Preparation of preliminary 2023 Gummy Shark base case stock assessment model using data to 2022 DRAFT

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1 Executive summary

This report prepares the 2023 Gummy Shark stock assessment (data to the end of 2022) for SharkRAG's 10-11 October 2023 meeting. Updates to the most recent 2020 Gummy Shark stock assessment (data to the end of 2019) include:

- Updated input data (e.g. catch, CPUE, length, age-at-length) from 2020 up to and including 2022 and annual length frequencies for shallow line.
- Several corrections made to the conditional age-at-length data including addition of data from 2015-2022.
- Extended plus age group in the model from 10 to 20 which improved model fits to the conditional age-at-length data.
- Exploration of alternate South Australia gillnet CPUE timeseries to reflect changes in fishing efficiency.

Overall, the model was highly stable to the addition of updated data and changes to the model, with relatively minor changes to estimates of natural mortality, productivity (as estimated by Maximum Sustainable Yield relative to the biomass at which MSY occurs) and pup depletion across the various bridging steps. This is likely due to the underlying historical tagging data which anchors the model to an extent, and due to the stability of the standardised CPUE timeseries which are used as indices of abundance. The most influential bridging steps included modifications to the South Australian gillnet CPUE timeseries, however even these changes resulted in minor changes to current estimates of pup depletion. A subset of sensitivity tests were influential as they were in 2020, with changes to assumptions around density dependence driving changes to estimated natural mortality and variability in estimates of pup depletion, which warrants further investigation.

A base case model is yet to be formally proposed to SharkRAG as remaining sensitivities and additions to the model are yet to be completed. Therefore the 2023 base case presented here should be considered preliminary. The preliminary 2023 base case stock assessment model (Bridge 17) varies from the 2020 base case model in several ways including:

- Updated input data (e.g. catch, CPUE, length, age-at-length) from 2020 up to and including 2022.
- Extension of the plus age group within the model from 10 to 20.
- Splitting of the South Australia gillnet CPUE timeseries into two, from 1984-1995 and 1996-2009 to account for a step change in the timeseries due to the introduction of colour sounders to the fleet.

Shark Industry Data Collection (SIDaC) program collected data are incorporated into the assessment, and good sample sizes are now available, annually, from the important shallow line sector. 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 preliminary base case model (63% and 69% respectively). For Bass Strait, the preliminary 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.

Additional bridging steps that include the incorporation of the Danish seine fleet and its associated input data (e.g. catches, CPUE, lengths, ages) into the model are underway as well as the incorporation of port length data for all fleets. It is noted that the extension of the plus age group from 10 to 20 did improve fits to the conditional age-at-length data, but underestimation of age at larger lengths is still occurring. Therefore, it is recommended that going forward efforts should be made to update the model to estimate growth rather than fix it, and potentially allow for it to be estimated separately for each stock to account for any spatial variability in growth. It is also noted here that the discard rates used in this stock assessment vary (slightly) from those used in the 2020 stock assessment report which leads to small changes in estimates of historical total removals of Gummy Shark. The authors suggest SharkRAG consider selecting a plausible historical discard rate that does not change over time that can be used going forward. Options for using an ensemble approach to combine a suite of 'base case models' each using an alternative option for density dependence will also be discussed by SharkRAG.

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 was last assessed in 2020 (Thomson 2020). This report presents initial data compilation and model exploration of an assessment update for 2023 to be presented to the Shark Resource Assessment Group (SharkRAG) at their 10-11 October 2023 meeting. This reports presents the 2020 base case along with a series of additional work and updates to the model along with data up to and including 2022.

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 timeseries to net length-based gillnet CPUE time series, trawl CPUE timeseries changing from a single index across all stocks to an index for each of the three stocks, and splitting the trawl CPUE timeseries 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 timeseries (Sporcic 2023). Explorations are also undertaken of the South Australia gillnet CPUE timeseries which traditionally has run from 1984–2009 due to management changes enacted in 2009. Below, this CPUE timeseries is tested running from 1988–2009, and by splitting it into two timeseries at 1995 as requested by SharkRAG. The split reflects the introduction of colour sounders to the fleet, 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 2015 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.

Age data for 2015–2022 have been incorporated into the stock assessment as conditional age-at-length data rather than as age composition data which is a continuation of updates made in the 2020 stock assessment (Thomson 2020). This required several updates and changes to the model in 2020. A number of corrections have also been made to the handling of this data which will be explored below in the bridging steps. This included converting partial length measurements to total lengths for a number of records, 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.

Incorporation of the Danish seine fleet to the Gummy Shark stock assessment was recommended in 2020 (Thomson 2020). In 2020, the data was explored and its incorporation into the model structure commenced. This work is ongoing. Explorations have also been undertaken to incorporate port length data into the model as they potentially sample a different portion of the fishery and gear types, providing more data for the model to fit to. This work is also ongoing.

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

- Uses net length based CPUE for gillnets, with the series for SA being broken into two at 1995 and ending in 2009.
- Uses trawl CPUE for each stock (not for all combined) but splits the series for BS into 1996–2005 and 2008–2022 to recognise the effect (and 'settling in') of management changes from 2005.
- Estimates effort saturation for all stocks.
- Does not estimate selectivity for gillnet gears (but does estimate availability) and does estimate logistic selectivity for trawl, shallow line, and deep line.
- 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 is unavailable (i.e. age composition).
- Extends the plus age group from 10 to 20 within the model.

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. Total catches (with 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 Commonwealth logbooks and CDRs

AFMA databases were used to calculate the catch time series where data exist. 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).

3.1.2 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.

3.1.3 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) with an additional eighth Danish seine fleet currently under exploration. Note, not all fleets fish each of the three stocks. 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. First, all records that had complete information were allocated to the relevant fleets. Next, gillnet records that had missing mesh size but did have position were allocated in proportion to the ratios of the catches with known mesh sizes. Next, records whose gear was unknown were allocated in proportion to the catches already allocated across fleets. Finally, the catches from records whose location was unknown were also allocated to fleet in proportion to the catch ratios between stocks. 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 is added to each category.

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."

3.2 Standardised CPUE

Standardised catch per-unit effort (CPUE) was obtained from Sporcic (2023). Sporcic (2023) provides CPUE timeseries 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 timeseries 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 timeseries (Sporcic 2020). At its August 2020 meeting, SESSFRAG (AFMA 2020) requested that CPUE timeseries using net length be incorporated into the 2020 Gummy Shark stock assessment (Thomson 2020).

The CPUE timeseries that use operation as the measure of effort are similar to those that use net length (Figure 2). The CPUE timeseries 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 timeseries 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 timeseries which are recommended going forward.

Sporcic (2023) also provides CPUE timeseries for gears other than gillnet including trawl, line, and Danish seine (Figure 3). Trawl was previously provided as a single CPUE timeseries for all stocks, however in 2020 this timeseries was split across the three stocks (Thomson 2020). The separate trawl CPUE timeseries for each stock are used in the 2023 stock assessment with the Tasmania trawl timeseries broken into two, from 1997–2005 and from 2008–2022to account for a license buyback in 2005 by management. The bottom line CPUE timeseries is restricted to records in the 0–200m range and is therefore used in the assessment for the

