Gummy Shark stock assessment update using data to 2022

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1 Executive summary

This report presents a Gummy Shark stock assessment model update for 2023, using the base case model chosen by sharkRAG at its 10–11 October 2023 meeting. The bridging analysis, which begins with the 2020 base case model (data to 2019) and ends with the new 2023 base case model, cumulatively altering the model one step at a time, is shown here.

The 2023 Gummy Shark stock assessment (data to the end of 2022) differs from the 2020 base case model (data to 2019) in the following ways:

- updated input data (e.g. catch, CPUE, length, age-at-length) from 2020 up to and including 2022 which greatly increased the number of annual length frequencies for shallow line,
- corrections made to data processing that impact data to 2019, including several corrections for conditional age-at-length data, which had only minor impact on model results,
- extended the plus group age in the model from 10 to 20 which improved model fits to the conditional age-at-length data,
- breaking the South Australian gillnet CPUE time series at 1995 into two sections for 1984–1995 and 1996–2009 to reflect improvements in fishing efficiency posibly due the introduction of colour sounders, or a switch in targetting away from school shark towards Gummy Shark - this improved model fit.

The model is highly sensitive to the assumption made regarding the form of density dependence in population growth, as has been noted in previous assessment updates.

After the removal of onboard observers from gillnet and line vessels in mid-2015, port-based industry led sampling has been undertaken by the Shark Industry Data Collection (SIDaC) program. These data have been incorporated into the assessment for the first time, as part of the onboard length time series. SIDaC also provides more frequent sampling from the important shallow line sector than was previously available.

The updated model provides results that are consistent with those of the 2016 and 2020 stock assessments - with pup depletion estimated to be at or above the target reference point (TRP) for all three stocks - Bass Strait, South Australia, and Tasmania. SharkRAG uses pup production as a proxy for spawning biomass; this is the number of pups, on average, expected to be produced each year by the stock's mature females, noting that larger females produce more pups on average compared to smaller females. Pup depletion is the pup production in any year compared to the estimated unfished pup production and is the value used in the harvest control rule. Estimated pup production shows an increasing trend in recent years in South Australia and is stable in Bass Strait and Tasmania. Pup depletion is well above the 48% target reference point in South Australia and Tasmania according to the base case model (63% and 69% respectively). For Bass Strait, the base case model estimates depletion to be just above the target (50%). Pup depletion is above the 20% limit reference point for all stocks and all sensitivity models.

RBC calculations and forward projections are presented in this report. Relative to the RBCs for the three stocks, the 2022 total removals for all stocks are similar to (for Bass Strait) or below (for South Australia and Tasmania) indicating that current fishing levels are sustainable. RBCs would be higher if all catches were taken using gillnet gear instead of shallow line gear.

The extension of the plus group age from 10 to 20 years did improve fits to the conditional age-at-length data, but fits are still poor, especially for female sharks due to underestimation of age at larger lengths. This suggests that the growth curve, which was calculated outside of the model and is pre-specified in the assessment, should be estimated within the model in future. Differences in growth rates among stocks and through time should also be investigated.

Retrospective analysis shows that the estimated value for adult natural mortality (M) tends to increase as more years of data are added, it is possible that this is a response to model mis-specification regarding growth. If estimation of growth within the model does not arrest the retrospective pattern in M then other possible model mis-specifications will need to be investigated.

A note regarding RBC to TAC calculations - estimated discards are added to the landed catches (which also include State catches) so that both discards and State catches will need to be deducted from the RBC when it is converted to a TAC.

2 Introduction

Gummy Shark in the Southern and Eastern Scalefish and Shark Fishery (SESSF) was last assessed in 2020 (Thomson 2020). In October 2023, Hill and Thomson (2023), presented a proposed base case model to the Shark Resource Assessment Group's (SharkRAG) 10-11 October 2023 meeting that used data up to and including 2022. Hill and Thomson (2023) bridged from the 2020 base case model to the proposed base case model by adding recalculated and new data one source at a time, followed by alternative treatments of the South Australian gillnet CPUE, and an alteration to the model in which the plus group age was raised from 10 to 20 years (except for fits to gillnet-derived age composition data, which remains at 10 years because that gear does not select older ages). SharkRAG accepted the proposed base case model, which is referred to in this report as the 2023 base case model.

This report builds on Hill and Thomson (2023), it includes their results and much of their text, as well as presenting:

- additional diagnostic plots for the 2023 base case model,
- results of sensitivity tests (in addition to those relating to density dependence that were presented in the October report),
- Recommended Biological Catches (RBCs) calculated using the Tier 1 Harvest Control Rule, and
- forward projections using a range of assumptions regarding future total removals, and splits of those removals among gears and stocks (regions).

Hill and Thomson (2023) raised concerns regarding poor fits to length-at-age data for female Gummy Shark and recommended that future gummy assessment updates should estimate growth curves internally. This work is beyond the scope of the 2023 update because it will involve either re-coding of the existing model (which is not currently capable of estimating growth), or moving the model to a stock assessment package. This is discussed further in the Future Work section. The 2020 stock assessment made several updates to the standardised CPUE time series used in the 2016 stock assessment model (Punt & Thomson 2016, Thomson 2020). These updates included shifting from operation-based gillnet CPUE time series to net length-based gillnet CPUE time series, trawl CPUE time series changing from a single index across all stocks to an index for each of the three stocks, and splitting the trawl CPUE time series for Bass Strait at 2005 to account for vessel and quota buyouts from management (Thomson 2020). These changes are retained in the 2023 stock assessment model with the addition of recent year's data to each of the CPUE time series (Sporcic 2023). Explorations are also undertaken of the South Australian gillnet CPUE time series which traditionally has run from 1984–2009 due to management changes enacted in 2009. Below, this CPUE time series is tested running from 1988–2009, and by splitting it into two time series at 1995 as requested by SharkRAG. The split reflects the introduction of colour sounders to the fleet, or a switch in targetting away from school shark towards Gummy Shark, which is likely to have increased fishing efficiency.

Length frequency data collected since 2019 have been processed and added to the model. Since the removal of onboard observers in the Gillnet, Hook and Trap (GHAT) sector in mid-2015, the collection of length frequency data has been undertaken by industry through the Shark Industry Data Collection (SIDaC) program. This stock assessment makes the first use of SIDaC collected data in a Gummy Shark stock assessment. SIDaC lengths add to the onboard length data time series of length frequency data. Gummy Shark vertebrae collected in every year between 2020 and 2022 inclusive have been read by Fish Ageing Services (Simon Robertson, FAS, pers. comm.) and have been included in the 2023 stock assessment. It is noted that the number of length samples available from line vessels has increased in recent years which was a request of SharkRAG and is appreciated.

Incorporation of the Danish seine fleet to the Gummy Shark stock assessment was recommended in 2020 (Thomson 2020). During 2021, the data were explored and a version of the model produced that has an additional fleet. During the 2023 assessment model update an attempt was made to incorporate a new Danish seine fleet into the model but it was found that because that gear selects much smaller sharks than other gears do, the code requires further modification to allow smaller length classes to be incorporated into the model. Additional exploration during 2021 assigned much of the available port data to fleets, where possible, but further examination is required to decide whether port data will need alternative selectivity curves to be estimated.

This report presents the 2023 base case stock assessment model for the three Gummy Shark stocks, Bass Strait (BS), South Australia (SA) and Tasmania (TS) that:

- models three stocks: Bass Strait (BS), South Australia (SA), and Tasmania (TS), each with its own recruitment series and CPUE power parameter, but with shared adult natural mortality parameter, gear selectivities, and productivity / density dependence,
- models sexes separately with fixed sex-specific growth rates but a shared adult natural mortality parameter,
- uses seven fleets: 6, 6.5, 7, and 8 inch gillnets, trawl, shallow (<183m) and deep (>=183m) longline,
- uses catch data for 1927 to 2022 for each stock and gear,
- uses stock specific standardized gillnet CPUE data where effort is reported net length (for combined mesh sizes) for BS (1976–2022), SA (split into 1984–1995 and 1996–2009 to reflect improved efficiency after the introduction of colour sounders - the series ends with 2009 because of management changes to protect Australian Sea Lions), and Tasmania (1990–2022)
- uses standardised trawl CPUE for BS (split into 1996–2005 and 2008–2022 to recognise the effect (and 'settling in') of management changes from 2005), SA (1996–2022) and TS (1996–2022)
- uses shallow (<183m) line standardised CPUE time series for all stocks combined ('bottom line' CPUE, from Sporcic, 2023, which uses data for 0–200m),
- uses stock, sex and gear specific age composition data from 1986 to 2008 for 6 inch and 7 inch gillnets (only for samples where length and age data are not available for each individual sampled) with a plus group of 10 years because gillnets seldom select animals older than 10 years,
- uses conditional age-at-length data for 1995 to 2022 for a range of gears where both age and length data are available for individual samples - a plus group of 20 years is used to reflect sampling of older animals by line gears; work during 2021 (not shown) showed that form of likelihood used is robust to setting a plus group age well above the ages of the animals sampled so that a larger plus group age could be used across gear types,
- uses stock, sex and gear specific length frequency data from 1974 to 2022,
- uses tag-recapture data for releases between 1952 and 2004,
- estimates effort saturation for each stock,
- does not estimate selectivity for gillnet gears (but does estimate availability) and does estimate logistic selectivity for trawl, shallow line, and deep line,
- estimates adult natural mortality (above age 2) for all stocks combined and calculates the juvenile natural mortality that would result in a stable stock in the absence of fishing given all estimated parameter values,
- does not use a Danish seine fleet,
- does not use port length data (apart from SIDaC data which is combined with ISMP onboard observer data),
- extends the plus group age from 10 to 20 years for the conditional length-at-age data.

3 Data

3.1 Catches

The catch time series used in the 2020 Gummy Shark stock assessment has been examined and re-analysed, and the updated catch time series to 2022 are shown in Figure 1 and in Appendix A. Discarding of Gummy Shark is estimated to be low (approximately 4%) and mainly relates to damage such as that due to sea lice. For that reason, the tonnage of the landed catch is inflated, across the time series, by the average of recent discard estimates. SharkRAG decided, at its 10-11 October 2023 meeting, to fix the discard rate that is applied to catches before 2016 at 4.9%. At the same meeting, SharkRAG decided that catches from 2016 will make use of the estimated trawl discard rates for those years, which will in future be presented in SESSF ISMP discard reports (eg Deng *et al.* 2023), and that the same report will compile and present logbook reported discards for non-trawl ISMP strata and that those will be used to reflect discarding for that sector. For the 2023 Gummy Shark assessment we have applied the 4.9% discard rate to all years.

Total catches (plus discards) have declined slightly from a peak in 2020 of 2021.3t across all three stocks to

1775.9t in 2021 and 1556.4t in 2022, with little change in catches across gear type evident. Catches in 2022 were below both the 5-year and 10-year average catches of 1812.8t and 1798.18t respectively most likely due to the TAC reduction (Burch *et al.* 2023).

3.1.1 Analysis of logbook data, treatment of unknowns, and historic information

The Gummy Shark stock assessment uses seven fleets (6, 6.5, 7, 8 inch gillnets, trawl, shallow and deep line) across each of the three stocks (Bass Strait, South Australia, Tasmania). Note, not all fleets fish each of the three stocks.

AFMA's logbook database includes Gummy Shark catches from mid-1985 for the trawl sector and from mid-1997 for the non-trawl sector. Most logbook catch records can be assigned to fleet and stock, but some have missing data such as gear type, gillnet mesh size, fishing depth, or fishing location. Records that had missing information in all, or some, of these fields were allocated to fleet and region in proportion to known catches. Because some records had partial information, this allocation was done in a stepwise fashion:

1. All records that had complete information were allocated to the relevant fleets.
2. Then gillnet records that had missing mesh size but did have position information (i.e. stock) were allocated in proportion to the ratios of the catches with known mesh sizes.
3. Next, records whose gear was unknown were allocated in proportion to the catches already allocated across fleets (from step 2).
4. Finally, the catches from records whose location was unknown were allocated to fleet in proportion to the catch ratios between stocks (from step 3).

Allocation of unknowns was always done in proportion to the known catches by year, but at each step in this process the 'known' catches change as more data are added to each category. Catches by Danish seine and other minor gear types are ignored at this stage but contribute to the CDR data, which is used to scale the catch totals, as described below.

The AFMA datasets, the State catches, and the 'allocation of unknowns' rules described above were used to generate catches by stock, fleet, and year, from 1997 onwards. For 1997 to 2001, logbook catches were scaled up using the average of the CDR to logbook ratios from 2011 to 2015. For 1927 to 1996, the catches that were used in the 2016 stock assessment were used again. The process of compiling these historical catches are detailed in Taylor *et al.* 1996 and Punt *et al.* 1999. An excerpt from Taylor *et al.* 1996 describes this process:

"The methods used to estimate catches for the years 1927–72 differ from those used to estimate catches for 1973 onwards because the early data were not recorded in a particularly systematic manner. The catches for three different periods were assembled from three separate sources: 1927–56 from Olsen (1959), 1957–64 from annual summaries in Fisheries Newsletter, and 1957–64 from computer summaries prepared by the Australian Bureau of Statistics. Mean ratio of Gummy Shark : school shark (i.e. 0.3:0.7) from Victorian catch and effort data available for the period 1952–64 was adopted to split the combined school and Gummy Shark catch presented by Olsen (1959) for the years before 1952 into separate species."

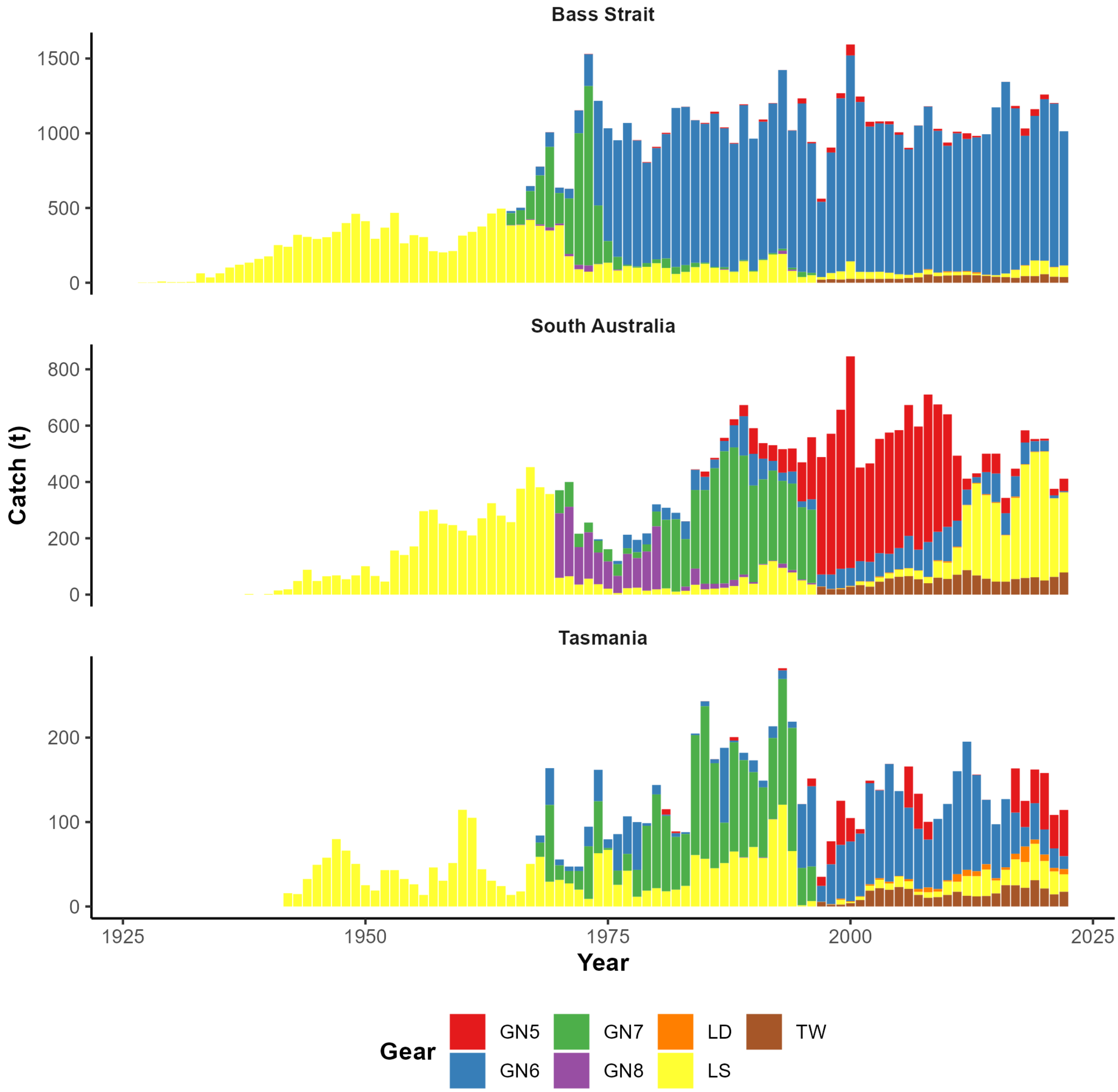


Figure 1: Gummy Shark catches (tonnes) by gear type and stock: 6 inch gillnet (GN6), 6.5 inch gillnet (GN5), 7 inch gillnet (GN7), eight inch gillnet (GN8), shallow line (LS), deep line (LD), and trawl (TW).

3.1.2 Commonwealth logbooks and CDRs

AFMA databases were used to calculate the catch time series where data exist (as described above), for 1997 onwards.

AFMA's logbook database includes Gummy Shark catches from mid-1985 for the trawl sector and from mid-1997 for the non-trawl sector. The Catch Disposal Record (CDR) dataset for Gummy Shark starts in 2001 when the species was first placed under quota. Note that CDR totals are typically slightly higher than logbook totals - landed catches are accurately weighed, in port, and entered into the CDR database whereas logbook records are the skipper's best guess and tend to err on the side of underestimation (Burch *et al.* 2023).

3.1.3 State catches and discards

Data on the landings of Gummy Shark by State authorities were taken from Burch *et al.* (2023), where missing years have been replaced by the nearest (in time) available landing for that State. Note that catches from WA and NSW are not used in Gummy Shark stock assessments. South Australian catches are added to the South Australian stock, Victorian catches to the Bass Strait stock, and Tasmanian catches to the Tasmanian stock. The State catches are assumed to be unbiased (i.e. the CDR to logbook ratio is not used to inflate those catches). Because the gear breakdown of the State catches are poorly known, these were assumed to have the same proportional breakdown as the Commonwealth catches except for deep line which was assumed not to have been used because State waters are close to the coast and therefore relatively shallow.

Discards were added to the landed catches (including the State catches) by applying the annual fishery-wide discard rates calculated by Burch *et al* (2023). For all years prior to 2011 the average discards over the 2011 to 2015 period was used (roughly 4% p.a.) which is consistent with 2020. From 2015 onwards, estimated discards are used. Because the reported discard rate is the discarded tonnage divided by the total catch (landings plus discards), the correction that is applied is `Corrected catch = Landed catch * 1 / (Discard rate)`. It is noted here that the 2011–2015 mean discard rate used in this stock assessment which is applied back to historical years varies slightly (4.78% in 2019, 4.91% in 2023) from those used in the 2020 version which leads to changes in estimates of total removals of Gummy Shark. The authors suggest SharkRAG consider selecting a plausible 'accepted value' that does not change over time that can be used for future Gummy Shark stock assessments.

3.2 Standardised CPUE

Standardised catch per-unit effort (CPUE) was obtained from Sporcic (2023). Sporcic (2023) provides CPUE time series for gillnets for each of the three Gummy Shark stocks: South Australia, Bass Strait, and Tasmania. Previously, the analyses have assumed that every gillnet fishing operation (i.e. shot) has equal effort. The 2010 (Punt and Thomson, 2010) and 2013 (Thomson & Sporcic, 2013) stock assessments used CPUE time series that were standardised in the same way, using operation as the unit of effort. In 2020, net length was explored as the unit of effort in standardising gillnet CPUE time series (Sporcic 2020). At its August 2020 meeting, SESSFRAG (AFMA 2020) requested that CPUE time series using net length be incorporated into the 2020 Gummy Shark stock assessment (Thomson 2020).

The CPUE time series that use operation as the measure of effort are similar to those that use net length (Figure 2). The CPUE time series between 2020 and 2023 are also very similar. The net length series are a little higher than the operation series in early years, and a little lower in recent years, indicating a somewhat greater decline in abundance than is indicated by the operation series. However, in recent years, both the net length and operation-based CPUE time series have increased for South Australia and Tasmania, and remained high for Bass Strait. For this stock assessment, operation-based CPUE time series were used in the early bridging steps, and then replaced by the net length time series which are recommended going forward.

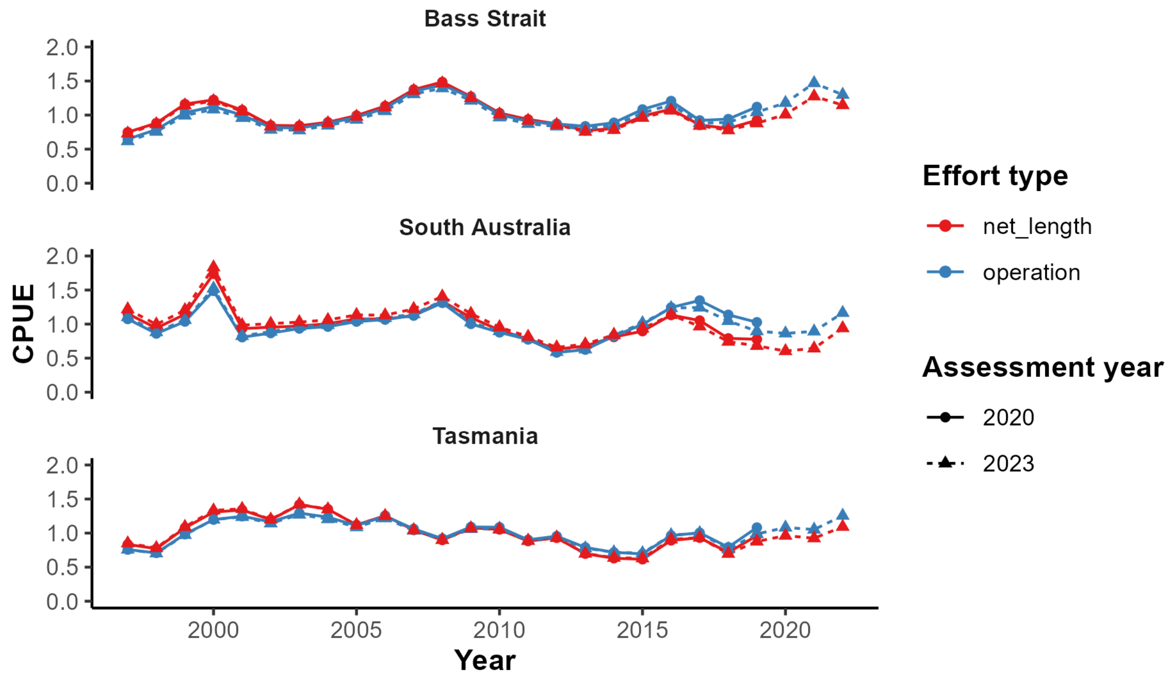


Figure 2: Standardised Gummy Shark gillnet CPUE time series by stock using operation (OP) and net length (NL) as the unit of effort from the 2020 (dashed) and 2023 stock assessment (solid). Stocks include: Bass Strait (BS), South Australia (SA), Tasmania (TS).

Sporcic (2023) also provides CPUE time series for gears other than gillnet including trawl, line, and Danish seine (Figure 3). Trawl was previously provided as a single CPUE time series for all stocks, however in 2020 this time series was split across the three stocks (Thomson 2020). The separate trawl CPUE time series for each stock are used in the 2023 stock assessment with the Tasmania trawl time series broken into two, from 1997–2005 and from 2008–2022 to account for a license buyback in 2005 by management. The shallow line CPUE time series is restricted to records in the 0–200m range and is therefore used in the assessment for the 'shallow' line fleet only. Relatively little catch of Gummy Shark has been landed from deeper than 200m so it is unlikely there are sufficient data to allow standardisation for the 'deep' line fleet.

Two further explorations to improve the standardised CPUE time series available for this assessment have been undertaken in this report. This includes the exploration of several alternate South Australian gillnet CPUE time series. One alternate scenario included starting the CPUE time series at 1988 rather than 1984, and the other involved breaking it into two time series from 1984–1995 and 1996–2009 to account for the introduction of colour sounders to the fleet. These modifications to the SA gillnet CPUE time series were a recommendation from previous SharkRAG meetings.

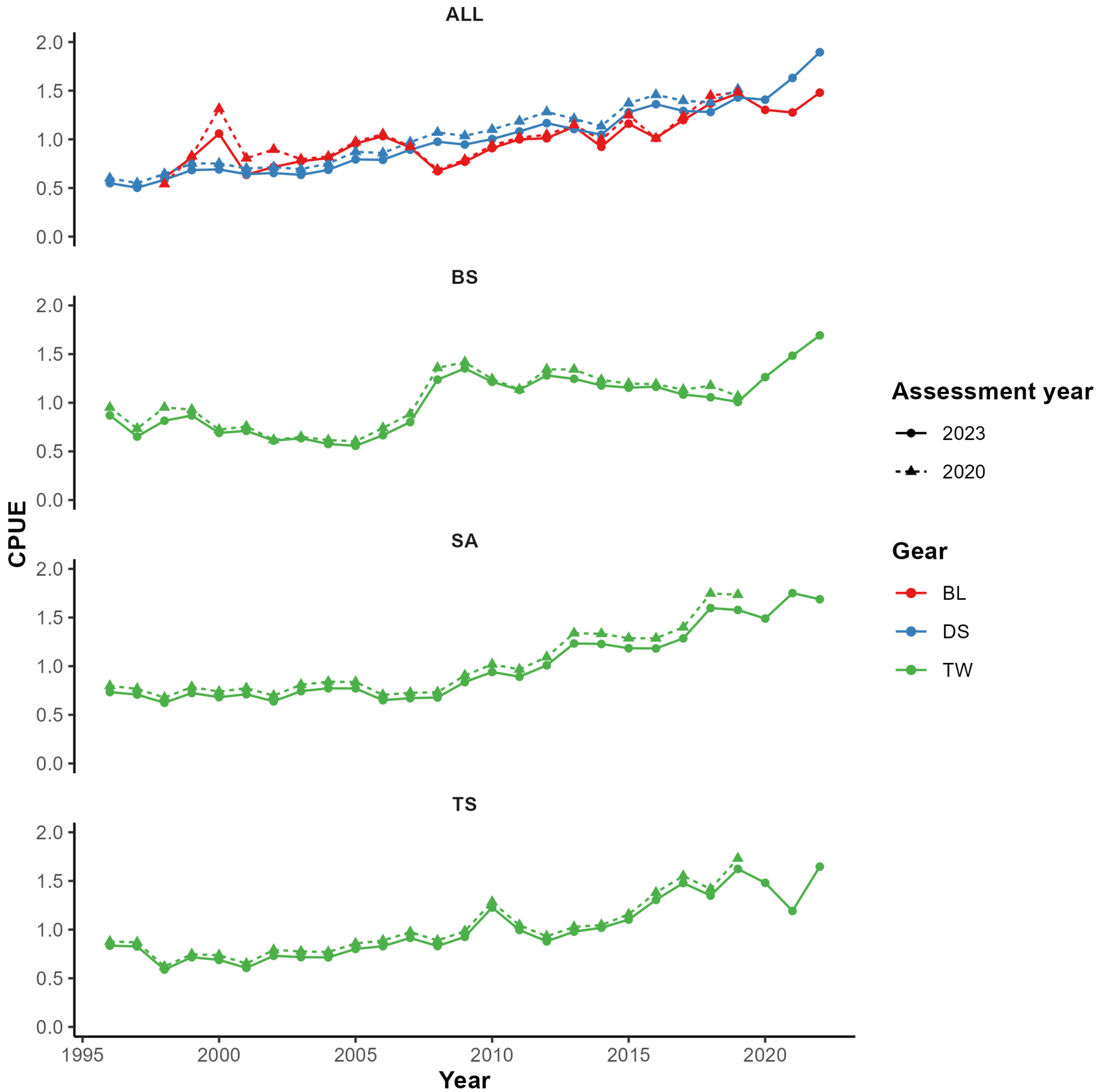


Figure 3: Standardised Gummy Shark CPUE time series for gears other than gillnet across stocks for the 2020 stock assessment (dashed) and 2023 stock assessment (solid). Gears include: shallow (bottom) line (BL), Danish seine (DS), Trawl (TW). Stocks include: stocks combined (ALL), Bass Strait (BS), South Australia (SA), Tasmania (TS).

3.2.1 Nominal effort

Nominal effort is the total effort for each year, by gear type, as reported in logbooks. For unknown gear types, and for gillnets of unknown mesh size, the effort data are assigned in proportion to known gear totals. Effort is input into the model so that the effect of gear competition can be accounted for (Pribac *et al.* 2005). A description of this is provided below in the section describing the stock assessment model. The effort totals used in the 2016 assessment are somewhat different from those calculated in 2020, which could be the result of improvements to the database, or due to differences in the methods used to calculate total effort. However, the differences are not large, and bridging showed that they had little effect on the model results (Thomson

2020). Effort totals updated for 2023 were similar to those produced in 2020 and showed little effect on the model during bridging.

