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



PART
1

2021



Principal investigator **G.N. Tuck**



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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
May 2022
Report 2019/0800

Australian Fisheries Management Authority

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

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1. Non-Technical Summary

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

PRINCIPAL INVESTIGATOR: Dr Geoffrey N. Tuck

ADDRESS: CSIRO Oceans and Atmosphere
GPO Box 1538
Hobart, TAS 7001
Australia
Telephone: 03 6232 5222 Fax: 03 6232 5053

OBJECTIVES:

- Provide quantitative and qualitative species assessments in support of the four SESSFRAG assessment groups, including RBC calculations within the SESSF harvest strategy framework
- 2020: Provide Tier 1 assessments for Gummy Shark, Eastern Redfish and School Whiting; Tier 4 assessments for John Dory, Mirror Dory, Ocean Perch, Oreobasket, Ribaldo, Royal Red Prawn, Sawshark and Silver Trevally; and Tier 5 for Blue-eye Trevalla
- 2021: Provide Tier 1 assessments for Eastern Orange Roughy, Blue Grenadier, Eastern Jackass Morwong and Silver Warehou; Tier 4 for Mirror Dory and Tier 5 for E/W Deepwater Shark

Outcomes Achieved - 2021

The 2021 assessments of stock status of the key Southern and Eastern Scalefish and Shark fishery (SESSF) species are based on the methods presented in this report. Documented are the latest quantitative assessments for the SESSF quota species. Typical assessment results provide indications of current stock status, in addition to an application of the recently introduced Commonwealth fishery harvest control rules that determine a Recommended Biological Catch (RBC). These assessment outputs are a critical component of the management and Total Allowable Catch (TAC) setting process for these fisheries. The results from these studies are being used by SESSFRAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

1.1 South East RAG Species

Blue Grenadier

This chapter updates the agreed base case for a Tier 1 assessment of Blue Grenadier (*Macruronus novaezelandiae*). The last full assessment was conducted in 2018. 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 agreed base case now includes estimation of both female and male natural mortality, and no longer includes 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). 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.

Eastern Jackass Morwong

This chapter updates the 2018 Tier 1 assessment of eastern Jackass Morwong (*Nemadactylus macropterus*) to provide estimates of stock status in the SESSF at the start of 2022. The 2018 stock assessment has been updated with the inclusion of data up to the end of 2020, comprising an additional three years of catch, discard, CPUE, length and age data and ageing error updates, including revisions to historical catch series, length frequencies and discard rates. A range of sensitivities were explored.

The base-case assessment estimates that the projected 2022 spawning stock biomass will be 15% of unexploited spawning stock biomass (SSB_0), with recruitment from 2016 onwards projected using a low recruitment scenario, using the average of the ten most recently estimated recruitment deviations, from 2006-2015. Under the agreed 20:35:48 harvest control rule, the 2022 recommended biological catch (RBC) is 0 t, with the long-term yield (assuming low recruitment in the future) of 91 t. The average RBC over the three-year period 2022-2024 is 0 t and over the five-year period 2022-2026, the average RBC is 1 t. If recruitment from 2016 onwards is assumed to be average, the projected 2022 spawning stock biomass would be 22% of SSB_0 .

The updated assessment produces markedly different results from the 2018 assessment, under both the average and the low recruitment scenarios. This is due to downward revisions to the 13 of most recent 15 years of recruitment estimates from the 2018 assessment (for the period 1998-2012), poor recruitment estimates for the three new years of recruitment estimated in the 2021 assessment (for the years 2013-2015), a continuing decline in recent catches, a continuing decline in the recent CPUE

indices and an improved fit to the most recent CPUE data points, partly due to the implementation of a low recruitment scenario.

Eastern Orange Roughy

This chapter updates the 2017 eastern zone Orange Roughy (*Hoplostethus atlanticus*) stock assessment to include revised modelling assumptions and new data for 2020. The objective of the 2021 assessment is to account for the uncertainty in M by estimating it within the assessment using an informative prior developed from New Zealand Orange Roughy assessments.

The 2021 base-case assessment updates the 2017 assessment with recent catch, relative estimates of female spawning biomass from the 2019 acoustic towed surveys at St Helens Hill and St Patricks Head, and new age composition data from the 2019 acoustic survey. Two major changes were made to the previous assessment: natural mortality is now estimated within the assessment and the plus-group are increased from 80 to 120 years.

The median estimate of unfished female spawning biomass from the MCMC analysis was 38,924 t, slightly lower than the MPD estimate of 40,479 t. The current 2022 female spawning biomass is estimated to be 11,644 t from the MCMC and 13,126 t from the MPD. Relative spawning biomass in 2022 is estimated at 30% of unfished levels from the MCMC and 32.4% of unfished levels from the MPD. Natural mortality was successfully estimated within the assessment. The median estimate of natural mortality from the MCMC analysis is $M=0.0393 \text{ yr}^{-1}$, which is slightly higher than the MPD estimate of $M=0.0386 \text{ yr}^{-1}$. The recommended biological catch (RBC) for 2022 from the MCMC analysis is 681 t, lower than the MPD estimate for 2022 of 944 t. The average RBC over the next three years (2022-2024) is 737 t from the MCMC analysis and 1,025 t from the MPD. There is a high level of uncertainty in the estimated RBC, with the 75% and 95% credible intervals from the MCMC analysis for the 2022 RBC being 287–1,316 t and 119–1,645 t respectively.

Further MCMC analysis was undertaken to evaluate scenarios of fixed catch projections of 550, 650, 737, 850 and 950 t yr^{-1} and a catch scenario proposed by industry of 1,166 t in 2022, 1,055 t in 2023 and 950 t yr^{-1} thereafter. The projections show that female spawning biomass is estimated to increase under all the fixed catch scenarios considered with the probability of the stock being below the limit reference point of 20% unfished spawning biomass in both 2024 and 2031 being less than 0.5%. Under the lowest constant catch scenario of 550 t yr^{-1} , stock status is estimated to be 0.317 and 0.348 in 2024 and 2031 respectively. Under the highest constant catch scenario of 950 t yr^{-1} , stock status is estimated to be 0.312 and 0.323 in 2024 and 2031 respectively. Under the industry proposed scenario stock status estimated to be 0.309 and 0.321 in 2024 and 2031 respectively. When the SESSF harvest control rule is used to set RBCs, the stock status is estimated to be 0.316 and 0.330 in 2024 and 2031 respectively.

School Whiting

This chapter presents School Whiting (*Sillago flindersi*) RBC projections from the 2020 stock assessment using a modified target MEY reference proxy of 40% instead of 48%. The 2020 School Whiting stock assessment estimates that current spawning stock biomass (at the beginning of 2021) is 41% of unexploited spawning stock biomass (SSB_0). Under the agreed 20:35:48 harvest control rule, the 2021 recommended biological catch (RBC) is 2,140 t. The RBC averaged over the three-year period of 2021-2023 is 2,237 t.

If the default (proxy) target reference point (48%) used in the SESSF harvest control rule, and specifically as used by AFMA for School Whiting, is reduced to 40%, a modified 20:35:40 harvest

control rule can be applied. This lower target allows the stock to be fished to a lower target biomass (40% of unfished spawning stock biomass (SSB_0)). Under a revised 40% target, the 2021 recommended biological catch (RBC) would be 2,753 t. The RBC, calculated under a 20:35:40 harvest control rule, averaged over the three-year period of 2021-2023 is 2,730 t.

Silver Warehou

This chapter presents a quantitative Tier 1 assessment of Silver Warehou (*Seriolella punctata*) to provide stock status estimates at the start of 2022 and describes the base case. The 2018 base case has been updated with the inclusion of data up to the end of 2020, which entails an additional three years of catch, discard, CPUE, length and age data, along with ageing error updates, revisions to historical catch series, length frequencies and discard rates.

The assessment estimates that the projected 2022 stock status will be 29% of unfished spawning stock biomass (SSB_0), projected assuming 2020 catches in 2021, with recruitment from 2016 onwards assumed to be below average, fixed at the average of 2011-2015 levels. The assessment suggests that stock status was as low as 21% of SSB_0 in 2016. Under the 20:35:48 harvest control rule, the 2022 recommended biological catch (RBC) is 587 t, while the long-term yield (assuming continuation of low recruitment) is 591 t. The average RBC over the three-year period 2022-2024 is 581 t.

This assessment has seen a continuation of below average recruitment noted in the last three assessments with the last 12 years of estimated recruitment all below average. This continuation of below average recruitment resulted in the base case for this assessment moving to low recruitments projected forward from 2016. This change reduced the severity of retrospective patterns observed in previous assessments.

Tiger Flathead

This chapter presents results of fixed catch projections for Tiger Flathead (*Neoplatycephalus richardsoni*) to provide information on possible projected stock status in light of changes to both catches and CPUE following the 2019 Tiger Flathead stock assessment.

Updated data used from the 2019 assessment, including preliminary catch (combined Commonwealth and state catch) for 2019-2020, estimated 2021 catch and updated CPUE series to the end of 2020 were included in this analysis. Updates to age and length composition data were not available and were not included. These updates to catch and CPUE alone resulted in a revision downwards to the 2020 stock status, from 34% in the last stock assessment to 32% in this analysis. These changes are due to revisions to the catches (2017-2021) and to the revised CPUE series, which has a downturn at the end of the time series (2019-2020) for the Danish seine CPUE. The eastern trawl and Tasmanian trawl CPUE series do not show the same downturn at the end of the CPUE series as Danish seine, with both trawl CPUE relatively flat in the period 2019-2020. Projecting forward to 2022 takes the stock status to 35% at the start of 2022, and this is expected to recover to 37% at the start of 2025, assuming that the RBC is caught in 2023 and 2024 and there is average recruitment from 2017 onwards. Changes to the projected stock status when the 2019 base case is updated are a consistent 1% reduction in stock status in the period 2020-2025, assuming the RBC is caught each year.

KEYWORDS: fishery management, southern and eastern scalefish and shark fishery, stock assessment, trawl fishery, non-trawl fishery

2. Background

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a Commonwealth-managed, multi-species and multi-gear fishery that catches over 80 species of commercial value and is the main provider of fresh fish to the Sydney and Melbourne markets. Precursors of this fishery have been operating for more than 85 years. Catches are taken from both inshore and offshore waters, as well as offshore seamounts, and the fishery extends from Fraser Island in Queensland to south west Western Australia.

Management of the SESSF is based on a mixture of input and output controls, with over 20 commercial species or species groups currently under quota management. For the previous South East Fishery (SEF), there were 17 species or species groups managed using TACs. Five of these species had their own species assessment groups (SAGs) – Orange Roughy (ORAG), Eastern Gemfish (EGAG), Blue Grenadier (BGAG), Blue Warehouse (BWAG), and Redfish (RAG). The assessment groups comprise scientists, fishers, managers and (sometimes) conservation members, meeting several times in a year, and producing an annual stock assessment report based on quantitative species assessments. The previous Southern Shark Fishery (SSF), with its own assessment group (SharkRAG), harvested two main species (Gummy and School Shark), but with significant catches of Saw Shark and Elephantfish.

In 2003, these assessment groups were restructured and their terms of reference redefined. Part of the rationale for the amalgamation of the previous separately managed fisheries was to move towards a more ecosystem-based system of fishery management (EBFM) for this suite of fisheries, which overlap in area and exploit a common set of species. The restructure of the assessment groups was undertaken to better reflect the ecological system on which the fishery rests. To that end, the assessment group structure now comprises:

- SESSFRAG (an umbrella assessment group for the whole SESSF)
- South East Resource Assessment Group (slope, shelf and deep water species)
- Shark Resource Assessment Group (shark species)
- Great Australian Bight Resource Assessment Group (GAB species)

Each of the depth-related assessment groups is responsible for undertaking stock assessments for a suite of key species, and for reporting on the status of those species to SESSFRAG. The plan for the Resource Assessment Groups (South East, GAB and Shark RAGs) is to focus on suites of species, rather than on each species in isolation. This approach has helped to identify common factors affecting these species (such as environmental conditions), as well as consideration of marketing and management factors on key indicators such as catch rates.

The quantitative assessments produced annually by the Resource Assessment Groups are a key component of the TAC setting process for the SESSF. For assessment purposes, stocks of the SESSF currently fall under a Tier system whereby those with better quality data and more robust assessments fall under Tier 1, while those with less reliable available information are in Tiers 4 and 5. To support the assessment work of the four Resource Assessment Groups, the aims of the work conducted in this report were to develop new assessments if necessary (under all Tier levels), and update and improve existing ones for priority species in the SESSF.

3. Need

A stock assessment that includes the most up-to-date information and considers a range of hypotheses about the resource dynamics and the associated fisheries is a key need for the management of a resource. In particular, the information contained in a stock assessment is critical for selecting harvest strategies and setting Total Allowable Catches.

4. Objectives

These Objectives include a description of the SESSFRAG agreed changes to the assessment schedule and may differ from the objectives in the original contract:

- Provide quantitative and qualitative species assessments in support of the four SESSFRAG assessment groups, including RBC calculations within the SESSF harvest strategy framework
- 2020: Provide Tier 1 assessments for Gummy Shark, Eastern Redfish and School Whiting; Tier 4 assessments for John Dory, Mirror Dory, Ocean Perch, Oreobasket, Ribaldo, Royal Red Prawn, Sawshark and Silver Trevally; and Tier 5 for Blue-eye Trevalla
- 2021: Provide Tier 1 assessments for Eastern Orange Roughy, Blue Grenadier, Eastern Jackass Morwong and Silver Warehou; Tier 4 for Mirror Dory and Tier 5 for E/W Deepwater Shark

5. Blue grenadier (*Macruronus novaezelandiae*) stock assessment based on data up to 2020 – development of a preliminary base case

Geoff Tuck and Pia Bessell-Browne

CSIRO Oceans and Atmosphere, Castray Esplanade, Hobart, TAS 7000,
Australia

5.1 Executive Summary

This document presents the preliminary base case for an updated quantitative Tier 1 assessment of Blue Grenadier (*Macruronus novaezelandiae*) for presentation at the SERAG2 meeting in October 2021. The last full assessment was conducted during 2018 (Castillo-Jordán and Tuck, 2018b). The preliminary base case has been updated with the inclusion of data up to the end of 2020, which entails an additional 3 years of catch, discard, CPUE, length and age data and ageing error updates since the 2018 assessment. This document describes the process used to develop a 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)).

This document describes the standard Bridge 1, which updates the assessment to the most recent version of Stock Synthesis, ensures correct settings are used and updates the historical catch series, and Bridge 2, which sequentially incorporates updated data through to 2020. The base case specifications agreed by the SERAG in 2018 were maintained into the preliminary base case presented here. The main differences between the model of 2018 and 2021 are: replacing the variable length bins with 2 cm length bins (standard method across SESSF Tier 1 assessments) and using the latest methods for assigning final weights to the various data sources.

Results of the preliminary base case show reasonably good fits to the length-composition data, conditional age at length, egg survey, discards and acoustic survey. 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, the 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.

The estimated virgin female spawning biomass (B_0) is 40,759 t tonnes and the projected 2022 spawning stock biomass will be 126% of virgin female spawning biomass (projected assuming 2020 catches in 2021), compared to 122% for 2019 in the 2018 assessment.

Further development and sensitivity testing should include the addition of the FIS lengths and estimating selectivity for the FIS fleet (rather than mirroring to the selectivity of the non-spawning fleet) and estimating male natural mortality.

5.2 Introduction

5.2.1 2021 Blue Grenadier assessment base case.

The 2021 preliminary 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 unexploited 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 (Methot, 2005).

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 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 are the FIS survey estimates for the non-spawning fishery. 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 first bridging exercise (Bridge 1) highlights changes that have occurred since 2018 simply through changes to software and assessment practices. The subsequent bridging exercise (Bridge 2) then sequentially updates the assessment model with new data through to 2020.

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 unexploited biomass with the corresponding equilibrium (unexploited) 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 M is estimated within the assessment. Following previous assessments, male M is assumed be 20% greater than that of females.
- 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 Punt and Smith 2001; 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 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.
- 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 inclusion of the FIS is considered for the non-spawning area, and the selectivity mirrors the corresponding non-spawning fleet (Fleet 2).
- k) The CVs of the CPUE indices were initially set at a value equal to the standard error from a loess fit (0.252; Sporic, 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.
- l) 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.
- m) 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 5.1.

Table 5.1. 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	$1.2 * M_f$
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	$0.01502 \text{ g}^{-1} \cdot \text{cm}$
b_f	Female allometric length-weight equations	2.728
a_m	Male allometric length-weight equations	$0.0168 \text{ g}^{-1} \cdot \text{cm}$
b_m	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

5.3 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 4 years for males and 5 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 GSIs 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 (Zone 40, months June, July and August) and non-spawning fisheries (all other months and zones).

5.4 Bridging methodology

The previous full quantitative assessment for Blue Grenadier was performed in 2018 (Castillo-Jordán and Tuck, 2018) using Stock Synthesis (version SS-V3.30.12.00, Methot et al. (2018)). The 2021 assessment uses the current version of Stock Synthesis (version SS-V3.30.17.00, Methot et al. (2021)).

As a first step in the process of bridging to a new model, the data used in the 2018 assessment was used in the new software (SS-V3.30.17.00). Once this translation was complete, improved features unavailable in SS-V3.12.00 were incorporated into the SS-V3.30.17 assessment. The catch series was then updated to include any amended estimates for the historical period from 1998 to 2017 since the 2018 assessment. Following this step, the model was re-tuned using the most recent tuning protocols (Pacific Fishery Management Council, 2018), thus allowing the examination of changes to both assessment practices and the tuning procedure on the previous model structure. These changes to software and tuning practices may lead to changes to key model outputs, such as the estimates of depletion and the trajectory of spawning biomass. This initial bridging phase (Bridge 1) highlights changes that have occurred since 2018 simply through changes to software and assessment practices.

The subsequent bridging exercise (Bridge 2) then sequentially updates the model with new data through to 2020. These additional data included new catch, discard estimates, CPUE, length composition data, conditional age-at-length data and an updated ageing error matrix. The last year of recruitment estimation and cohort dependent growth was extended to 2017 (from 2014 in Castillo-Jordán and Tuck (2018b)). The final step is to re-tune the model.

5.5 Bridge 1

The 2018 Blue Grenadier assessment (labelled ‘GRE_2018_30_12_00’) was converted to the most recent version of the software, Stock Synthesis version SS-V3.30.17.00 (labelled ‘GRE_2018_30_17_00’). This resulted in no changes to the stock status estimates throughout the timeseries (Figure 5.1). There were no discernible changes that resulted from alteration of settings. Likewise, updating catches to 2017 also resulted in no discernible changes (labelled ‘Updated_catch’ and includes the previous changes (Figure 5.1)). The assessment was then tuned using the latest tuning protocol (labelled ‘Tuned’). This process demonstrates the outcomes that could theoretically have been achieved with the last assessment if we had the latest software, tuning protocols and corrected data available in 2018. This initial bridging step, Bridge 1, does not incorporate any data after 2017 or any structural changes to the assessment. Re-tuning led to a reduction in the initial estimate of virgin biomass (Figure 5.1). Sensitivity to this parameter has been noted in previous assessments (Figure 5.2; Castillo-Jordán and Tuck, 2018a).

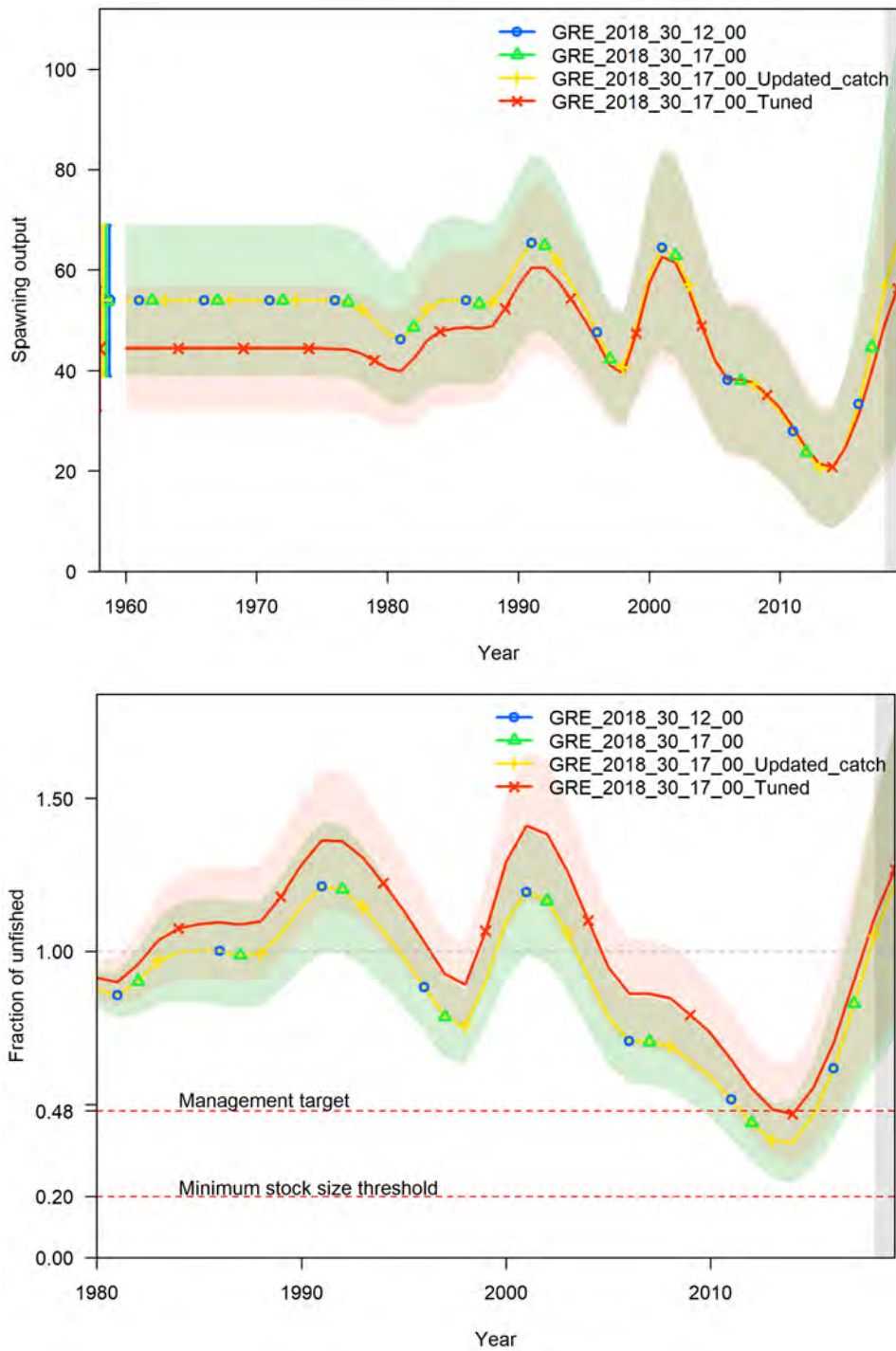


Figure 5.1. Comparison of the spawning (top) and relative (bottom) biomass time series for the 2018 assessment (SS3-30.12), a model converted to SS-V3.30.17, with updated settings and catches (Updated_catch) and then re-tuned (Tuned).

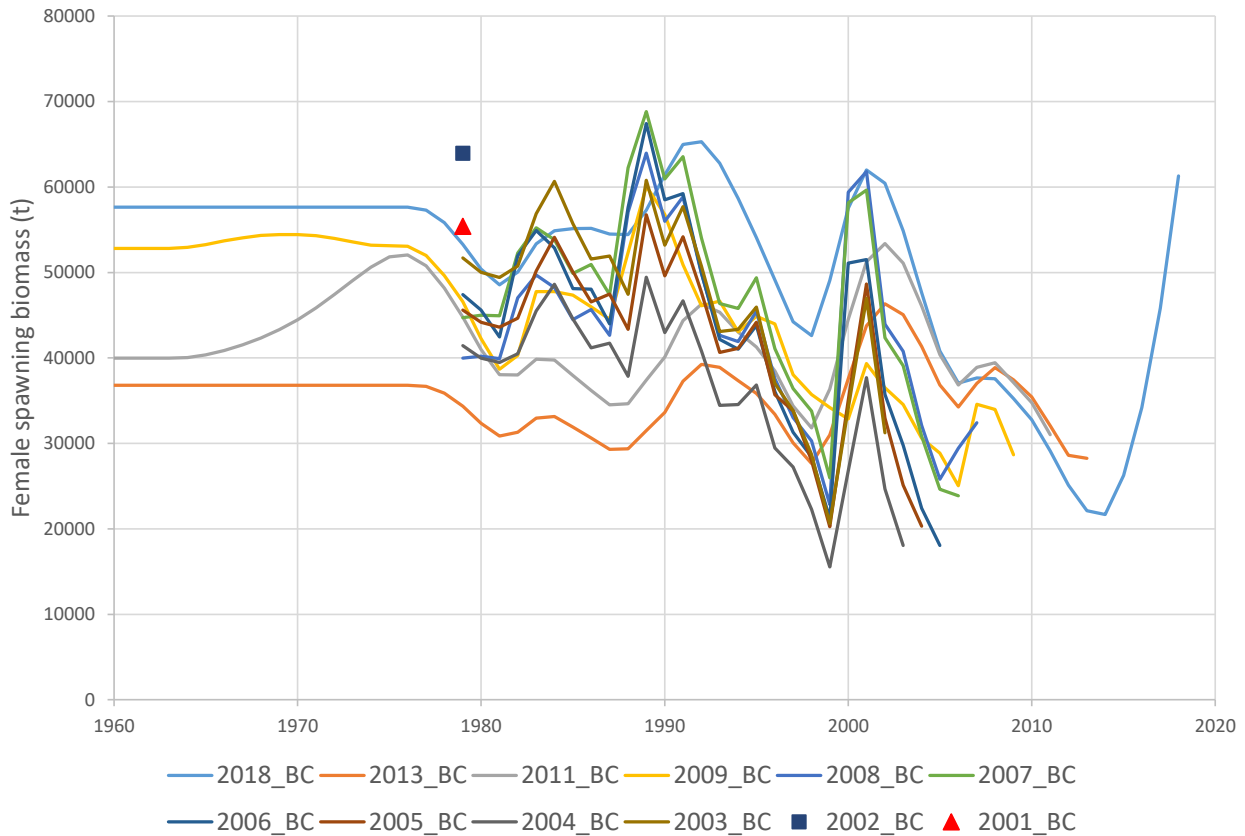


Figure 5.2. A retrospective of assessment outputs of female spawning biomass from each stock assessment from 2001 to 2018. Note that for 2001 and 2002 only values of biomass at 1979 were available (from Castillo-Jordán and Tuck, 2018a).

5.6 Bridge 2

5.6.1 Inclusion of new data

The data inputs to the assessment comes from multiple sources, including: length and conditional age-at-length data, updated standardized CPUE series (Sporcic, 2021), the annual total mass landed, discard mass, and age-reading error.

Starting from the converted 2018 base case model (labelled GRE_2018_Updated) additional and updated data to 2020 were added sequentially to develop a preliminary base case for the 2021 assessment, these steps included:

1. Change final assessment year to 2020, add catch to 2020 (addCatch2020).
2. Add CPUE to 2020 (from Sporcic (2021)) (addCPUE2020).
3. Add updated discard estimates to 2020 (add_Discards2020).
4. Update length frequency data, including both port and onboard length frequencies (addLengths2020). Conditional-age-at-length were also updated at this step due to changing the length bins used in the assessment.
5. Add updated age error matrix (addAgeErr2020).

6. Change the final year for which recruitments are estimated from 2014 to 2017 (extendRec2017).
7. Change the final year for which cohort dependent growth is estimated from 2014 to 2017 (extendCGD2017).
8. Retune using latest tuning protocols, including Francis weighting on length-compositions and conditional age-at-length data (Tuned_3).

5.6.2 Results – base case

Inclusion of the new data resulted in a series of changes to the outputs of the model. The addition of updated catch data and catch rate data made minimal difference to the estimated spawning biomass (Figure 5.3). The addition of updated discard estimates markedly reduced initial and final estimates of spawning biomass (Figure 5.3). There were minimal changes resulting from the addition of length and age data (Figure 5.3). Extending recruitment deviations and cohort dependent growth led to an increase in initial and final biomass due to the greater freedom to fit to recent input data (e.g. the catch rate series, Figure 5.3). Tuning resulted in downward revisions to the biomass series, with initial biomass similar to the updated 2018 assessment (Figure 5.3).

The sequential addition of data resulted in various changes to the recruitment estimates (Figure 5.4). The addition of further recruitment years (to 2017; GRE_2021_extendRec2017) has led to a marked increase in the magnitude of recent recruitment (between 2014 -2017) over the assumed values from the recruitment curve (Figure 5.4). Final tuning also increased the estimates of recruitment from the early years of the fishery (late 1970s and mid 1980s, Figure 5.4).

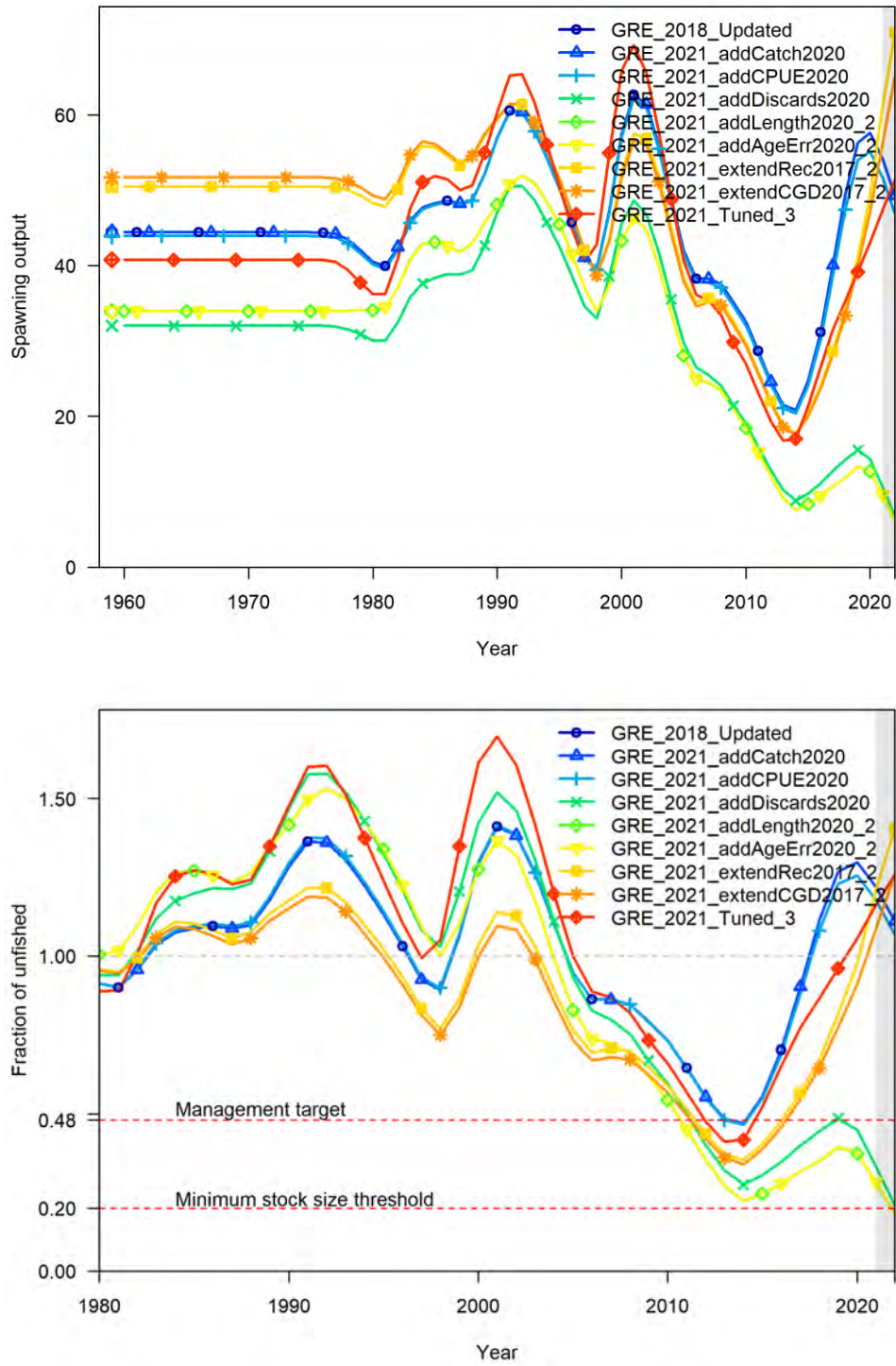


Figure 5.3. Comparison of the absolute (top) and relative (bottom) spawning biomass for the updated 2018 assessment converted to SS-V3.30.17 (GRE_2018_Updated – dark blue) with various bridging models leading to the 2021 base case (GRE_2021_Tuned_3 - red)

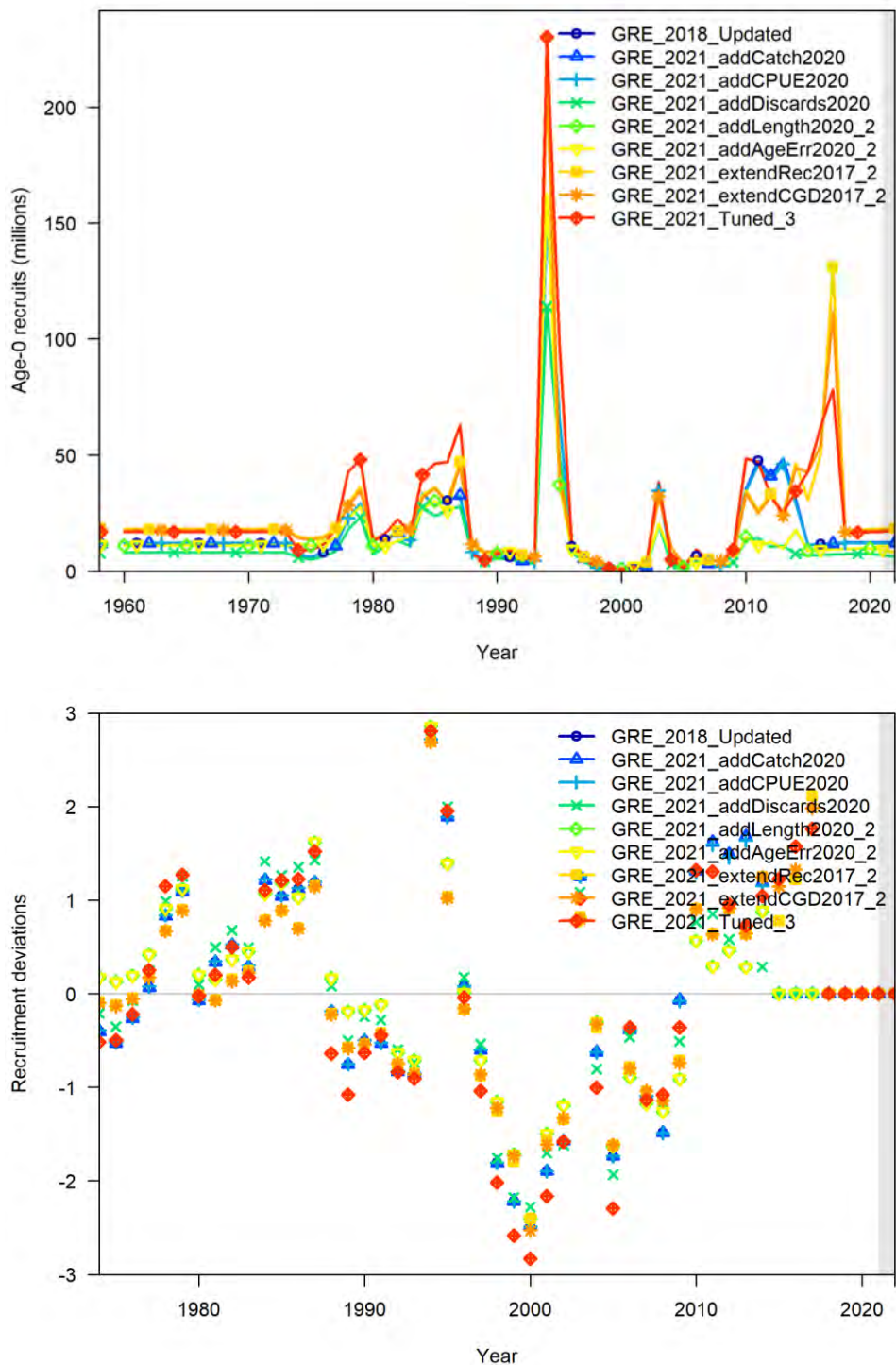


Figure 5.4. Comparison of the estimated recruitment (top) and deviations (bottom) for the updated 2018 assessment model converted to SS-V3.30.17 (GRE_2018_Updated – dark blue) with various bridging steps leading to the 2021 base case (GRE_2021_Tuned_3 - red)

The impacts of inclusion of new data on fits to the non-spawning fishery CPUE series are illustrated in Figure 5.5. As has been noted before, the fits to CPUE are generally poor until the mid-2000s. The addition of new data and extending recruitment estimation to 2017 has allowed a reasonable fit to the recent marked increase in CPUE since 2018.

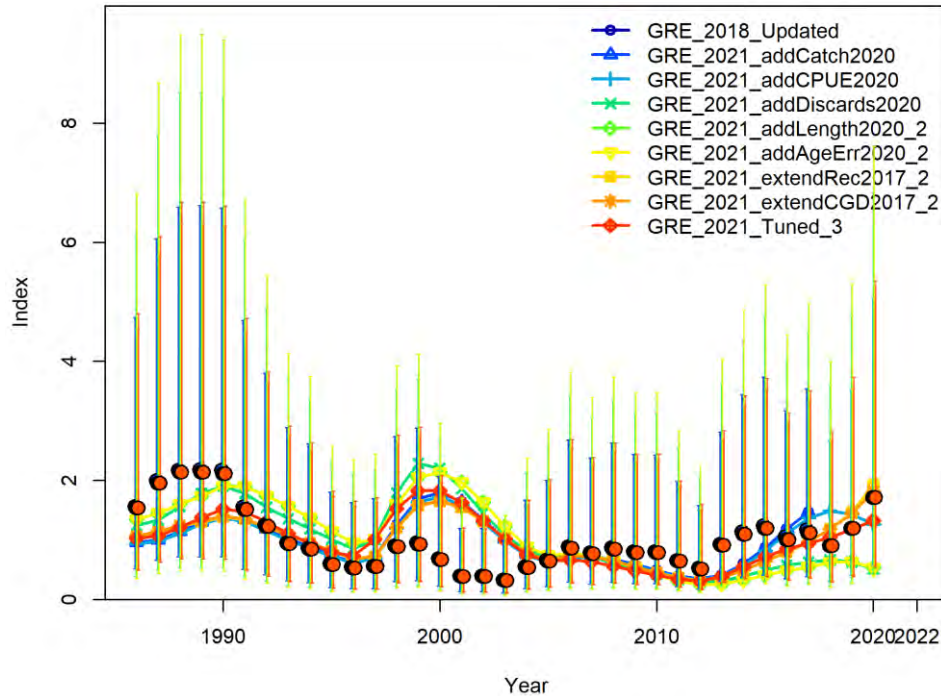


Figure 5.5. Comparison of the fit to the non-spawning fishery CPUE index for the updated 2018 assessment model converted to SS-V3.30.17 (GRE_2018_Updated – dark blue) with various bridging models leading to the 2021 preliminary base case (GRE_2021_Tuned_3 - red)

5.6.3 Fits to data – base case

Estimated outputs and fits to the data of the preliminary base case are presented in Figure 5.6–Figure 5.13. Fits are comparable to those in the previous assessment (see Castillo- Jordán and Tuck (2018b)). Fits to the acoustic and FIS surveys are reasonable, although there is little variation in the estimated values and the fit is relatively flat while passing through the confidence intervals. The fit to discard mass is reasonable, although there is some under-fitting from 2015-17. Fits to the length composition data are good across the retained and discard lengths, and for port and onboard lengths. Note the saw-tooth port lengths which may be due to in-port rounding of measurements. This will be further investigated.

5.6.4 Assessment outcomes -base case

The estimated virgin female biomass is 40,759 tonnes (compared to 53,909 tonnes in 2018 and 36,815 tonnes in the 2013 assessments). Initial biomass is known to be sensitive in this model and often has varied between 35,000 tonnes and 60,000 tonnes. Castillo- Jordán and Tuck (2018a) showed that there is uncertainty regarding the initial biomass from the likelihood profile for $\ln R_0$ (Figure 5.15). A likelihood profile on initial biomass (amongst others) will be conducted for SERAG3 in 2021 to further investigate this sensitivity.

The projected 2022 spawning stock biomass will be 126% 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.

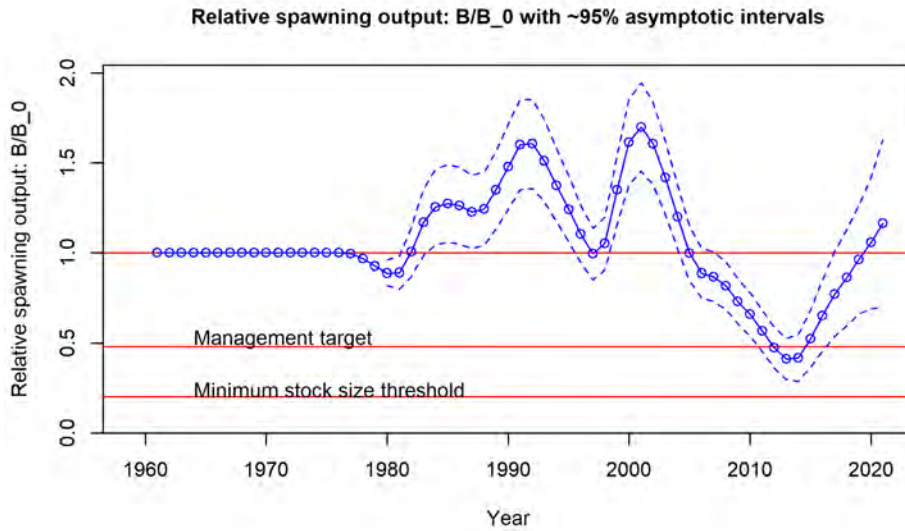


Figure 5.6. The estimated time-series of relative spawning biomass for the 2021 preliminary base case assessment

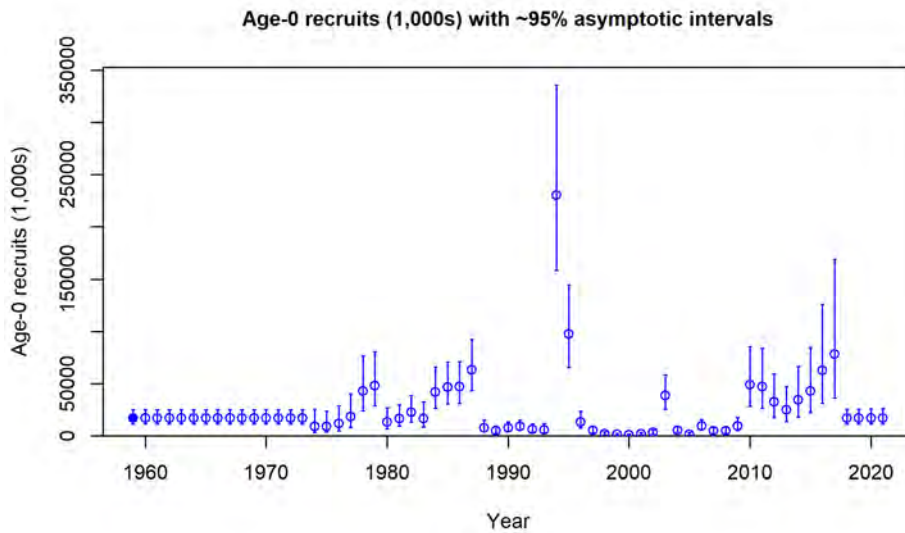


Figure 5.7. The estimated time-series of recruitment for the 2021 preliminary base case assessment

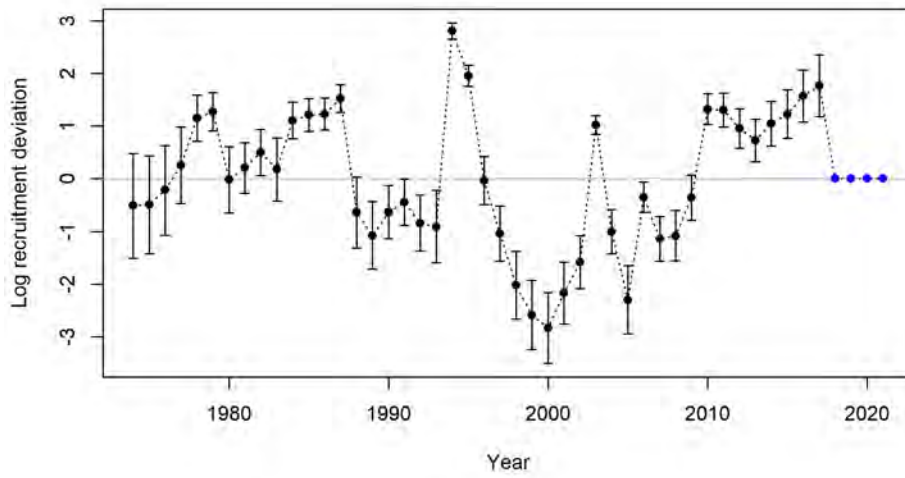


Figure 5.8. The estimated time-series of recruitment deviations for the 2021 preliminary base case assessment

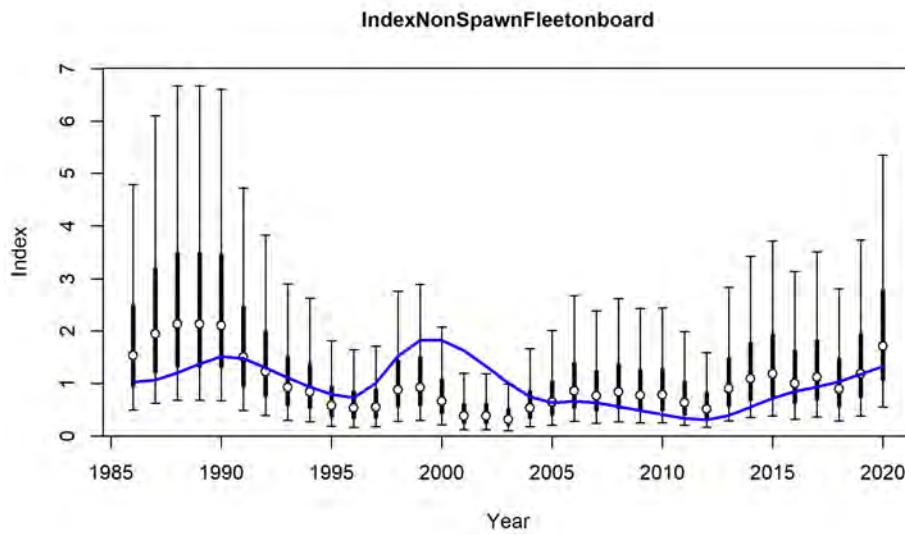


Figure 5.9. Fits to the non-spawning fishery CPUE for the 2021 preliminary base case assessment

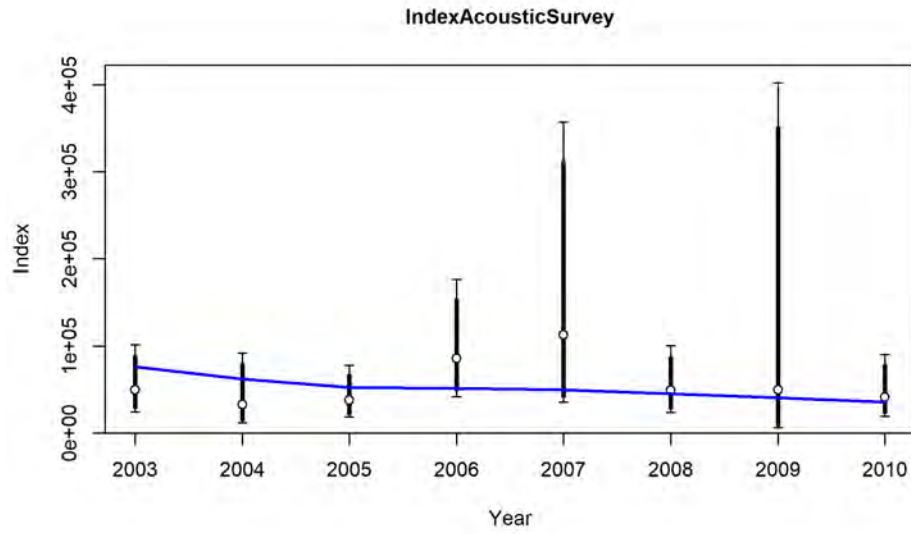


Figure 5.10. Fits to the acoustic survey for the 2021 preliminary base case assessment

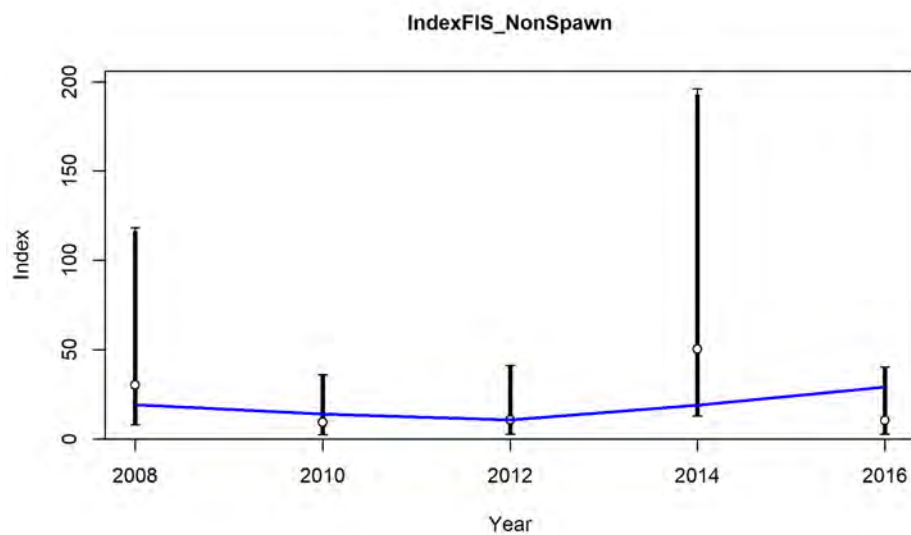


Figure 5.11. Fits to the FIS winter non-spawning survey for the 2021 preliminary base case assessment

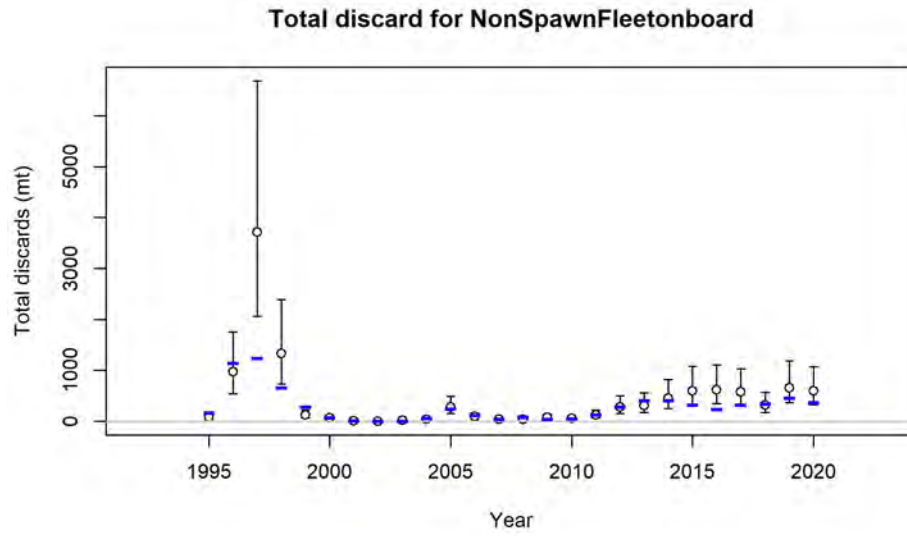


Figure 5.12. Fits to the non-spawning fishery discards for the 2021 preliminary base case assessment