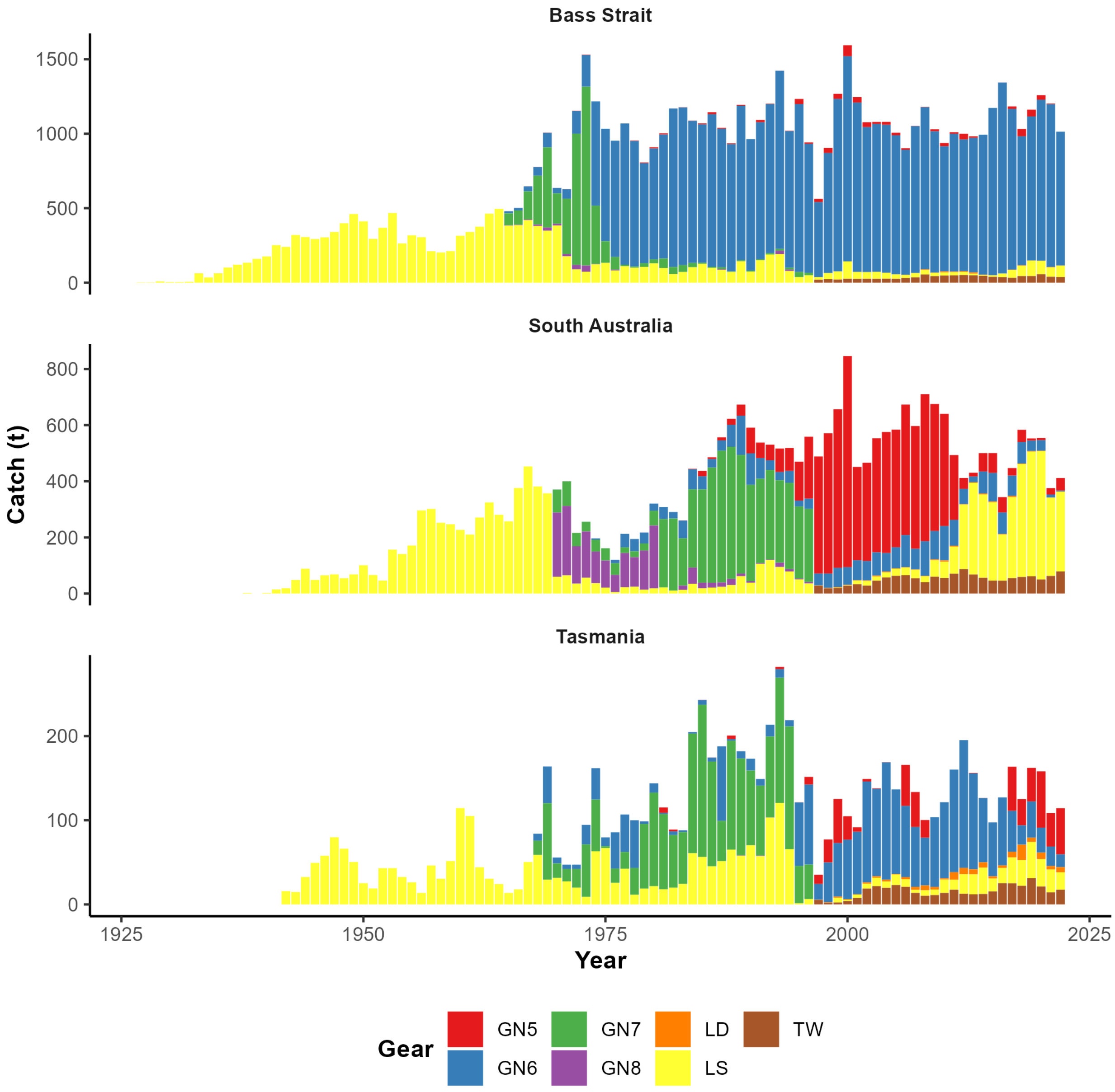

Figure 1: Gummy Shark catches (tonnes) by gear type and stock: 6 inch gillnet (GN6), 6.5 inch gillnet (GN5), 7 inch gillnet (GN7), eight inch gillnet (GN8), shallow line (LS), deep line (LD), and trawl (TW).

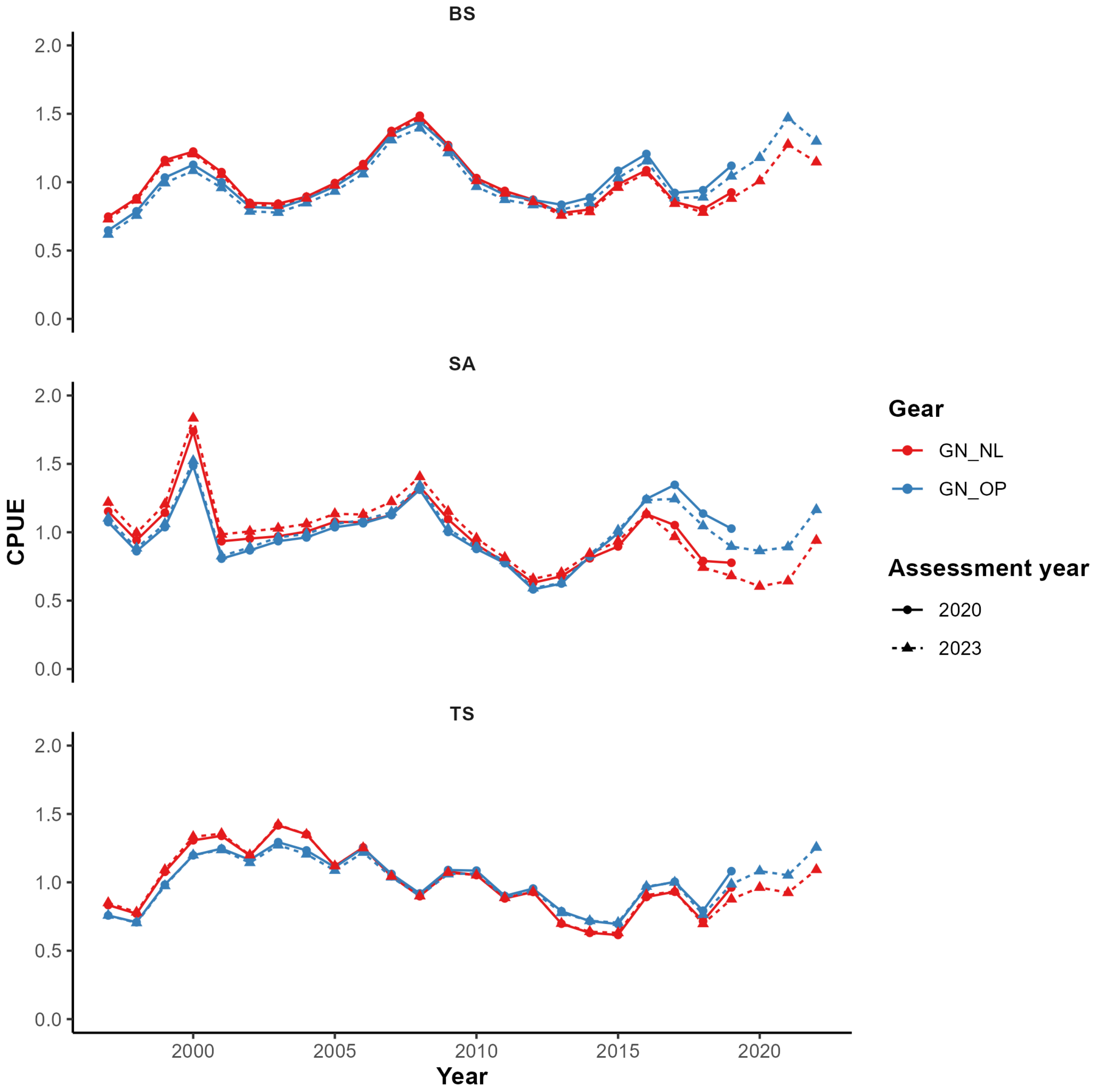

Figure 2: Standardised Gummy Shark gillnet CPUE timeseries by stock using operation (OP) and net length (NL) as the unit of effort from the 2020 (dashed) and 2023 stock assessment (solid).Stocks include: Bass Strait (BS), South Australia (SA), Tasmania (TS).

‘shallow’ line fleet only. Relatively little catch of Gummy Shark is 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 timeseries available for this assessment have been undertaken in this report. This includes the exploration of several alternate South Australian gillnet CPUE timeseries. One alternate scenario included starting the CPUE timeseries at 1988 rather than 1984, and the other involved breaking it into two timeseries from 1984–1995 and 1996–2009 to account for the introduction of colour sounders to the fleet. These modifications to the SA gillnet CPUE timeseries were a recommendation from previous SharkRAG meetings.

A combined Danish seine CPUE timeseries was also produced by Sporcic (2023), and its incorporation into the model is ongoing after initial exploration in 2020 (Thomson 2020). 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. Including zero and 1-year old sharks in the model would, however, have major implications for the way density dependence is handled in the model and would require considerable model exploration.