3.3 Length frequencies

The 2016 stock assessment (and earlier versions) used some length frequencies that were 'inherited' from older assessment updates which were processed (by Terry Walker and Anne Gason, Marine and Freshwater Resources Institute (MAFRI), prior to 2006) from Gummy Shark length measurements that are not available to the authors of the 2023 stock assessment. Those length frequencies are included in the 2023 stock assessment unchanged. The remaining length frequencies were provided from the AFMA observer database, and these have been reprocessed and updated to include data from 2020–2022 inclusive. The 2016 stock assessment made use of length frequencies based on as few as seven sharks per strata (lengths per sex, gear, year, region etc). The 2020 stock assessment imposed a threshold of a minimum of 100 measurements for any length frequency used in the assessment for all gear types and a threshold of 50 for trawl, otherwise all trawl data would be excluded. In addition, the 2016 stock assessment excluded 11 length frequencies: some had small sample sizes but the reason for excluding the others is unknown. These were restored in the 2020 stock assessment and the effect on the model included in the bridging analysis. These same changes made in 2020 were retained in the 2023 stock assessment.

The length frequencies used in the 2023 stock assessment and model fits are shown below in the results. The length frequencies have been divided into those collected before 2003, 2003–2007, and 2008 onwards. For years prior to 2003, length frequencies were copied from the 2016 stock assessment which were sourced from when data collection and processing was done in Victoria (MAFRI). These data are not available to the authors and therefore, this data remains unchanged from this assessment relative to previous assessments. For 2003–2007, there is some length data in the AFMA database that was used in the 2016 assessment, but not all. For 2007 onwards, all the data used is stored in the Observer section of the AFMA database. Most of these more recent length frequencies match very closely between the 2020 and 2023 versions. It is also noted there has been an improved effort to collect length samples from line vessels which generally encounter a larger size class of Gummy Shark than other gears which is appreciated and shown below in Figure 4.

Below, length frequency distribution by gear type is plotted to show that different gear types encounter different sized Gummy Sharks which must be accounted for within the model via selectivity (Figure 5). It can be seen that Danish seine for example, selects for smaller individual Gummy Sharks then other gear types, and gillnet and shallow line select for larger individuals. The sample sizes in the legend also show the variable number of samples taken from the various gear types with gillnet clearly responsible for the majority of length frequency samples.

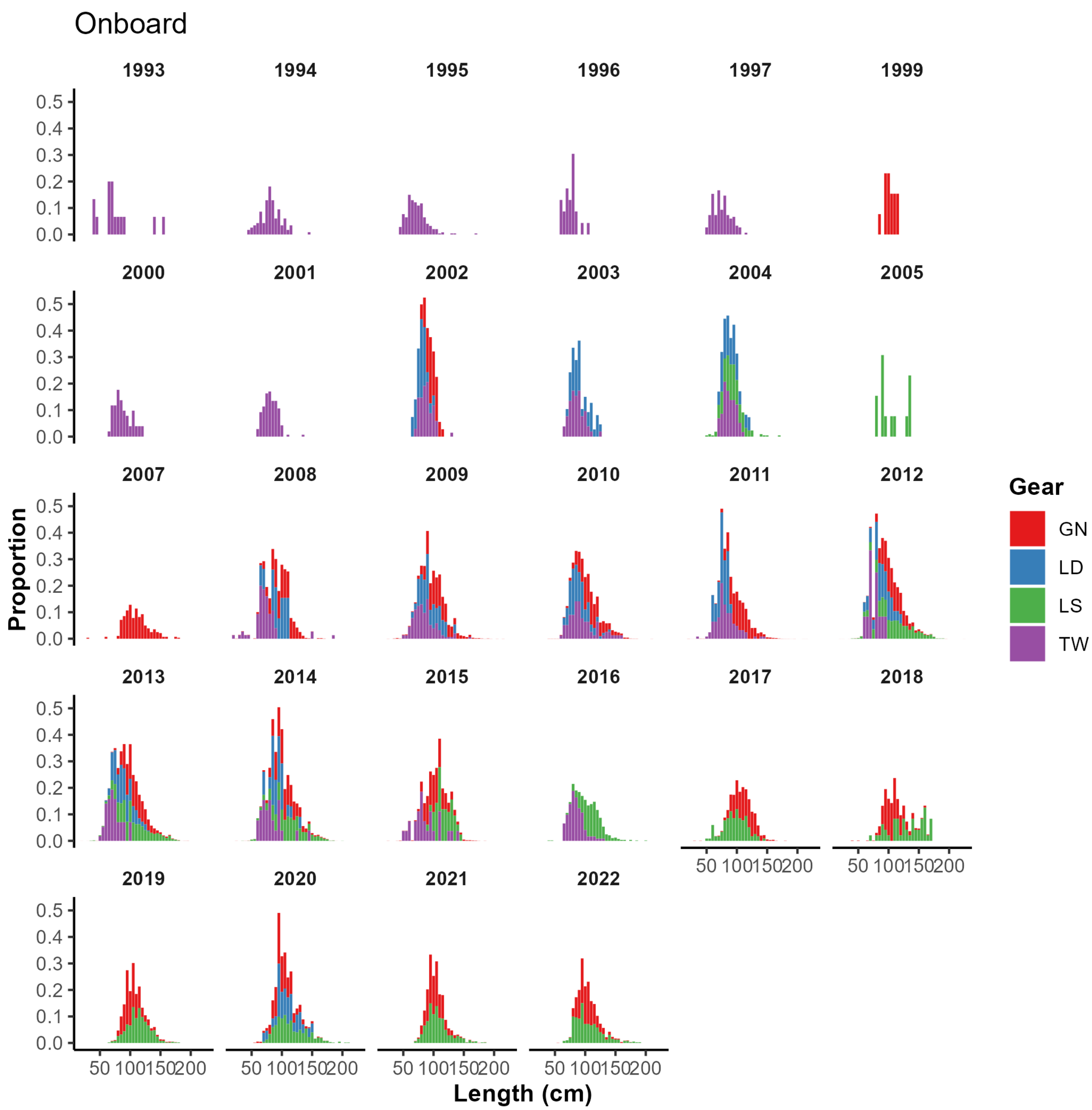


Figure 4: Stacked length frequency distribution of sampled Gummy Sharks by year and gear. Gillnet (GN) - red, Deep line (LD) - blue, Shallow line (LS) - green, Trawl (TW) - purple.

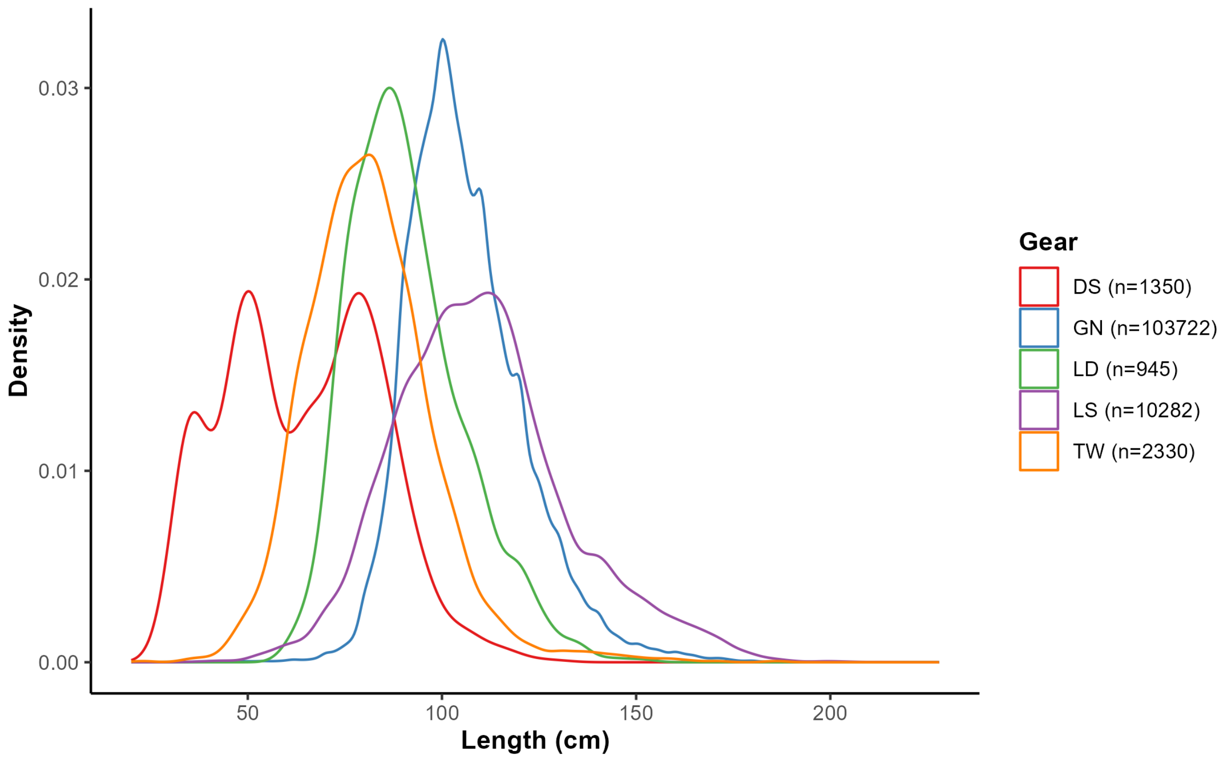


Figure 5: Length frequency generated by kernel density method applied to all length observations from Danish seine (DS) - red, Gillnet (GN) - blue, Deep line (LD) - green, Shallow line (LS) - purple, and Trawl (TW) - orange. Total sample sizes are provided in the legend.

3.4 Age data

The 2016 stock assessment used age composition data collected between 1986 and 2008 that had been used in earlier stock assessment updates, as well as data for 1995, 1997, 2002 and 2003 that were not previously available. For the 2020 stock assessment, age data from 2010–2015 were also made available (Thomson 2020). The reason that more recent age data (than 2015) was not available for the 2020 stock assessment is presumably that observers were removed from GHAT vessels in mid-2015 and sampling was replaced by the SIDaC program, and as such samples were not able to be processed in time. For the 2023 stock assessment, age data are now available for years from 2015–2022 inclusive and have been incorporated into the model as conditional age-at-length data as was established in the 2020 stock assessment (Thomson 2020).

The 2010–2022 age data, along with data from 1995, 1997, 2002 and 2003 have been incorporated in the assessment as conditional age-at-length (CAL) data rather than as age composition data (Figure 6). In the past, the age data were formed into age-length keys which represent the distribution of ages in each length class, and these were multiplied by the length frequency to give (after summing over length) a representative age frequency / age composition for the catch. A more modern way to use the age-length information is to enter it all into the model as age-at-length and allow the model to fit to those data. The older method enters only length composition data, and independent age composition data, so that the coupled age and length information for individuals is not available to the model. Using conditional age-at-length allows estimation of both growth and selectivity within the model. The primary advantage of estimating growth within the model is that the effect of gear selectivity can be allowed for so that it does not bias the estimated growth parameters. No attempt has yet been made to estimate growth within the model, but now that conditional age-at-length has been implemented, there is potential to do this in the future.

The age dataset for Gummy Sharks collected prior to 1995 is not available to the authors (i.e. age compositions are available, but 'raw' age and length data are not), so the conditional age-at-length method cannot be applied for those years. These would have been formulated using the age-length key method described above, and are retained in the model as age composition data that are assumed to be representative of the age distribution of Gummy Sharks in the catch. See the 2020 stock assessment for a more detailed explanation of the conditional age-at-length approach, and approach undertaken by the 2016 stock assessment (Thomson 2020). Several corrections have been made to the processing code used to analyse the conditional age-at-length data. This included converting partial length measurements to total length for some Gummy Sharks, and a correction where the ages of individual sharks were incorrectly assigned one year older than they should have been (two year olds were considered three, three year olds as four etc). This was corrected and its impact on the model explored during the bridging process.

For the 2023 stock assessment, the impact of extending the plus group age from 10 to 20 was explored during the bridging process. In previous stock assessments, it was noted that the data did not fit well to the growth curves used in the model, particularly for older ages (Thomson 2020). To minimise the impact of these poor fits, a plus group age of 10 was used in previous assessments. However, now that a larger number of older individuals have been sampled, particularly by the shallow line fleet, the plus group age can now be extended and the model allowed to fit to the additional data. By extending the plus group age to 20, it was hoped that the model would be able to better fit to the conditional age-at-length data where previously the model was underestimating age relative to length. Here, the impact of extending the plus group age to 20 was explored. This was an issue that has been noted in previous assessments as an area for future work.

Size at age is similar for both sexes, although females attain greater maximum lengths and ages than males (Figure 7). The overall age composition of Gummy Shark has been stable in recent years with mean age stable for both sexes and conditional age-at-length data also stable. Currently, growth is pre-specified (fixed) in the assessment based on estimates from vertebral readings in 1973–1976 (Moulton *et al.* 1992). Growth is currently not estimated by the model but this would be something useful to explore in the future as it may vary spatially or over time. This was identified by Moulton *et al.* 1992, which found spatial differences in growth between Gummy Sharks sampled in Bass Strait and South Australia in 1986-1987, and also temporal differences in growth between Gummy Sharks sampled in Bass Strait from 1973–1976 and 1986–1987. Below, conditional age-at-length data are plotted with approximate smoothers fit by stock (Figure 6) and sex (Figure 7) as an exploration. It should be noted that these data will be influenced by the varying selectivities of different gears which is not accounted for in the plots below.

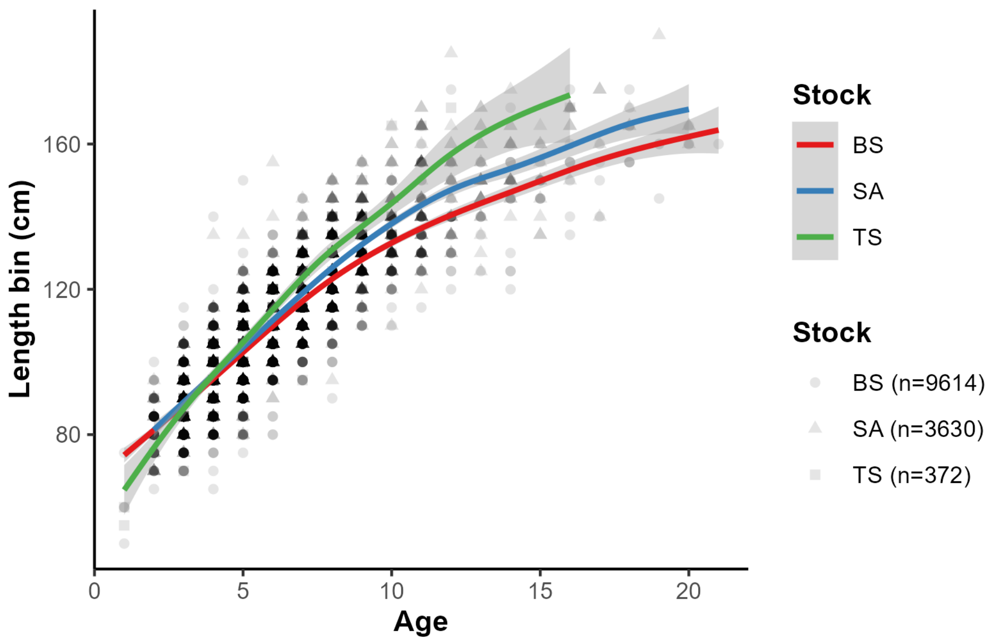


Figure 6: Observed age and length for Gummy Shark by stock. Smoothers are fit to the data to show approximate growth curves.

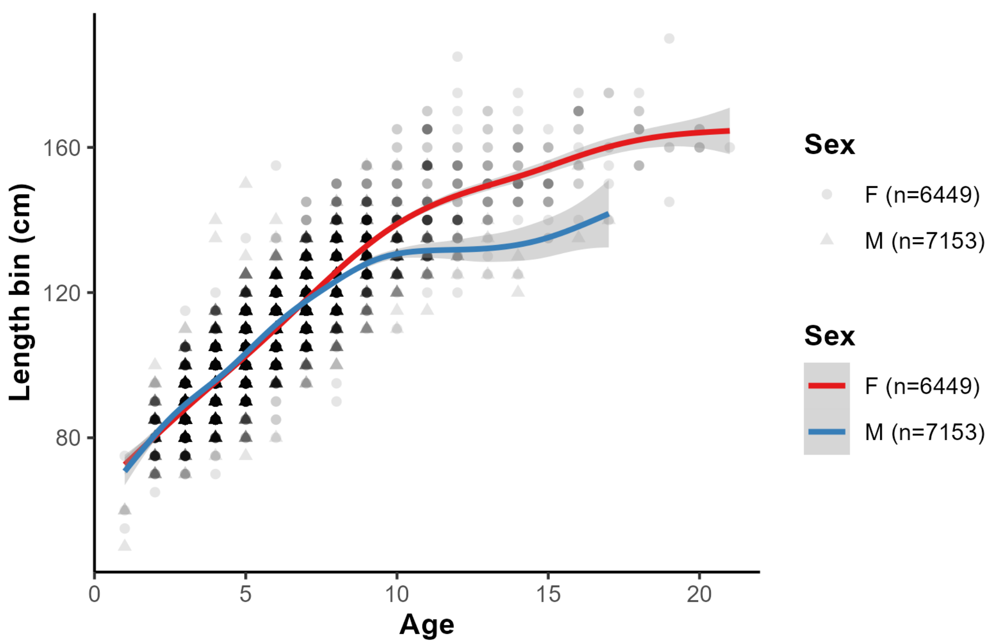


Figure 7: Observed age and length for Gummy Shark by sex for all stocks combined. Smoothers are fit to the data to show approximate growth curves.

3.5 Danish seine

At its September 2020 meeting, SharkRAG decided to include a Danish seine fleet in the base case assessment model for Gummy Shark. It is hoped that inclusion of the Danish seine fleet and its associated data could provide useful information on recruitment as it samples a component of the population (i.e. young individuals) that is not sampled by other gear types. A standardised Danish seine CPUE time series is presented by Sporcic (2023) and some length and conditional-length-at-age data are available.

Data exploration for the Danish seine fleet was presented in 2020 (Thomson 2020) and in 2021, and code development during 2021 allowed for the inclusion of an additional fleet, with estimated selectivity parameters, into the model. Further work (not shown) this year attempted to apply the model to the Danish seine data, allowing for two alternative forms of dome-shaped selectivity, but it was found that the model has a minimum input length class of 70-75cm which excludes nearly half the Danish seine length data (Figure 5). Further model re-coding would be required to incorporate smaller length classes so that the Danish seine fleet can be used.

Because the Danish seine fleet selects for a smaller size class of Gummy Shark compared to most other gear types, its inclusion could provide an index of recruitment. However, the data available from the Danish seine fleet is patchy. Catches are only above 10t annually for the Bass Strait stock and less than 100 age samples have been collected in total. SharkRAG decided not to make use of length samples collected in port because of strong size-related discarding. The patchiness of this data could make it difficult for the model to estimate selectivity. In addition, the absence of larger Gummy Sharks in the Danish seine length frequency indicates that the selectivity is not logistic but has a declining right-hand side. This will require the estimation of additional parameters to capture the slope and position of the right-, as well as the left-hand side of the selectivity curve, thus increasing the model's data requirements.

Including zero and 1-year old sharks in the model could, however, have major implications for the way density dependence is handled in the model and this too might require model exploration and possible further model development.

4 Assessment Method

The Gummy Shark stock assessment model structure is not described in detail here; interested readers are referred to Pribac *et al* (2005) and Punt & Thomson (2016). However, a description of the behaviour of the 'effort saturation' feature of the model follows, as well as a description of bridging analysis.

4.1 Effort saturation

The gillnet fleets are thought (see Pribac *et al.* 2005) to compete with one another in such a way that when effort is high, catches do not increase proportionally so that CPUE is lowered. To account for this, Pribac *et al.* (2005) modeled CPUE as a non-linear function of effort as shown in Equation 1, where B = biomass, E = effort, and gamma (γ) = effort saturation parameter. Figure 8 shows a theoretical scenario in which *true available biomass* is unchanging, but effort is increasing. If effort saturation / gear competition is occurring, then the observed CPUE would be expected to decrease as effort increases, instead of remaining steady. Biomass is unchanged, so a true index of abundance should also be unchanging. Equation 1 predicts observed CPUE in the face of effort saturation. A stronger effort saturation effect results in increasingly depressed CPUE at higher effort levels. If the parameter that governs effort saturation (i.e. gamma) is zero, then CPUE is considered to be linearly related to biomass so that CPUE in the scenario depicted in Figure 8, both CPUE and biomass are steady. If effort saturation is estimated to be very strong, then the model will interpret a decline in CPUE, which is accompanied by an increase in effort, as indicating little or no decline in biomass. The effort saturation parameter is, itself, non-linearly related to the strength of the effort saturation effect so that a 'jump' in value from 0 to 0.5 has a greater impact on predicted CPUE at high effort than a 'jump' from 32 to 50.

$$CPUE = \frac{B}{1+\gamma E} \qquad (1)$$

The Gummy Shark stock assessment model estimates an 'availability' function that modifies the pre-specified (fixed) gear selectivity for gillnet gears only. Empirical evidence for non-uniform availability arises from analyses of length-composition data collected during fishery independent surveys (A. E. Punt, unpubl. data, cited by Pribac *et al.* 2005). Non-uniform availability may be a consequence of behavioural changes associated with ontogenetic changes in prey preference (Punt & Thomson 2016).

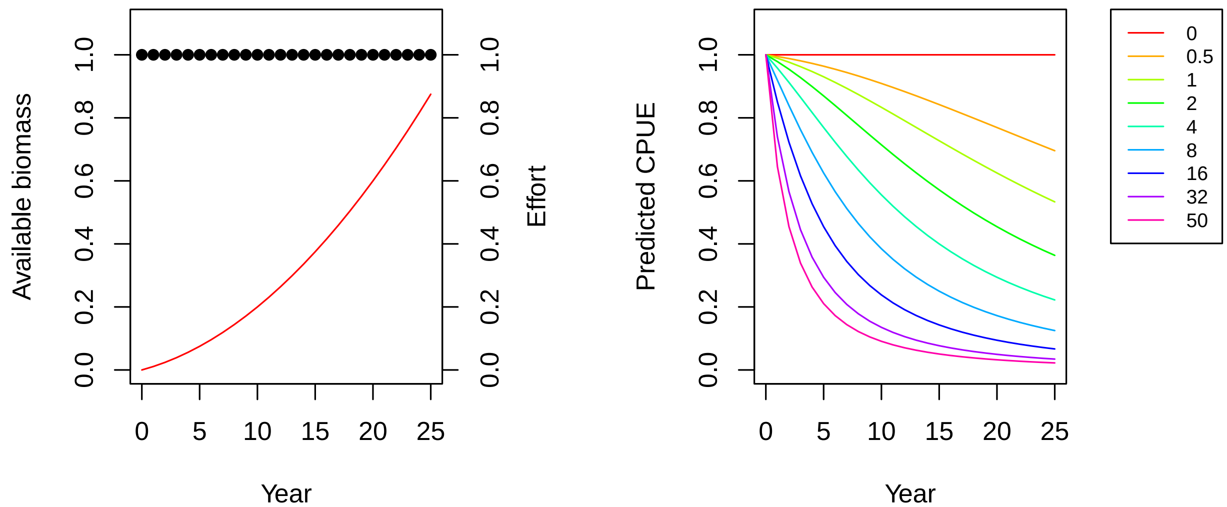


Figure 8: A theoretical scenario in which biomass (black line) is steady, but effort (red line) is increasing (left plot), illustrating the influence of the effort saturation parameter on predicted CPUE (right plot) where colours represent different effort saturation parameter values.

4.2 Bridging analysis for 2020 to 2023 base cases

The base case stock assessment presented by Thomson (2020) is repeated here. A number of structural changes were made to the code and input files to make it easier to change components of the data and re-run the model for bridging and sensitivity analyses. The model parameters were re-estimated after making each change, to ensure that no inadvertent changes were made to the results. Those results are not shown here because all were identical to the 2020 base case model, as they should be.

We present a 'bridging analysis' which bridges from the 2020 base case stock assessment model to a 2023 base case stock assessment model by making one change to the model at a time, cumulatively, to assess the effect of each change on the model result. Essentially, we are stepping from an old model to a new model and assessing the effect of every step. The steps involve making changes to the model structure, and assumptions, as well as the adding of new data (from 2020 to 2022 inclusive). The bridging analysis is followed by a sensitivity analysis where a single change is made to the base case model and the results are presented. Here, the changes are not cumulative, instead every model differs from the base case model in having had just one change made to it.

5 Assessment Results

The tables that follow show estimated parameter values and negative log likelihoods (a measure of how well the model can reproduce the observed data) for a range of model runs. The abbreviations used are shown in Table 1. A lower negative log likelihood value indicates a better model fit, however this comparison can only be made for models with the same data and compatible (nested) structure. Each alternate model has been assigned an abbreviated name in the results tables below, those are given fuller descriptions in Tables 2 and 6. First, the 'bridging' analysis (see Assessment Methods section above) is presented, which bridges from the

Table 1: Abbreviations used in the tables that present assessment model results and quantities of interest.

abbrs	full
M	(Instantaneous) natural mortality rate
B0	Unfished biomass
MSYR	Maximum sustainable yield rate (MSY / BMSY)
Pem73	Depletion in pup production in 1973
Pem final	Depletion in pup production in final year of model (2019 or 2022)
Satn	Effort saturation parameter
negLL	Negative log-likelihood
Pr	Prior for recruitment residuals
BS	Bass Strait
SA	South Australia
TS	Tasmania

2020 base case model to a base case model for 2023. Then, sensitivity tests are presented which assess how sensitive the model results are to alternate datasets and model assumptions.

5.1 Bridging

Code written in 2020 to improve data processing of input data was used to implement and explore the data processing and modelling for the 2023 stock assessment. Very few changes were made to this processing code short of a small number of corrections (e.g. in the age-at-length data). This processing code documented the work, making it more reproducible and less error-prone.

The data processing code was used to produce model input files that contained a combination of old and new data, adding one piece of new data at a time to see its effect on model results. This is termed a 'bridging analysis' because it bridges from the old to the new data and new model structures. The order in which changes were made is as follows:

1. Re-analysed 2020 data were sequentially added to the 2020 base case (Bridges 1-4a) - changes could be due to late additions to the database (particularly for 2020, corrections made to the database by AFMA staff, corrections made to the data processing code by the authors). The abundance (pup production) for each stock generated from the models that altered the 2019 data are shown in Figure 9 and Table 3.
2. Next, data from 2020–2022 are sequentially added to each input data file (i.e. catch, length, CPUE etc) in the next set of bridging steps (Bridge 5–14), results are shown in Figure 10 and Table 4.
3. Next, adjustments are made, sequentially, to the model (Bridge 15–17; Figure 11 and Table 5). These included:
   - Bridge 15: extension of the plus group age from 10 to 20 years,
   - Bridge 16: altering the South Australian gillnet CPUE time series to begin at 1988 rather than 1984,
   - Bridge 17: breaking the South Australian gillnet CPUE time series into two from 1984–1995 and 1996–2009 (this is the 2023 base case model).

The error correction of conditional age-at-length data up to and including 2019 in bridges (from 3a–3c) led to substantial changes to the input files for the 2020 base case. These corrections fixed two errors: a) converting partial lengths to total lengths for some individuals, and b) fixing an error that made individuals one year older then they should have been (2 year olds were wrongly considered 3 years old etc). However, these changes led to only a slight downward correction of pup depletion for the Bass Strait, and little change for the other two stocks. Bridge 4 switched the 2019 gillnet CPUE time series from operation-based to net length, and as in the 2020 stock assessment, had little effect overall. This is likely because the net length and operation-based CPUE gillnet time series output by Sporcic (2023) are very similar to each other (Figure 2). These early bridging steps updating 2019 data were highly consistent with the 2020 stock assessment with little changes to model results showing the stability of the model, and consistency of data processing.

Introducing the new catch, CPUE and length frequency data did not substantially influence the results of the model, which remained relatively stable across all bridges (Figure 10 and Table 4). Pup depletion of the South Australian stock was more sensitive to the addition of new data, while the Bass Strait and Tasmania stocks were stable. Updated catch (Bridge 5), CPUE (Bridge 6–12), length (Bridge 13) and age data to 2022 (Bridge 14) were sequentially added to the 2020 base case model during this bridging process. Conditional age-at-length data were updated from 2015–2022, yet still had little influence on pup depletion (Bridge 14).

From Bridge 15–17, changes to the model and/or data were made (Figure 11; Table 5). In Bridge 15, the plus group age was extended from 10 to 20 years, which allowed the model to better fit to the conditional age-at-length data. This bridge was the largest structural change undertaken in the 2023 stock assessment, but drove little change to the results. This may be because growth is not estimated in the model, and it can be seen that the model is still underestimating the age of Gummy Sharks relative to larger lengths in most instances. It should be noted that the conditional age-at-length likelihood in Table 5 cannot be directly compared between Bridge 14 and subsequent models because the increased plus group age increases the size of that likelihood component simply because more numbers are used. The most influential bridging steps on pup depletion estimates were Bridges 16 and 17 where alternate South Australian gillnet CPUE time series were explored. This shows that estimates of pup depletion and production are influenced by CPUE time series. The estimate of natural mortality increased from 0.16 to 0.18, and caused a slight decline in B_0 estimates. Because M is estimated across all stocks, the effect of this bridging step also influenced the B_0 for the Bass Strait and Tasmania stocks although their pup depletion timelines remain relatively unchanged. For the South Australian stock, pup depletion was revised downward, but it still remains above the TRP.

Bridges 18 and 19 explore the impact on the model of alternative assumed growth parameters; these are actually sensitivity tests rather than part of the bridging analysis. Growth curves were estimated for male and female Gummy Shark by fitting a von Bertalanffy growth curve to the age-and-length data that is used to form the conditional-age-at-length data. The estimated growth curve for males is very similar to that of Moulton *et al.* (1992) that is used by the model, but the female curve allowed females to grow larger at older ages. Because the male new male growth curve is similar to that used in the model, the results from Bridge 18, which replace both male and female curves with the new values, are very similar to those for Bridge 19 which uses only the new female values. The new female growth curve results in slower estimated stock status for all stocks, with Bass Strait below the target reference point (TRP)and South Australia and Tasmania close to the TRP.

