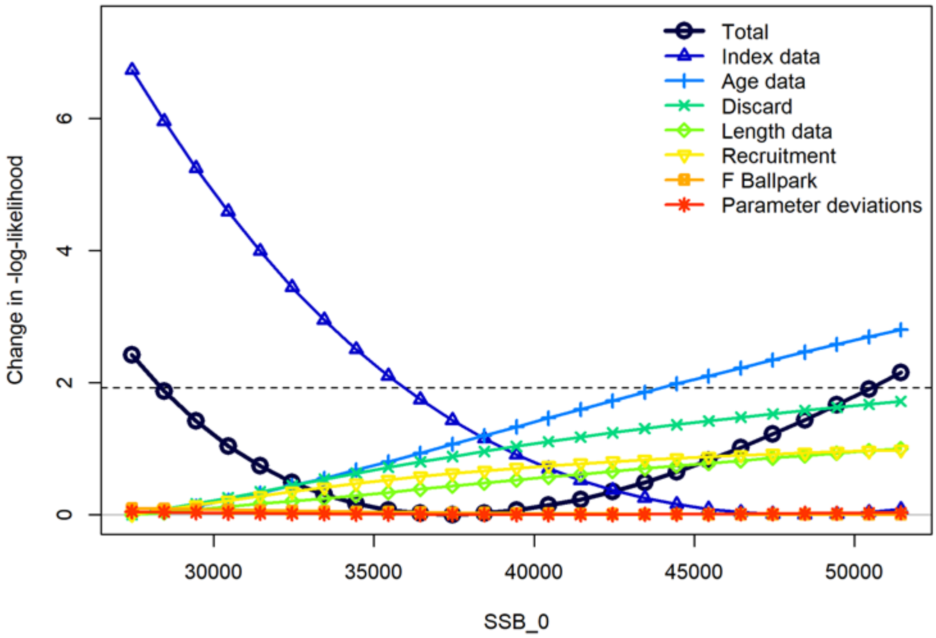


Figure 6.14. The likelihood profile (top) for female natural mortality, with 95% CIs for M_f ranging from 0.21 to 0.26. The estimated value for M is 0.23 yr^{-1}. Piner plot (bottom) for the likelihood profile showing components of the change in likelihood for index, discard, length and age in addition to the changes in the total likelihood.



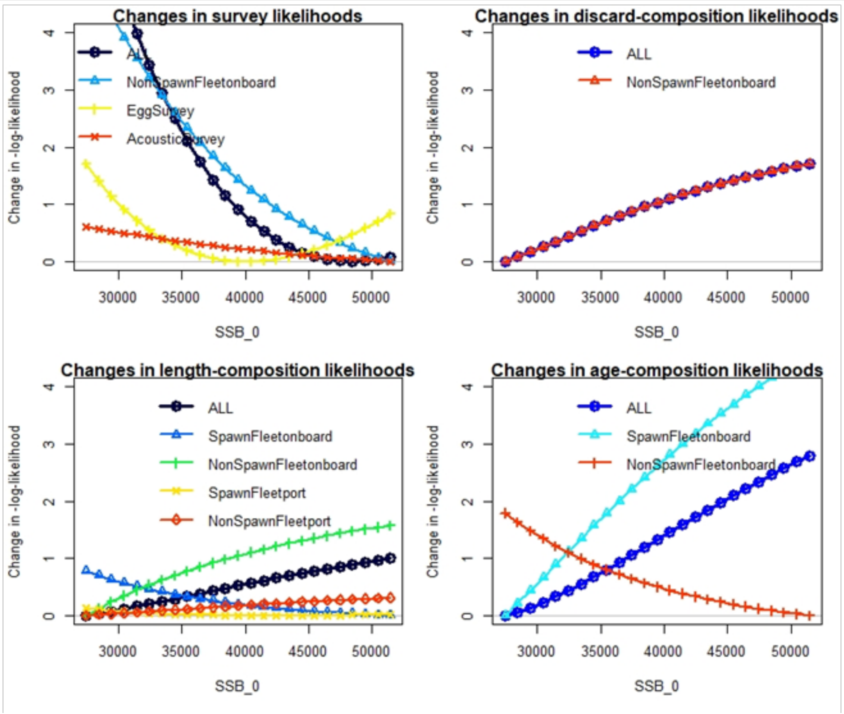


Figure 6.15. The likelihood profile (top) for virgin spawning biomass, with 95% CIs ranging from 27,000 t to 52,000 t. The estimated value is 37,000 t. Piner plot (bottom) for the likelihood profile showing components of the change in likelihood for index, discard, length and age in addition to the changes in the total likelihood.

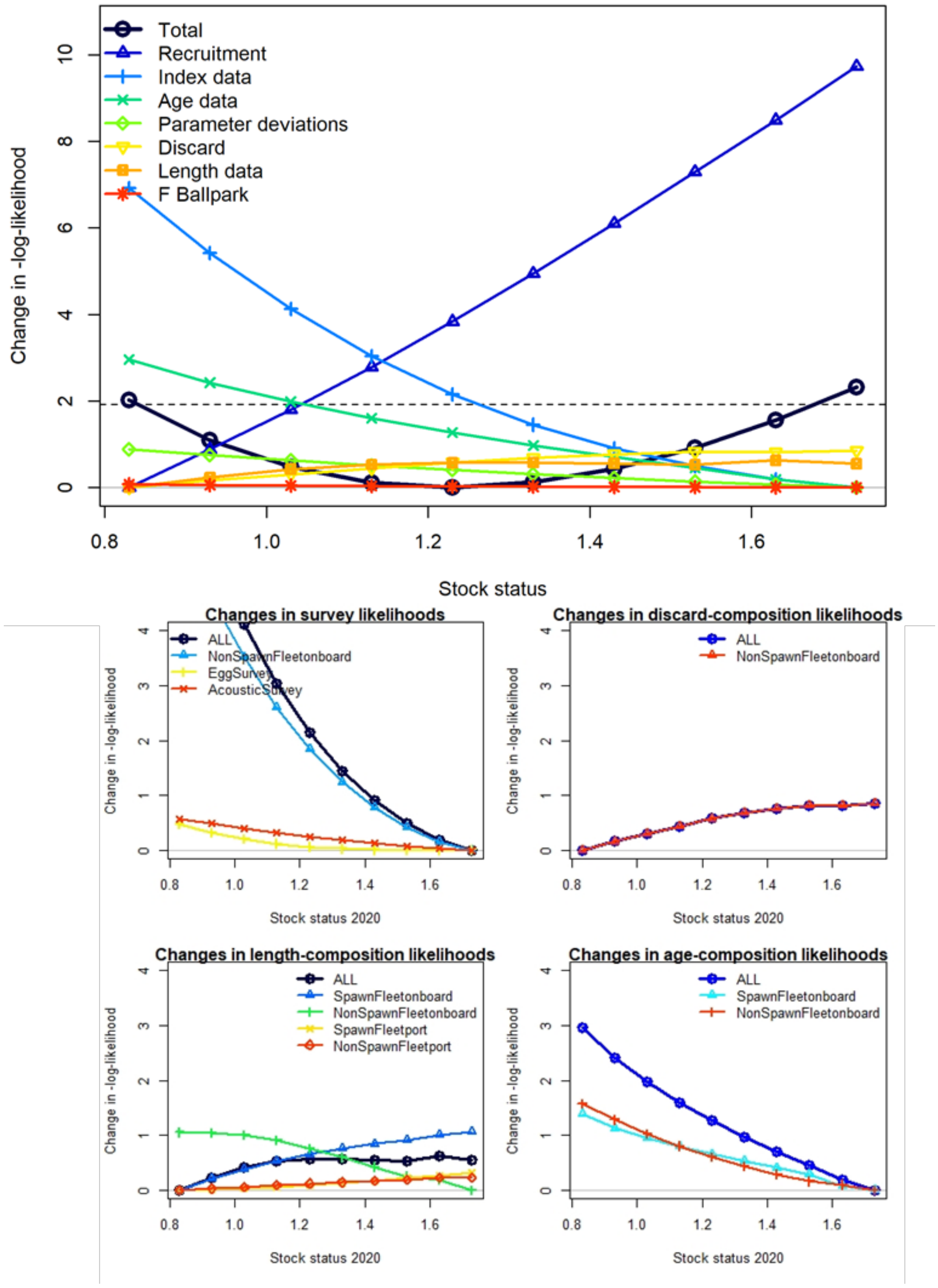


Figure 6.16. The likelihood profile (top) for 2020 stock status, with 95% CIs ranging from 0.8 to 1.7. The estimated value is 1.25. Piner plot (bottom) for the likelihood profile showing components of the change in likelihood for index, discard, length and age in addition to the changes in the total likelihood.

6.6.3 *Retrospectives*

A retrospective analysis was completed, starting from the most recent year of data, working backward in time and removing five successive years of data from the assessment. This analysis can highlight potential problems and instability in an assessment (Cadrin and Vaughan, 1997; Mohn, 1999). The severity of retrospective patterns can be quantified using a statistic called Mohn's rho, which is defined as the average of the relative differences between an estimate from an assessment with a truncated time series and an estimate of the same quantity from an assessment using the full time series (Hurtado-Ferro et al., 2015). Mohn's rho values are calculated for a range of effects, including SSB, recruitment, F and stock status. As a general rule, values of Mohn’s rho higher than 0.20 or lower than −0.15 are cause for concern in an assessment (Hurtado-Ferro et al., 2015). The retrospective analysis for relative and absolute spawning biomass, fit to non-spawning catch rate, and recruitment is shown in Figure 6.17, with the base case model in dark blue, and then successive years data removed back to 2015 (shown in red).

There is some evidence of over-optimistic estimation of the spawning biomass in the last year of the SSB trajectory in each case, which is also supported by Mohn’s Rho being 0.26 for biomass, -0.49 for recruitment, -0.1 for F and 0.26 for stock status. Of these, estimates for biomass, recruitment and stock status are higher or lower than threshold values and indicate retrospective patterns of concern, suggesting some misspecification within this assessment.

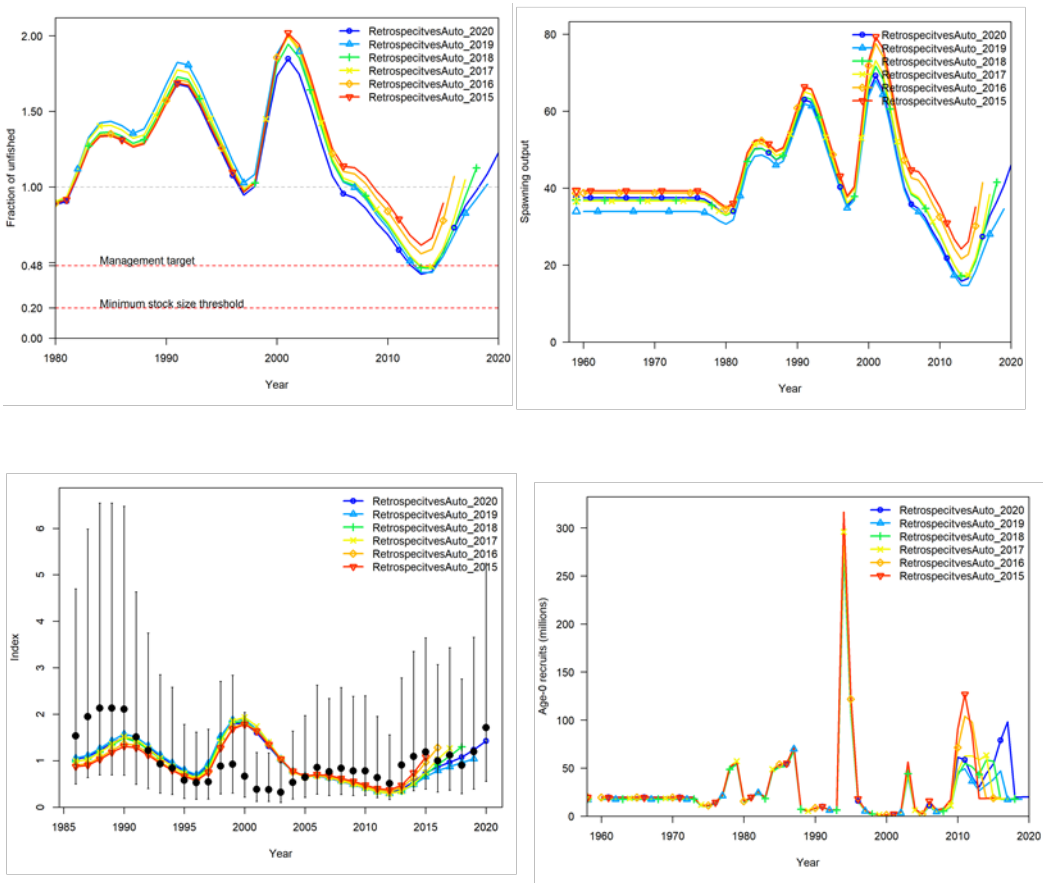


Figure 6.17. Retrospectives for relative and absolute spawning biomass, CPUE and recruitment for Blue Grenadier, with the most recent base case assessment shown (blue) and then successive years removed back to 2015 (red).

6.6.4 *Jitter analysis*

Jitter analysis is a technique used to test the optimality, robustness and stability of the maximum likelihood estimate obtained for a particular model. This involves randomly changing the starting values used for all estimated parameters and re-running the model, to test what alternative solutions may be found by the optimisation algorithm from different initial locations, which is sometimes referred to as sensitivity to initial conditions. Two diagnostics are of interest with a jitter analysis, initially a check on whether a better "optimal solution" may be found, with a higher likelihood value, and also to see how frequently the optimal solution is found. As all estimated parameters are randomly modified, or "jittered," simultaneously, this can sometimes result in a model either failing to converge or finding a local maximum in a different (suboptimal) part of the multi-dimensional parameter space. A jitter analysis was conducted with 25 replications, modifying initial values by 0.1.

For the base case eight of the 25 jitter replicates found the same optimum solution, with a likelihood of 1922.81. The remaining 17 replicates found worse 'optimal' solutions with 16 replicated with a likelihood of 1923.24 and the last with a likelihood of 1930.00.

6.6.5 *Sensitivities*

Results of the sensitivities to the potential base case are listed in Table 6.9. The usual set of sensitivities are provided (which includes sensitivities on natural mortality, steepness, σ_R and halving and doubling the weighting on length, age and index data). Relative spawning biomass varies between 1.35 and 2.12 of virgin biomass, but with most sensitivities near 1.6.

Unweighted likelihood components for the base case and differences for the sensitivities are shown in Table 6.10. This table tends to show that for most alternatives, the fit to the data is degraded by moving away from base case model values or weighting schemes.

Table 6.9. Summary of results for the base case model BC and sensitivity tests. RBC 2022-24 is the average 3-year RBC. RBC 2022-26 is the average 5-year RBC. Note that only the base case is tuned.

Model	SB0	SB_Curr	CurrDepl	2022 RBC	RBC 2022-2024	RBC 2022-2026	RBC Long-term
Base Case Model (M_f=0.23, M_m=0.24, h=0.75)	37,445	57,991	1.55	23,777	21,365	18,684	7,100
M_f = 0.21	36,245	48,939	1.35				
M_f = 0.25	38,442	65,679	1.71				
h = 0.65	39,149	69,311	1.77				
h = 0.85	38,350	66,991	1.75				
σ_R= 0.6	34,745	48,002	1.38				
σ_R = 0.8	42,079	84,083	2.00				
Double weight on Index data	43,313	91,726	2.12				
Half weight on Index data	32,439	44,700	1.38				
Double weight on Length data	38,551	72,653	1.88				
Half weight on Length data	39,971	70,952	1.78				
Double weight on Age data	35,639	61,653	1.73				
Half weight on Age data	41,872	69,796	1.67				

Table 6.10. 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.

Model	TOTAL	Survey	Discard	Length comp	Age comp	Recruitment
Base Case Model (M_f=0.23, M_m=0.24, h=0.75)	1922.81	-6.73	25.55	308.00	1505.08	66.61
M_f = 0.21	0.97	0.86	-0.01	-1.16	1.53	-0.57
M_f = 0.25	0.87	-0.53	0.03	1.61	-0.56	0.59
$h = 0.65$	1.44	0.32	7.91	-9.84	0.27	2.40
$h = 0.85$	-0.34	0.72	7.45	-9.89	0.00	0.91
σ_R = 0.6	21.41	0.74	2.62	1.14	4.79	12.35
σ_R = 0.8	-7.65	-3.02	-2.10	9.81	-5.15	-6.98
Double weight on Index data	8.51	-5.54	2.25	8.83	0.14	2.95
Half weight on Index data	1.49	4.43	6.24	-9.52	-0.28	0.09
Double weight on Length data	14.04	0.10	24.20	-41.84	23.55	4.76
Half weight on Length data	18.63	-1.07	-9.22	50.88	-18.75	-0.57
Double weight on Age data	12.46	0.80	2.32	27.02	-29.93	10.35
Half weight on Age data	11.58	-0.29	6.61	-24.43	38.63	-7.34

6.7 Discussion

The estimated virgin female biomass is 37,445 t (compared to 53,909 t in 2018 and 36,815 t in the 2013 assessments). Initial biomass is known to be sensitive in this model and often has varied between 35,000 t and 60,000 t. The likelihood profiles reinforce that initial biomass is uncertain, as is the estimate of current stock status. However, all model sensitivities showed current relative biomass being well above the target and likely to be above initial biomass levels. There continues to be strong estimates of recent recruitment (eight years above average) which is a good sign for the fishery. As with all assessments, recent estimates of recruitment are generally less well estimated (as there are less data to inform those estimates) and so some caution should be taken with regard to the estimated recent recruitments. In addition, reducing the broad estimates of relative current biomass would be beneficial, and additional acoustic estimates of spawning biomass will likely assist in this regard. As has been observed in previous assessments of Blue Grenadier, the fit to the non-spawning fishery catch rate, especially in the early years, is poor. Further refinement of the model should consider alternative GLM models for CPUE standardisation, or potential changes to model structure to account for the poor fit. The assessment shows retrospetive patterns of concern for biomass, F and stock status estimates. These results suggest that there could be some misspecification in the assessment with a time varying factor that may not be accounted for in the assessment. Further investigation of these patterns in future assessments is warranted.

Assessment outcome:

The projected 2022 spawning stock biomass will be 155% of virgin female spawning biomass (projected assuming 2020 catches in 2021), compared to 122% for 2019 in the 2018 assessment, and 94% for 2014 in the 2013 assessment.

For the base case model, the 2022 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 23,777 t, with 245 t estimated discards (23,532 t retained). The long-term RBC is 7,100 t, with 183 t discards.

6.8 Acknowledgements

Age data were provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Paul Burch, Robin Thomson, Roy Deng, Franzis Althaus, Toni Cannard and Caroline Sutton (CSIRO) pre-processed the data. Miriana Sporcic provided standardised CPUE. Malcolm Haddon provided useful code for auto-balancing, Athol Whitten provided useful R code for organising plots. Paul Burch provided an updated ageing error matrix. Jemery Day, Andre Punt, Robin Thomson and Paul Burch (CSIRO) provided valuable review and discussion of this work. Ian Taylor, Chantel Wetzel, Kathryn Doering and Kelli Johnson (NOAA) are thanked for helpful reccomendations and fixes in relation to the the r4ss package. The r4ss package maintained by Ian Taylor (https://github.com/r4ss/r4ss) was critical for producing multiple diagnostic plots, and tuning models.