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 is 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 after 2007. 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). This data is 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 AFMA Observer database. Most of these more recent length frequencies match very closely between the 2020 and 2023 versions. It is also noted there has been

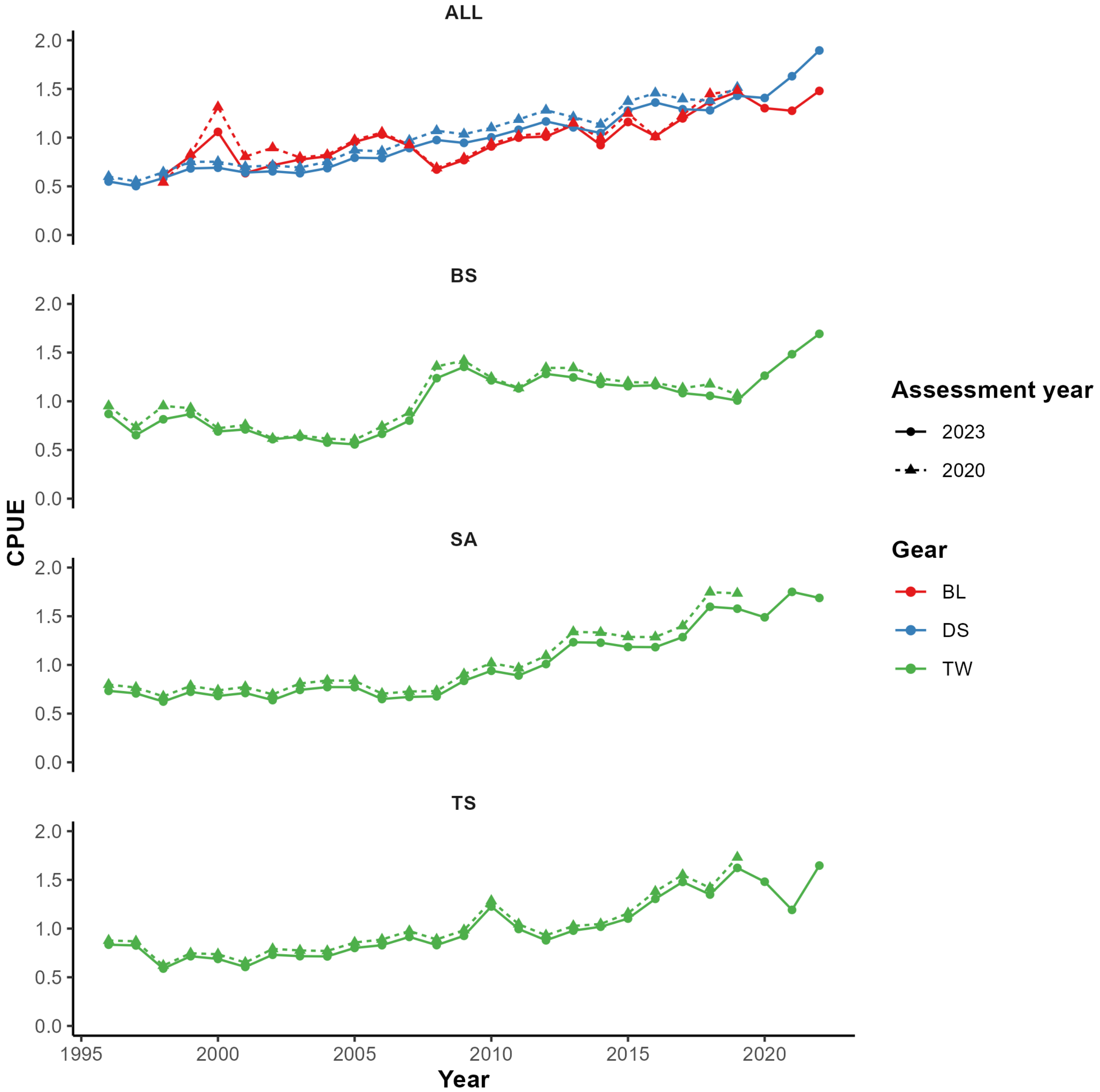

Figure 3: Standardised Gummy Shark CPUE time series for gears other than gillnet across stocks for the 2020 stock assessment (dashed) and 2023 stock assessment (solid). Gears include: Bottom line (BL), Danish seine (DS), Trawl (TW). Stocks include: stocks combined (ALL), Bass Strait (BS), South Australia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

an improved effort to collect length samples from line vessels which generally encounter a larger size class of Gummy Shark then 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.

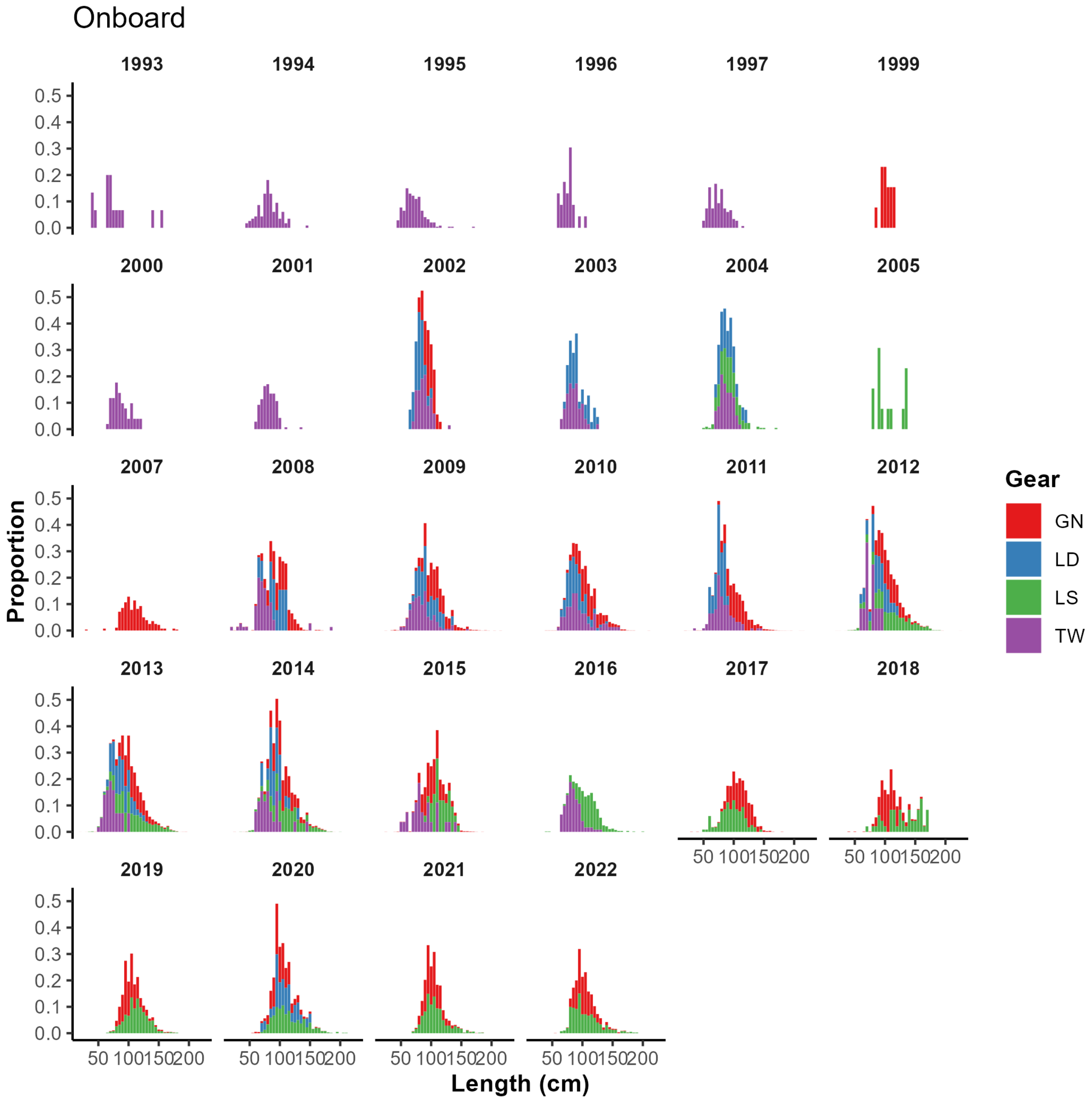

Figure 4: Length frequency distribution of sampled Gummy Sharks by year and gear. Gillnet (GN) - red, Deep line (LD) - blue, Shallow line (LS) - green, Trawl (TW) - purple.