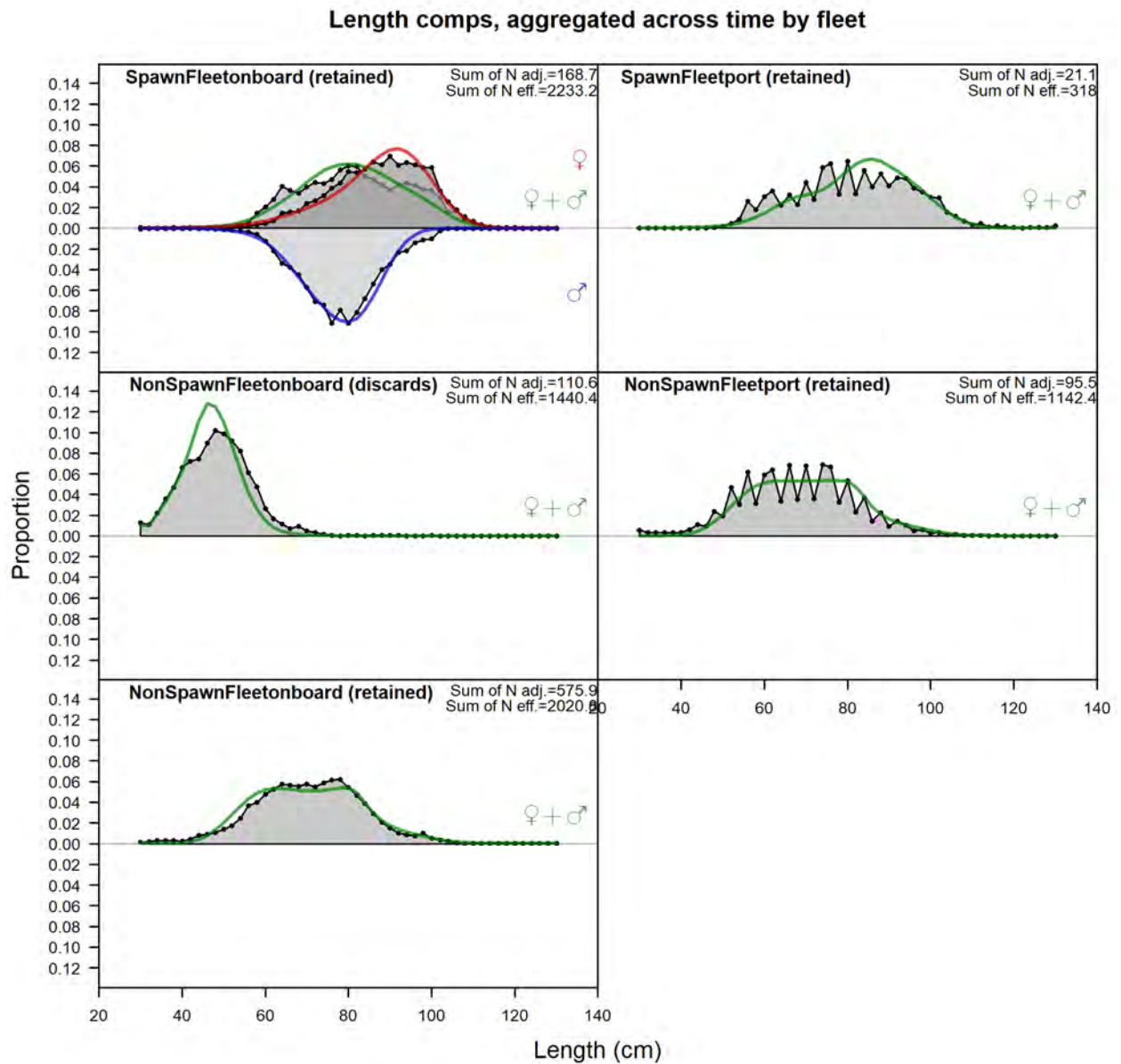


Figure 5.13. Fits to the aggregated length data for the 2021 preliminary base case assessment

5.7 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 recommendations and fixes in relation to 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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5.9 Appendix

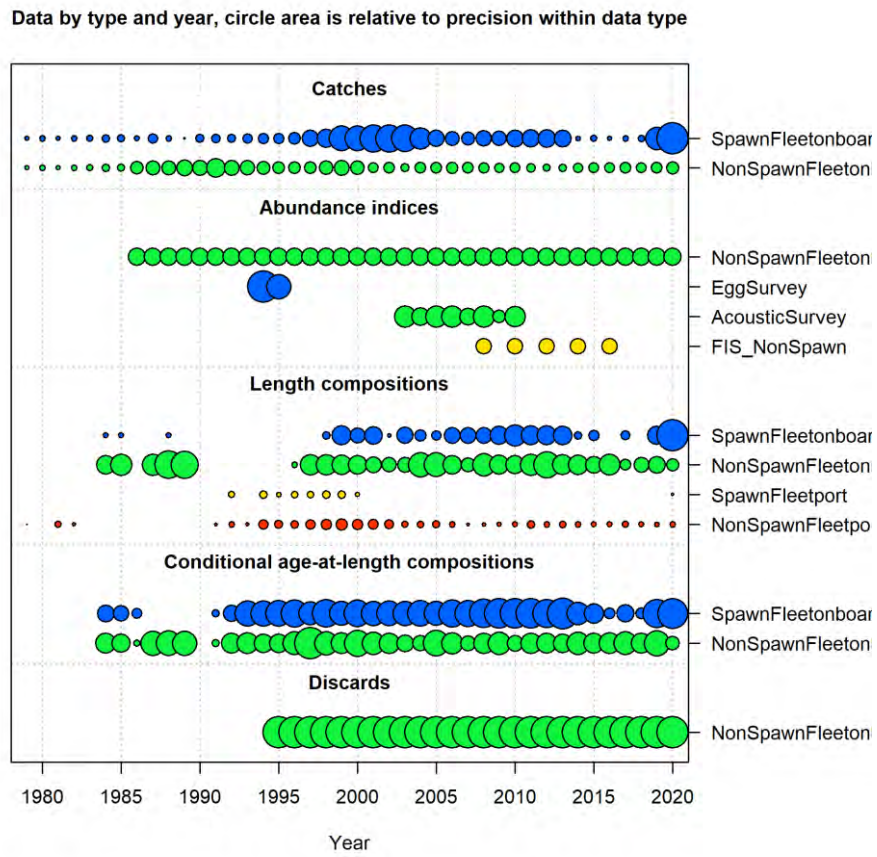


Figure 5.14. Summary of Blue Grenadier data sources

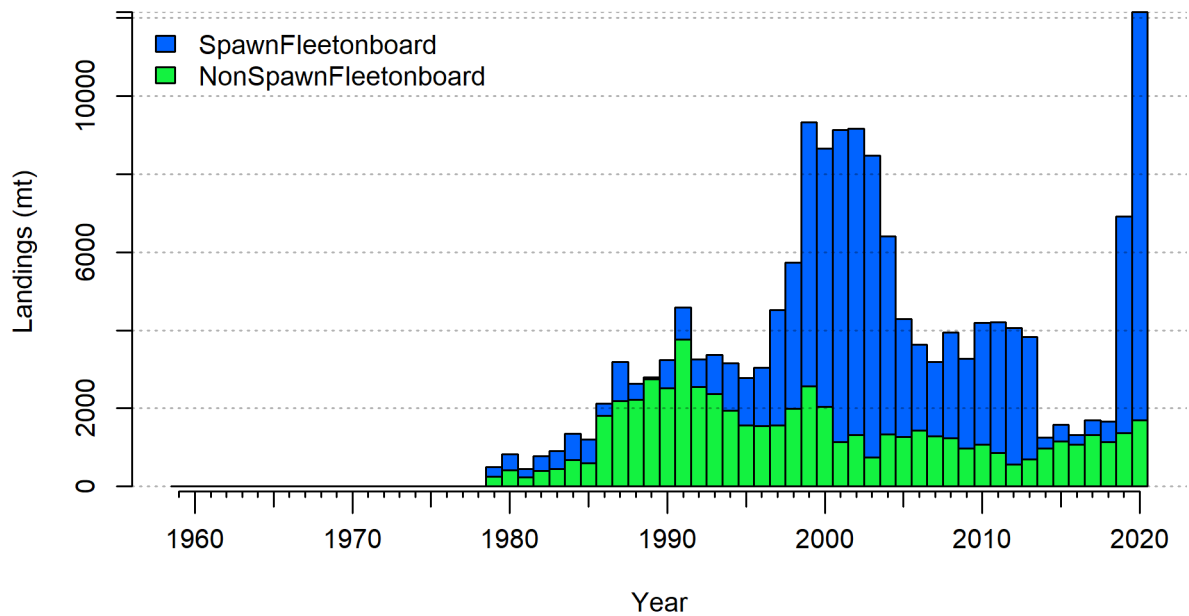


Figure 5.15. Summary of catch by fleet

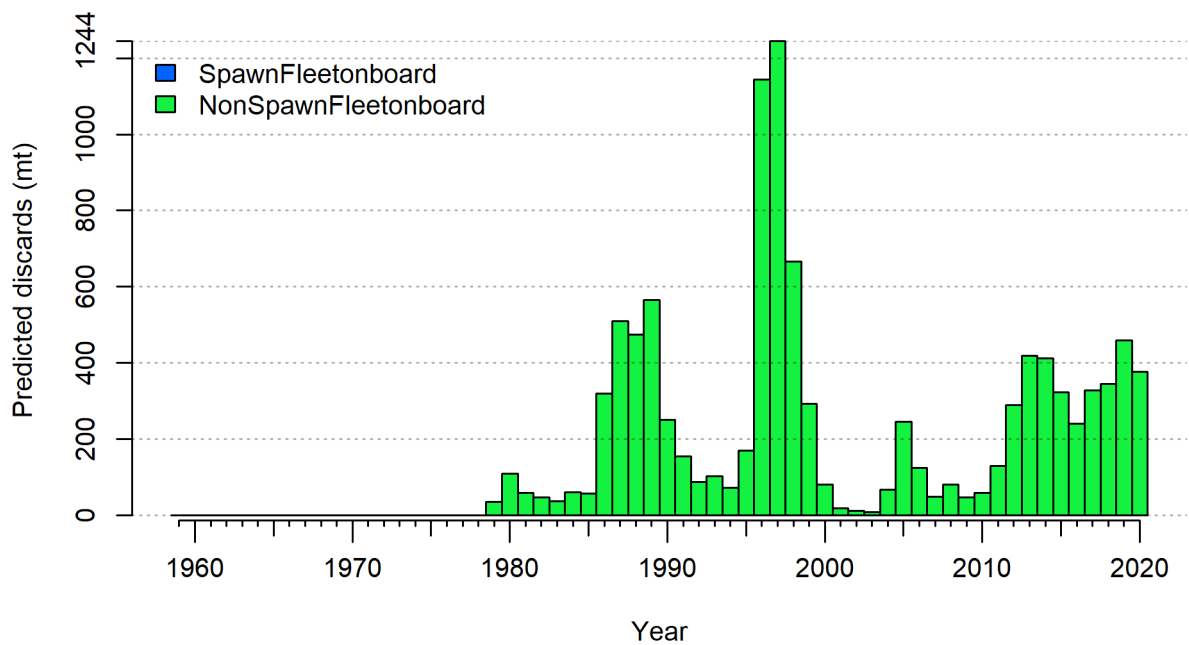


Figure 5.16. Summary of total discards by fleet

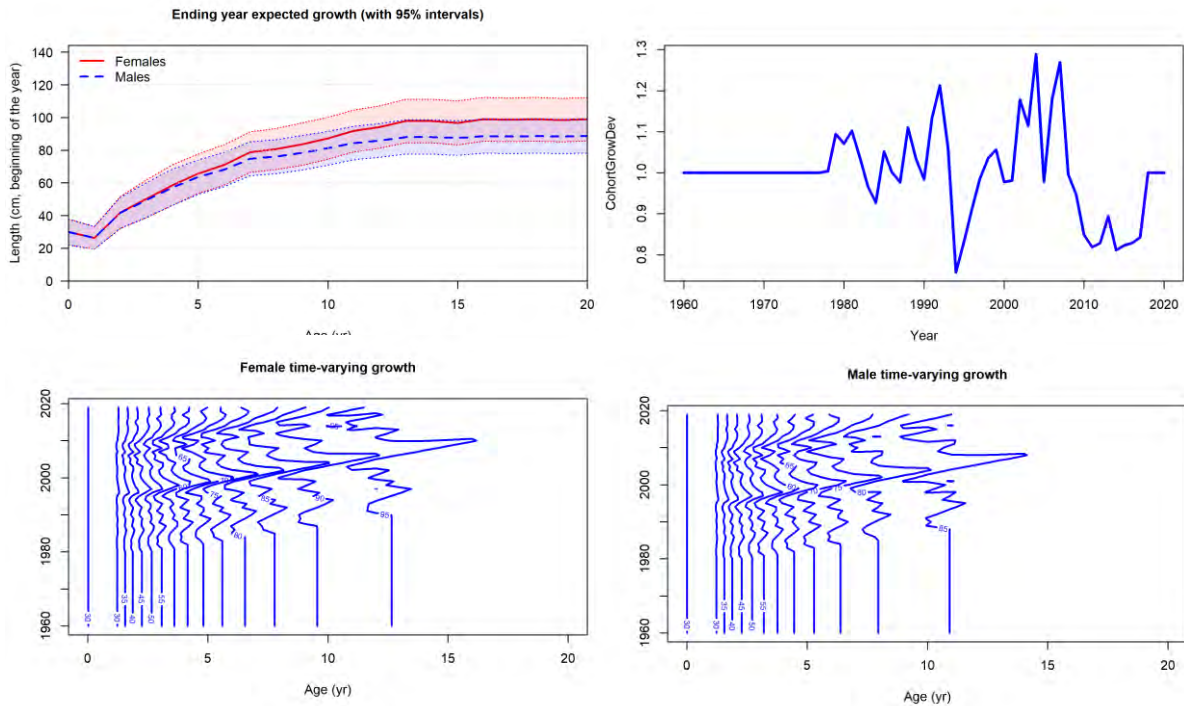


Figure 5.17. Estimated growth for Blue Grenadier

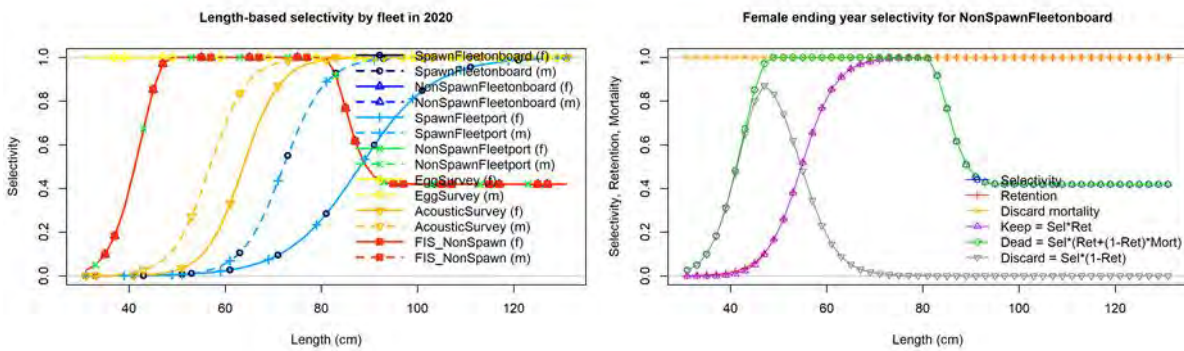


Figure 5.18. Estimated selectivity and retention by fleet for the base case

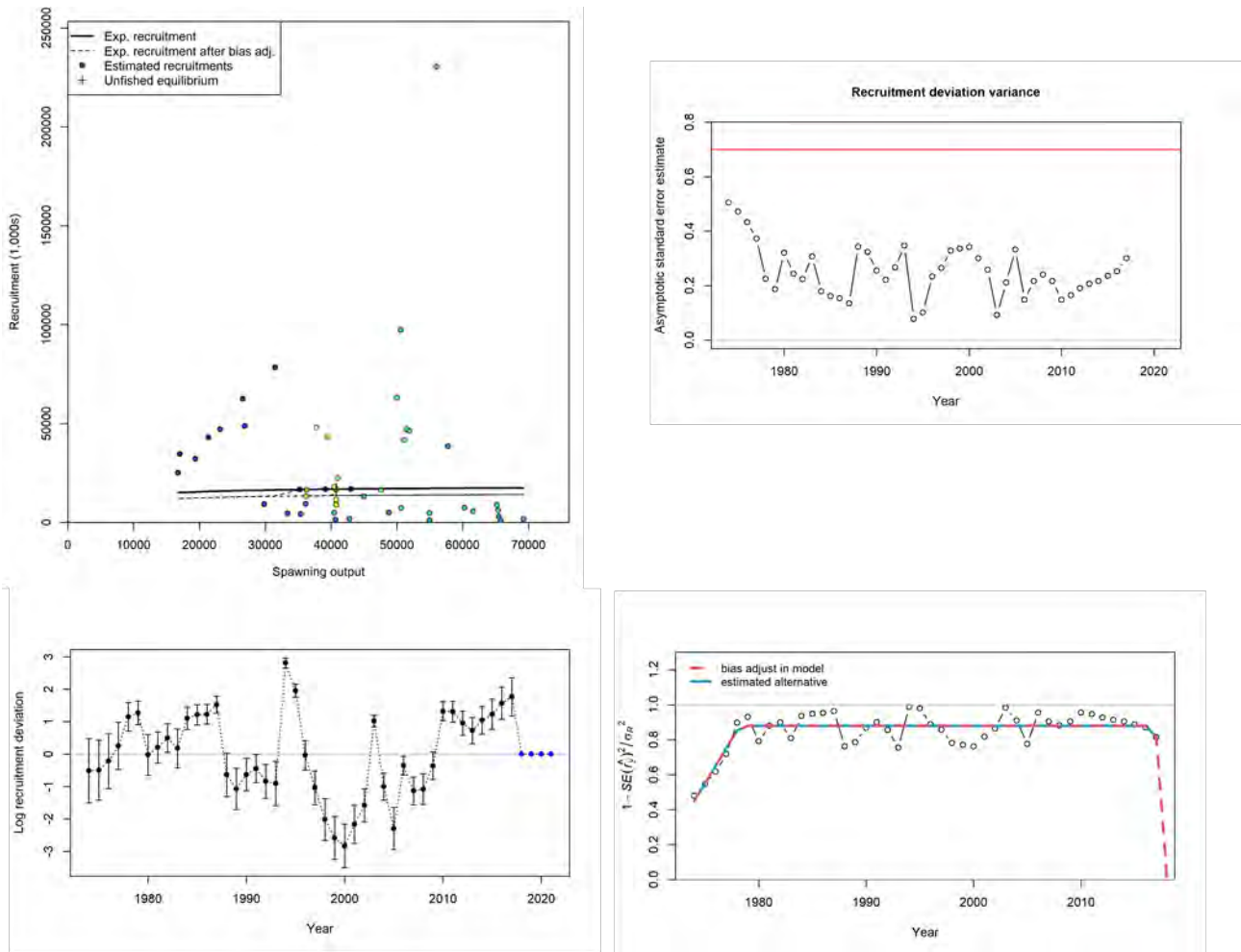


Figure 5.19. Time series showing the stock recruitment curve, recruitment deviations and recruitment deviation variance check for blue grenadier.

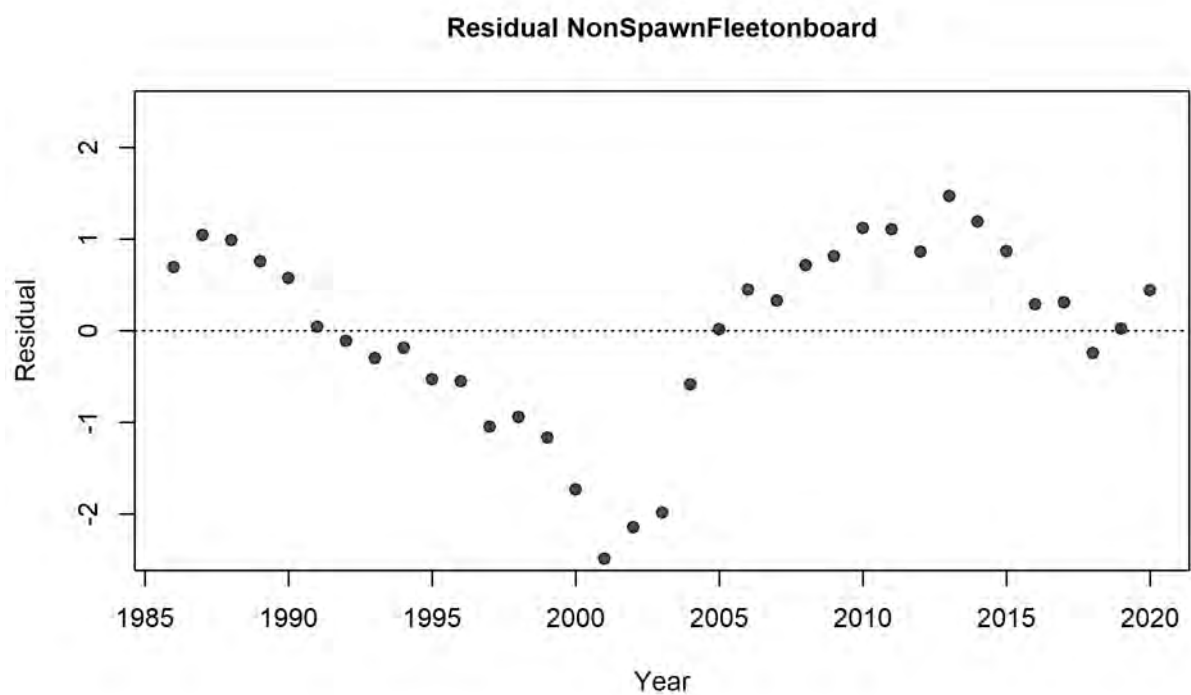


Figure 5.20. Residuals for fits to CPUE.

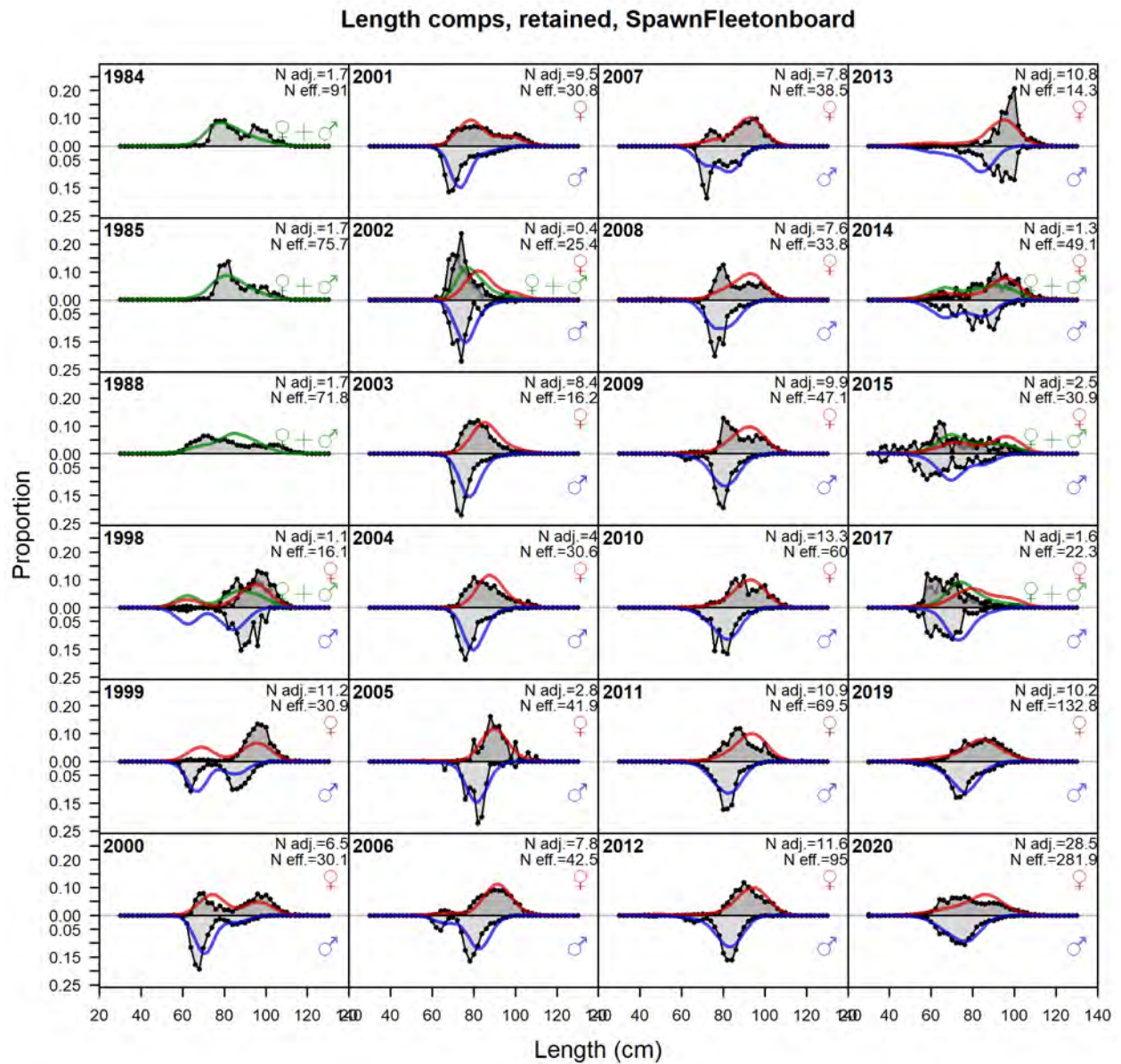


Figure 5.21. Length composition fits: onboard spawning fleet retained.

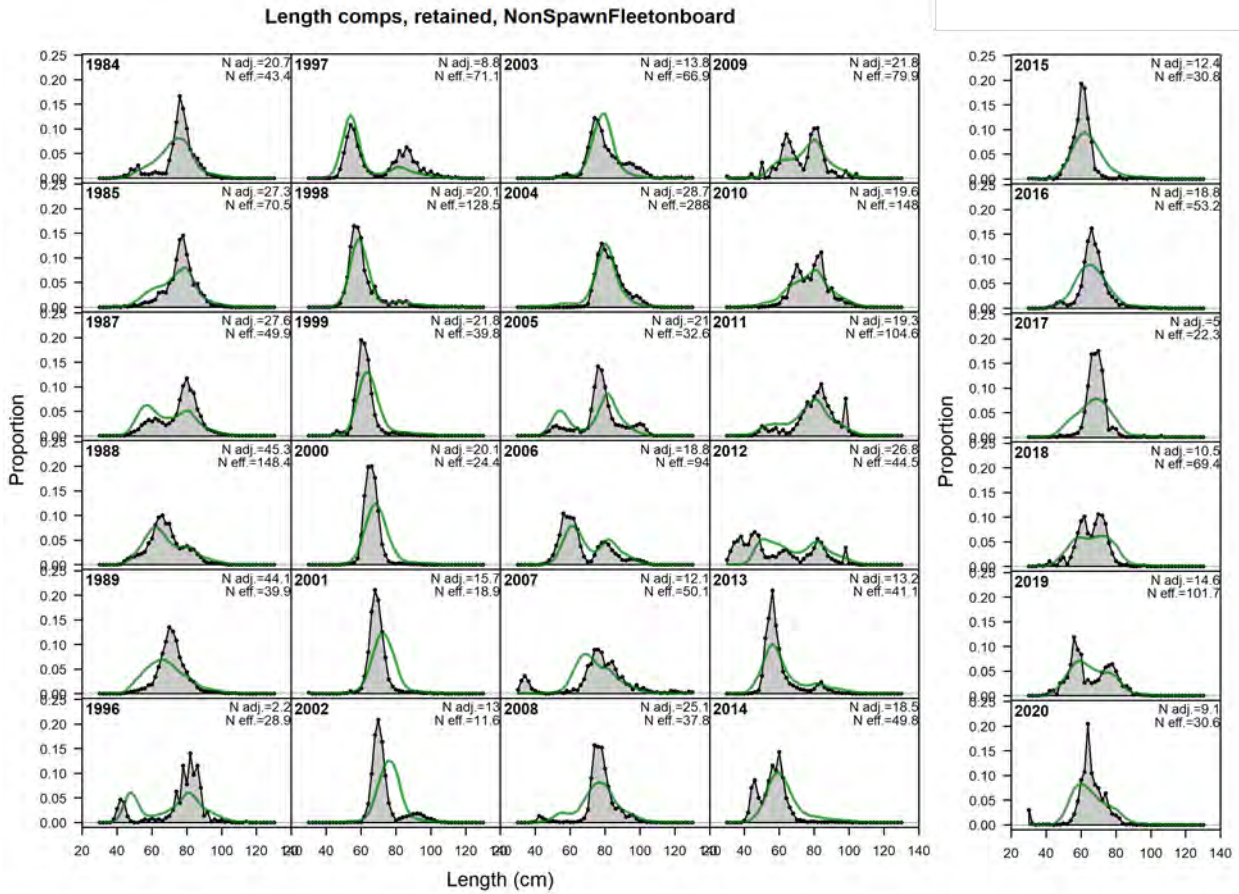


Figure 5.22. Length composition fits: onboard non-spawning fleet retained.

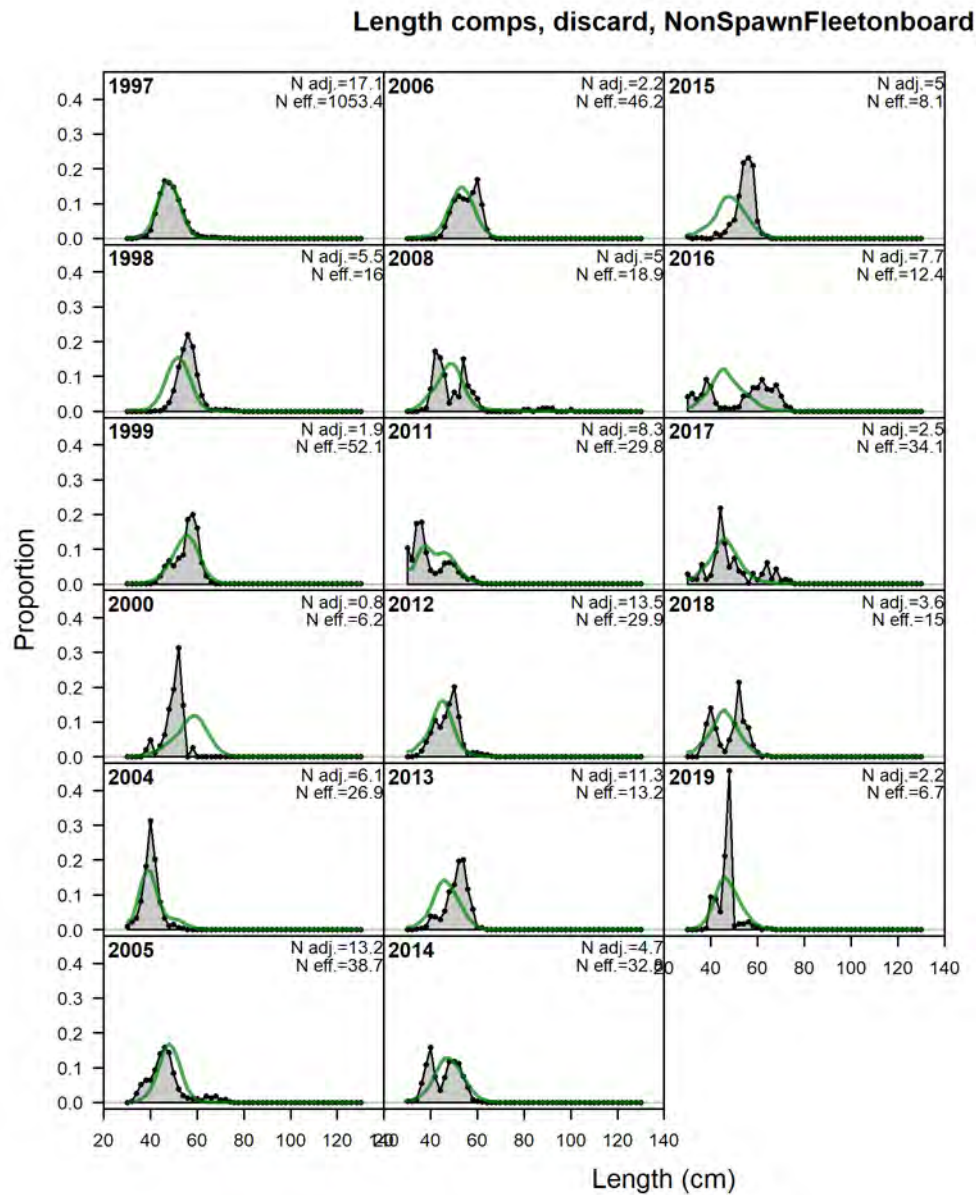


Figure 5.23. Length composition fits: onboard non-spawning fleet discard.

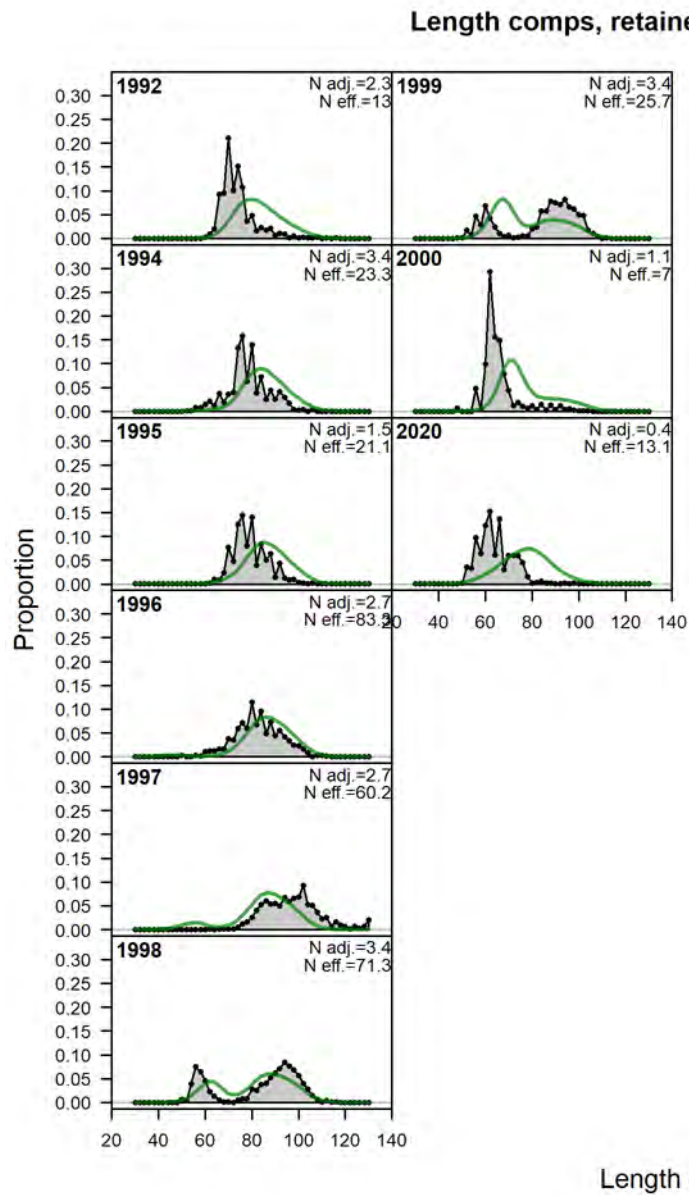


Figure 5.24. Length composition fits: port spawning fleet retained.

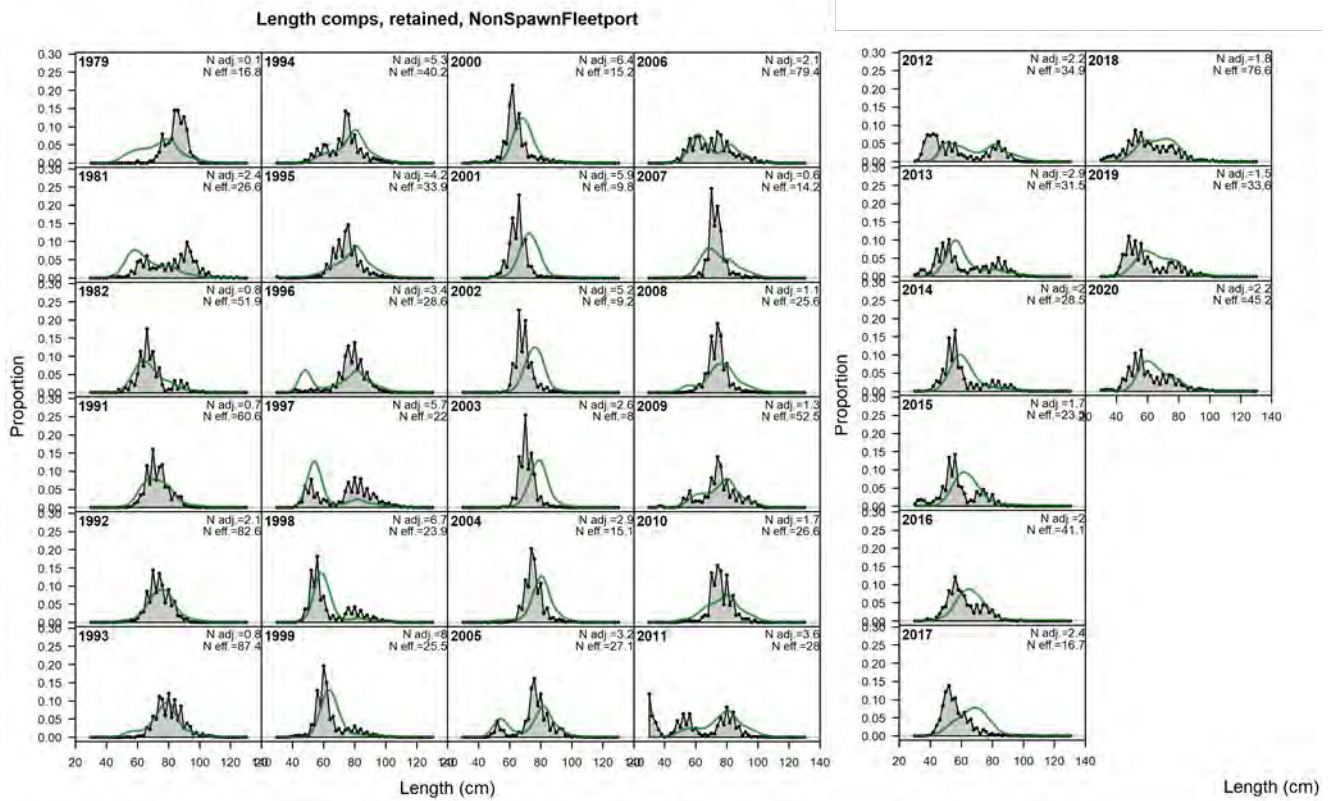


Figure 5.25. Length composition fits: port non-spawning fleet retained.

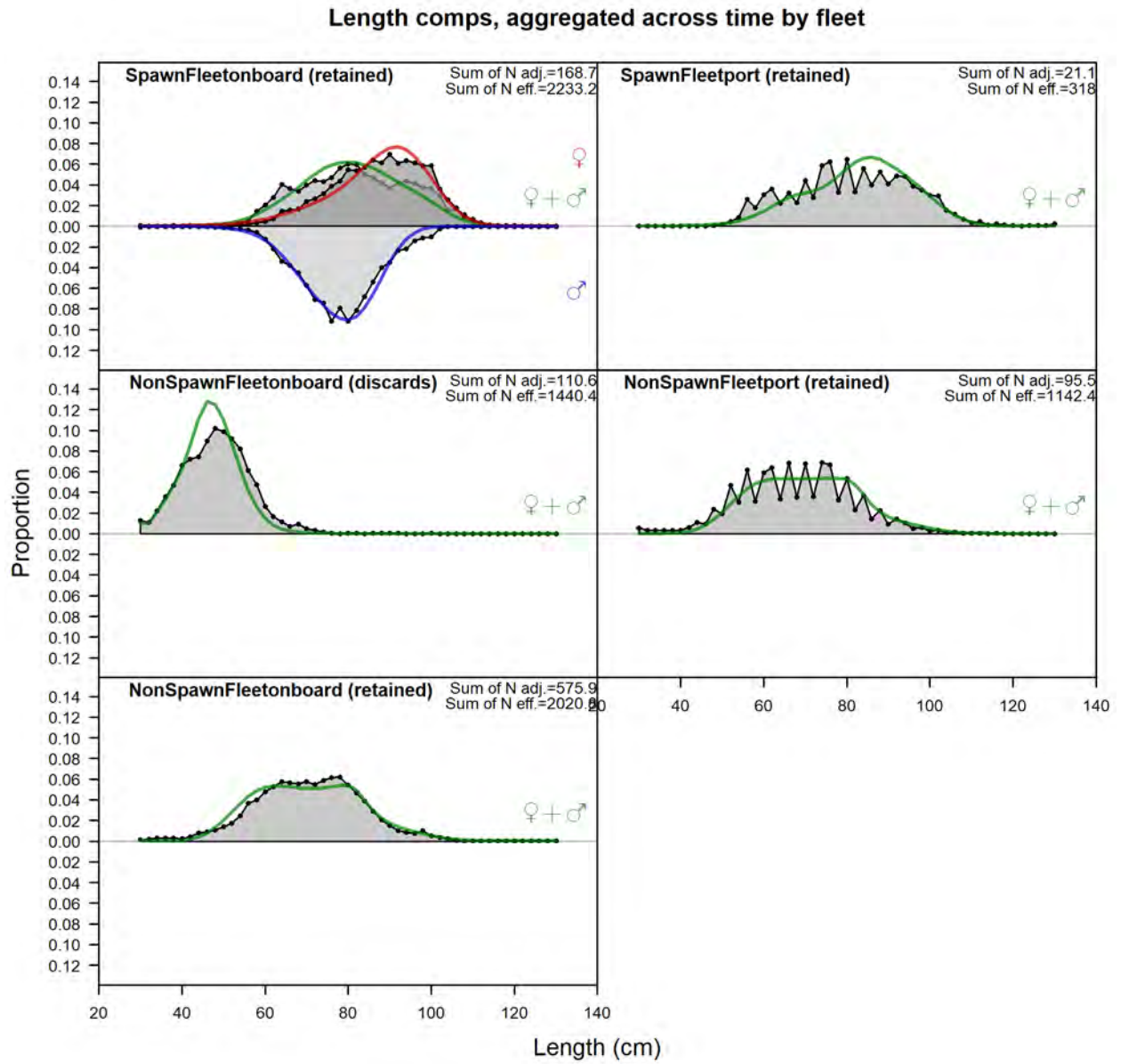


Figure 5.26. Length composition fits aggregated across years.

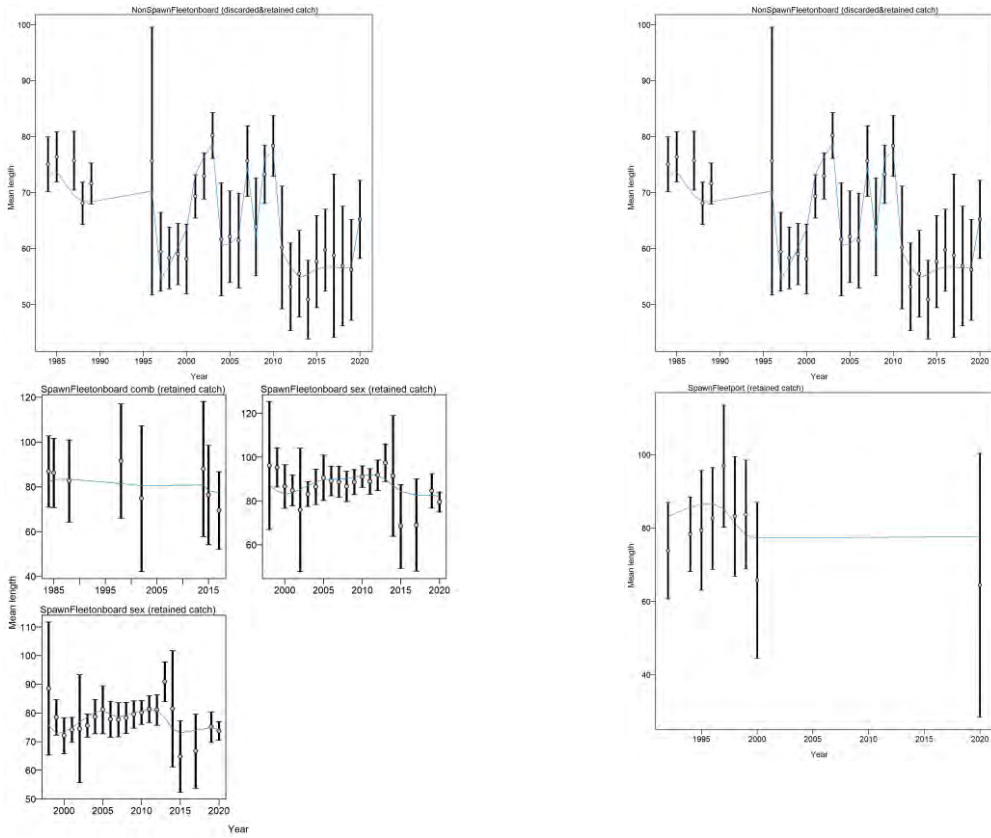


Figure 5.27. Length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.