Given the sharp increase in the SA gillnet CPUE time series at 1995, consistent with anecdotal reports from Industry members of SharkRAG regarding the introduction of colour sounders to the fishery at this time, SharkRAG chose the Bridge 17 model, which splits the SA gillnet CPUE at 1995 for the 2023 base case stock assessment model.

Table 2: Description of the bridging models presented in this report. The 2020 base case (BC2020) is altered, one cumulative step at a time. 'Bridge 17' is the 2023 base case model.

modname	fulldesc
BC2020	The 2020 base case model
Bridge 1	New processing and database used to generate catches to 2019
Bridge 2	New processing and database used to generate length frequencies to 2019
Bridge 3a	New processing and database used to generate age-at-length to 2019
Bridge 3b	Age-at-length to 2019 with error correction
Bridge 3c	2023 age-at-length data trimmed to 2019 with error correction
Bridge 4	Switch 2019 gillnet CPUE timeseries from operation to net length
Bridge 5	New catches from 2020-2022 added and model run to 2022
Bridge 6	New BS gillnet CPUE timeseries from 2020-2022 added
Bridge 8	New TS gillnet CPUE timeseries from 2020-2022 added
Bridge 9	New BS trawl CPUE timeseries from 2020-2022 added
Bridge 10	New SA trawl CPUE timeseries from 2020-2022 added
Bridge 11	New TS trawl CPUE timeseries (two series) from 2020-2022 added
Bridge 12	New line CPUE timeseries from 2020-2022 added
Bridge 13	New length frequencies from 2020-2022 added
Bridge 14	New age-at-length from 2016-2022 added
Bridge 15	Plus age group extended from 10 to 20
Bridge 16	SA gillnet CPUE timeseries starts at 1988 rather than 1984
Bridge 17	SA gillnet CPUE timeseries split into two at 1995
Bridge 18	Updated growth parameters for both sexes
Bridge 19	Updated growth parameters for females only

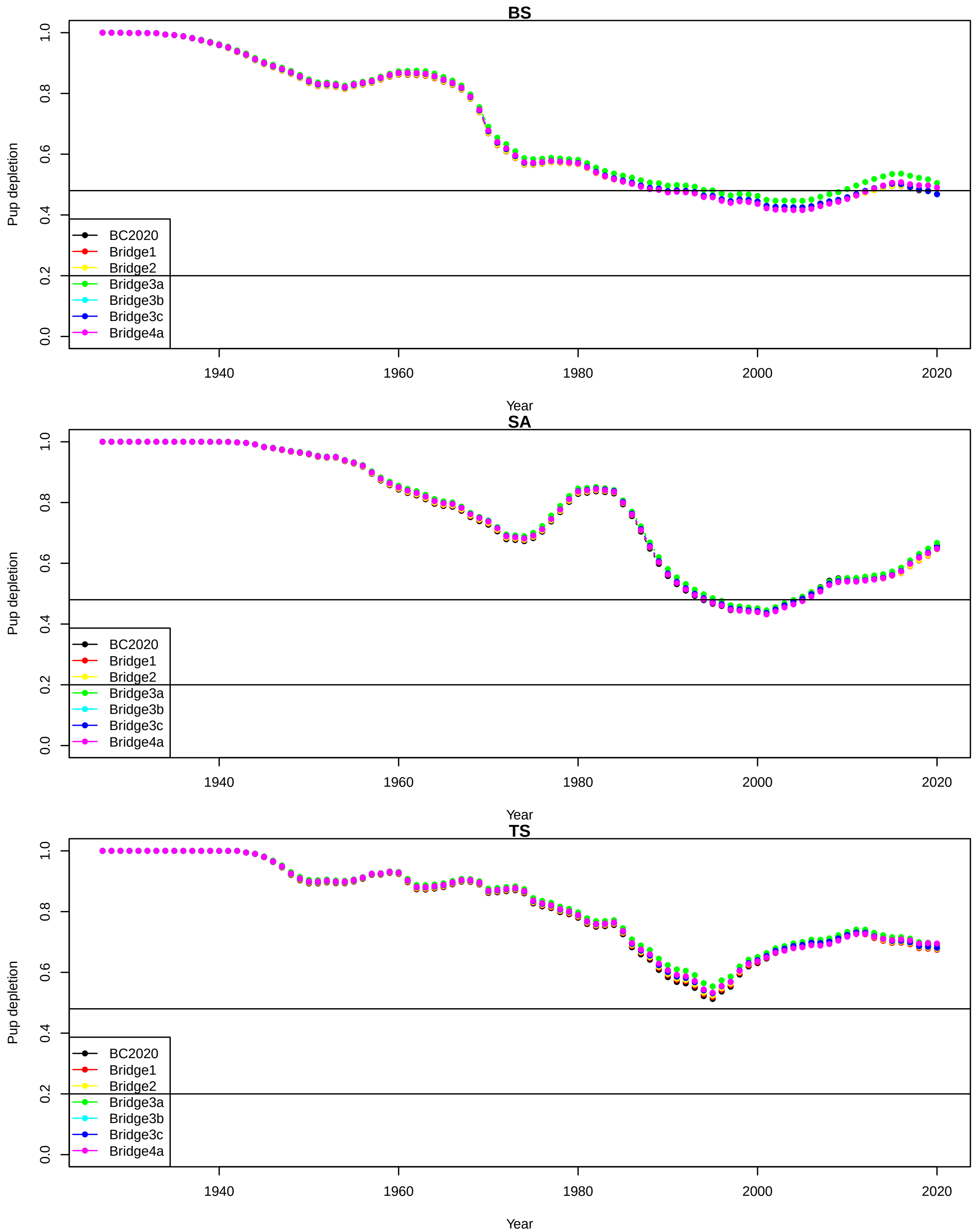


Figure 9: Gummy Shark pup depletion by stock for models with updated 2019 data. The 2020 base case (black) is shown for comparison. Limit (20%) and target (48%) reference points are shown as horizontal lines.

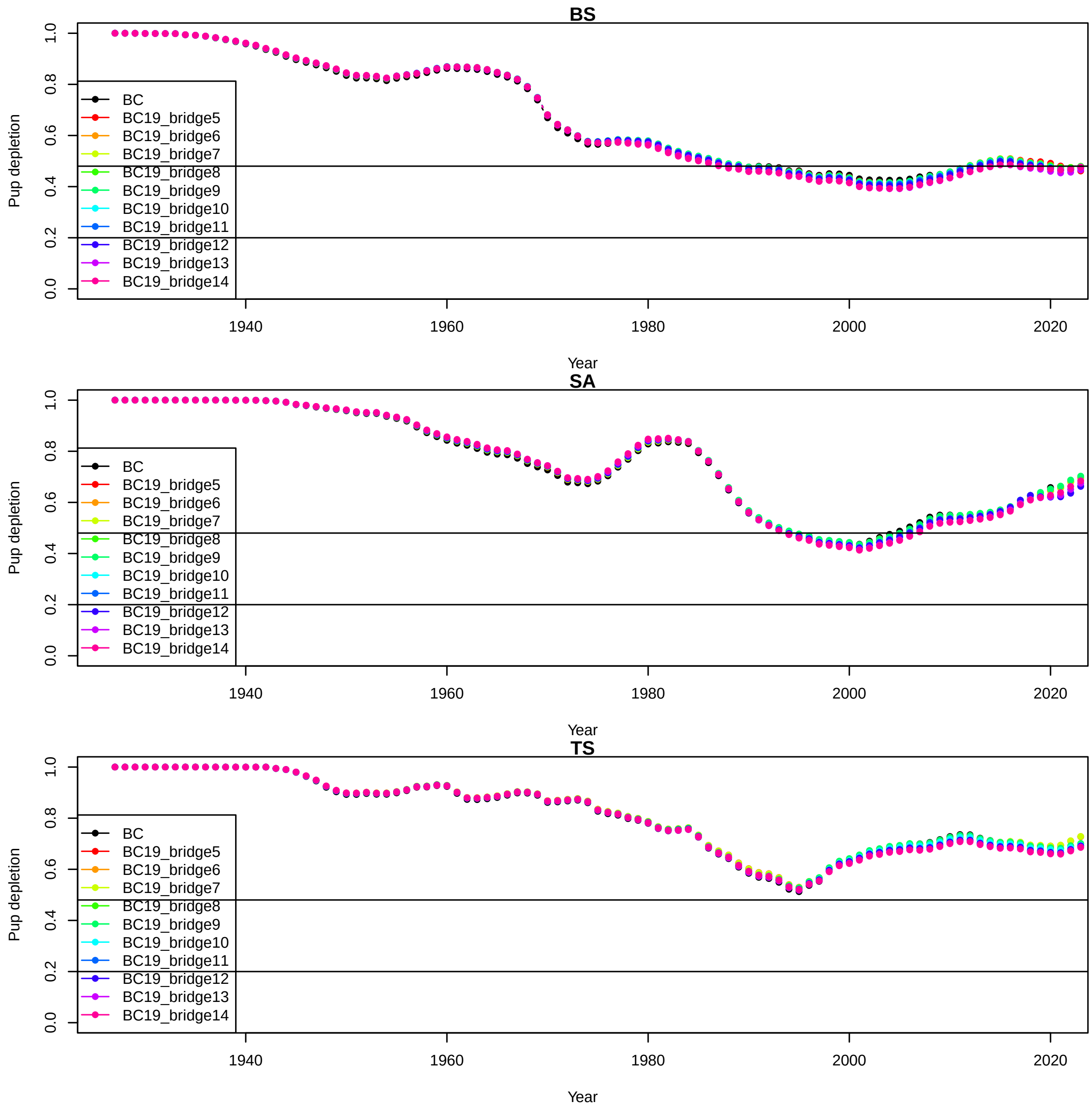


Figure 10: Gummy Shark pup depletion by stock for models that use data to 2022. The 2020 base case model (black) is shown for comparison.

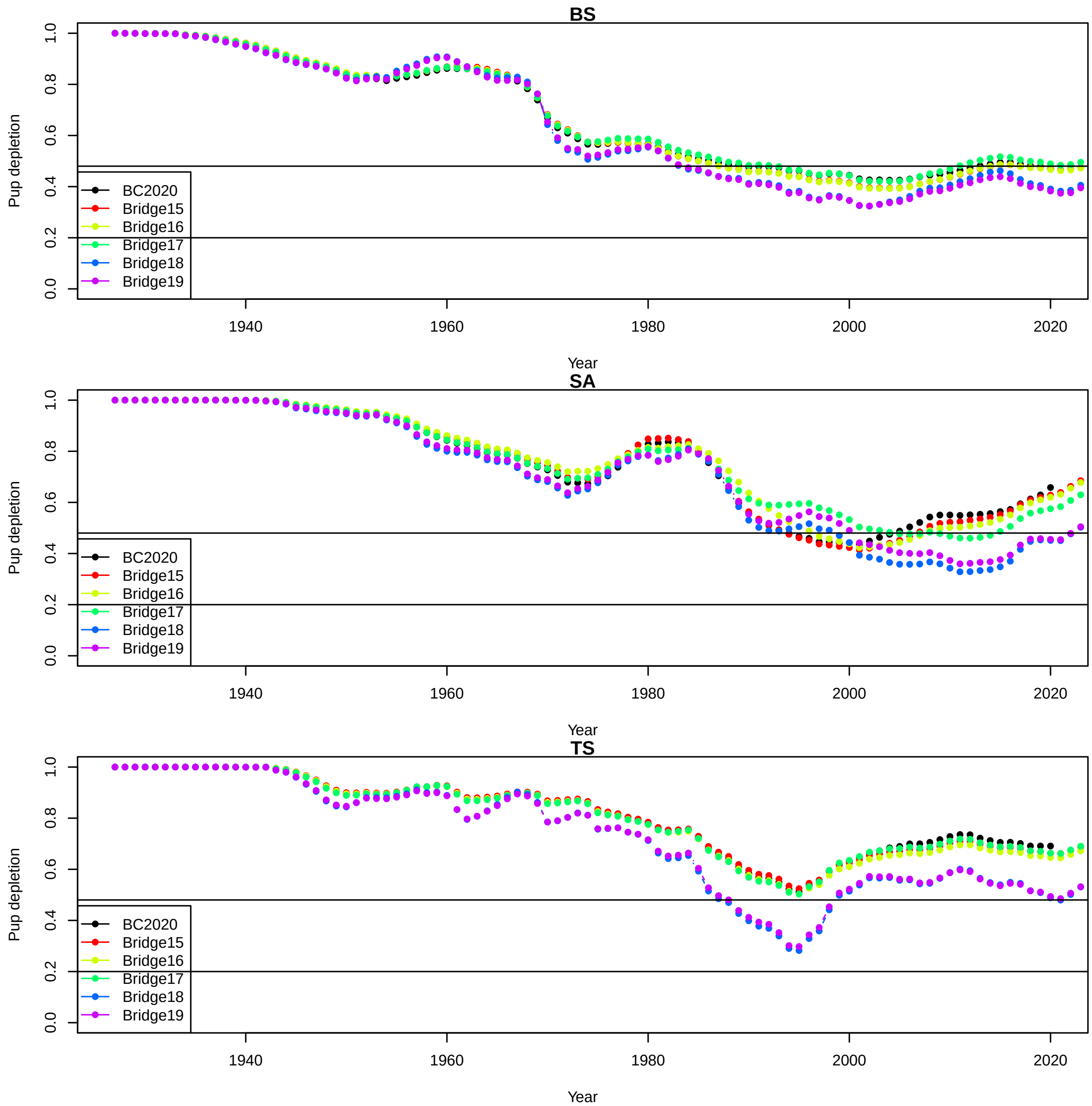


Figure 11: Gummy Shark pup depletion by stock for models that use data to 2022, and differ from the 2020 base case model design. The 2020 base case model (black) is shown for comparison.

Table 3: Quantities of interest from the 2020 base case model (BC2020), and models that have updated data to 2019. Abbreviations are described in Tables 1 and 2.

		B0			MSYR			Pem73			Pem final			Satn			negLL						
Model	M	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	Sum	Cpue	Len	Age	CAL	Tag	Pr
BC2020	0.16	9983	6212	2053	0.2	0.22	0.2	59	68	87	47	66	69	1.74	2.33	0	1767	195	631	156	389	326	70
Bridge 1	0.16	9983	6286	2079	0.2	0.22	0.2	59	68	87	47	65	67	1.75	2.33	0	1769	195	631	156	389	326	71
Bridge 2	0.16	9988	6291	2095	0.2	0.22	0.2	59	68	87	47	65	68	1.75	2.32	0	1765	195	627	156	389	326	71
Bridge 3a	0.15	10938	6745	2296	0.19	0.21	0.19	61	69	88	51	67	69	1.3	2.24	0	1758	199	630	156	376	330	68
Bridge 3b	0.16	10183	6408	2130	0.2	0.22	0.2	59	69	88	47	65	68	1.43	2.27	0	1613	200	626	157	237	326	68
Bridge 3c	0.16	10184	6408	2130	0.2	0.22	0.2	59	69	88	47	65	68	1.42	2.27	0	1613	200	626	157	237	326	68
Bridge 4	0.16	10344	6421	2164	0.2	0.22	0.2	60	69	88	49	65	70	1.42	2.13	0	1600	187	625	157	237	325	69

Table 4: Quantities of interest from the 2020 base case model (BC2020) and models that sequentially add data to 2022. Abbreviations shown in column headings are are described in Table 1 and abbreviated model names (rows) in Table 2.

		B0			MSYR			Pem73			Pem final			Satn			negLL						
Model	M	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	Sum	Cpue	Len	Age	CAL	Tag	Pr
BC2020	0.16	9983	6212	2053	0.2	0.22	0.2	59	68	87	47	66	69	1.74	2.33	0	1767	195	631	156	389	326	70
Bridge 5	0.16	10290	6396	2140	0.2	0.22	0.2	60	69	88	46	69	73	1.42	2.14	0	1597	184	625	157	236	324	70
Bridge 6	0.16	10264	6354	2120	0.2	0.22	0.2	60	69	88	48	70	73	0.62	2.17	0	1602	188	627	158	236	322	71
Bridge 7	0.16	10264	6354	2120	0.2	0.22	0.2	60	69	88	48	70	73	0.62	2.17	0	1602	188	627	158	236	322	71
Bridge 8	0.16	10309	6436	2100	0.2	0.22	0.2	60	69	87	48	70	70	0.62	2.3	0	1617	206	626	157	235	322	70
Bridge 9	0.16	10316	6423	2094	0.2	0.22	0.2	60	69	87	48	70	70	0.58	2.6	0	1619	208	627	157	235	321	71
Bridge 10	0.16	10458	6510	2098	0.19	0.21	0.19	60	69	87	48	66	69	0.6	2.59	0	1631	210	627	158	235	319	82
Bridge 11	0.16	10485	6526	2111	0.19	0.21	0.19	60	69	87	47	66	69	0.6	2.58	0	1642	220	627	158	235	319	83
Bridge 12	0.16	10512	6540	2121	0.19	0.21	0.19	60	69	87	47	66	69	0.59	2.62	0	1641	216	628	158	235	320	85
Bridge 13	0.16	10612	6699	2136	0.19	0.2	0.19	60	69	87	47	67	69	0.63	2.59	0	1697	222	678	158	236	322	80
Bridge 14	0.16	10910	6864	2190	0.18	0.2	0.18	60	69	87	48	68	69	0.79	2.55	0	1767	225	680	157	302	324	79

Table 5: Quantities of interest from the 2020 base case model (BC2020) and models use data to 2022 and differ in design from BC2020. Abbreviations shown in column headings are are described in Table 1 and abbreviated model names (rows) in Table 2.

		B0			MSYR			Pem73			Pem final			Satn			negLL						
Model	M	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	Sum	Cpue	Len	Age	CAL	Tag	Pr
BC2020	0.16	9983	6212	2053	0.2	0.22	0.2	59	68	87	47	66	69	1.74	2.33	0	1767	195	631	156	389	326	70
Bridge 15	0.16	10943	6883	2207	0.18	0.2	0.18	60	69	87	48	68	69	0.78	2.56	0	1842	225	680	156	377	325	79
Bridge 16	0.17	10840	7038	2115	0.18	0.2	0.18	60	72	87	47	68	67	0.76	50	0	1796	198	686	153	378	316	65
Bridge 17	0.18	9709	5986	1914	0.21	0.23	0.21	59	69	87	50	63	69	0.7	0.91	0.7	1757	175	680	162	381	305	53
Bridge 18	0.3	9558	5682	1556	0.22	0.23	0.22	53	64	82	41	50	53	0.73	0.53	0.29	1784	206	716	181	334	288	60
Bridge 19	0.3	9080	5501	1480	0.22	0.23	0.22	55	65	82	40	50	53	0.68	0.62	0.33	1785	193	736	168	334	290	64

5.1.1 Selectivity

The selectivities for the seven gear types are shown in Figure 12 across several models (BC2020, Bridge 4, Bridge 10, Bridge 17). The gear selectivity for the gillnet fleets is fixed at theoretical values, but varied through the estimation of an availability function (a function of age), whereas that for the trawl and line fleets is an estimated logistic function of length. There is good agreement between both the fixed and estimated selectivity and the data across the various model bridges.

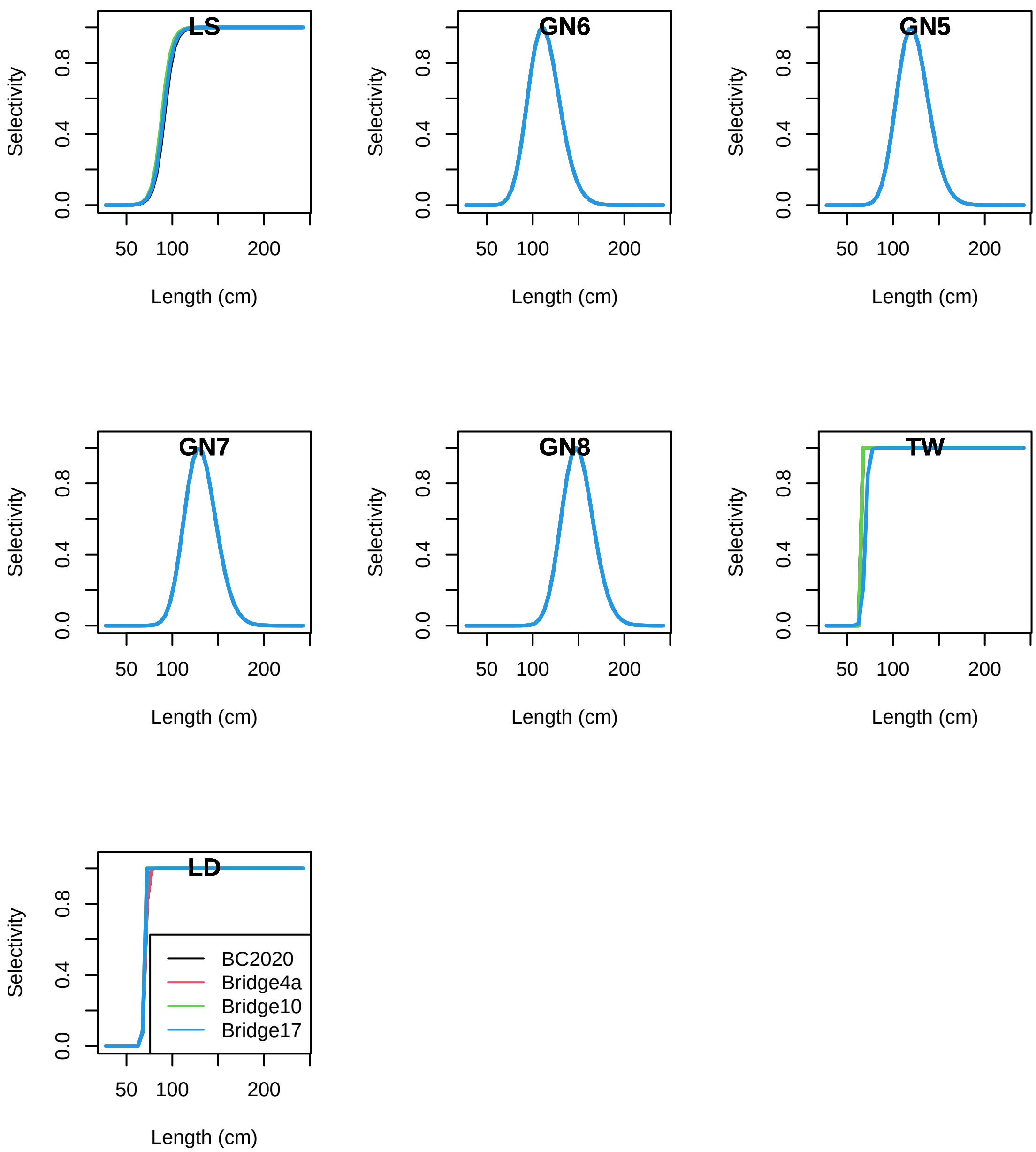


Figure 12: Selectivity functions for the seven gear types for selected model runs. Shallow line (LS), 6in Gillnet (GN6), 6.5in Gillnet (GN5), 7in Gillnet (GN7), 8in Gillnet (GN8), Trawl (TW), Deep line (LD).

5.2 2023 Base case

At its 10-11 October 2023 meeting SharkRAG selected “Bridge 17” as the base case model for the 2023 Gummy Shark assessment update. This model makes the following choices:

- net length based CPUE for gillnets, with the series for SA being broken into two at 1995 and ending in 2009 (unlike previous assessments where this series was not split),
- estimates effort saturation for all stocks,
- does not estimate selectivity for gillnet gears,
- estimates natural mortality,
- does not use a Danish seine fleet,
- does not use port length data,
- uses both the age and length measurements from shark whose vertebrae were sampled, where both are available (i.e. conditional age-at-length) and only age data where length data are unavailable (i.e. age composition),
- extends the plus group age from 10 to 20 years.

This base case model was used for sensitivity tests, RBC calculations and forward projections. Base case model fits to data are shown below or in Appendix B. Retrospectives and a likelihood profile for adult natural mortality (M) are shown below.

5.2.1 Recruitments

Below, the recruitment deviations for the 2023 base case model (Bridge 17) are plotted (Figure 13). In the early years of the model, there is little variability in the recruitment deviations given a lack of data to inform them as only catch is available in these time periods. Once more data are available (i.e. CPUE, length, age) the recruitment deviations seem to oscillate across all three stocks with a mix of peak and troughs throughout the timelines, and are most pronounced for the South Australia stock. Interestingly, the model has estimated above average recruitment for both the South Australian and Bass Strait stocks quite consistently in recent years. Tasmania’s recruitment is also above average, but this is more recent and less pronounced. Recruitment deviations are at or near maximum estimated values for all three stocks. Note, that these time series end five years prior to the end year of the model, which is 2017 for the updated 2022 models.

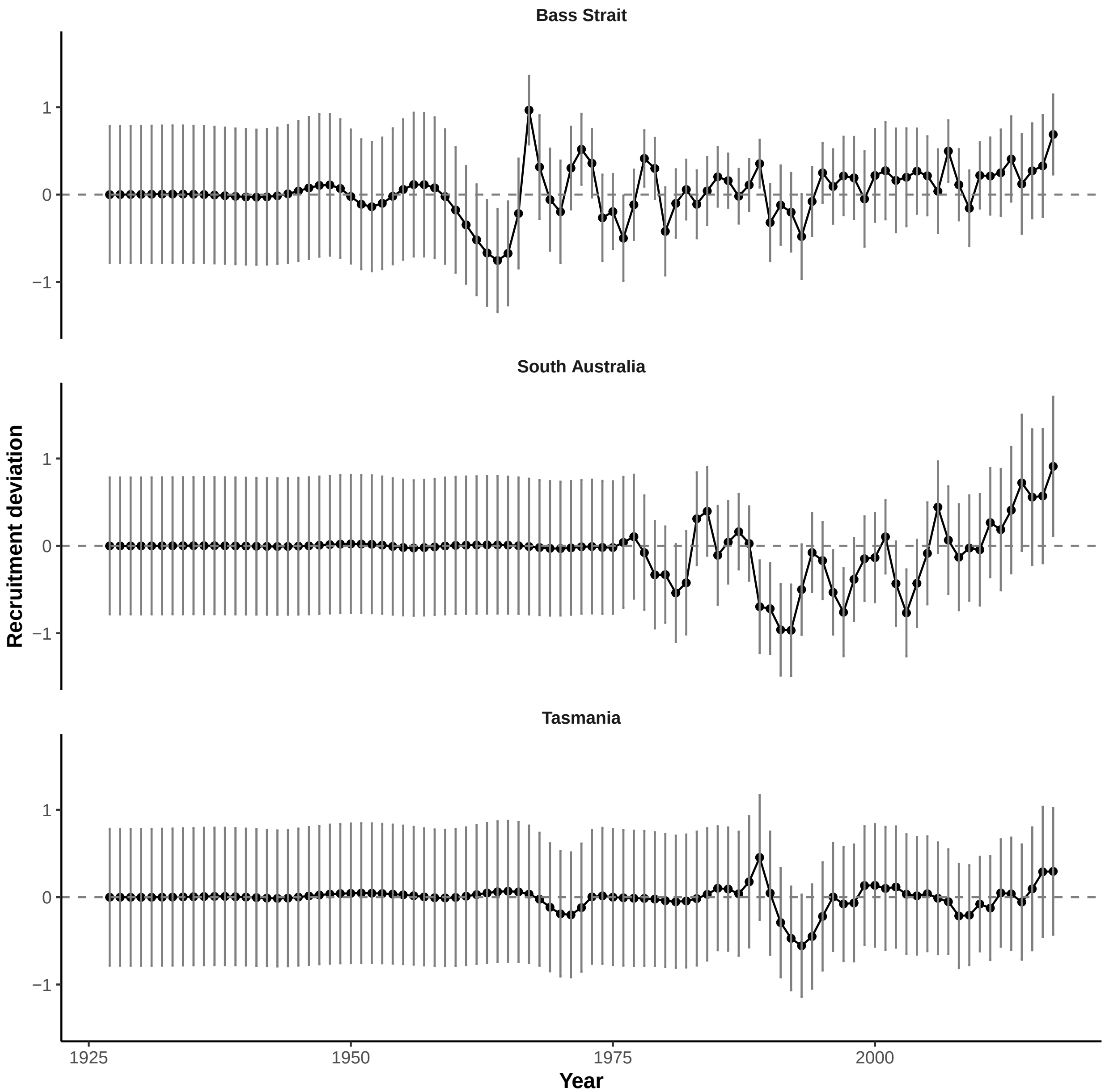


Figure 13: Gummy Shark recruitment deviations by stock for the 2023 base case stock assessment.

5.2.2 Fit to CPUE

The fits to the standardised CPUE time series used by three of the bridging model steps are shown below (Bridge 15–17) to compare the model fits to the modified South Australian gillnet CPUE time series relative to the traditional time series used (Figure 14). Starting the CPUE time series at 1988 rather than 1984 in Bridge 16 led to an improved fit to the early data, with the sharp decline in the model fit in the early years of Bridge 15 removed. Splitting the time series at 1995 in Bridge 17 allows the model to account for quite a large step change in the South Australian gillnet CPUE time series that occurred around 1995 where values shifted from averaging around 20–40, to 60–70. This step change represents a shift in targeting from in the South Australian fleet for school shark to Gummy Shark. Therefore, the model fits to two stable CPUE time series, rather than a single increasing CPUE time series. Outputs from these steps suggest that the South Australian gillnet CPUE time series should be split at 1995 as there is quite a clear step change in CPUE around this time where targeting of Gummy Sharks increased.