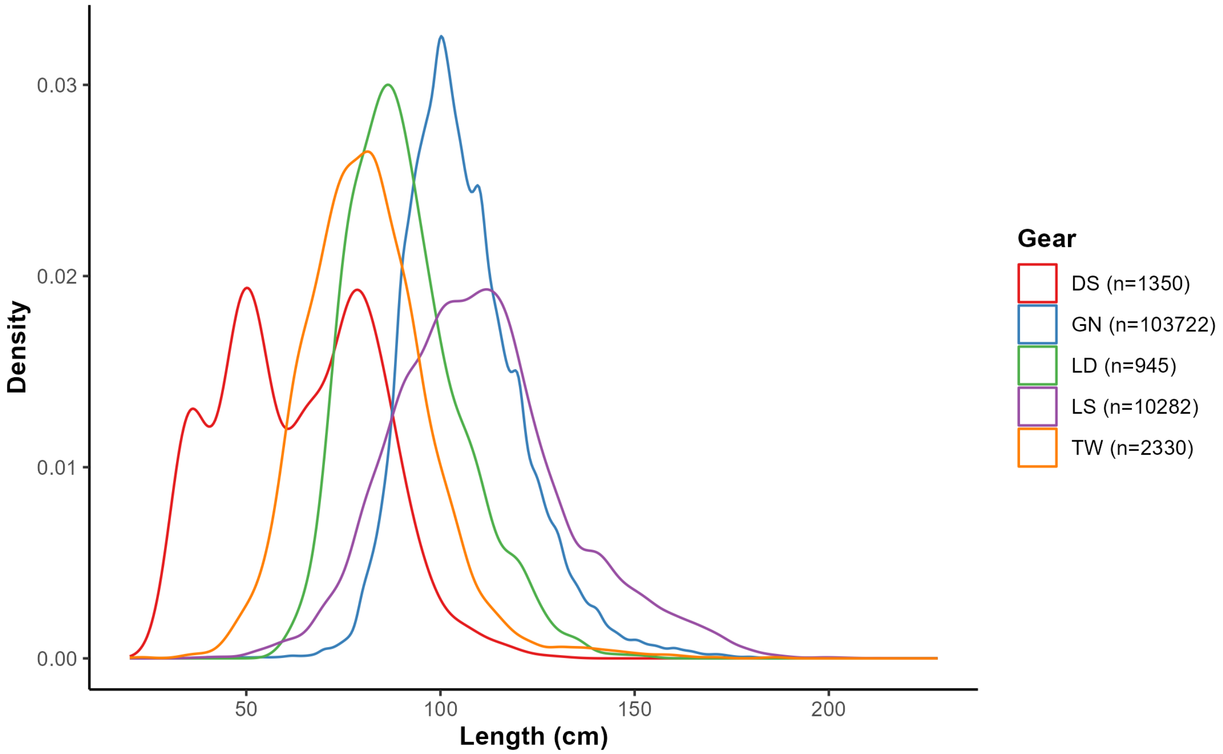

Figure 5: Length frequency generated by kernel density method applied to all length observations from Danish seine (DS) - red, Gillnet (GN) - blue, Deep line (LD) - green, Shallow line (LS) - purple, and Trawl (TW) - orange. Total sample sizes in the legend.

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 weren't able to be processed in time. For the 2023 stock assessment, age data is now available for years from 2015–2022 inclusive and has 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, but now that conditional age-at-length has been implemented, there is potential for estimating growth within the model in 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 is 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 age group 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 age group 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, this plus age group can now be extended and the model allowed to fit to the additional data. By extending the plus age group 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 age group 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 fixed 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 is 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.

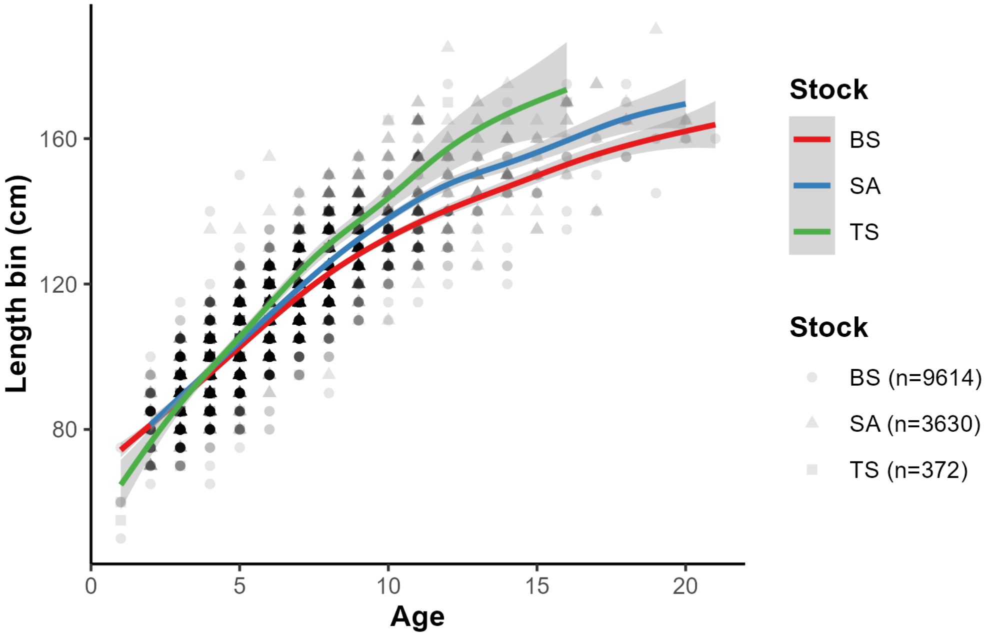

Figure 6: Observed age and length for Gummy Shark by stock. Smoothers are fit to the data to show approximate growth curves.

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. This was not achieved in 2020, although data exploration for the Danish seine fleet was presented (Thomson 2020). Incorporation of the Danish seine fleet is still in development for the 2023 stock assessment model. The Danish seine fleet selects for a smaller size class of Gummy Shark compared to most other gear types and should help the assessment to model smaller, younger Gummy Sharks in the population, potentially providing an index of recruitment (Figure 5). 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. However, there are 100 plus length samples collected annually for a number of years, particularly from port sampling. The patchiness of this data may make it difficult for the model to estimate selectivity and as a result, the earlier year classes (i.e. recruits) of Gummy Shark.

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 brief description of the ‘effort saturation’ feature of the model follows. 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

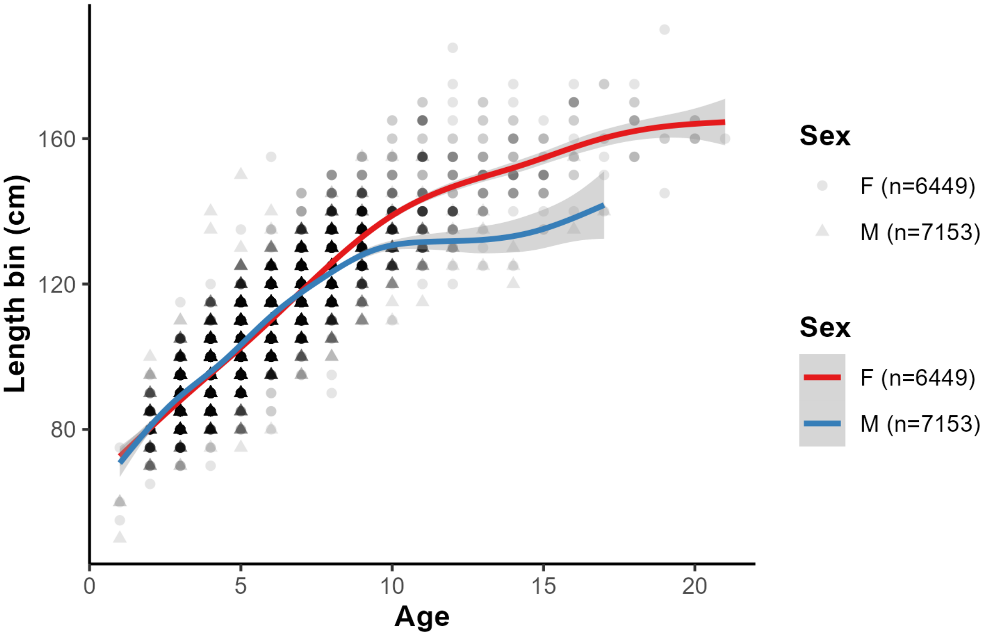

Figure 7: Observed age and length for Gummy Shark by sex for all stocks combined. Smoothers are fit to the data to show approximate growth curves.