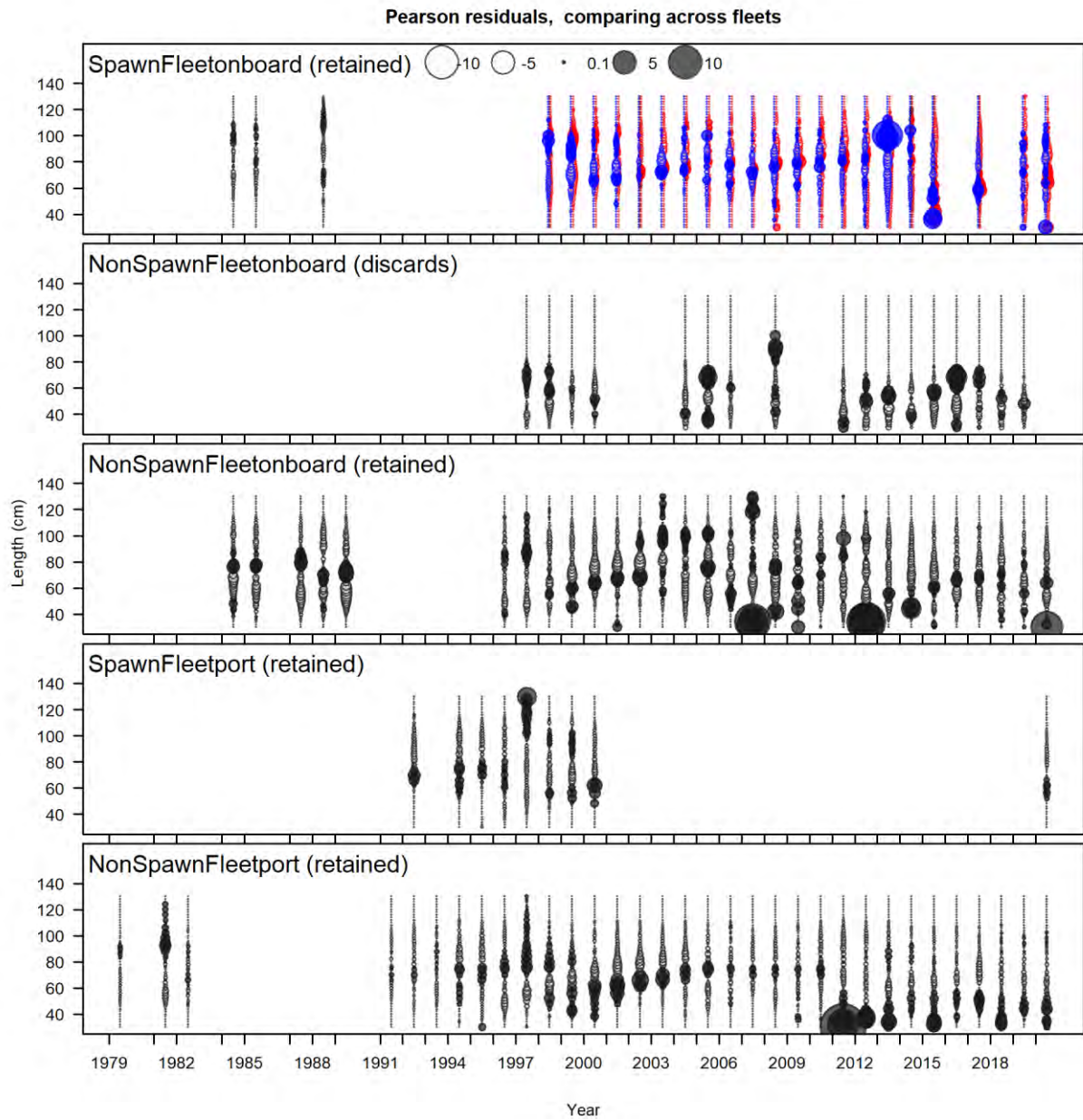
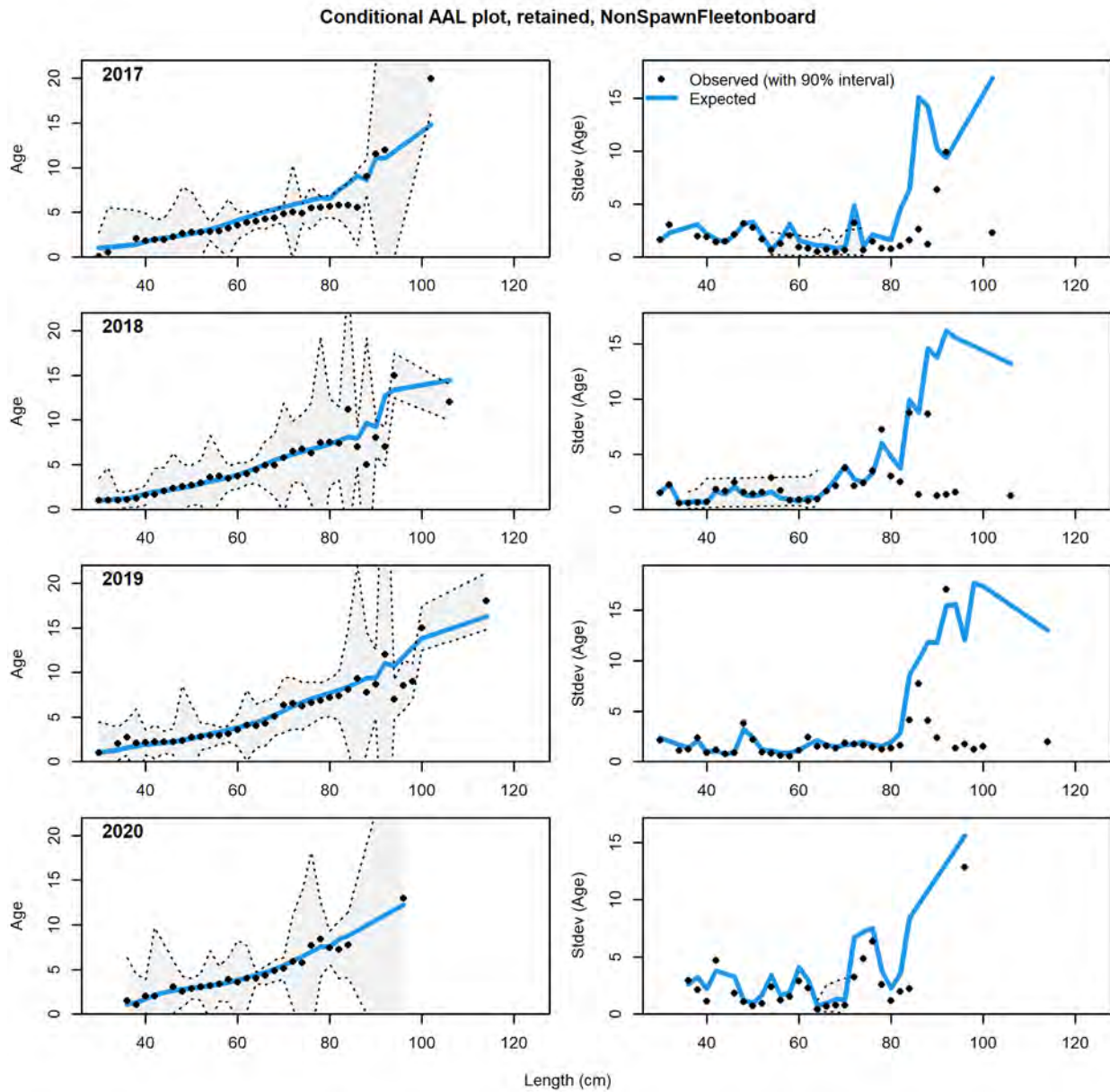
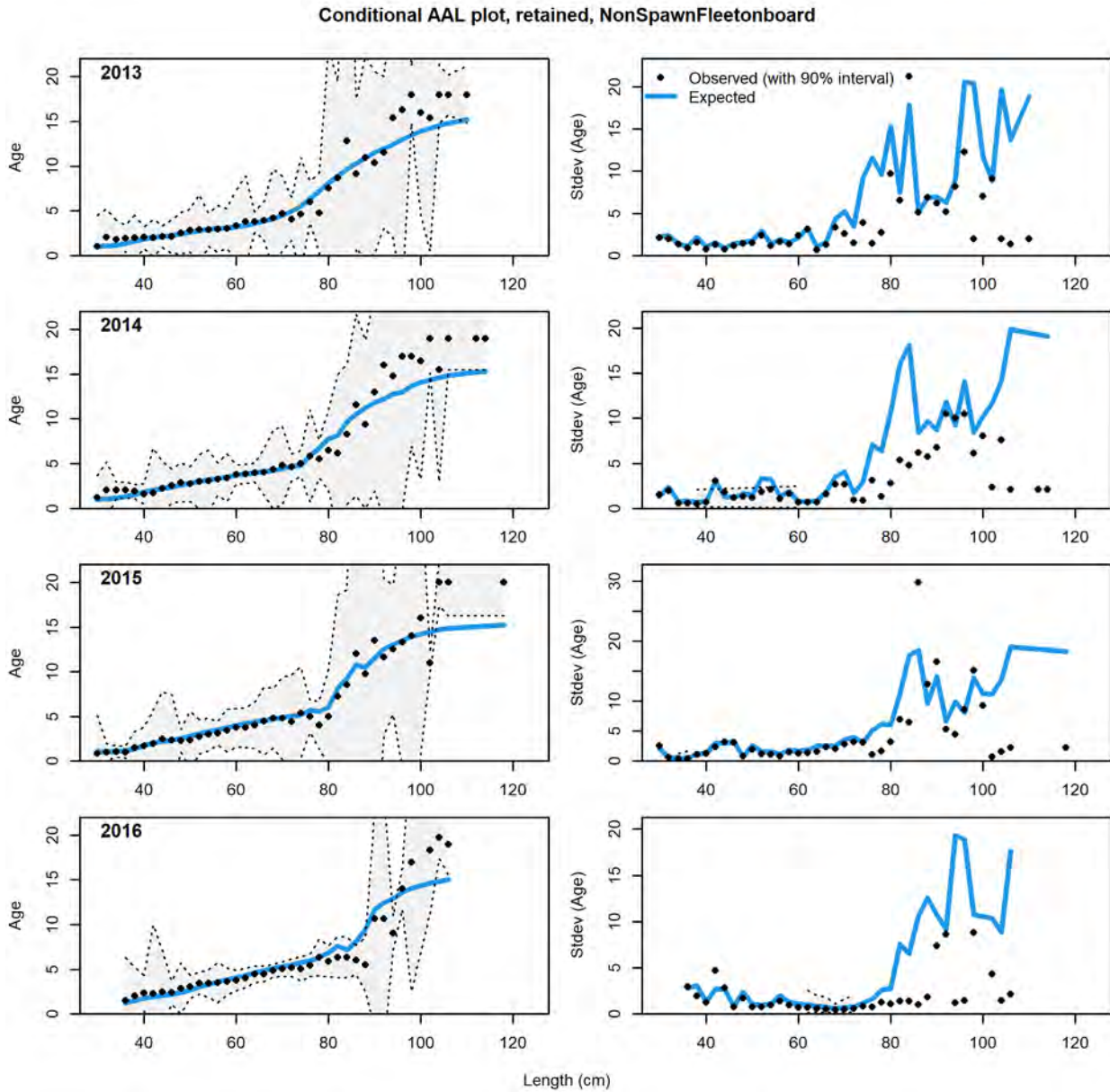
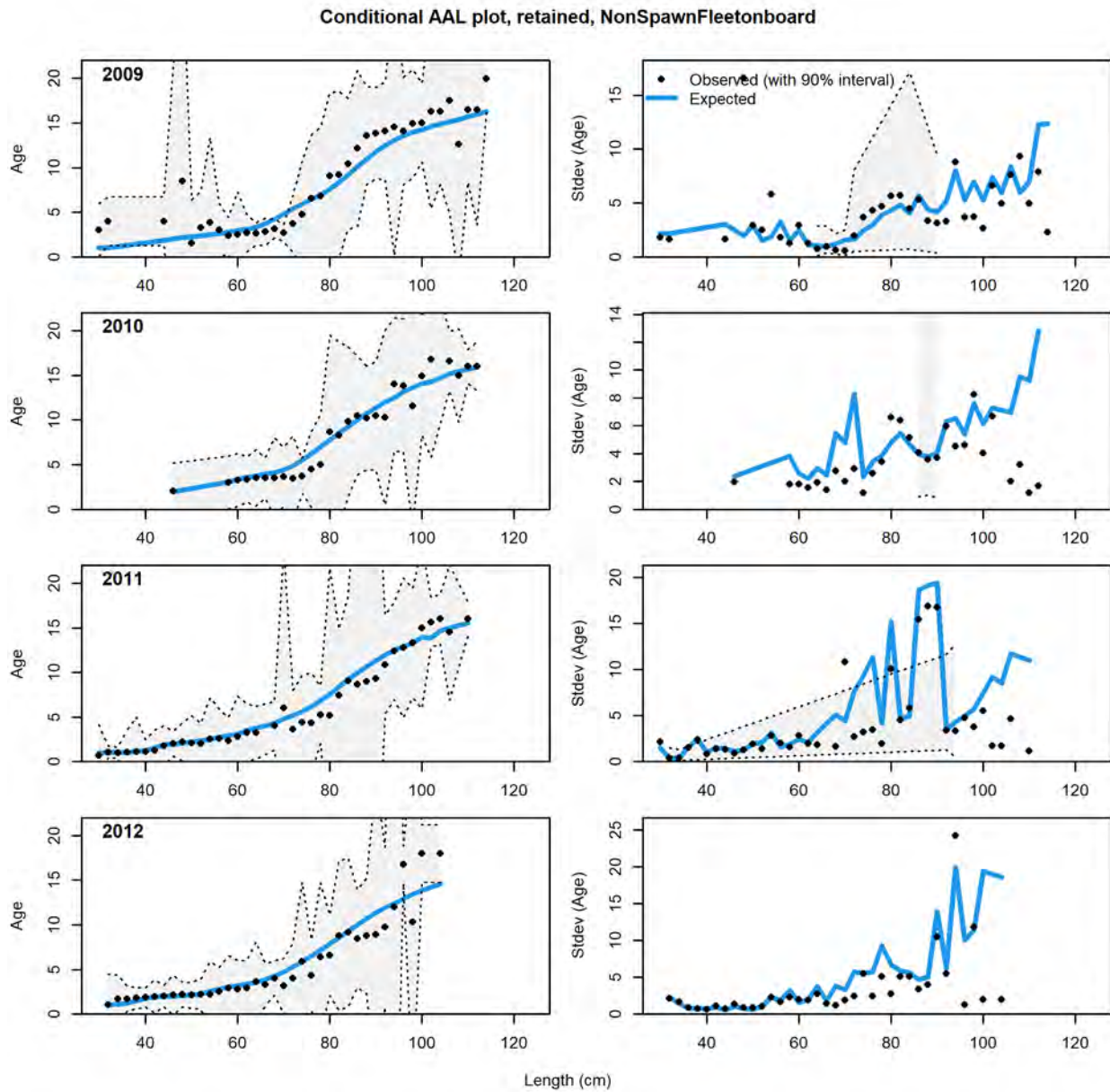
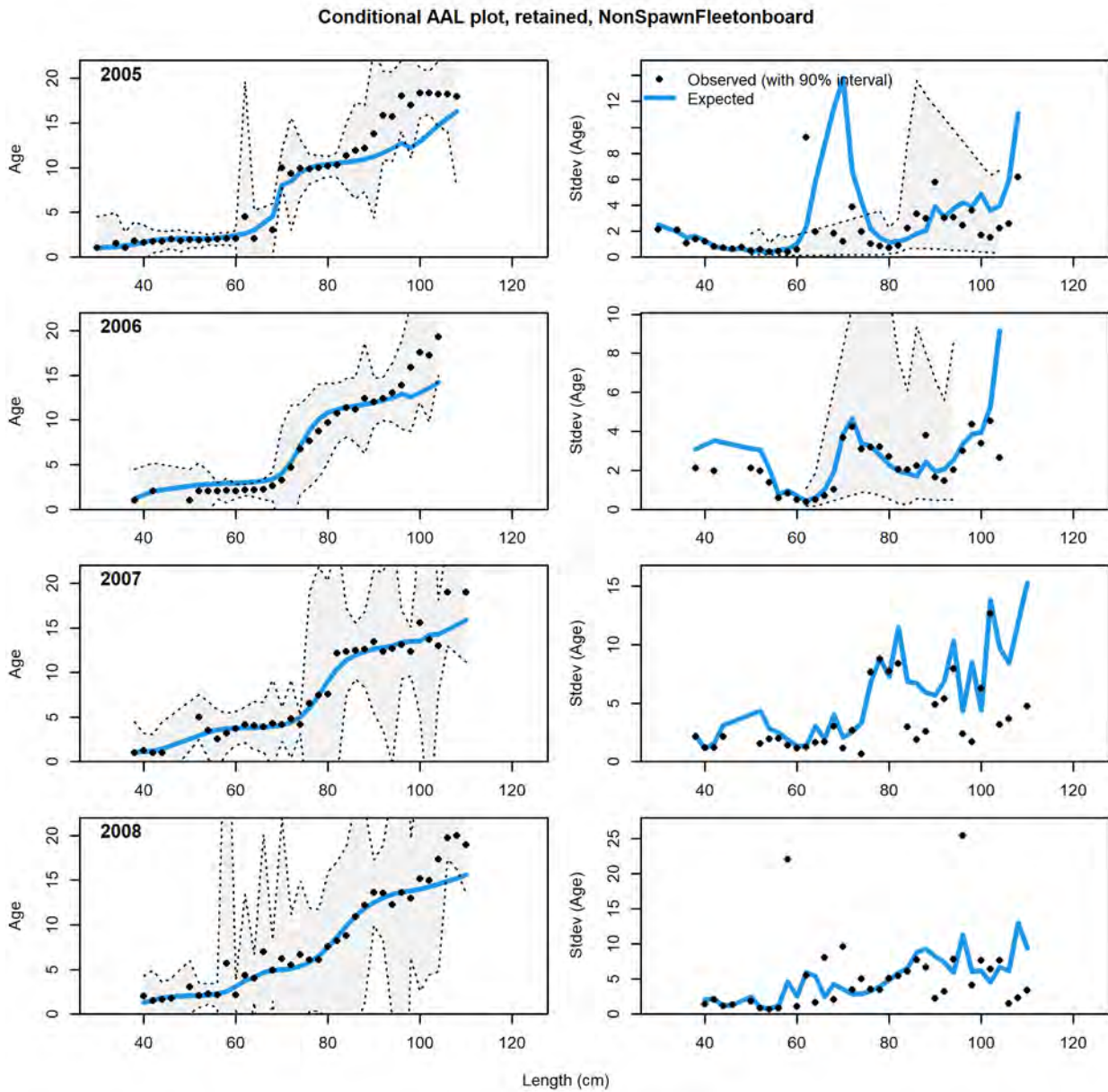


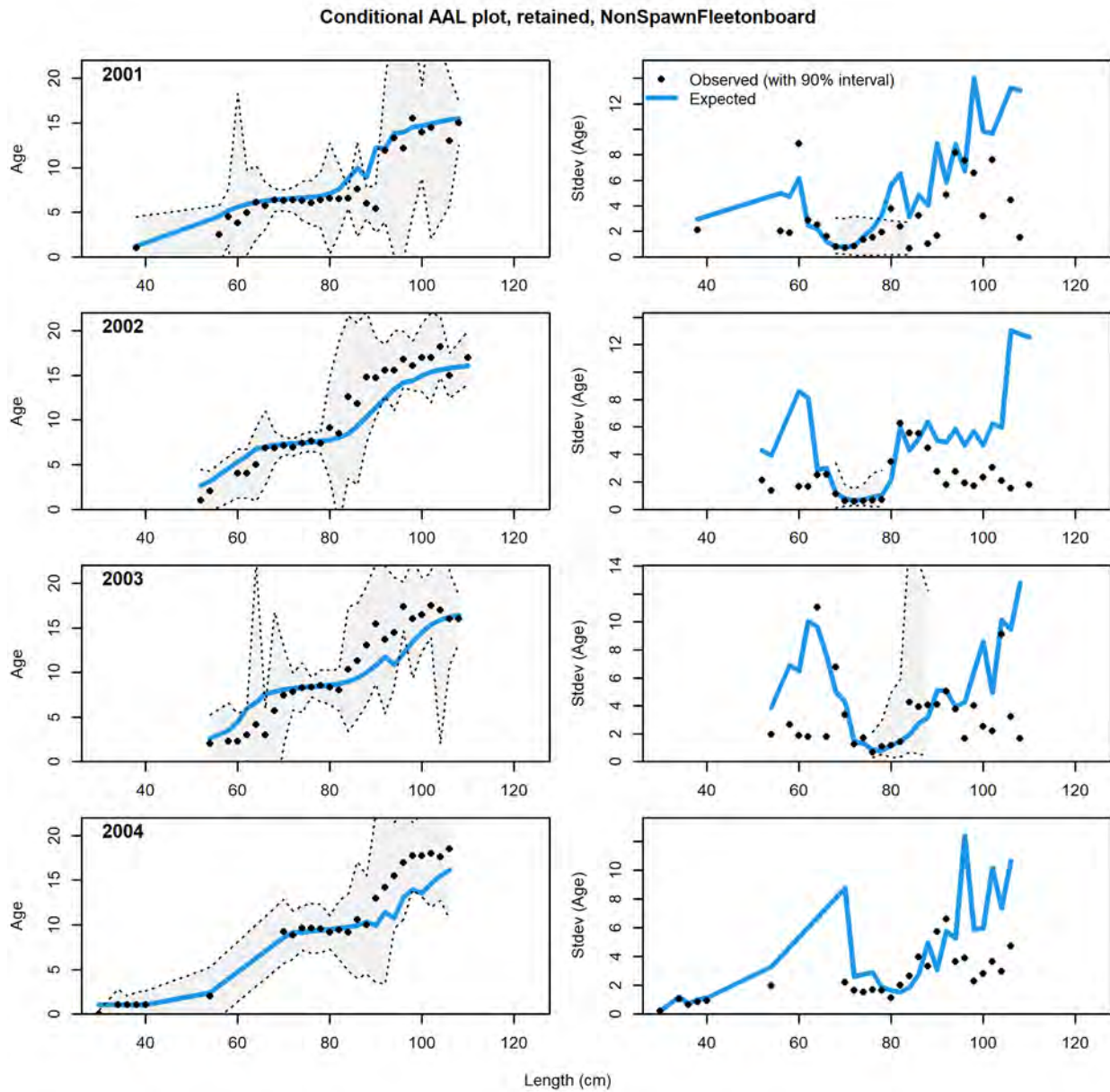
Figure 5.28. Residuals from the annual length compositions for base case.

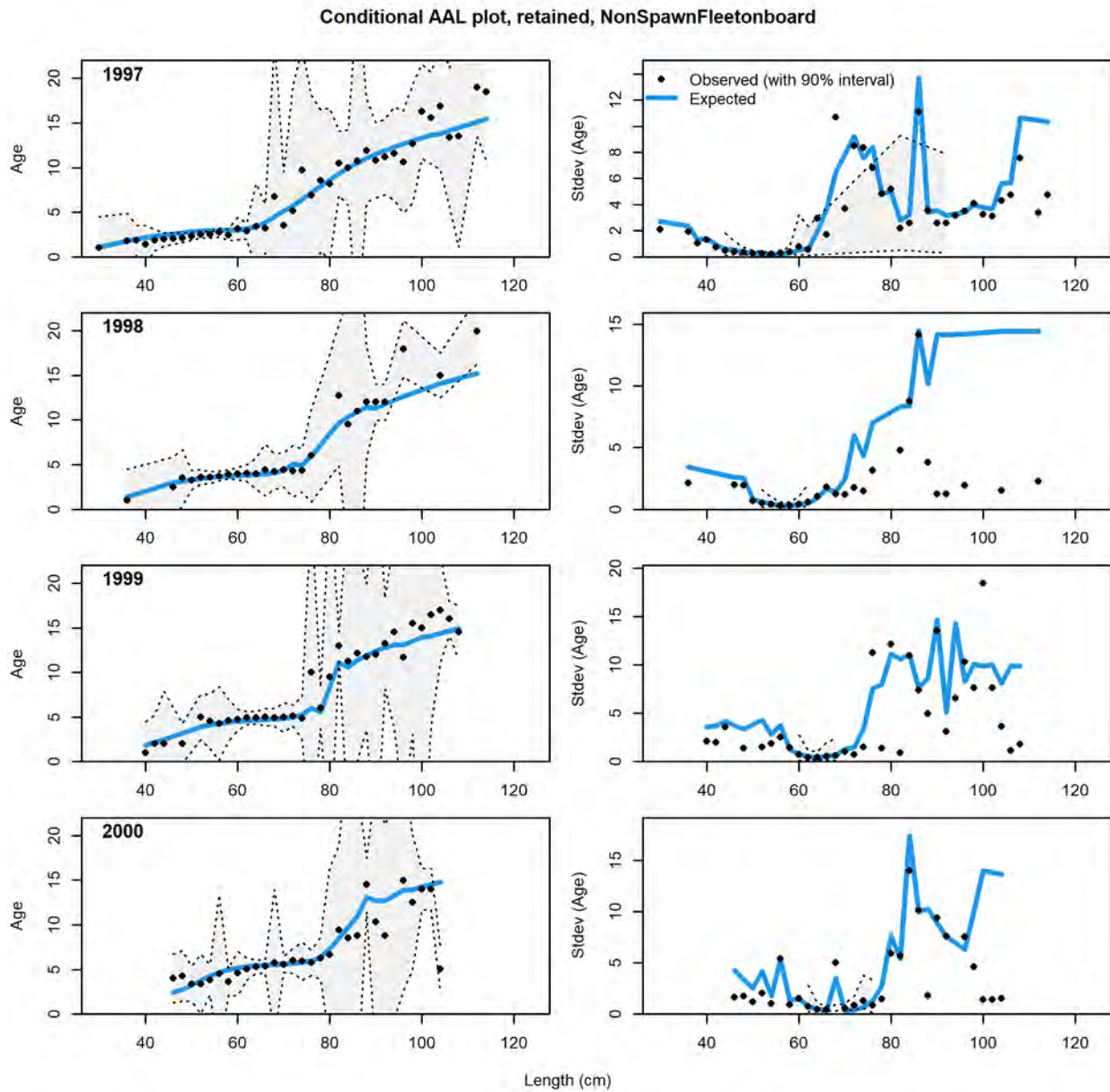




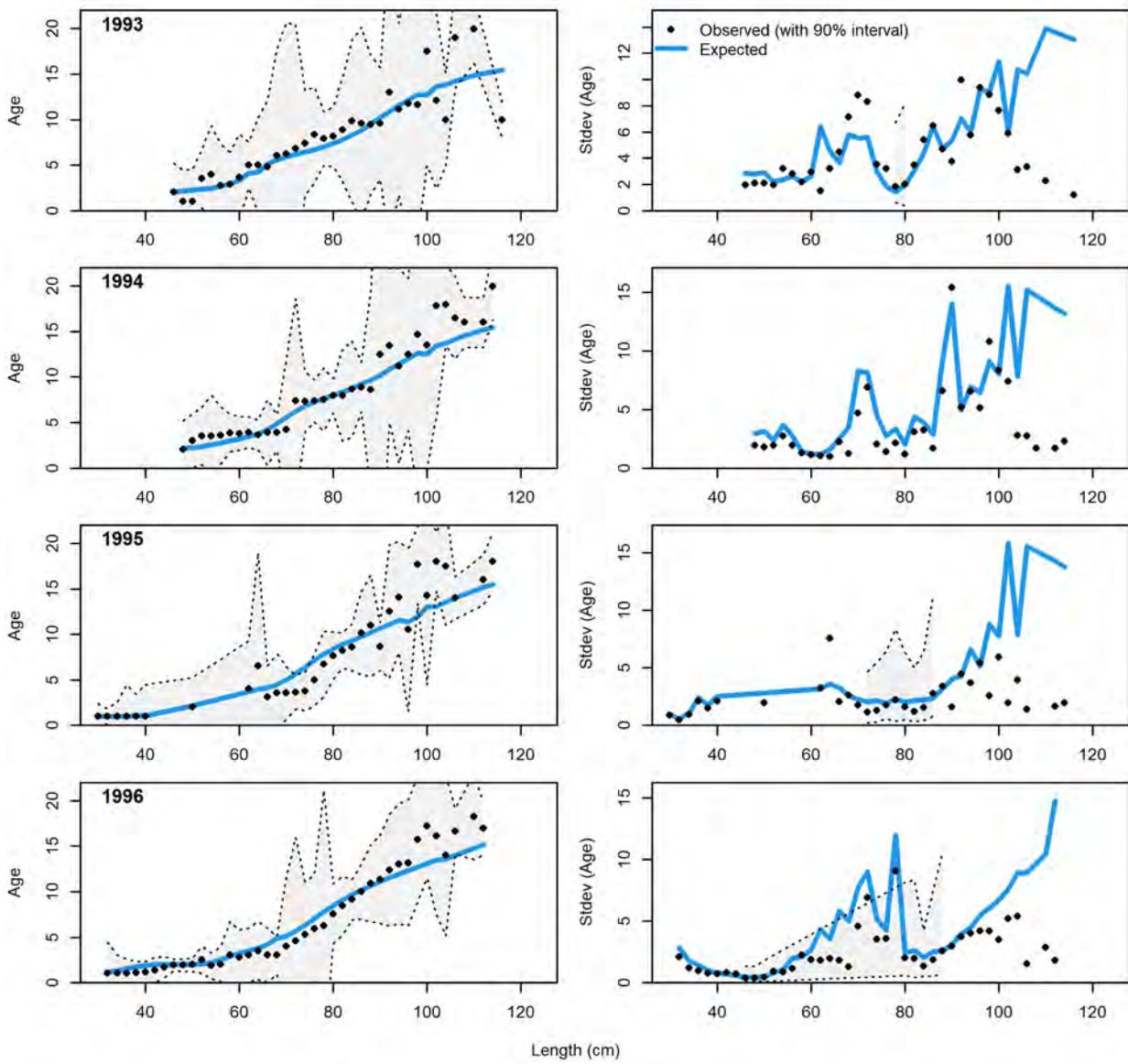


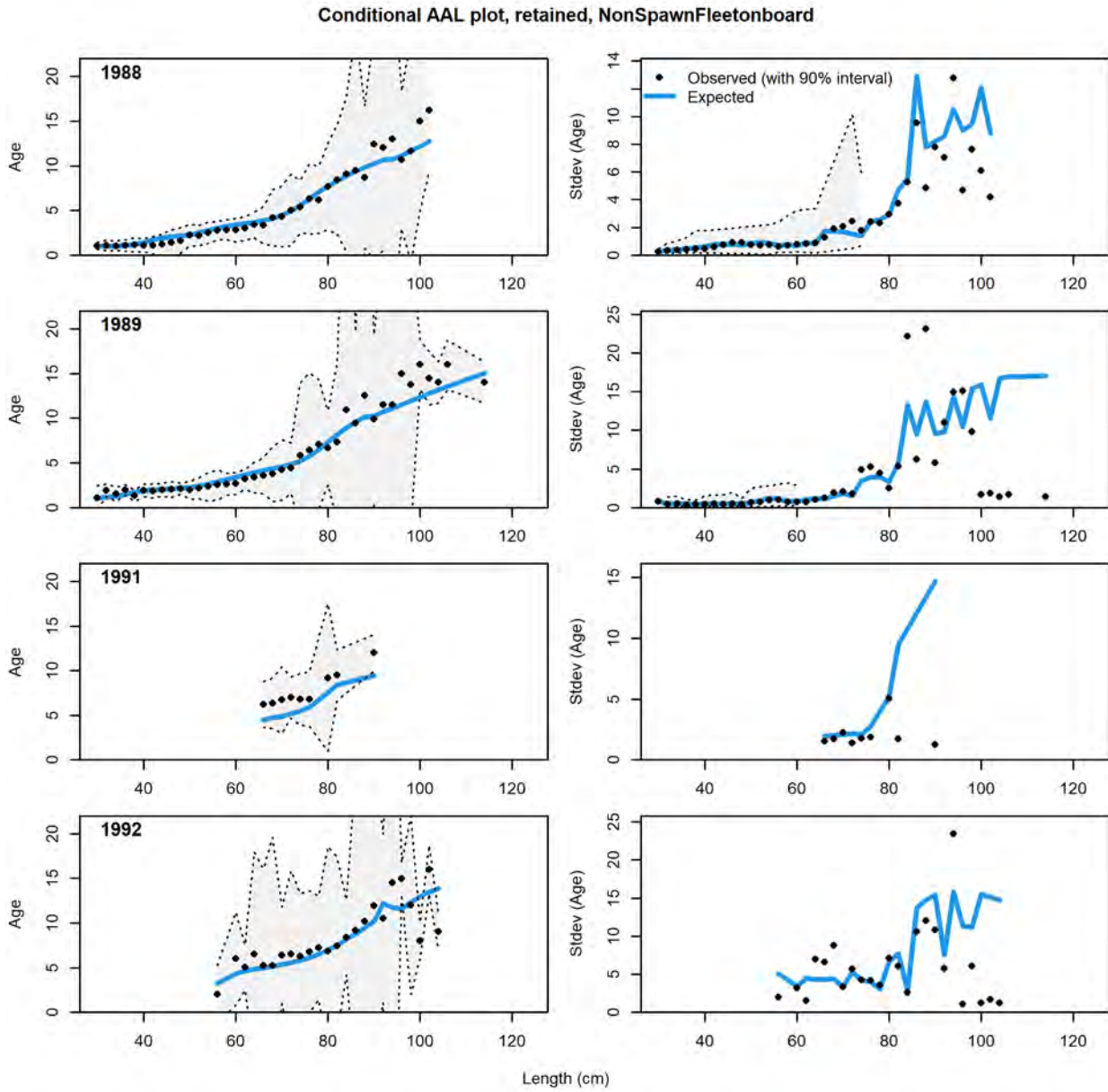


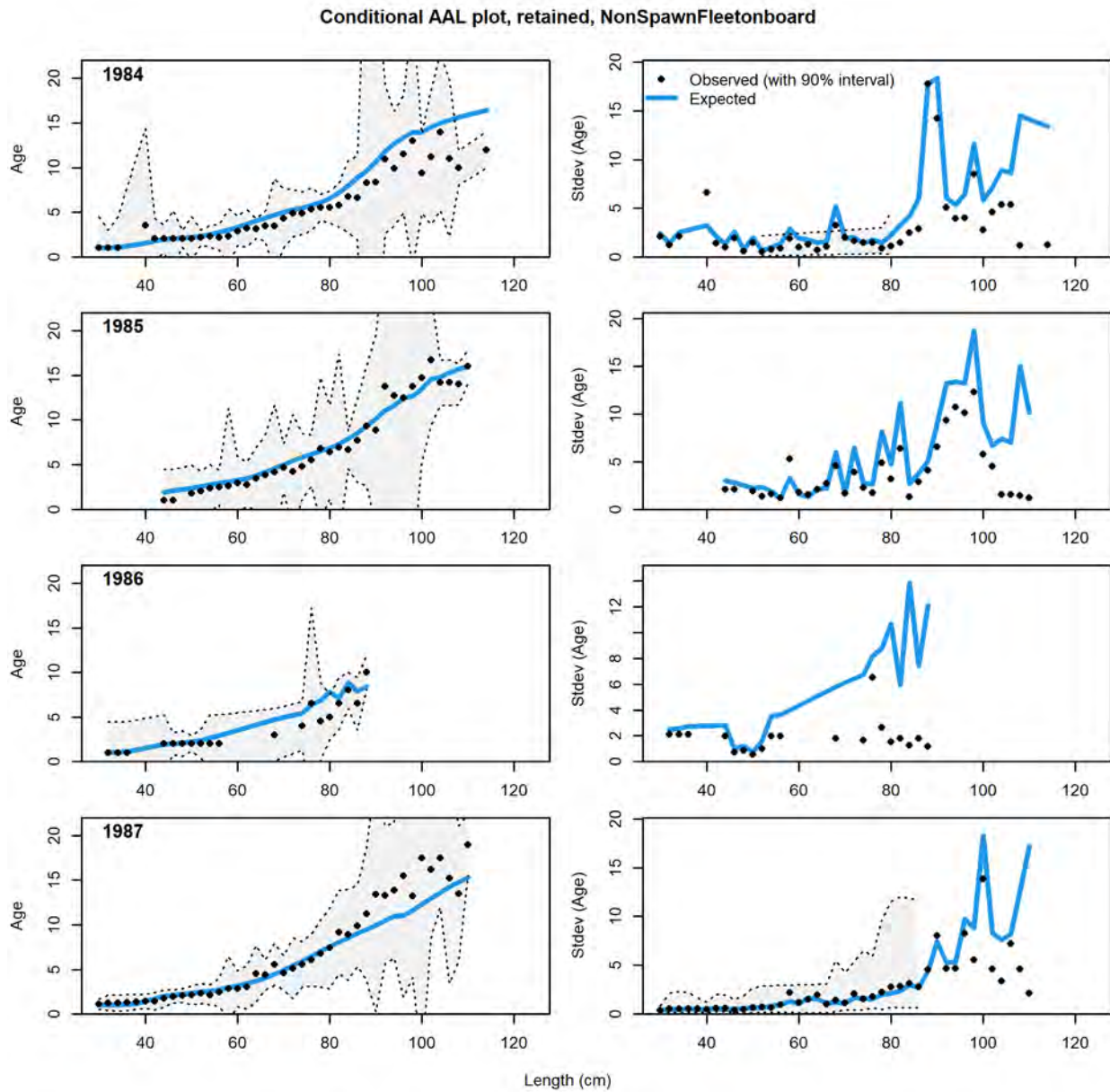




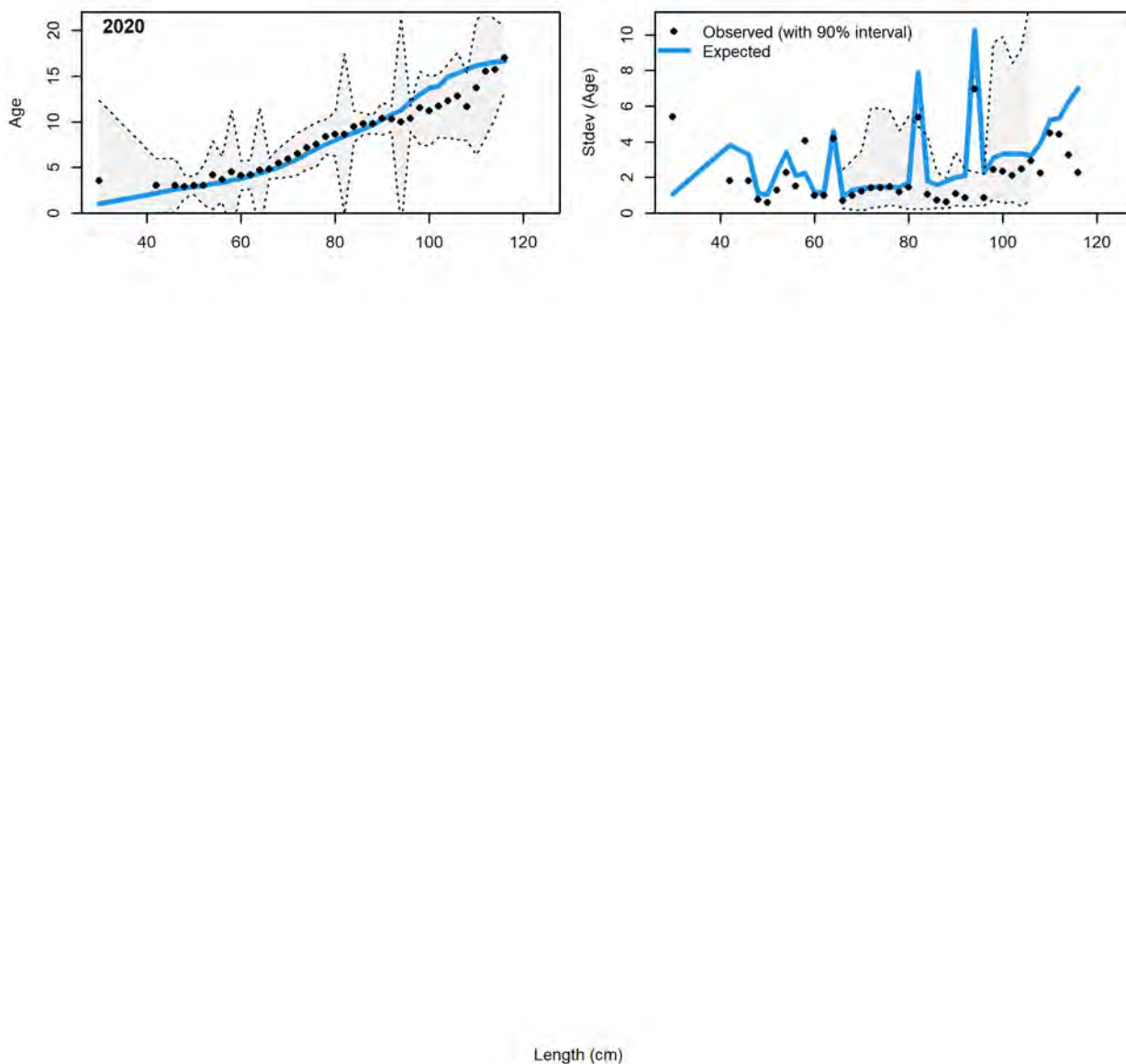
Conditional AAL plot, retained, NonSpawnFleetonboard



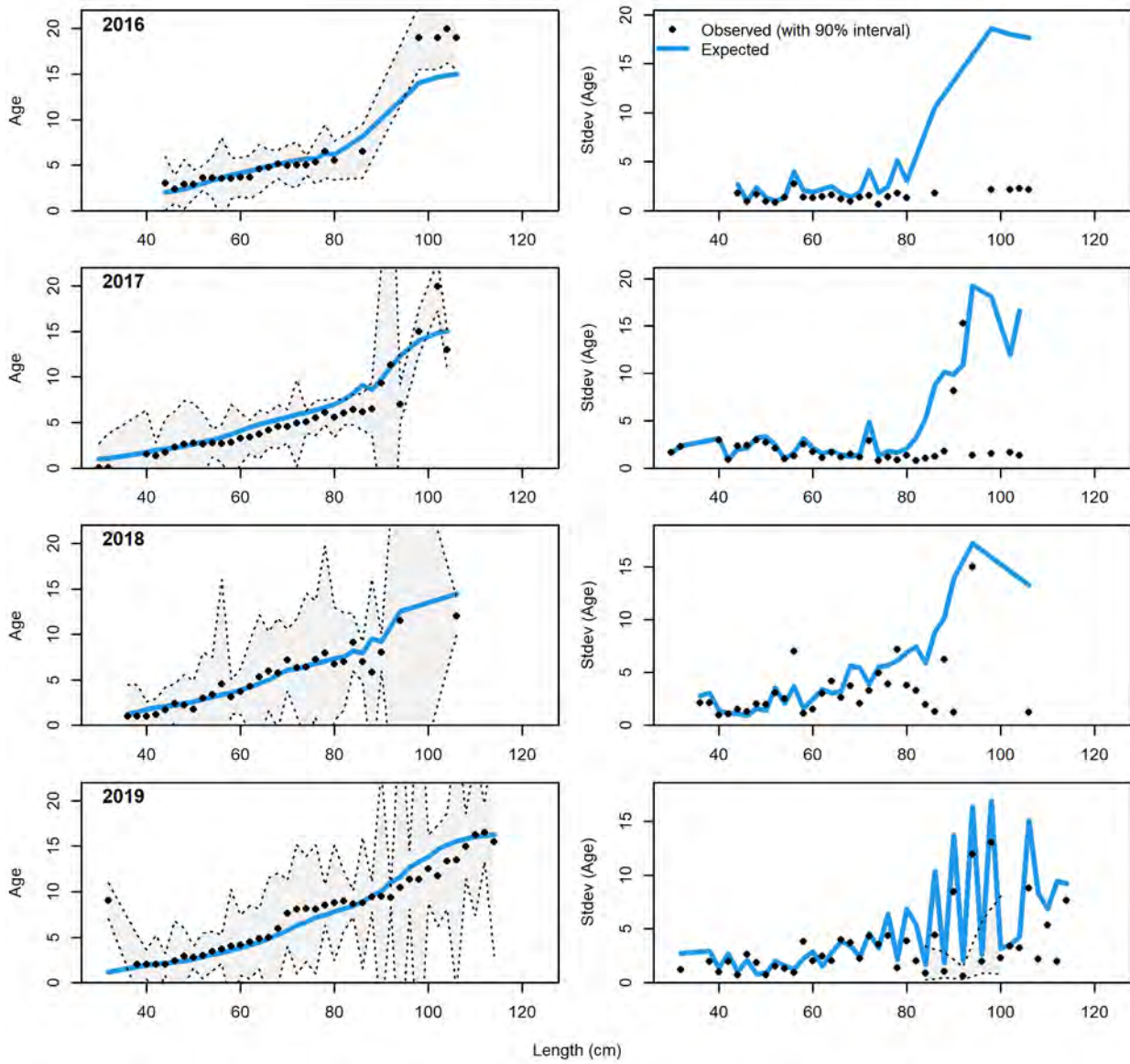




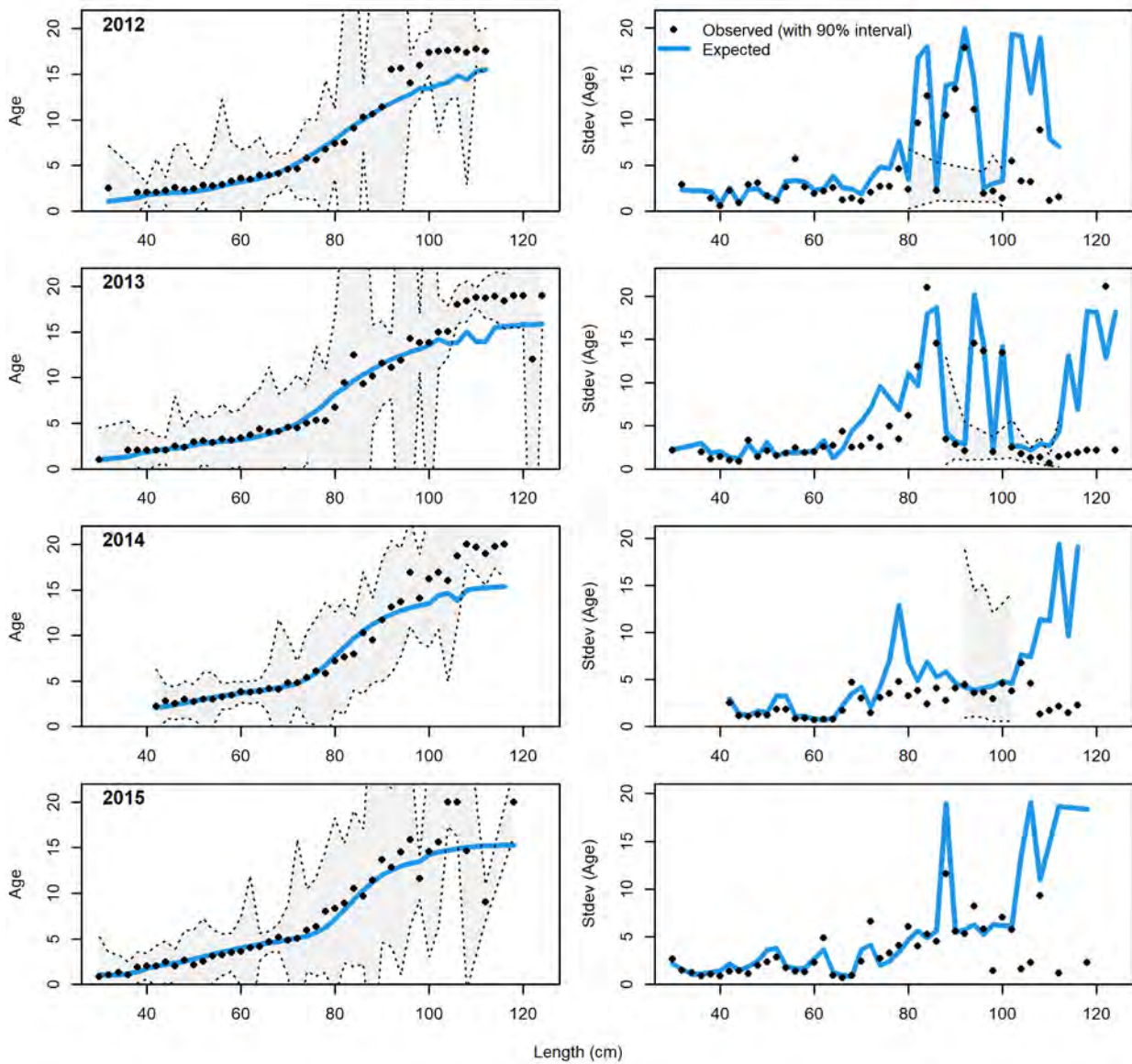
Conditional AAL plot, retained, SpawnFleetonboard



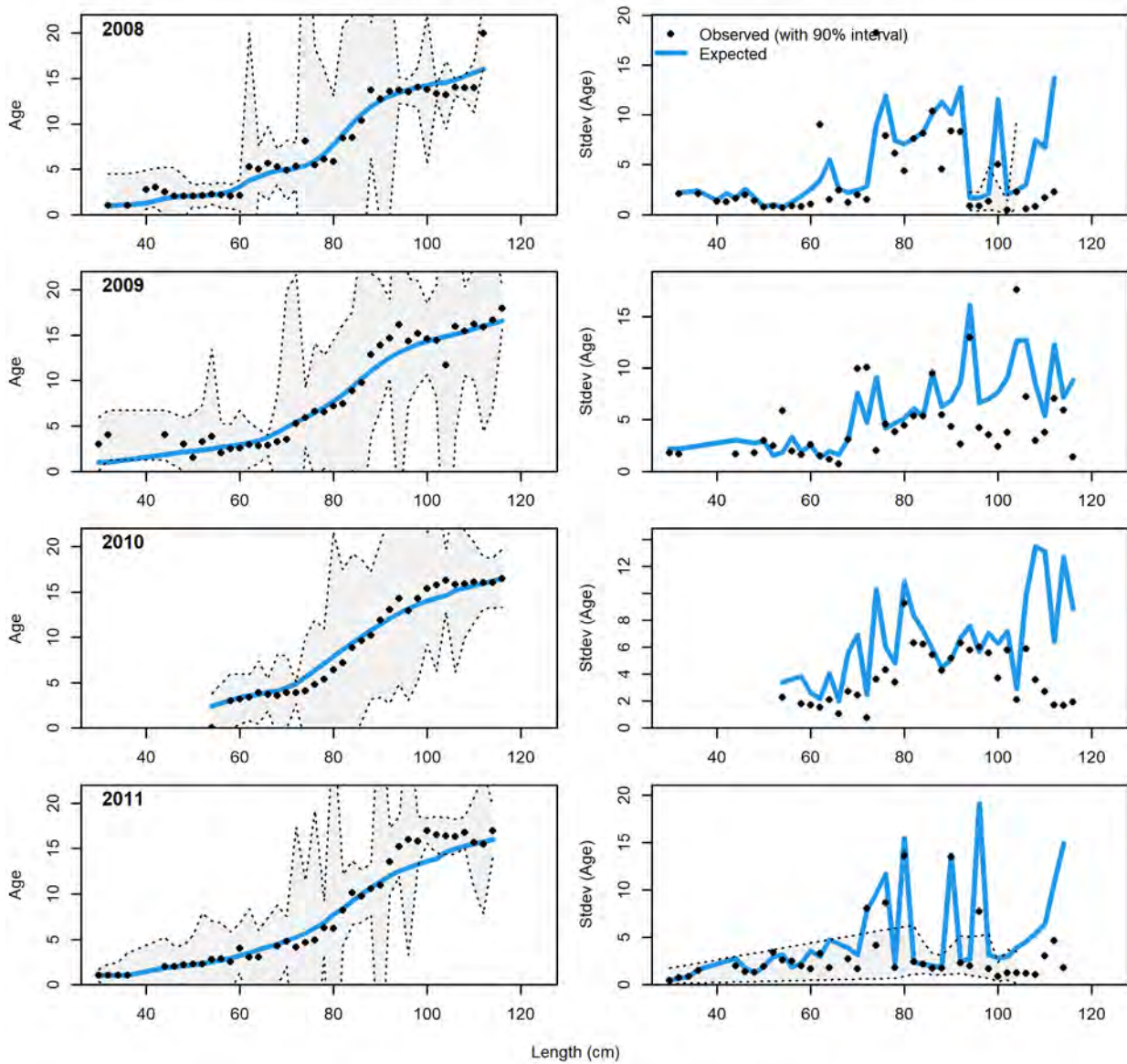
Conditional AAL plot, retained, SpawnFleetonboard



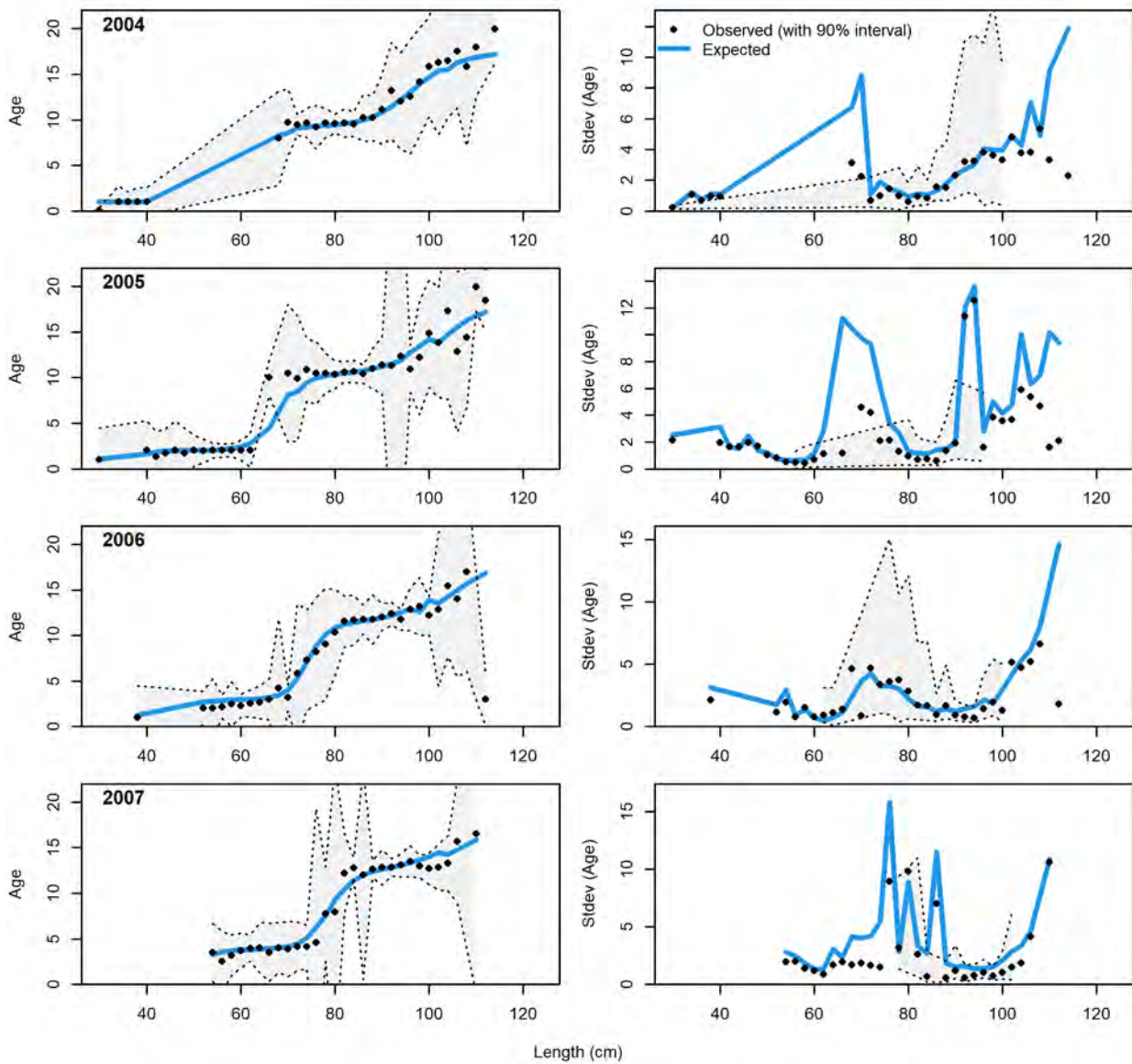
Conditional AAL plot, retained, SpawnFleetonboard