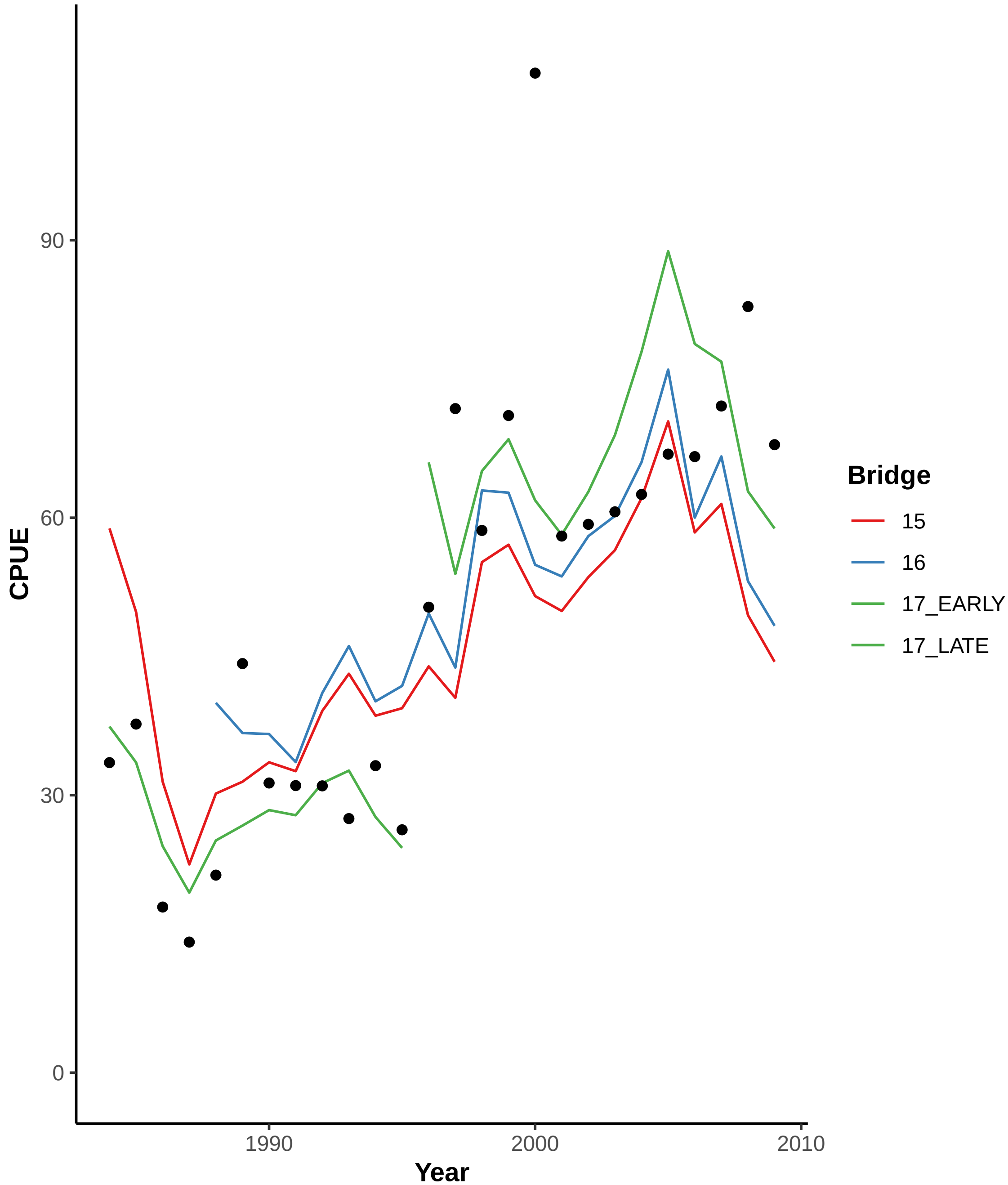


Figure 14: Standardised CPUE time series (Observed) and associated model estimated relative exploitable biomass (Predicted) for Bridge 17 where South Australian gillnet CPUE time series is broken into two at 1995.

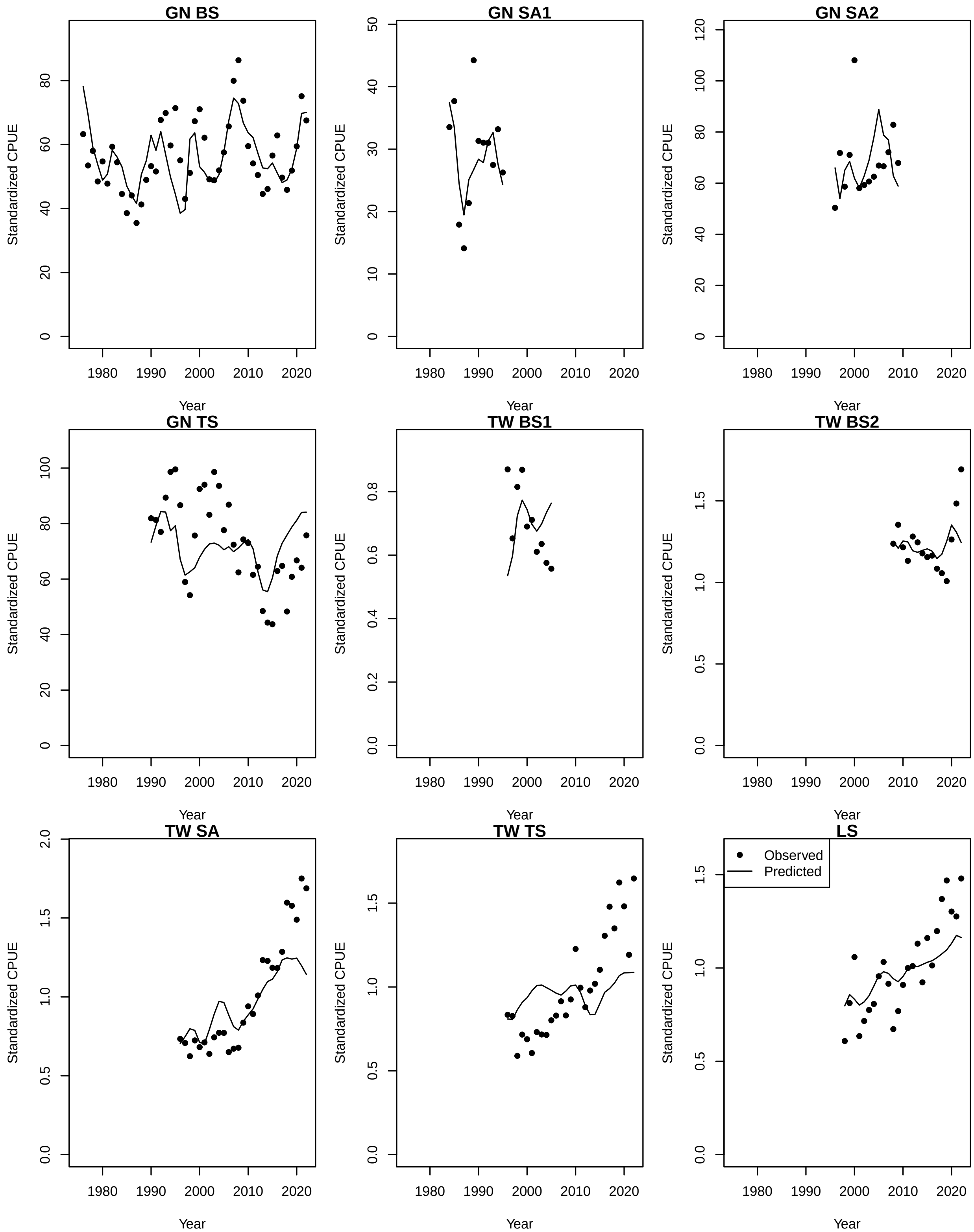


Figure 15: Standardised CPUE time series (Observed) and associated model estimated relative exploitable biomass (Predicted) for Bridge 17 where South Australian gillnet CPUE time series is broken into two at 1995.

5.2.3 Fit to age data

The original Gummy Shark stock assessment model was conditioned using age composition data, not to conditional age-at-length (Pribac *et al.* 2005). Any measurements of both the length and the age of individual fish were turned into age-length keys and applied to length frequency data to generate age composition data. Those length frequencies were then excluded from the model as they are subsumed into the age composition that was generated from them. A better, and more modern, method of using age and length data, is to fit the model to the age-length key. This is known as conditional age-at-length data. Where possible, historical age and length measurements have been obtained and included in the model as conditional age-at-length data and any age compositions that were generated using those data have been removed. However, several age compositions remain for which individual age-length measurements were not available to the authors. The overall base case model fit to age compositions by sex, gear and region are shown in Figure 16 and the individual yearly fits are shown in Appendix B.

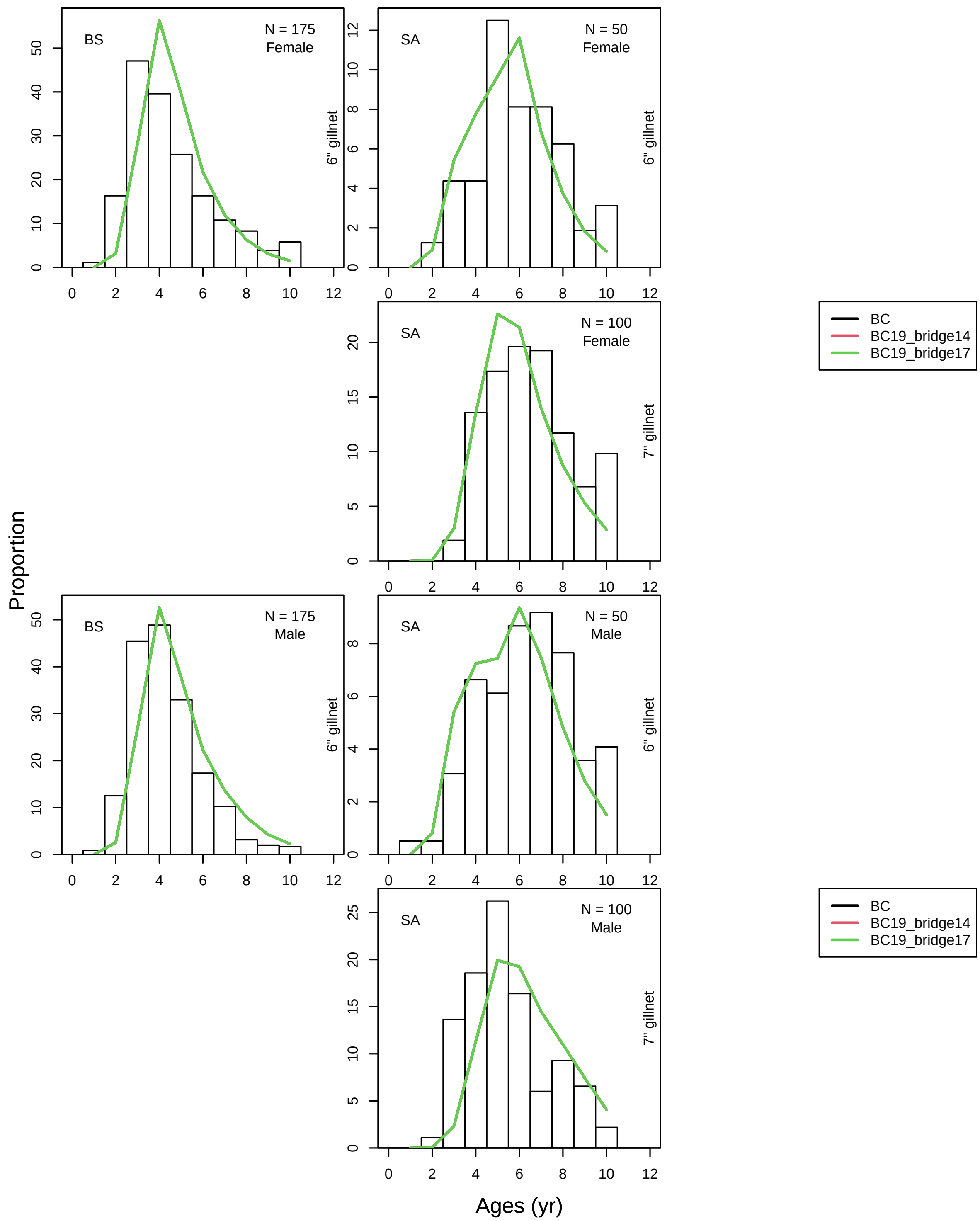


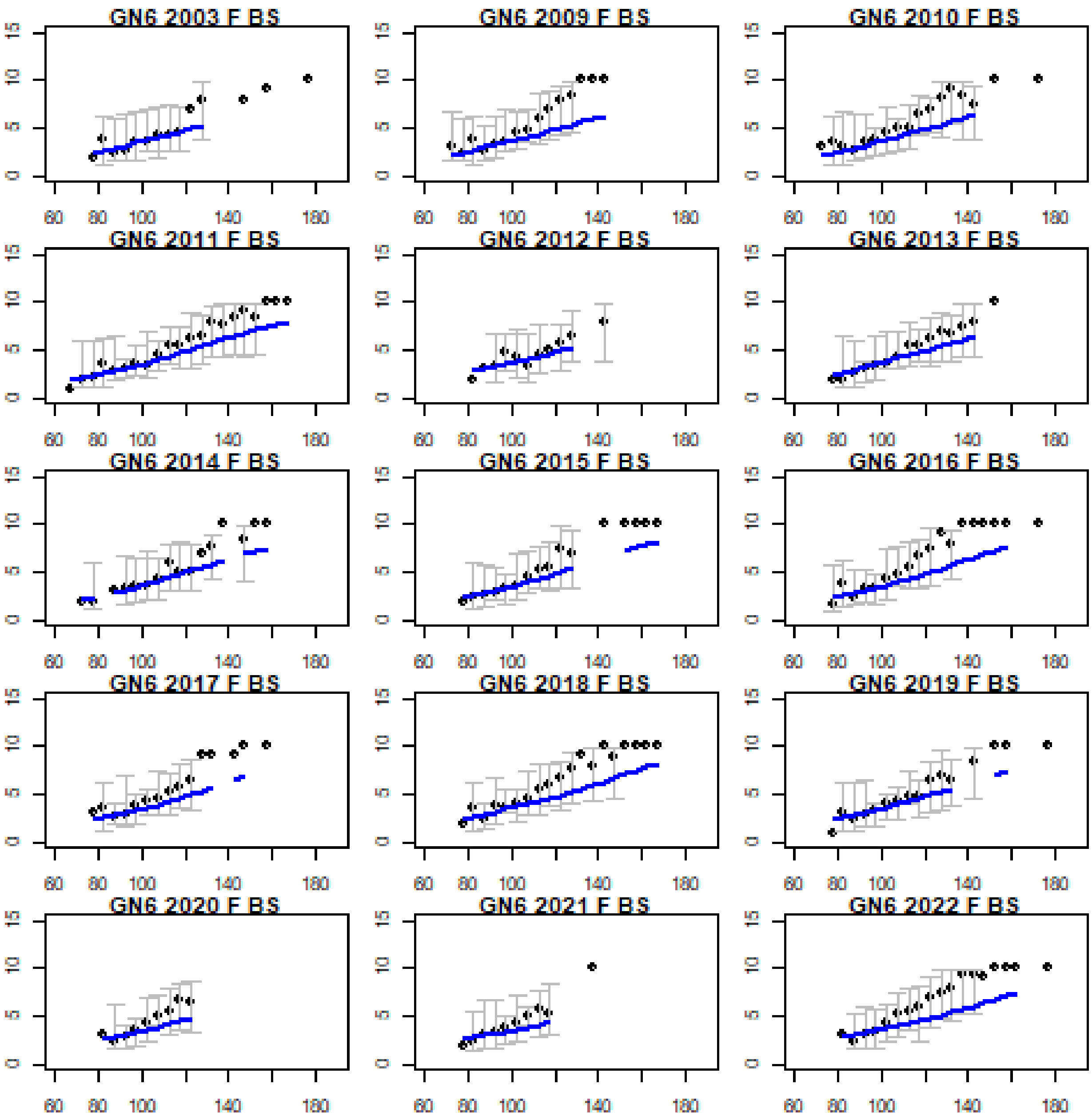
Figure 16: Observed (bars) and predicted (lines) age frequencies for the final model. Observations and predictions have been summed over all years. The assumed effective sample size is shown (N). Results are shown for females and then males.

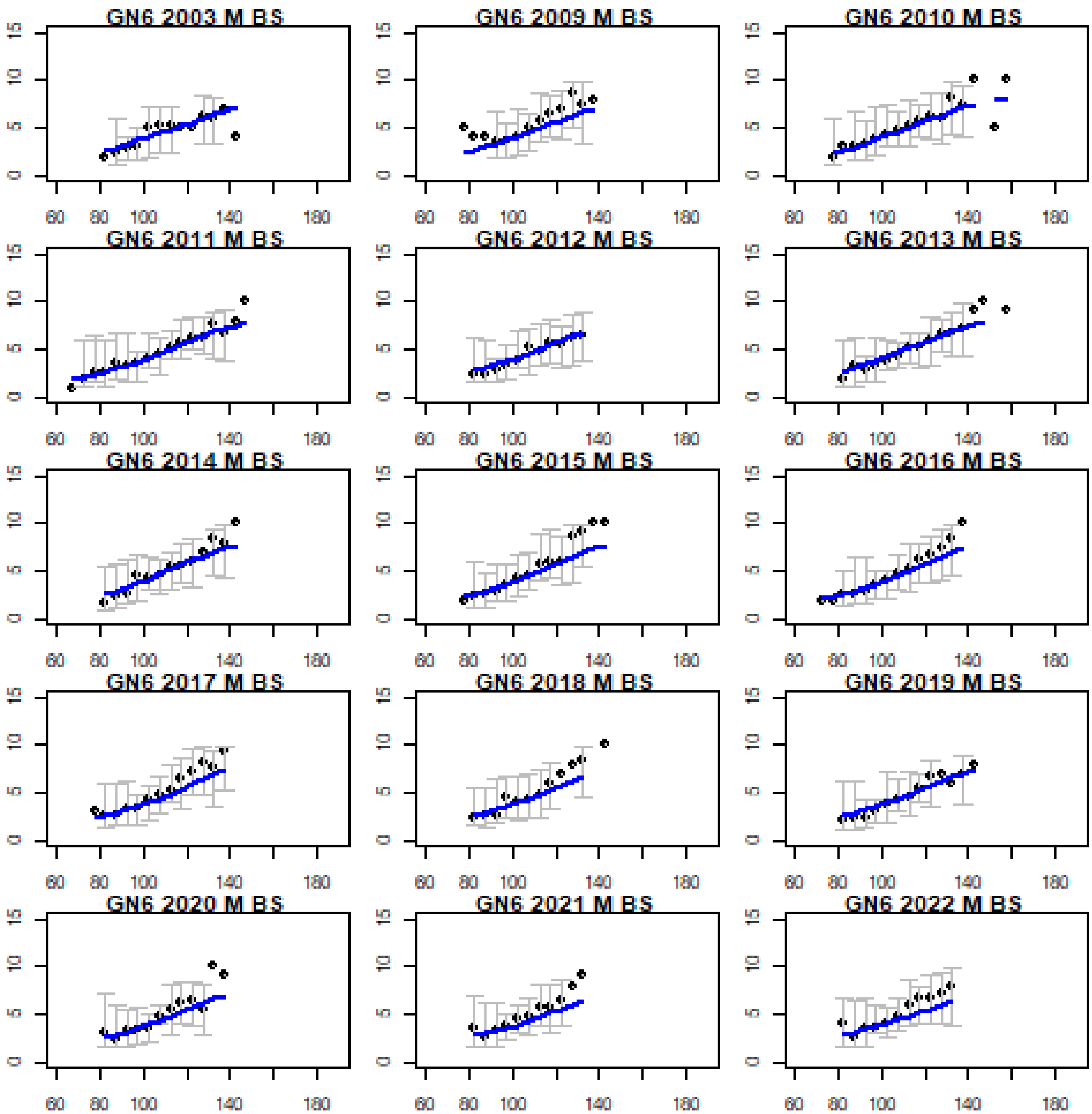
5.2.4 Conditional age-at-length fit

Conditional age-at-length data were introduced to the Gummy Shark assessment model in 2020. Consequently, poor correspondence was noted between the model estimated and observed ages at larger lengths. The model used a plus group of 10 years, which clearly forced poor fits for some data where observed ages were much greater than 10 years. Model development work in 2022 showed that the conditional-age-at-length fitting procedure was robust to higher plus group ages, and did not attempt to fit, disproportionately, to relatively small sample sizes for the higher age categories. The plus group age was therefore raised to 20 years for all gears, years and stocks. A plus group age of 10 years is retained when fitting to age composition data, all of which is from gillnet gears and does not contain ages older than 10 years. Fits are shown for conditional-age-at-length when the plus group age is 10 years (Figure17; Bridge 14) and 20 years (Figure 18; Bridge 17, 2023 base case).

Extending the plus group age was a recommendation as a result of the 2020 stock assessment in an attempt to improve fits of the model to larger Gummy Sharks where their ages are currently being underestimated. Extending the plus group age to 20 does result in better model fits as the length data does not plateau at age 10. However, the model still seems to be underestimating age at larger lengths. To investigate the impact of alternative growth curves, the base case model was re-run with the growth curves replaced by curves that were estimated, outside the model, from the age-length data (Bridge 18). The new growth curve for males was similar to that used in the base case, so another sensitivity was run in with only the female growth parameters were replaced (Bridge 19). Note that these new growth curves do not account for the impact of selectivity, which can result in incorrect, apparent growth. For example, the fastest growing individuals become available to the gear at younger ages than individuals that grow at the average rate - so growth curves calculated from samples taken from the fishery will exaggerate growth rates for younger fish. These sensitivities should not be taken as alternative base case models.

It may be that growth varies spatially and needs to be estimated separately across the three stocks, as was suggested by the study from which the base case model's growth parameters were drawn (Moulton *et al.* 1992). However, this may be difficult given the variable sampling undertaken for each stock.


GN6 2003 F BS
GN6 2009 F BS
GN6 2010 F BS
GN6 2011 F BS
GN6 2012 F BS
GN6 2013 F BS
GN6 2014 F BS
GN6 2015 F BS
GN6 2016 F BS
GN6 2017 F BS
GN6 2018 F BS
GN6 2019 F BS
GN6 2020 F BS
GN6 2021 F BS
GN6 2022 F BS


GN6 2003 M BS
GN6 2009 M BS
GN6 2010 M BS
GN6 2011 M BS
GN6 2012 M BS
GN6 2013 M BS
GN6 2014 M BS
GN6 2015 M BS
GN6 2016 M BS
GN6 2017 M BS
GN6 2018 M BS
GN6 2019 M BS
GN6 2020 M BS
GN6 2021 M BS
GN6 2022 M BS
0 5 10 15
60 80 100 140 180

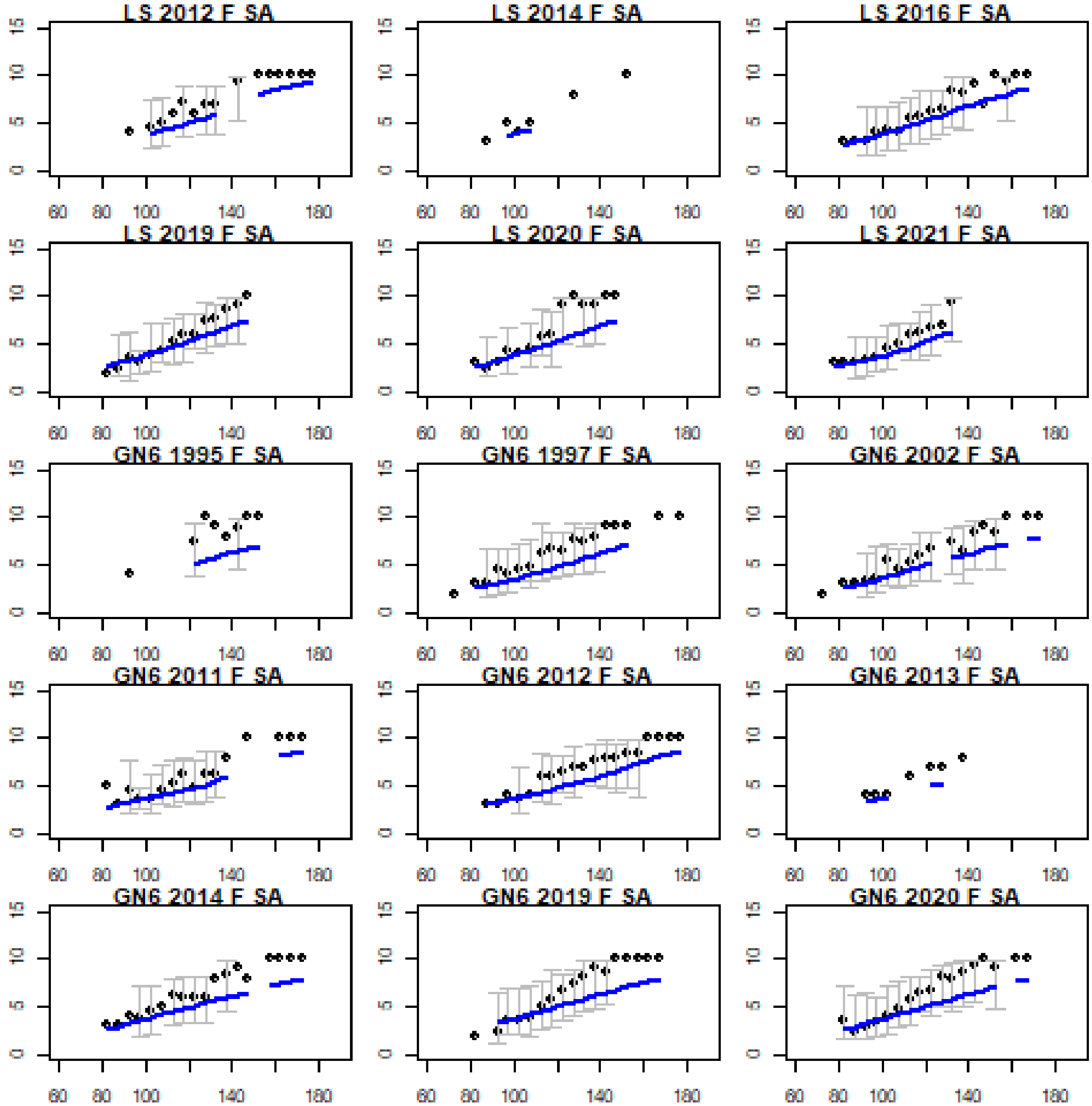
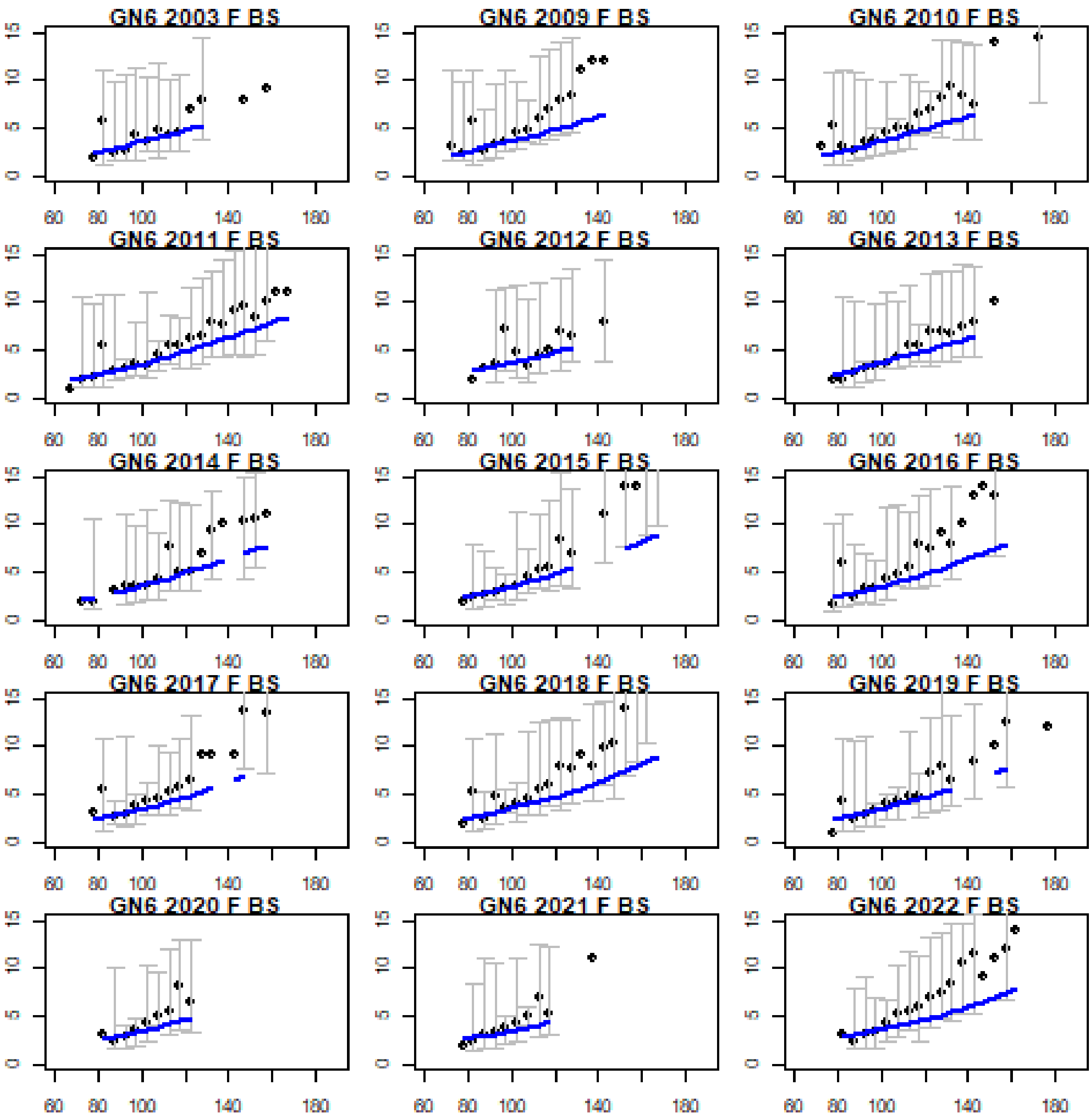
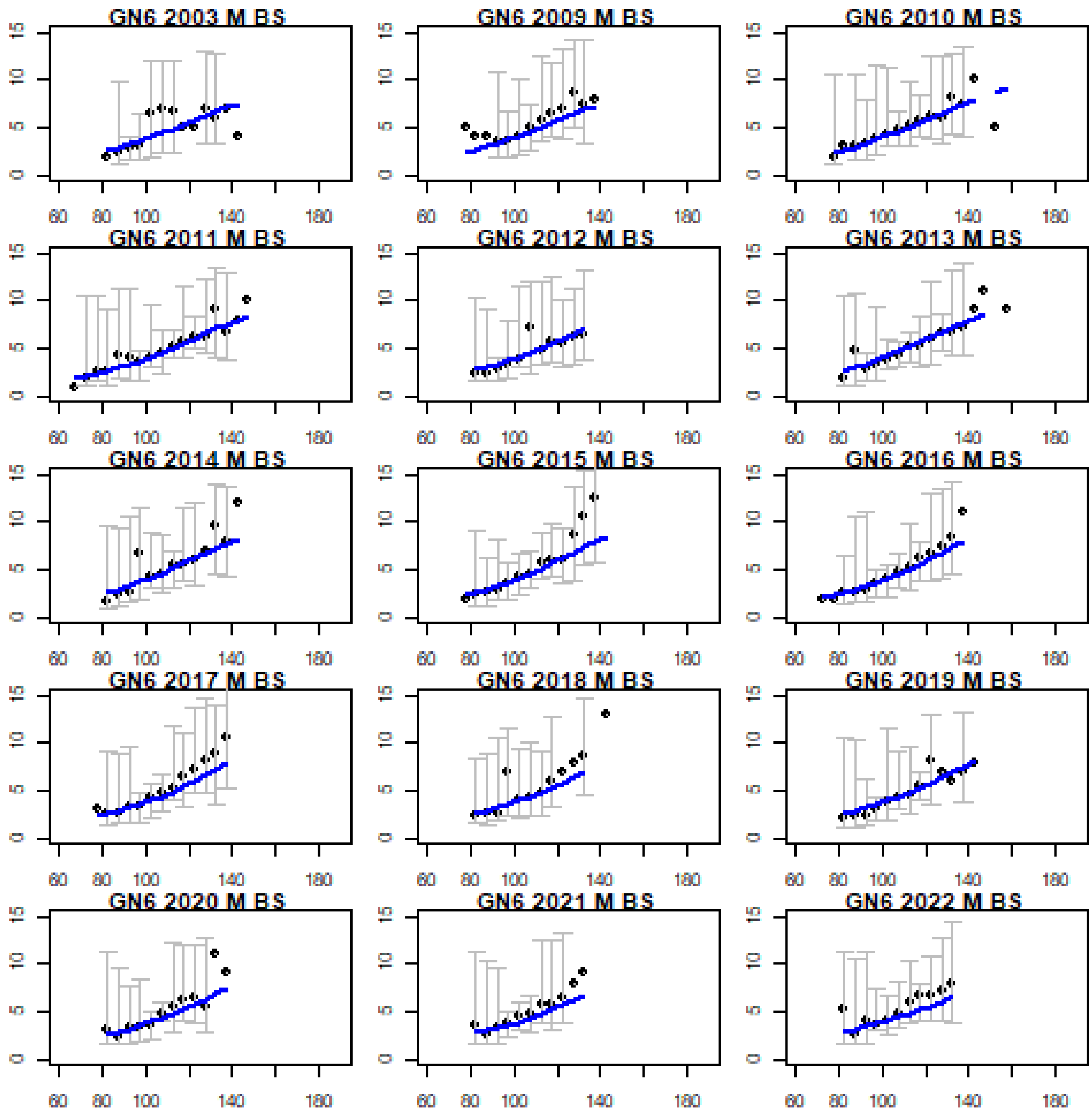


Figure 17: Observed conditional age-at-length (dots and 90% error bars) and expected age-at-length (blue line) for model Bridge 14 where the plus group age is 10 years.