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6.10 Appendix

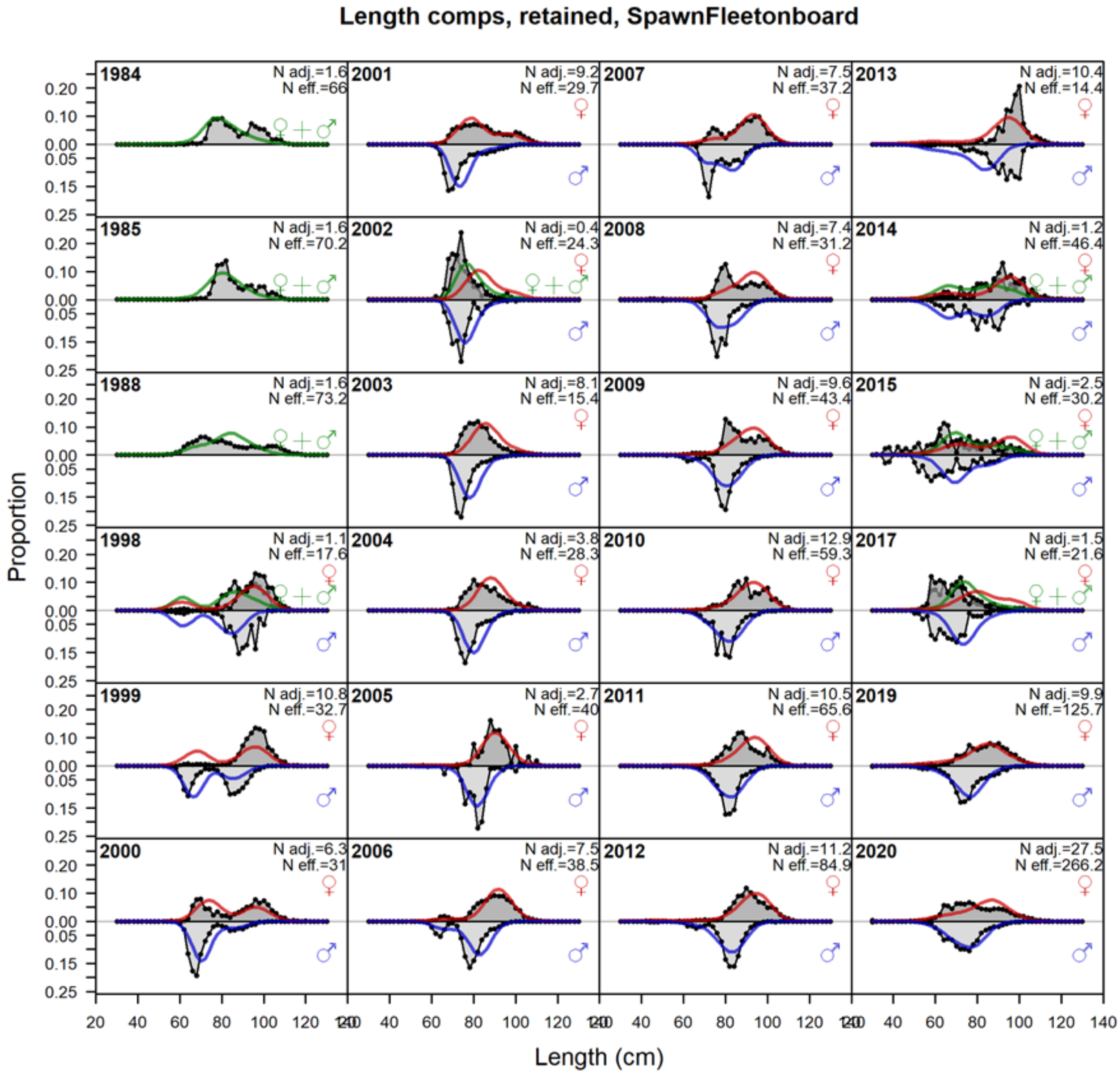


Figure 6.18. Length composition fits: onboard spawning fleet retained.

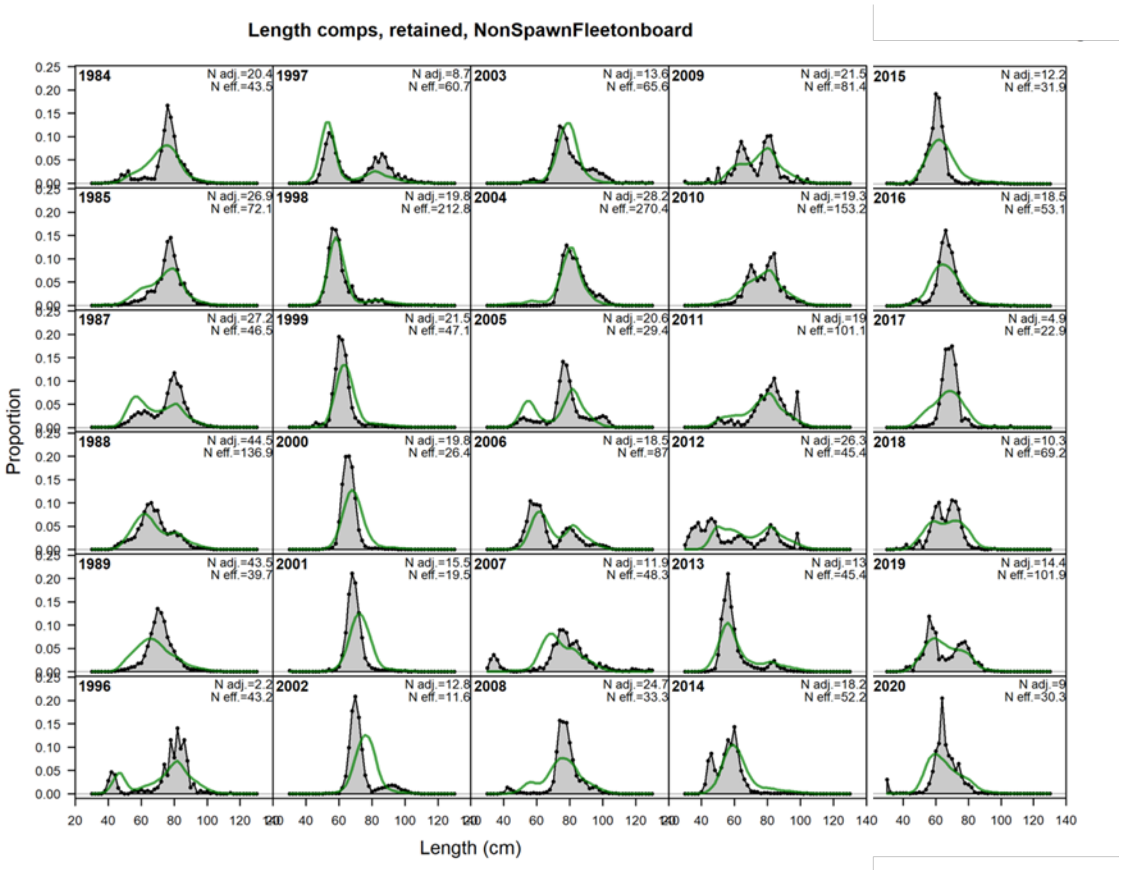


Figure 6.19. Length composition fits: onboard non-spawning fleet retained.

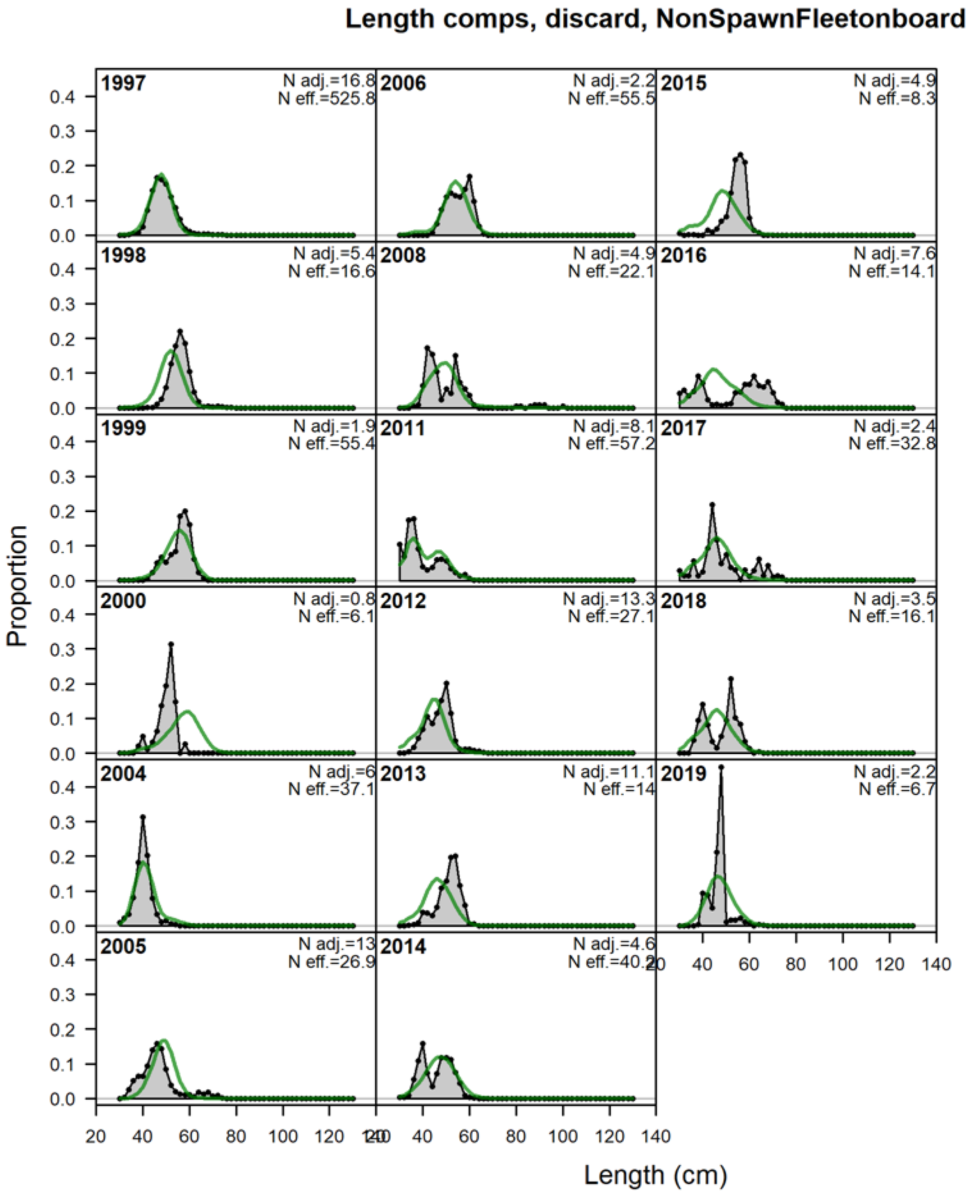


Figure 6.20. Length composition fits: onboard non-spawning fleet discard.

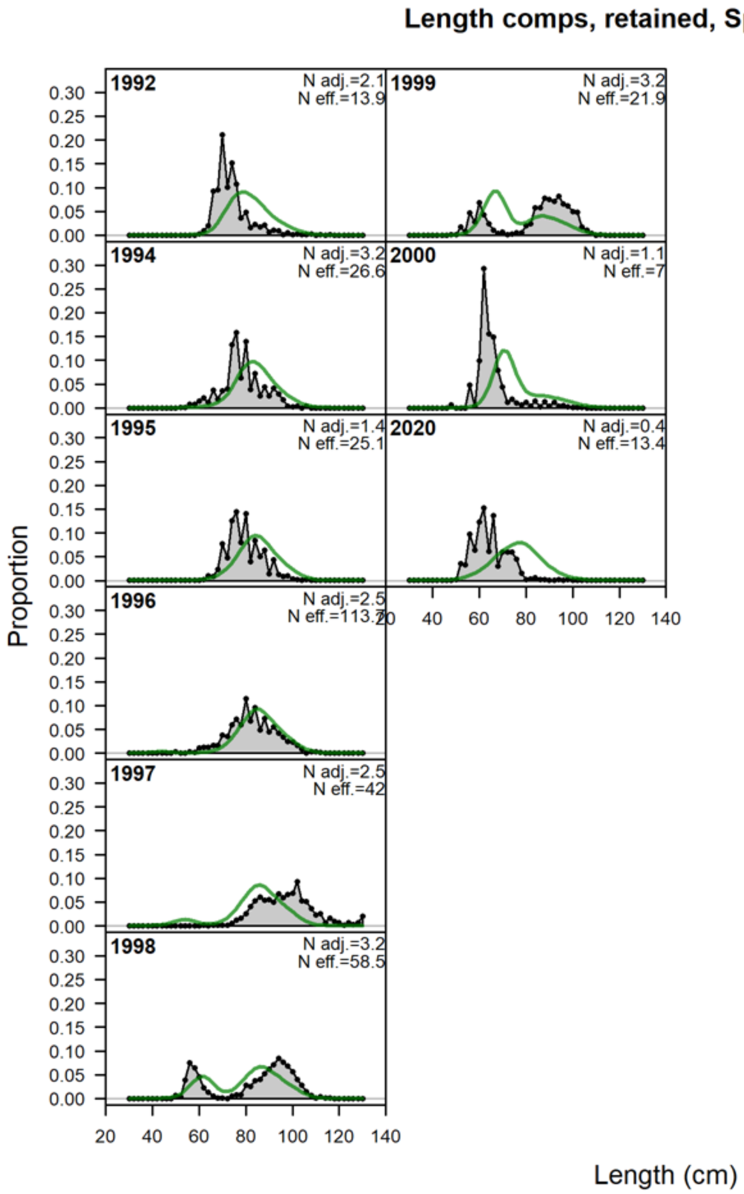


Figure 6.21. Length composition fits: port spawning fleet retained.

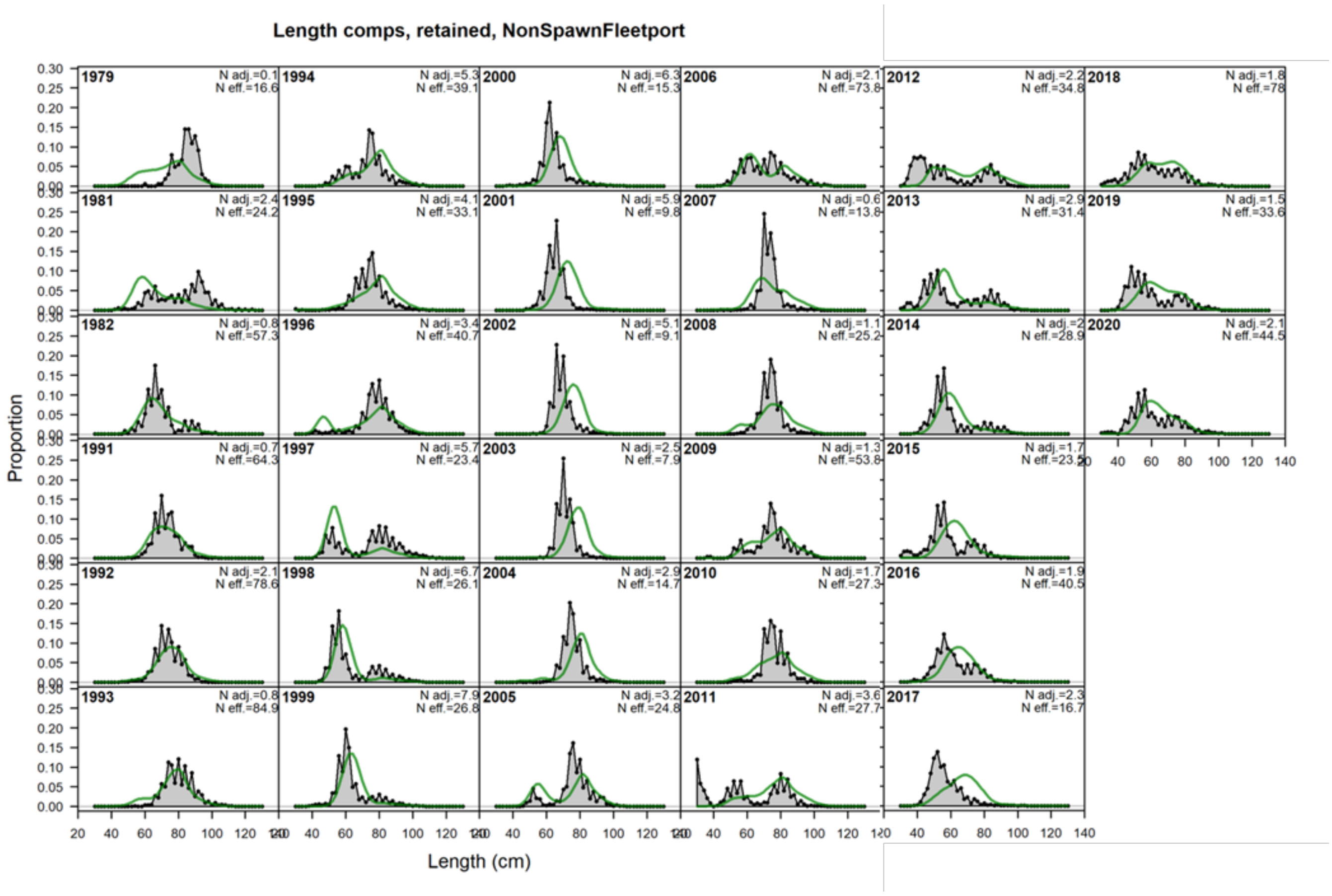


Figure 6.22. Length composition fits: port non-spawning fleet retained.

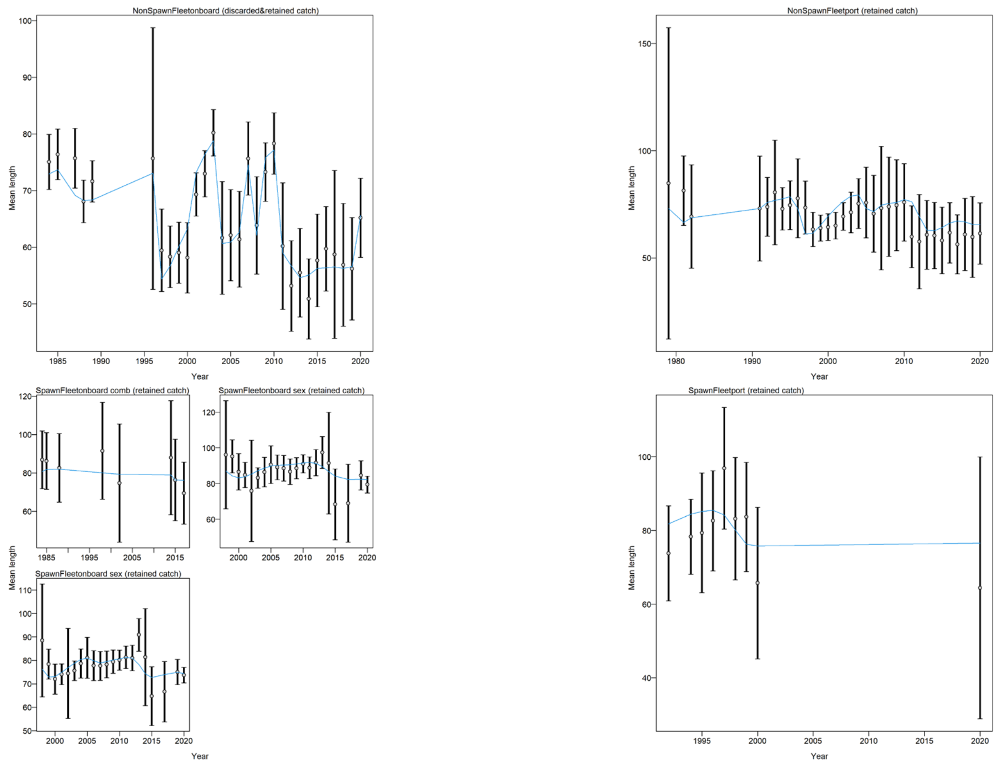


Figure 6.23. Length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.