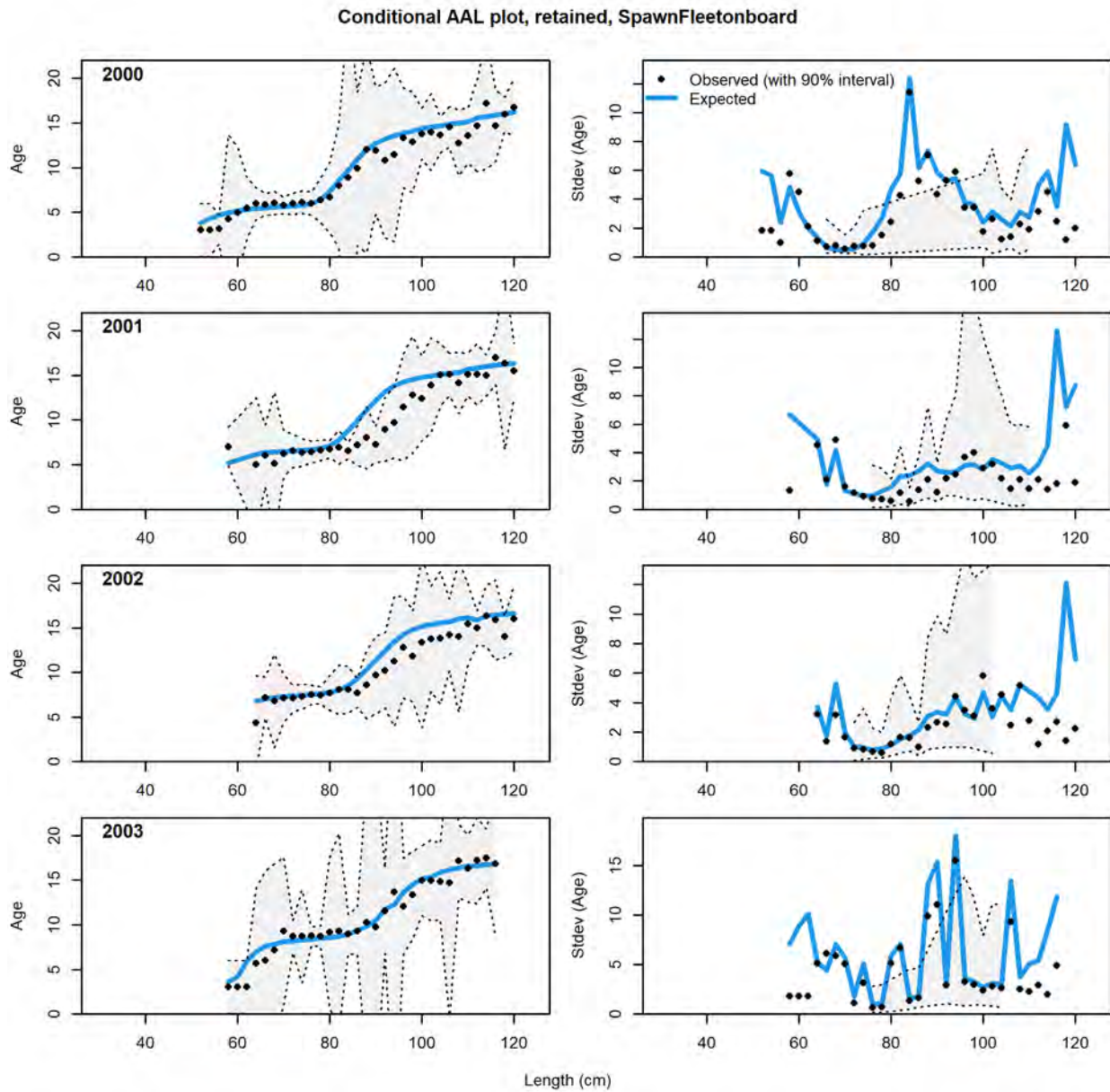


Conditional AAL plot, retained, SpawnFleetonboard

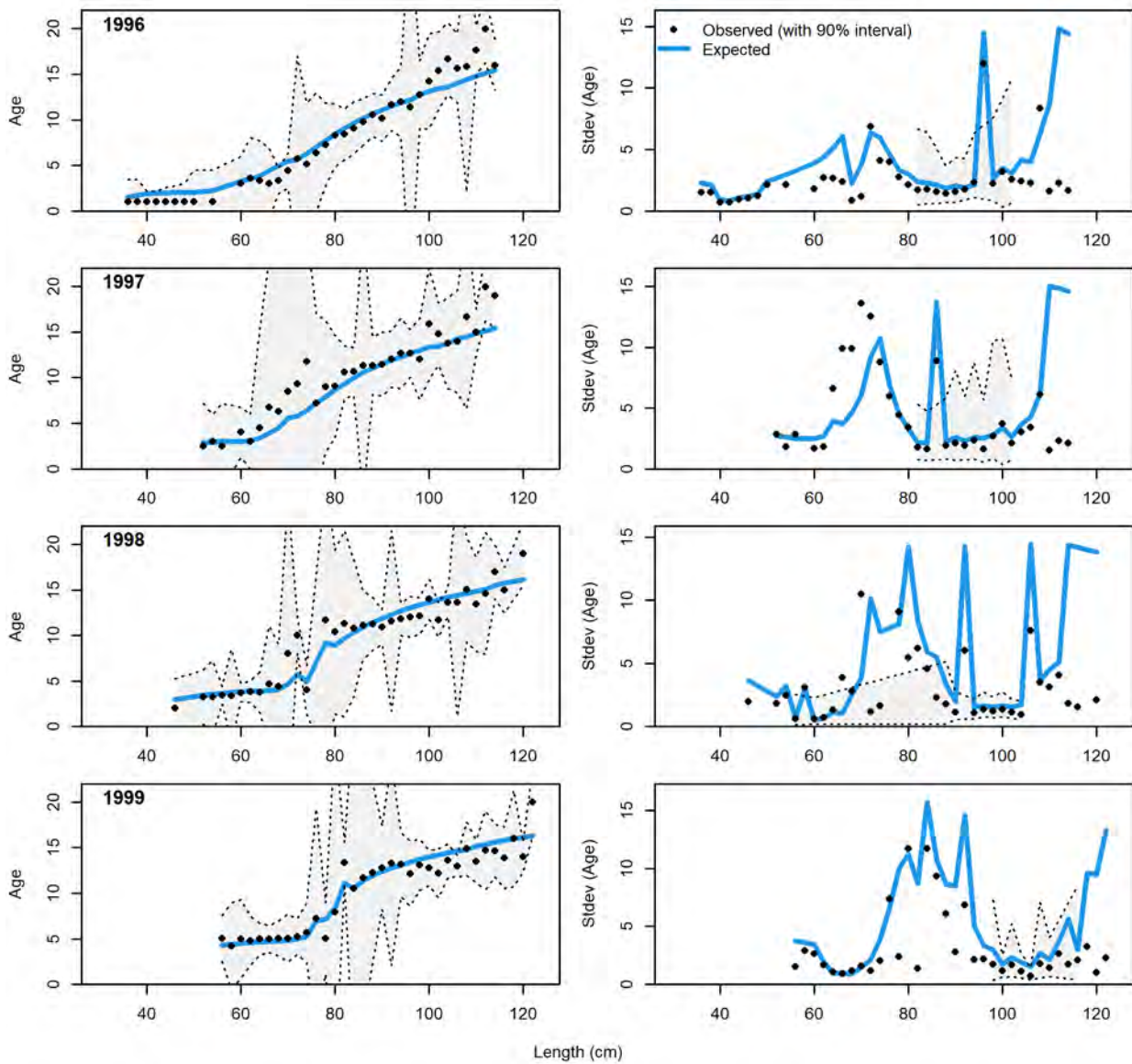


Conditional AAL plot, retained, SpawnFleetonboard

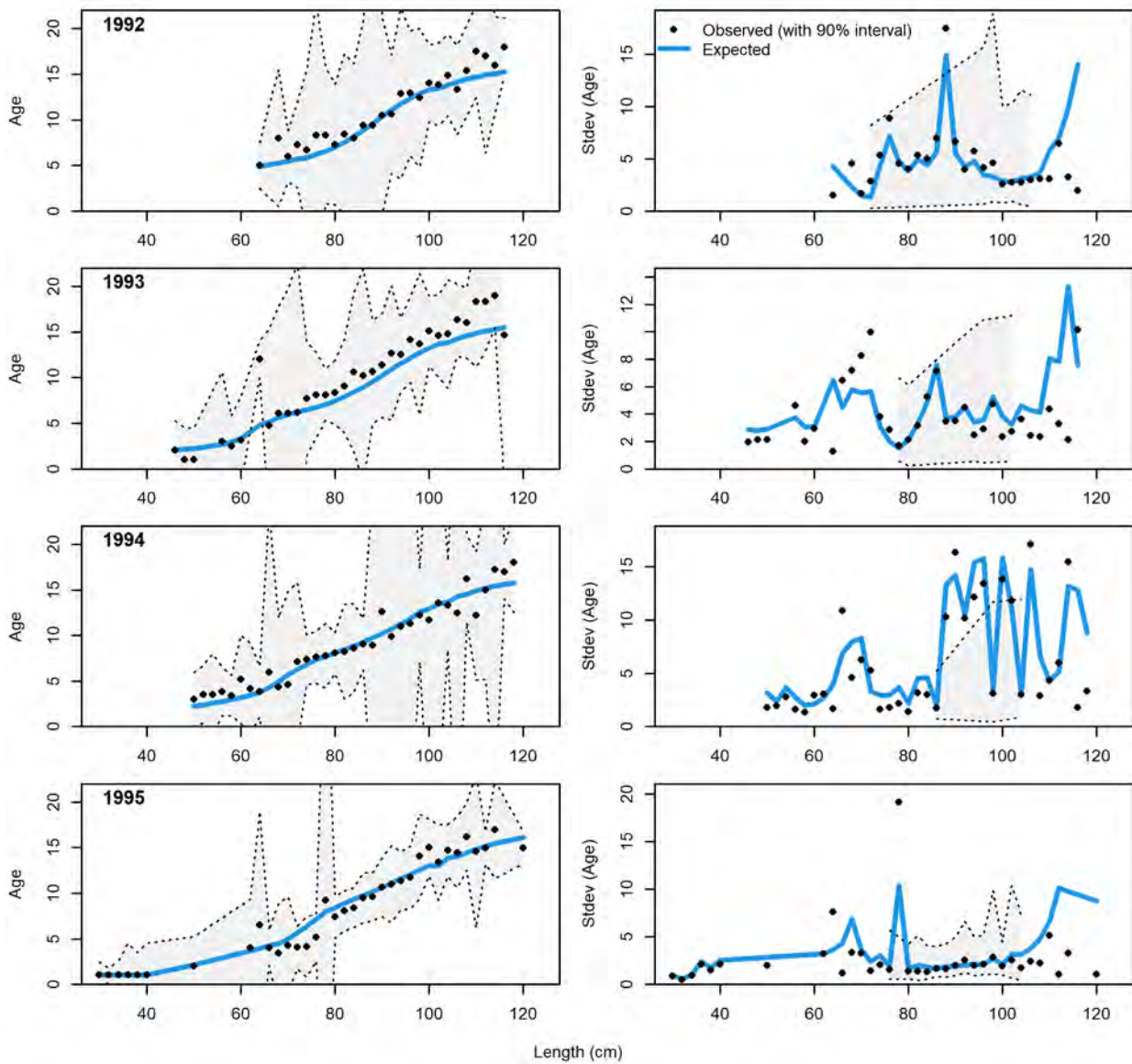




Conditional AAL plot, retained, SpawnFleetonboard



Conditional AAL plot, retained, SpawnFleetonboard



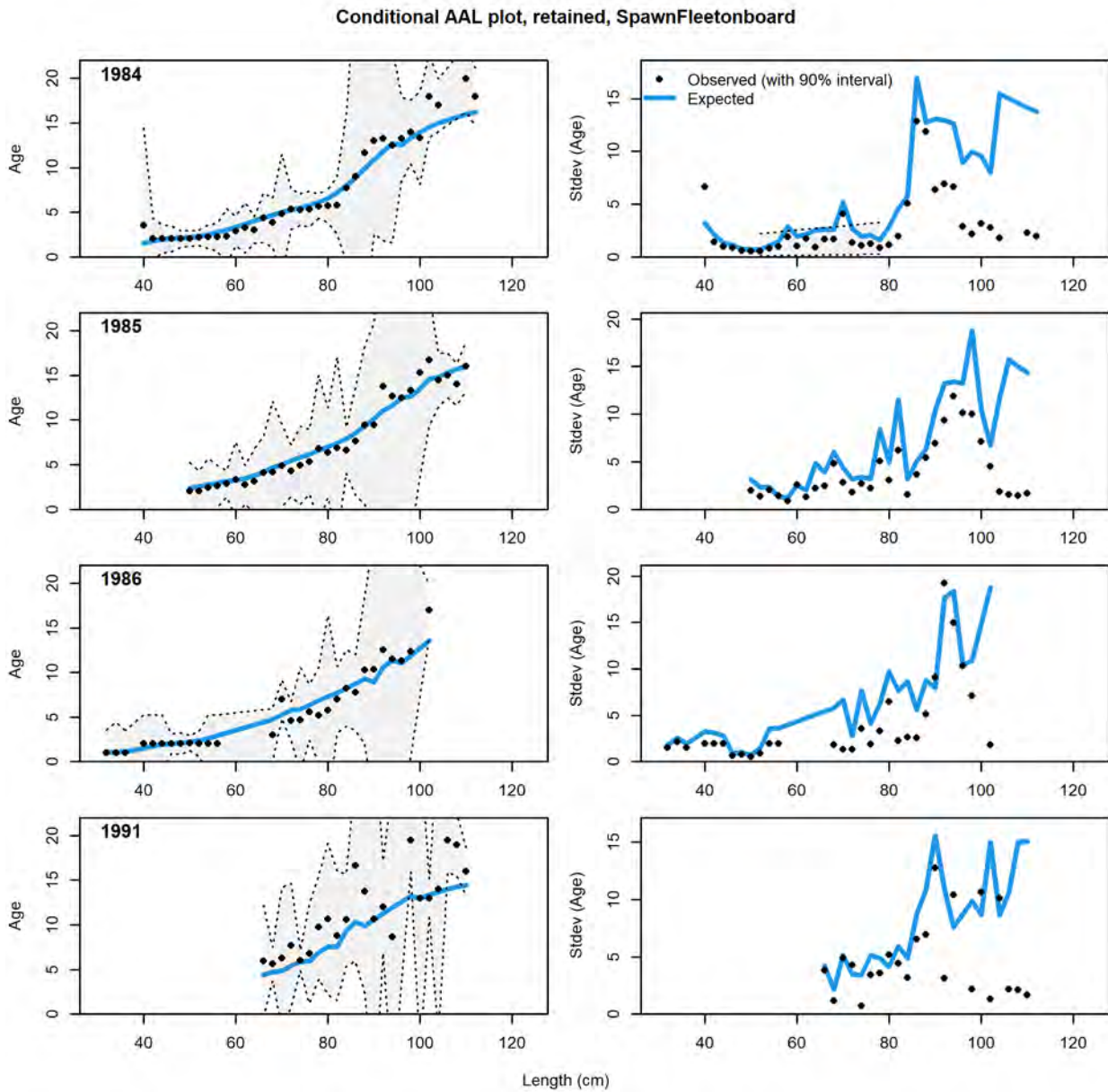


Figure 5.29. Fits to conditional age at length data.

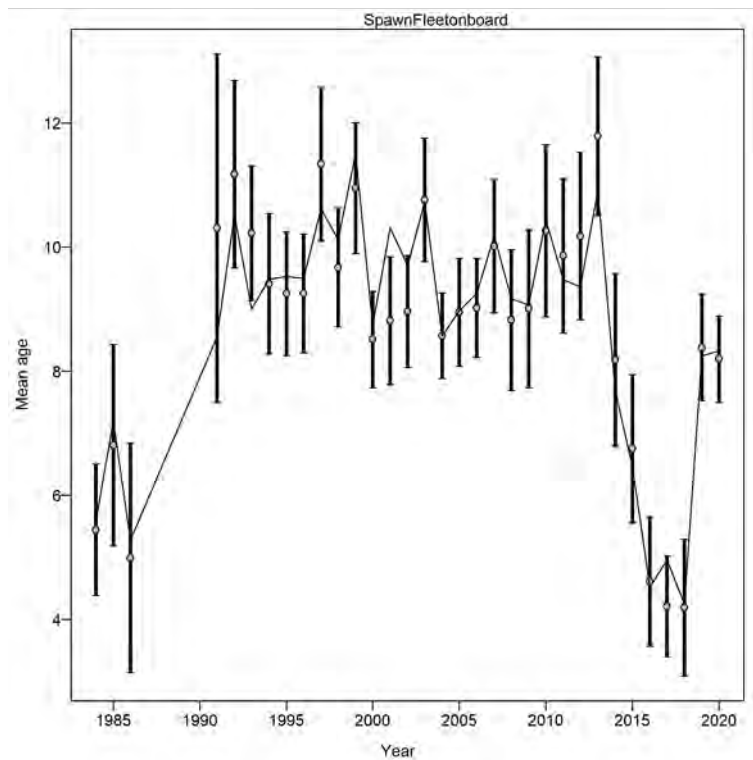
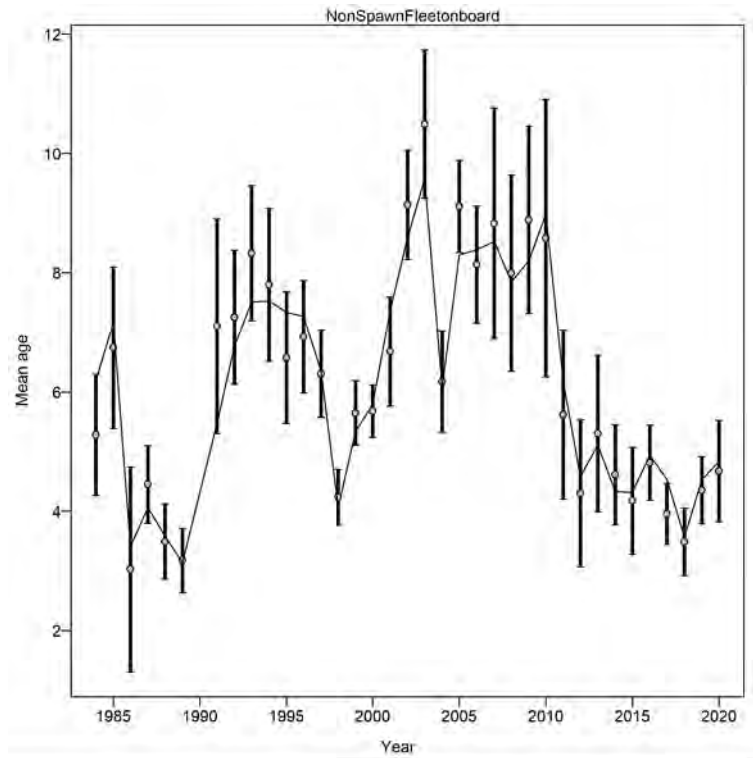
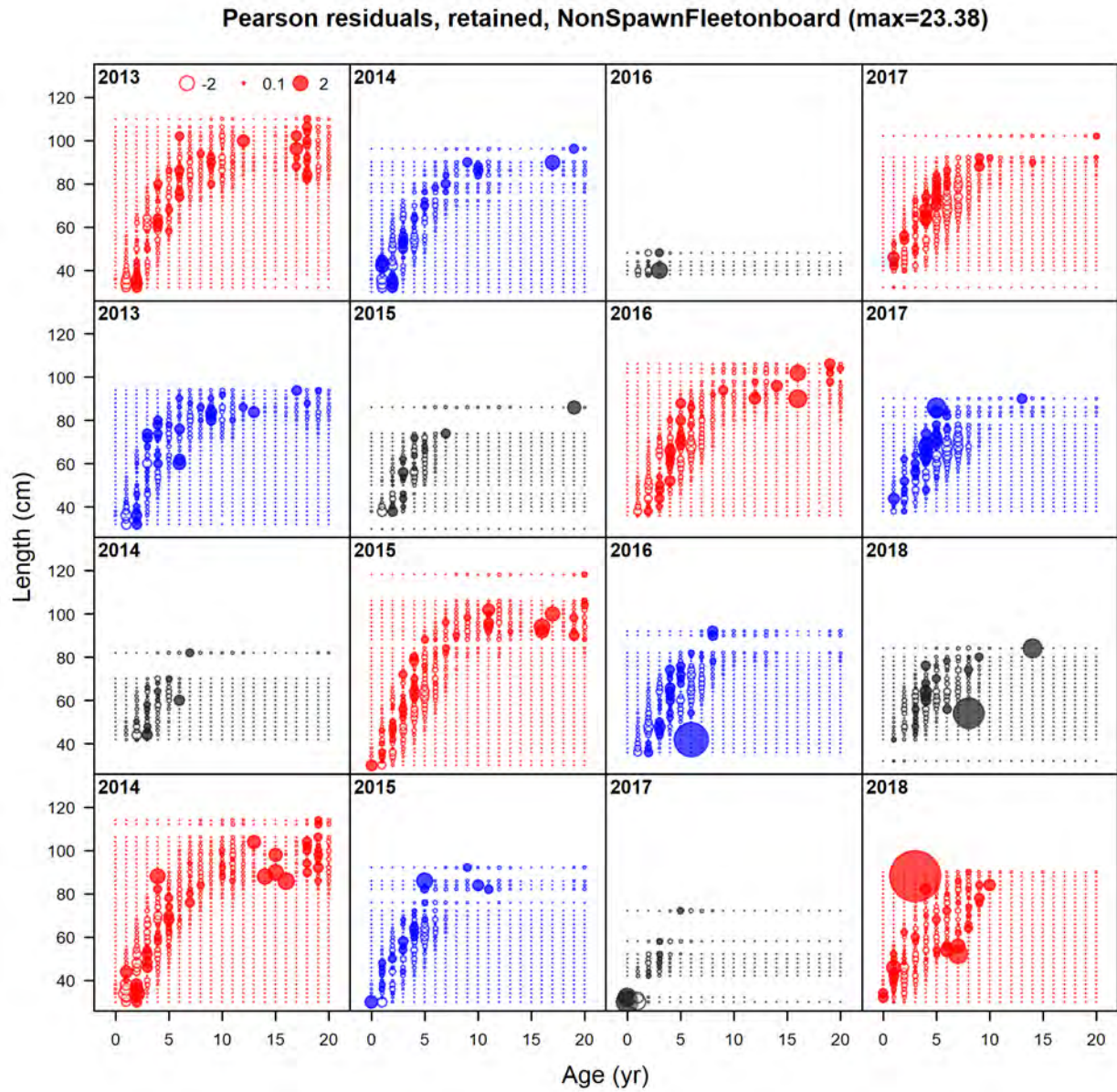
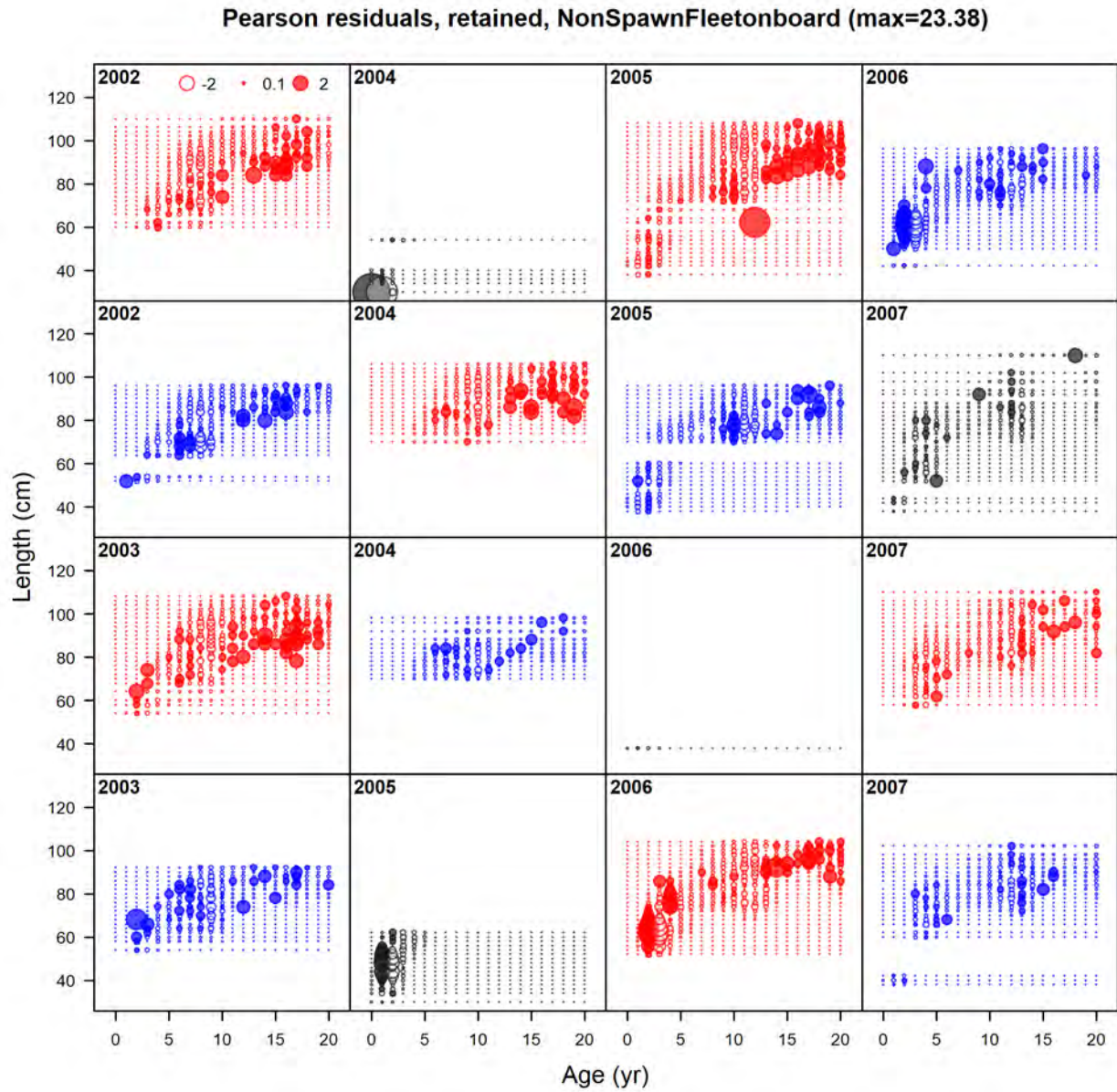


Figure 5.30. Data weighting of conditional age at length data for the onboard non spawning and spawning fleets.

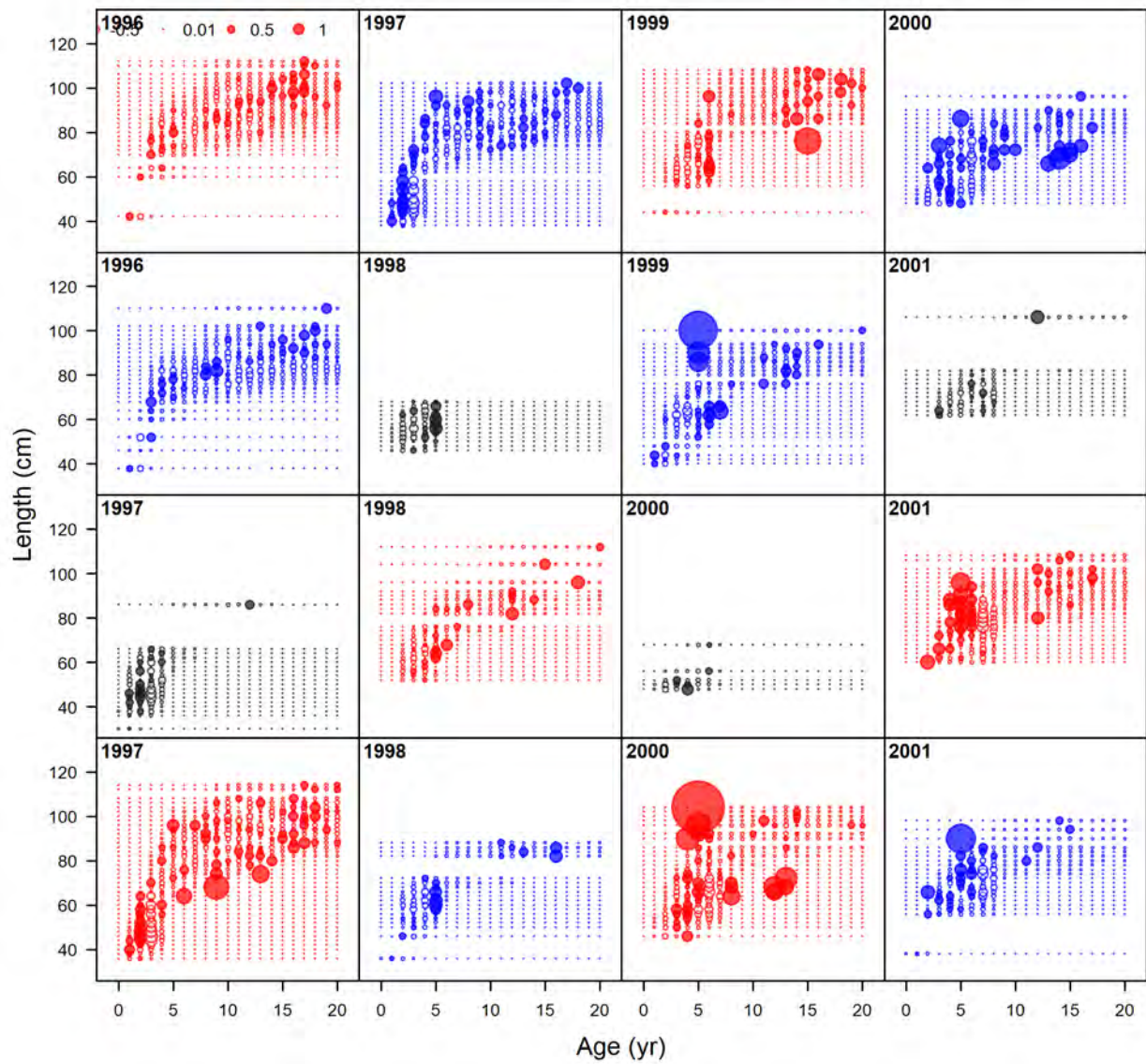


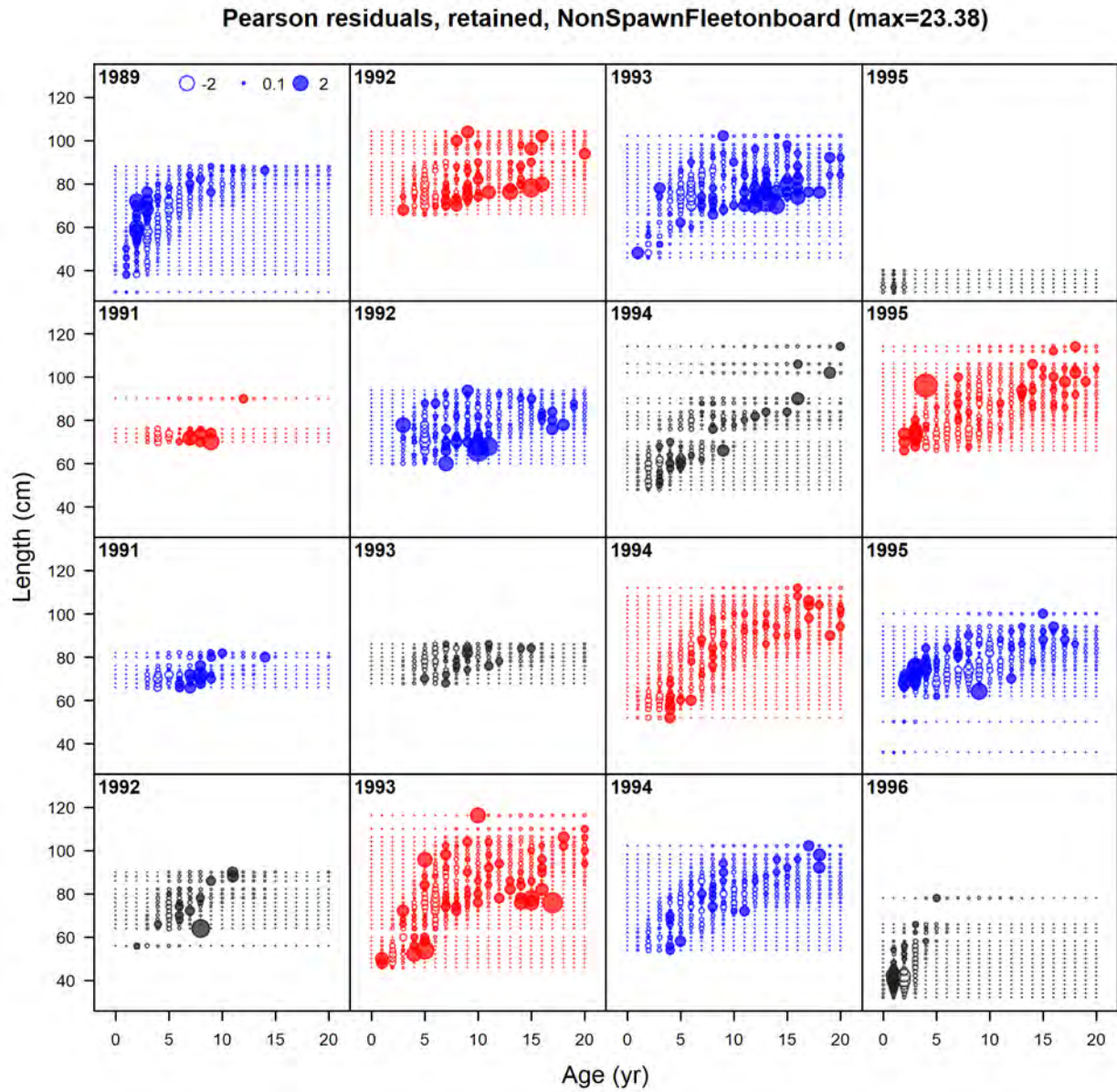
Pearson residuals, retained, NonSpawnFleetonboard (max=23.38)



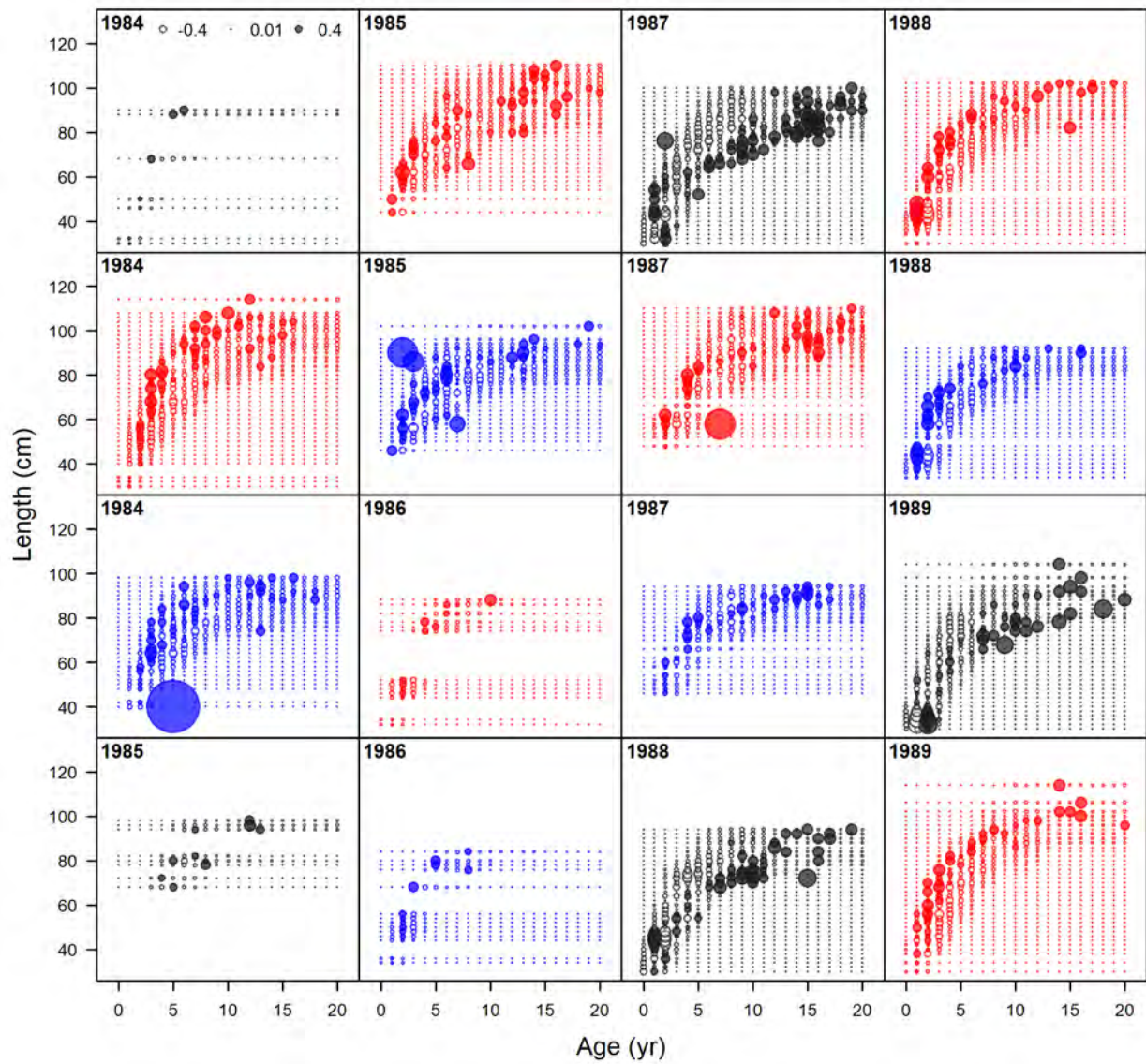


Pearson residuals, retained, NonSpawnFleetonboard (max=23.38)

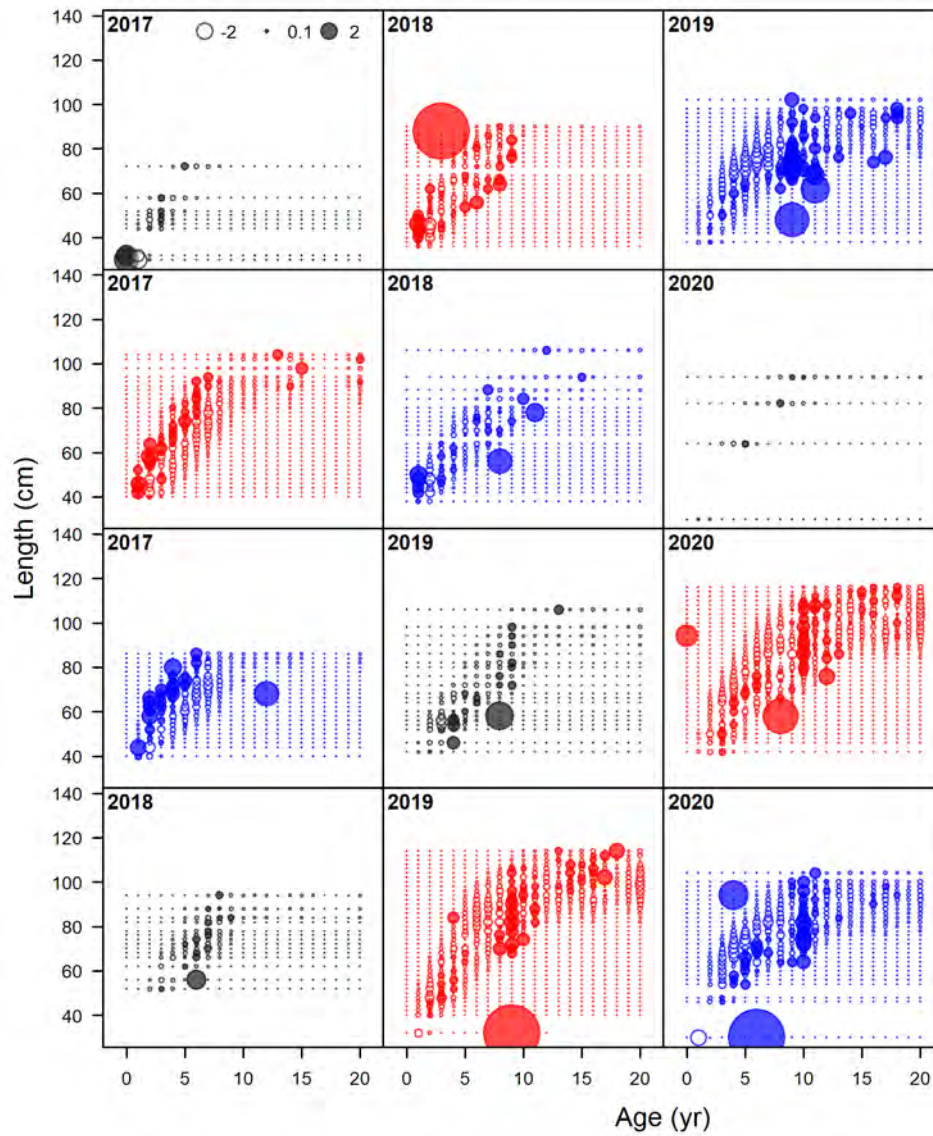




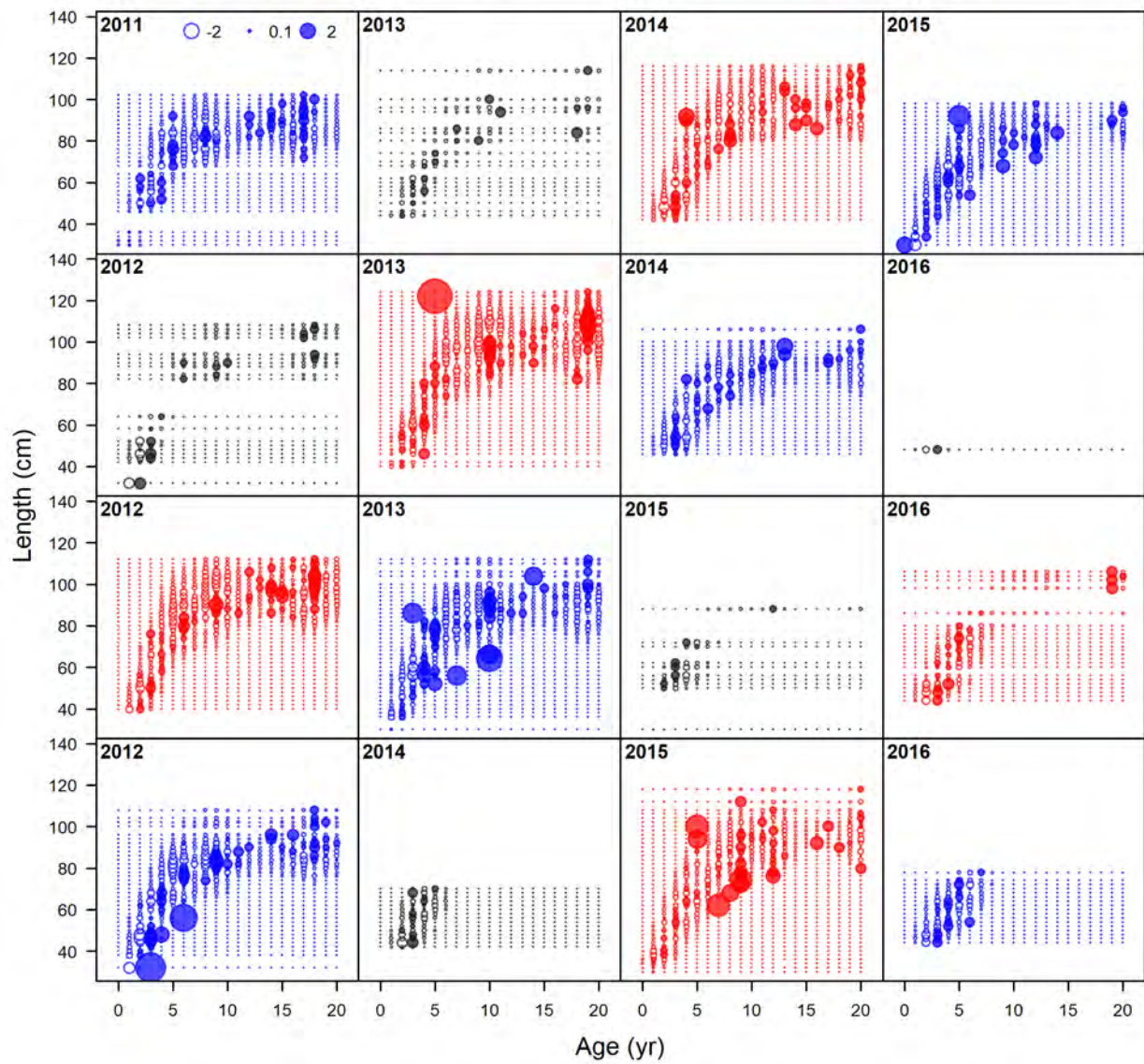
Pearson residuals, retained, NonSpawnFleetonboard (max=23.38)



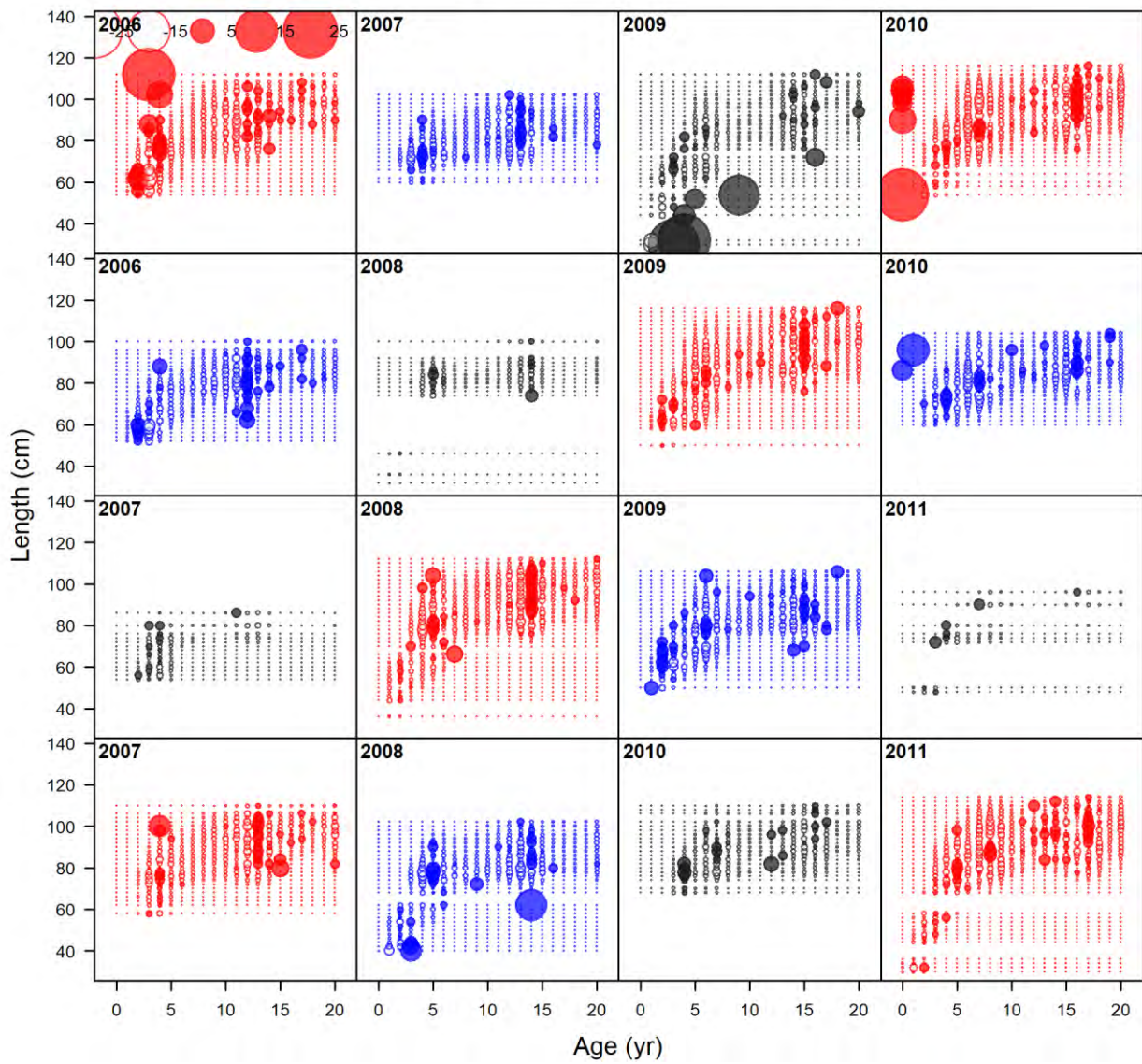
Pearson residuals, retained, SpawnFleetonboard (max=23.39)



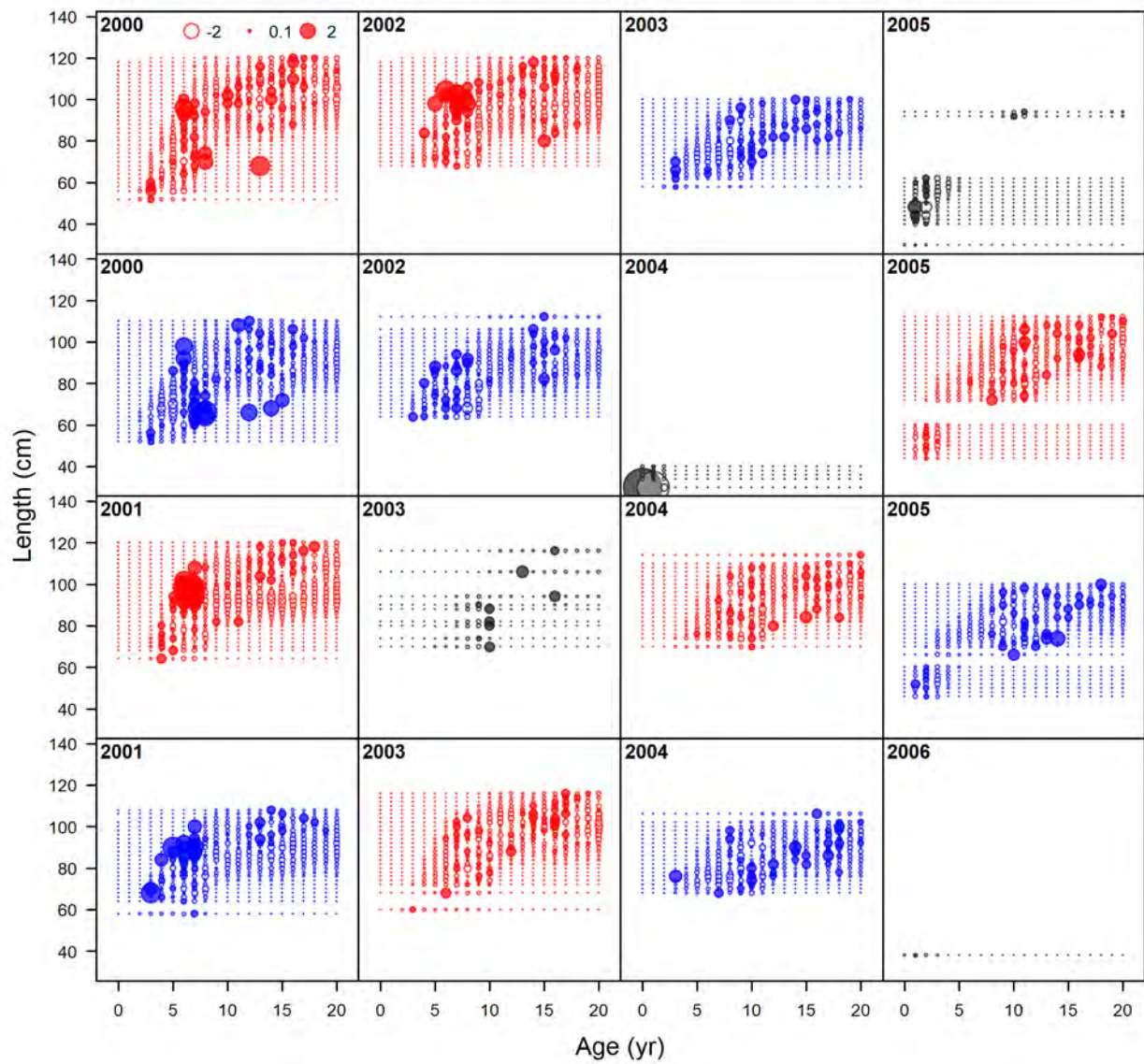
Pearson residuals, retained, SpawnFleetonboard (max=23.39)