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.

$$CPUE = \frac{B}{1+\gamma E} \tag{1}$$

The Gummy Shark stock assessment model estimates an 'availability' function that modifies the 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).

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 preliminary 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.

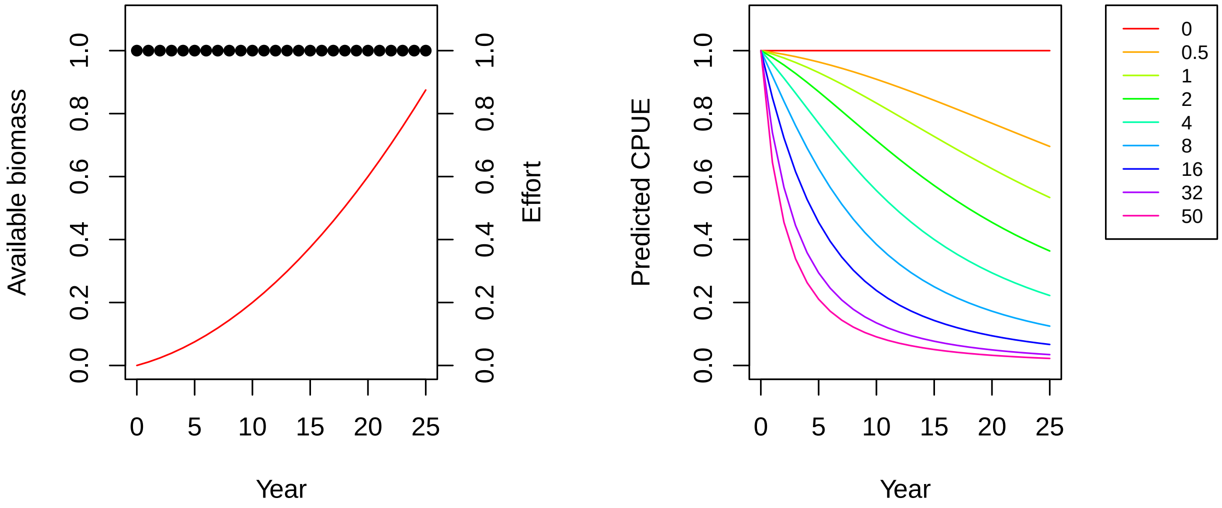

Figure 8: A theoretical scenario in which biomass (black line) is steady, but effort (red line) is increasing (left plot), illustrating the influence of the effort saturation parameter on predicted CPUE (right plot) where colours represent different effort saturation parameter values.

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 structure. Each alternate model has been assigned an abbreviated name in the results tables below, those are given fuller descriptions in Table 2. First, the ‘bridging’ analysis (see Assessment Methods section above) is presented, which bridges from the 2020 base case model to a prelimininary 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 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 made it easier and less likely to produce errors during the data processing phase. This process was applied to both the 2020 and 2023 data to ensure that reproducible outputs were achieved. The new data processing code was then 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.

To begin with, 2020 data run through the updated processing code (although very few changes) was sequentially added to the 2020 base case and any differences identified (Bridges 1-4a). The abundance (pup production) for each stock generated from the models that altered the 2019 data are shown in Figure 9 and Table 3. Then, 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) are shown in Figure 10 and Table 4. Then, those that make adjustments to the model (Bridge 15–17) are shown in Figure 11 and Table 5. Lastly, a subset of sensitivity tests are applied to the preliminary 2023 base case model (Bridge 17) and are shown in Figure 12

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

Table 2: Description of the models presented in this report. 'Bridge 17' is the preliminary 2023 base case, models listed above Bridge 17 are bridging steps whose changes are cumulative (except for Bridge 16); those below are sensitivities that differ from the base case by just the described change.

modname	fulldesc
BC2019	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 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

and Table 6.

Besides adding updated data to the model, several exploratory bridges were undertaken that involved including additional data or altering the structure of the model. These included:

- Bridge 15: Extension of the plus age group from 10 to 20.
- Bridge 16: Altering the South Australia gillnet CPUE timeseries to begin at 1988 rather than 1984.
- Bridge 17: Breaking the South Australia gillnet CPUE timeseries into two from 1984–1995 and 1996–2009.

The error correction of conditional age-at-length data up to and including 2019 in bridges (from 3a–3c) led to substantial changes in the input files from 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 timeseries 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 timeseries 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 was 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 age group was extended from 10 to 20 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 at 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 those beyond as the model structure has changed. The most influential bridging step on pup depletion was Bridges 16 and 17 where alternate South Australia gillnet CPUE timeseries were explored. This shows that estimates of pup depletion and production are influenced by CPUE timeseries. 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 Australia stock, pup depletion was revised downward, but it still remains above the TRP.

Given the jump in the SA gillnet CPUE timeseries at 1995, consistent with anecdotal reports from SharkRAG regarding the introduction of colour sounders to the fishery at this time, it is recommended that this split (Bridge 17) be used for a 2023 base case stock assessment model. This preliminary base case model consists of the following:

- net length based CPUE for gillnets, with the series for SA being broken into two at 1995 and ending in 2009,
- uses trawl CPUE for each stock (not for all combined) but splits the series for BS into 1996–2005 and 2008–2022 to recognise the effect (and ‘settling in’) of management changes from 2005,
- 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 is unavailable (i.e. age composition),
- extends the plus age group from 10 to 20.

5.2 Sensitivities

Several standard sensitivity tests are routinely conducted for the Gummy Shark stock assessment (Thomson 2020). Once a base case stock assessment model has been chosen by SharkRAG, sensitivities and forward projections are proposed to be performed. The following sensitivities are proposed for SharkRAG2:

- No effort saturation for gillnet CPUE (i.e. linear relationship with biomass).
- All age classes are equally available to gillnet gear.
- Selectivity for gillnet fleets is estimated (and so is availability).
- Selectivity for gillnet fleets is estimated but all age classes are equally available.
- M is 0.1 lower than the base case estimate (0.16).
- M is 0.1 greater than the base case estimate (0.16).
- density dependence acts on M for ages 0–15, as a function of 1+ biomass.
- density dependence acts on M for ages 0–4, as a function of 1+ biomass.
- density dependence acts on M for ages 0–2, as a function of 1+ biomass.
- density dependence acts on M for ages 0–30, as a function of mature biomass.
- density dependence acts on M for ages 0–15, as a function of mature biomass.
- density dependence acts on M for ages 0–4, as a function of mature biomass.
- density dependence acts on M for ages 0–2, as a function of mature biomass.
- the weight given to the CPUE data is doubled.
- the weight given to the CPUE data is halved.
- the weight given to the length frequency data is halved.
- the weight given to the age composition data is halved.
- the weight given to the conditional age-at-length data is halved.
- the weight given to the tagging data is halved.

For the preliminary 2023 base case stock assessment model presented here, the density dependence sensitivity tests have been run (Figure 12; Table 6). 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. 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). Further discussion by SharkRAG regarding which density dependence assumption to use in the base case, or whether to return to using model averaging to provide management advice, is warranted.