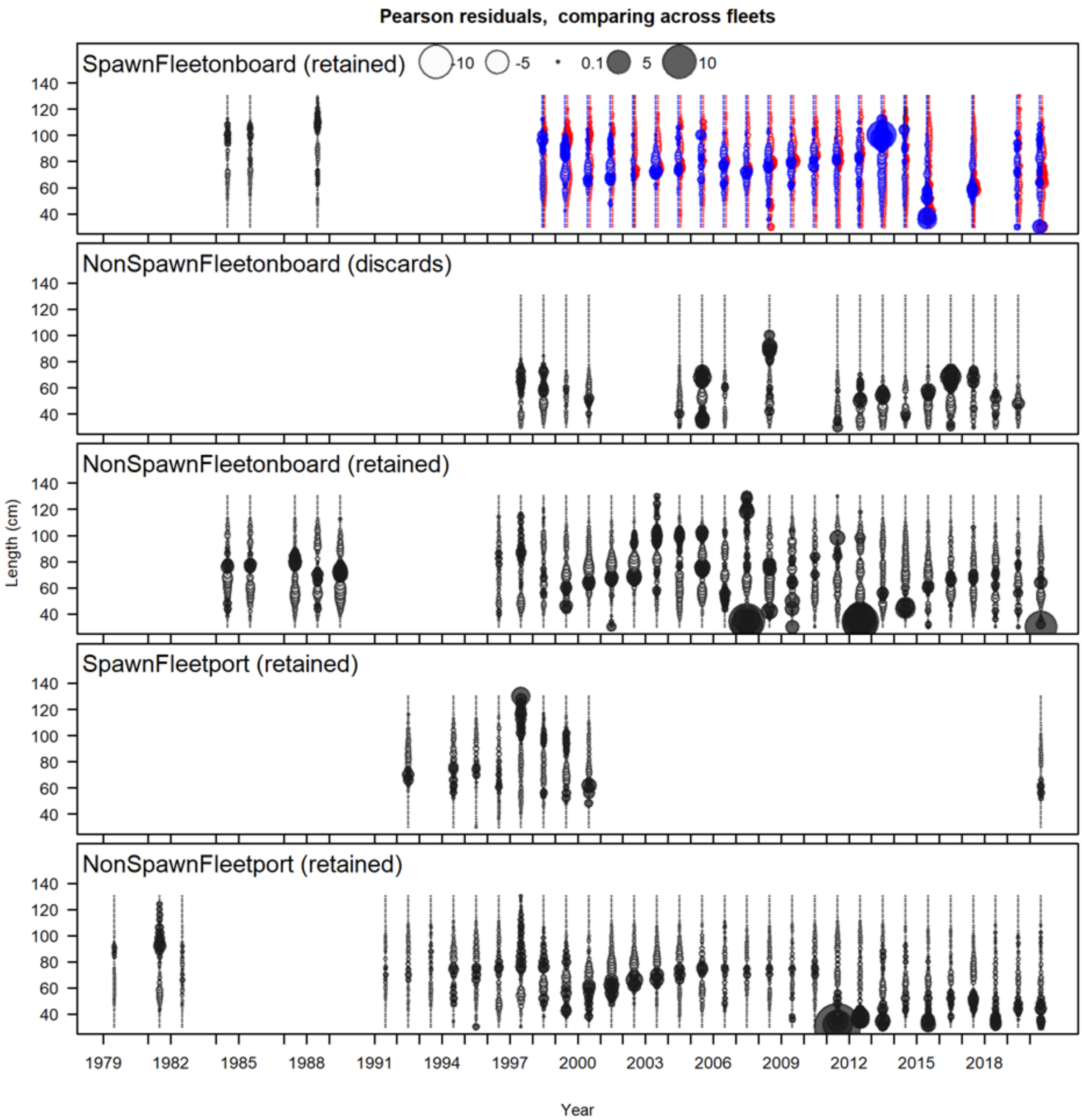


Figure 6.24. Residuals from the annual length compositions for base case

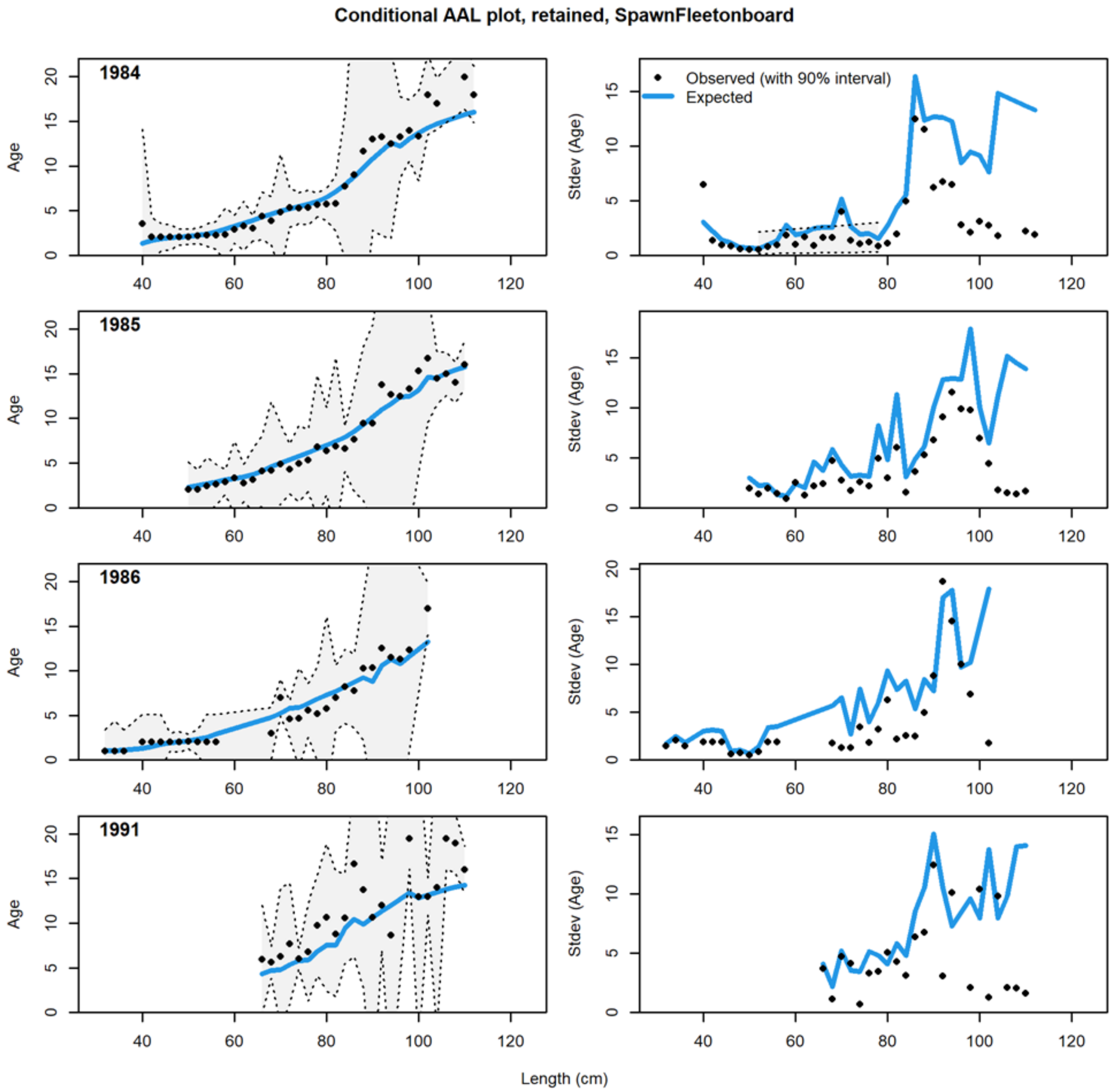
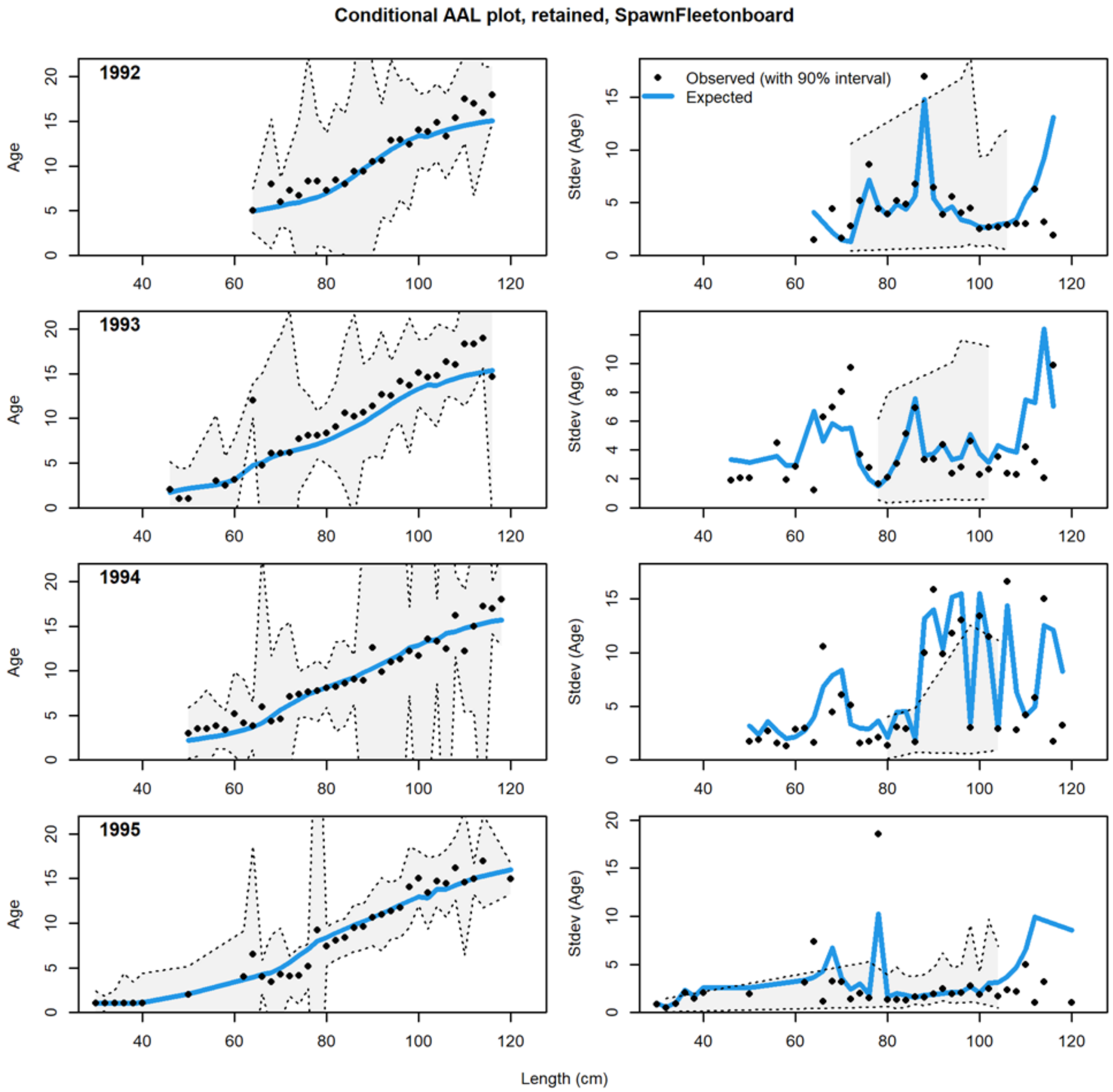
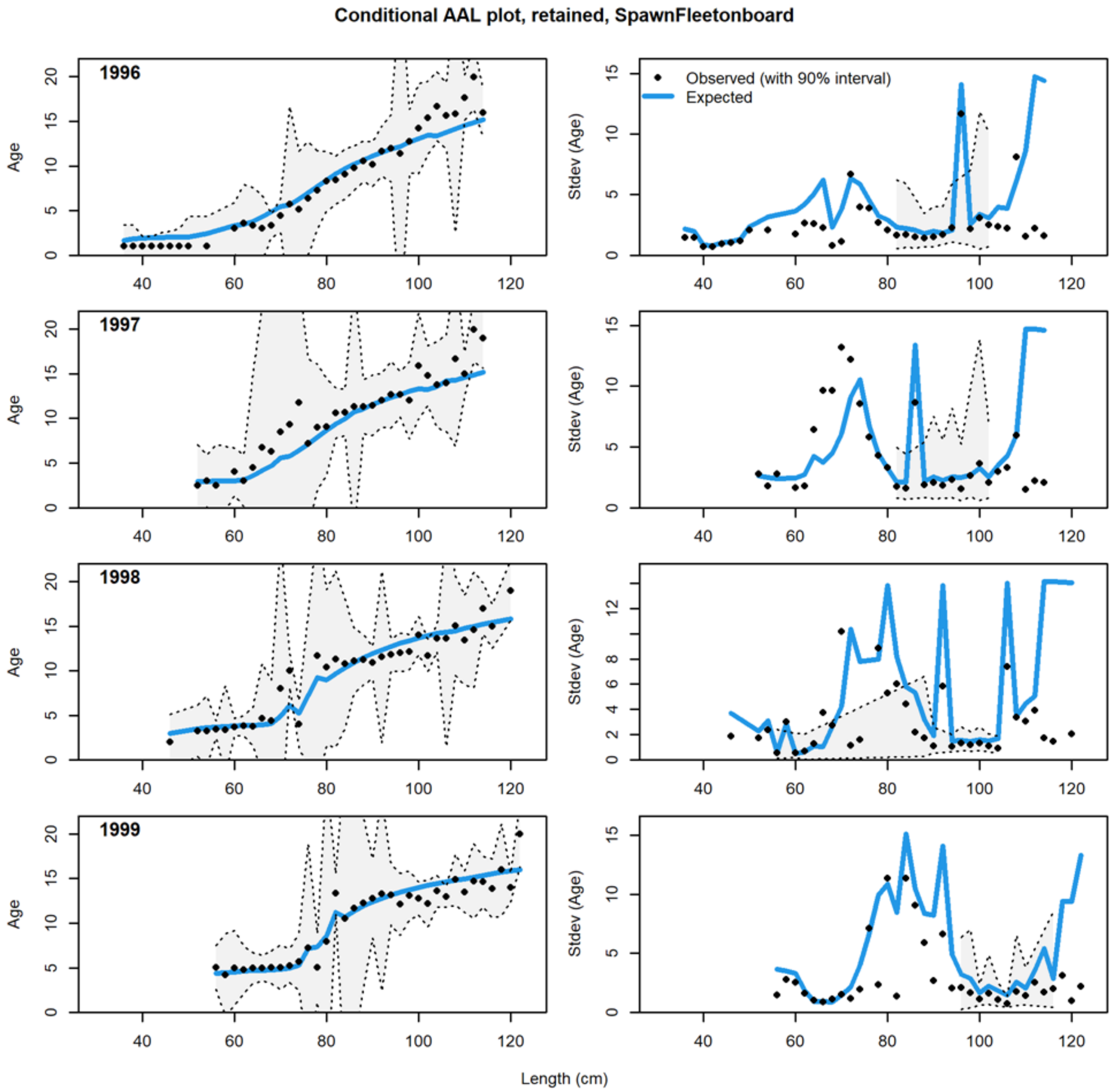


Figure 6.25. Fits to conditional age at length data.