GN6 2003 F BS
GN6 2009 F BS
GN6 2010 F BS
GN6 2011 F BS
GN6 2012 F BS
GN6 2013 F BS
GN6 2014 F BS
GN6 2015 F BS
GN6 2016 F BS
GN6 2017 F BS
GN6 2018 F BS
GN6 2019 F BS
GN6 2020 F BS
GN6 2021 F BS
GN6 2022 F BS
0 5 10 15
60 80 100 140 180


GN6 2003 M BS
GN6 2009 M BS
GN6 2010 M BS
GN6 2011 M BS
GN6 2012 M BS
GN6 2013 M BS
GN6 2014 M BS
GN6 2015 M BS
GN6 2016 M BS
GN6 2017 M BS
GN6 2018 M BS
GN6 2019 M BS
GN6 2020 M BS
GN6 2021 M BS
GN6 2022 M BS

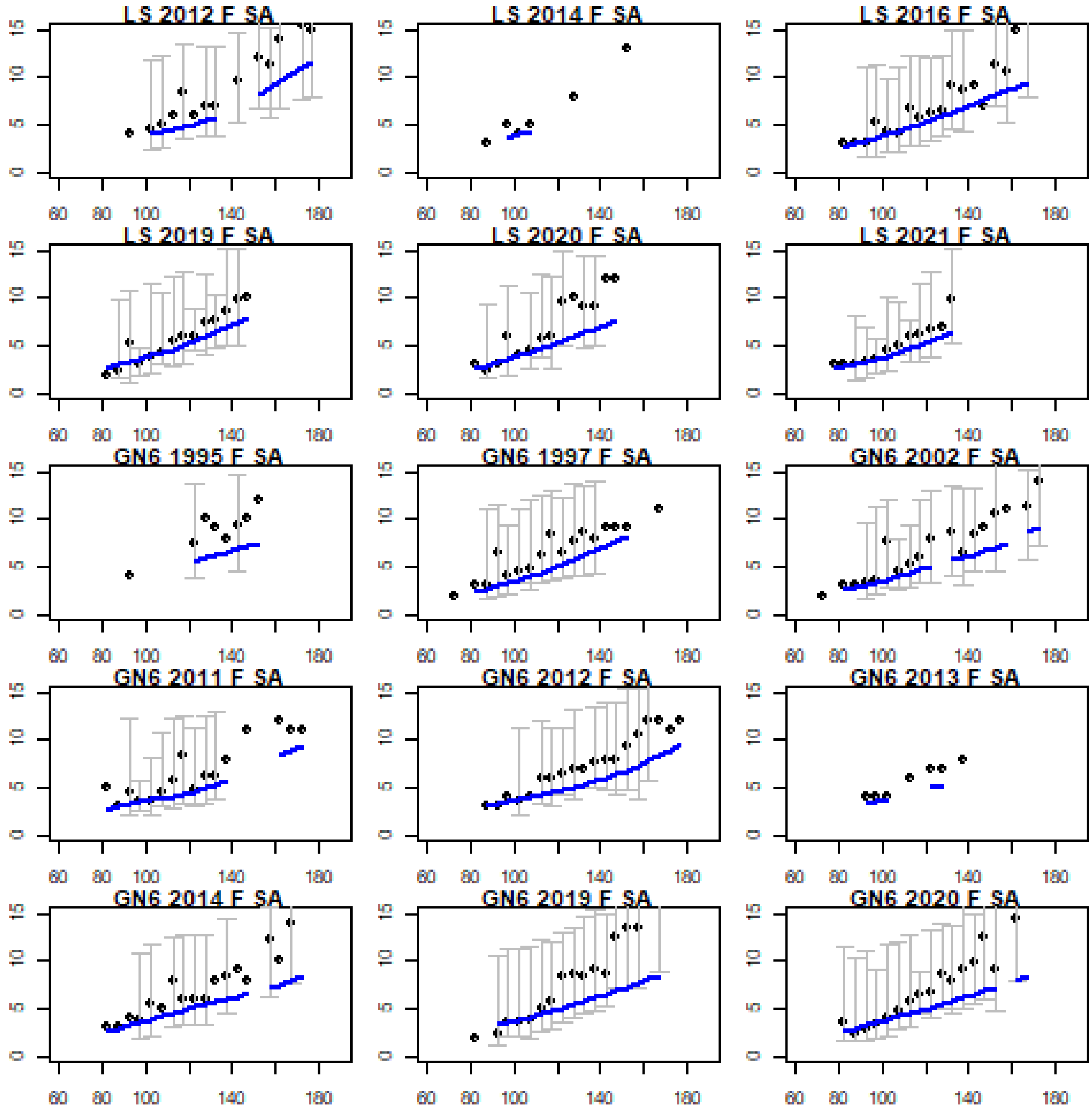
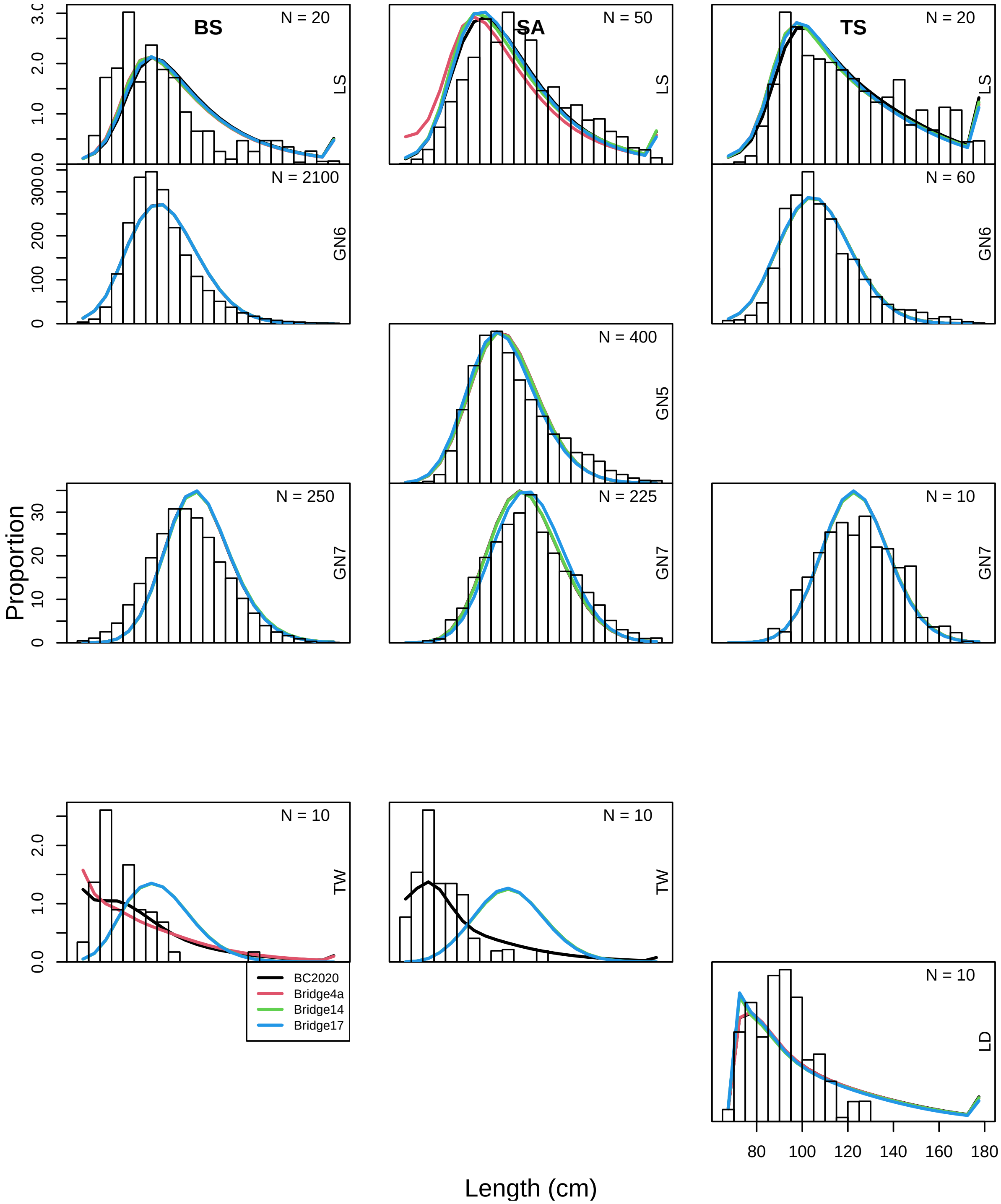


Figure 18: Observed conditional age-at-length (dots and 90% error bars) and expected age-at-length (blue line) for the 2023 base case model (Bridge 17) where the plus group age is extended to 20 years.

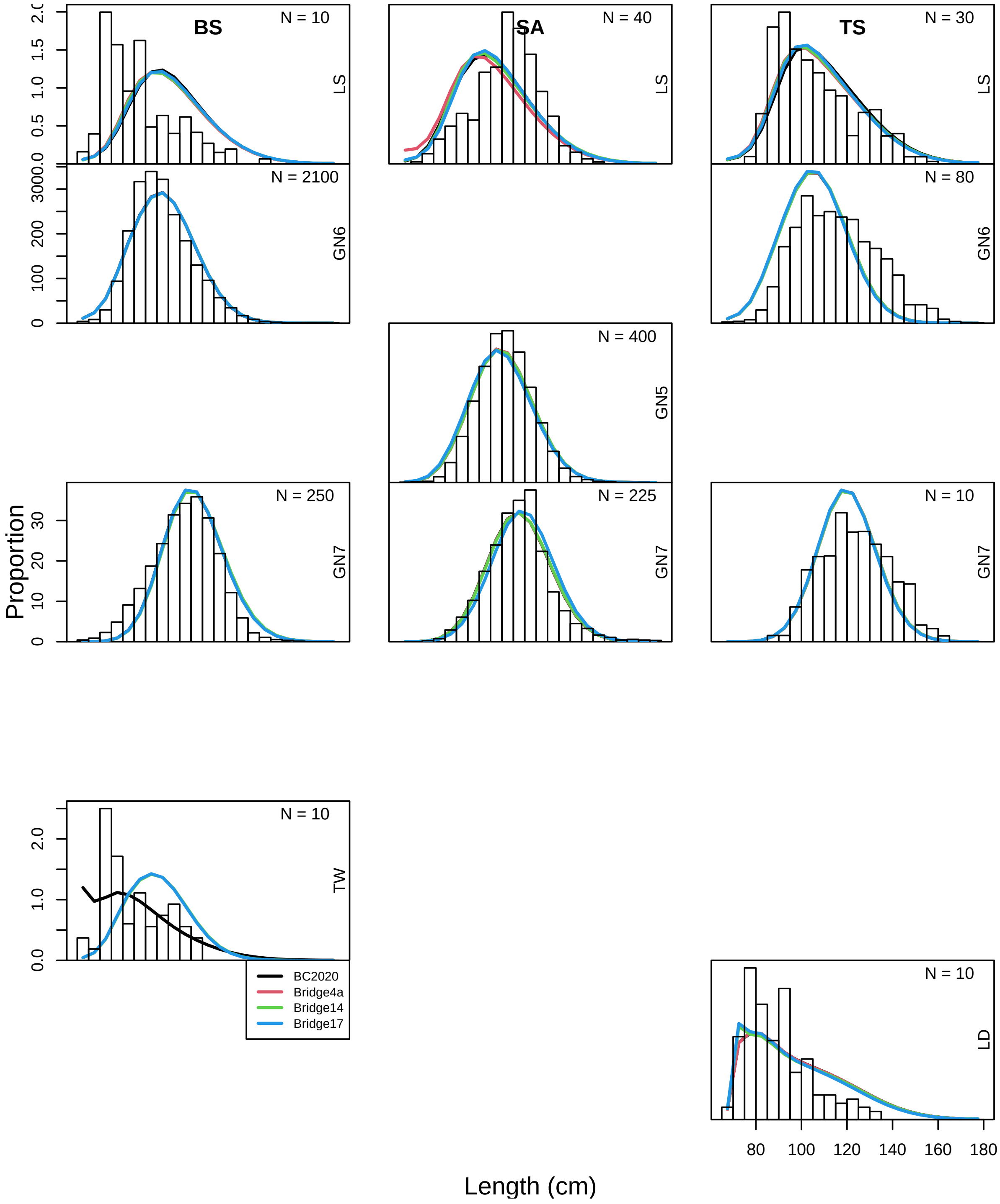
5.2.5 Fit to length frequencies

Overall (summed over years) observed and predicted length frequencies are shown in Figure 19 and 20. Fits to individual length frequencies (by sex, year, stock, and gear) are shown in Appendix B.

These fit well for gillnet gears, but the plus group is poorly estimated for the trawl and line gears, which are expected to catch more larger animals than they do. This could indicate the mortality rates are higher than estimated (either natural or fishing mortality), or that larger animals are unavailable to the gear (i.e. dome-shaped selectivity). There are also differences between the early and late bridges as to how they fit to the trawl data. Early bridges (2020 base case and Bridge 4) almost fit a linear, declining slope whereas the later bridges (e.g. Bridge 17) fit a dome, but the dome is overestimating the length of individuals encountered by the trawl fleet. It should be noted the sample sizes for these are low and so the model does not have much data to fit to. This also means that these fits should not be given much weight by the model.



BS
SA
TS
N = 20
N = 50
N = 20
LS
N = 2100
N = 60
GN6
N = 400
GN5
N = 250
N = 225
N = 10
GN7
N = 10
N = 10
TW
N = 10
LD
BC2020
Bridge4a
Bridge14
Bridge17
Proportion
Length (cm)
80
100
120
140
160
180



BS
SA
TS
N = 10
N = 40
N = 30
LS
N = 2100
N = 80
GN6
N = 400
GN5
N = 250
N = 225
N = 10
GN7
N = 10
TW
N = 10
LD
BC2020
Bridge4a
Bridge14
Bridge17
Proportion
Length (cm)
80
100
120
140
160
180

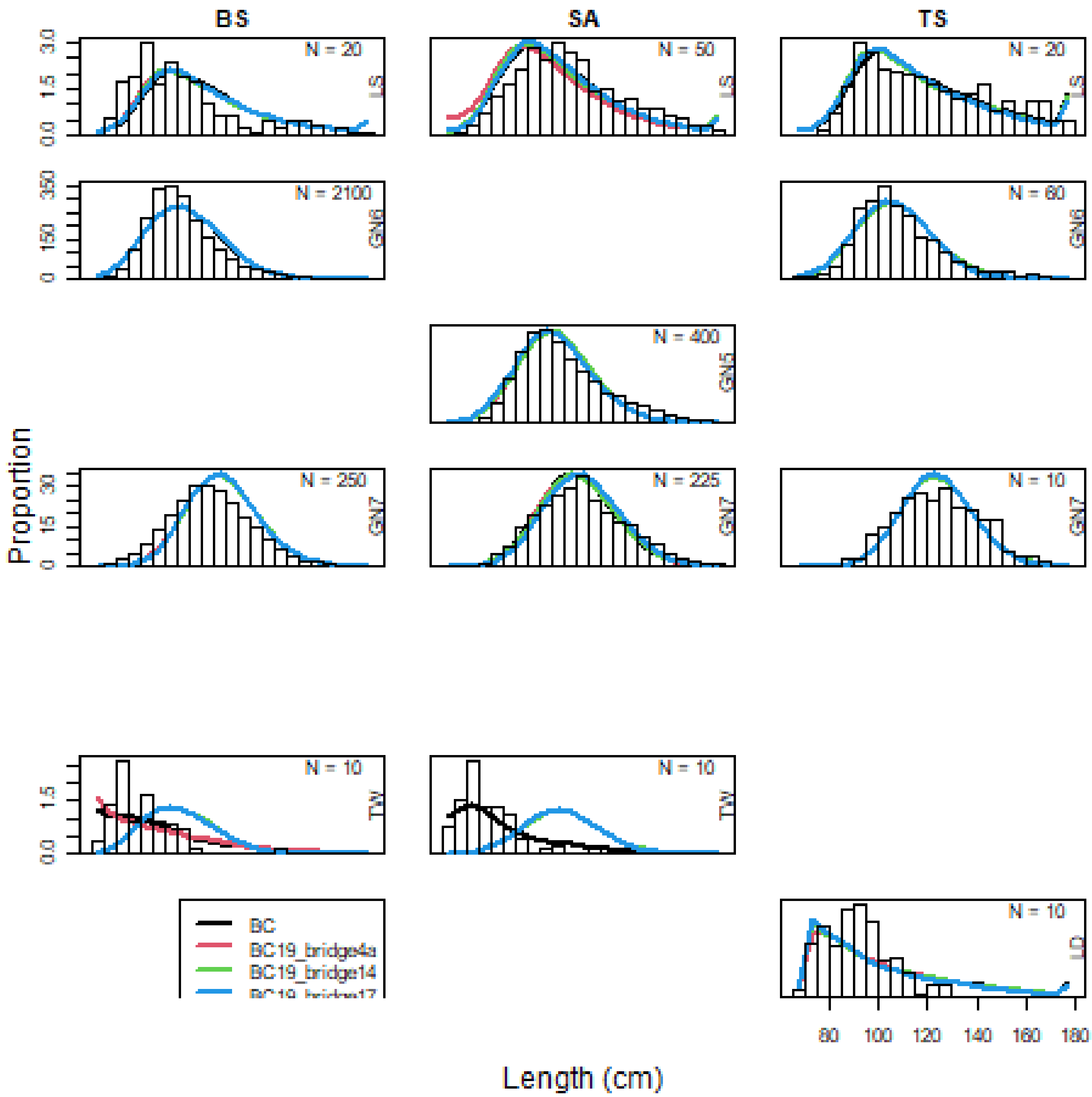


Figure 19: Observed (bars) and predicted (lines) length frequencies for females for selected models during bridging. Observations and predictions have been summed over all years. The assumed effective sample size is shown (N).

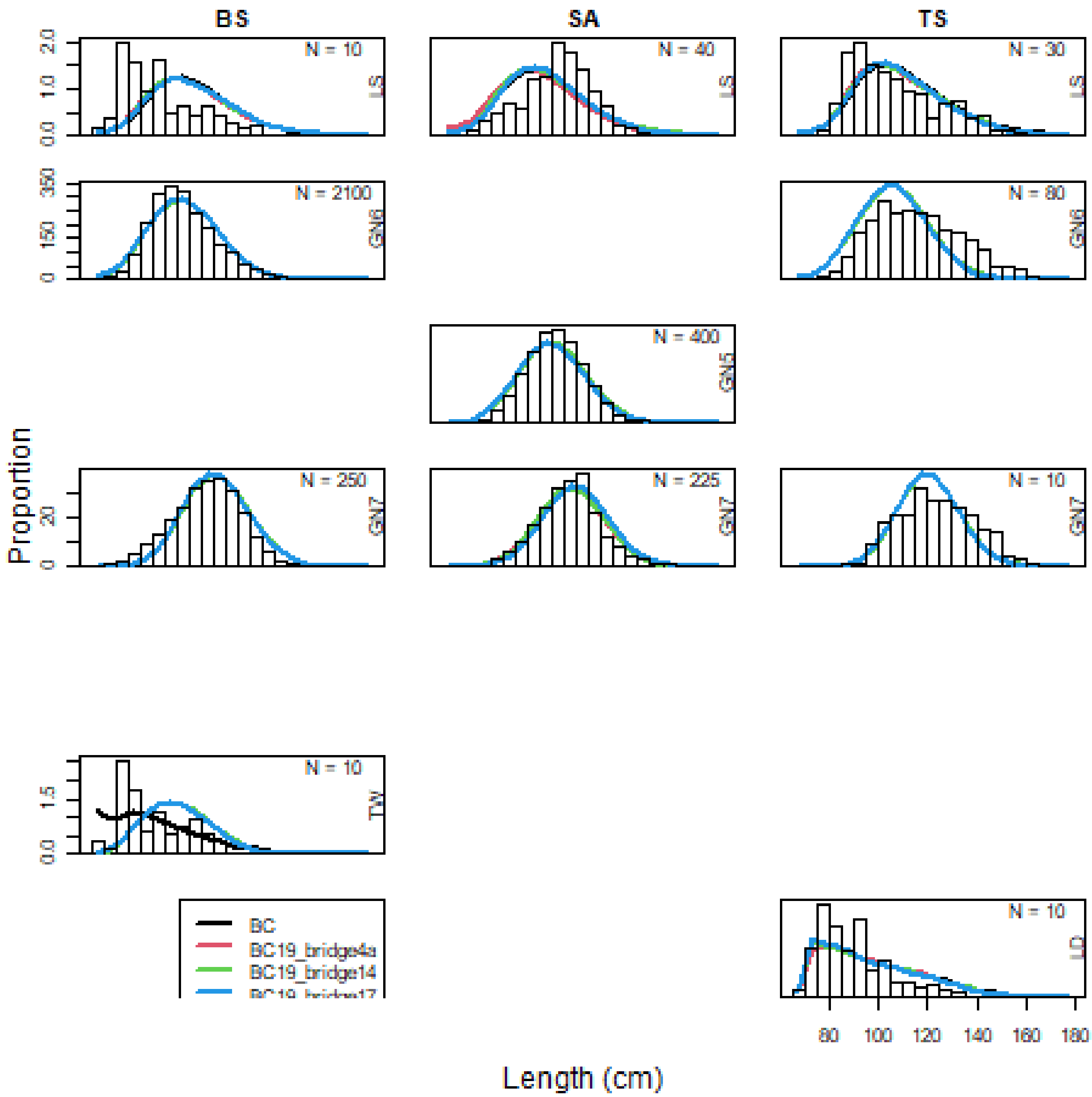


Figure 20: Observed (bars) and predicted (lines) length frequencies for males for selected models during bridging. Observations and predictions have been summed over all years. The assumed effective sample size is shown (N).

5.2.6 Fit to tagging data

Tag release and return data resulting from work done during 1940 to the early 2000s is included in the Gummy Shark stock assessment mode, along with calculated estimates of tag loss rates, and expert judgment on tag return rates (which change over time - higher when targeted advertising campaigns and incentives were availabe to the fishing industry). After the early 2000s, changes at the Victorian fisheries research agency (MAFRI) meant that there was no longer a mechanism for recording any recaptured tags so the model no longer expects any returns after 2005. Observed and base case model expected numbers of releases aggregated to stock and year, are shown in Figure 21.

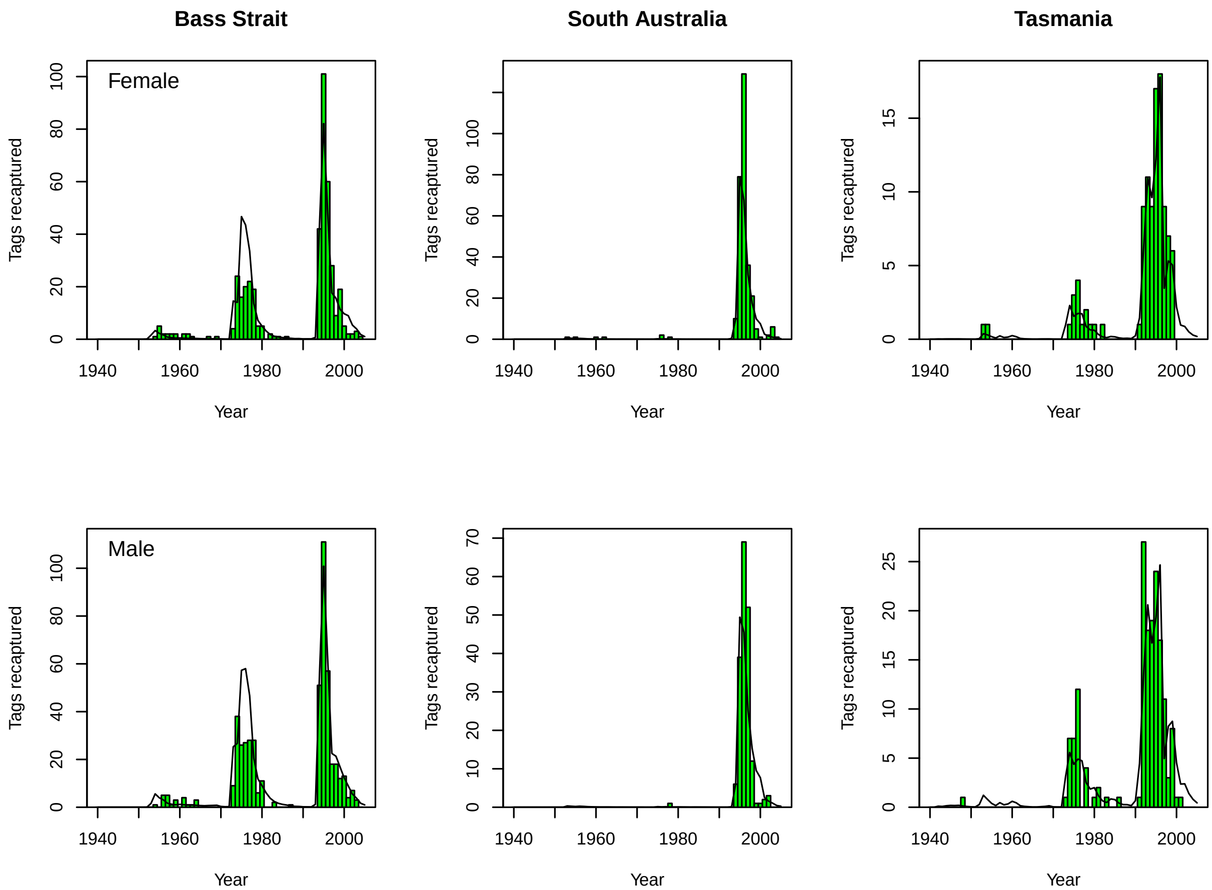


Figure 21: Observed (green bars) and expected (lines) numbers of tags returned by population and year.