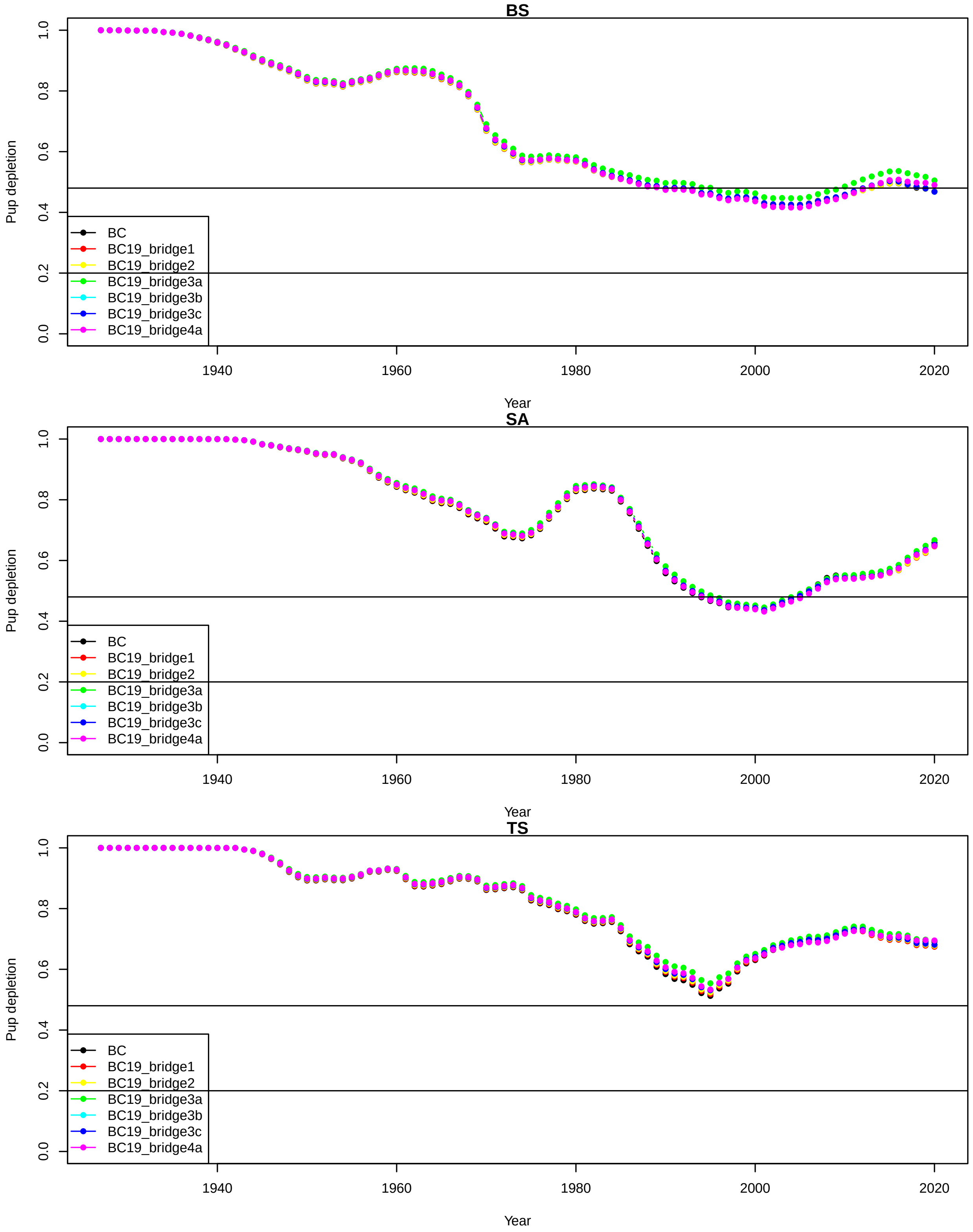

Figure 9: Gummy Shark pup depletion by stock for models with updated 2019 data. The 2020 base case (black) is shown for comparison. Limit (20%) and target (48%) reference points are shown as horizontal lines.

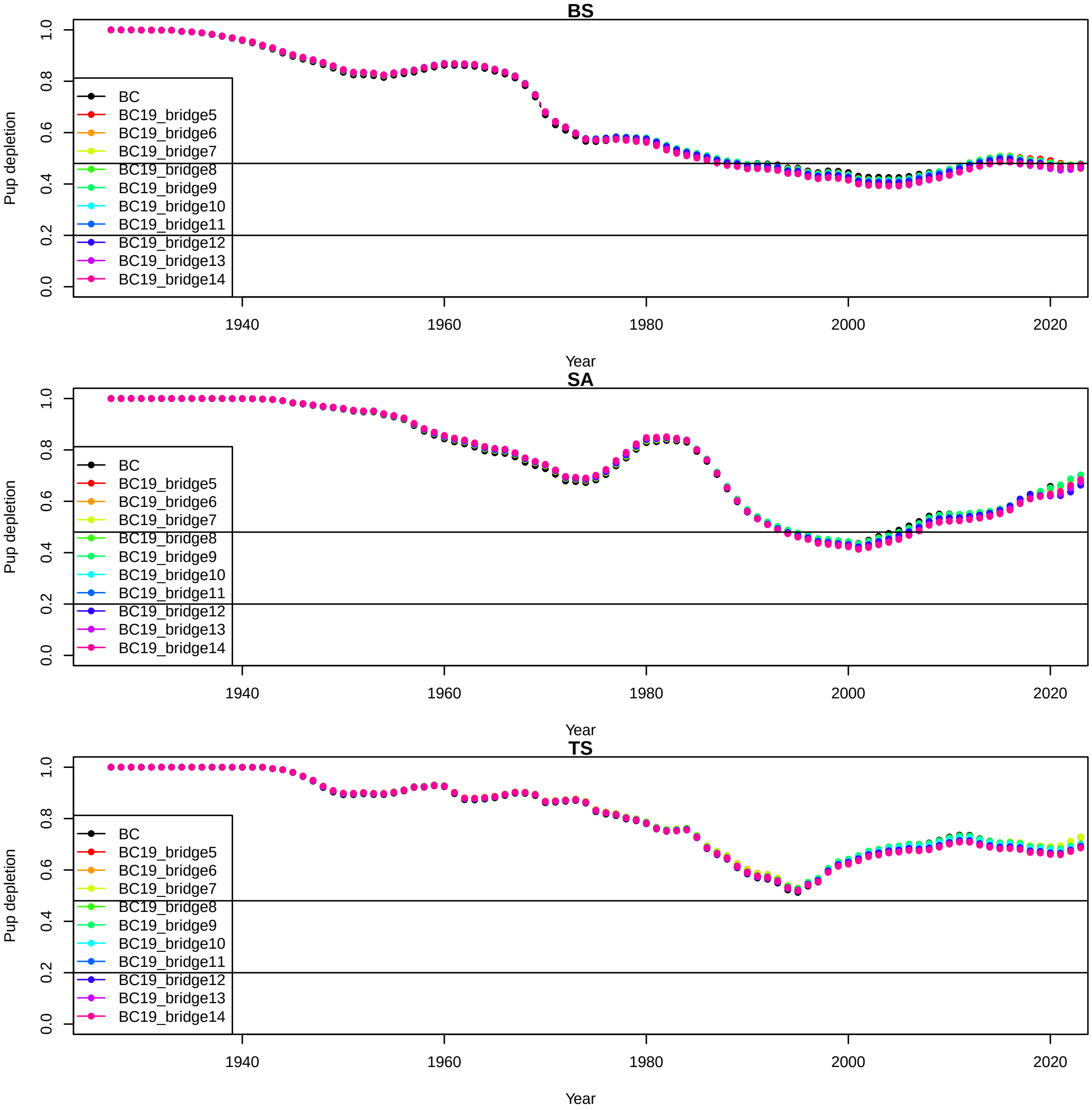

Figure 10: Gummy Shark pup depletion by stock for models that add data to 2022. The 2020 base case model (black) is shown for comparison.