Conditional AAL plot, retained, SpawnFleetonboard
1992
1993
1994
1995
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)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1997
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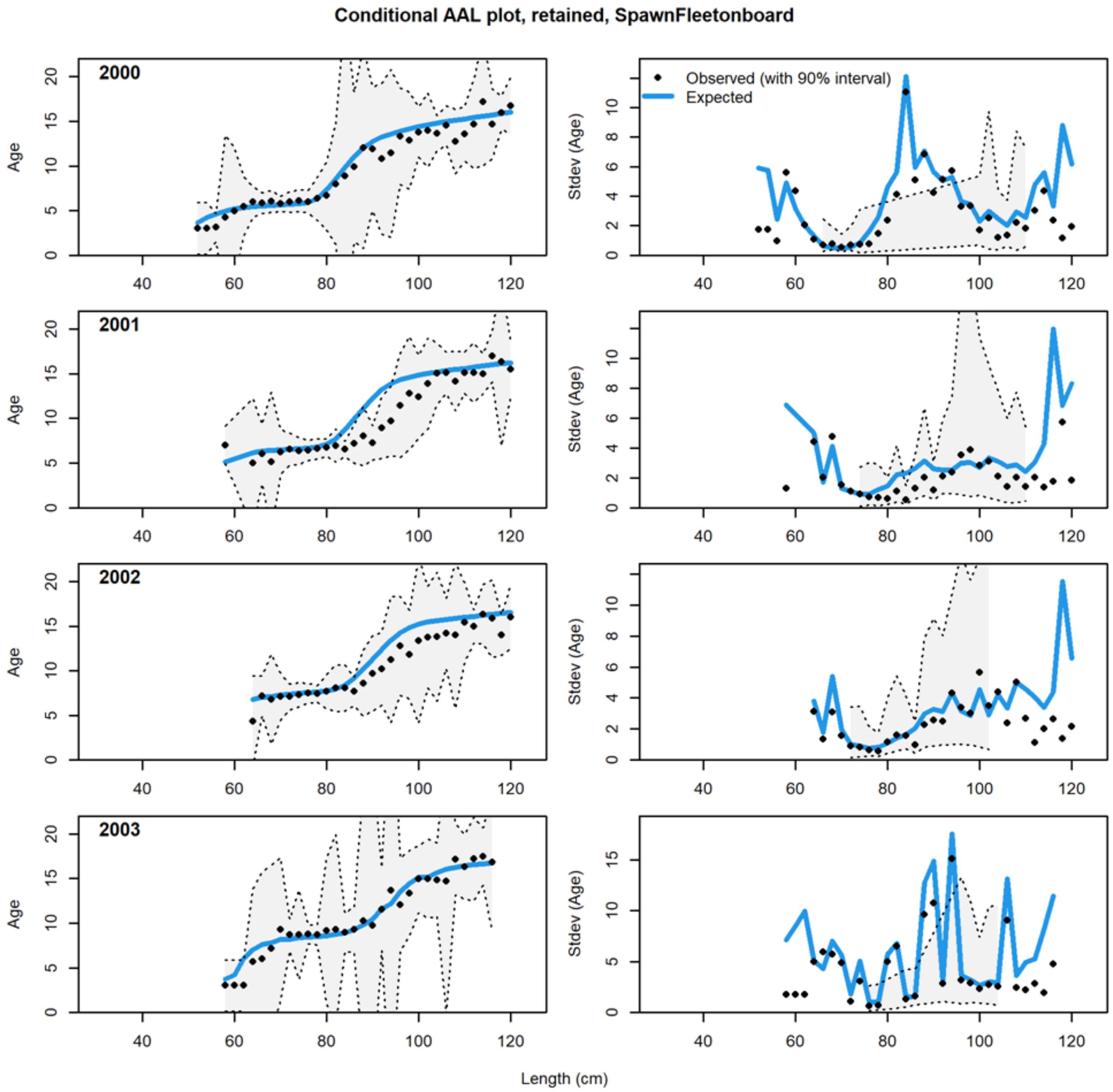
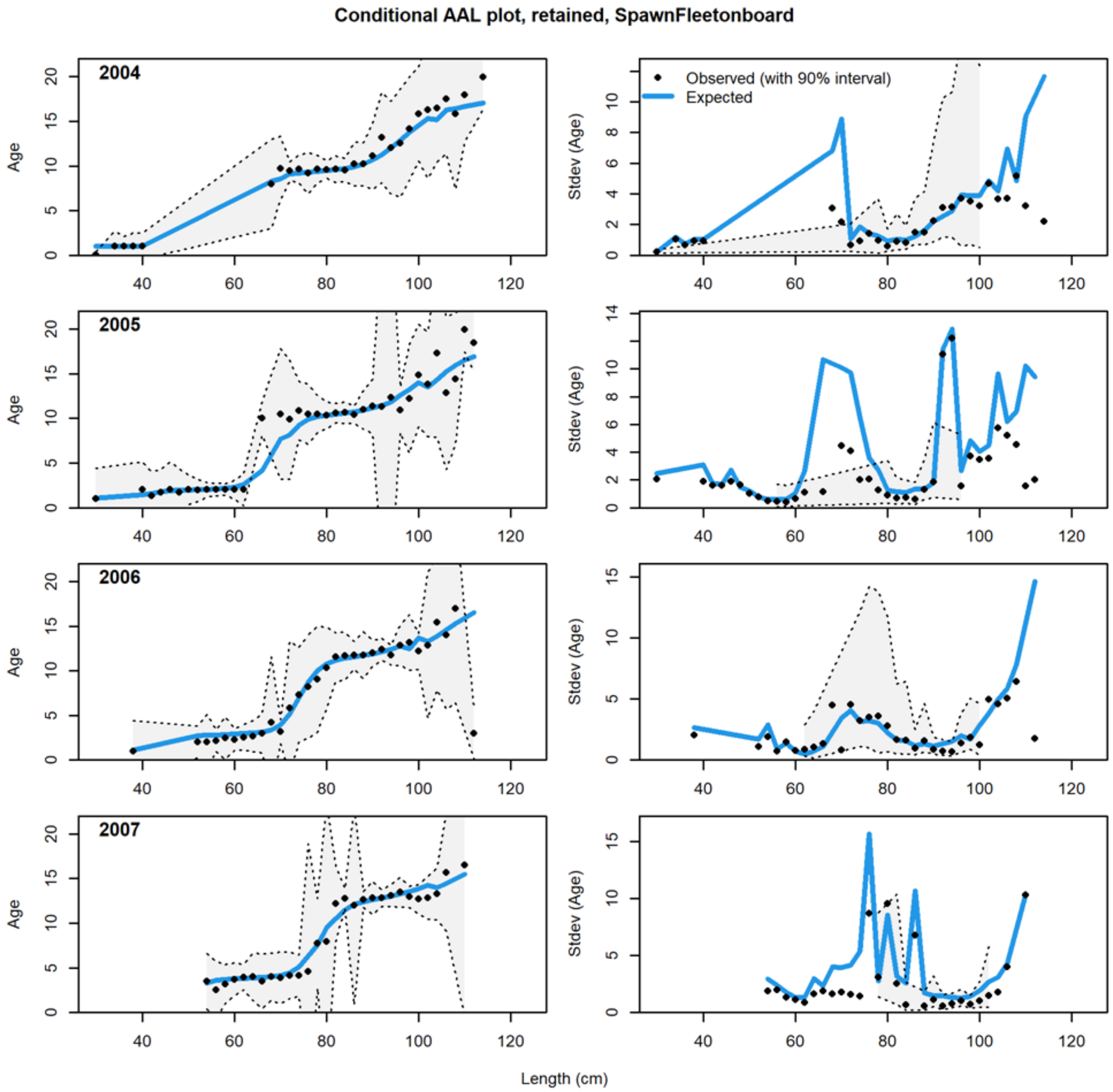
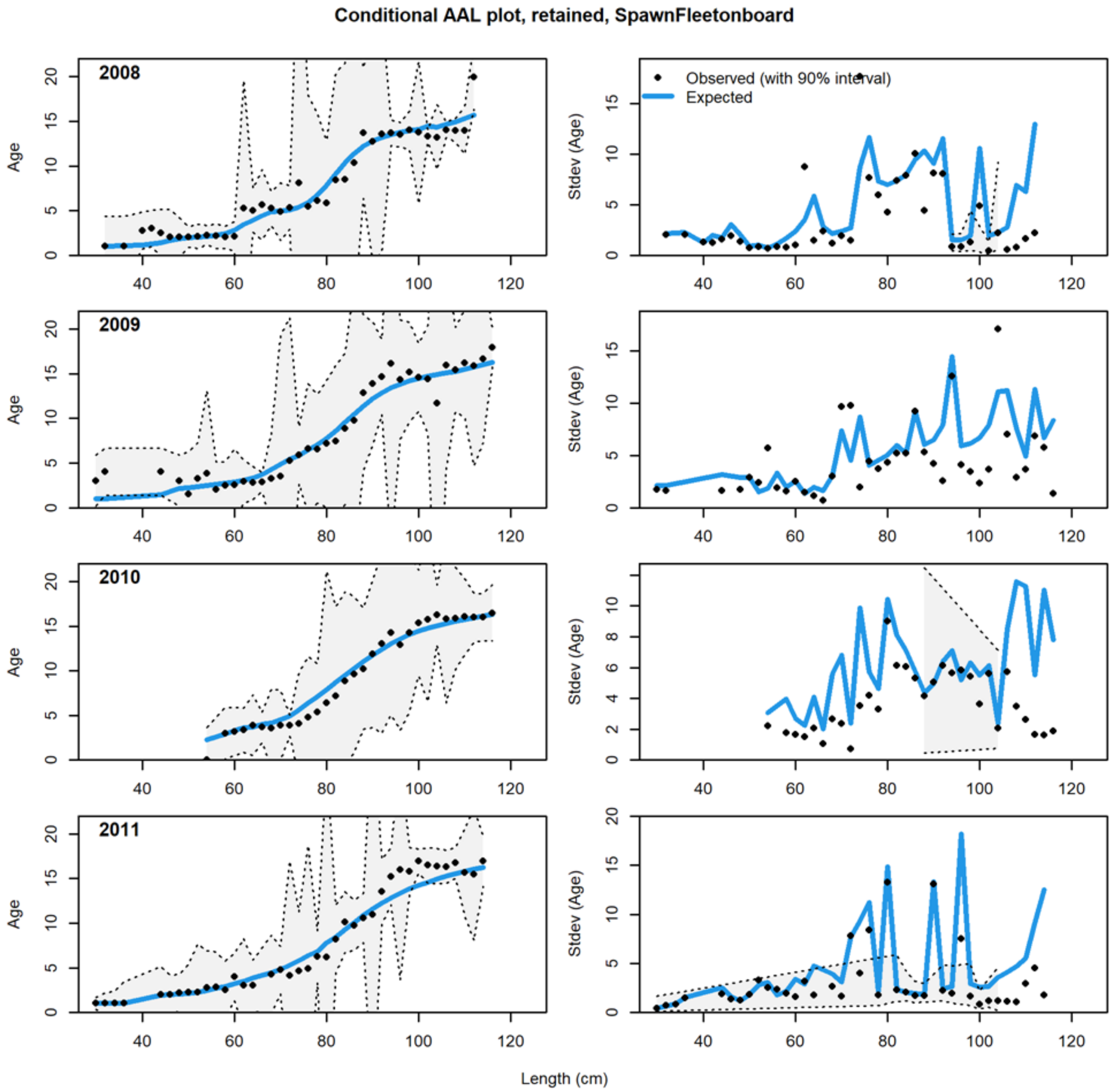
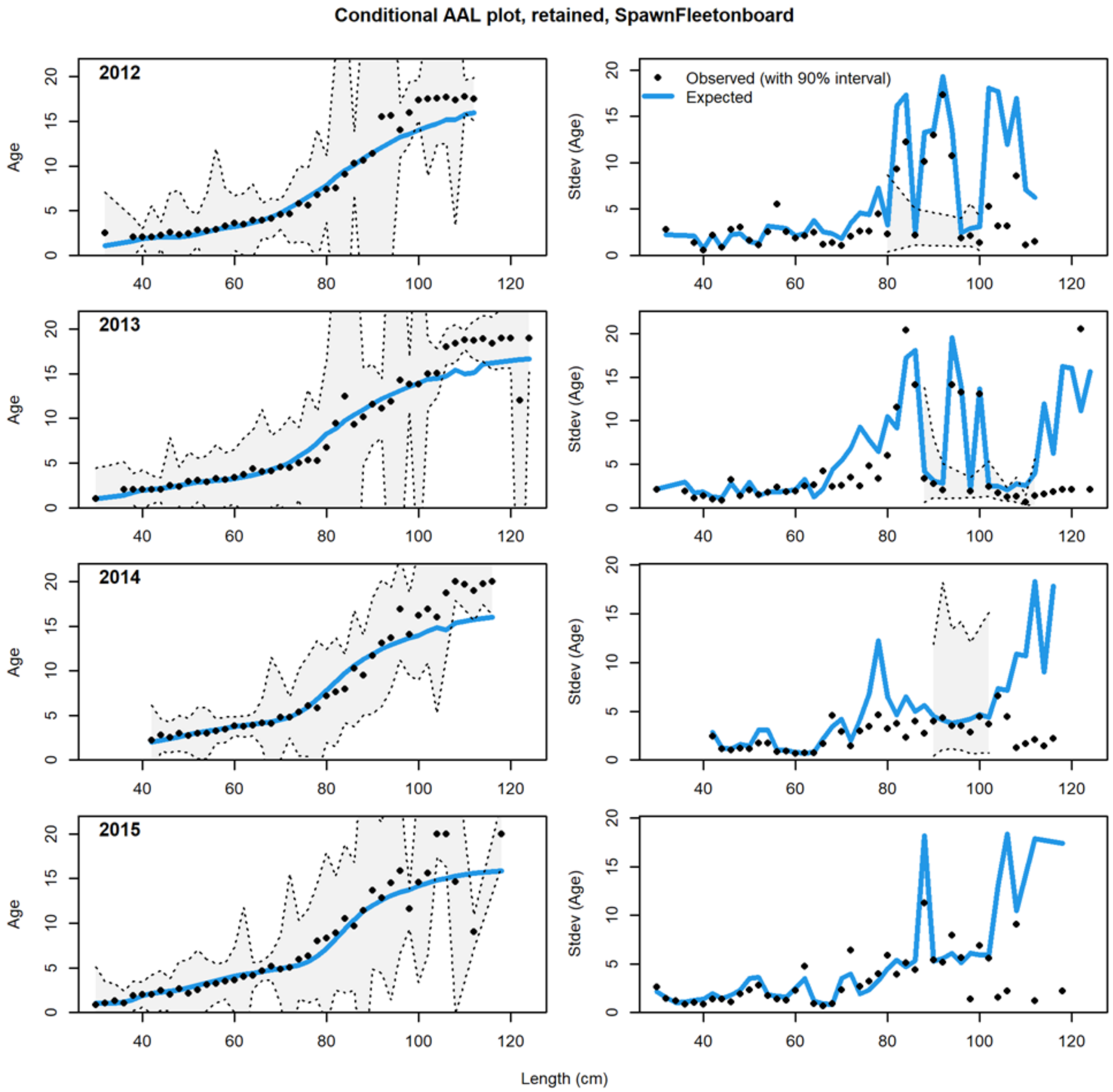
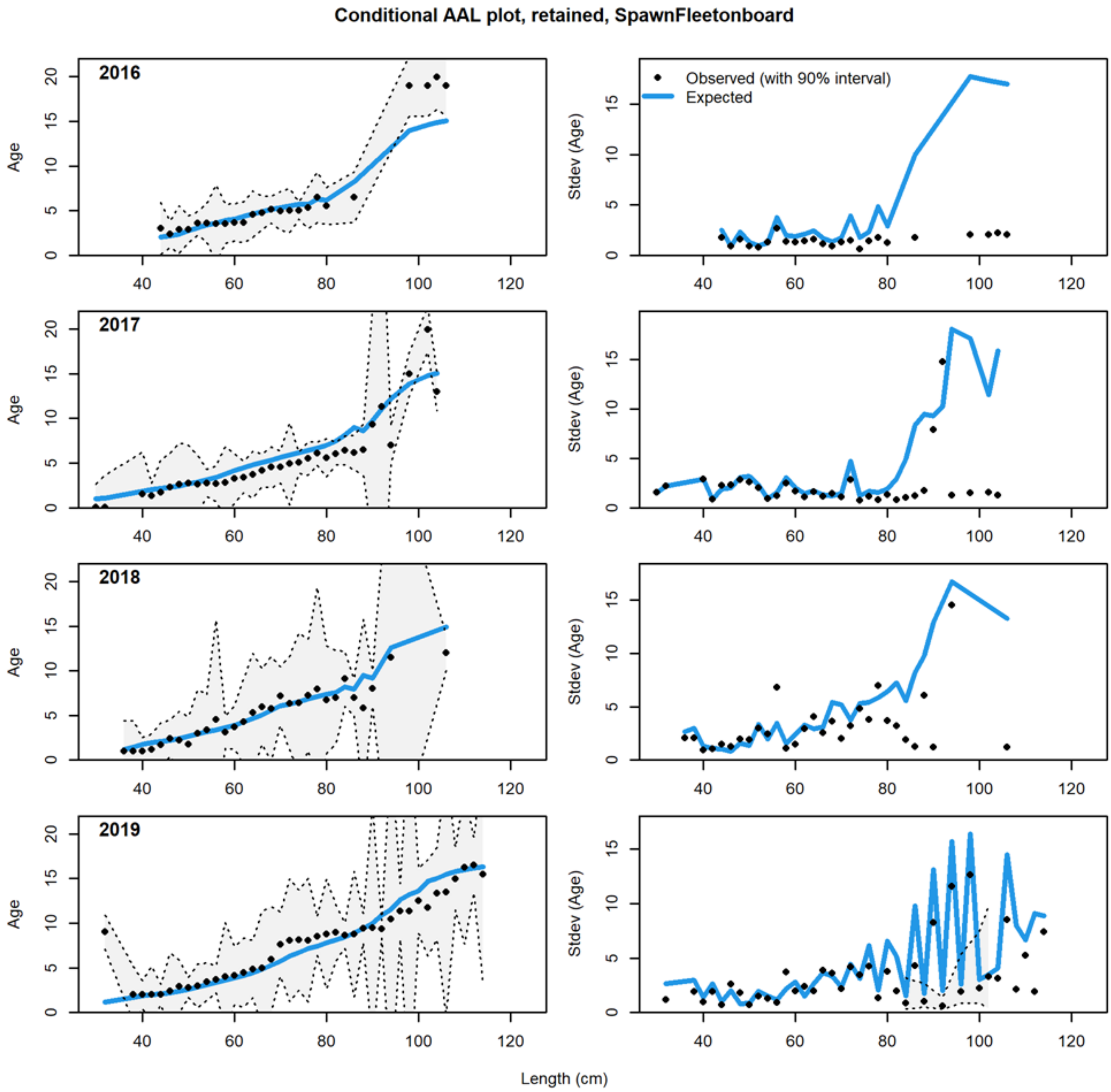
1999
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, SpawnFleetonboard
2000
2001
2002
2003
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

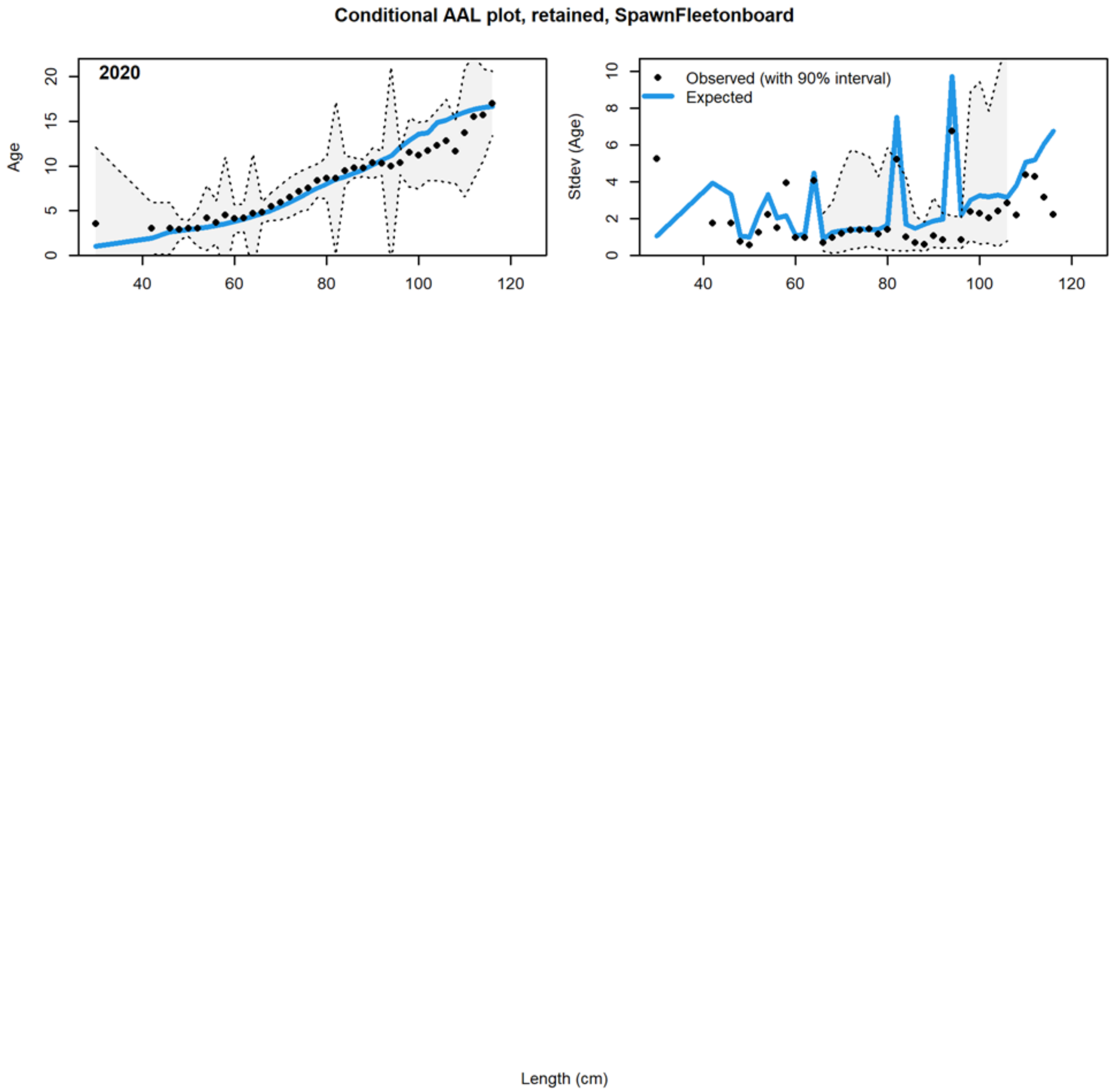

Conditional AAL plot, retained, SpawnFleetonboard
2004
2005
2006
2007
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

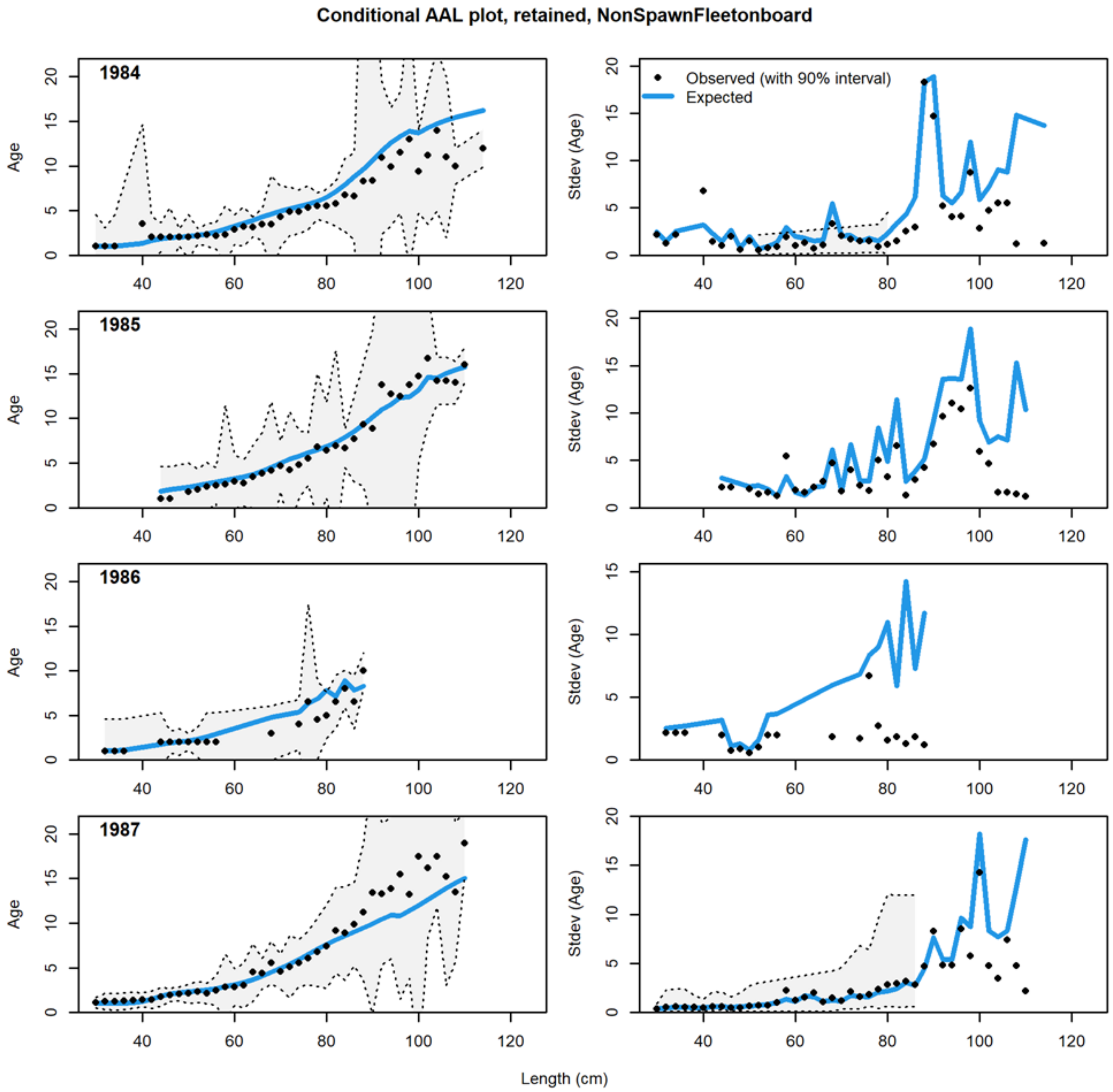

Conditional AAL plot, retained, SpawnFleetonboard
2008
2009
2010
2011
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