5.3 Restrospectives

Retrospective analyses are shown for the base case Gummy Shark model (bridge 17). This commonly used diagnostic test is used to reveal possible model misspecification. If the model does not include an important aspect of the dynamics of the stock then it is possible that the value of an estimated parameter will slowly increase or decrease as more years of data are added. Such a pattern can be revealed by removing one year of data at a time and looking for such a change. Data were removed, from 2022 up to an including 2016, which constitutes seven so-called 'peels' and the Mohn's rho statistic was calculated using the icesAdvice R package. Values outside of the range [-0.15, 0.2] are considered a sign of a retrospective pattern and therefore possible model misspecification (Brooks & Legault 2015). Retrospective analysis for estimated pup production resulted in Mohn's rho statistics that are within the bounds for all three stocks (-0.09, -0.05 and -0.06, Figure 22).

Although the estimated pup production does not raise concern via the Mohn's rho statistic, it is notable that the estimates of natural mortality show an upward trend as each year of data is removed. The estimate of M from the base case model using all data to 2022 is 0.177, as each successive year of data is removed the estimates of Ms are (starting with the full model): 0.177, 0.180, 0.178, 0.181, 0.186 and 0.19. Coupled with the clear misfit to conditional-age-at-length data this does suggest model misspecification that could impact the RBC calculations and therefore the sustainable management of the Gummy Shark stocks. Interestingly, the base case model in 2020 and 2016 base case model estimates of M were both 0.16 and the 2013 base case was 0.18, so other changes in the model structures have interacted with these estimates.

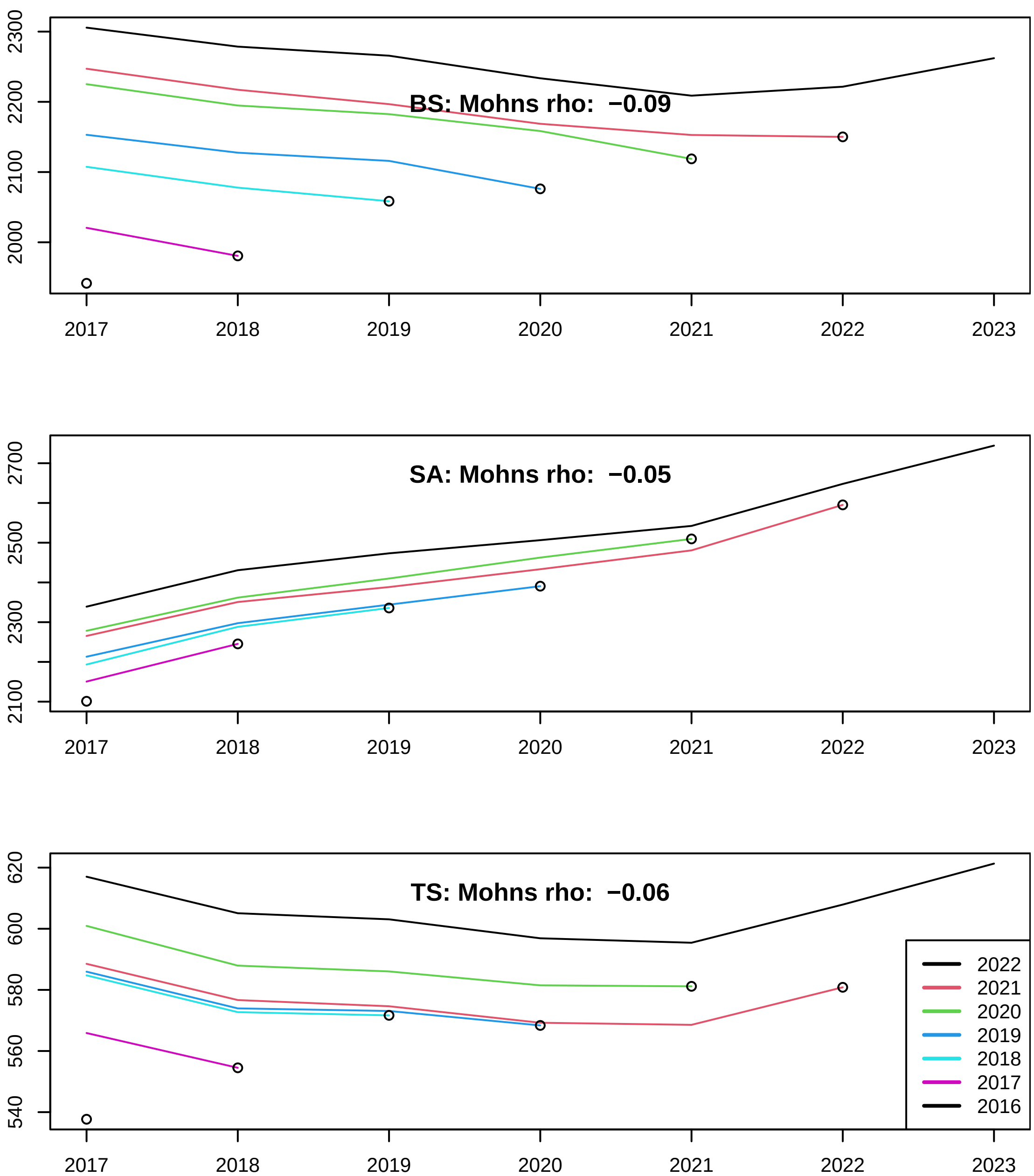


Figure 22: Estimated pup production in Bass Strait (top), South Australia (middle) and Tasmania (bottom) for seven retrospective peels. The Mohn's rho statistic is shown.

5.4 Likelihood profiles

A likelihood profile for adult natural mortality is shown for the base case model in Figure 23. The tagging data indicates a relatively high value for M, above 0.24, whereas other data sources (CPUE, Length, conditional age-at-length (ALK)) and the prior that keeps the variance in recruitment deviations close to 0.4, all point to an M value below 0.15. The age composition data indicates an M value close to 0.15. The result, for the 2023 Gummy Shark base case model, is a maximum likelihood value of 0.177 with a relatively narrow confidence interval.

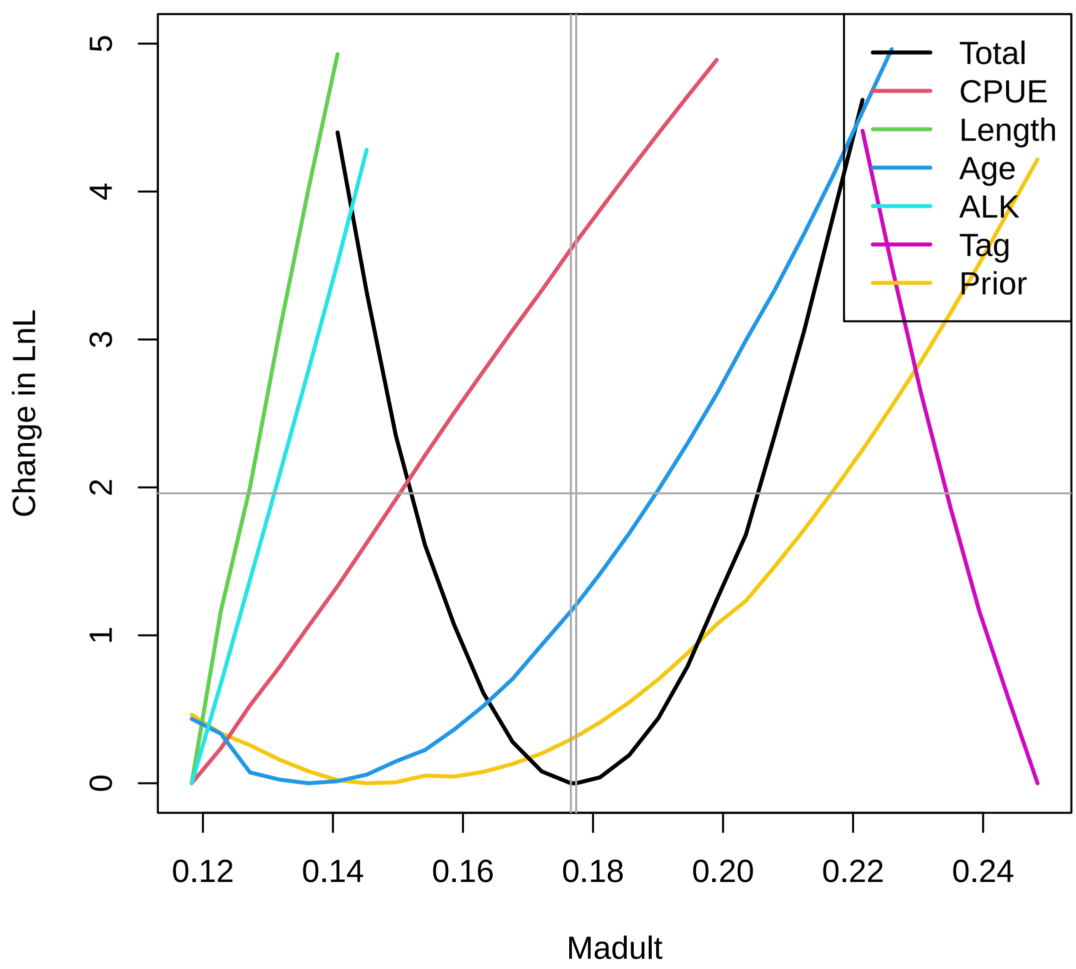


Figure 23: Likelihood profile for adult natural mortality for the base case model.

5.5 Sensitivities

Several standard sensitivity tests are routinely conducted for the Gummy Shark stock assessment (Thomson 2020). The following sensitivity tests have been performed:

1. density dependence acts on M for ages 0–15, as a function of 1+ biomass.
2. density dependence acts on M for ages 0–4, as a function of 1+ biomass.

3. density dependence acts on M for ages 0–2, as a function of 1+ biomass.
4. density dependence acts on M for ages 0–30, as a function of mature biomass.
5. density dependence acts on M for ages 0–15, as a function of mature biomass.
6. density dependence acts on M for ages 0–4, as a function of mature biomass.
7. density dependence acts on M for ages 0–2, as a function of mature biomass.
8. no effort saturation for gillnet CPUE (i.e. linear relationship with biomass).
9. all age classes are equally available to gillnet gear.
10. Estimate gillnet selectivity and availability
11. Estimate gillnet selectivity but not availability
12. M is 0.01 lower than the base case estimate (0.17).
13. M is 0.01 greater than the base case estimate (0.19).
14. the weight given to the CPUE data is doubled.
15. the weight given to the CPUE data is halved.
16. the weight given to the length frequency data is halved.
17. the weight given to the age composition data is halved.
18. the weight given to the conditional age-at-length data is halved.
19. the weight given to the tagging data is halved.
20. the weight given to the trawl CPUE is reduced to almost nothing (a new sensitivity).

Two sensitivity tests relating to estimation of selectivity for gillnet fleets (with or without additional estimation of an availability function) have been dropped due to lack of time. Some changes, such as moving from using gillnet CPUE that use operation as the effort unit, to net length based CPUE, were included in the bridging analysis and have not been repeated in the sensitivity analysis because their effect has been shown to be minimal.

The assumption made regarding how density dependence operates has a strong effect on the results (Figure 23; Table 7). As noted by Punt & Thomson (2016) the models that alter natural mortality on just ages 0–2 provide the best fits to the data. Because those models apply relatively large natural mortality rates (M) to 0–2 year olds, they consequently lower M for adult sharks. Estimated depletion is profoundly different amongst these sensitivity tests, with a range of 33 to 54% in Bass Strait, 55 to 106% in South Australia, and 60 to 73% in Tasmania. Similar results were shown by Thomson (2020).

Setting the effort saturation parameters to zero for all stocks (sens 8, Table 8) has minimal influence on model results. It reduces the estimated size of the stock during the peak effort period during the 1980s (not shown) but does not greatly alter the early and recent part of the time series and therefore has little impact on estimated recent stock status.

Removing the availability function (sens 9, Table 8) has a large impact on model results, with an unrealistically high estimate for adult mortality. The availability function was noted to have flipped, compared with earlier models (Pribac *et al.* 2005) so that whereas it used to make the youngest ages unavailable to the fishery it, now makes the older ages unavailable. This 'flip' is seen in the 2023, 2020 and 2016 base case models. Further investigation of the reason for this change is recommended.

The sensitivities that raise or lower the value of adult natural mortality, compared with the base case lead to only slight changes compared to the base case (sens 12 and 13, Table 8).

Altering the relative weights given to the CPUE data, age composition, length composition, conditional-age-at-length and tagging data has minimal impact on the results (sens 12–18, Tables 8 and 9) although there is variation in the estimated adult natural mortality values (M), suggesting some conflict amongst data sources regarding the value of M.

A new sensitivity test was added, which reduces the weight for all four trawl CPUE time series to almost zero, to assess the impact of these, increasing, time series. As expected, estimated stock status is lower for South Australia and Tasmania but surprisingly is higher for Bass Strait. The changes are not large (sens 20, Table 9).

Table 6: Description of the sensitivity tests presented in this report. The way in which each differs from 'Bridge 17', the 2023 base case model, is described above

modname	fulldesc
Bridge 17_sens1	density dependence acts on M for ages 0-15, as a function of 1+ biomass
Bridge 17_sens2	density dependence acts on M for ages 0-4, as a function of 1+ biomass
Bridge 17_sens3	density dependence acts on M for ages 0-2, as a function of 1+ biomass
Bridge 17_sens4	density dependence acts on M for ages 0-30, as a function of mature biomass
Bridge 17_sens5	density dependence acts on M for ages 0-15, as a function of mature biomass
Bridge 17_sens6	density dependence acts on M for ages 0-4, as a function of mature biomass
Bridge 17_sens7	density dependence acts on M for ages 0-2, as a function of mature biomass
Bridge 17_sens8	No effort saturation for gillnet CPUE (i.e. linear relationship with abundance)
Bridge 17_sens9	All age classes are equally available to gillnet gear
Bridge 17_sens10	Selectivity for gillnet fleets is estimated (and so is availability) (not completed)
Bridge 17_sens11	Selectivity for gillnet fleets is estimated but all age classes are equally available (not completed)
Bridge 17_sens12	M is 0.1 lower than the base case estimate
Bridge 17_sens13	M is 0.1 greater than the base case estimate
Bridge 17_sens14	the weight given to the CPUE data is doubled
Bridge 17_sens15	the weight given to the CPUE data is halved
Bridge 17_sens16	the weight given to the length frequency data is halved
Bridge 17_sens17	the weight given to the age composition data is halved
Bridge 17_sens18	the weight given to the conditional age-at-length data is halved
Bridge 17_sens19	the weight given to the tagging data is halved
Bridge 17_sens20	trawl CPUE series are given negligable weight

Table 7: Quantities of interest for the 2020 base case (BC2020), the 2023 base case (Bridge 17), and sensitivity tests relating to density dependence. Abbreviations shown in column headings are are described in Table 1 and abbreviated model names (rows) in Table 6.

		B0			MSYR			Pem73			Pem final			Satn			negLL						
Model	M	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	Sum	Cpue	Len	Age	CAL	Tag	Pr
BC2020	0.16	9983	6212	2053	0.2	0.22	0.2	59	68	87	47	66	69	1.74	2.33	0	1767	195	631	156	389	326	70
Bridge 17	0.18	9709	5986	1914	0.21	0.23	0.21	59	69	87	50	63	69	0.7	0.91	0.7	1757	175	680	162	381	305	53
sens1	0.18	9519	5870	1855	0.23	0.25	0.23	56	66	85	44	60	65	0.68	0.9	0.68	1759	177	685	160	381	301	55
sens2	0.13	10805	6489	2412	0.23	0.25	0.23	50	61	84	35	56	64	1.03	1.06	2.23	1761	166	694	153	376	319	52
sens3	0.12	11294	6666	2382	0.21	0.24	0.21	48	60	83	33	55	60	1.17	0.99	2.44	1751	165	684	154	376	318	55
sens4	0.17	9366	5801	2029	0.17	0.19	0.17	53	82	88	54	95	73	0.96	0.65	1.14	1728	158	666	156	376	321	50
sens5	0.17	9424	5758	2030	0.17	0.18	0.17	49	82	87	49	95	70	0.98	0.64	1.1	1728	158	670	155	375	322	50
sens6	0.14	8837	5260	2121	0.16	0.18	0.16	39	82	87	42	99	68	1.08	0.86	1.37	1719	156	657	152	377	327	50
sens7	0.14	7138	4261	1746	0.18	0.2	0.18	27	82	84	42	106	67	1.21	0.97	1.28	1704	159	640	154	381	320	49

Table 8: Quantities of interest for the 2020 base case, the 2023 base case (Bridge 17), and sensitivity tests relating to alternative assumptions. Abbreviations shown in column headings are are described in Table 1 and abbreviated model names (rows) in Table 6.

		B0			MSYR			Pem73			Pem final			Satn			negLL						
Model	M	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	Sum	Cpue	Len	Age	CAL	Tag	Pr
BC2020	0.16	9983	6212	2053	0.2	0.22	0.2	59	68	87	47	66	69	1.74	2.33	0	1767	195	631	156	389	326	70
Bridge 17	0.18	9709	5986	1914	0.21	0.23	0.21	59	69	87	50	63	69	0.7	0.91	0.7	1757	175	680	162	381	305	53
sens8	0.18	9624	5936	1769	0.22	0.24	0.22	59	69	86	50	63	66	0	0	0	1789	201	682	161	382	306	56
sens9	0.3	7195	4593	1228	0.24	0.26	0.24	48	63	79	38	54	54	0	0	0	1846	210	715	164	403	282	72
sens12	0.17	9944	6115	1990	0.21	0.23	0.21	60	70	87	50	64	70	0.71	0.92	0.7	1757	175	680	161	380	309	53
sens13	0.19	8636	5422	1940	0.23	0.25	0.23	56	67	88	46	63	72	0.69	0.86	0.68	1865	176	764	157	395	307	66
sens14	0.18	10098	6307	1764	0.2	0.22	0.2	60	70	85	48	65	62	0	0	0	1970	334	690	175	384	313	73

Table 9: Quantities of interest for the 2020 base case, the 2023 base case (Bridge 17), and sensitivity tests relating to data weighting. Abbreviations shown in column headings are are described in Table 1 and abbreviated model names (rows) in Table 6.

		B0			MSYR			Pem73			Pem final			Satn			negLL						
Model	M	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	Sum	Cpue	Len	Age	CAL	Tag	Pr
BC2020	0.16	9983	6212	2053	0.2	0.22	0.2	59	68	87	47	66	69	1.74	2.33	0	1767	195	631	156	389	326	70
Bridge 17	0.18	9709	5986	1914	0.21	0.23	0.21	59	69	87	50	63	69	0.7	0.91	0.7	1757	175	680	162	381	305	53
sens15	0.18	9181	5603	1759	0.23	0.26	0.23	59	69	86	51	62	68	0	0	0	1678	125	676	150	380	300	46
sens16	0.19	10513	5888	1673	0.2	0.22	0.2	63	68	84	52	60	60	0	0	0	1438	198	367	154	378	287	54
sens17	0.19	9381	5682	1713	0.22	0.24	0.22	59	68	85	49	61	65	0	0	0	1705	194	678	93	384	301	55
sens18	0.2	9007	5622	1648	0.22	0.24	0.22	58	68	85	48	62	64	0	0	0	1596	200	679	163	194	301	59
sens19	0.13	10202	6782	2262	0.22	0.24	0.22	59	72	88	49	68	73	0	0	0	1621	199	650	158	375	188	52
sens20	0.17	9351	5550	1846	0.24	0.26	0.24	60	68	87	55	60	66	1.05	0.97	1.56	1645	92	673	154	376	305	45

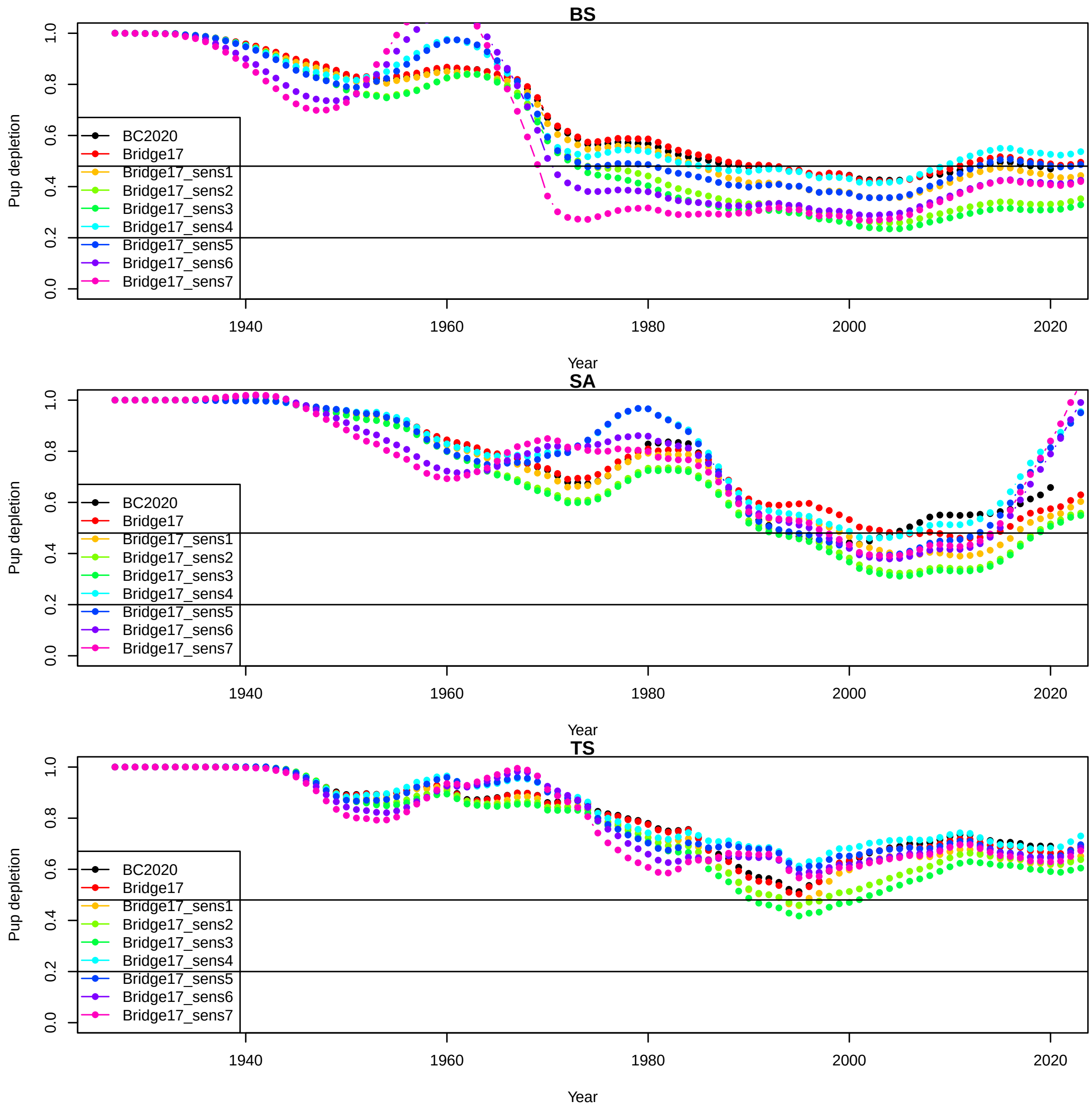


Figure 24: Gummy Shark pup depletion by stock for the 2023 base case model (Bridge 17 - red) and sensitivities that vary how density dependence is implemented. The 2020 base case model (black) is shown for comparison.

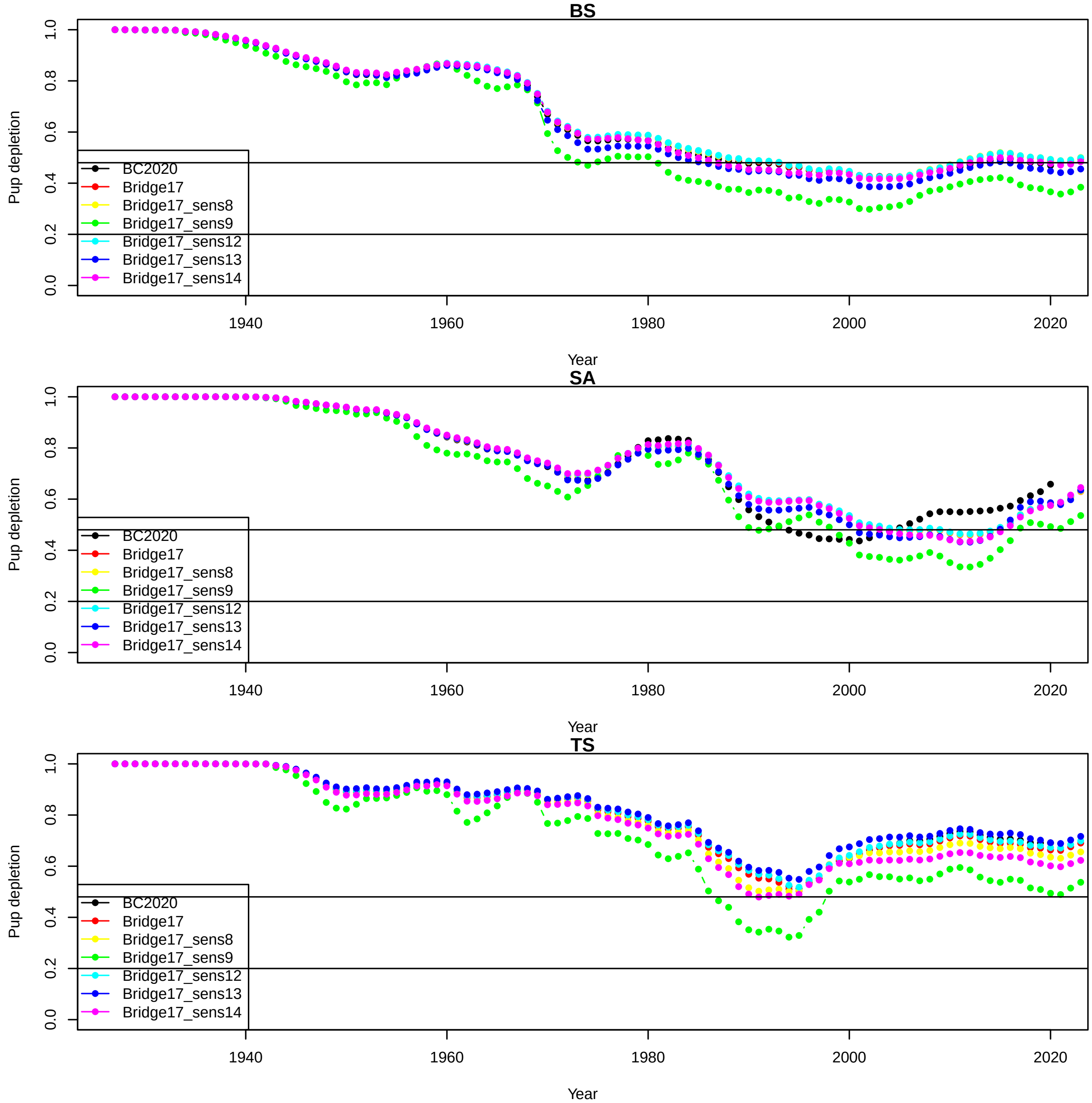


Figure 25: Gummy Shark pup depletion by stock for a range of sensitivity models for the 2023 base case model (Bridge 17 - red). The 2020 base case model (black) is shown for comparison.

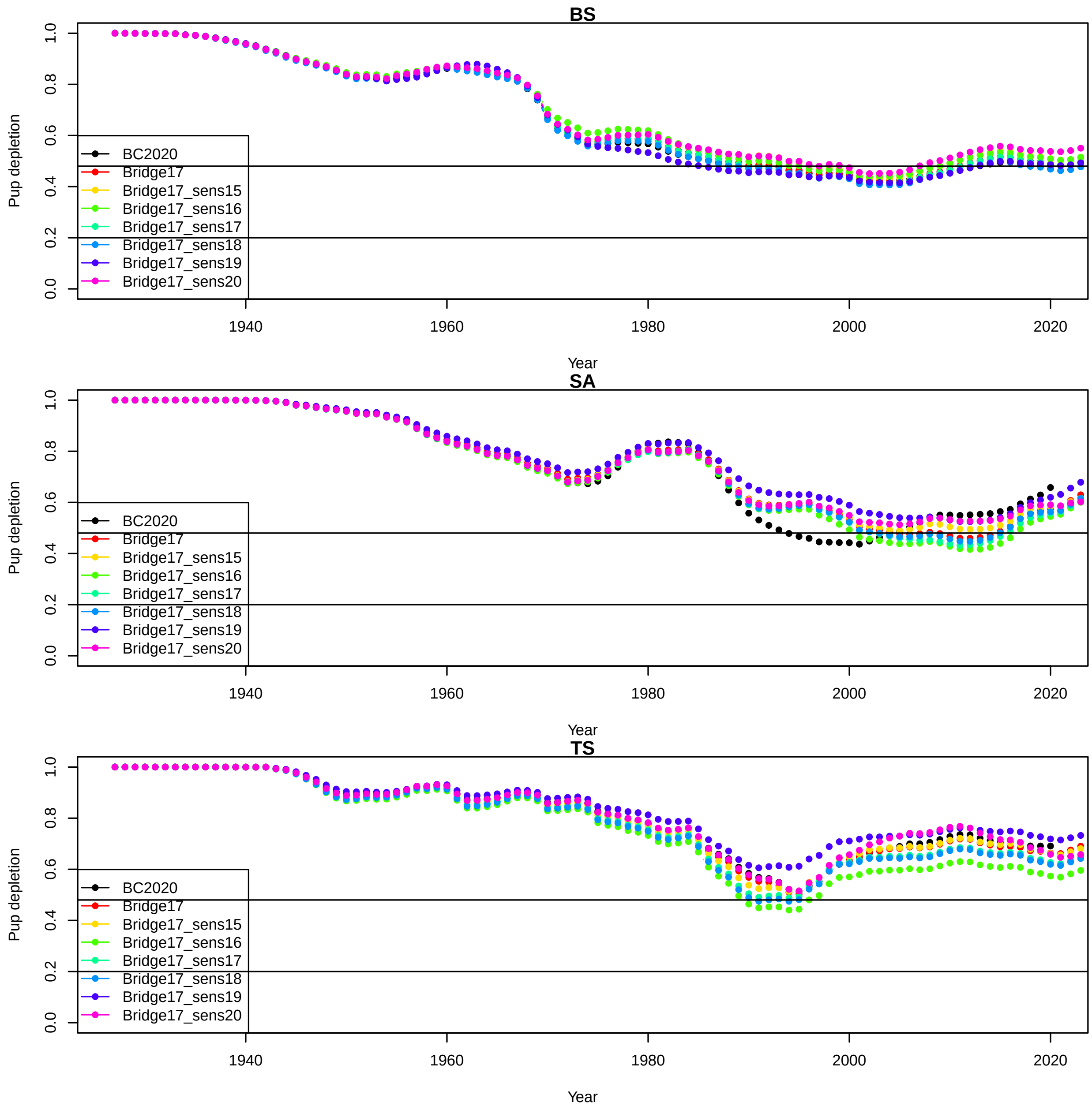


Figure 26: Gummy Shark pup depletion by stock for alternate weighting sensitivity model runs on the 2023 base case model (Bridge 17 - red). The 2020 base case model (black) is shown for comparison.