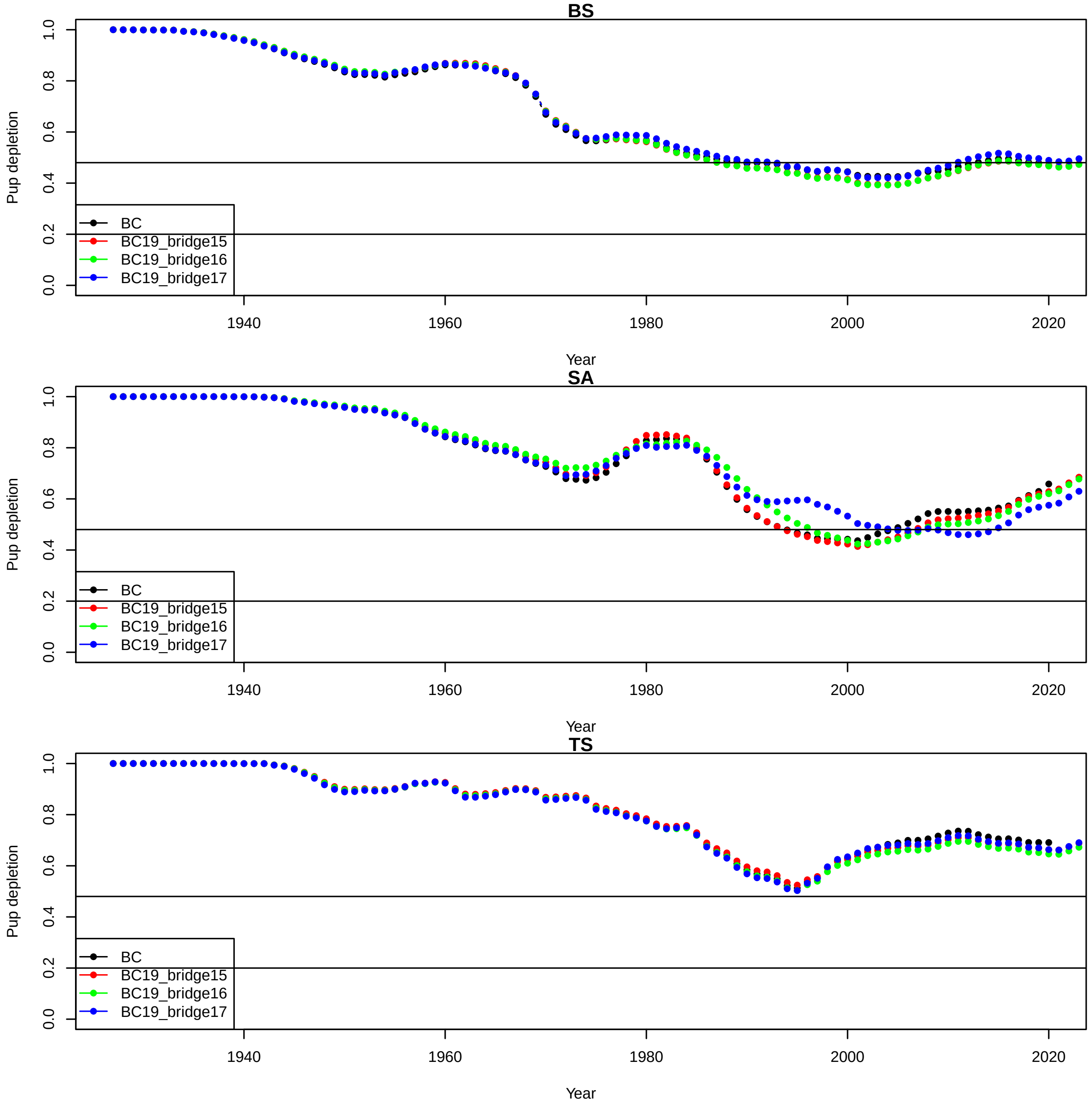

Figure 11: Gummy Shark pup depletion by stock for models that have data to 2022 and alter model design. The 2020 base case model (black) is shown for comparison.

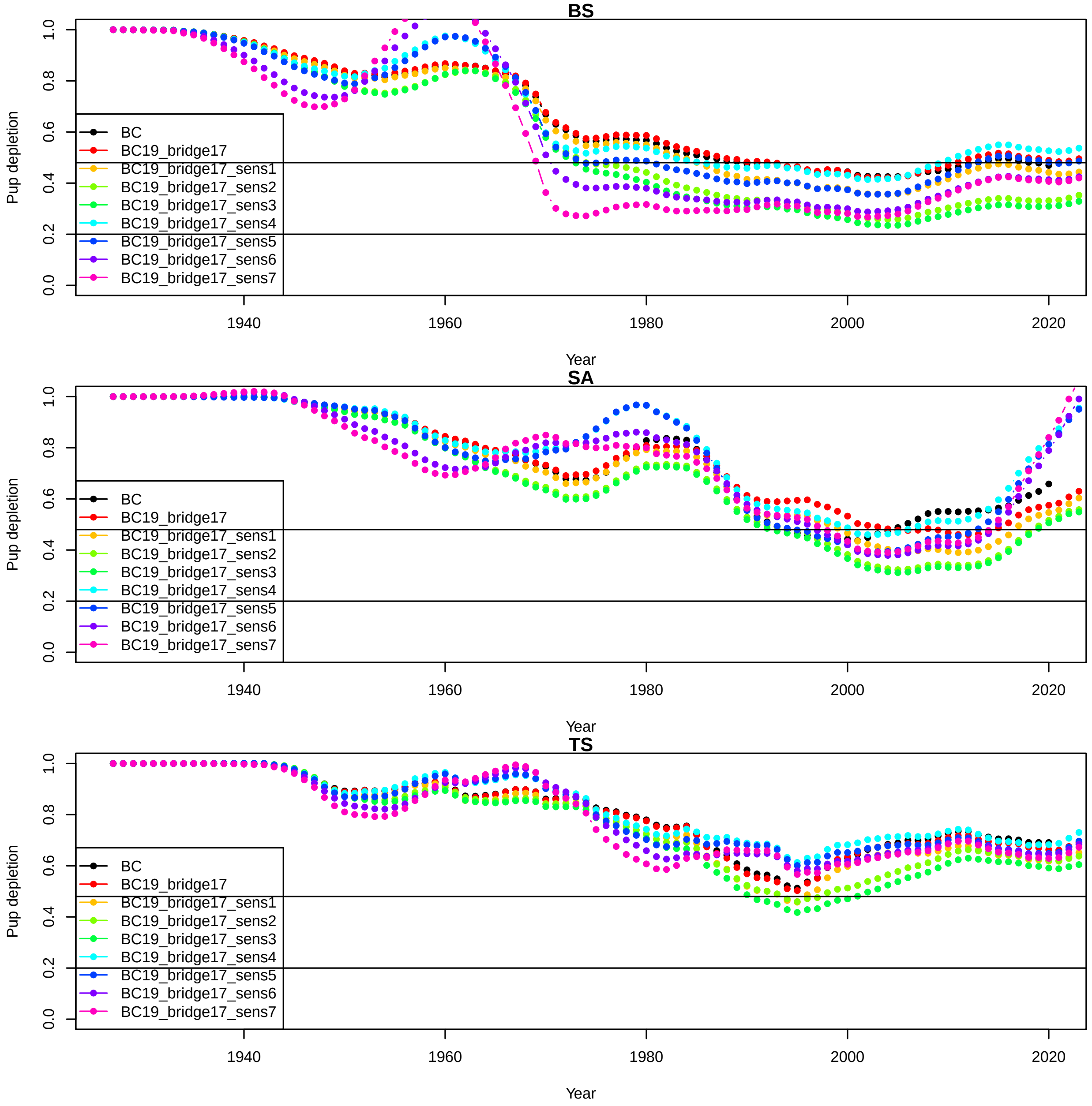

Figure 12: Gummy Shark pup depletion by stock for sensitivity model runs on the preliminary 2023 base case model (Bridge 17 - red). The 2020 base case model (black) is shown for comparison.

Table 3: Model estimates from the 2019 base case compared with those using 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
BC2019	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: Model estimates from the 2020 base case compared with those using updated data to 2022. 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
BC2019	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: Model estimates from the 2020 base case compared with those using updated data to 2022 and changed model structure. 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
BC2019	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

Table 6: Model estimates from the 2020 base case and preliminary 2023 base case compared with sensitivity test results. 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
BC2019	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
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
Bridge 17 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
Bridge 17 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
Bridge 17 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
Bridge 17 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
Bridge 17 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
Bridge 17 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
Bridge 17 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

5.3 Results plots

5.3.1 CPUE

The fits to the standardised CPUE timeseries used by three of the bridging model steps are shown below (Bridge 15–17) to compare the model fits to modified South Australia gillnet CPUE timeseries relative to the traditional timeseries used (Figure 13 – 15). Starting the CPUE timeseries 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 Australia gillnet CPUE timeseries that occurred around 1995 where values shifted from averaging around 20–40, to 60–70. Therefore, the model fits to two stable CPUE timeseries, rather than a single increasing CPUE timeseries. Although, the model does not fit that well to each series. Outputs from these steps suggest that the South Australia gillnet CPUE timeseries should be split at 1995 as there is quite a clear step change in CPUE around this time where colour sounders were introduced to the fleet.