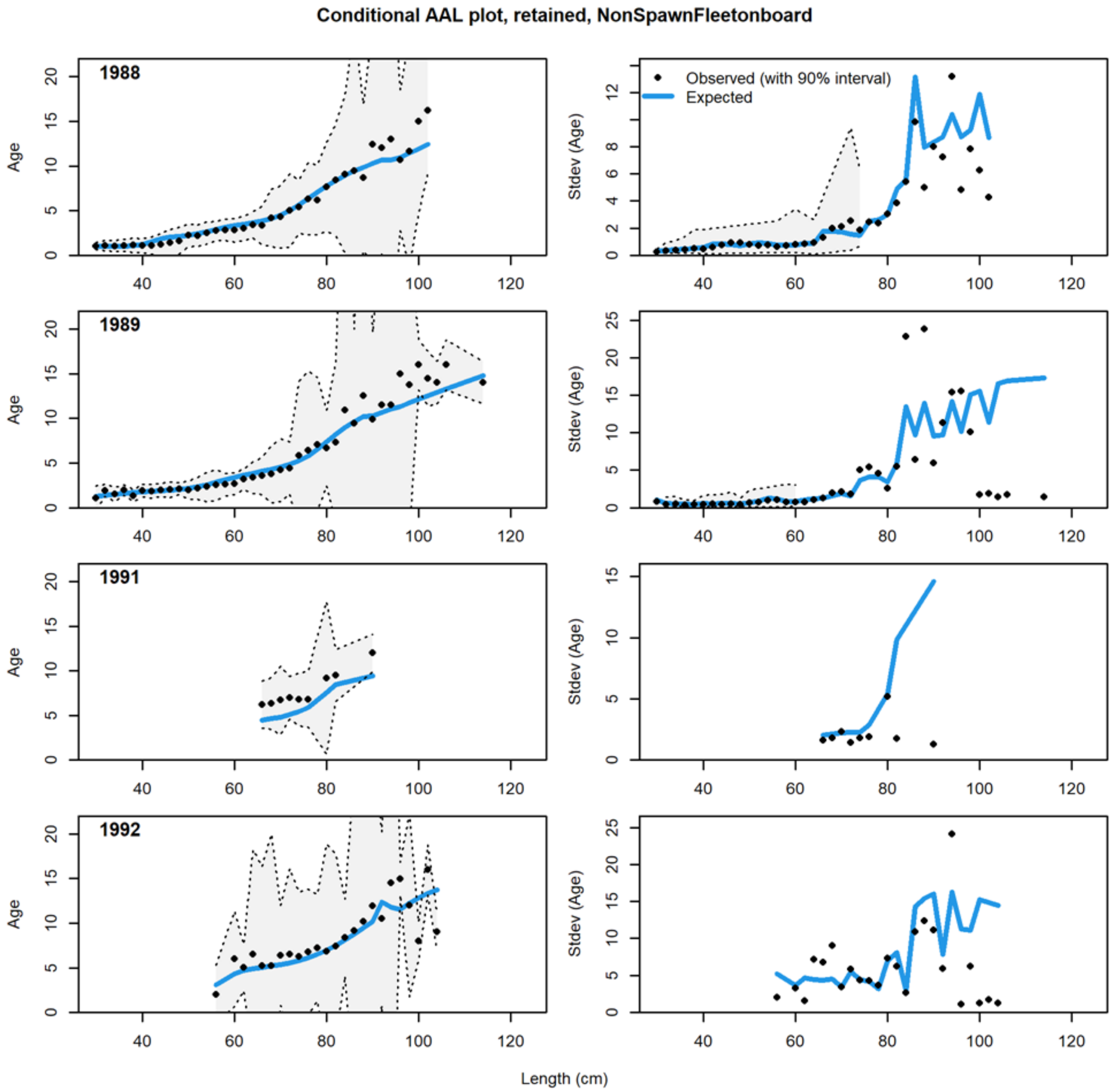

Conditional AAL plot, retained, SpawnFleetonboard
2012
2013
2014
2015
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)



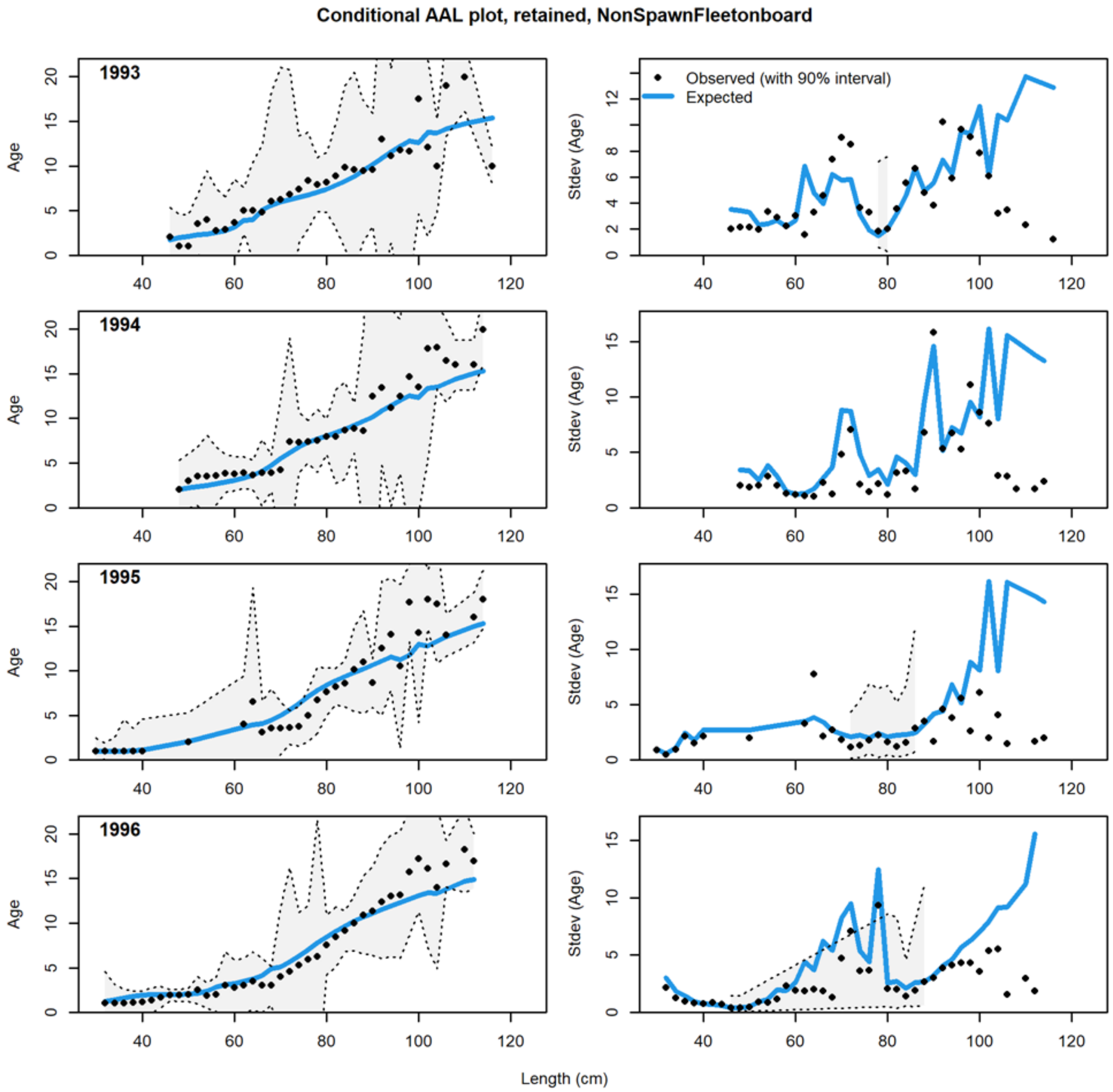
Conditional AAL plot, retained, SpawnFleetonboard
2016
2017
2018
2019
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

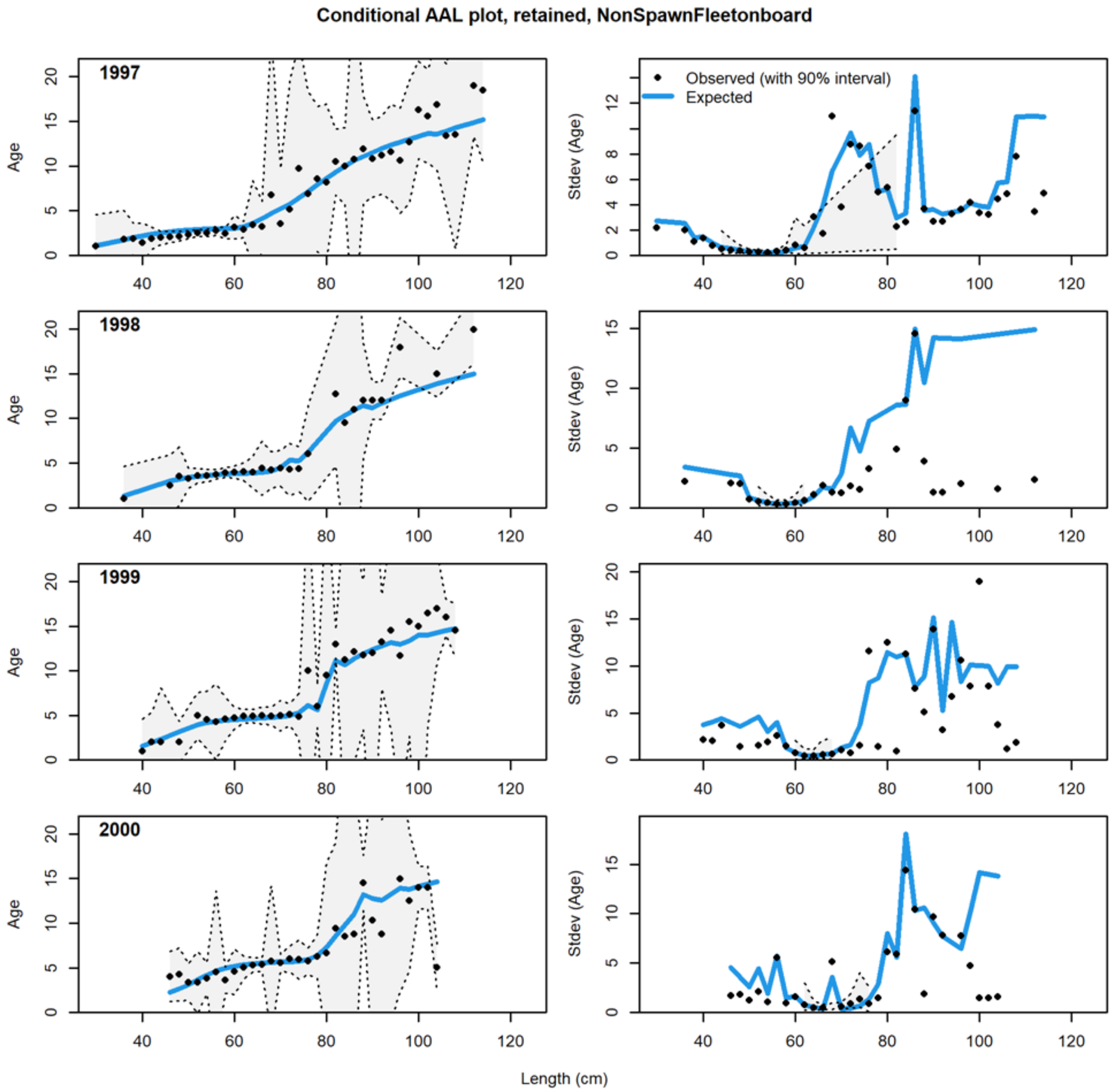

Conditional AAL plot, retained, SpawnFleetonboard
2020
Age
Stdev (Age)
Observed (with 90% interval)
Expected
0
5
10
15
20
0
2
4
6
8
10
40
60
80
100
120
Length (cm)


Conditional AAL plot, retained, NonSpawnFleetonboard
1984
1985
1986
1987
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

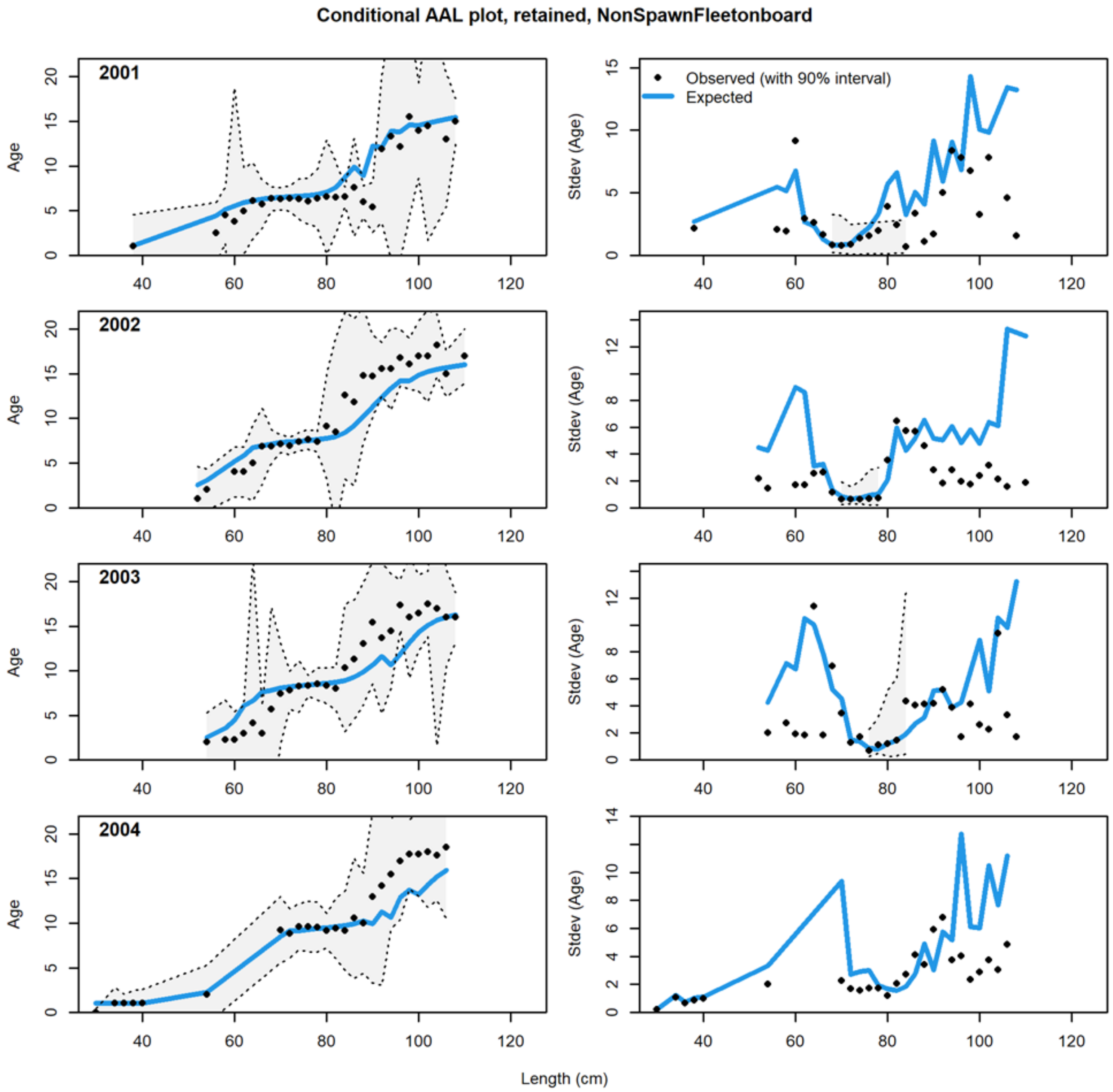


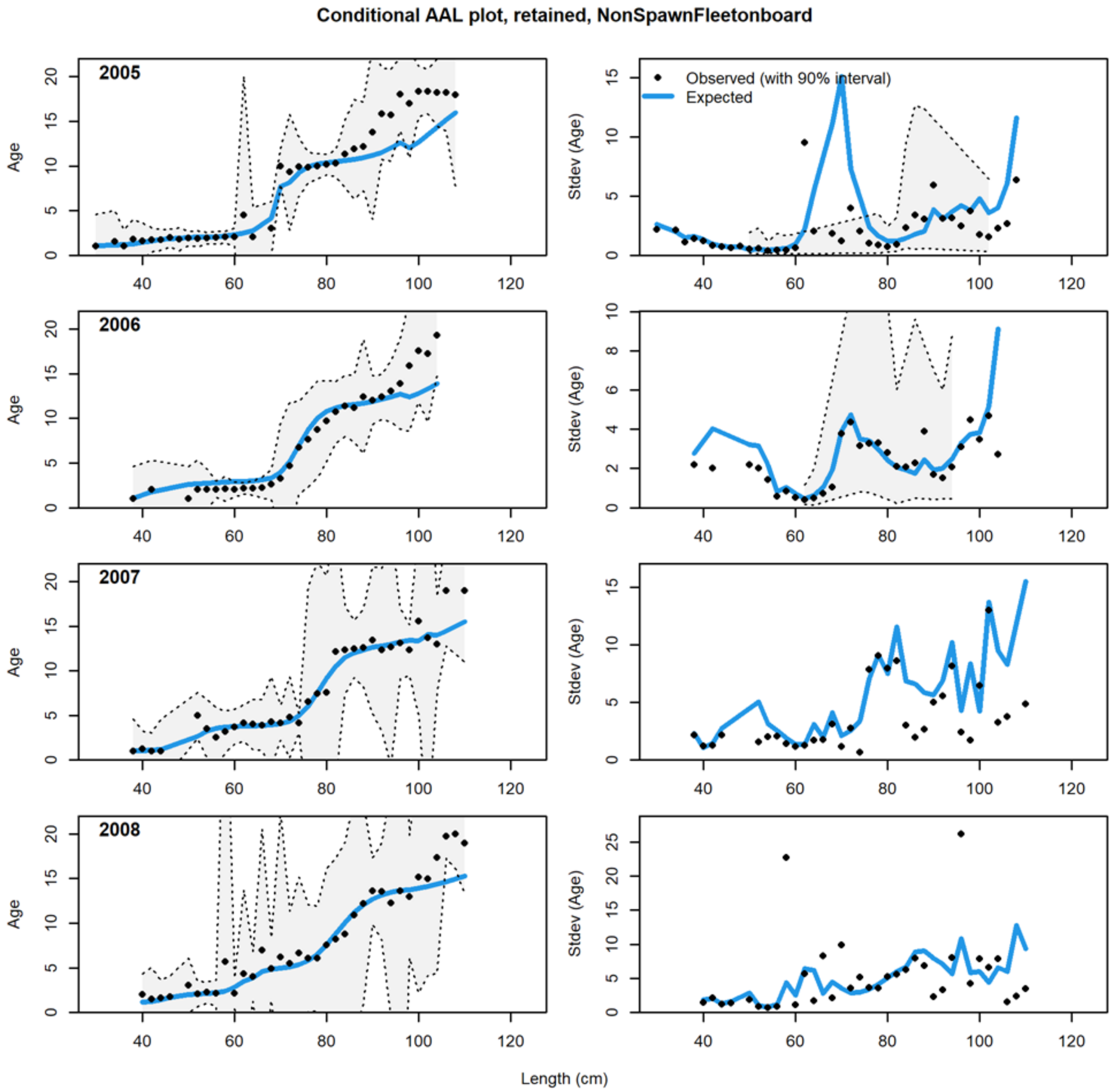
Conditional AAL plot, retained, NonSpawnFleetonboard
1988
1989
1991
1992
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

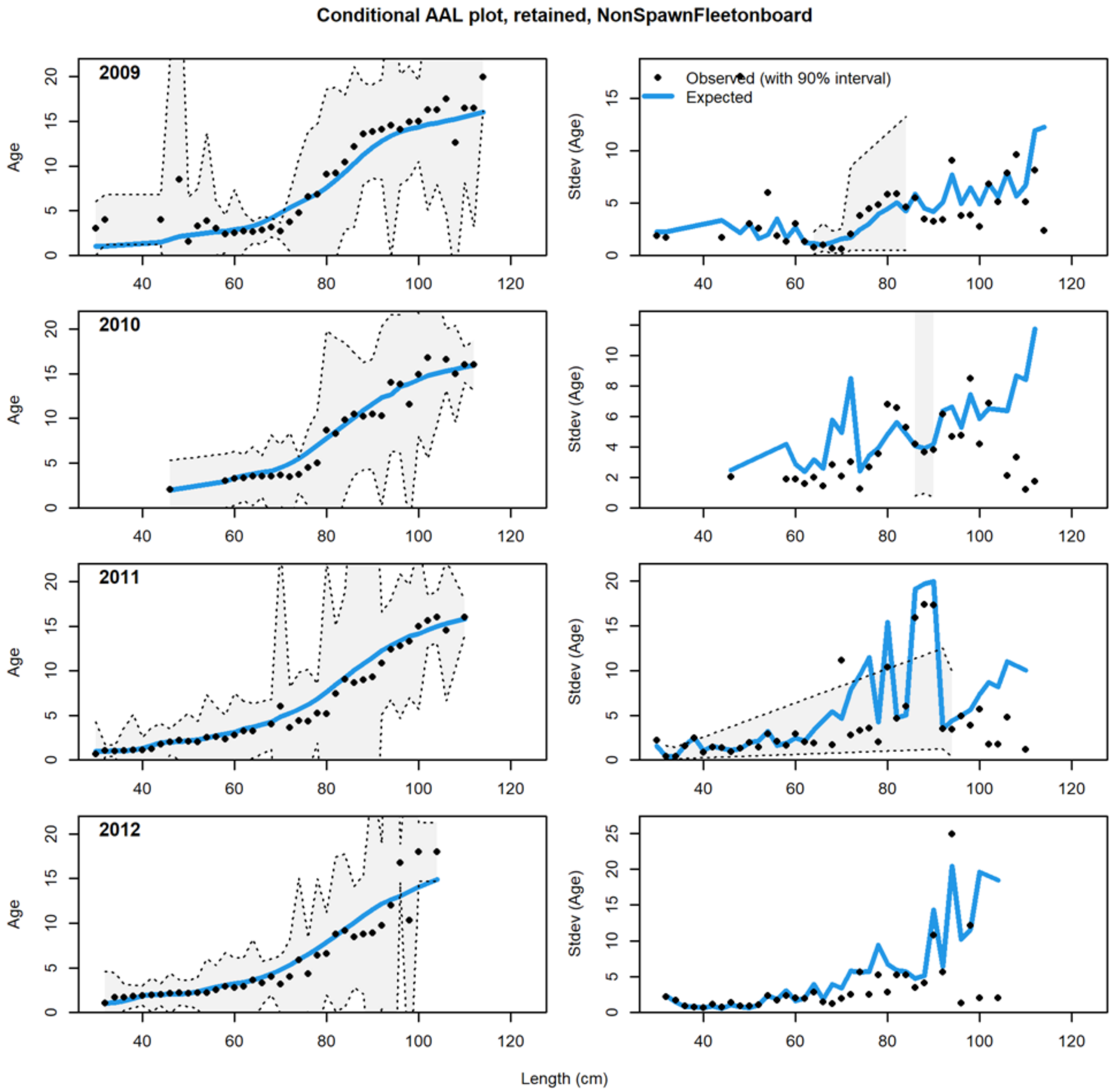

Conditional AAL plot, retained, NonSpawnFleetonboard
1993
1994
1995
1996
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