5.6 RBCs and projections

The annual RBCs, calculated by applying the Tier 1 Harvest Control Rule, for each stock, and their total, is shown in Table 10 for 2023 to 2031. Note that the assumption was made that the total 2023 catch will match the 2022 catch because the TAC remained the same. The 2022 removals for Bass Strait are almost equal to the long-term RBC whereas those for South Australia and Tasmania are below the long-term RBCs for those stocks (Table 11).

For each stock, the annual RBC dips below the long-term RBC between 2025 or 2026 and 2028; it then shifts slightly above the long-term RBC from 2030 for a few years before settling to the long-term average (not shown). These fluctuations are likely be impacted to some extent by estimated recruitment deviations in the recent past although this might not present a full explanation. The Gummy Shark stock assessment model can show cyclicity relating to the impact of density dependence (results not shown but presented to sharkRAG in 2021 as part of exploration of alternative density dependence assumptions).

Fishing at the long-term RBC, or the 3 year or 5 year averages from 2024 onwards, results in eventual pup depletion estimates at or within 3 percentage points of 48% (not shown).

Averaging the RBCs for each stock over the 3 years 2024 to 2026 or the 5 years 2024 to 2028 resulted in similar RBCs to the long-term average (Table 11).

SharkRAG requested the following forward projections using the base case model (note that projections using the annual RBCs have been changed to projections using the 2022 catches, for 5–7 below):

1. project using annual RBC by region from the Harvest Control Rule, using 2022 gear splits,
2. project (3y) average 2024 to 2026 RBCs, using 2022 gear splits,
3. project (5y) average 2024 to 2028 RBCs, using 2022 gear splits,
4. project using the 2022 catch (including discards) by gear and region,
5. use 2022 catches but move 20% of SA line catch to BS,
6. use 2022 catches but move 20% of BS gillnet catch to SA,
7. both (5) and (6) above,

and an additional two projections have been added to explore the impact of line gear selectivity compared with gillnet selectivity:

8. use annual RBCs for all regions but assume that catches are taken exclusively by shallow line,
9. use annual RBCs for all regions but assume that catches are taken exclusively by gillnet.

Pup depletions from these future projections are shown in Table 12 and Figure 27 for those that use the 2022 gear and region splits. Bass Strait is estimated to be close to the 48% target reference point (TRP) and the RBC is similar to the current catches so continuing to fish at the 2022 level, or at the RBC, or an average of the first few years of the RBC keep the population relatively steady. Both South Australia and Tasmania are estimated to be above the TRP so fishing at the RBC reduces the stock status in those regions. The 2022 catches in South Australia and Tasmania are below their RBCs so continuing to fish at the 2022 level does not reduce stock status, or reduces it more slowly than the RBC.

Future projections that alter the gear and region catch splits, compared to those in 2022, are shown in Table 13 and Figure 28. For all regions, taking all catches (at the annual RBC level) using shallow line leads to greater decline in stock status than taking all catches using gillnets. The RBC for SA (which is based on current gear splits, with a large proportion taken by shallow line) results in increased stock status in that state when the RBC is instead taken by gillnets. Taking the 2022 catches but moving 20% of gillnet line catch from BS to SA results in increased stock status in Bass Strait and decreased stock status in South Australia, albeit at a rate similar to that resulting from fishing at the RBC.

Table 10: Annual Recommended Biological Catches and predicted depletions for the three Gummy Shark stocks and the total across stocks (the figures for 2023 are not used as removals for forward projections, instead, 2022 removals are assumed for 2023).

	RBC				Depletion		
Year	BS	SA	TS	Total	BS	SA	TS
2023	1148	687	243	2078	50	63	69
2024	1026	597	208	1831	50	62	67
2025	971	548	189	1708	50	62	65
2026	956	525	179	1660	50	62	63
2027	968	524	177	1670	50	60	62
2028	989	539	181	1709	50	59	60
2029	1008	558	186	1752	50	57	58
2030	1019	575	191	1785	50	55	56
2031	1023	585	194	1801	50	53	55

The average RBC, by stock, over 3 and 5 years are shown in Table 11 along with the long-term RBC. The totals over stocks are also shown.

Table 11: The average RBC over three or five years from 2023, the long term RBC as calculated for this report and for the 2020 and 2016 assessment reports, the 2023 RBCs, and the 2022 removals by stock and with 20% shifts of gillnet catch from BS to SA and shark line catch from SA to BS.

Case	BS	SA	TS	Total
3y average	984	557	192	1733
5y average	982	547	187	1716
Long term 2023	1010	559	186	1755
Long term 2020	976	588	192	1757
Long term 2016	1098	650	213	1961
2023 RBC	1148	687	243	2078
2022 removals	1014	412	114	1539
GN shift	834	591	114	1539
Line shift	1070	355	114	1539
GN and Line	891	534	114	1539

Table 12: Predicted pup depletions for the three Gummy Shark stocks under a range of future catches, all using the 2022 proportional catch splits between gears.

	Annual RBCs			3y average			5y average			Long term RBC			2022 removals		
Year	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS
2023	49.5	63.0	69.0	49.5	63.0	69.0	49.5	63.0	69.0	49.5	63.0	69.0	49.5	63.0	69.0
2024	50.4	65.1	70.6	50.4	65.1	70.6	50.4	65.1	70.6	50.4	65.1	70.6	50.4	65.1	70.6
2025	51.0	64.9	69.2	51.2	65.4	69.7	51.2	65.5	69.9	51.0	65.3	69.9	51.0	66.9	72.1
2026	51.3	64.5	67.8	51.5	64.9	68.2	51.5	65.1	68.6	51.2	64.8	68.6	51.2	68.0	73.1
2027	51.4	63.4	66.1	51.5	63.4	66.2	51.5	63.8	66.7	51.1	63.4	66.8	51.0	68.3	73.8
2028	51.3	61.7	64.2	51.3	61.4	63.7	51.4	61.8	64.5	50.7	61.3	64.6	50.6	67.9	74.1
2029	51.1	59.7	62.1	51.1	59.1	61.2	51.2	59.6	62.1	50.3	58.9	62.3	50.2	67.2	74.2
2030	50.9	57.5	60.1	50.9	56.8	58.9	51.0	57.5	59.9	49.9	56.7	60.2	49.8	66.3	74.2

Table 13: Predicted pup depletions for the three Gummy Shark stocks under a range of future catches, using altered catch splits between gears: 20% gillnet shift from BS to SA (GN to SA), 20% shallow line shift to BS (LL to BS), both of the previous shifts (Both), all catch in all regions taken by line (All LL) or gillnet (All GN).

	GN to SA			LL to BS			Both			All LL			All GN		
Year	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS	BS	SA	TS
2023	49.5	63.0	69.0	49.5	63.0	69.0	49.5	63.0	69.0	49.5	63.0	69.0	49.5	63.0	69.0
2024	50.4	65.5	70.6	50.3	65.1	70.6	50.2	65.6	70.6	48.1	64.8	69.9	50.7	66.6	71.4
2025	51.7	66.1	72.1	50.5	67.5	72.1	51.2	66.8	72.1	46.8	64.4	67.4	51.5	68.6	71.2
2026	52.9	65.7	73.1	50.3	69.3	73.1	52.0	67.1	73.1	45.9	63.7	65.2	52.0	69.9	70.7
2027	53.8	64.3	73.8	49.6	70.3	73.8	52.5	66.4	73.8	45.2	62.4	63.0	52.3	70.4	69.8
2028	54.7	62.2	74.1	48.8	70.5	74.1	52.9	65.1	74.1	44.7	60.6	60.7	52.3	70.1	68.5
2029	55.5	59.8	74.2	47.9	70.4	74.2	53.2	63.3	74.2	44.2	58.4	58.4	52.2	69.3	67.0
2030	56.3	57.5	74.2	47.0	70.0	74.2	53.6	61.5	74.2	43.6	56.1	56.1	52.1	68.2	65.5

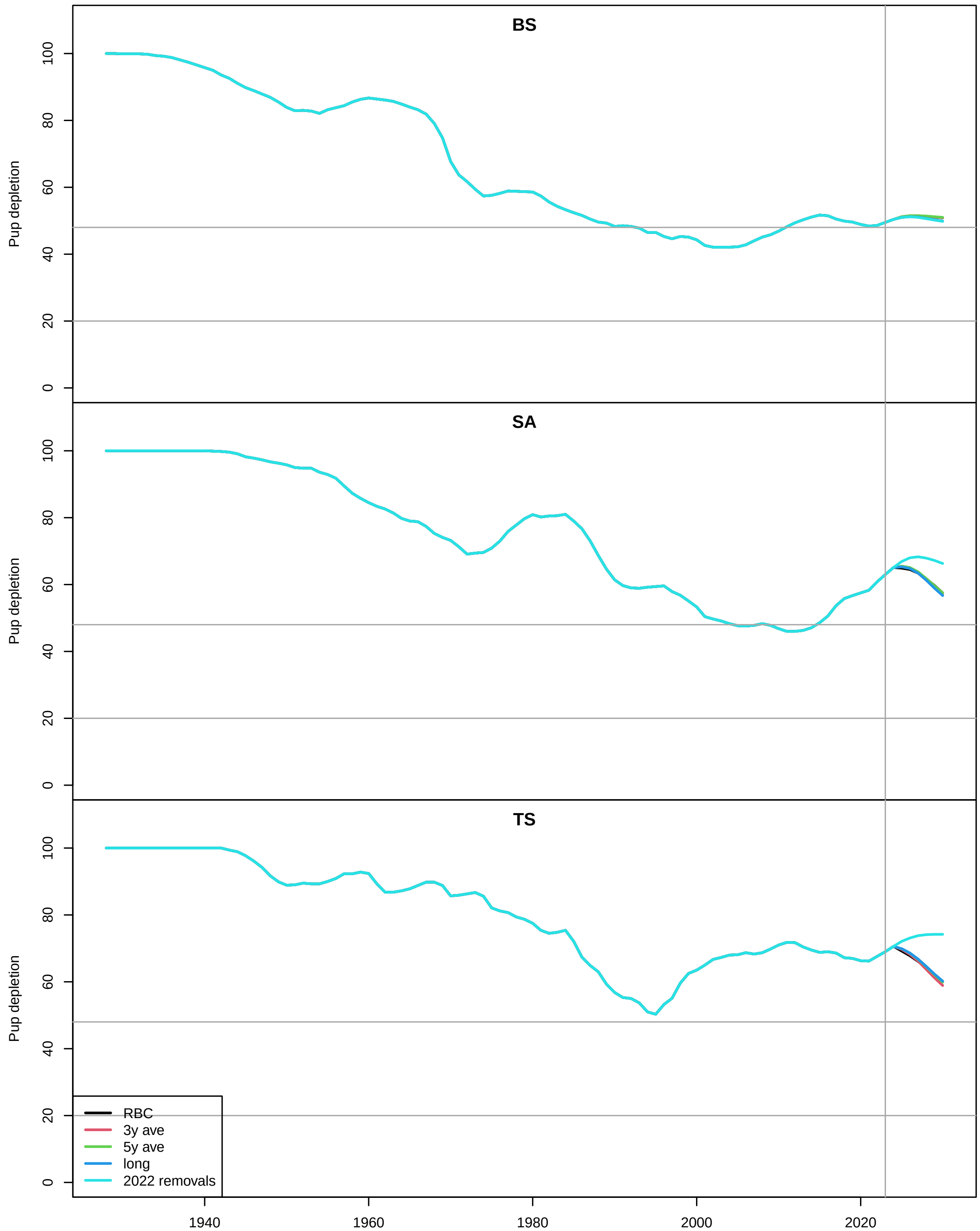


Figure 27: Pup depletion for the three gummy stocks showing future projections using annual RBC (RBC), the average over the most recent three RBCs (3y ave) and the most recent five (5y ave) as well as the long-term RBC (long) and the 2022 removals. A vertical grey line marks the first projection year (2023), and horizontal grey lines mark the 20% and 48% reference points.

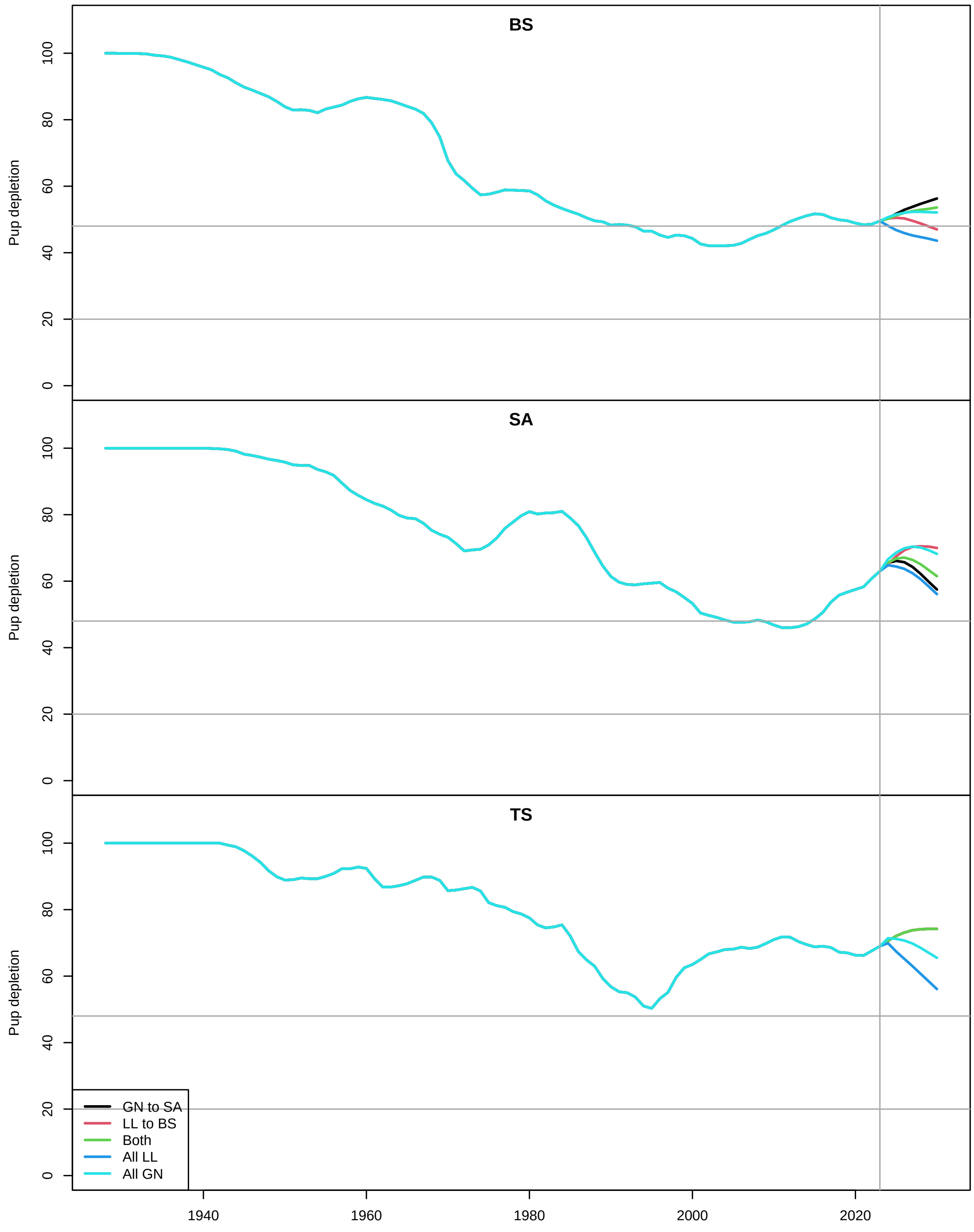


Figure 28: Pup depletion for the three gummy stocks showing future projections that alter future gear splits among regions and gears: 20% gillnet shift from BS to SA (GN to SA), 20% shallow line shift from SA to BS (LL to BS), both of the previous shifts (Both), all catch in all regions taken by line (All LL) or gillnet (All GN). A vertical grey line marks the first projection year (2023), and horizontal grey lines mark the 20% and 48% reference points.

6 Discussion

Extensive work was done to automate and improve data processing for the 2020 Gummy Shark stock assessment (Thomson 2020). This same data processing pipeline was used this year to update the stock assessment to 2022 inclusive and made it more efficient, repeatable, and less error prone. In this report, data from 2020–2022 were added to the model. Model upgrade work that occurred during 2021 was incorporated into the model, with the extension of the plus group age from 10 to 20 years, and the use of the diagnostic tests: retrospective analysis and likelihood profiles. In addition, we explored alternative treatments of the gillnet CPUE time series for South Australia. Model estimates of pup depletion have remained largely stable and consistent with the previous 2020 base case stock assessment (Thomson 2020). However, retrospective analysis revealed a steady increase in estimated adult natural mortality (M). Conditional age-at-length data are not well estimated for older ages, suggesting that the growth curve, which is pre-specified (fixed) in the model, is incorrect. This could explain the retrospective pattern in M. Further investigation of the growth curve problem is strongly recommended.

The updated model provides results that are consistent with those of the 2020 stock assessment (Thomson 2020) - pup depletion and productivity estimates are reasonably similar in 2022 to those estimated in 2019. SharkRAG uses pup production as a proxy for spawning biomass; this is the number of pups, on average, expected to be produced each year by the stock's mature females, noting that larger females produce more pups on average compared to smaller females. Pup depletion is the pup production in any year compared to the unfished pup production and is the value used in the harvest control rule. Estimated pup production shows an increasing trend in recent years in South Australia and is steady in Bass Strait and Tasmania. Pup depletion is above the target reference point of 48% for all stocks, and is estimated at 50% for Bass Strait, 63% for South Australia, and 69% for Tasmania in the 2023 base case model (Bridge 17).

The 2023 Gummy Shark base case stock assessment model (Bridge 17) differs from the 2020 base case stock assessment model in the following ways: the addition of data for 2020–2022 inclusive, plus group age is 20 years (from 10 years), and the South Australian gillnet CPUE time series has been split at 1995 (1984–1995; 1996–2009). The plus group change allowed the 2023 model to better fit the conditional age-at-length data for larger, older Gummy Sharks better than the 2020 model, although the fit is still poor. The break in the SA gillnet CPUE time series allows the 2023 model to better fit to the CPUE data which has quite a clear step change at approximately 1995. Overall however, the impacts of these changes are minor on the overall pup depletion of Gummy Shark across the three stocks highlighting the stability of the model.

The Gummy Shark stock assessment incorporates an unusual formula that allows CPUE to index abundance non-linearly, and in a way that varies by stock through the estimation of an 'effort saturation' parameter. It is concerning that the 2016 assessment included an effort saturation parameter that had hit its upper bound (of 50) for one stock and the lower bound (of zero) for another, potentially indicating that the model might be mis-specified. When the new data (for 2020 to 2022 inclusive) are added, the model estimates parameters that are comfortably within the bounds for two stocks and only Tasmania remains at its lower bound. The lower bound is less concerning than the upper bound because it results in a linear relationship between CPUE and biomass. It is recommended that a linear relationship is assumed for gillnet CPUE going forward so that the effort saturation parameter is no longer estimated. This should improve model stability and therefore estimation performance, while not influencing parameters that influence management including the estimation of virgin pup depletion or current pup depletion. The base case model assumes a linear relationship for trawl and line CPUE series, but effort saturation for gillnets. When a more conventional linear relationship between CPUE and biomass is assumed, the model gives similar results to those that use effort saturation, except for a better fit to the CPUE data. Retrospective analysis might be a useful tool to examine this issue further.

Extension of the plus group age from 10 to 20 years was undertaken to allow the model to better fit to the conditional age-at-length data. Although improved fits were achieved, there was still a relatively consistent underestimation by the model of the age of older Gummy Sharks relative to their length. The model seems to be fitting better to males than females which may be because females are more likely to grow larger and live longer. Currently, the model uses the same value of adult natural mortality for bosh sexes, and uses fixed growth parameters that were calculated using vertebral ages for Gummy Sharks collected during the 1970s and 1980s (Moulton *et al.* 1992). These estimates were consistent with growth curves calculated using tag-recapture data, which are independent of vertebral ageing (Moulton *et al.* 1992). Moulton *et al.* (1992) speculate on the possibility of differing growth rates between areas, and decades. Moulton *et al.* (1992) also discuss the impact of gear selectivity on apparent growth rate (‘Rosa Lee’s effect’). It may be that these growth parameters were not well estimated, are no longer accurate, growth has changed over time, or growth varies spatially. This would not be surprising as Moulton *et al.* 1992 found variable growth both in time between Bass Strait samples collected from 1973–1976 and 1986–1987, and spatially between samples collected in the Bass Strait and South Australia in 1986–1987. It is recommended that future updates of this stock assessment look to estimate growth within the model which should be achievable given the inclusion of conditional age-at-length data. However, given differences in sample numbers among stocks, estimation of growth for each stock independently may not be possible. The majority of age-with-length measurements currently available are from Gummy Shark catches, sampling less tightly selective gears would be desirable. Line gears are the least selective, but samples from Danish seine would help to capture accurate growth estimates for younger sharks.

Estimation of adult natural mortality rates for males, separately from females, should be considered along with estimation of growth rates as males are not observed to live as long as females do and this is likely to interact with estimates of sex-specific growth as well as with the retrospective pattern observed for M.

Model results, including estimated depletion, are very sensitive to the assumption made regarding which ages density dependence operates on. The models that apply density dependence to just ages 0–2 achieve the best fit to the data, but also provide highly variable estimates of depletion across the three stocks (33-54% for BS, 55-106% for SA, 60-73% for TS; Table 7). Estimates of natural mortality also vary from 0.12–0.18 across these sensitivities. Furthermore, it is clear that male Gummy Shark do not attain the same maximum ages as female Gummy Shark, suggesting higher natural mortality rates.

Current (2022) catches are similar to estimated RBCs for Bass Strait and below RBCs in South Australia and Tasmania. Shifts of 20% of the catch between gears and between Bass Strait and South Australia are not greatly influential over a 10 year projection period. Catches taken by shallow line gear are more impactful on stock status than catches taken by gillnet gear, therefore any future effort shifts from gillnet to line gear will therefore reduce future estimated RBCs (because these will be based on the existing catch ratios among gear types).

6.1 Future modelling work

In 2021, sixteen items of work were suggested to improve the Gummy Shark assessment model - prioritised into high, medium and low importance. The seven ‘high’ importance items were addressed during 2022 and that work has been incorporated into the 2023 stock assessment, except for two that require some additional work. These remaining two items that need to be addressed, as well as work from the ‘medium’ importance list that also have yet to be addressed, are listed below:

1. Model-tuning / data weighting - further work is needed to implement recursive data weighting or ‘tuning’ for recruitment deviation, CPUE, and conditional-age-at length data sources, as is done for SESSF scalefish assessments. Francis weighting is already implemented for length composition and age composition data but is needed for conditional-age-at-length data.
2. Incorporate port-collected length data for the trawl fleet; consider the value of incorporating port length data for gillnets and line gear – requires examination of model fits to onboard versus port length data to evaluate impact of size-related discarding.
3. Add a Danish seine fleet to the model, using onboard but not port collected length frequency data: requires an alteration to the minimum length class allowed for data incorporated into the model.

The ‘medium’ importance items of work identified in 2021 were:

1. Update the ageing error matrix.
2. Estimate sex specific M.
3. Estimate growth within the model, including consideration of population-specific growth parameters, also possible change with time.
4. Replace logistic with knife-edged selectivity for trawl and line gears.

5. Re-code the Gummy Shark model in Template Model Builder (TMB) (it is currently coded in ADMB).

The lack of fit to conditional-age-at-length data cause the third 'medium' importance item (estimate growth within the model) to increase in importance. The first, second and fourth items are relatively easy to achieve and could be done as part of an assessment update, provided all other aspects of the work progress smoothly. The fifth 'medium' importance item, regarding recoding the model in a more modern programming platform, assumes that it is best to retain the current, bespoke, Gummy Shark model and to continue to invest in that model. Arguably, it might be better to use an existing assessment modelling package, for which state-of-the-art techniques and diagnostic statistics are continually implemented by platform developers. The disadvantage of a bespoke model such as the Gummy Shark model is that AFMA will have to fund the additional coding needed to incorporate new procedures into the model. There will also be less error checking because the Gummy Shark model has a single user. The advantage of this bespoke model is that is specifically tailored to southern Australia's Gummy Shark stocks, fishery and data collection. Most existing packages have been developed for application to scalefish stocks and do not allow for the tight relationship that exists between the numbers of mature females present in the stock, and the numbers of pups that they are likely to produce, further taking account of the size distribution of the female population. Although Stock Synthesis (SS, Methot and Wetzel 2013) includes a stock-recruitment relationship tailored to mimic shark recruitment, it deals crudely with tagging data, of which a considerable amount exists for Gummy Shark in the SESSF, forming an important part of the SESSF assessment. Arguably, it might be possible to adequately represent shark recruitment using the standard Beverton-Holt stock recruitment function along with a relatively low value for steepness, e.g. in the h=0.3–0.4 range (oceanic whitetip shark in SS, Trembley-Boyer 2019).

Dichmont *et al* (2016) list eleven age-structured assessment model packages; some are production or delay-difference models and are therefore unsuitable for Gummy Shark. Stock Synthesis (SS) and packages based on SS such as SSS and XSSS are not considered further. Two are purely size rather than age based. Some are VPA models, which are not widely supported within Australia. That leaves AMAK, ASAP, BAM and CASAL. Another three packages exist that are not discussed by Dichmont *et al* (2016), possibly because their development has been more recent, or they were not considered because they were not used by the Australian assessment scientists interviewed by Dichmont *et al* (2016). These are CASAL 2 (the replacement for CASAL, Bull *et al.* (2012)), and SAM and WHAM both of which are state-space models. WHAM was initially very similar to SAM but is undergoing more active development so will have developed beyond SAM, it is intended that it will replace ASAP. SS is set to be replaced by a package named FIMS, currently under development and not expected to be available in the near future (Andre Punt *pers comm*). CASAL 2 has been developed for application not only to fish but also to marine mammal and seabird populations (Doonan *et al.* 2016) and therefore might be suitable for Gummy Shark.

Once the Gummy Shark assessment has been implemented on a platform that allows estimating of growth rates within the model, estimation of gillnet selectivity (and whether that needs to be modified by an additional age-based availability function) can be examined. The retrospective pattern for estimated adult natural mortality, it is hoped, will disappear. If it does not, further investigation would be required. Note that the gear saturation function might need to be dropped, depending on what CPUE-Biomass relationship options are available to the platform used.

6.2 Future sampling work

Estimation of Gummy Shark growth rates within the model would an important improvement but this has to be backed by representative collection of age and length information where both are taken from the same shark. Currently, the bulk of available age-length data is from the highly selective gillnet fishery. Collections of larger sharks from line gears, and smaller sharks from trawl or Danish seine gears, is necessary.

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9 Appendix A: Total removals (landed catches plus discards) used in the 2023 stock assessment.

Table 14: Bass Strait Gummy Shark catches as input into the 2023 stock assessment. Note, only some model runs include Danish seine catches. Line shallow (LS), Gillnet 6 inch (GN6), Gillnet 6.5 inch (GN5), Gillnet 7 inch (GN7), Gillnet 8 inch (GN8), Trawl (TW), Line deep (LD), Danish seine (DS).