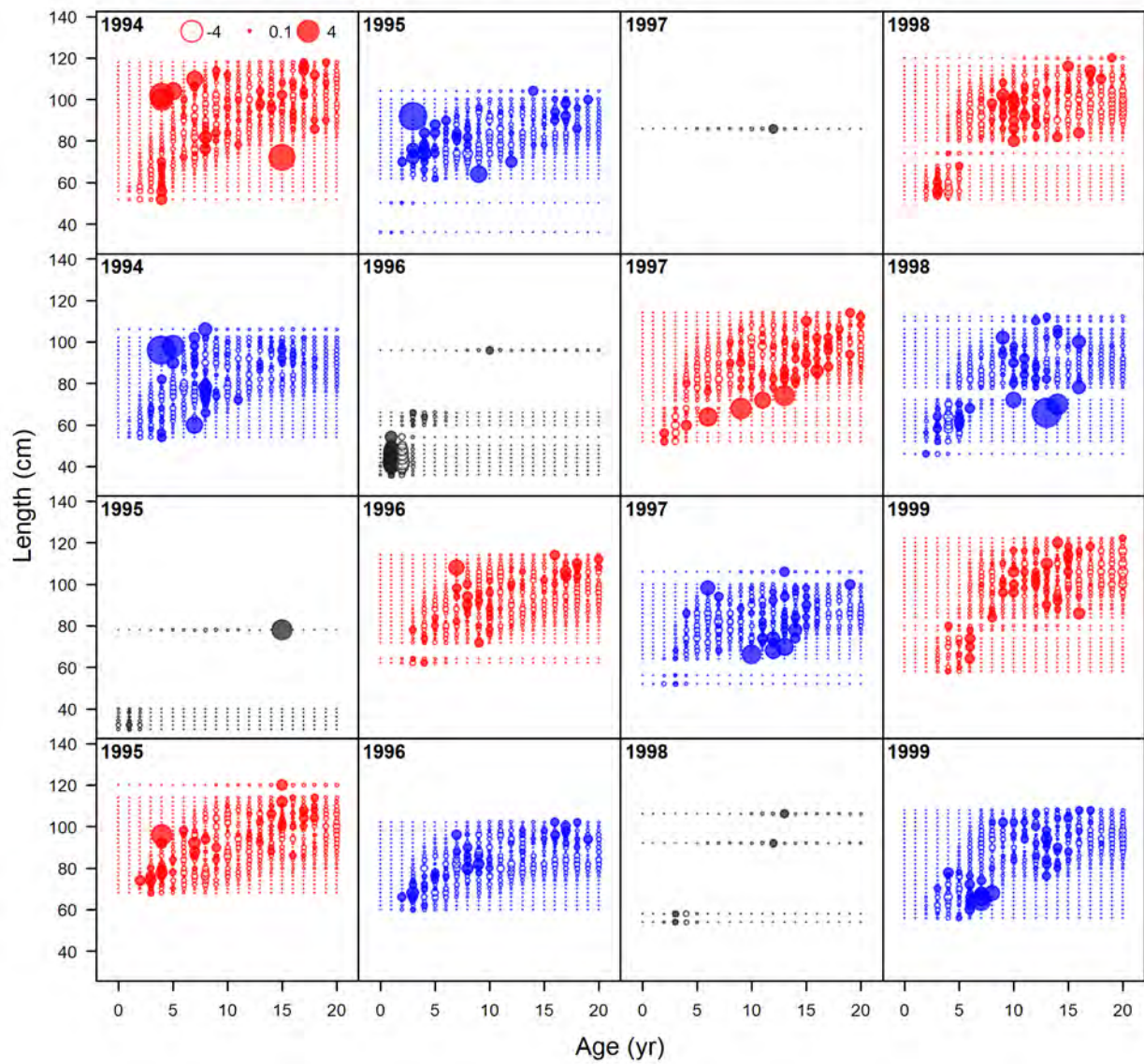
Pearson residuals, retained, SpawnFleetonboard (max=23.39)



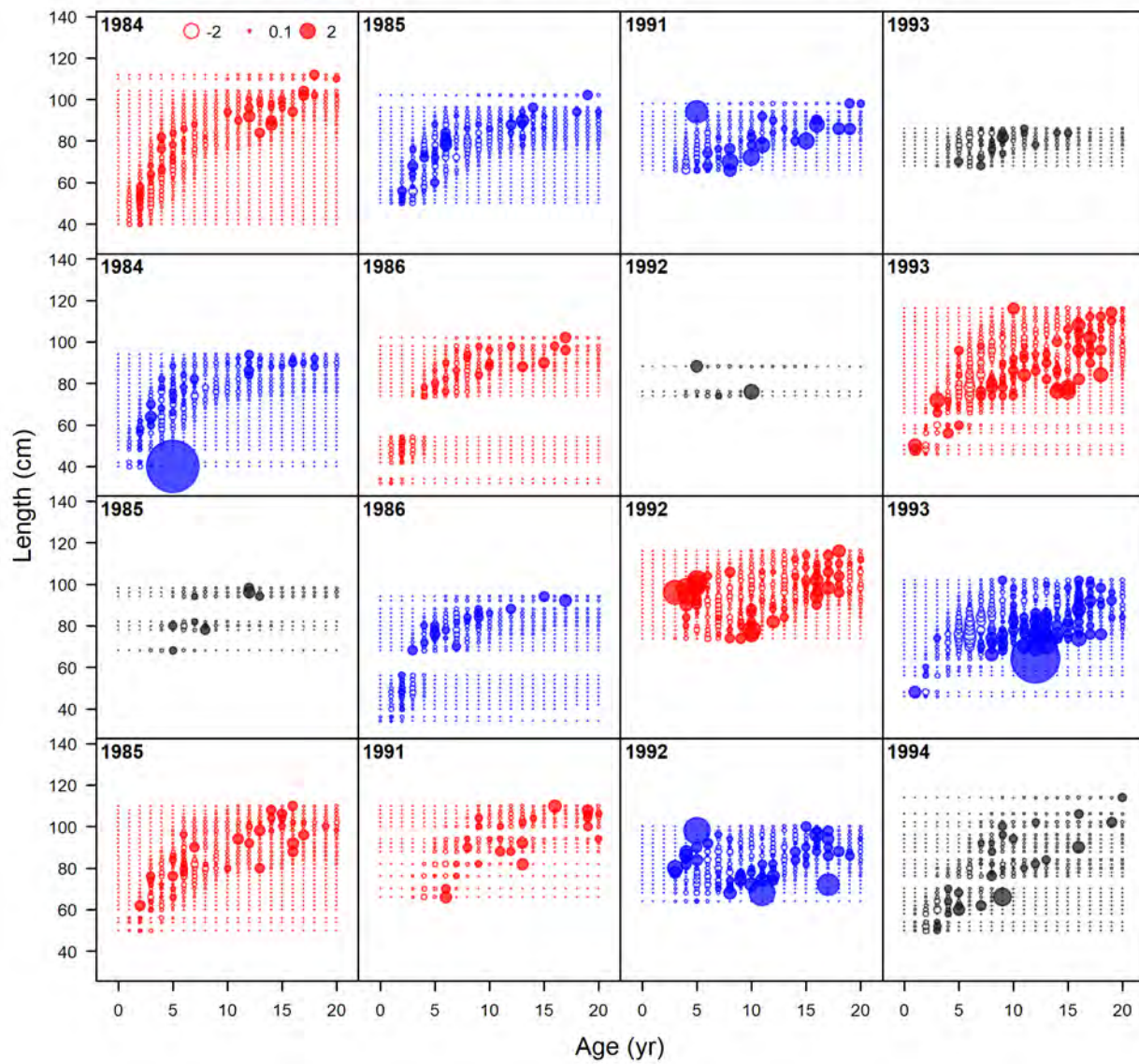
Pearson residuals, retained, SpawnFleetonboard (max=23.39)



Pearson residuals, retained, SpawnFleetonboard (max=23.39)



Pearson residuals, retained, SpawnFleetonboard (max=23.39)



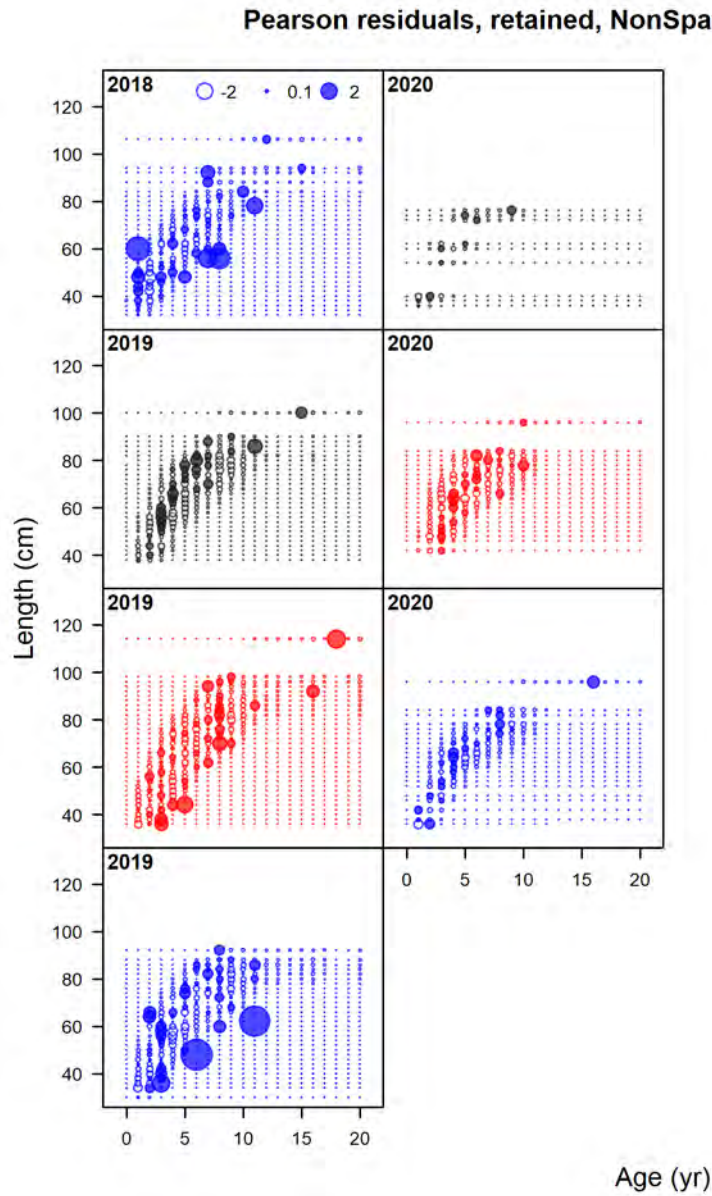


Figure 5.31. Pearson residuals of conditional age at length data.

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

Geoff Tuck and Pia Bessell-Browne

CSIRO Oceans and Atmosphere, Castray Esplanade, Hobart, TAS 7000, Australia

6.1 Executive Summary

This document presents the agreed base case for an updated quantitative Tier 1 assessment of Blue Grenadier (*Macrurus 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.

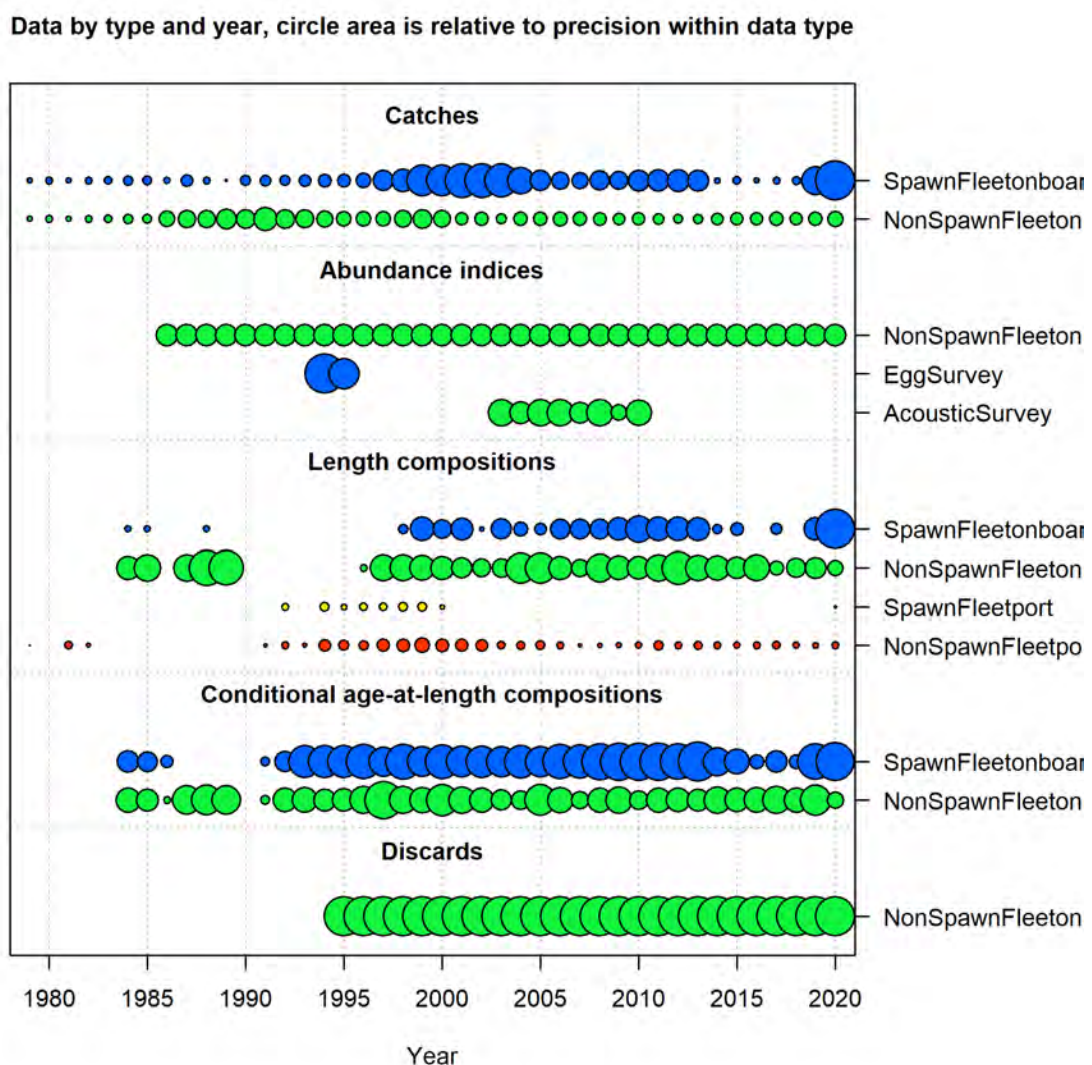


Figure 6.1. A summary of the input data for the base case Blue Grenadier assessment.

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.

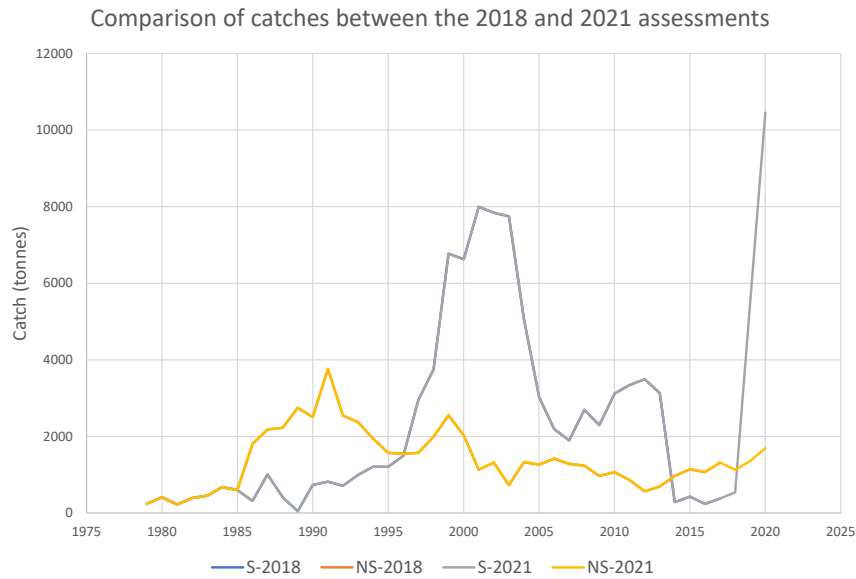


Figure 6.2. A comparison of total annual catches from the 2018 base case assessment and the updated catch used in the 2021 assessment for the spawning (S) and non-spawning (NS) fisheries.

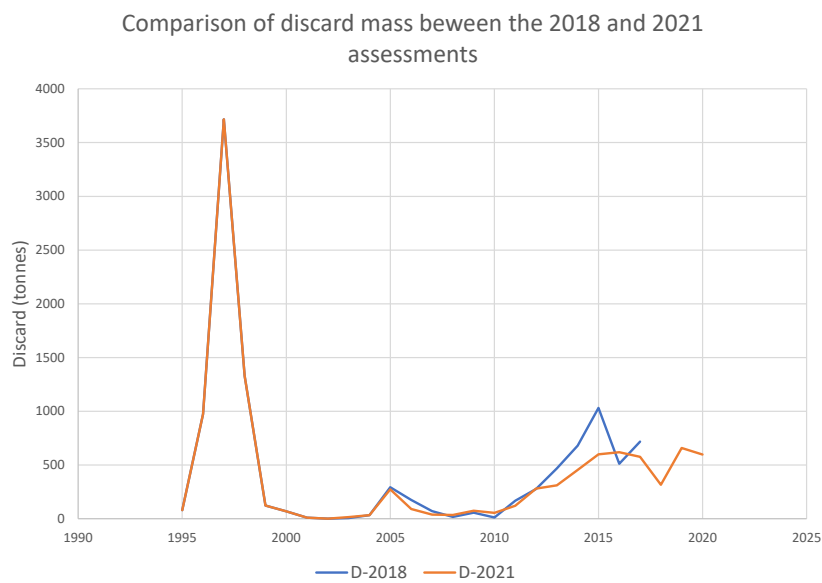


Figure 6.3. A comparison of total annual estimated discard mass from the 2018 base case assessment and the updated catch used in the 2021 assessment for the non-spawning fishery.

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	1.071	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.

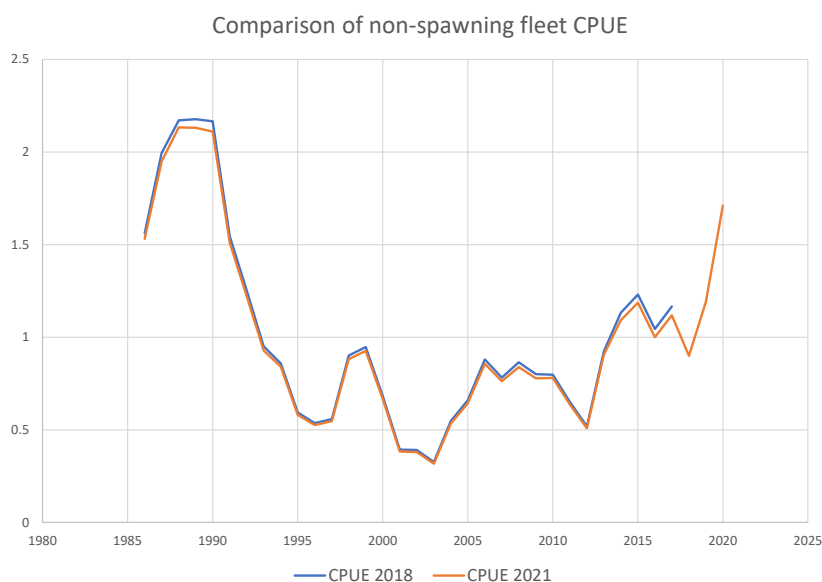


Figure 6.4. A comparison of the annual standardised catch rates series for Blue Grenadier between the 2018 and 2021 assessments.

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 (Russell 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.

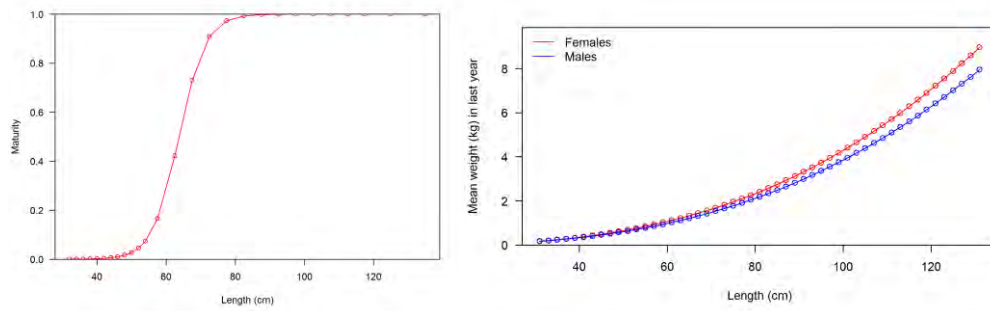


Figure 6.5. The maturity ogive by length for female Blue Grenadier (parameters from Russell and Smith (2006)) and the length-weight relationship for males and females.

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.

Age	St Dev	
	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 unexploited 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 unexploited biomass with the corresponding equilibrium (unexploited) 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; Sporlic, 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. $\sigma_r = 0.6, 0.8$ (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 Parameter 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), $\ln(R_0)$, is 9.89 for the base case.

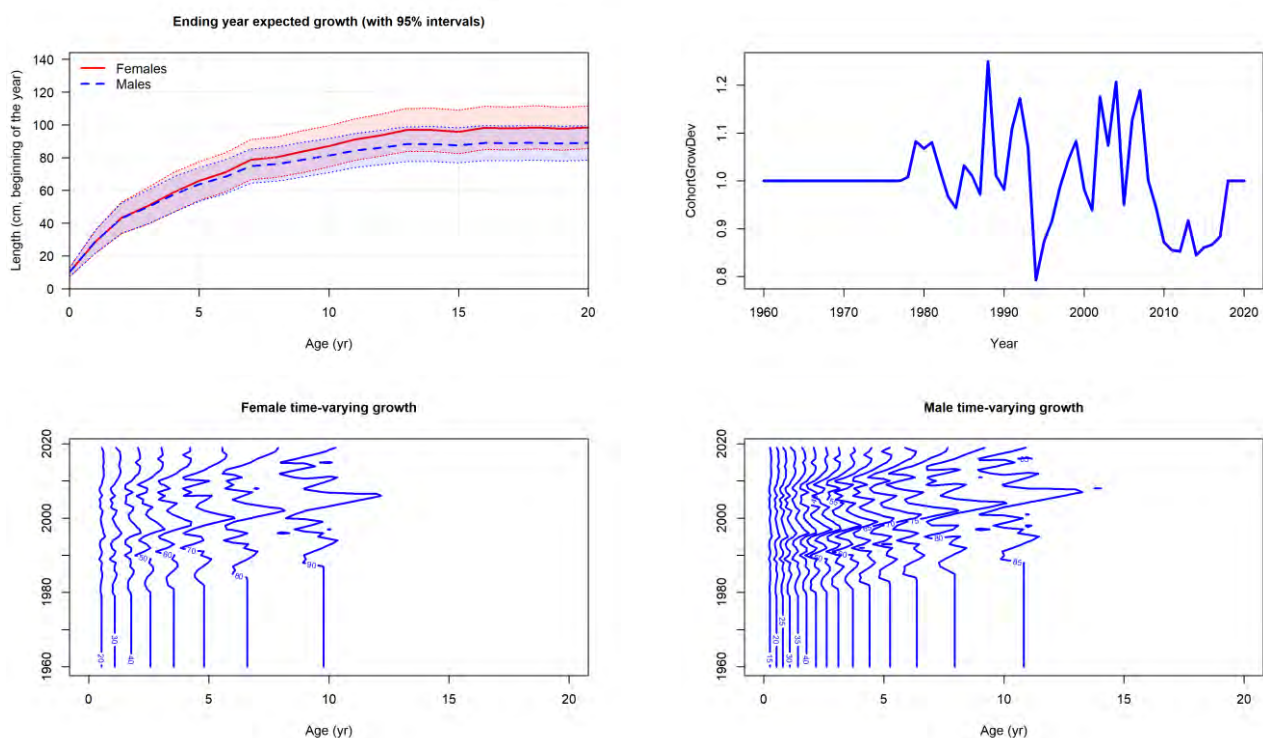


Figure 6.6. The estimate growth curve, with cohort dependent growth for Blue Grenadier.

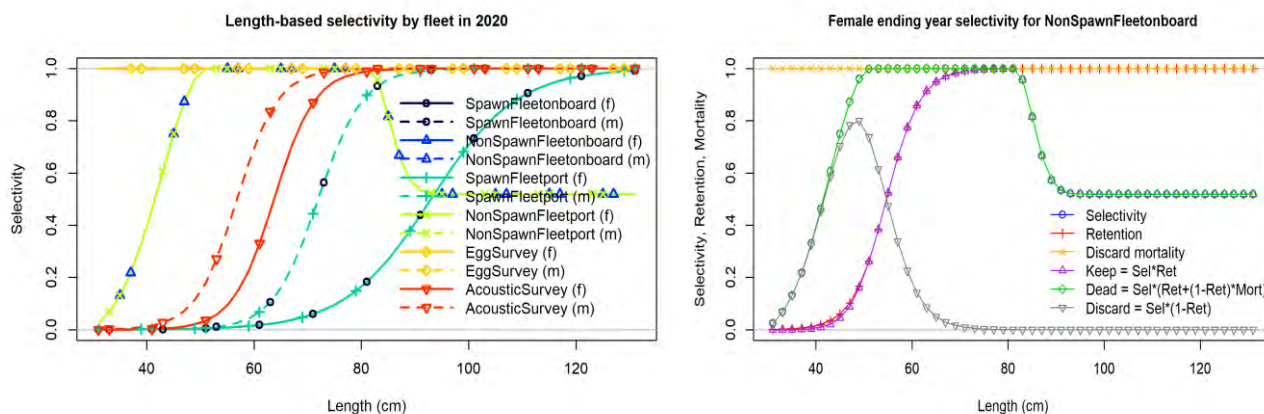


Figure 6.7. Estimated selectivity for the spawning and non-spawning fleets, port and onboard samples and for males (m) and females (f) and the estimated retention function for the non-spawning fleet.

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.

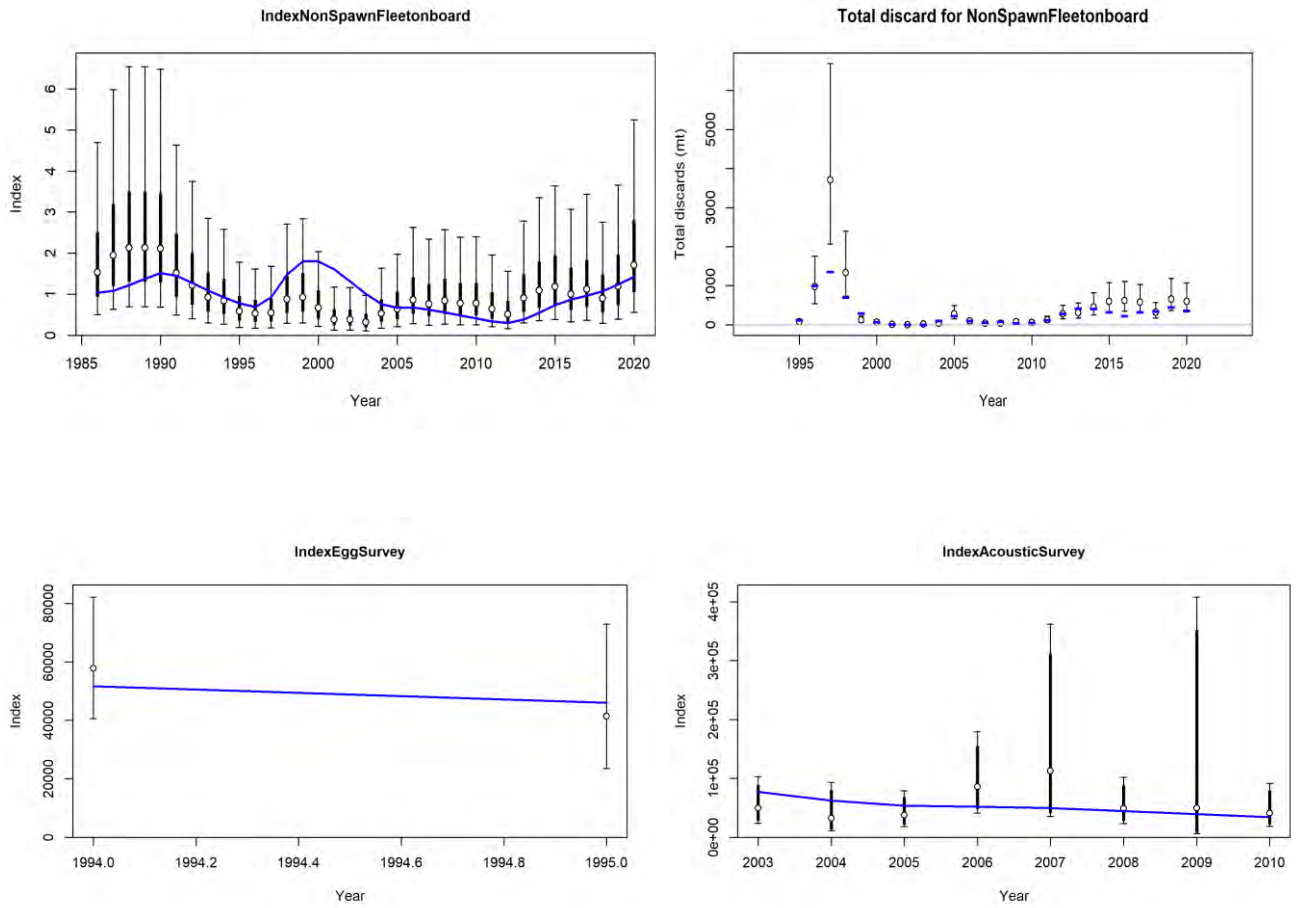


Figure 6.8. Fits to the non-spawning CPUE index, discard mass, egg survey and acoustic survey.

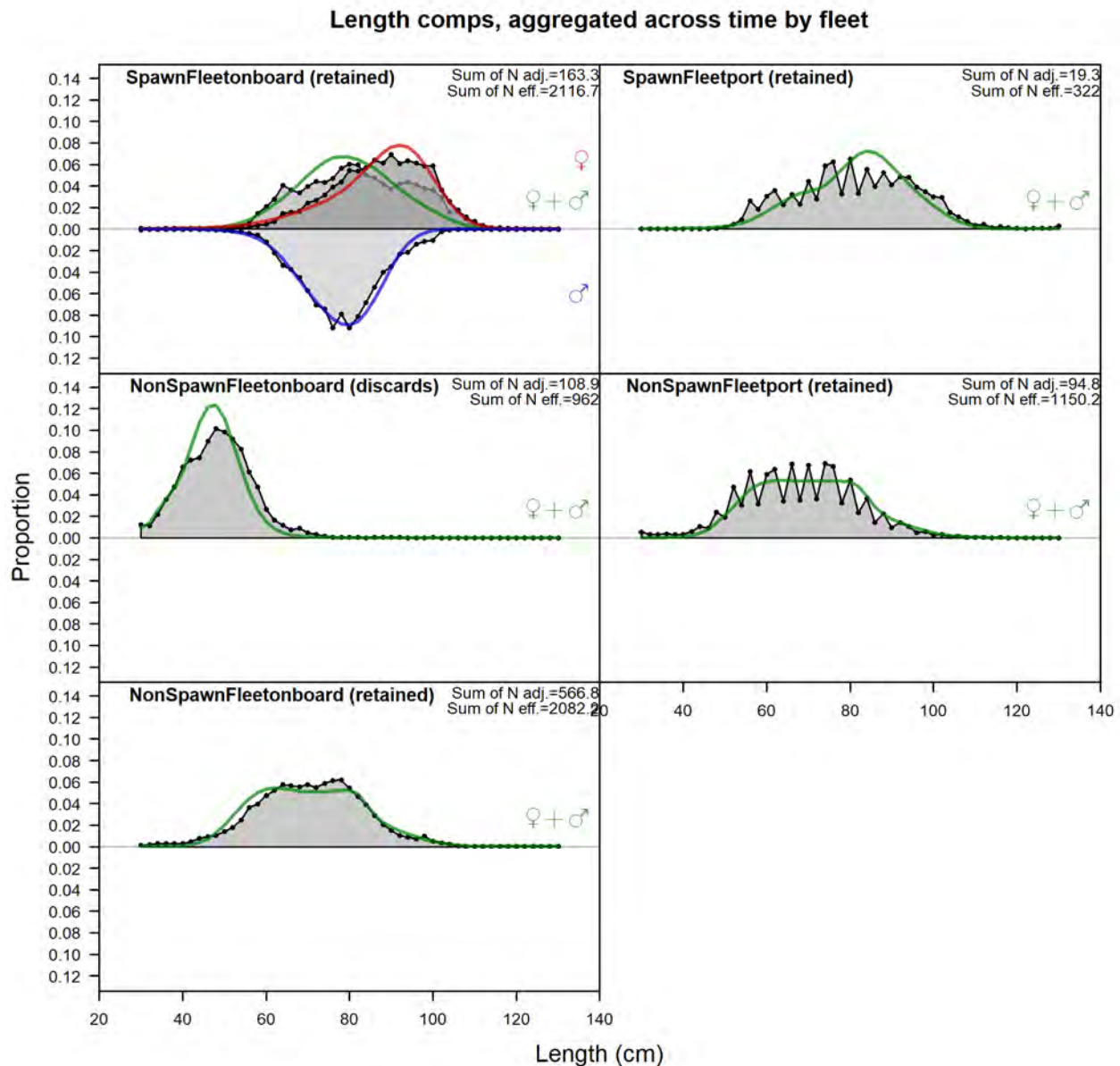


Figure 6.9. Length composition fits aggregated across years.

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 between 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

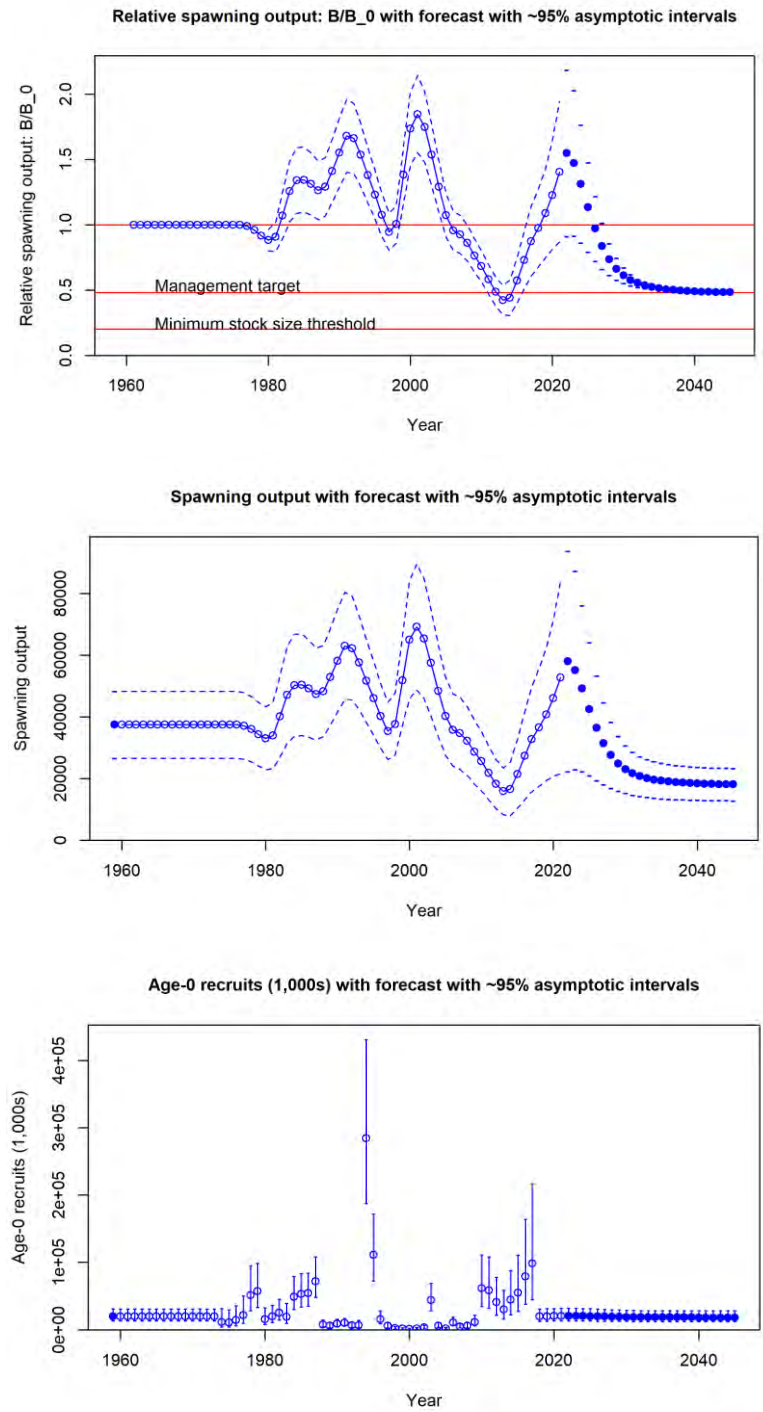


Figure 6.10. The estimated time-series of relative spawning biomass and annual recruitment for the 2021 base case assessment for Blue Grenadier.

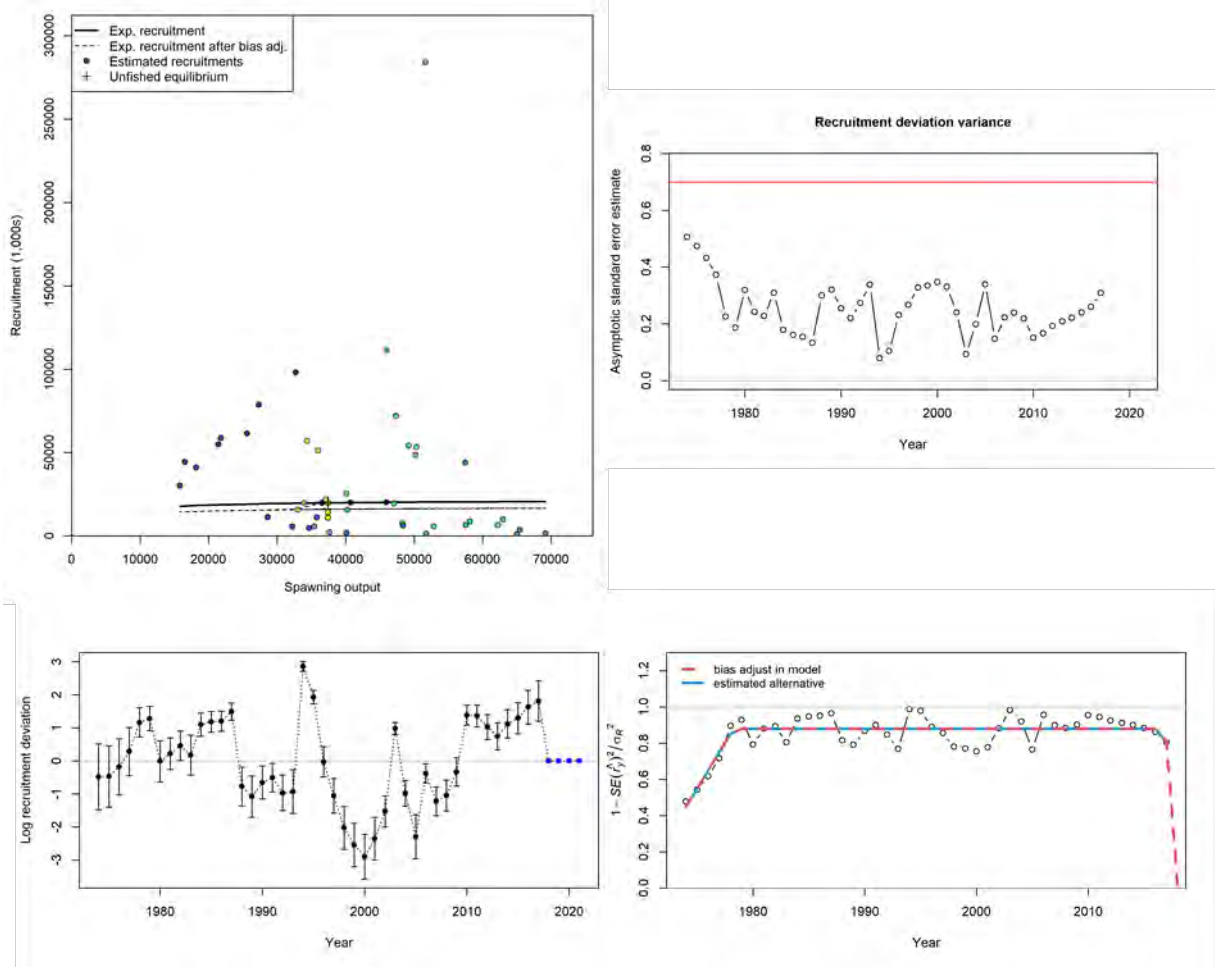


Figure 6.11. Time series showing the stock recruitment curve, recruitment deviations, recruitment deviation variance check and bias ramp for Blue Grenadier.

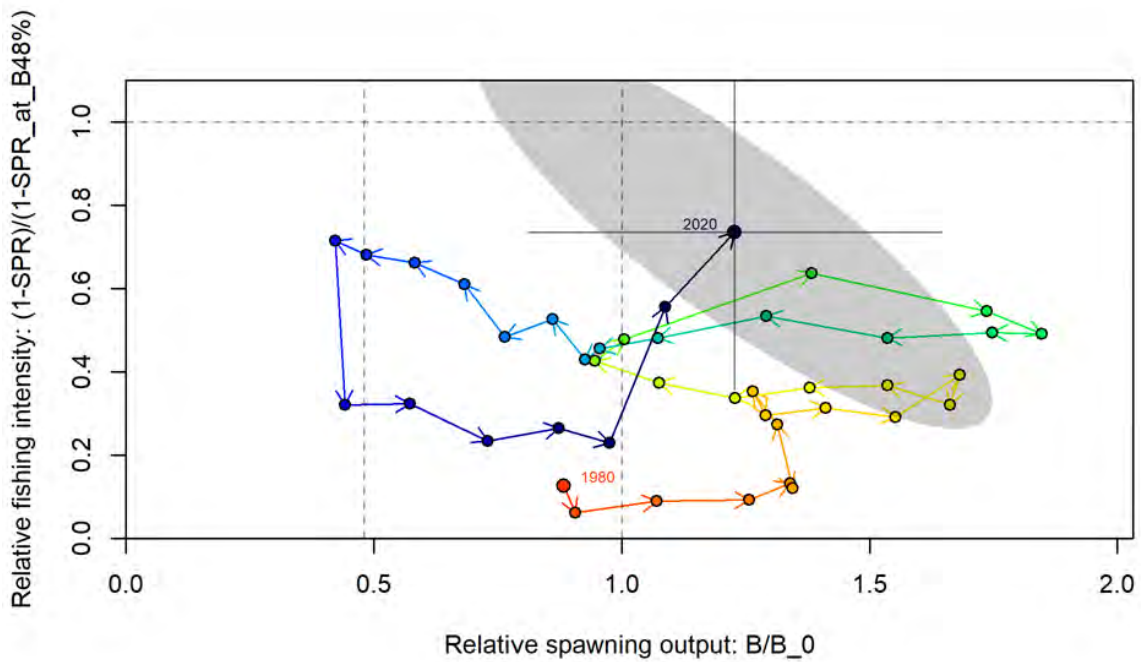


Figure 6.12. Kobe plot showing relative fishing mortality (y-axis) versus relative spawning biomass (x-axis).

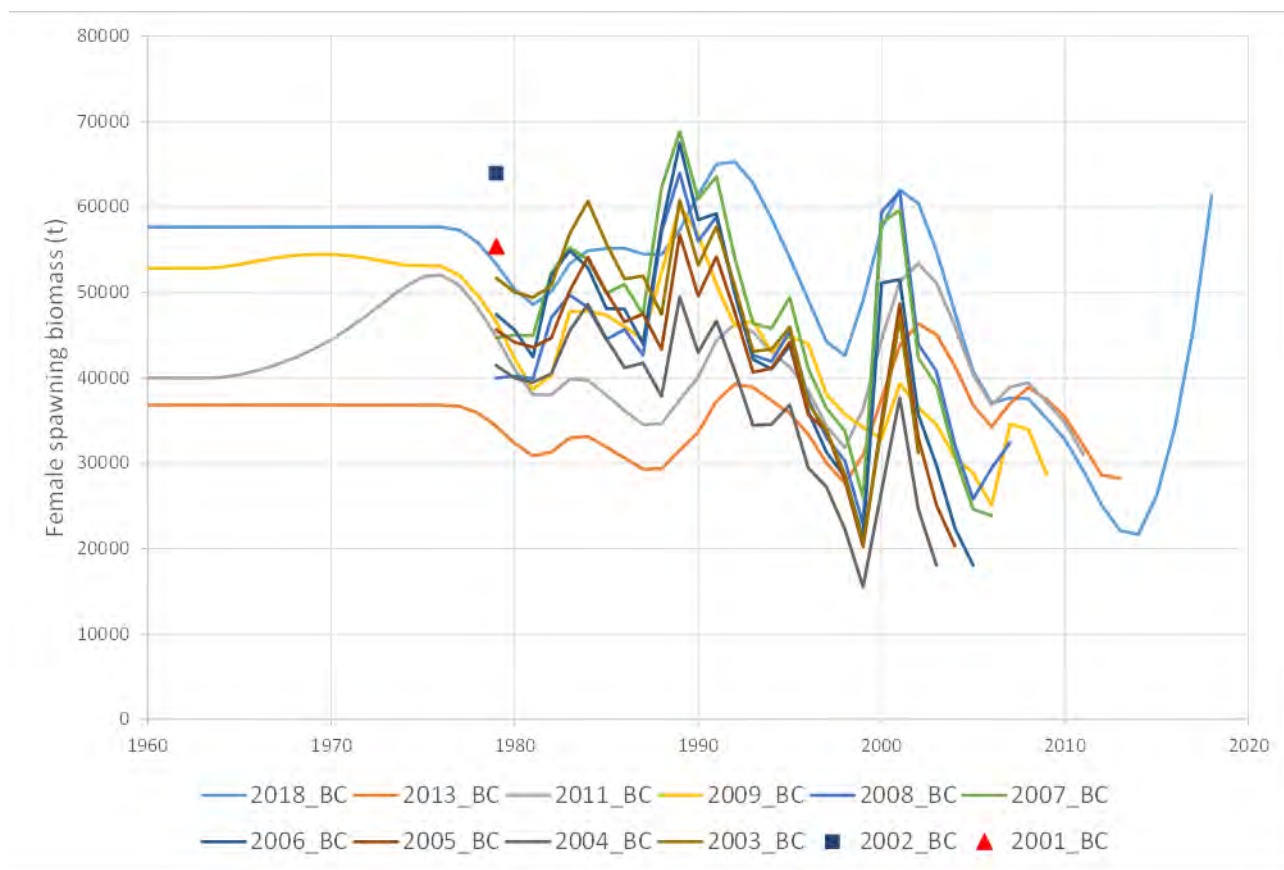


Figure 6.13. A retrospective of assessment outputs of female spawning biomass from each stock assessment from 2001 to 2018. Note that for 2001 and 2002 only values of biomass in 1979 were available (from Castillo-Jordán and Tuck, 2018a).

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 ($M=0.23 \text{ yr}^{-1}$) 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.