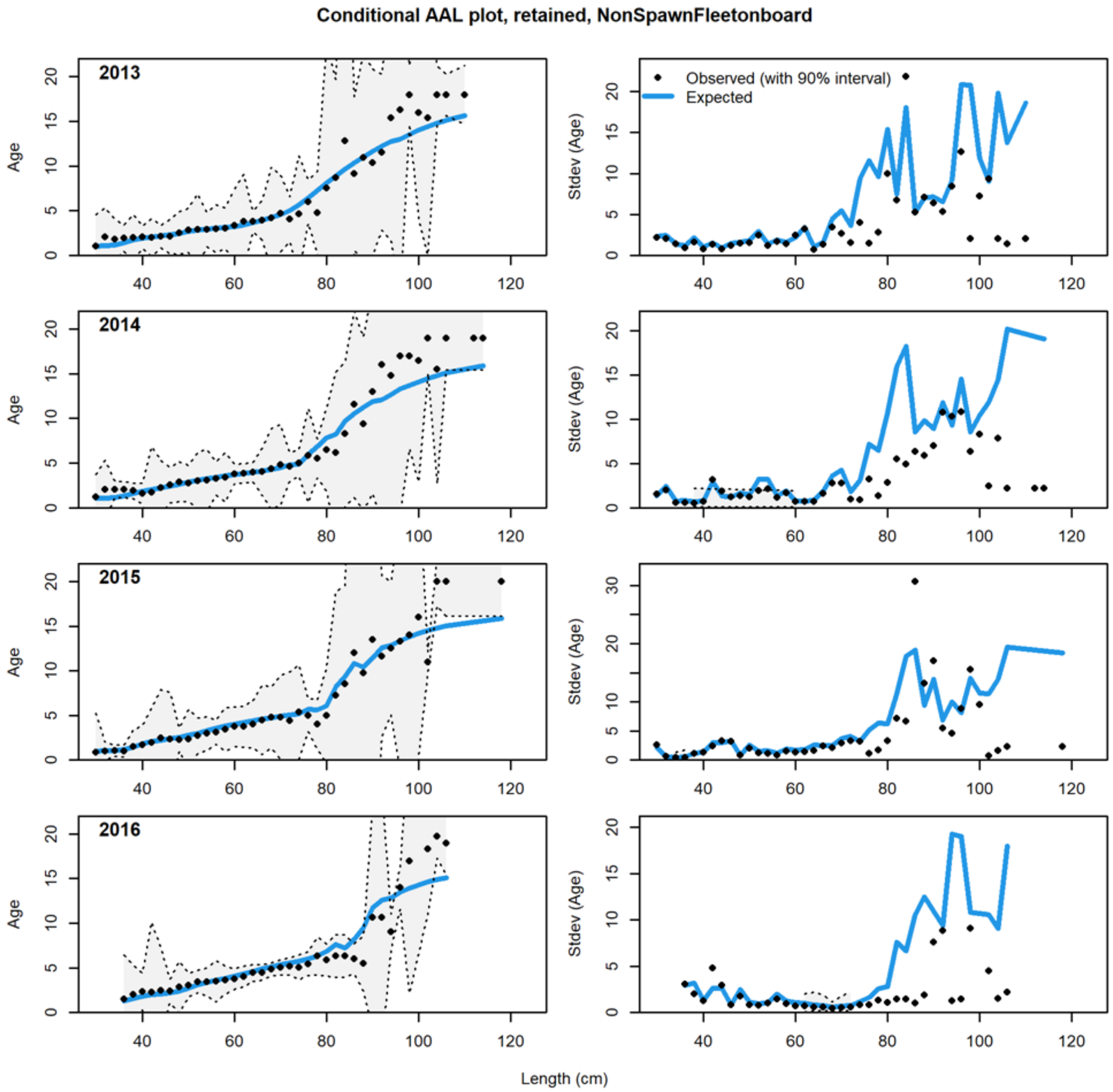


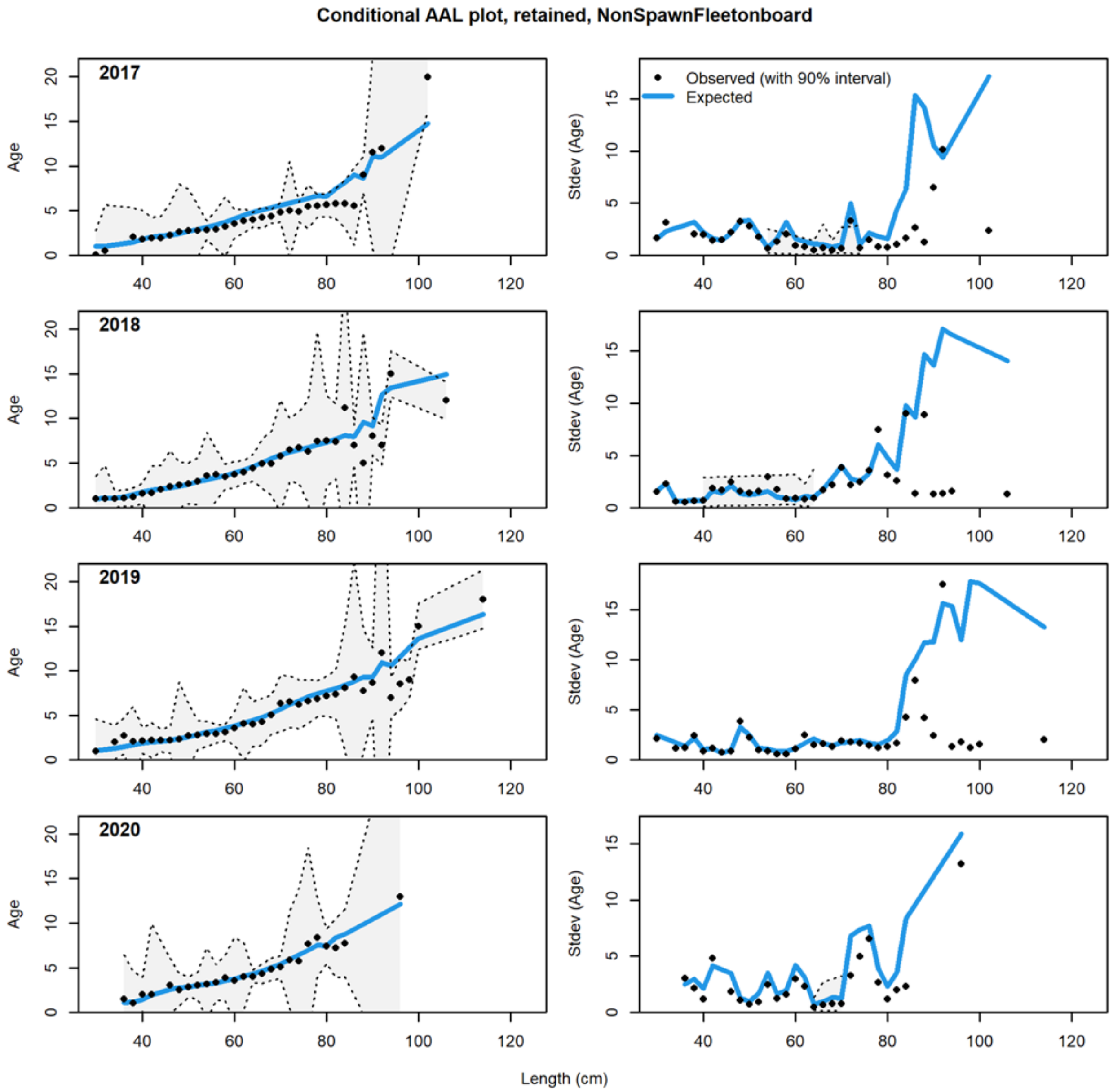
Conditional AAL plot, retained, NonSpawnFleetonboard
1997
1998
1999
2000
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, NonSpawnFleetonboard
2001
2002
2003
2004
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, NonSpawnFleetonboard
2005
2006
2007
2008
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, NonSpawnFleetonboard
2009
2010
2011
2012
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, NonSpawnFleetonboard
2013
2014
2015
2016
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)


Conditional AAL plot, retained, NonSpawnFleetonboard
2017
2018
2019
2020
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

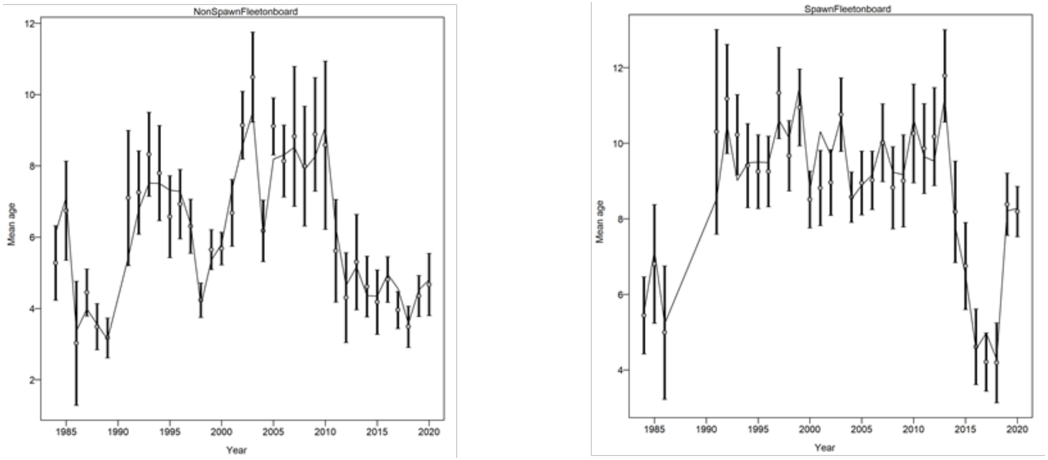


Figure 6.26. Data weighting of conditional age at length data for the onboard non spawning and spawning fleets