Year	LS	GN6	GN5	GN7	GN8	TW	LD	DS
1927	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1928	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1929	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1930	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1931	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1932	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1933	63.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1934	35.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1935	63.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1936	101.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1937	120.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1938	134.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1939	159.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1940	176.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1941	252.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1942	240.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1943	320.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1944	306.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1945	293.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1946	304.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1947	340.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1948	399.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1949	461.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1950	411.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1951	294.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1952	368.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1953	467.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1954	263.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1955	318.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1956	305.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1957	211.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1958	202.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1959	212.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1960	315.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1961	340.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	376.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	463.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	495.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1965	383.4	14.2	0.1	80.3	1.9	0.0	0.0	0.0
1966	386.5	17.1	0.2	95.9	2.4	0.0	0.0	0.0
1967	420.1	33.4	0.3	188.7	4.4	0.0	0.0	0.0
1968	381.3	58.9	0.6	327.5	9.0	0.0	0.0	0.0

1969	349.8	97.8	1.1	538.2	20.4	0.0	0.0	0.0
1970	384.4	36.5	0.3	204.1	11.2	0.0	0.0	0.0
1971	177.5	64.9	0.5	371.1	15.2	0.0	0.0	0.0
1972	90.3	152.3	1.1	880.7	28.9	0.0	0.0	0.0
1973	74.0	213.5	2.0	1200.3	41.3	0.0	0.0	0.0
1974	123.9	700.1	0.0	391.3	1.5	0.0	0.0	0.0
1975	133.9	755.1	0.0	144.1	0.3	0.0	0.0	0.0
1976	82.4	780.4	0.0	85.4	5.0	0.0	0.0	0.0
1977	111.4	948.1	0.0	8.6	0.7	0.0	0.0	0.0
1978	101.2	843.6	2.5	7.2	0.2	0.0	0.0	0.0
1979	106.2	671.8	4.1	25.0	0.2	0.0	0.0	0.0
1980	130.7	744.9	7.6	25.9	0.0	0.0	0.0	0.0
1981	98.9	833.0	7.6	63.2	0.0	0.0	0.0	0.0
1982	59.0	1063.8	0.1	46.1	0.2	0.0	0.0	0.0
1983	72.7	1058.5	1.2	45.4	0.0	0.0	0.0	0.0
1984	104.5	954.0	1.1	28.2	0.0	0.0	0.0	0.0
1985	127.0	929.1	6.1	7.3	0.0	0.0	0.0	0.0
1986	100.4	1024.6	13.1	6.1	0.0	0.0	0.0	0.0
1987	86.8	930.0	5.7	11.7	5.1	0.0	0.0	0.0
1988	72.7	854.6	4.8	3.0	0.3	0.0	0.0	0.0
1989	143.9	1036.2	5.5	6.9	0.9	0.0	0.0	0.0
1990	75.1	882.5	0.0	6.2	0.0	0.0	0.0	0.0
1991	151.8	920.0	14.7	5.5	0.1	0.0	0.0	0.0
1992	189.4	1001.0	2.6	8.4	0.0	0.0	0.0	0.0
1993	192.8	1196.0	0.4	12.5	21.4	0.0	0.0	0.0
1994	79.2	917.8	1.9	12.2	8.8	0.0	0.0	0.0
1995	38.4	1126.9	34.2	33.6	0.0	0.0	0.0	0.0
1996	50.5	866.7	9.1	15.3	0.0	0.0	0.0	0.0
1997	17.2	503.6	20.6	0.0	0.0	20.4	0.4	9.7
1998	41.3	806.0	32.9	0.0	0.0	23.4	0.4	12.2
1999	54.7	1157.6	33.8	0.0	0.0	21.3	0.4	14.2
2000	116.8	1377.3	73.3	0.0	0.0	26.0	0.3	11.5
2001	47.5	1136.1	36.5	0.0	0.0	25.1	0.4	14.7
2002	45.8	972.9	32.0	0.0	0.0	25.8	0.3	13.9
2003	47.4	992.3	13.1	0.0	0.0	25.6	0.5	8.6
2004	39.6	992.9	19.5	0.0	0.0	26.5	1.1	12.0
2005	30.6	932.9	16.7	0.0	0.0	25.7	0.5	17.1
2006	20.6	839.2	10.1	0.0	0.0	31.3	1.1	9.3
2007	28.9	985.4	1.0	0.0	0.0	36.1	0.6	13.4
2008	30.6	1088.8	1.9	0.0	0.0	54.9	4.6	16.7
2009	22.3	948.8	13.1	0.0	0.0	44.0	1.5	14.9
2010	21.6	840.3	21.5	0.0	0.0	48.0	6.5	15.3
2011	22.2	924.6	10.7	0.0	0.0	49.4	3.4	27.3
2012	21.7	884.1	37.6	0.0	0.0	51.6	4.7	28.9
2013	11.3	903.0	9.8	0.0	0.0	49.9	8.3	28.4
2014	6.0	940.1	0.0	0.0	0.0	45.6	1.9	20.4
2015	10.6	1122.3	0.0	0.0	0.0	39.6	0.4	25.1
2016	24.4	1281.3	0.4	0.0	0.0	37.5	0.1	28.2
2017	53.1	1079.5	16.2	0.0	0.0	32.4	1.6	26.5
2018	70.6	865.5	49.1	0.0	0.0	44.2	2.7	27.0
2019	104.3	966.6	45.3	0.0	0.0	44.3	0.7	38.9

2020	89.6	1080.6	31.0	0.0	0.0	57.0	0.7	36.3
2021	62.6	1093.5	4.1	0.0	0.0	40.1	2.2	25.5
2022	76.6	897.9	0.0	0.0	0.0	38.2	0.9	34.0

Table 15: South Australia Gummy Shark catches as input into the 2023 stock assessment. Note, only some model runs include Danish seine catches. Line shallow (LS), Gillnet 6 inch (GN6), Gillnet 6.5 inch (GN5), Gillnet 7 inch (GN7), Gillnet 8 inch (GN8), Trawl (TW), Line deep (LD), Danish seine (DS).

Year	LS	GN6	GN5	GN7	GN8	TW	LD	DS
1927	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1928	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1929	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1933	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1934	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1935	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1936	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1937	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1938	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1939	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1940	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1941	14.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1942	18.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1943	48.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1944	88.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1945	48.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1946	65.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1947	68.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1948	54.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1949	68.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1950	100.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1951	66.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1952	46.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1953	156.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1954	140.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1955	171.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1956	296.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1957	301.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1958	252.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1959	246.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1960	226.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1961	210.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	271.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	324.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	280.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1965	257.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1966	376.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1967	452.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1968	381.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1969	357.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1970	59.9	0.4	0.0	81.8	228.8	0.0	0.0	0.0
1971	65.1	0.4	0.0	87.9	246.8	0.0	0.0	0.0

1972	35.7	0.2	0.0	47.5	132.9	0.0	0.0	0.0
1973	56.6	0.3	0.0	34.4	164.5	0.0	0.0	0.0
1974	36.9	4.8	0.0	42.3	112.5	0.0	0.0	0.0
1975	21.1	0.1	0.0	43.5	96.5	0.0	0.0	0.0
1976	5.5	11.8	0.0	41.6	60.8	0.0	0.0	0.0
1977	22.8	48.1	0.0	20.2	121.6	0.0	0.0	0.0
1978	24.6	43.9	0.0	20.9	105.0	0.0	0.0	0.0
1979	14.1	39.0	0.1	25.3	138.9	0.0	0.0	0.0
1980	18.8	25.7	0.0	52.5	223.5	0.0	0.0	0.0
1981	22.1	42.9	0.0	243.4	0.0	0.0	0.0	0.0
1982	10.7	23.1	0.0	256.8	0.0	0.0	0.0	0.0
1983	13.4	63.2	0.3	168.8	14.8	0.0	0.0	0.0
1984	35.0	72.0	1.5	279.0	57.4	0.0	0.0	0.0
1985	19.0	47.0	18.7	332.5	19.8	0.0	0.0	0.0
1986	21.2	31.0	5.9	410.1	17.3	0.0	0.0	0.0
1987	24.3	36.9	11.0	469.2	15.3	0.0	0.0	0.0
1988	30.6	78.7	21.4	470.5	21.5	0.0	0.0	0.0
1989	62.2	139.9	39.5	422.4	9.1	0.0	0.0	0.0
1990	38.8	112.6	91.2	342.9	5.5	0.0	0.0	0.0
1991	106.0	73.5	55.1	300.8	2.4	0.0	0.0	0.0
1992	119.1	34.7	55.7	319.1	2.0	0.0	0.0	0.0
1993	95.0	29.4	83.3	293.9	14.8	0.0	0.0	0.0
1994	78.7	42.8	81.6	307.4	8.2	0.0	0.0	0.0
1995	50.7	21.1	138.5	256.5	2.8	0.0	0.0	0.0
1996	36.1	37.2	220.2	260.3	4.9	0.0	0.0	0.0
1997	0.4	42.9	416.8	0.0	0.0	27.1	1.1	0.0
1998	0.3	51.5	499.7	0.0	0.0	18.7	1.0	0.0
1999	1.6	68.7	564.7	0.0	0.0	19.3	2.1	0.0
2000	2.1	63.2	751.7	0.0	0.0	27.8	1.2	0.0
2001	12.9	71.5	332.5	0.0	0.0	33.4	1.0	0.0
2002	17.1	69.4	349.7	0.0	0.0	28.2	1.6	0.0
2003	15.2	83.1	405.8	0.0	0.0	45.8	3.1	0.0
2004	18.5	66.4	430.6	0.0	0.0	57.2	2.6	0.0
2005	25.3	75.3	418.7	0.0	0.0	63.2	1.5	0.0
2006	27.6	114.4	464.7	0.0	0.0	65.5	1.0	0.1
2007	30.7	73.6	437.0	0.0	0.0	54.4	1.0	0.0
2008	21.4	123.7	523.6	0.0	0.0	40.5	1.1	0.0
2009	58.7	101.4	452.3	0.0	0.0	60.0	2.9	0.0
2010	58.0	122.5	399.4	0.0	0.0	55.7	4.5	0.0
2011	96.7	92.2	230.7	0.0	0.0	70.6	3.0	2.7
2012	230.6	54.4	38.7	0.0	0.0	86.8	1.1	2.7
2013	326.5	20.4	13.5	0.0	0.0	68.0	2.1	2.1
2014	297.2	78.5	65.3	0.0	0.0	56.3	3.1	2.9
2015	279.2	101.8	70.5	0.0	0.0	46.1	2.9	2.0
2016	164.5	76.9	54.5	0.0	0.0	45.9	1.7	2.4
2017	288.7	72.4	26.8	0.0	0.0	55.0	4.2	0.5
2018	402.9	76.5	43.4	0.0	0.0	58.9	1.6	2.2
2019	444.7	37.2	7.4	0.0	0.0	61.5	1.6	2.0
2020	457.3	37.9	7.0	0.0	0.0	50.2	1.3	2.4
2021	279.2	10.1	23.1	0.0	0.0	62.7	0.5	3.4
2022	284.1	3.5	44.2	0.0	0.0	78.7	1.0	1.0

Table 16: Tasmania Gummy Shark catches as input into the 2023 stock assessment. Note, only some model runs include Danish seine catches. Line shallow (LS), Gillnet 6 inch (GN6), Gillnet 6.5 inch (GN5), Gillnet 7 inch (GN7), Gillnet 8 inch (GN8), Trawl (TW), Line deep (LD), Danish seine (DS).

Year	LS	GN6	GN5	GN7	GN8	TW	LD	DS
1927	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1928	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1929	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1933	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1934	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1935	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1936	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1937	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1938	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1939	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1940	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1941	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1942	15.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1943	14.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1944	32.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1945	49.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1946	57.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1947	79.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1948	66.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1949	50.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1950	25.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1951	18.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1952	43.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1953	43.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1954	32.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1955	26.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1956	13.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1957	46.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1958	30.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1959	51.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1960	114.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1961	105.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	44.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	30.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	24.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1965	13.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1966	17.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1967	50.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1968	58.8	8.4	0.0	16.8	0.0	0.0	0.0	0.0
1969	29.4	43.6	0.0	90.8	0.0	0.0	0.0	0.0
1970	31.5	7.0	0.0	17.2	0.0	0.0	0.0	0.0
1971	27.3	5.2	0.0	14.7	0.0	0.0	0.0	0.0

1972	20.0	5.2	0.0	22.1	0.0	0.0	0.0	0.0
1973	9.0	23.3	0.0	62.2	0.0	0.0	0.0	0.0
1974	63.1	37.3	0.0	61.5	0.0	0.0	0.0	0.0
1975	67.0	10.3	0.0	2.3	0.0	0.0	0.0	0.0
1976	25.7	43.2	0.0	16.9	0.0	0.0	0.0	0.0
1977	42.4	44.5	0.0	19.9	0.0	0.0	0.0	0.0
1978	11.6	56.7	0.0	31.8	0.0	0.0	0.0	0.0
1979	18.8	3.1	0.0	76.8	0.0	0.0	0.0	0.0
1980	21.7	11.2	0.0	111.0	0.0	0.0	0.0	0.0
1981	18.0	1.5	6.4	89.2	0.0	0.0	0.0	0.0
1982	19.9	4.5	2.0	62.4	0.0	0.0	0.0	0.0
1983	24.4	2.2	0.0	61.5	0.0	0.0	0.0	0.0
1984	60.9	1.9	0.0	142.0	0.0	0.0	0.0	0.0
1985	56.5	5.8	0.1	180.7	0.0	0.0	0.0	0.0
1986	45.4	4.7	0.1	124.3	0.0	0.0	0.0	0.0
1987	51.4	88.7	0.0	47.7	0.0	0.0	0.0	0.0
1988	65.1	2.0	4.1	129.3	0.0	0.0	0.0	0.0
1989	57.8	8.7	0.0	115.1	0.4	0.0	0.0	0.0
1990	70.4	14.0	0.0	88.6	0.0	0.0	0.0	0.0
1991	57.5	8.0	0.0	83.0	0.6	0.0	0.0	0.0
1992	103.2	13.9	0.0	96.1	0.2	0.0	0.0	0.0
1993	120.6	10.3	2.5	148.8	0.0	0.0	0.0	0.0
1994	65.6	7.4	0.0	145.8	0.0	0.0	0.0	0.0
1995	1.5	75.5	0.1	44.2	0.0	0.0	0.0	0.0
1996	6.4	95.2	9.1	40.9	0.0	0.0	0.0	0.0
1997	0.3	18.7	10.8	0.0	0.0	5.4	0.0	0.0
1998	0.2	47.3	27.2	0.0	0.0	2.1	0.3	0.0
1999	5.7	63.7	52.2	0.0	0.0	2.2	1.4	0.0
2000	1.6	70.7	27.8	0.0	0.0	3.9	0.7	0.0
2001	3.9	74.2	5.3	0.0	0.0	7.6	0.6	0.0
2002	5.9	119.8	3.0	0.0	0.0	18.8	1.6	0.0
2003	10.1	104.0	0.6	0.0	0.0	21.7	1.7	0.0
2004	7.5	139.5	0.1	0.0	0.0	19.8	2.1	0.0
2005	12.6	100.6	0.0	0.0	0.0	23.0	0.6	0.0
2006	9.0	84.7	48.7	0.0	0.0	20.9	2.6	0.0
2007	3.7	71.2	41.5	0.0	0.0	13.7	3.4	0.1
2008	6.6	56.8	21.0	0.0	0.0	10.3	5.7	0.0
2009	6.6	83.1	0.0	0.0	0.0	11.0	3.0	0.0
2010	16.0	90.4	0.0	0.0	0.0	13.6	1.4	0.0
2011	12.0	122.0	0.0	0.0	0.0	17.4	8.9	0.0
2012	23.4	151.8	0.0	0.0	0.0	12.7	7.3	0.0
2013	24.0	113.9	0.5	0.0	0.0	12.0	5.8	0.1
2014	31.4	76.3	0.1	0.0	0.0	12.4	6.3	0.1
2015	15.4	64.0	0.0	0.0	0.0	15.5	2.6	0.0
2016	18.2	80.8	0.0	0.0	0.0	25.2	2.9	0.0
2017	30.8	48.8	52.3	0.0	0.0	25.1	6.6	1.3
2018	30.6	23.2	31.0	0.0	0.0	22.1	18.2	3.6
2019	43.1	43.1	39.9	0.0	0.0	31.1	5.0	2.7
2020	32.6	29.7	66.9	0.0	0.0	21.3	7.6	3.5
2021	27.3	23.2	39.6	0.0	0.0	14.3	4.1	3.9
2022	20.7	15.3	54.7	0.0	0.0	17.4	6.2	2.0

10 Appendix B: Base case model fits to length frequencies and age compositions

This appendix shows observed versus expected length frequencies, by year, gear, population and sex, and similarly age compositions in the figures below.

Figure 29: Observed (bars) and base case model expected (lines) length frequencies by year, gear, population and sex. Effective sample size, calculated using Francis weighting, is shown (N).

Figure 30: Observed (bars) and base case model expected (lines) length frequencies by year, gear, population and sex. Effective sample size, calculated using Francis weighting, is shown (N).

Figure 31: Observed (bars) and base case model expected (lines) length frequencies by year, gear, population and sex. Effective sample size, calculated using Francis weighting, is shown (N).

Figure 32: Observed (bars) and base case model expected (lines) length frequencies by year, gear, population and sex. Effective sample size, calculated using Francis weighting, is shown (N).

Figure 33: Observed (bars) and base case model expected (lines) length frequencies by year, gear, population and sex. Effective sample size, calculated using Francis weighting, is shown (N).

Figure 34: Observed (bars) and base case model expected (lines) length frequencies by year, gear, population and sex. Effective sample size, calculated using Francis weighting, is shown (N).

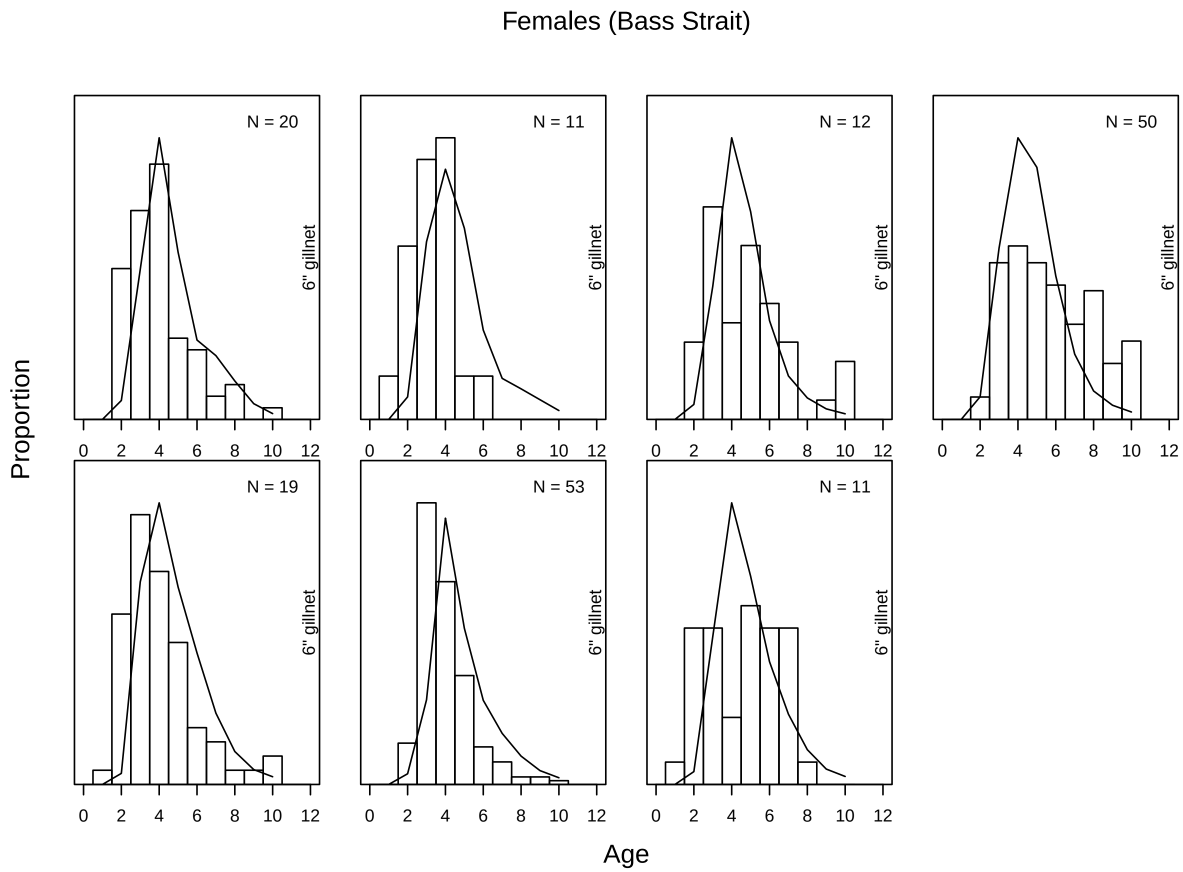

Figure 35: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex. Effective sample size, calculated using Francis weighting, is shown (N).

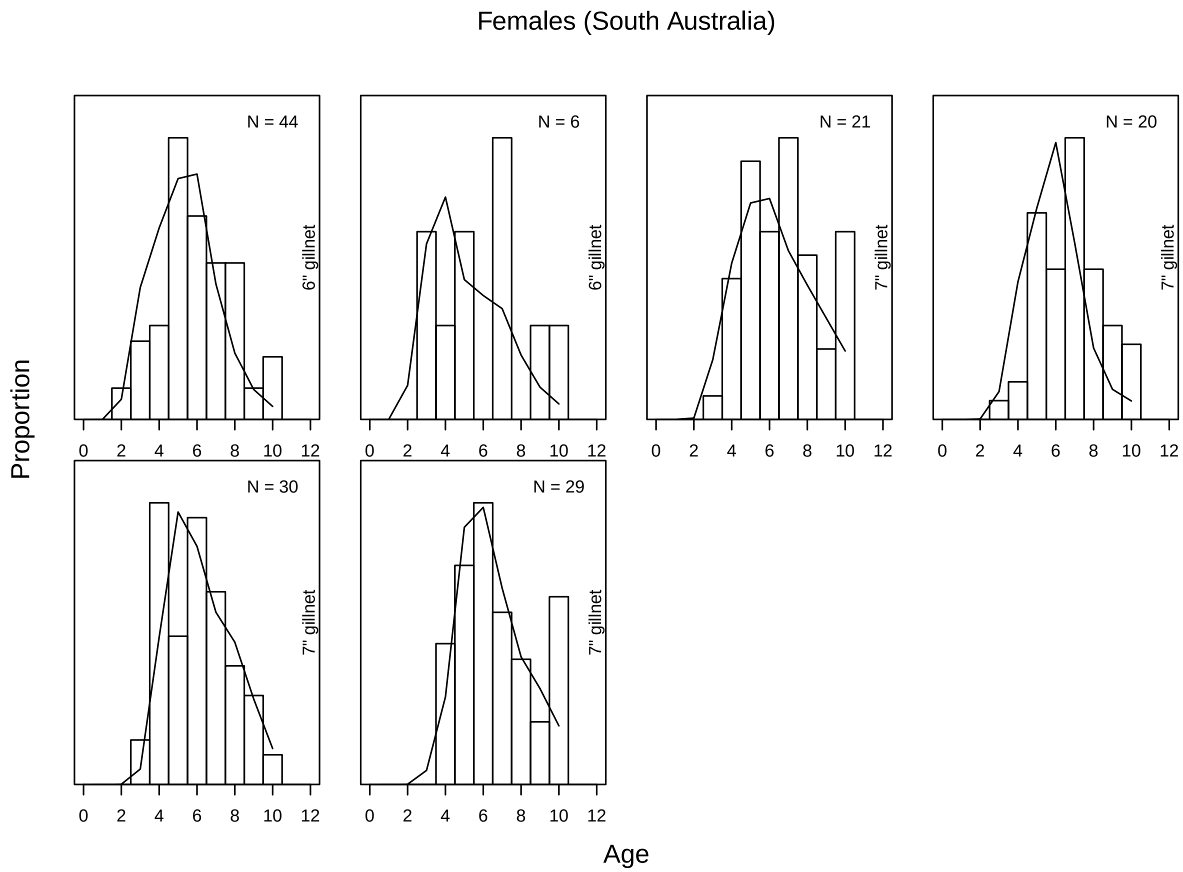

Figure 36: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex. Effective sample size, calculated using Francis weighting, is shown (N).

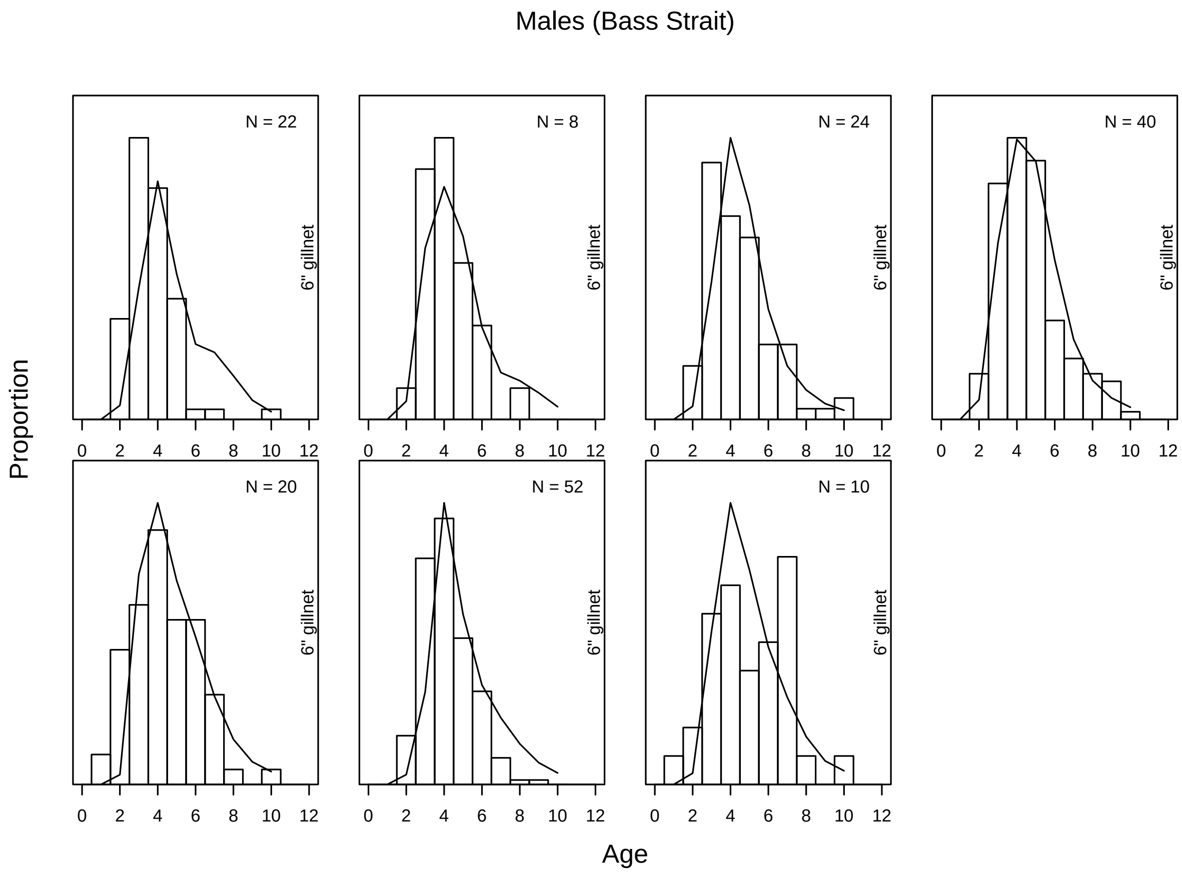

Figure 37: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex. Effective sample size, calculated using Francis weighting, is shown (N).

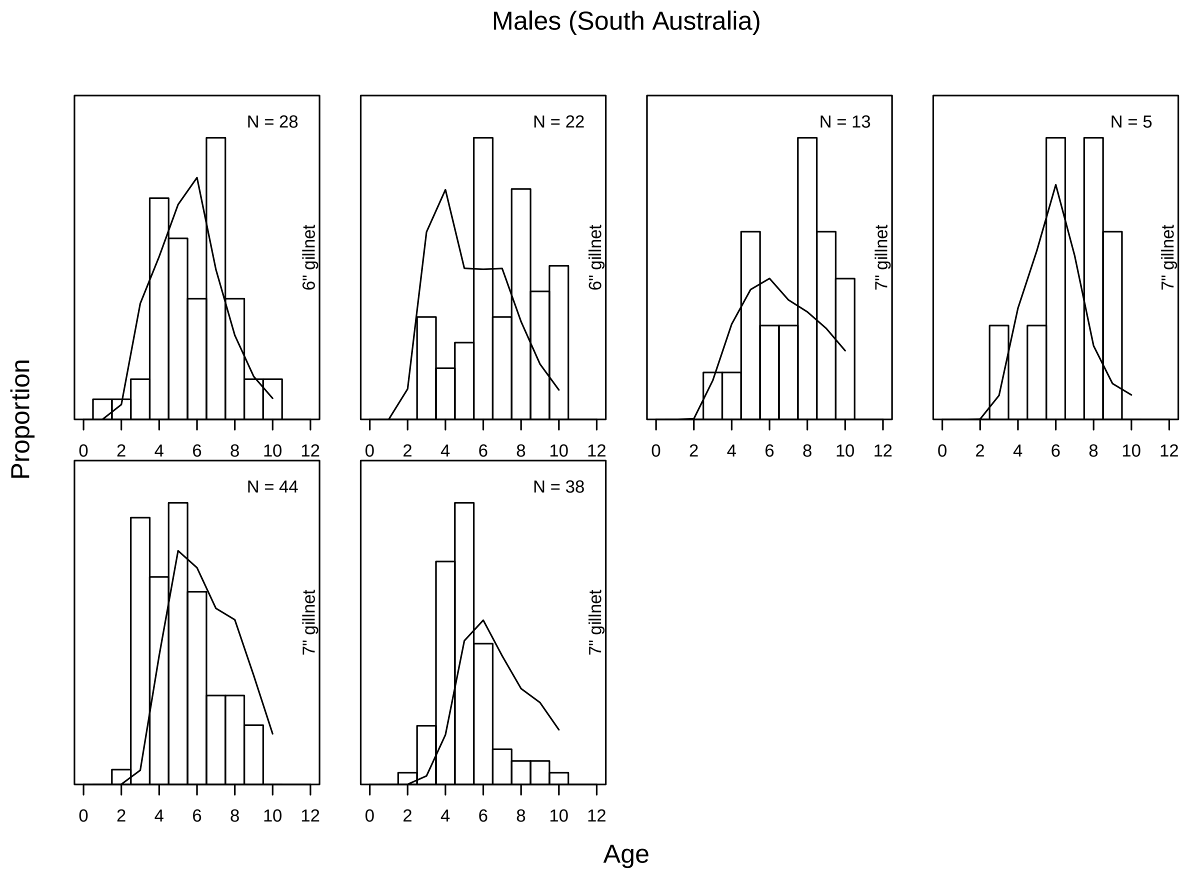

Figure 38: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex. Effective sample size, calculated using Francis weighting, is shown (N).