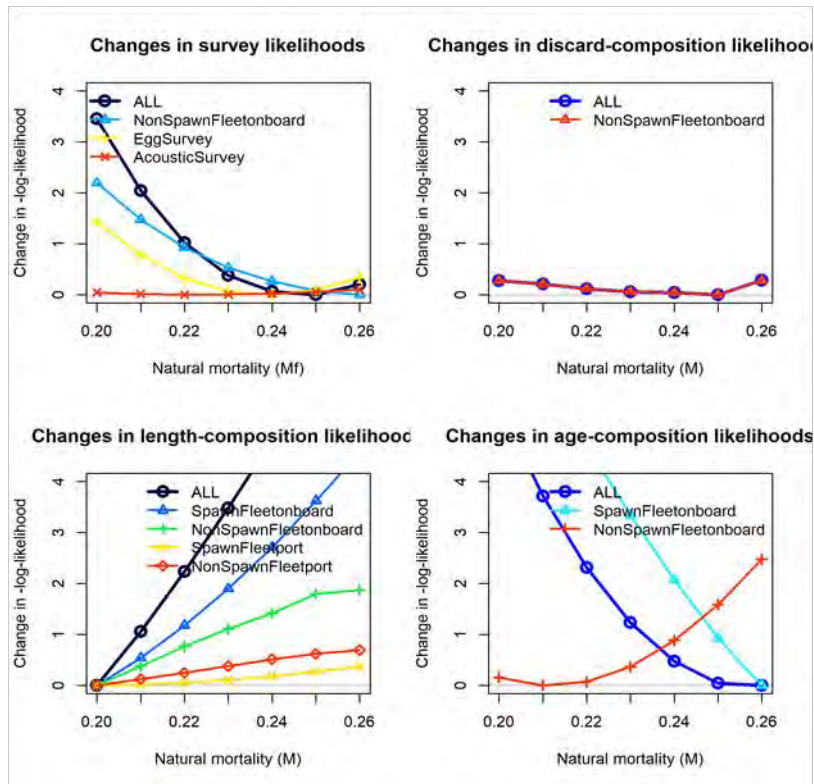
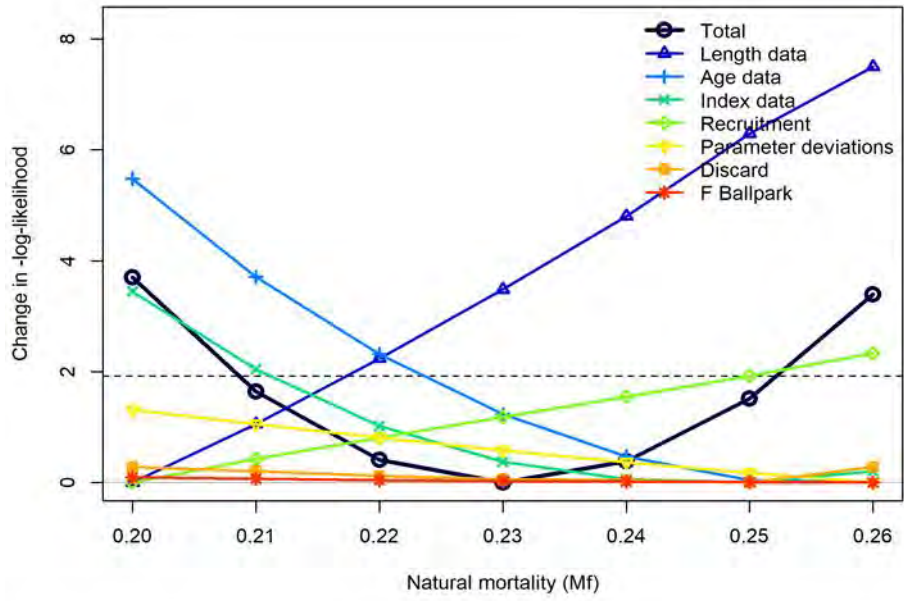


Figure 6.14. The likelihood profile (top) for female natural mortality, with 95% CIs for M_f ranging from 0.21 to 0.26. The estimated value for M is 0.23 yr⁻¹. Piner plot (bottom) for the likelihood profile showing components of the change in likelihood for index, discard, length and age in addition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

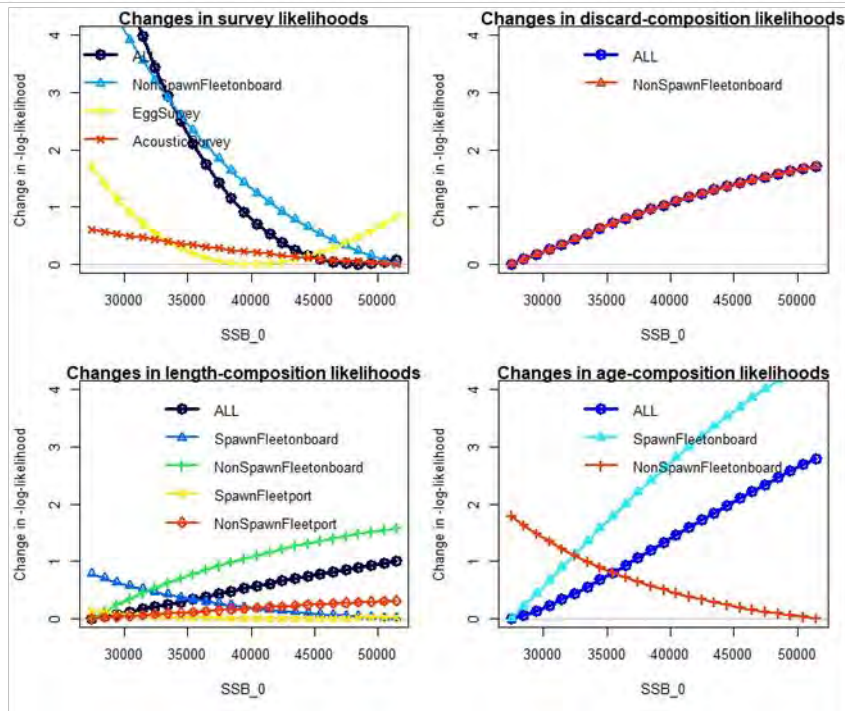
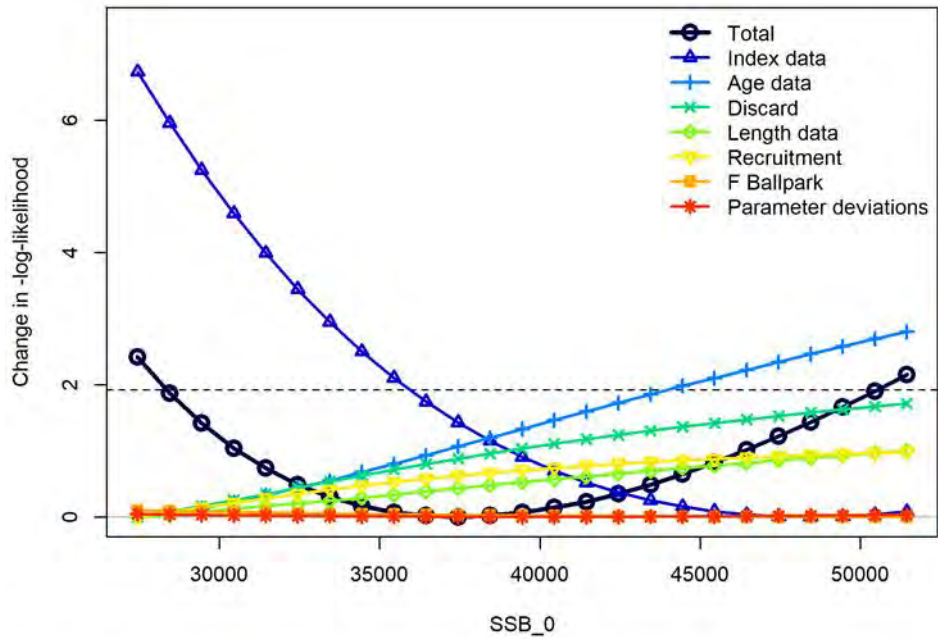


Figure 6.15. The likelihood profile (top) for virgin spawning biomass, with 95% CIs ranging from 27,000 t to 52,000 t. The estimated value is 37,000 t. Piner plot (bottom) for the likelihood profile showing components of the change in likelihood for index, discard, length and age in addition to the changes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

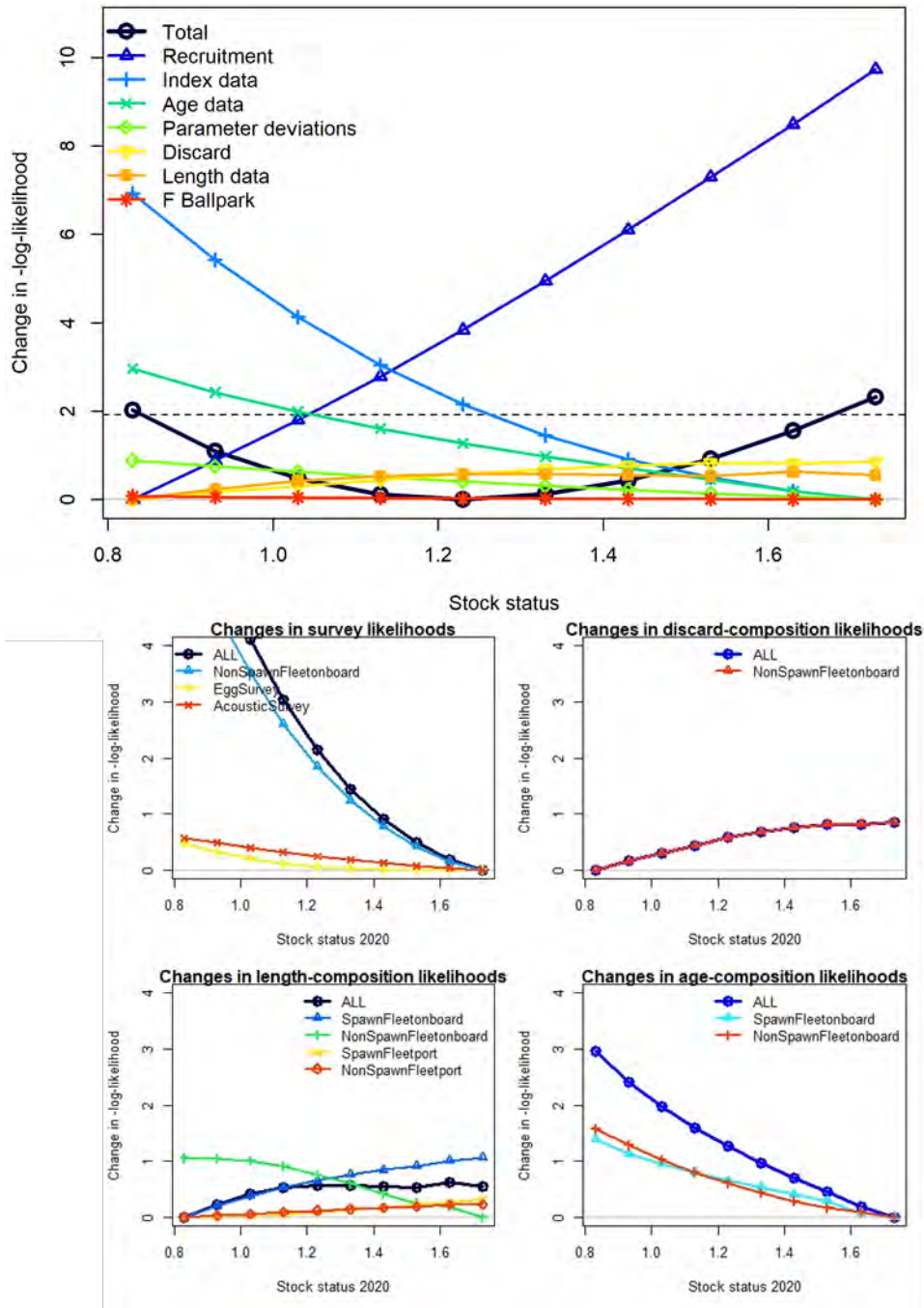


Figure 6.16. The likelihood profile (top) for 2020 stock status, with 95% CIs ranging from 0.8 to 1.7. The estimated value is 1.25. Pincer plot (bottom) for the likelihood profile showing components of the change in likelihood for index, discard, length and age in addition to the changes in the total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

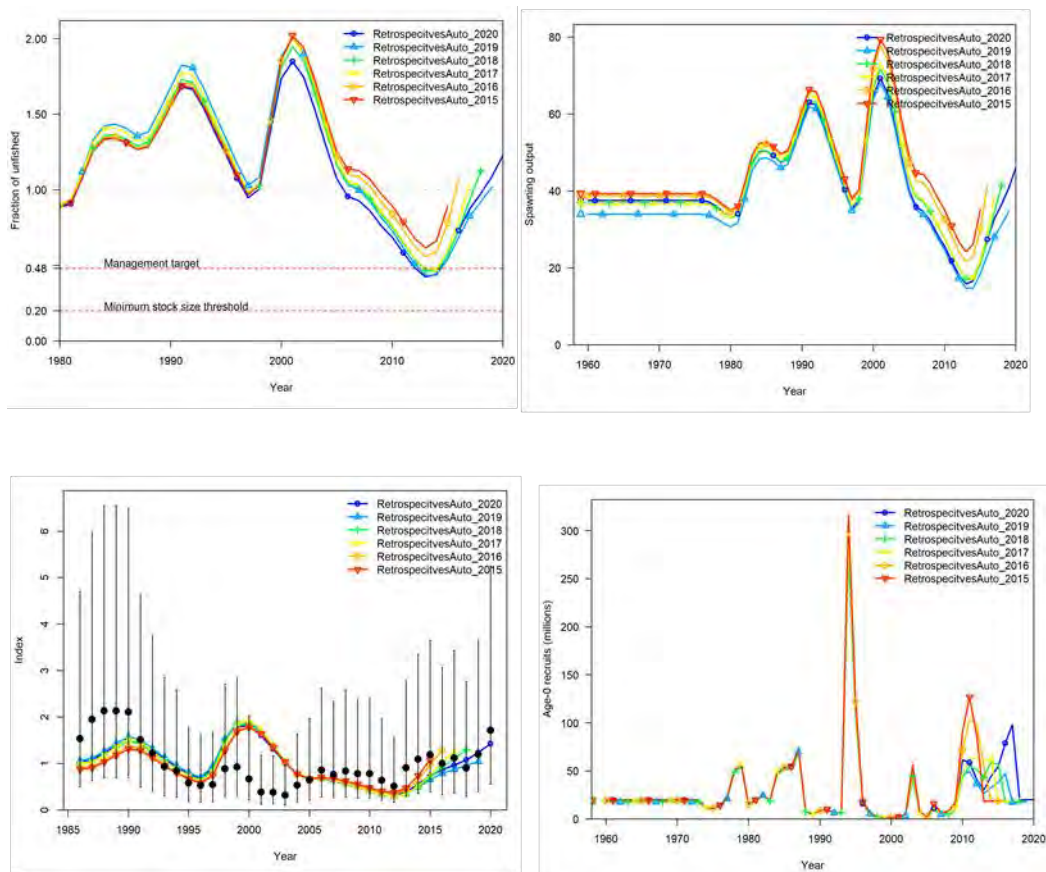


Figure 6.17. Retrospectives for relative and absolute spawning biomass, CPUE and recruitment for Blue Grenadier, with the most recent base case assessment shown (blue) and then successive years removed back to 2015 (red).

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				
$\sigma_R = 0.6$	34,745	48,002	1.38				
$\sigma_R = 0.8$	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
$\sigma_R = 0.6$	21.41	0.74	2.62	1.14	4.79	12.35
$\sigma_R = 0.8$	-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 retrospective 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 recommendations and fixes in relation to 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.

6.9 References

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6.10 Appendix

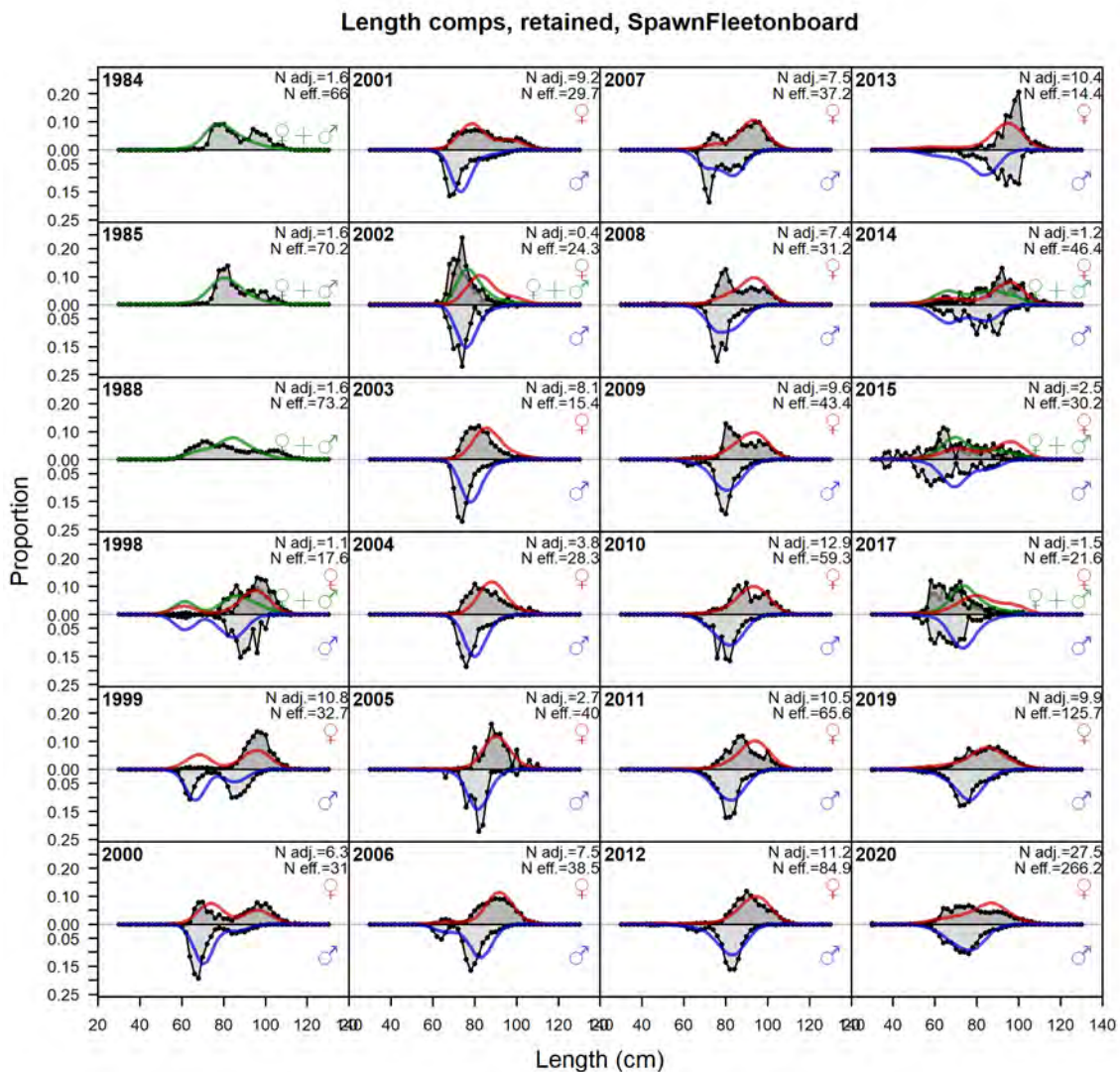


Figure 6.18. Length composition fits: onboard spawning fleet retained.

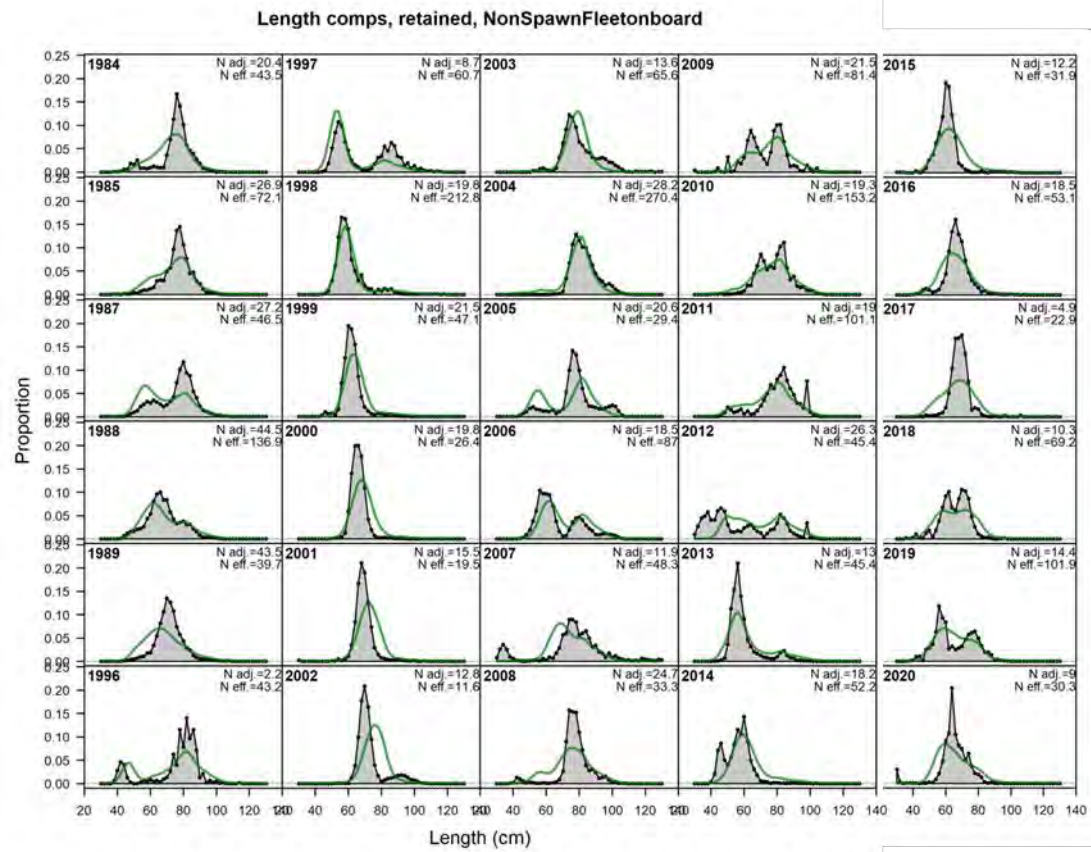


Figure 6.19. Length composition fits: onboard non-spawning fleet retained.

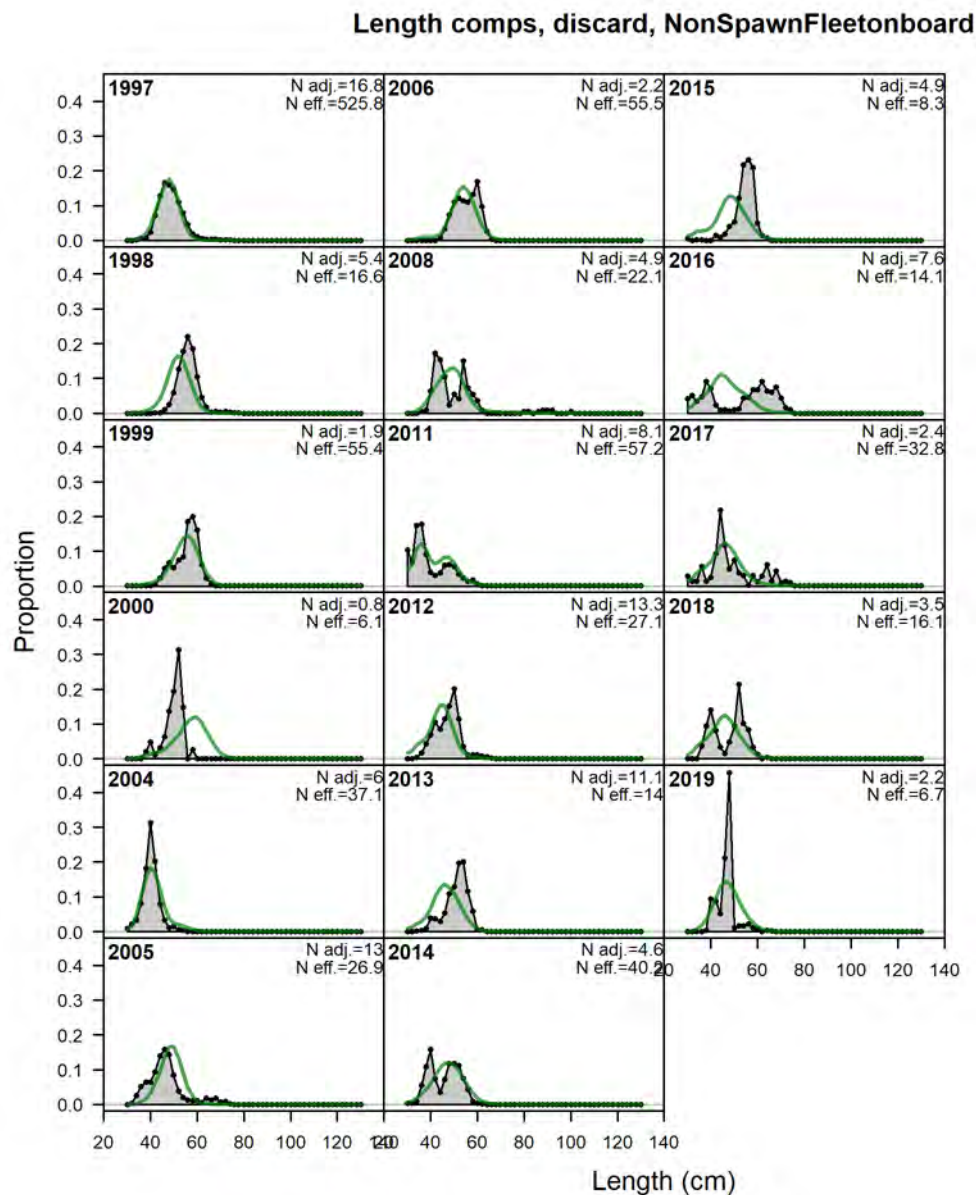


Figure 6.20. Length composition fits: onboard non-spawning fleet discard.

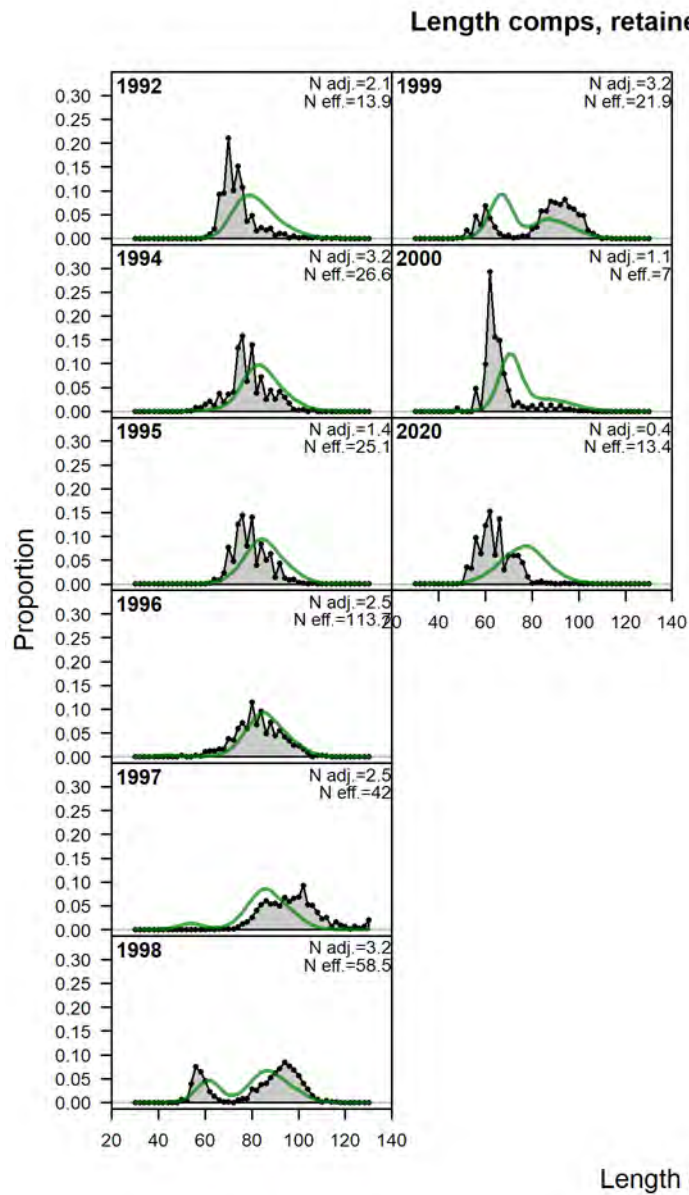


Figure 6.21. Length composition fits: port spawning fleet retained.

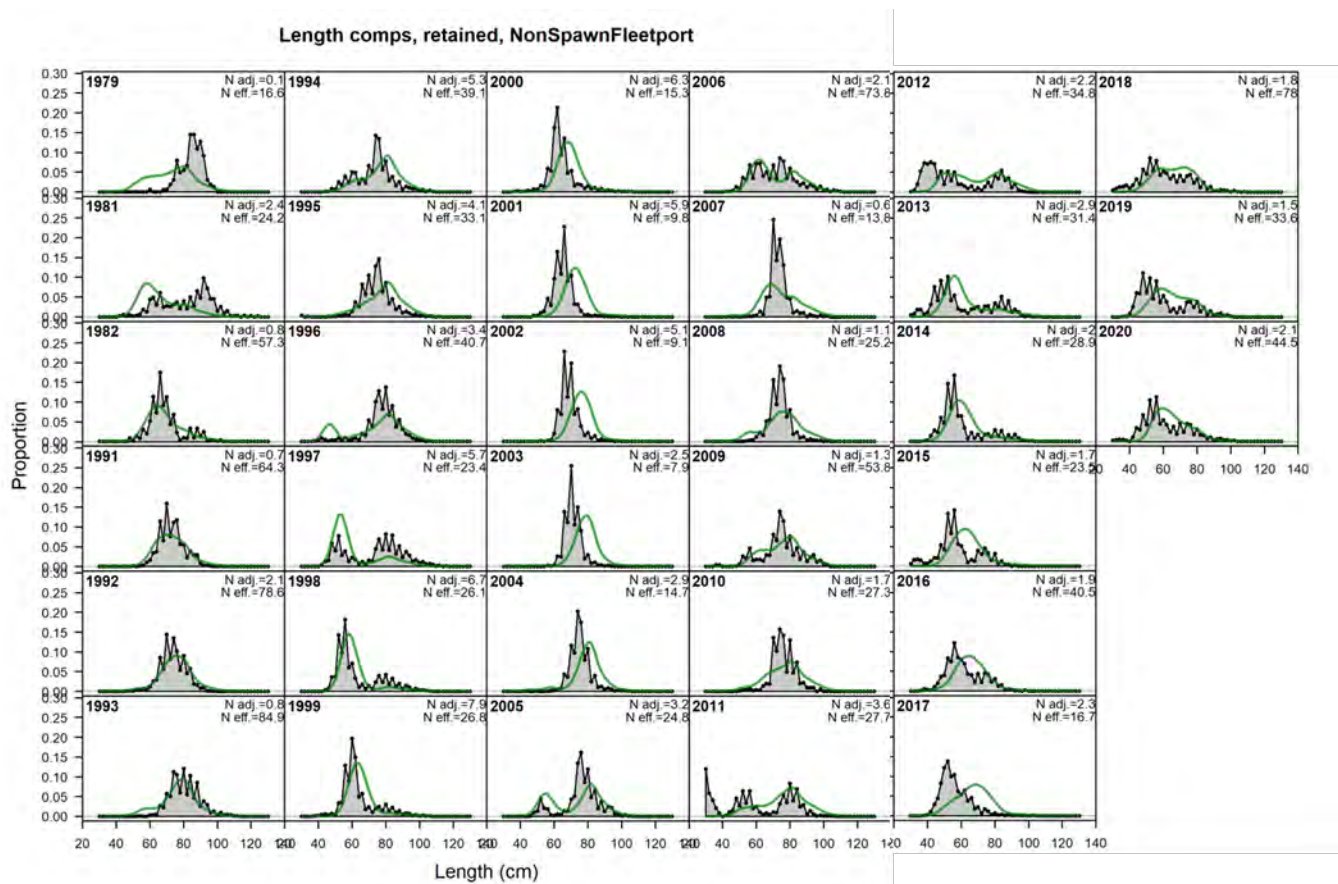


Figure 6.22. Length composition fits: port non-spawning fleet retained.

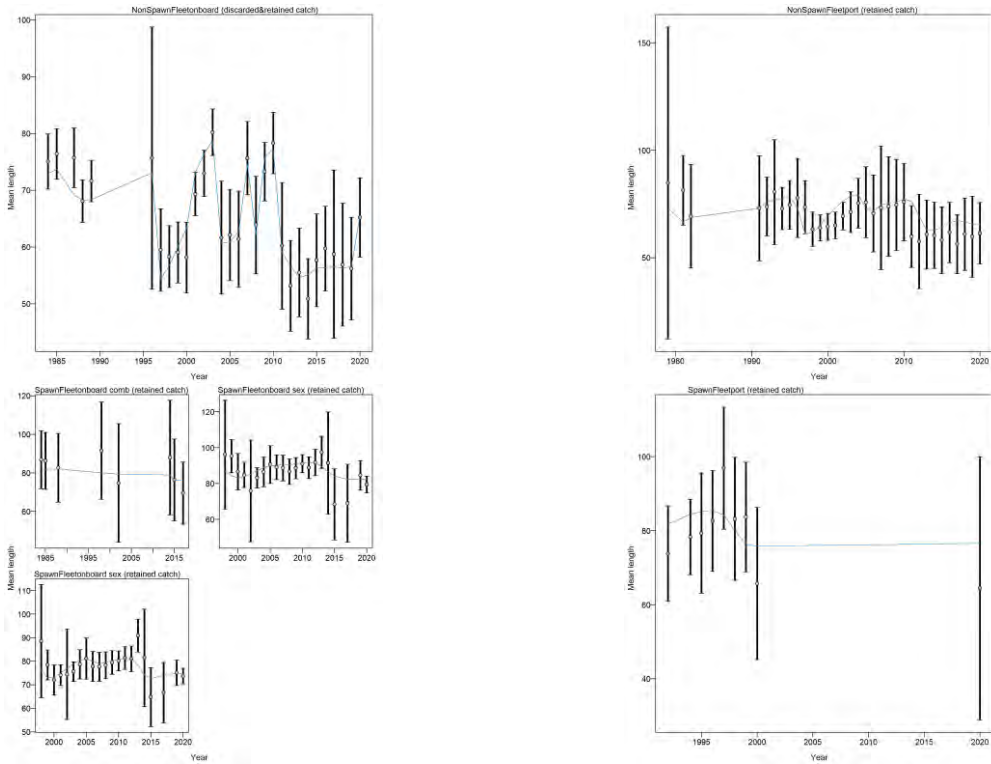


Figure 6.23. Length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.

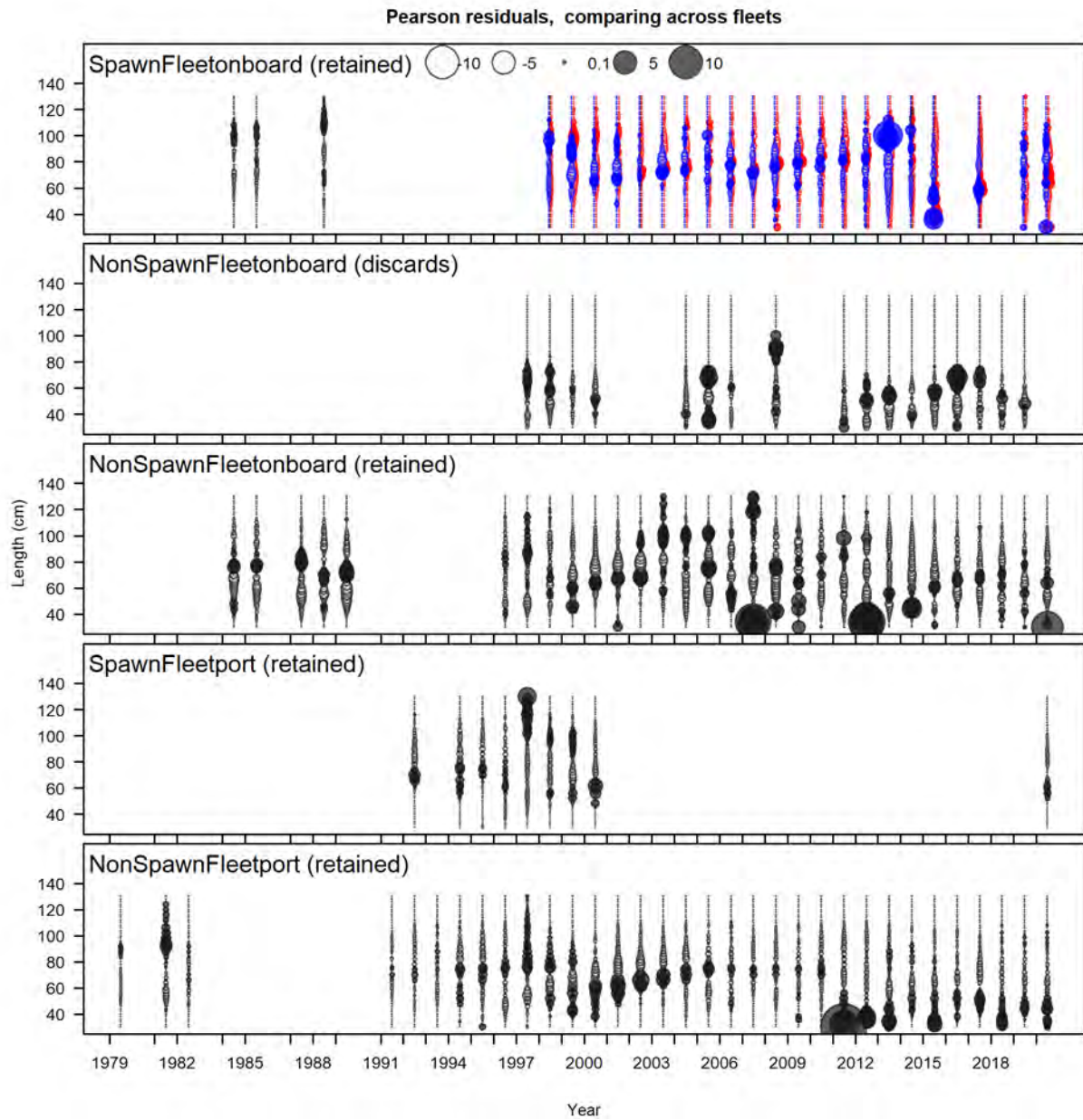


Figure 6.24. Residuals from the annual length compositions for base case

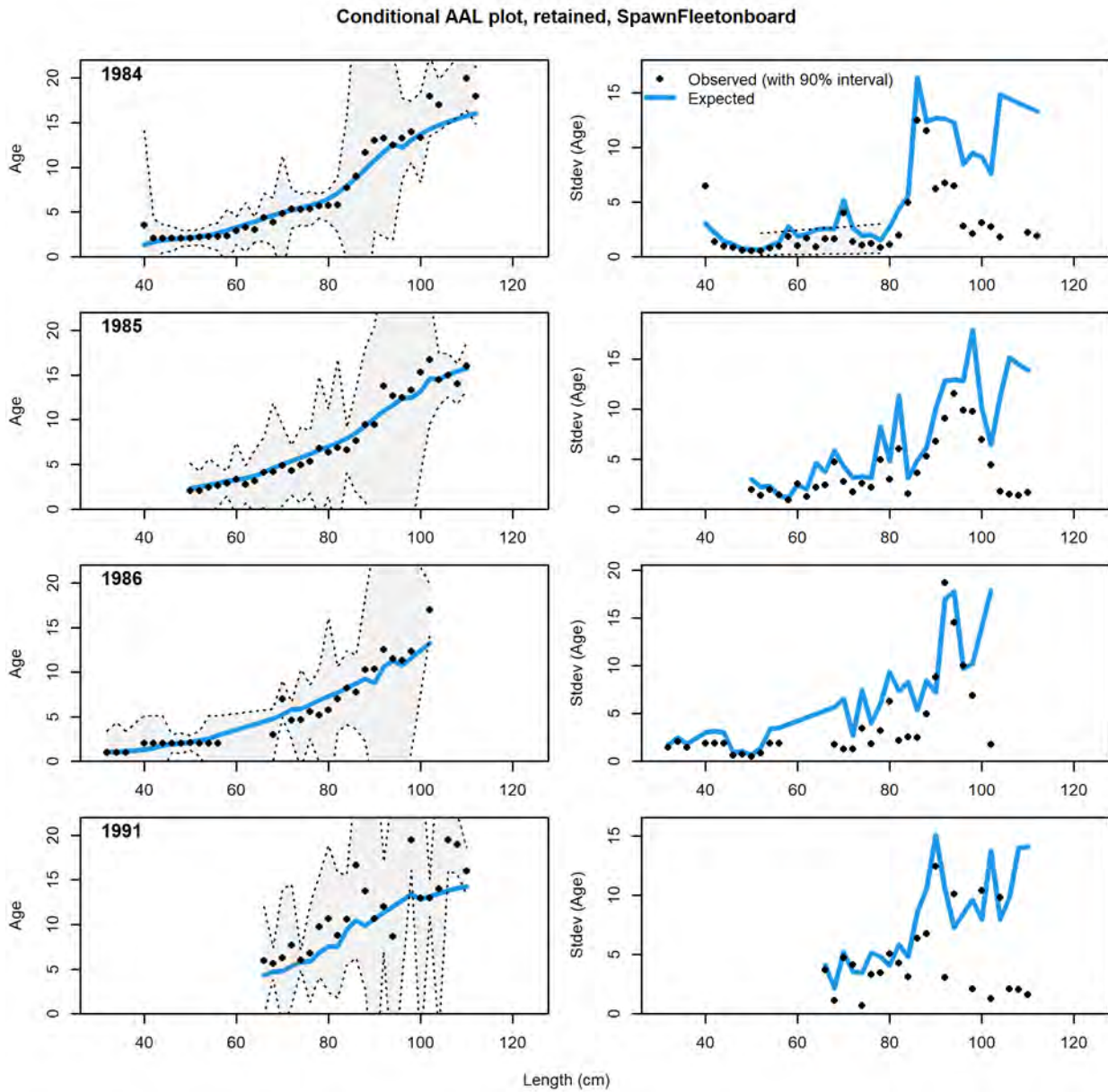
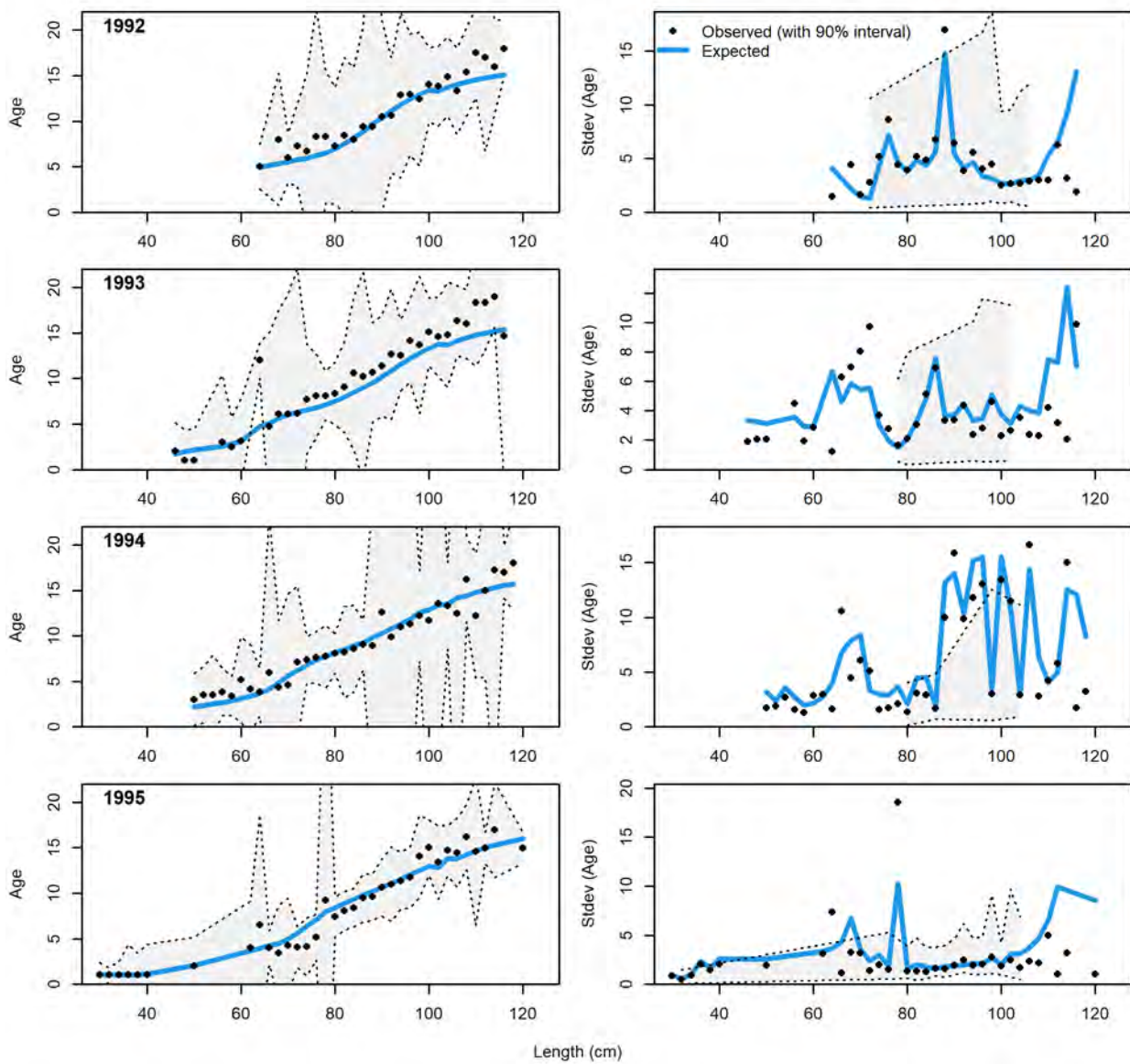
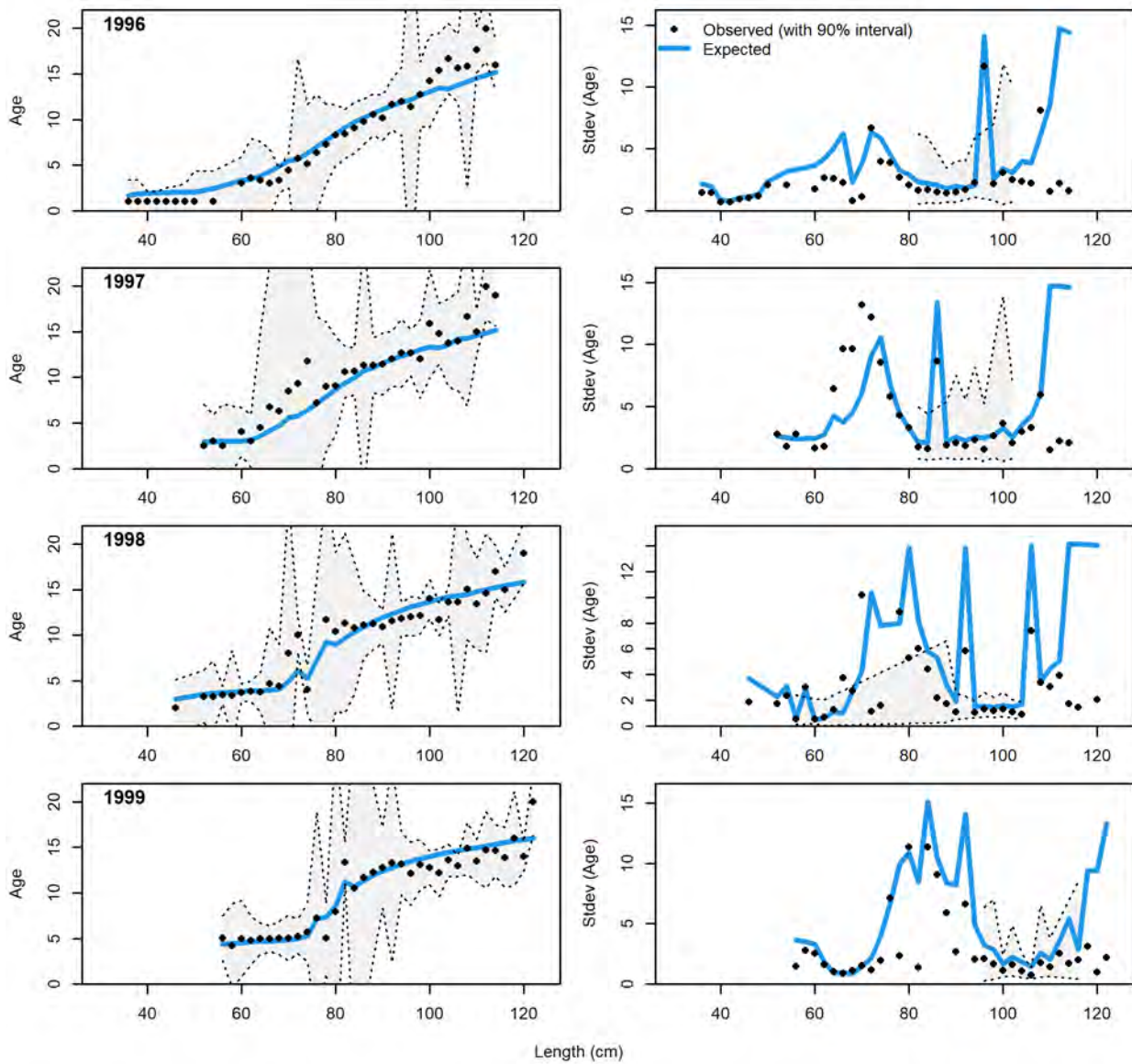


Figure 6.25. Fits to conditional age at length data.