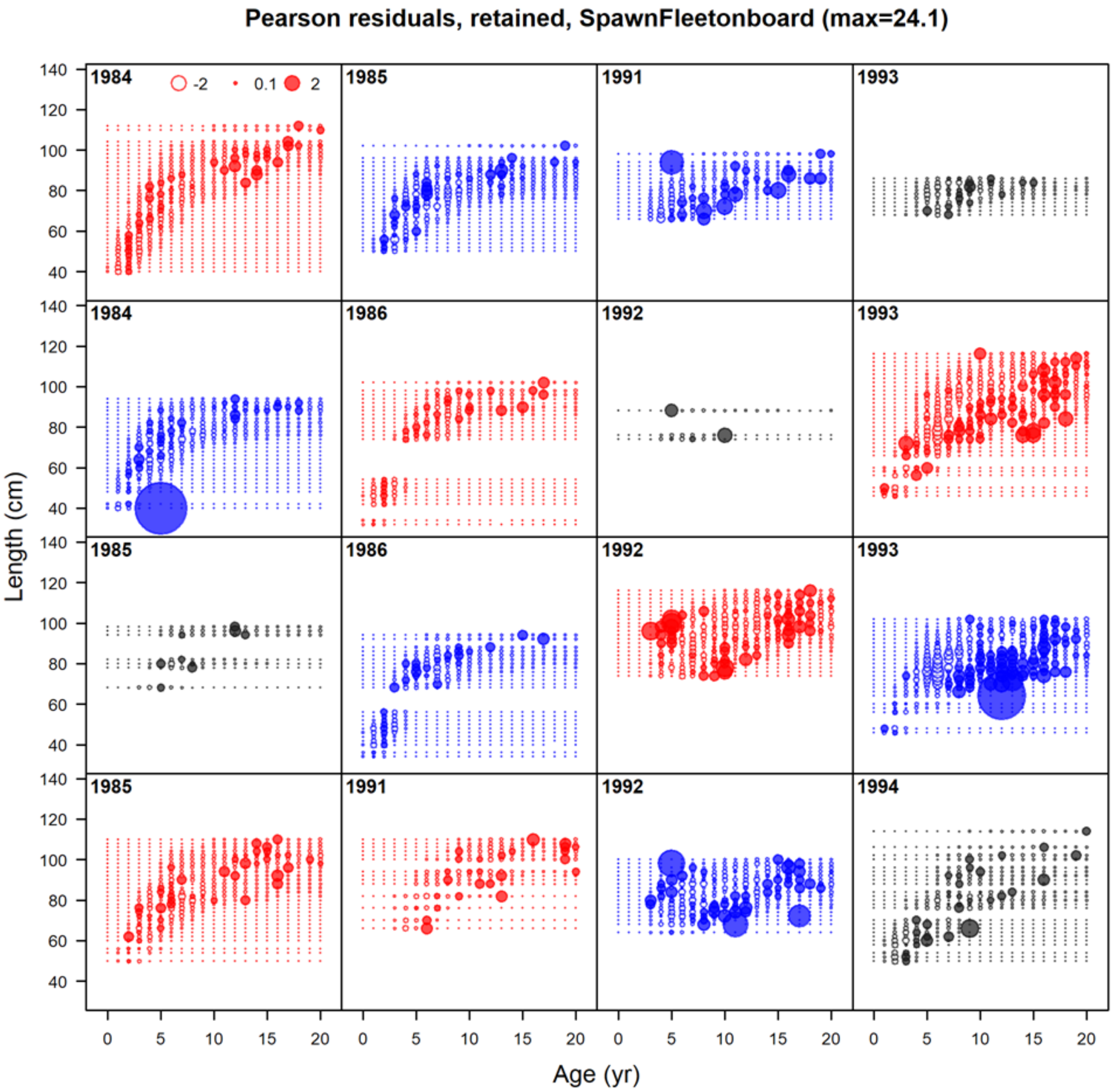
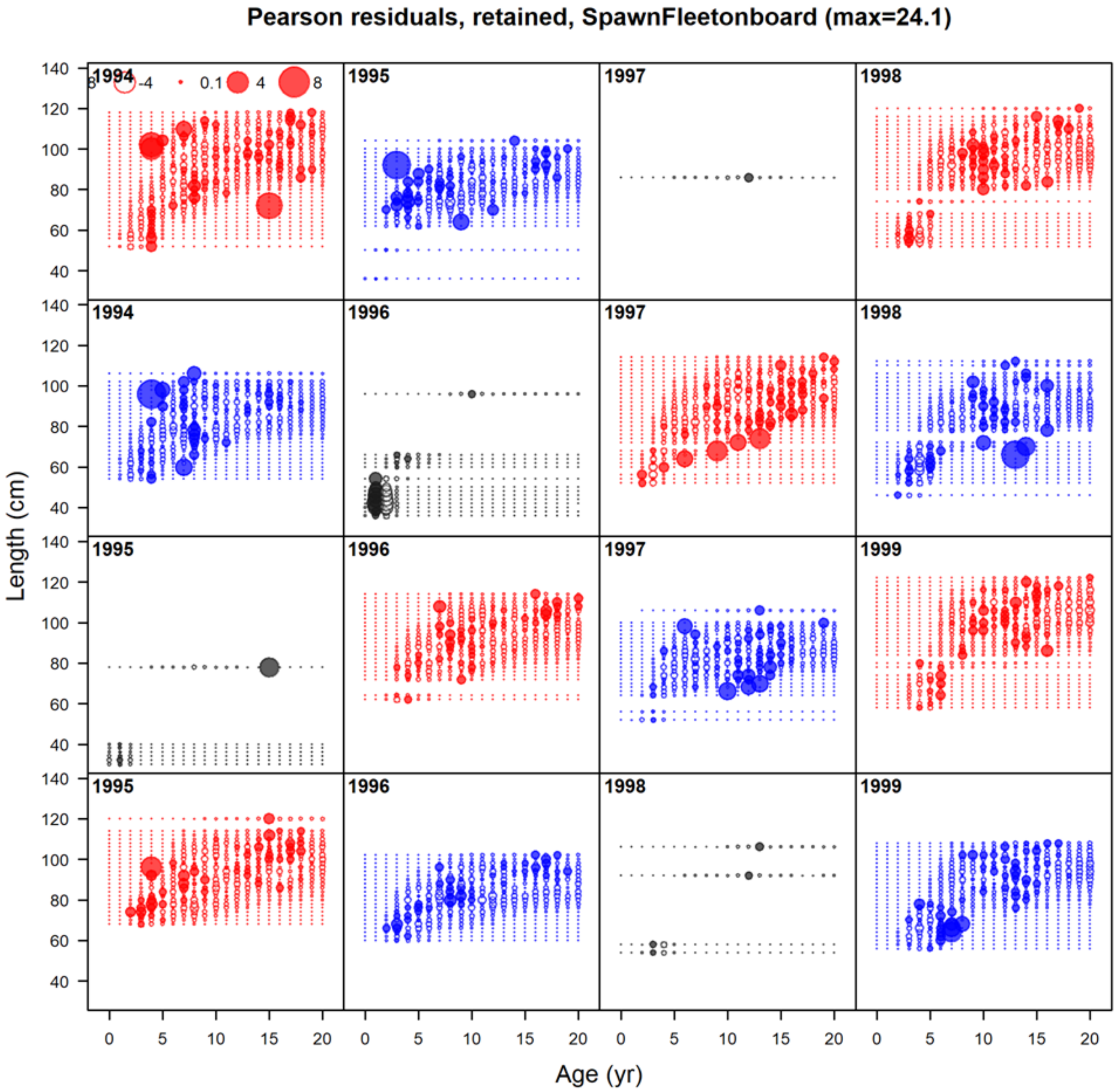
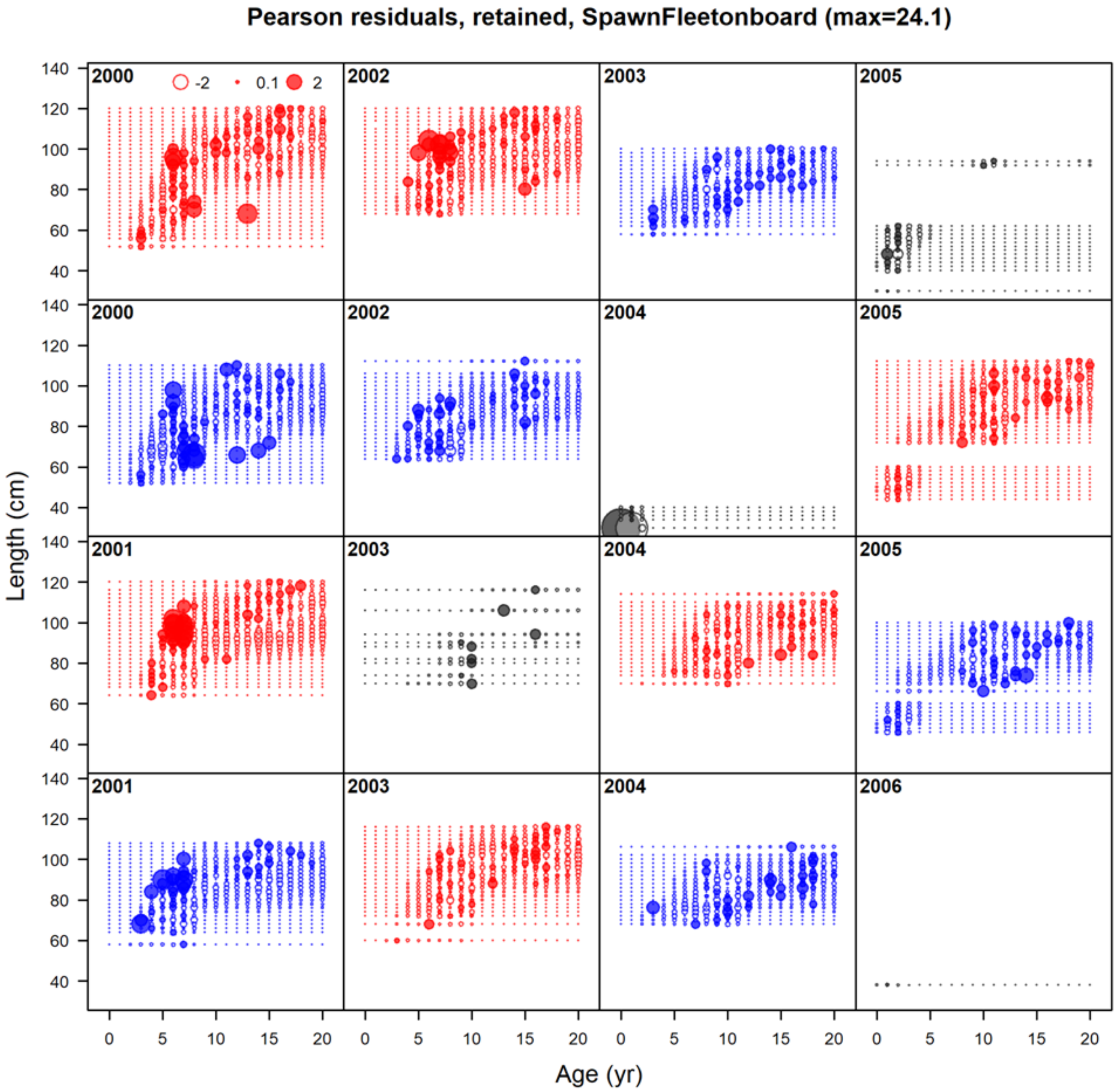
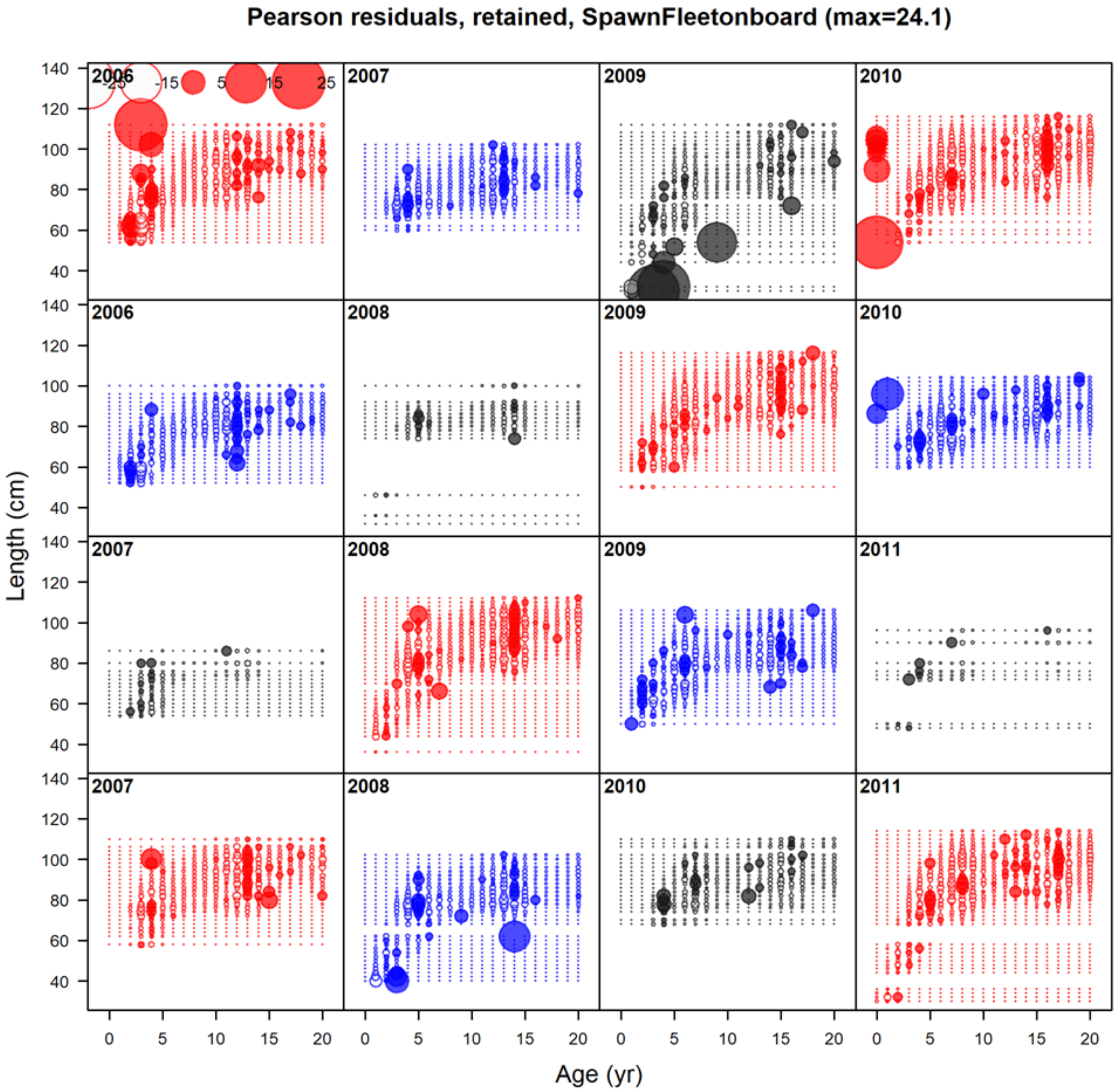
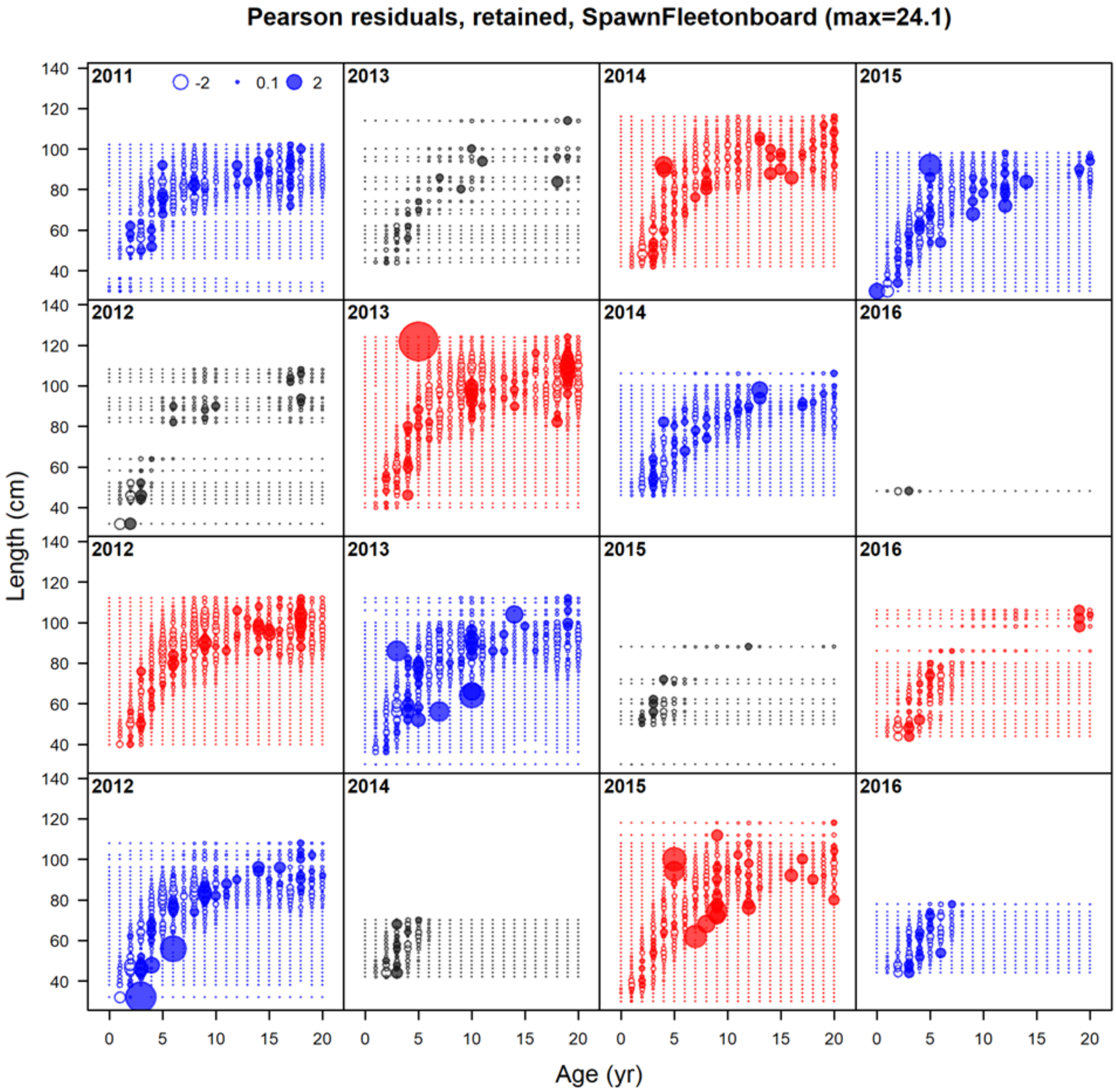


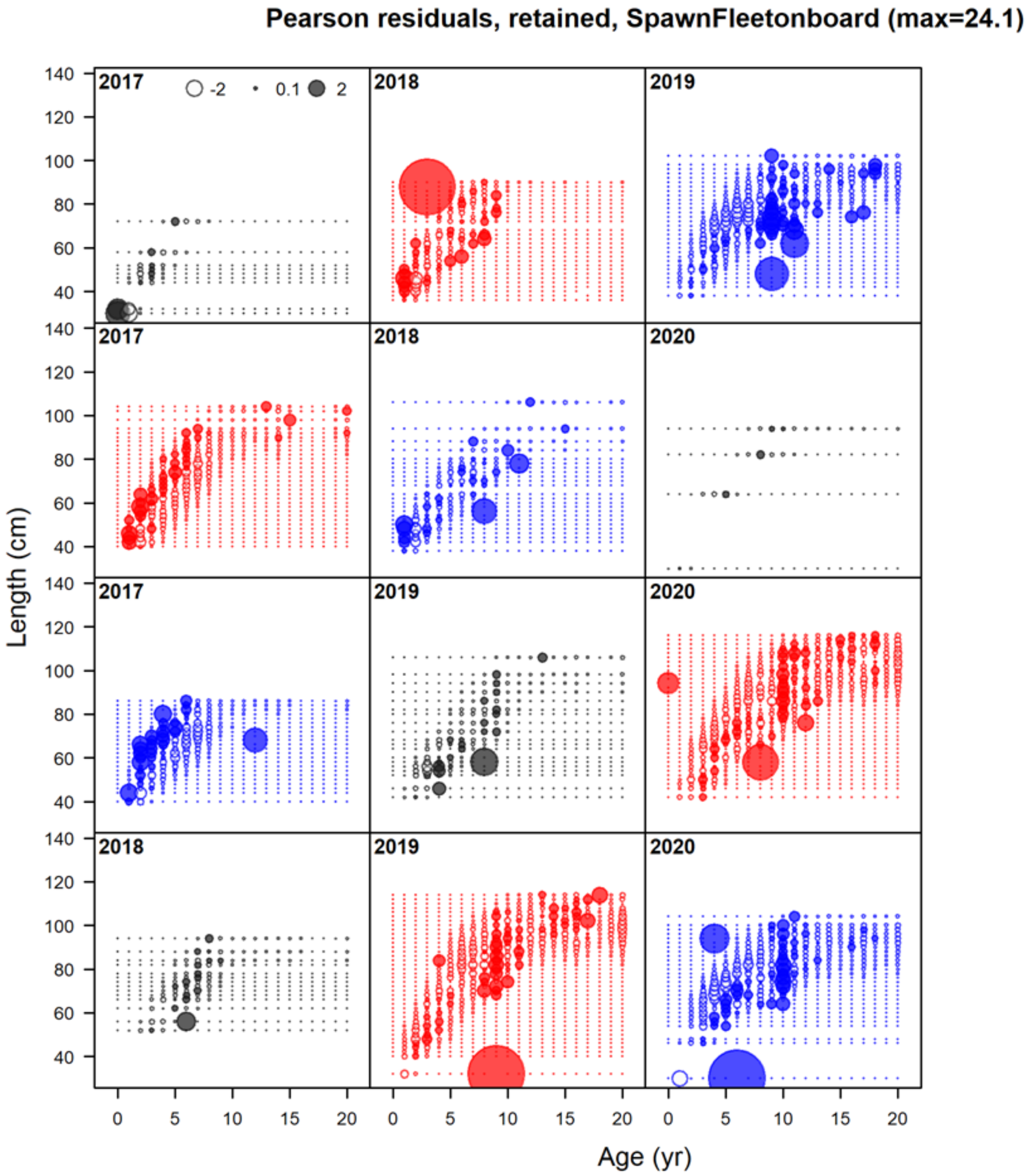
Figure 6.27. Pearson residuals of conditional age at length data.

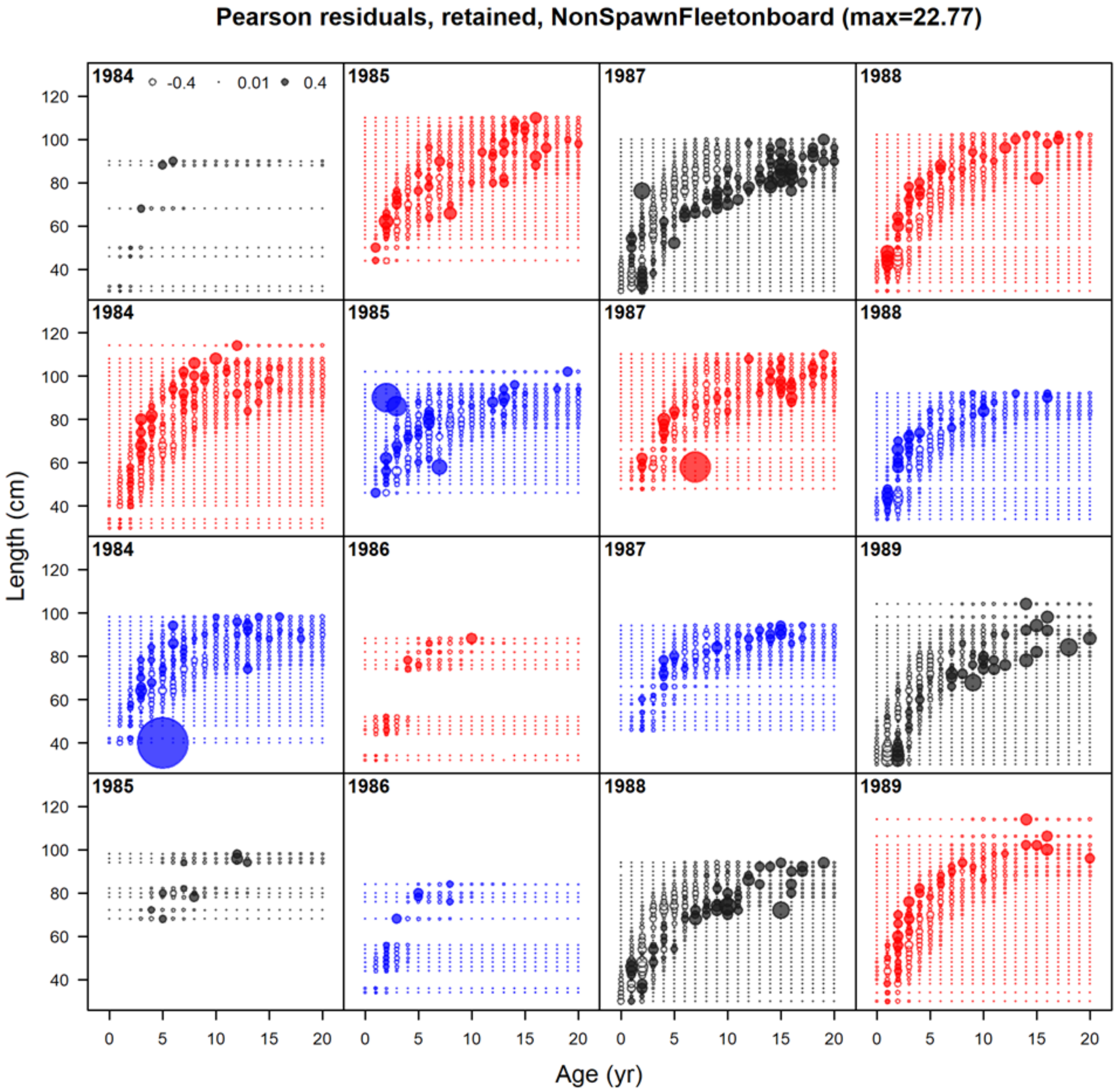

Pearson residuals, retained, SpawnFleetonboard (max=24.1)
-4
0.1
4
8
1994
1995
1997
1998
1994
1996
1997
1998
1995
1996
1997
1999
1995
1996
1998
1999
Length (cm)
Age (yr)


Pearson residuals, retained, SpawnFleetonboard (max=24.1)
2000
-2
0.1
2
2002
2003
2005
2000
2002
2004
2005
2001
2003
2004
2005
2001
2003
2004
2006
Length (cm)
Age (yr)

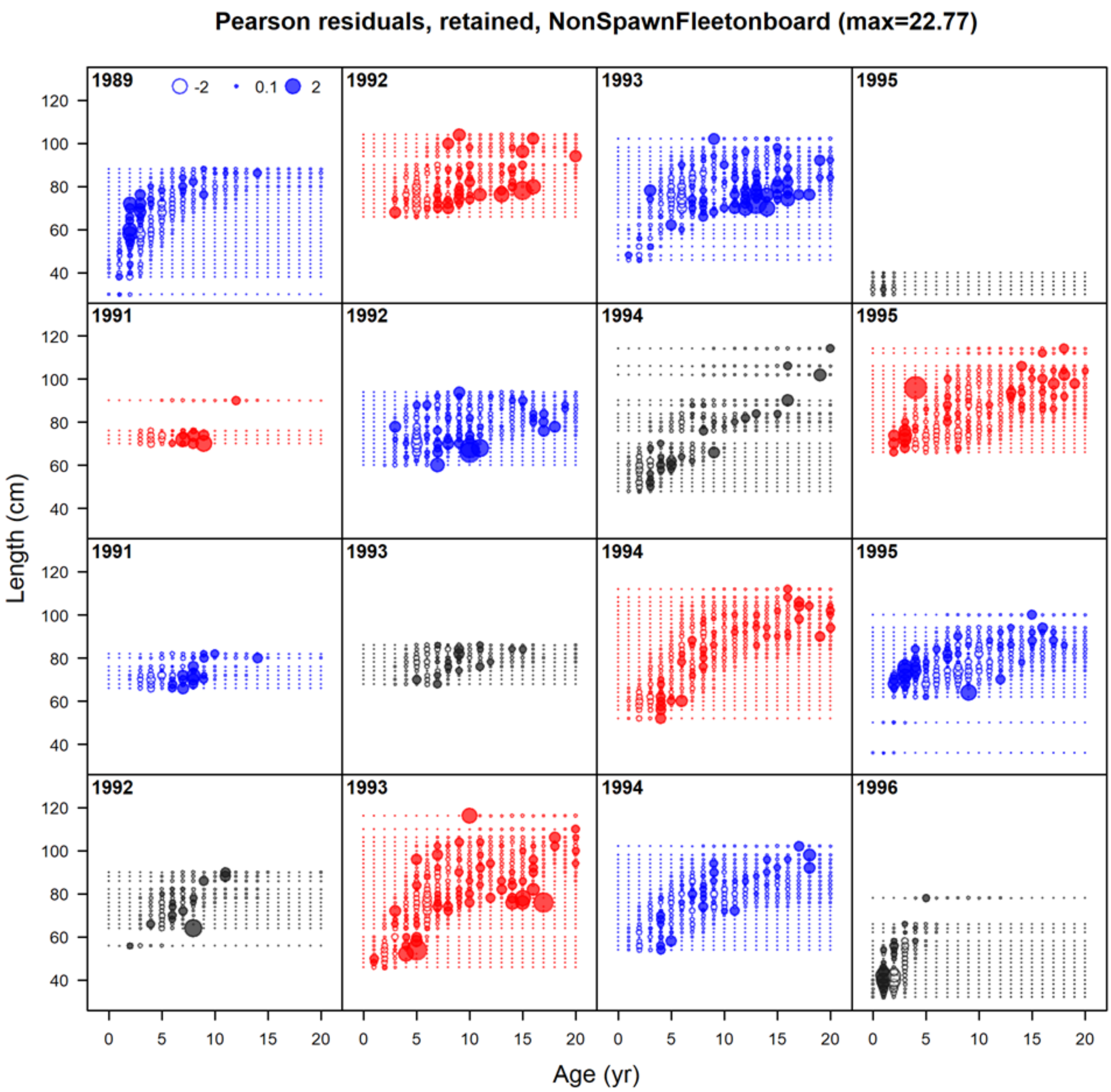

Pearson residuals, retained, SpawnFleetonboard (max=24.1)
-25 -15 5 15 25
2006
2007
2009
2010
2006
2008
2009
2010
2007
2008
2009
2011
2007
2008
2010
2011
Length (cm)
Age (yr)
140 120 100 80 60 40
0 5 10 15 20