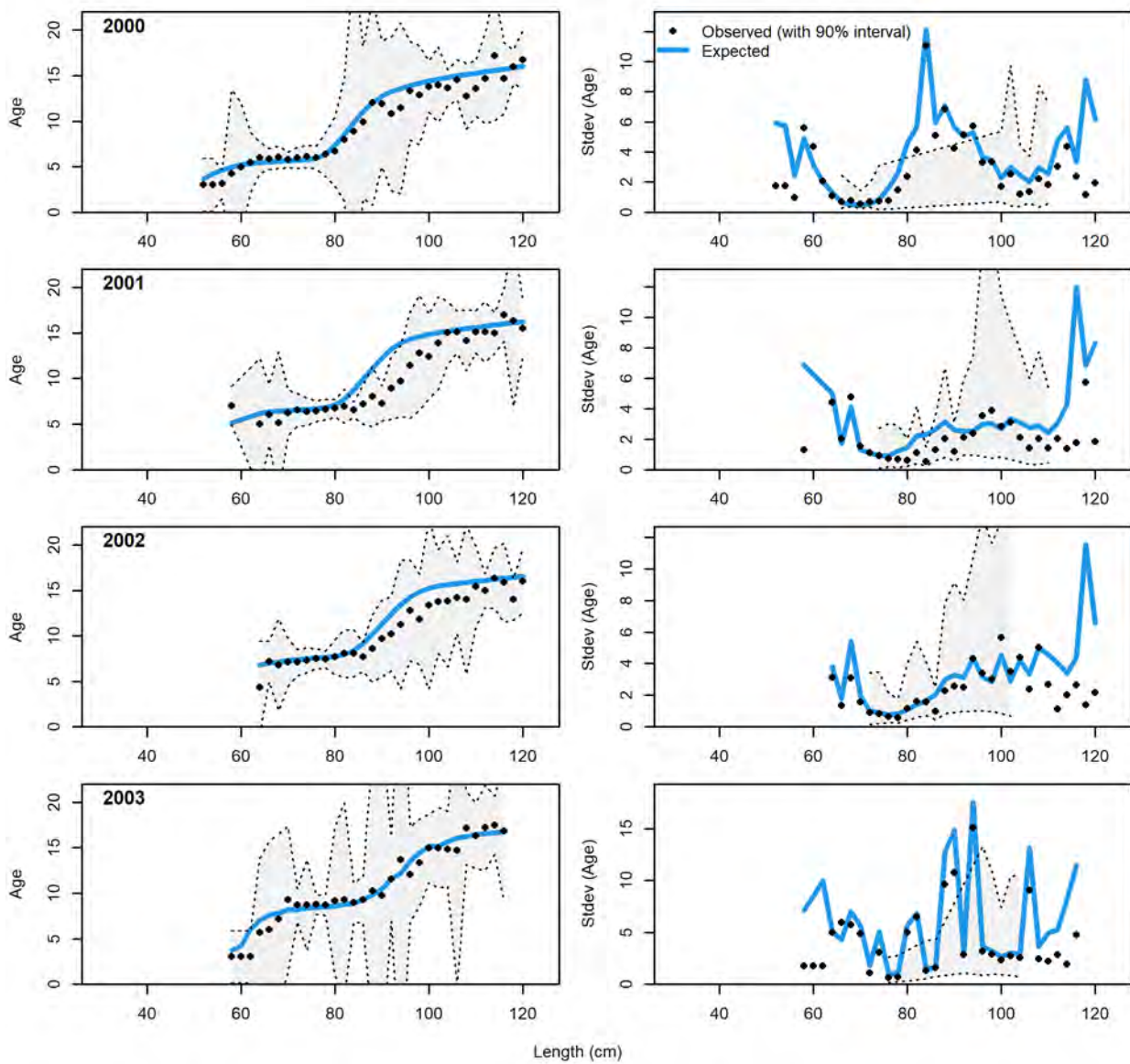
Conditional AAL plot, retained, SpawnFleetonboard



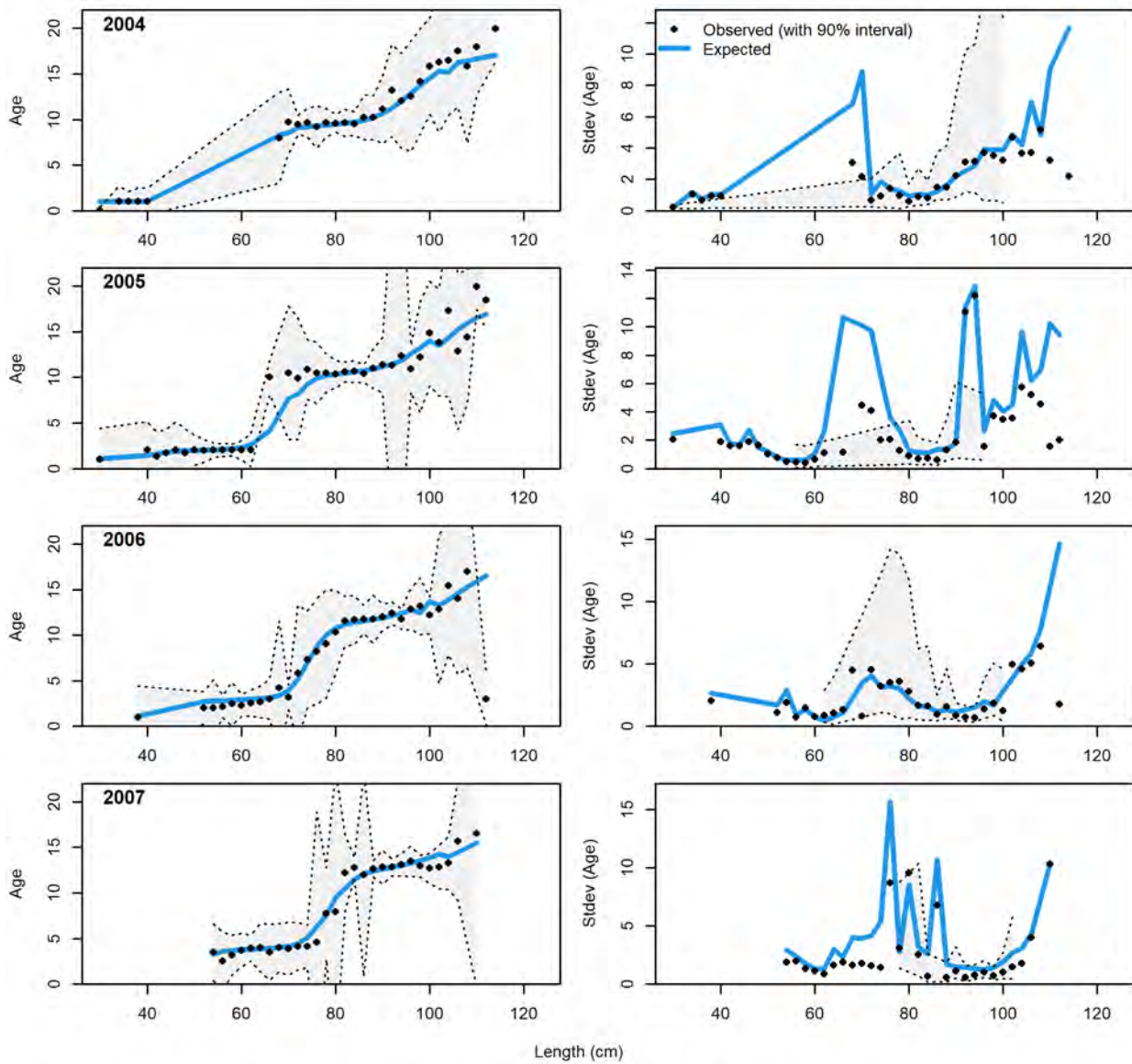
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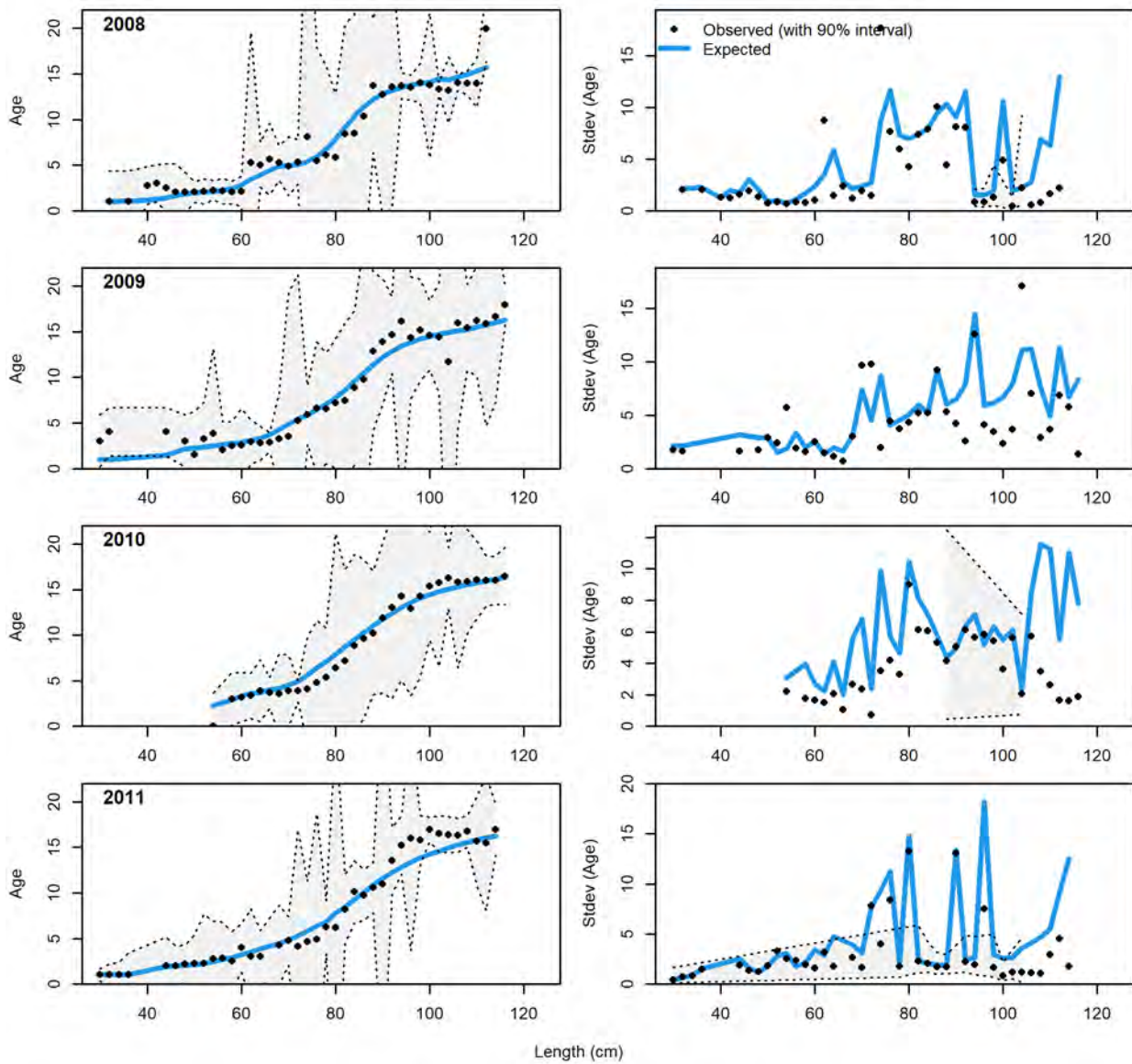
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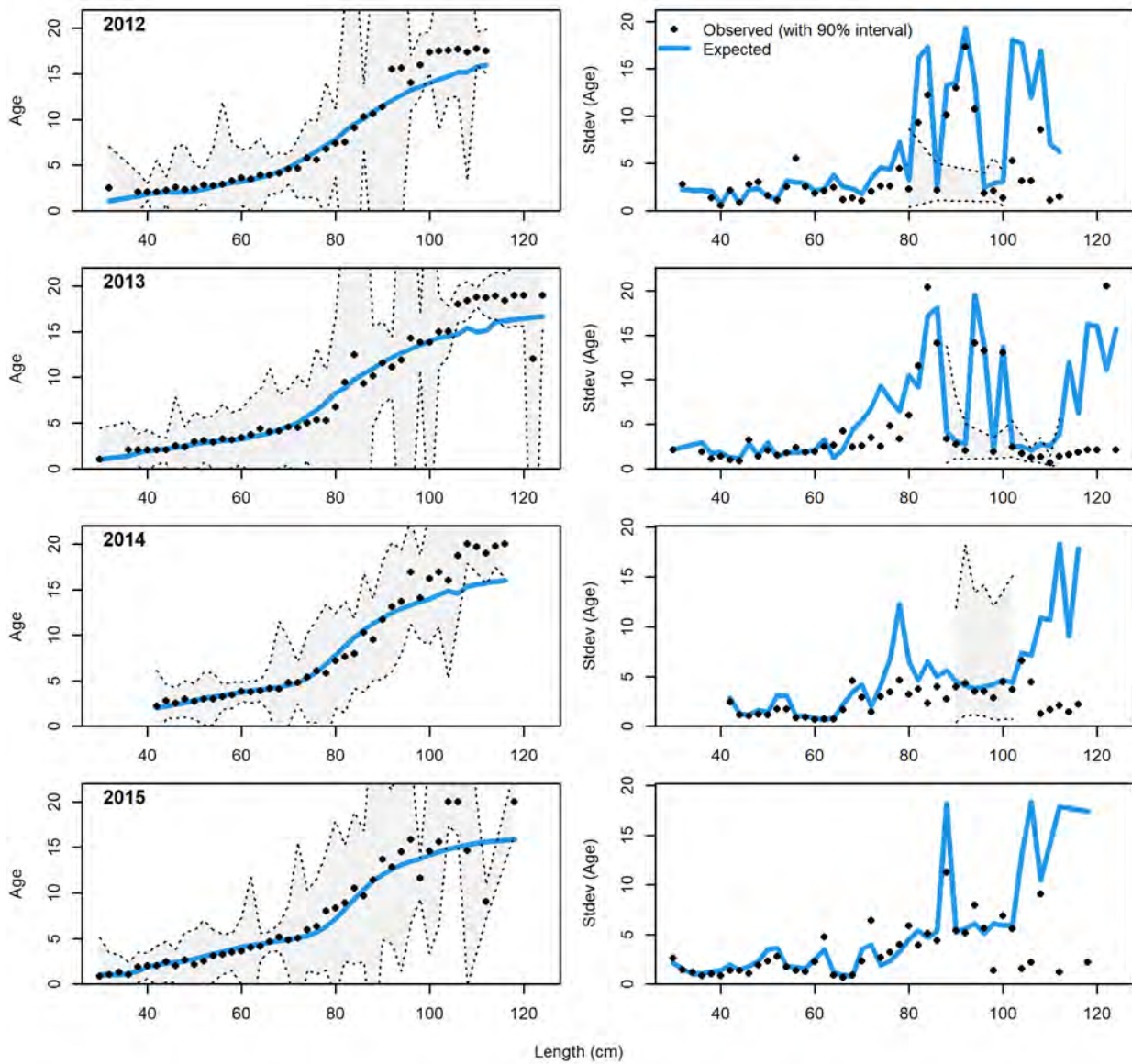
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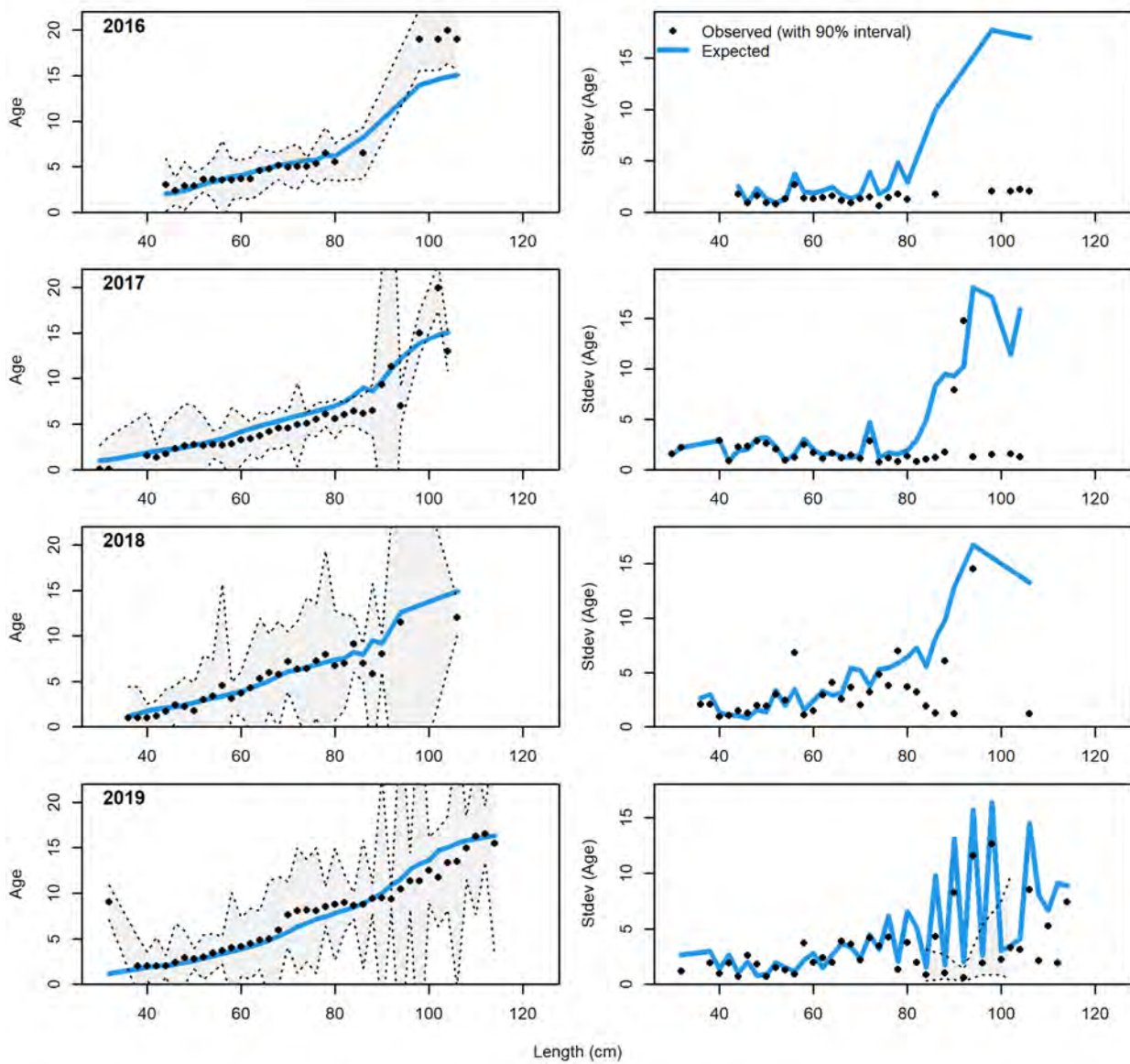
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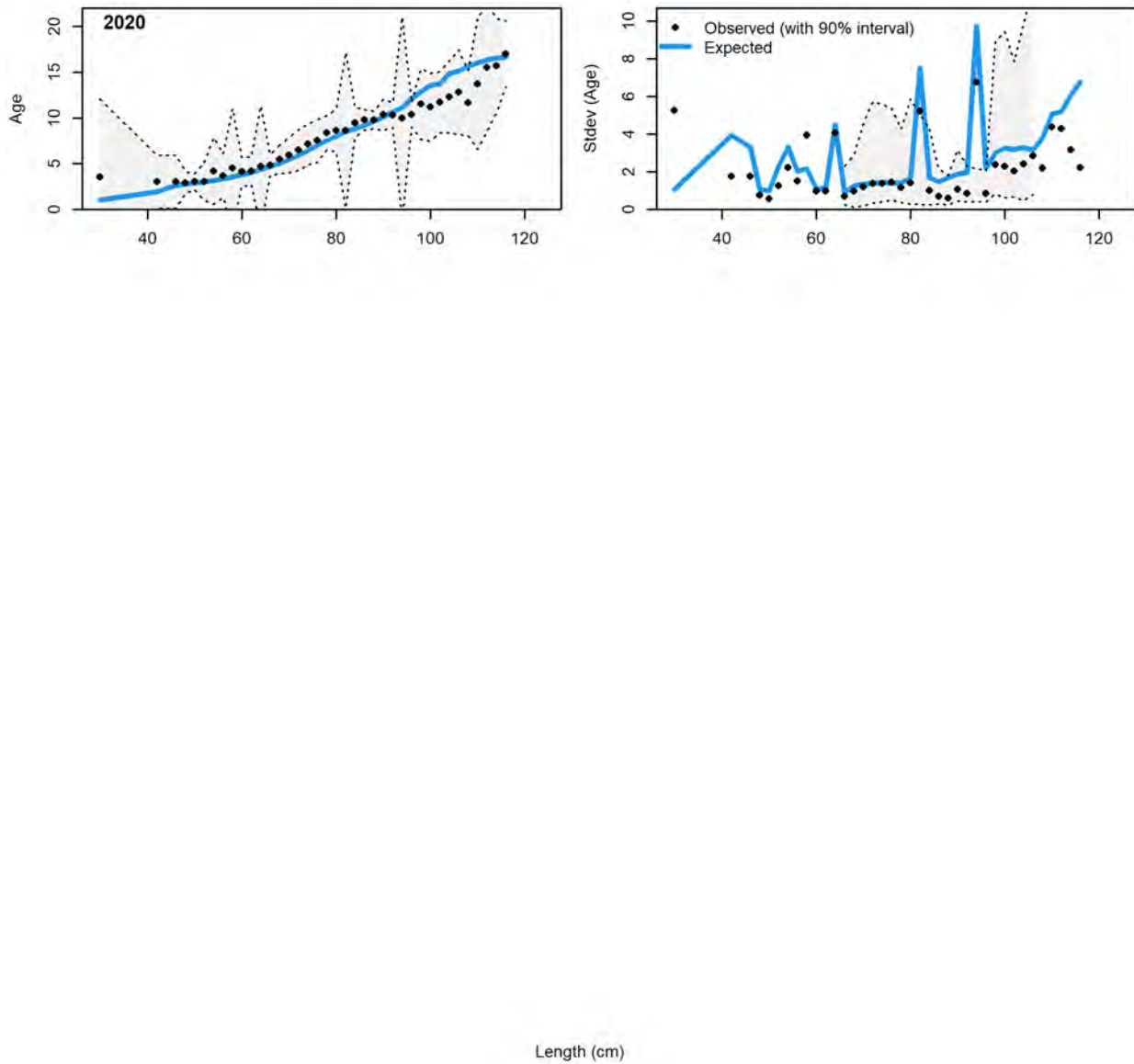
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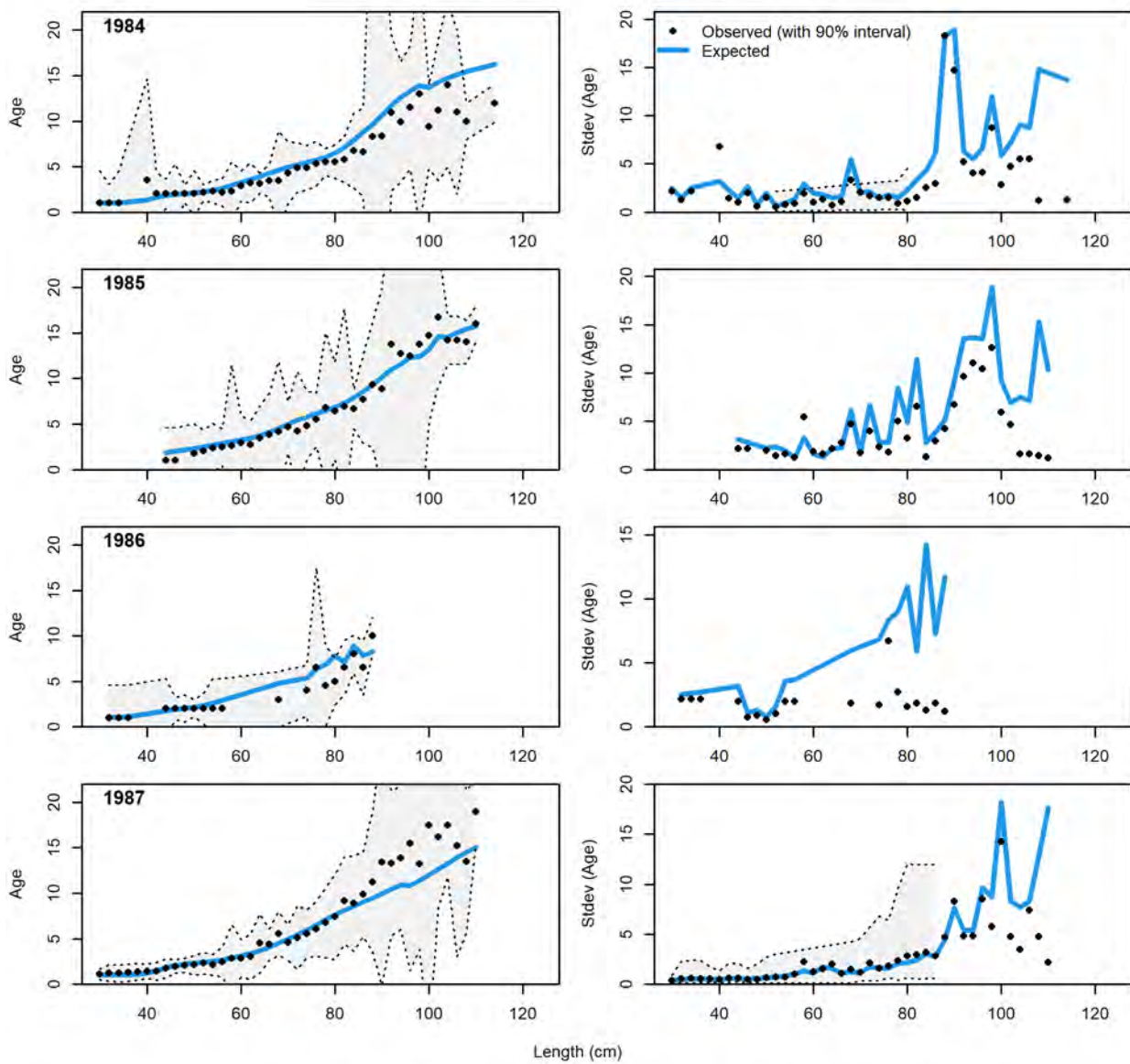
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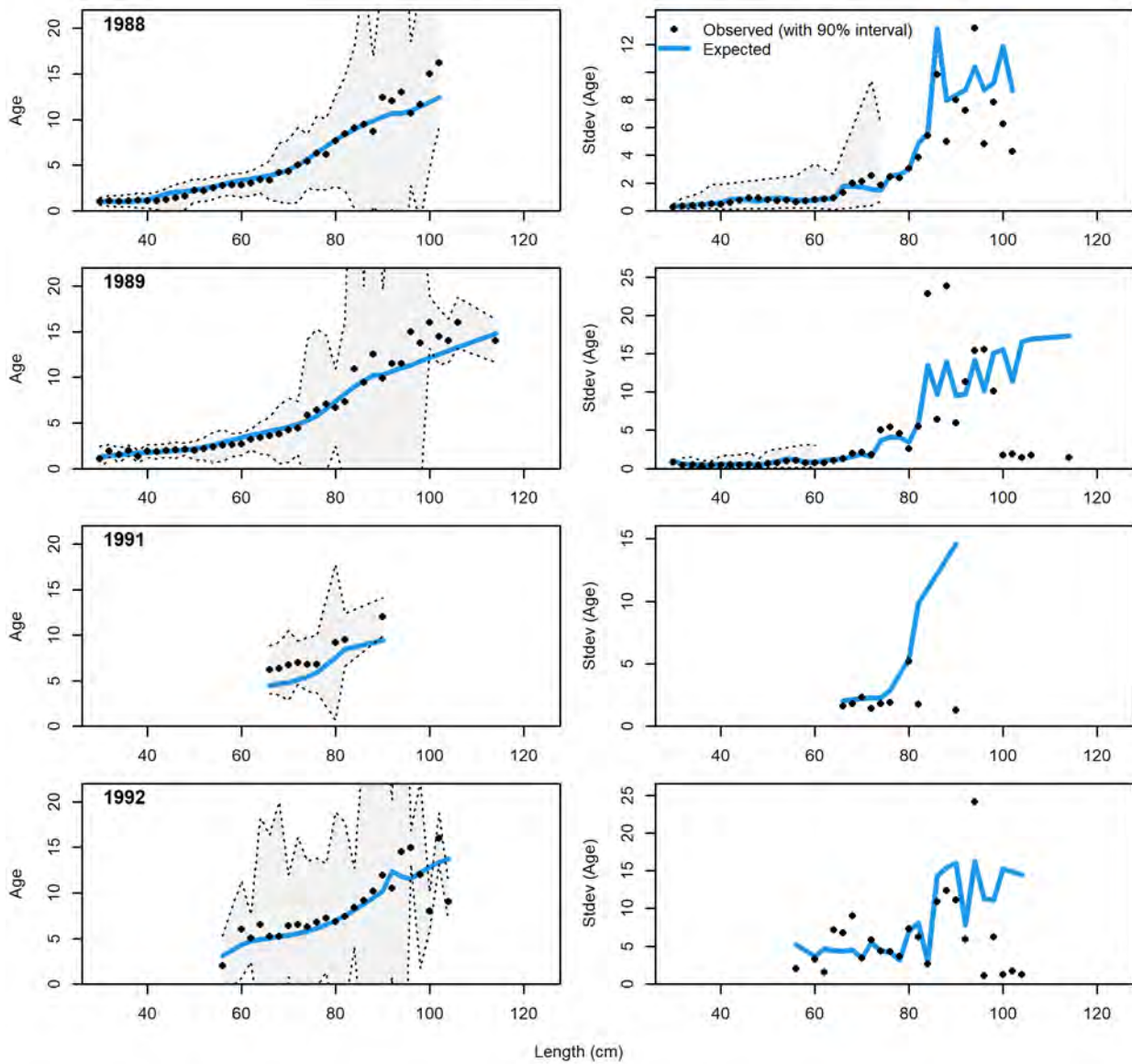
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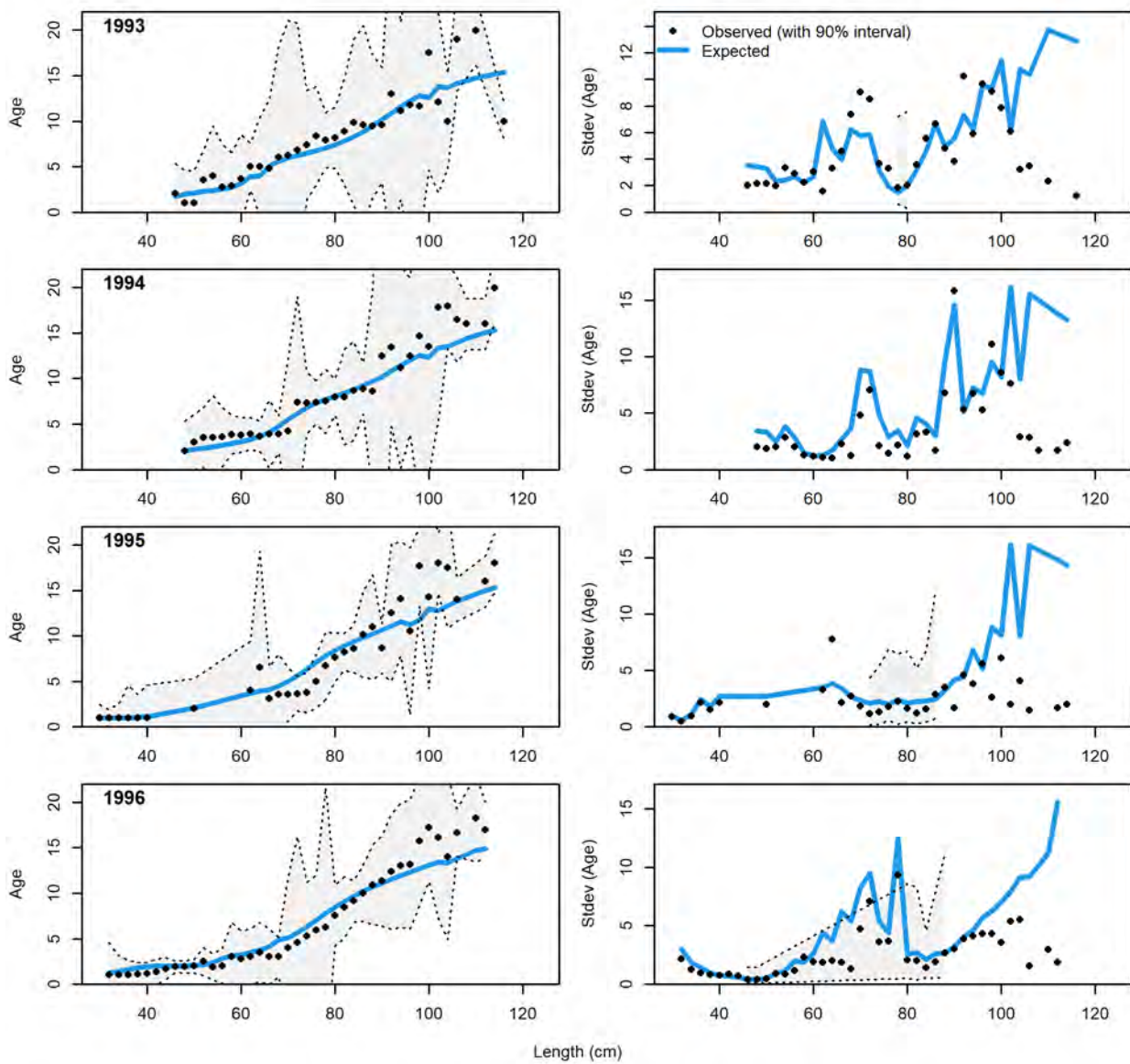
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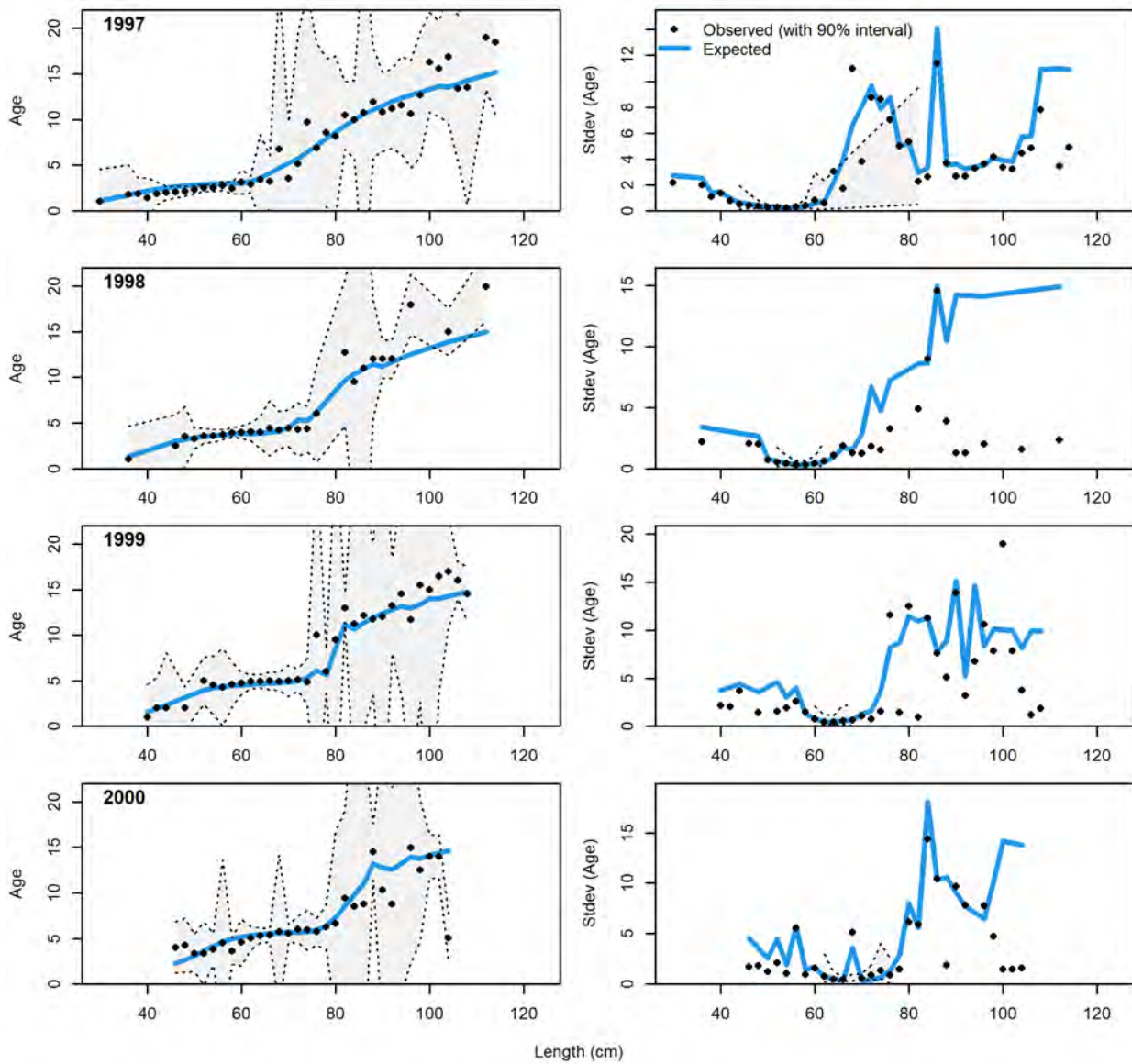
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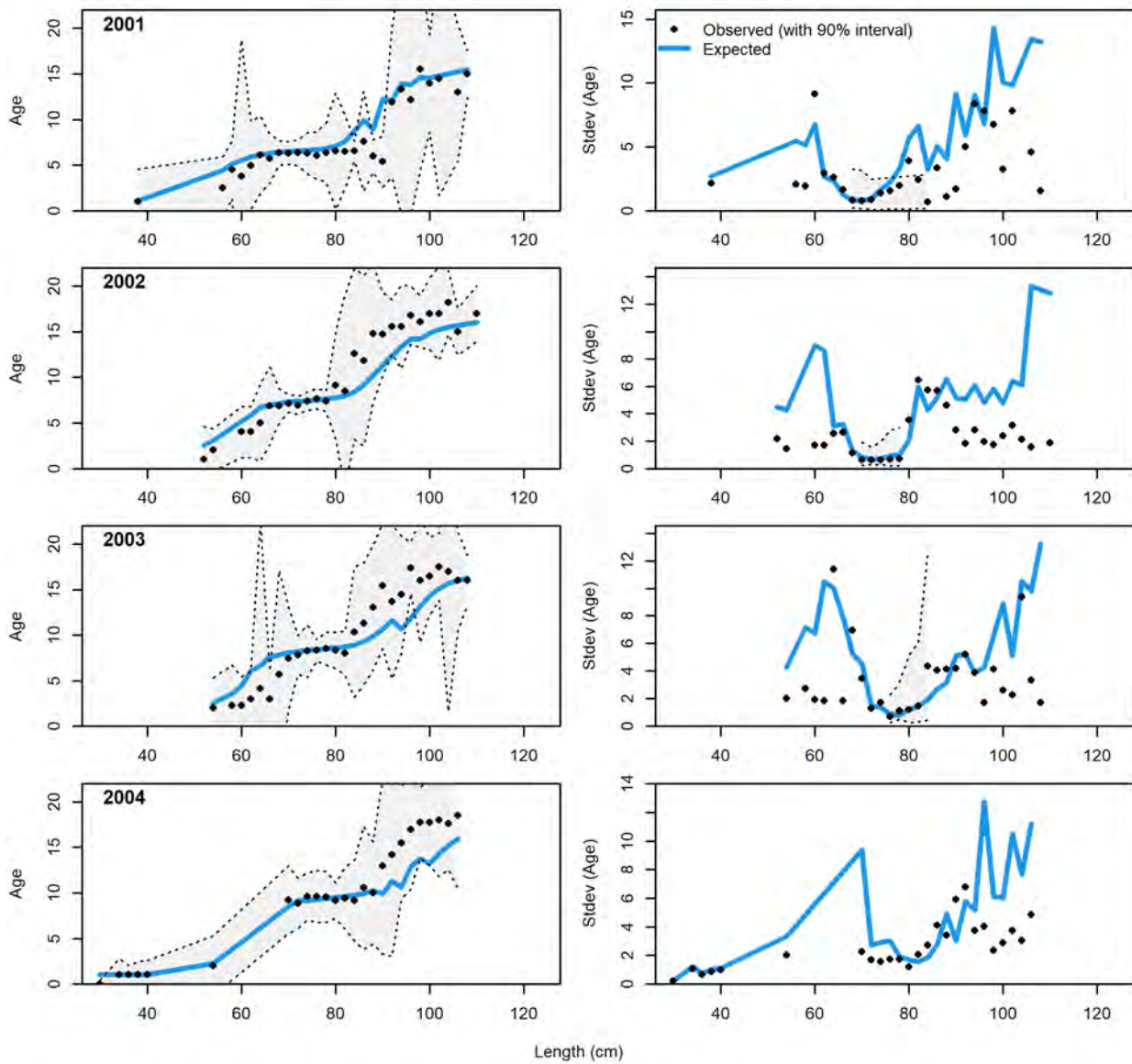
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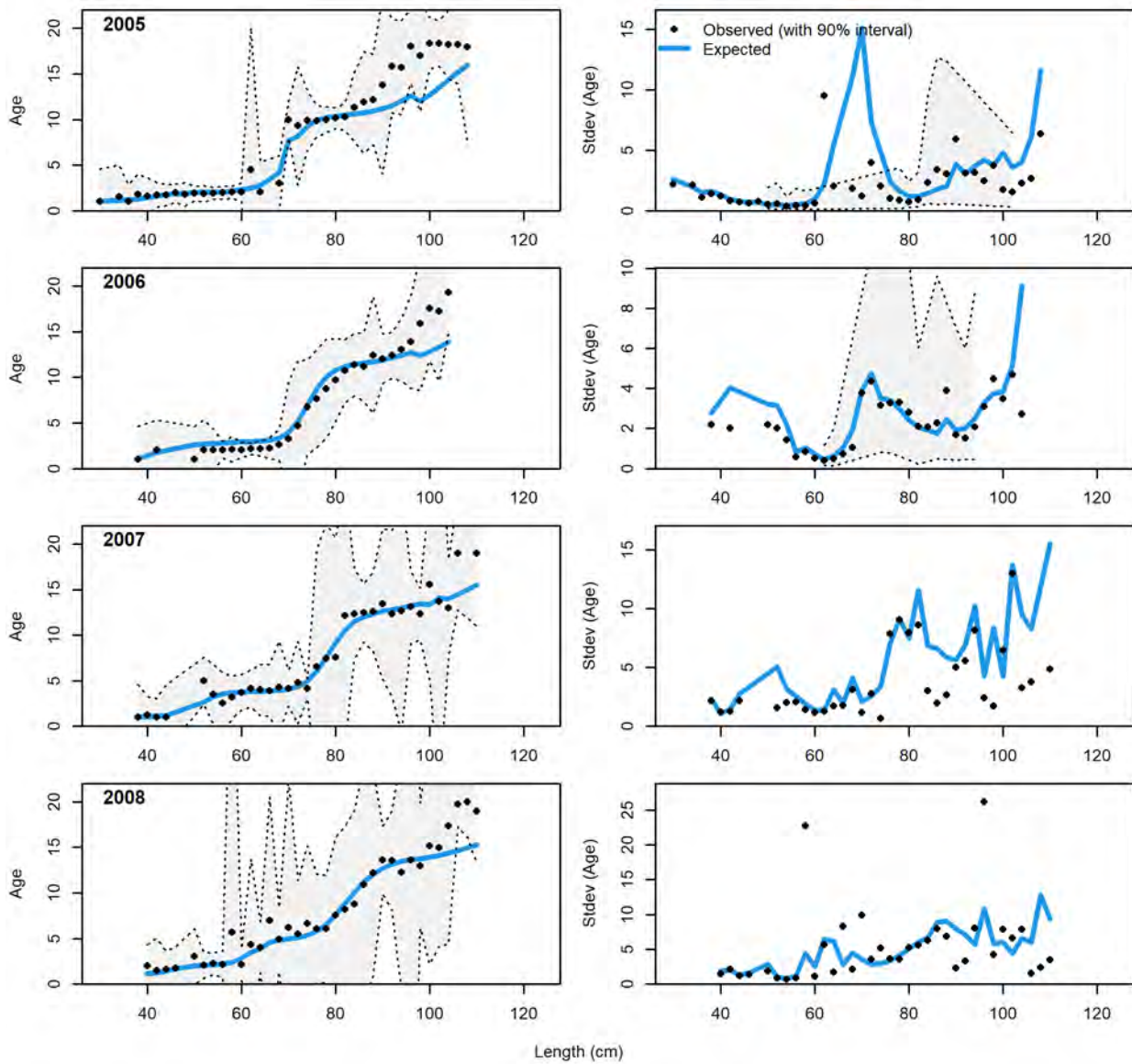
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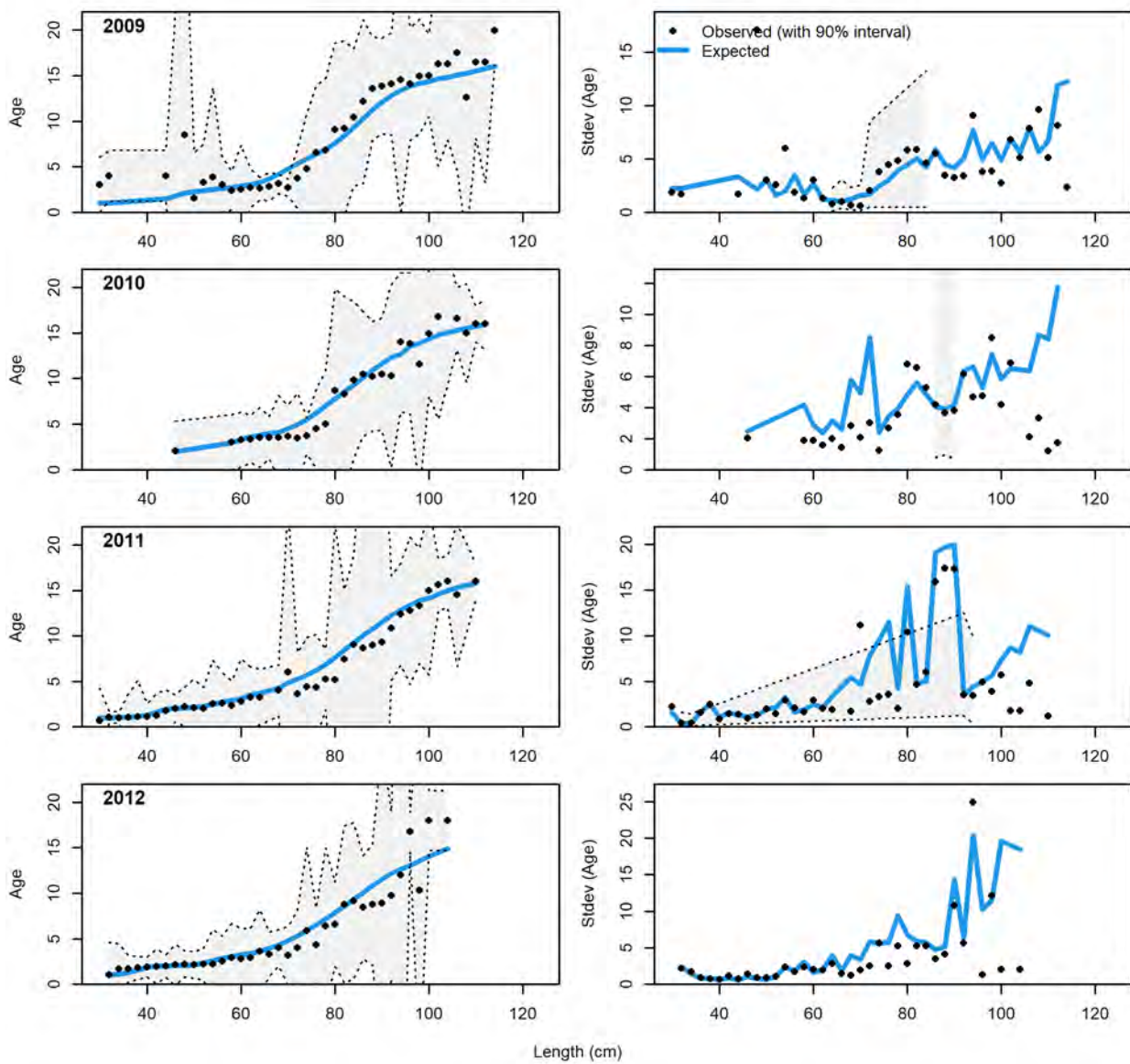
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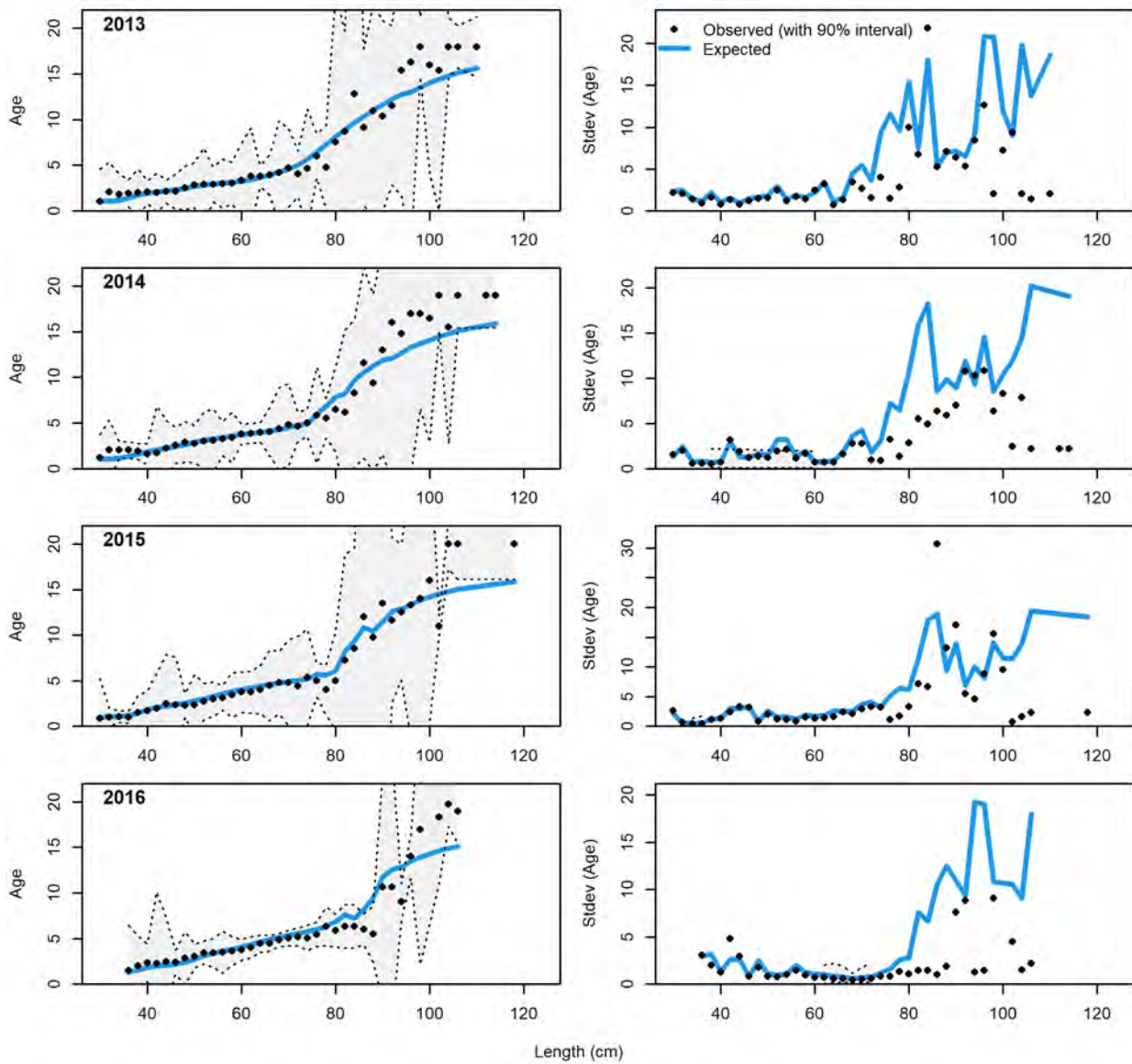
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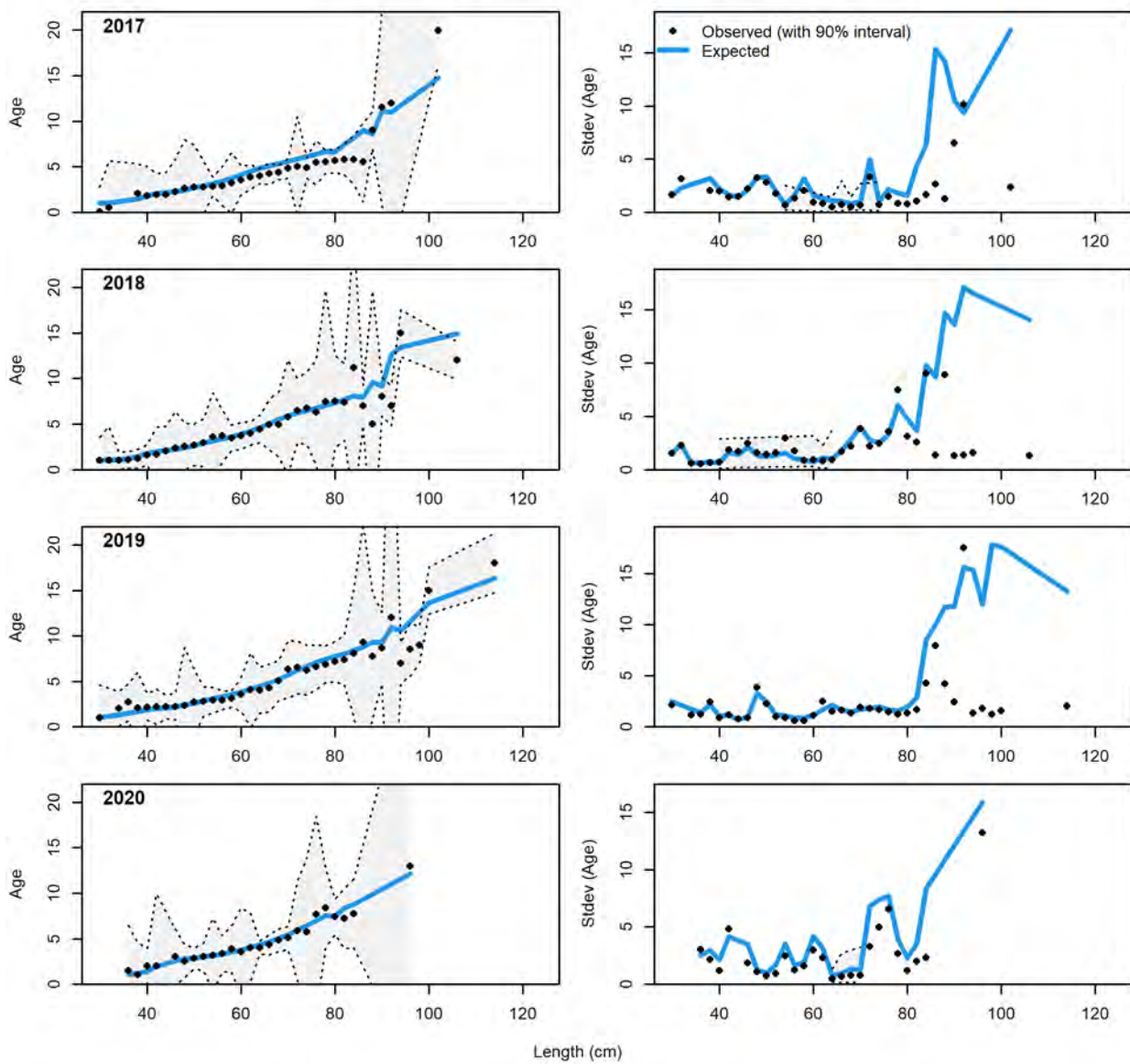
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Conditional AAL plot, retained, NonSpawnFleetonboard



Conditional AAL plot, retained, NonSpawnFleetonboard



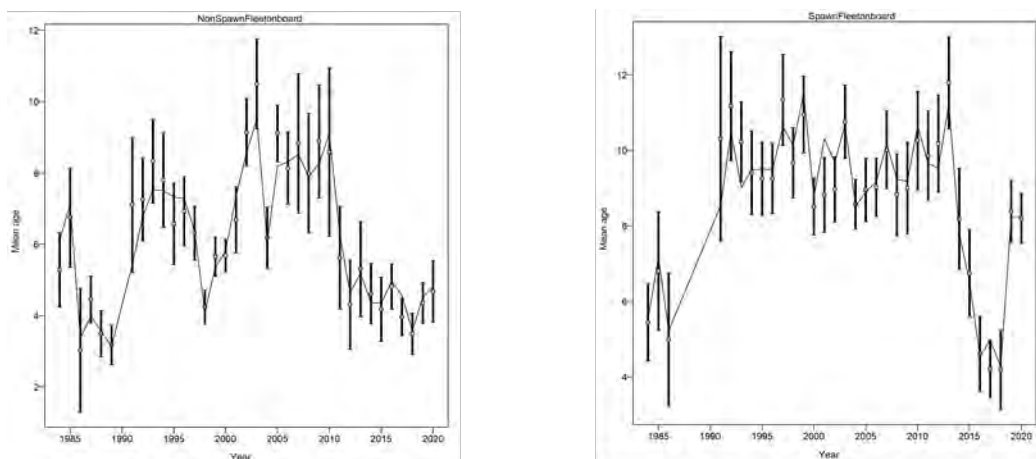


Figure 6.26. Data weighting of conditional age at length data for the onboard non spawning and spawning fleets