Pearson residuals, retained, SpawnFleetonboard (max=24.1)
-2
0.1
2
2011
2013
2014
2015
2012
2013
2014
2016
2012
2013
2015
2016
2012
2014
2015
2016
Length (cm)
Age (yr)

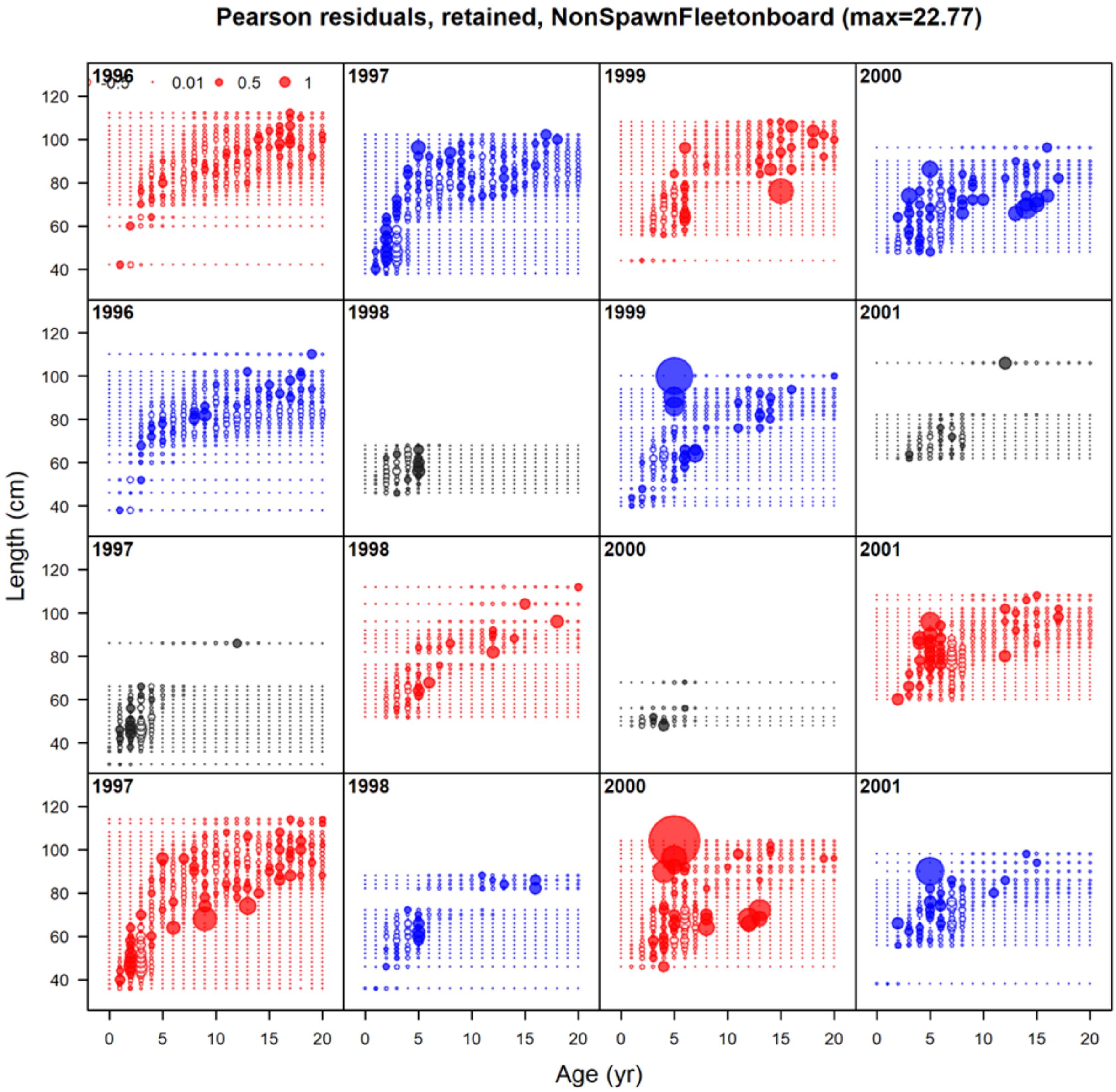

Pearson residuals, retained, SpawnFleetonboard (max=24.1)
-2
0.1
2
2017
2018
2019
2017
2018
2020
2017
2019
2020
2018
2019
2020
Length (cm)
Age (yr)

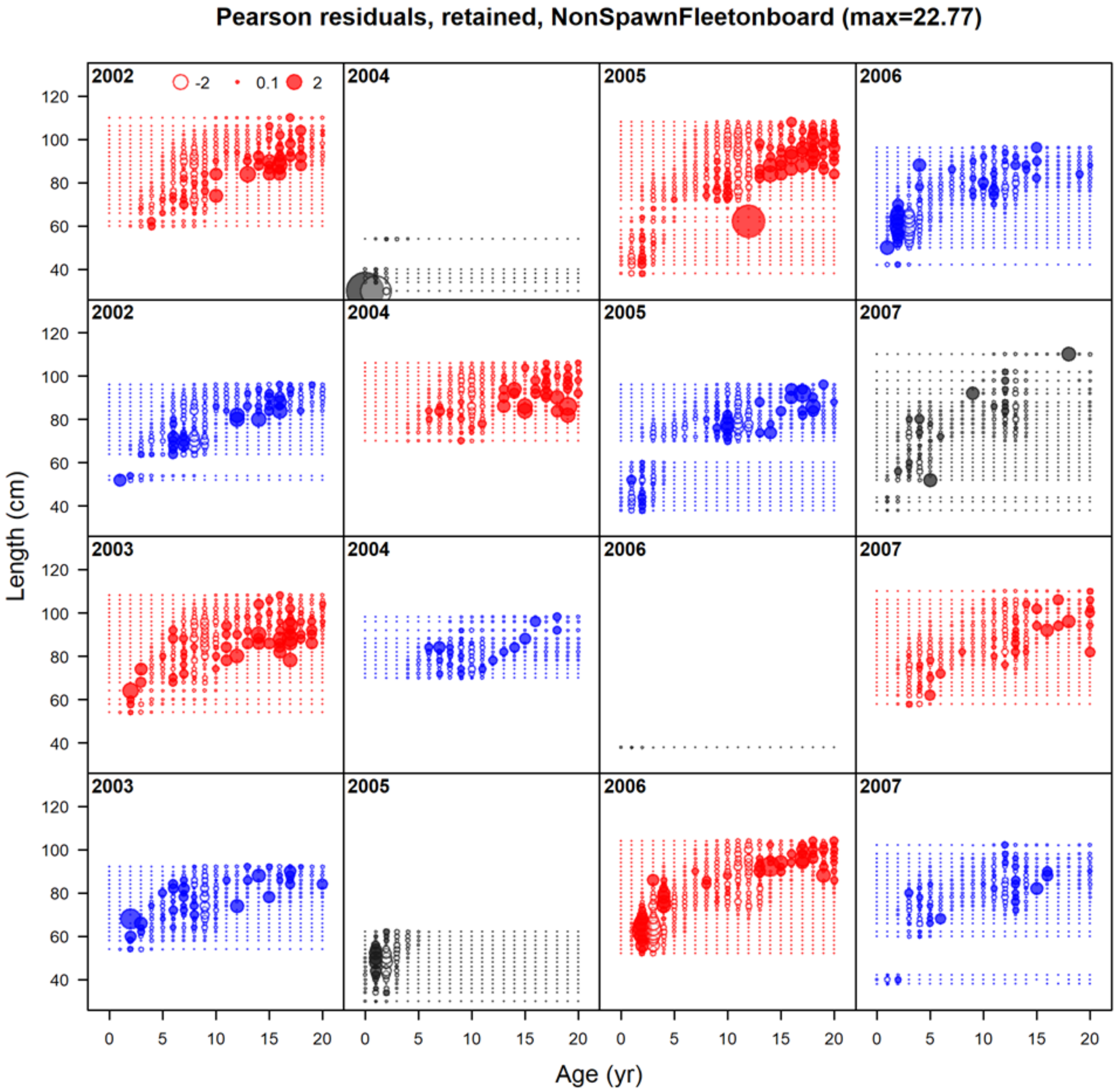


Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
1984
-0.4
0.01
0.4
1985
1987
1988
1984
1985
1987
1988
1984
1986
1987
1989
1985
1986
1988
1989
Length (cm)
Age (yr)

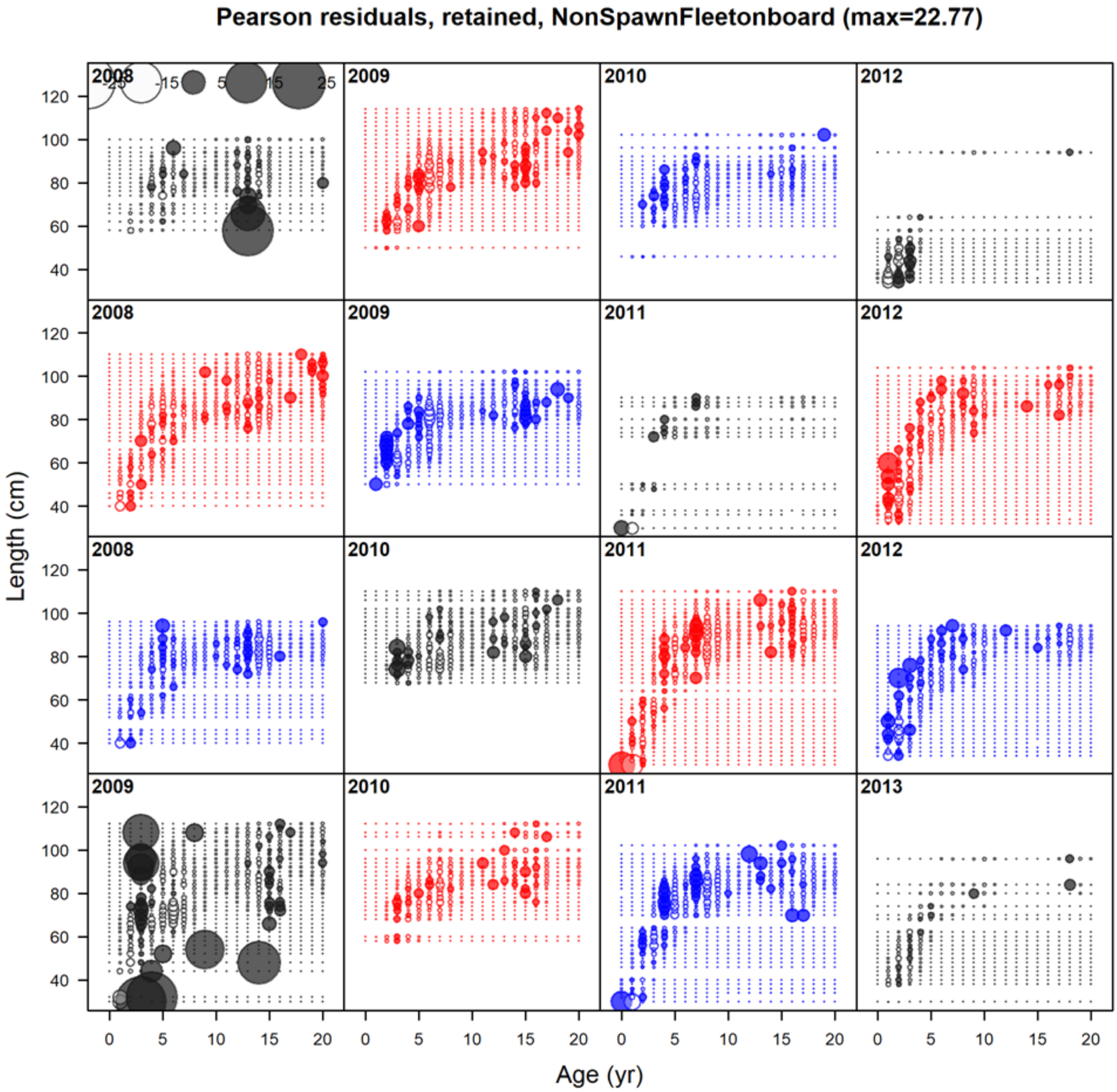


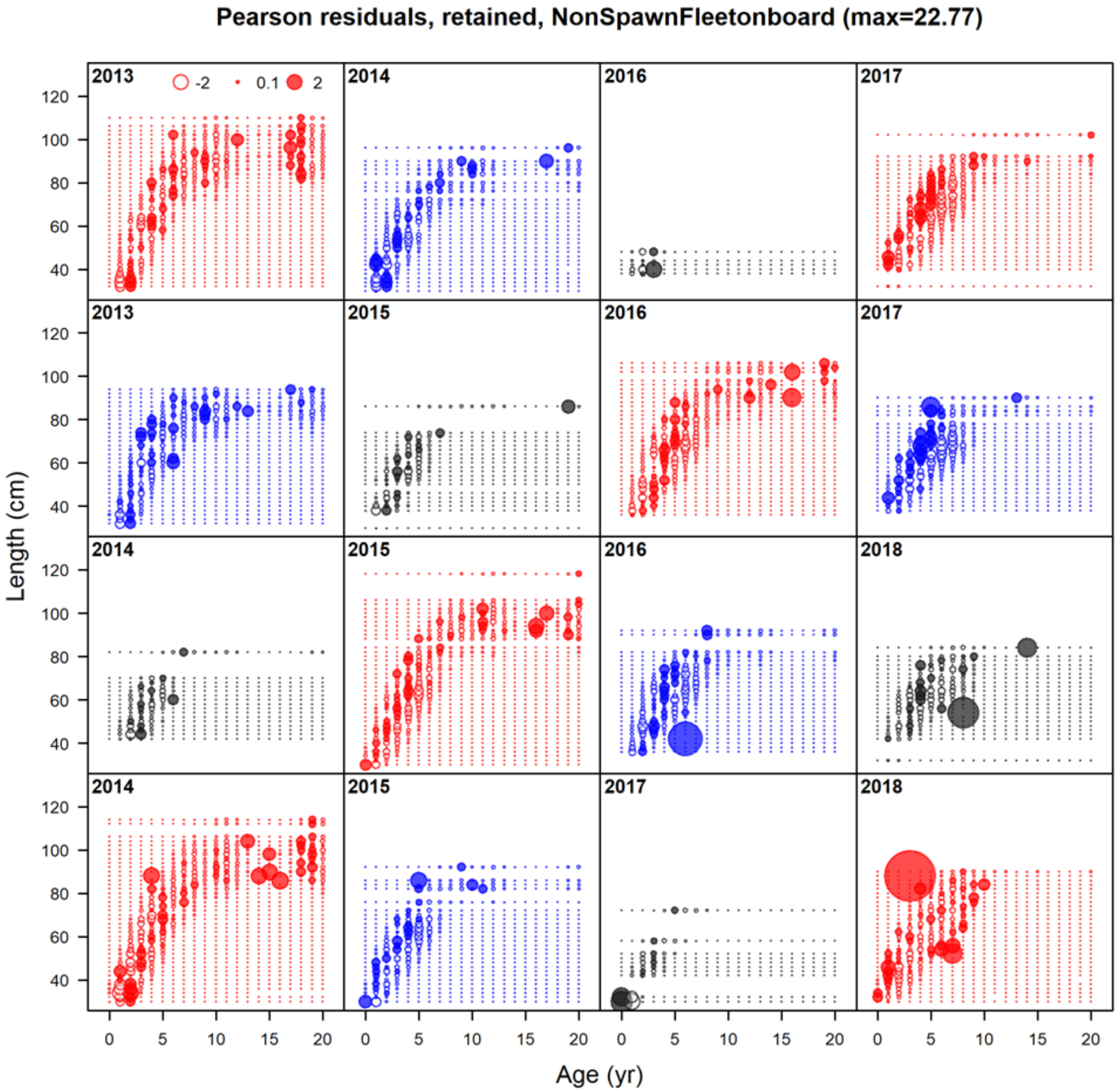
Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
1989
-2
0.1
2
1992
1993
1995
1991
1992
1994
1995
1991
1993
1994
1995
1992
1993
1994
1996
Length (cm)
Age (yr)

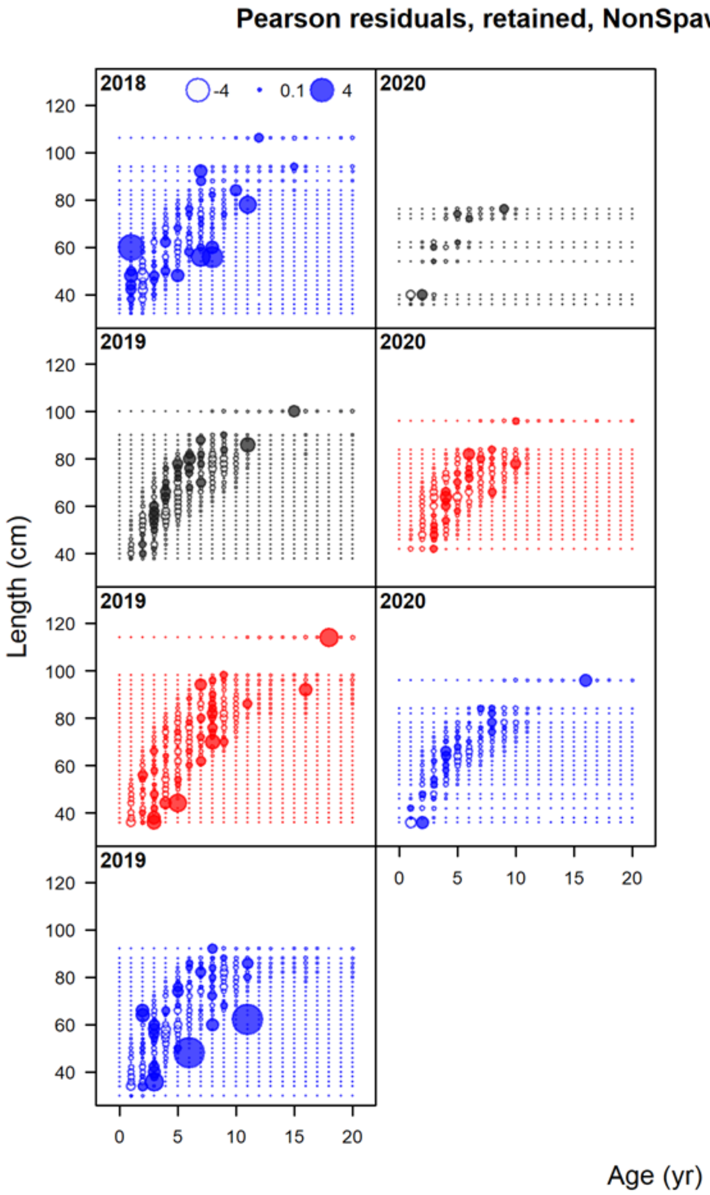

Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
-0.5
0.01
0.5
1
1996
1997
1999
2000
1996
1998
1999
2001
1997
1998
2000
2001
1997
1998
2000
2001
Length (cm)
Age (yr)



Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
2002
-2
0.1
2
2004
2005
2006
2002
2004
2005
2007
2003
2004
2006
2007
2003
2005
2006
2007
Length (cm)
Age (yr)


Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
2008
-25
-15
5
15
25
2009
2010
2012
2008
2009
2011
2012
2008
2010
2011
2012
2009
2010
2011
2013
Length (cm)
Age (yr)


Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
2013
-2
0.1
2
2014
2016
2017
2013
2015
2016
2017
2014
2015
2016
2018
2014
2015
2017
2018
Length (cm)
Age (yr)


Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)
2018
-4
0.1
4
2020
2019
2020
2019
2020
2019
Length (cm)
Age (yr)
120
100
80
60
40
0
5
10
15
20