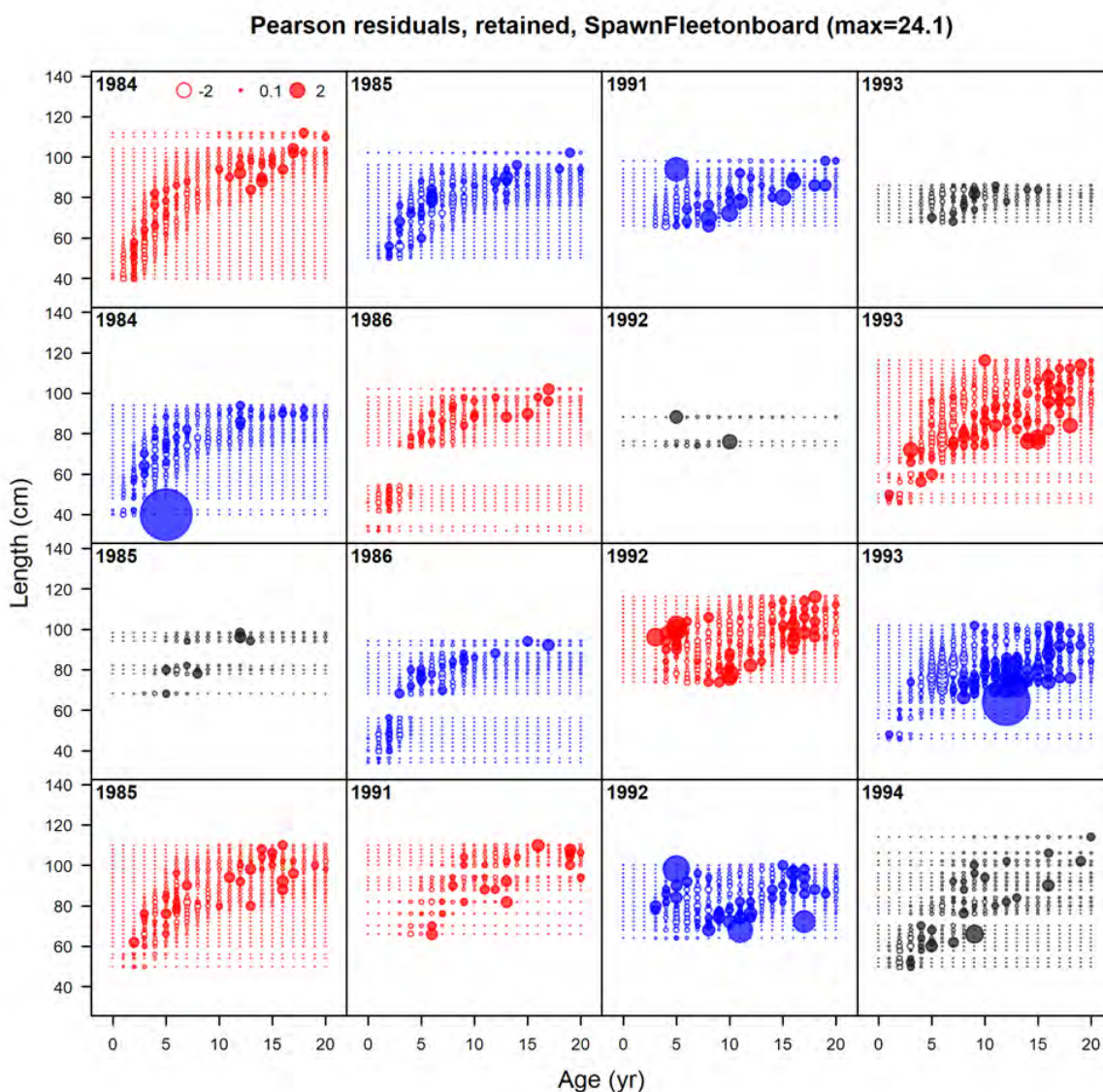
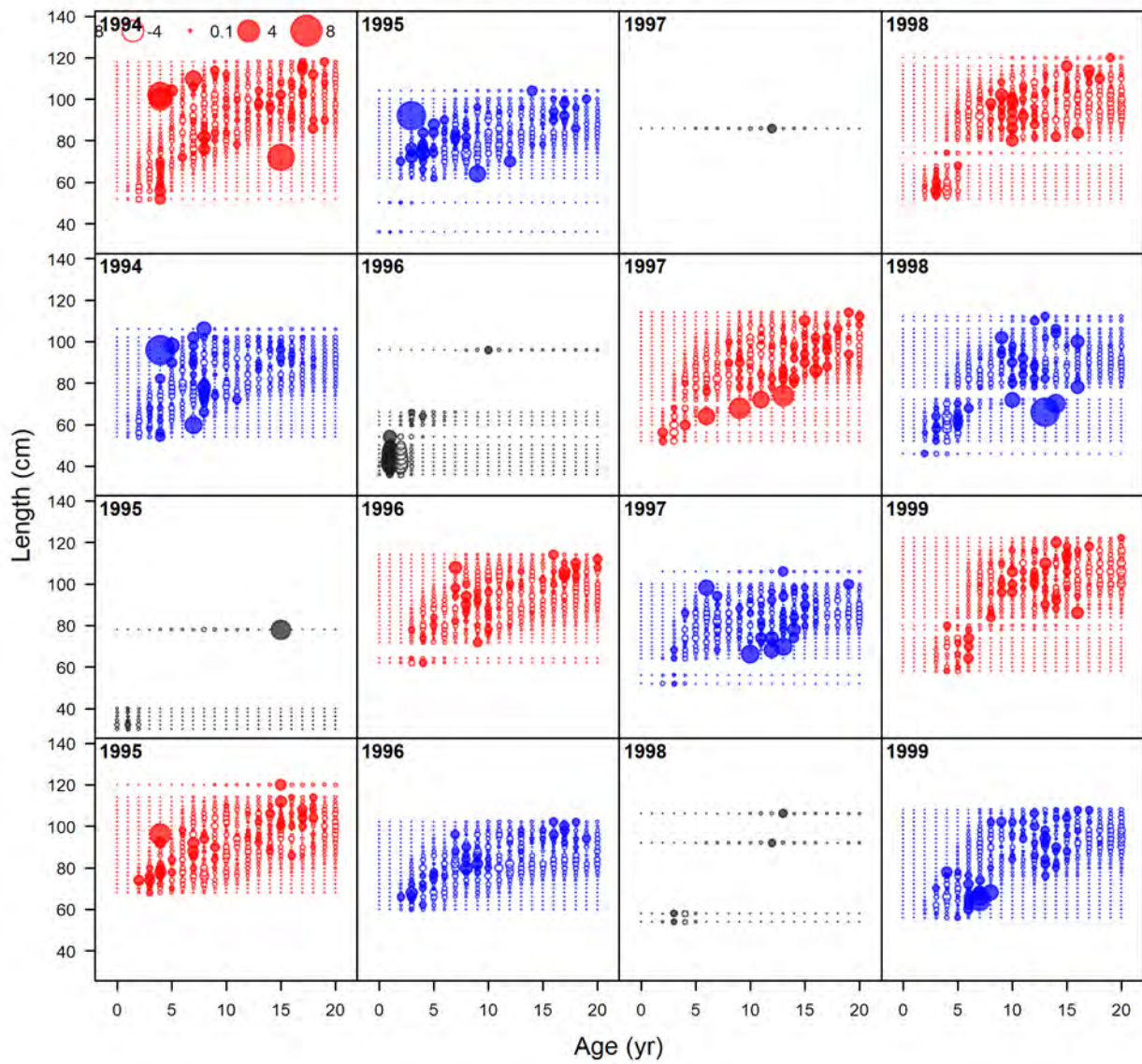
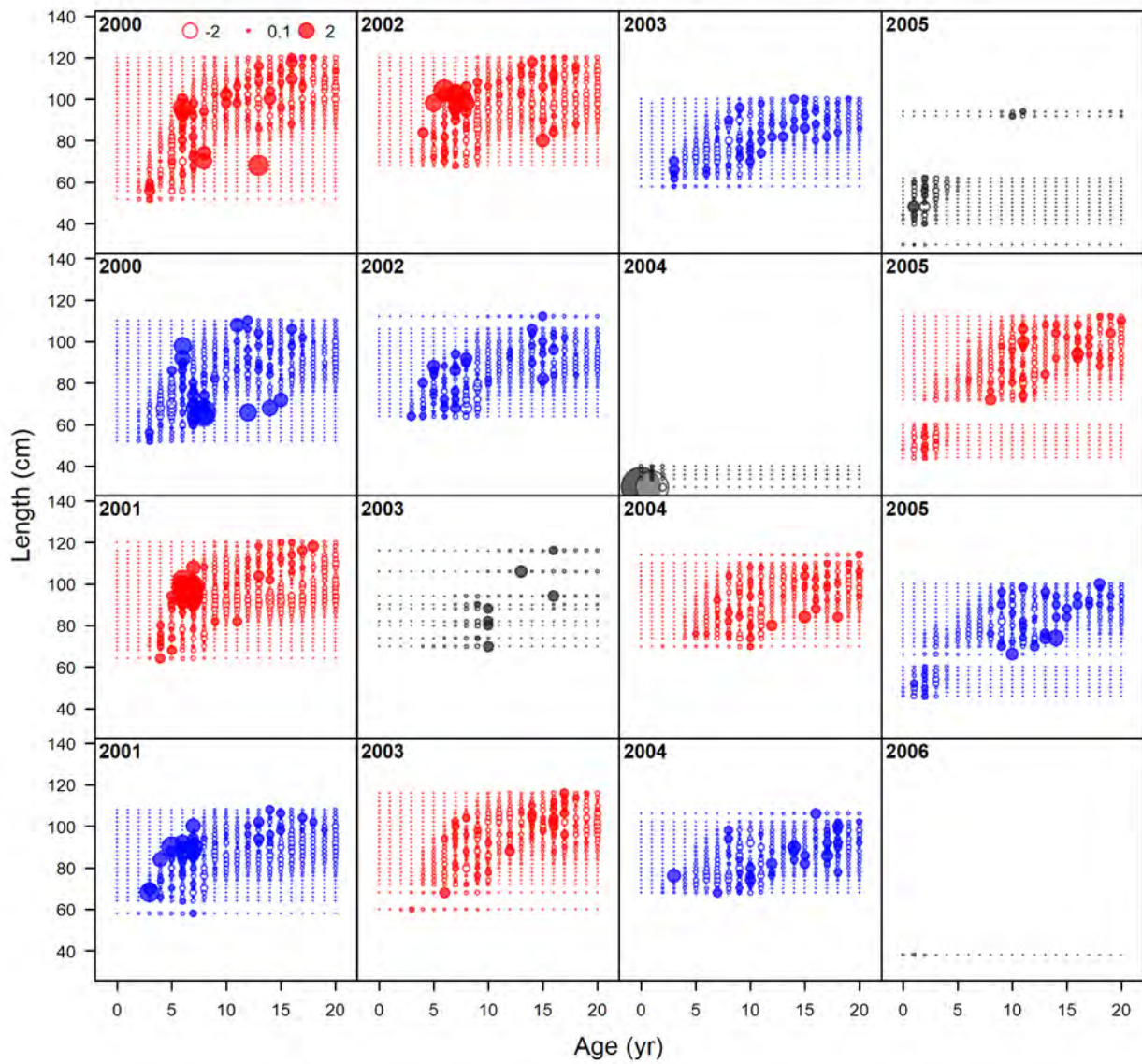


Figure 6.27. Pearson residuals of conditional age at length data.

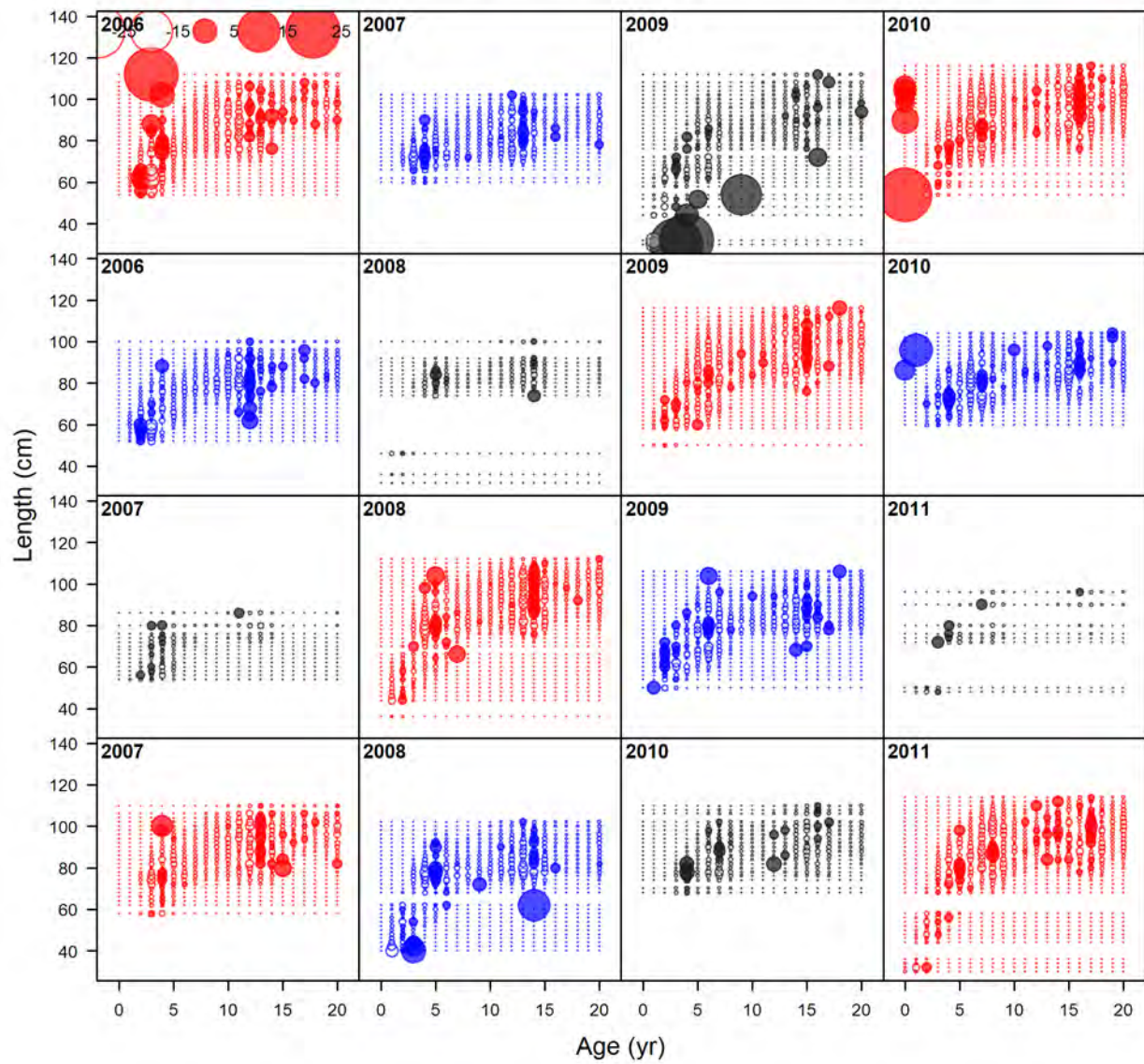
Pearson residuals, retained, SpawnFleetonboard (max=24.1)



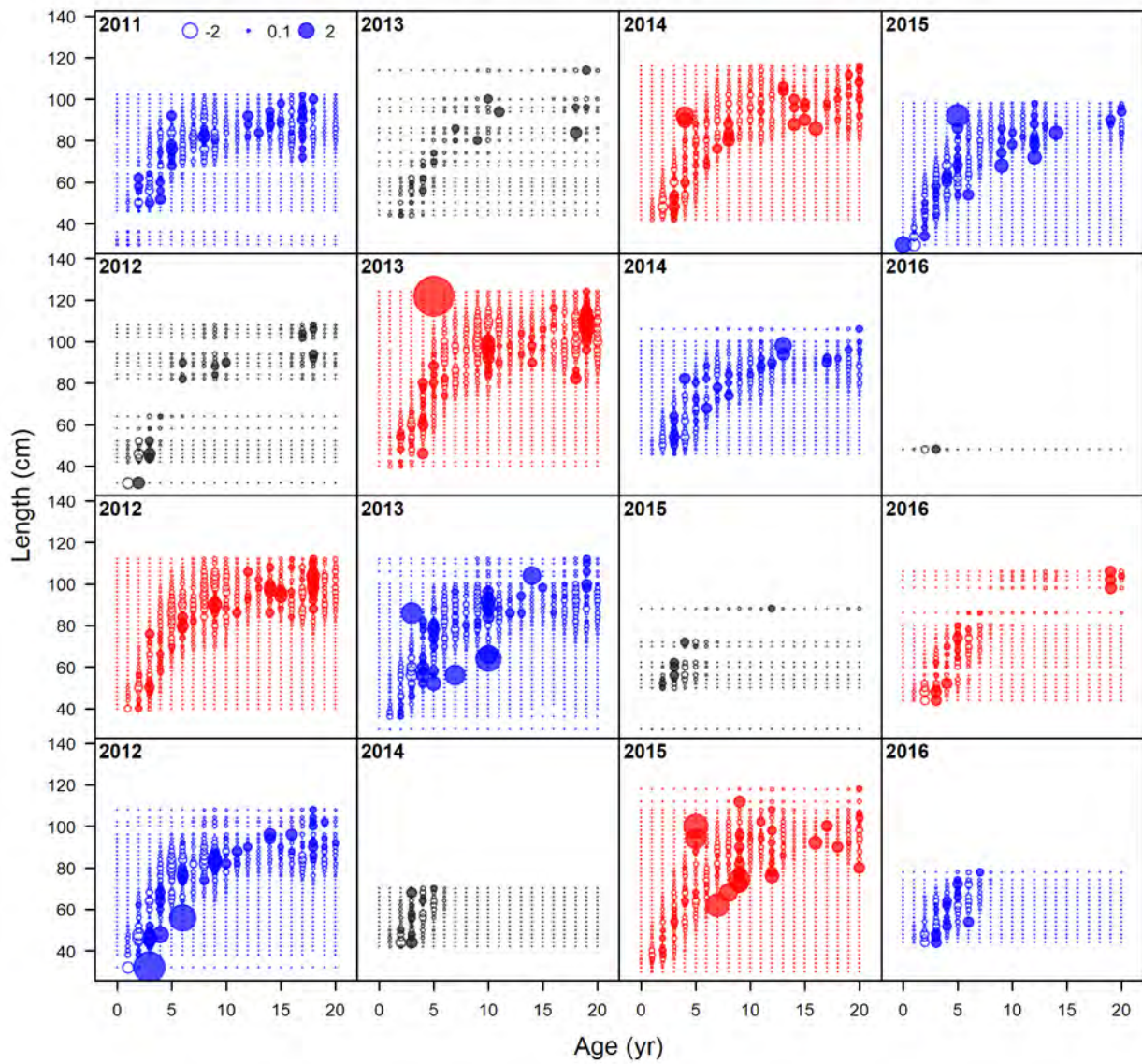
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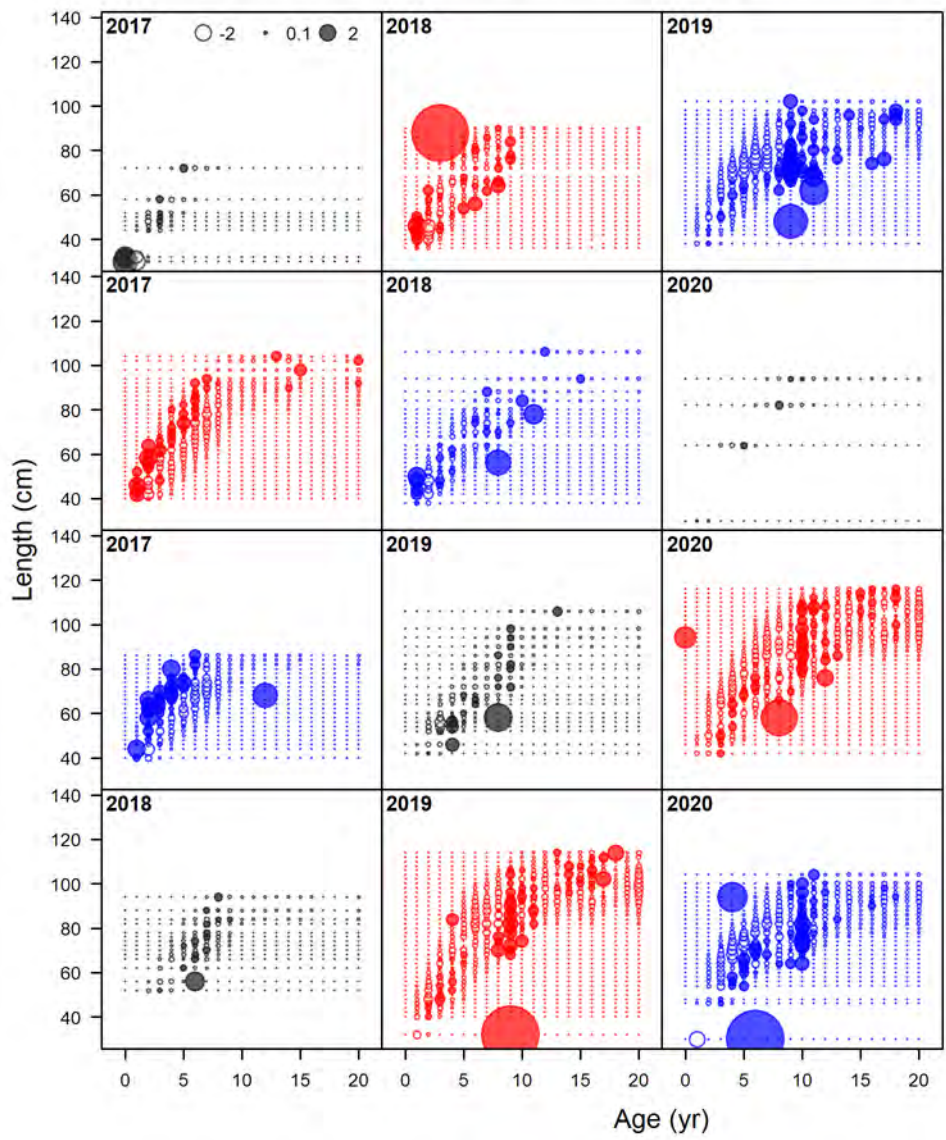
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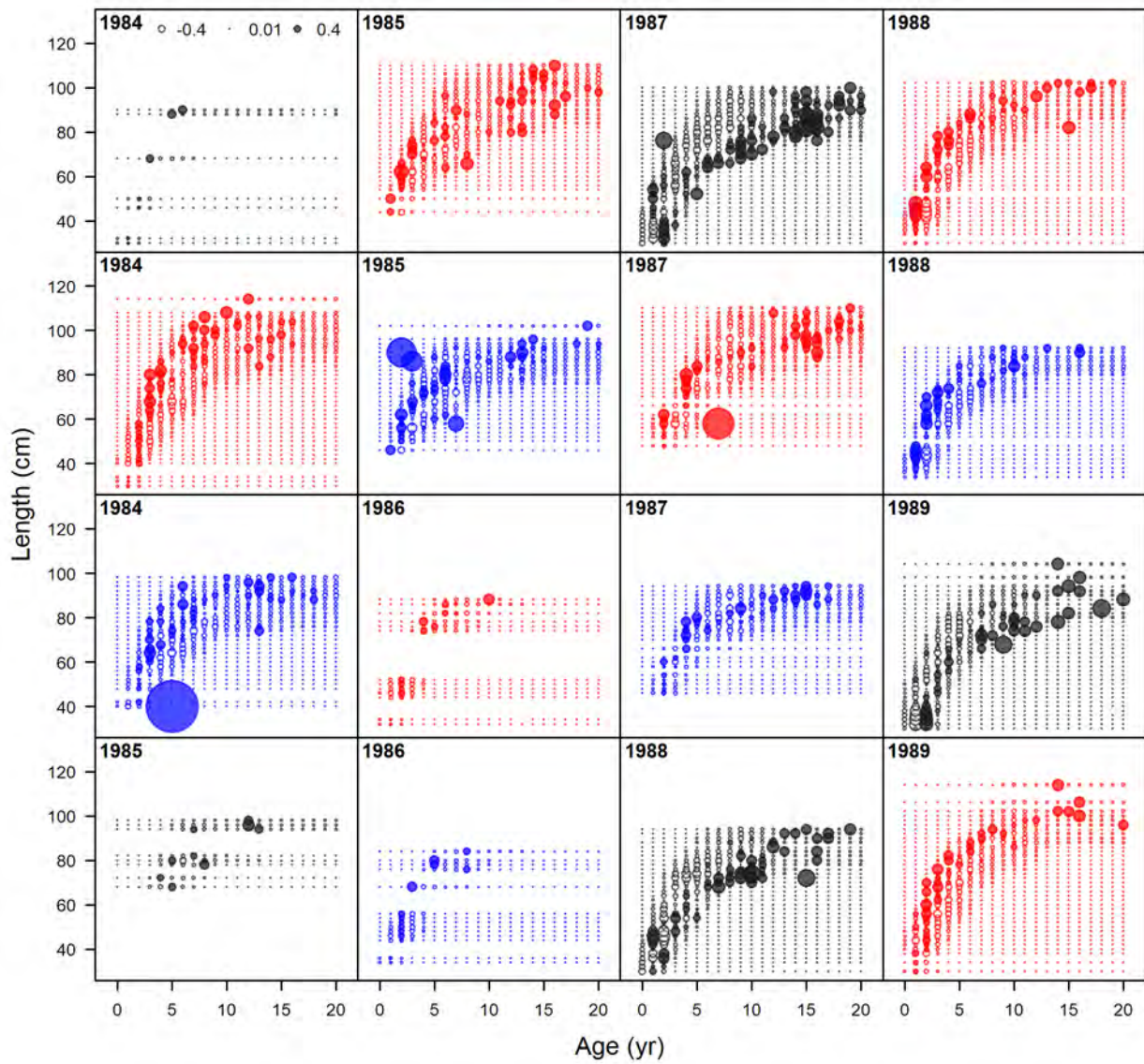
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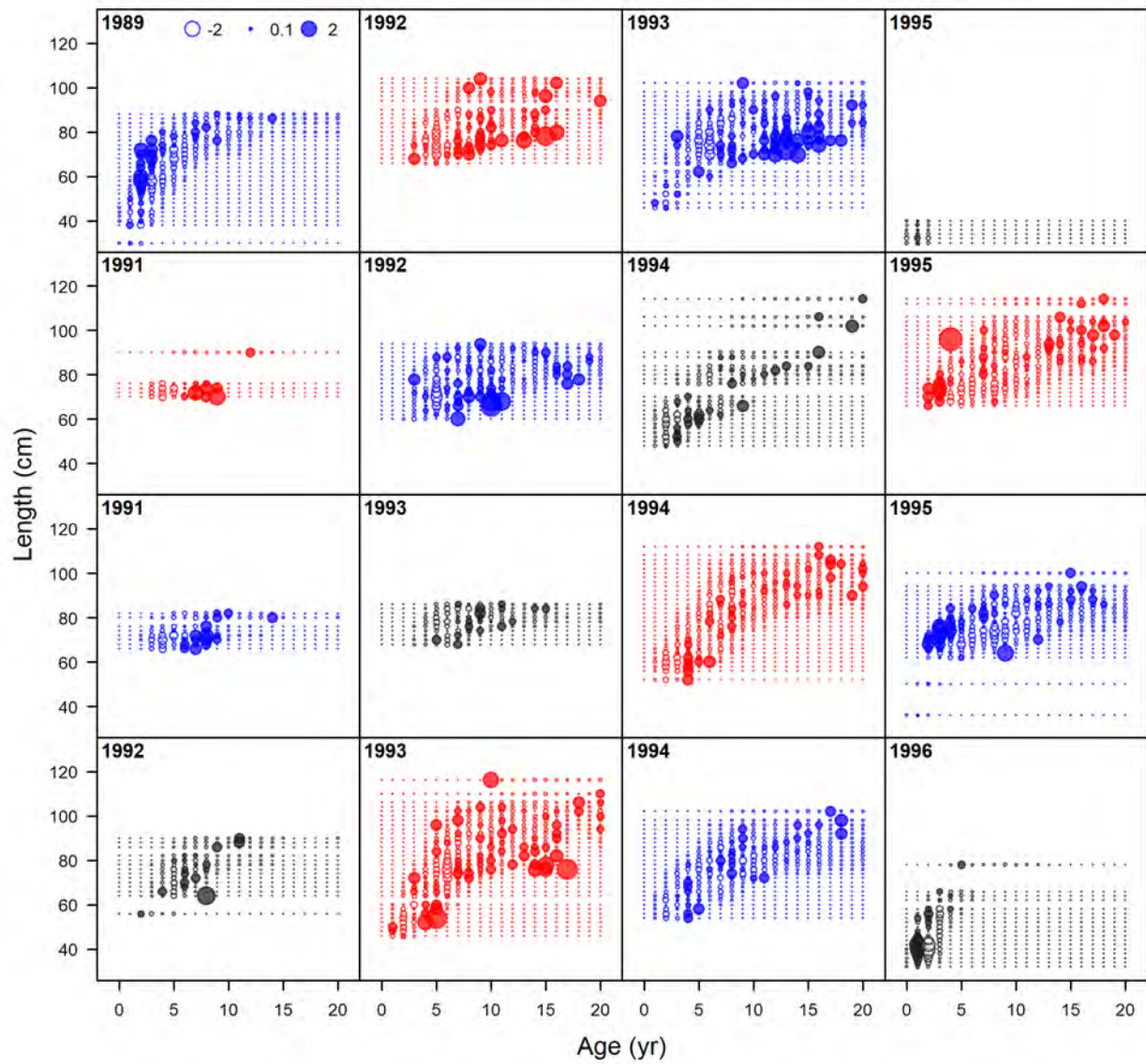
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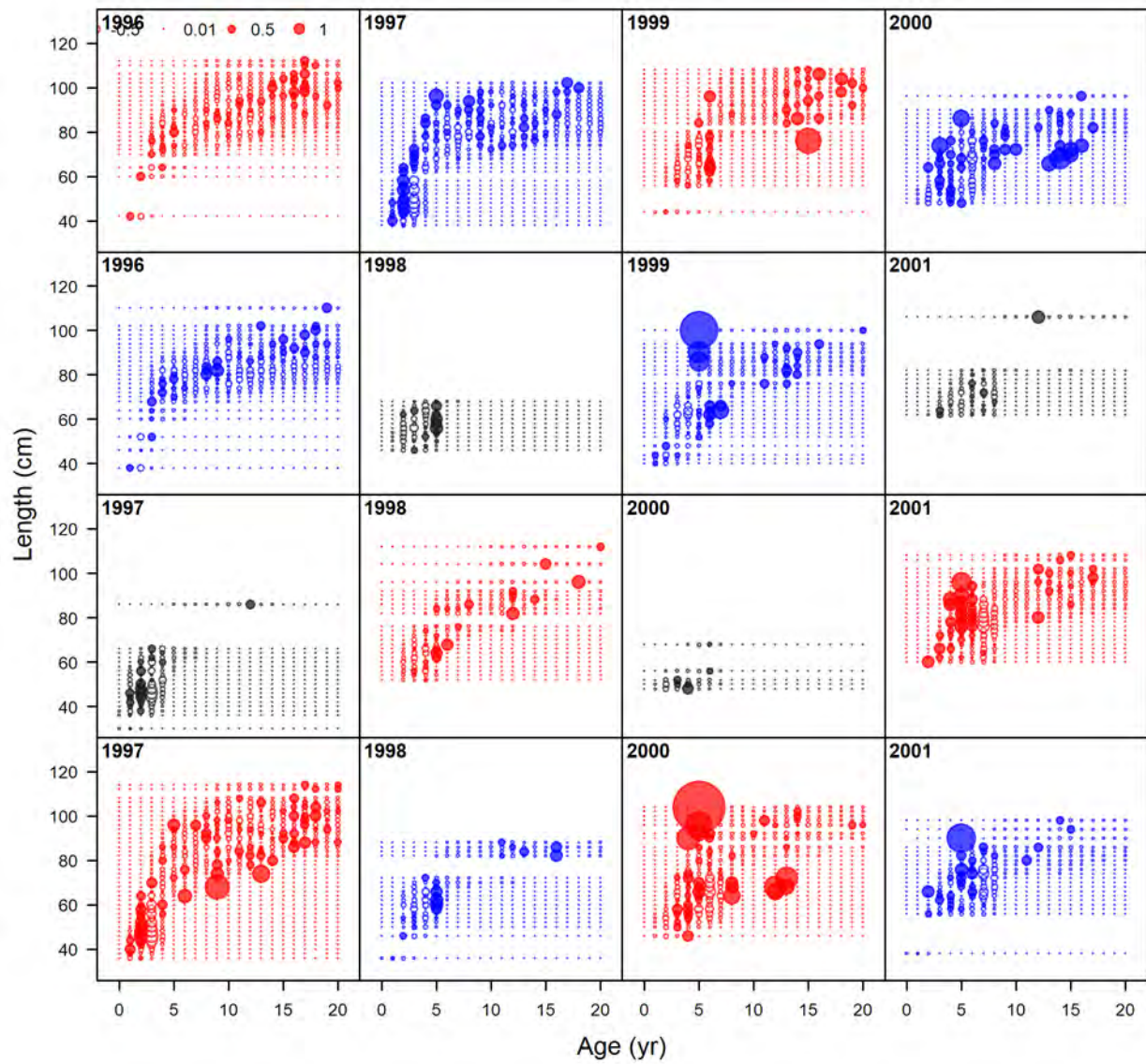
Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)



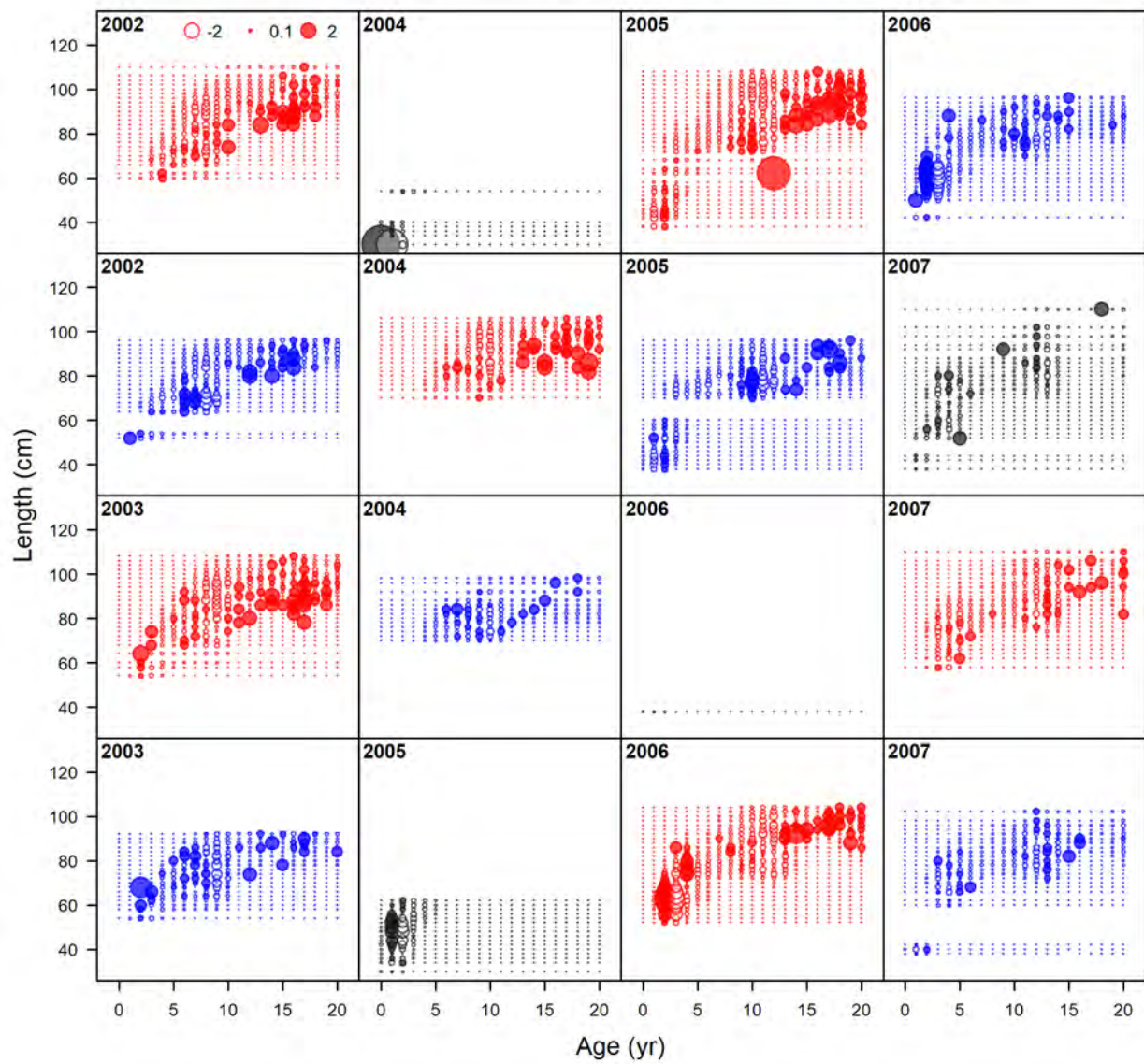
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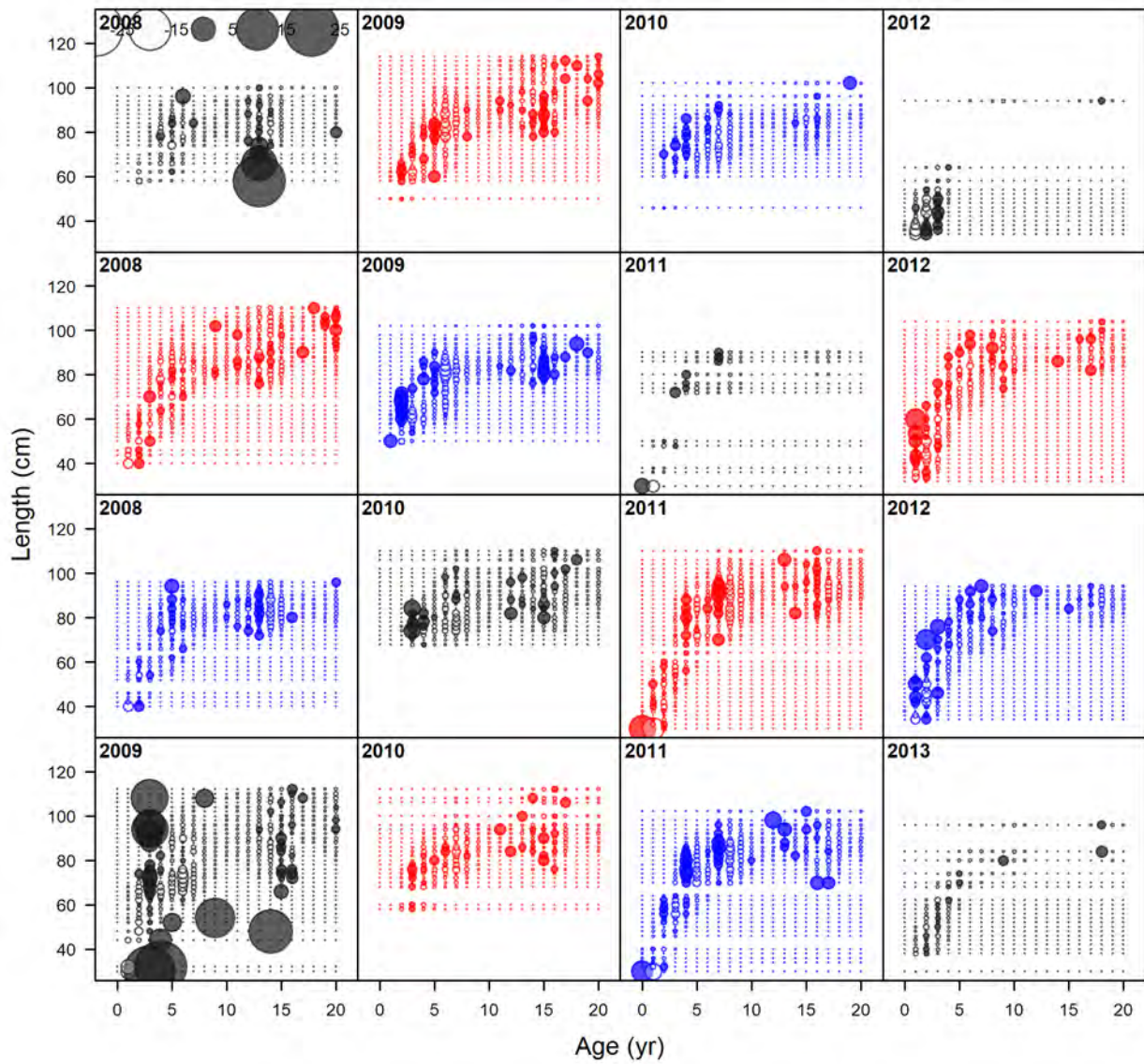
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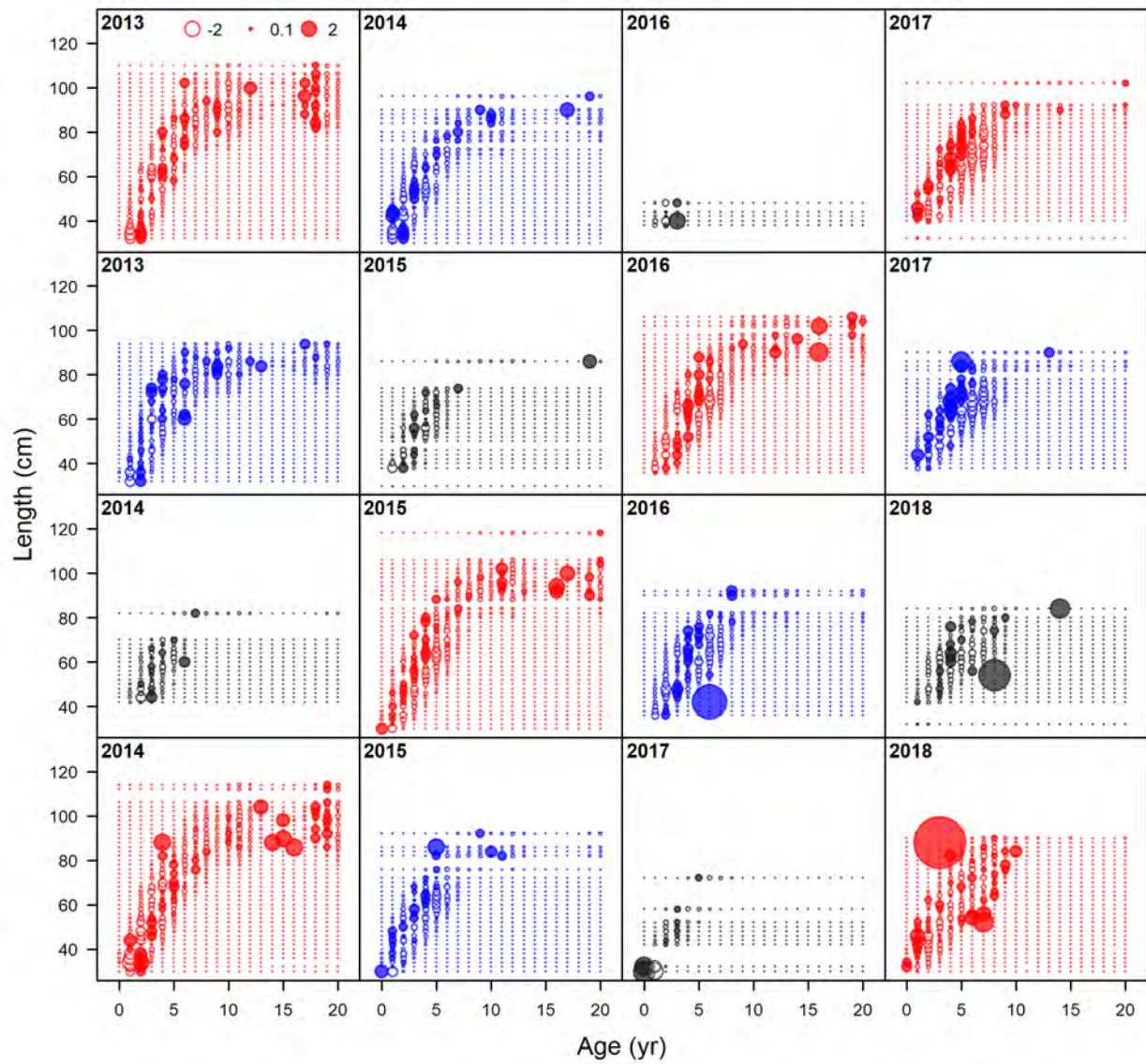
Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)



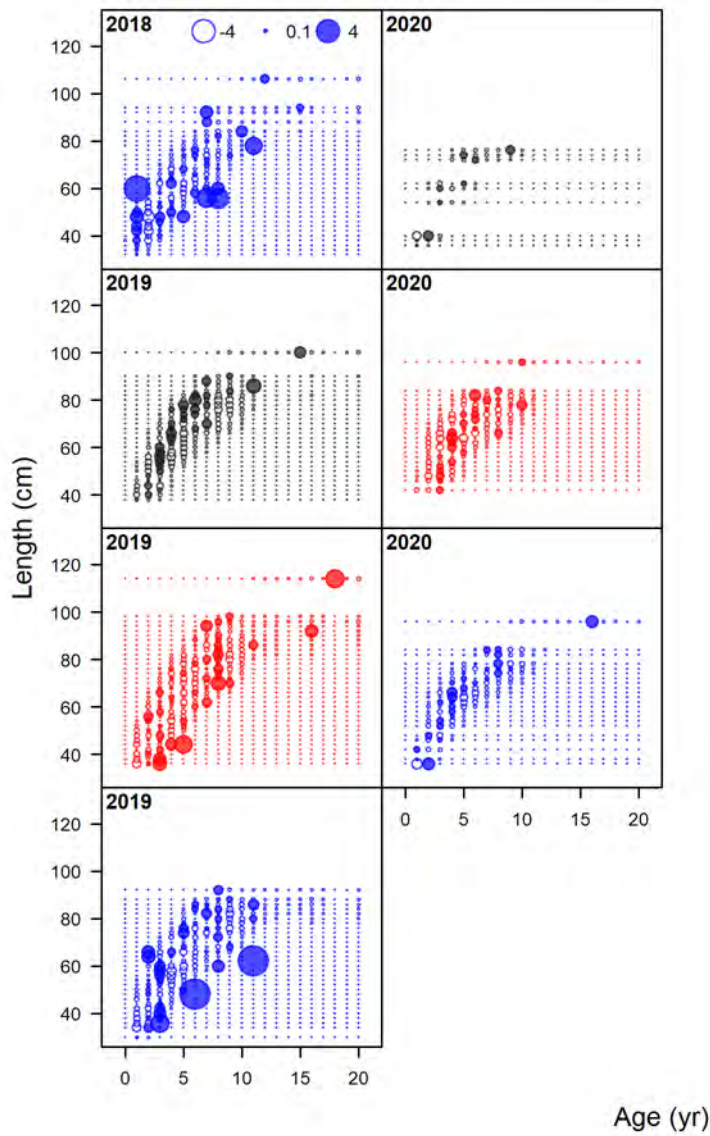
Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)



Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)



Pearson residuals, retained, NonSpawnFleetonboard (max=22.77)



15. Benefits

The results of this project have had a direct bearing on the management of the Southern and Eastern Scalefish and Shark Fishery. Direct benefits to the commercial fishing industry in the SESSF have arisen from improvements to, or the development of, assessments under the various Tier Rules of the Commonwealth Harvest Strategy Policy for selected quota and non-quota species. Information from the stock assessments has fed directly into the TAC setting process for SESSF quota species. As specific and agreed harvest strategies are being developed for SESSF species (a process required by and agreed to under EPBC approval for the fishery), improvements in the assessments developed under this project have had direct and immediate impacts on quota levels or other fishery management measures (in the case of non-quota species).

Participation by the project's staff on the SESSF Resource Assessment Groups has enabled the production of critical assessment reports and clear communication of the reports' results to a wide audience (including managers, industry). Project staff's scientific advice on quantitative and qualitative matters is also clearly valued.

The stock assessments presented in this report have provided managers and industry greater confidence when making key commercial and sustainability decisions for species in the SESSF. These assessments have provided the most up-to-date information, in terms of data and methods, to facilitate the management of the Southern and Eastern Scalefish and Shark Fishery.

16. Conclusion

The 2021 assessment of the stock status of key Southern and Eastern Scalefish and Shark fishery species is based on the methods presented in this report. Documented are the latest quantitative assessments (Tier 1) for key quota species (Blue Grenadier, Silver Warehou, Eastern Jackass Morwong and Eastern Zone Orange Roughy), projection updates for School Whiting and Tiger Flathead, as well as CPUE standardisations for shelf, slope, deepwater and shark species, Tier 4 and Tier 5 analyses. Typical assessment outputs provided indications of current stock status and an application of the Commonwealth Harvest Strategy framework. This framework is based on a set of assessment methods and associated harvest control rules, with the decision to apply a particular combination dependent on the type and quality of information available to determine stock status (Tiers 1 to 5).

The assessment outputs from this project are a critical component of the management and TAC setting process for these fisheries. The results from these studies are being used by SESSFRAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

Stock status and Recommended Biological Catch (RBC) conclusions (Tier 1):

For Blue Grenadier, 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). 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.

For Eastern Jackass Morwong, the base-case assessment estimates that the projected 2022 spawning stock biomass will be 15% of SSB_0 , with recruitment from 2016 onwards projected using a low recruitment scenario, using the average of the ten most recently estimated recruitment deviations, from 2006-2015. Under the agreed 20:35:48 harvest control rule, the 2022 RBC is 0 t, with the long-term yield (assuming low recruitment in the future) of 91 t.

For Eastern Orange Roughy, the median estimate of SSB_0 from the MCMC analysis was 38,924 t, slightly lower than the MPD estimate of 40,479 t. The current 2022 female spawning biomass is estimated to be 11,644 t from the MCMC and 13,126 t from the MPD. Relative spawning biomass in 2022 is estimated at 30.0% of unfished levels from the MCMC and 32.4% of unfished levels from the MPD. The RBC for 2022 from the MCMC analysis is 681 t, lower than the MPD estimate for 2022 of 944 t. The average RBC over the next three years (2022-2024) is 737 t from the MCMC analysis and 1,025 t from the MPD.

For Silver Warehou, the assessment estimates that the projected 2022 stock status will be 29% of SSB_0 , projected assuming 2020 catches in 2021, with recruitment from 2016 onwards assumed to be below average, fixed at the average of 2011-2015 levels. The assessment suggests that stock status was as low as 21% of SSB_0 in 2016. Under the 20:35:48 harvest control rule, the 2022 RBC is 587 t, while the long-term yield (assuming continuation of low recruitment) is 591 t.

For School Whiting, if the default (proxy) target reference point (48%) used in the SESSF harvest control rule, and specifically as used by AFMA for School Whiting, is reduced to 40%, a modified 20:35:40 harvest control rule can be applied. This lower target allows the stock to be fished to a lower target biomass (40% of SSB_0). Under a revised 40% target, the 2021 RBC would be 2,753 t.

For Tiger Flathead, updates to catch and CPUE resulted in a revision downwards to the 2020 stock status, from 34% in the last stock assessment to 32% in this analysis. These changes are due to revisions to the catches (2017-2021) and to the revised CPUE series, which has a downturn at the end of the time series (2019-2020) for the Danish seine CPUE. The eastern trawl and Tasmanian trawl CPUE series do not show the same downturn at the end of the CPUE series as Danish seine, with both trawl CPUE relatively flat in the period 2019-2020. Projecting forward to 2022 takes the stock status to 35% at the start of 2022, and this is expected to recover to 37% at the start of 2025, assuming that the RBC is caught in 2023 and 2024 and there is average recruitment from 2017 onwards

17. Appendix: Intellectual Property

No intellectual property has arisen from the project that is likely to lead to significant commercial benefits, patents or licenses.

18. Appendix: Project Staff

Franzis Althaus	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Pia Bessell-Browne	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Paul Burch	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Jemery Day	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Roy Deng	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Mike Fuller	CSIRO Oceans and Atmosphere, Hobart, Tasmania
André Punt	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Miriana Sporcic	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Robin Thomson	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Geoff Tuck	CSIRO Oceans and Atmosphere, Hobart, Tasmania