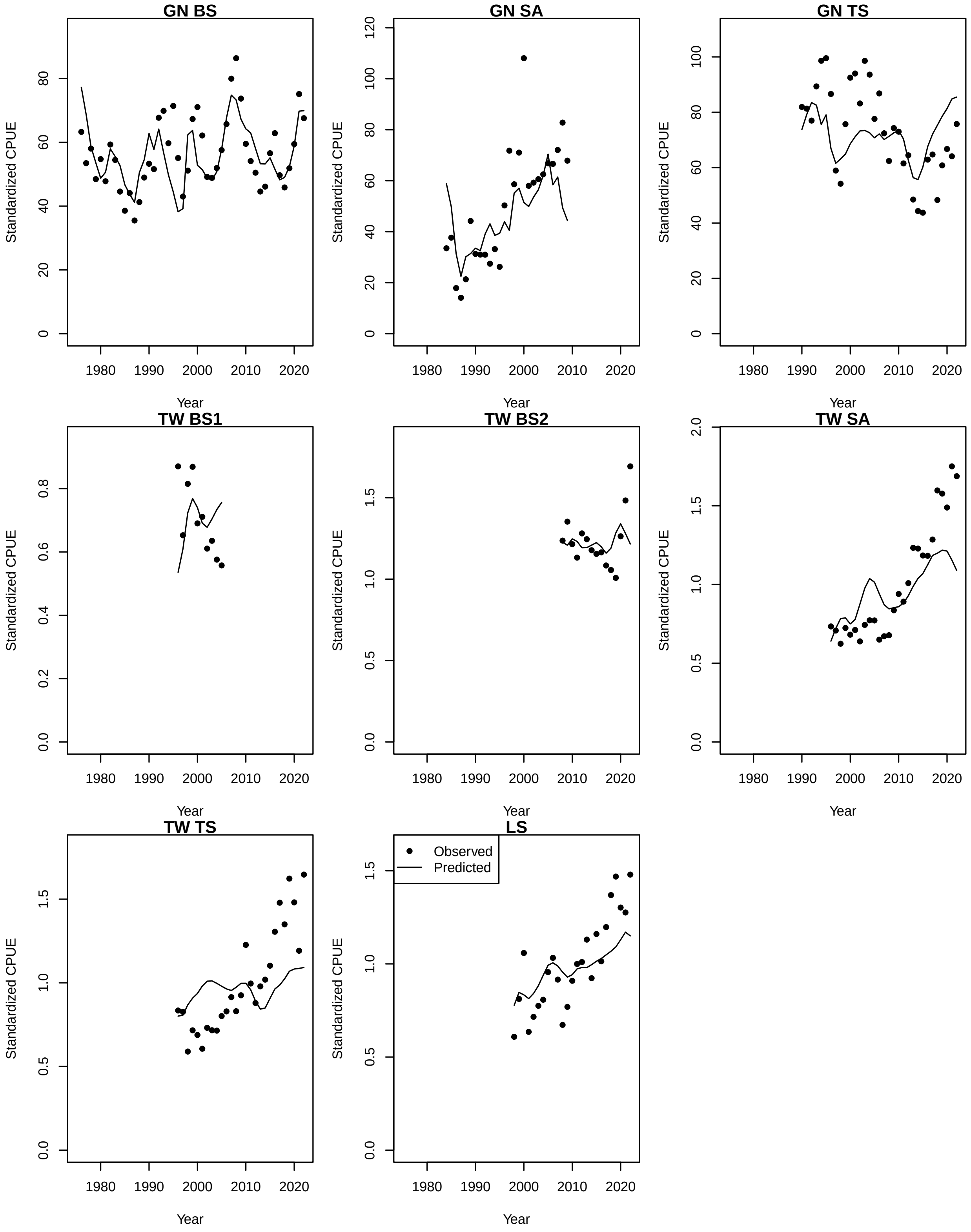

Figure 13: Standardised CPUE time series (Observed) and associated model estimated relative exploitable biomass (Predicted) for Bridge 15 where South Australia gillnet CPUE timeseries runs from 1984-2009.

5.3.2 Conditional age-at-length

Even though growth is not estimated within the model, the fits between observed and predicted age-at-length are reasonable (Figure 18; Figure 21). It is noted that the poor correspondence between observed and predicted male growth, particularly at older ages, was attempted to be overcome by restricting the plus age group to 10. Below, fits of the model to the conditional age-at-length data for Bridgs 14 where 2022 data is added but the plus group is 10, and for the preliminary 2023 base case (Bridge 17) where the plus group is extended to 20 is shown (Figure 18; Figure 21). Extending the plus age group was a recommendation as a result 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 age group 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. Modifications to the model to estimate growth have yet to be explored and should be a priority in future assessments. It may be that growth varies spatially and needs to be estimated separately across the three stocks which was identified in the initial study used to define the input growth parameters in the stock assessment (Moulton *et al.* 1992). However, this may be difficult given the variable sampling undertaken for each stock.

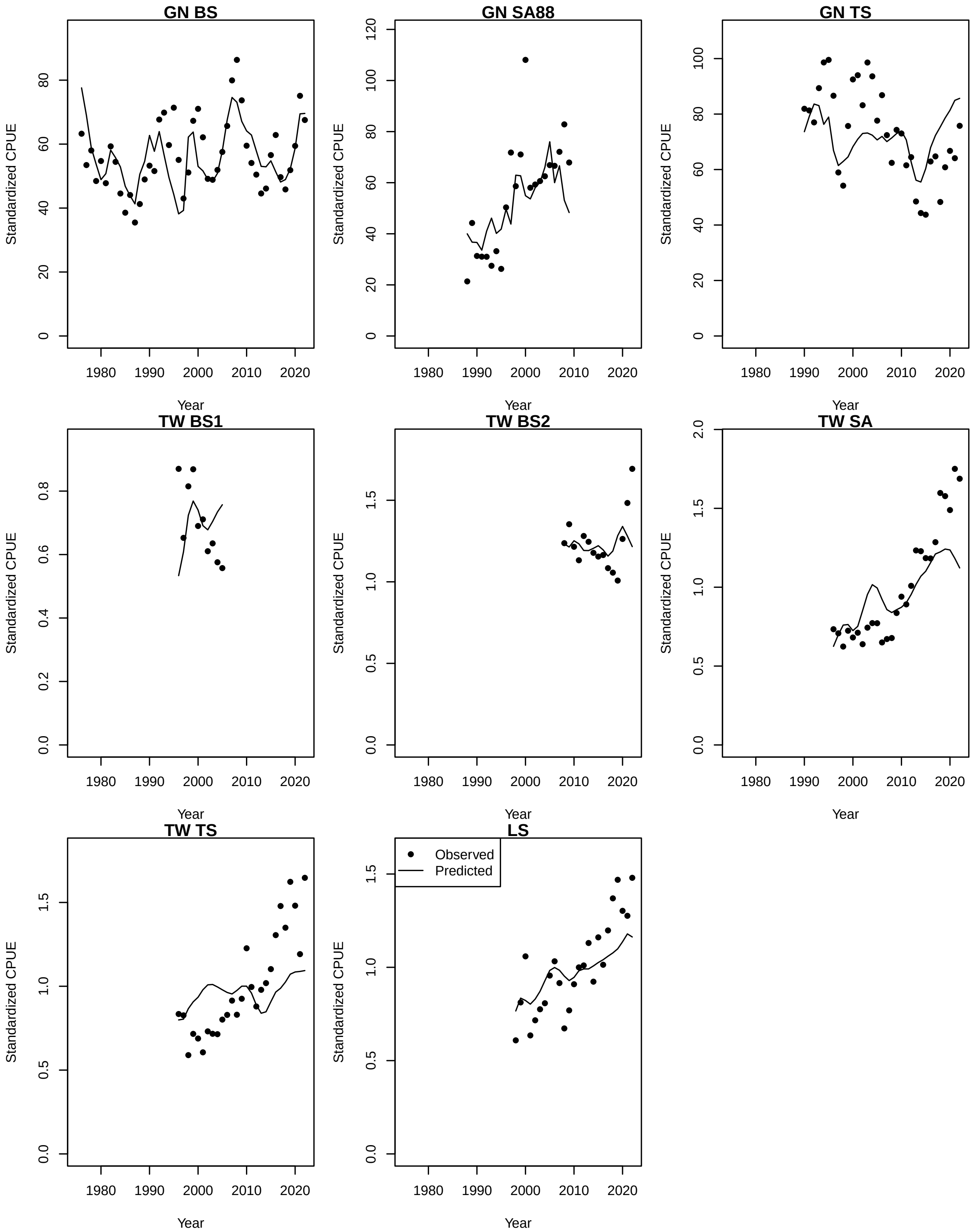

Figure 14: Standardised CPUE time series (Observed) and associated model estimated relative exploitable biomass (Predicted) for Bridge 16 where South Australia gillnet CPUE timeseries runs from 1988-2009.

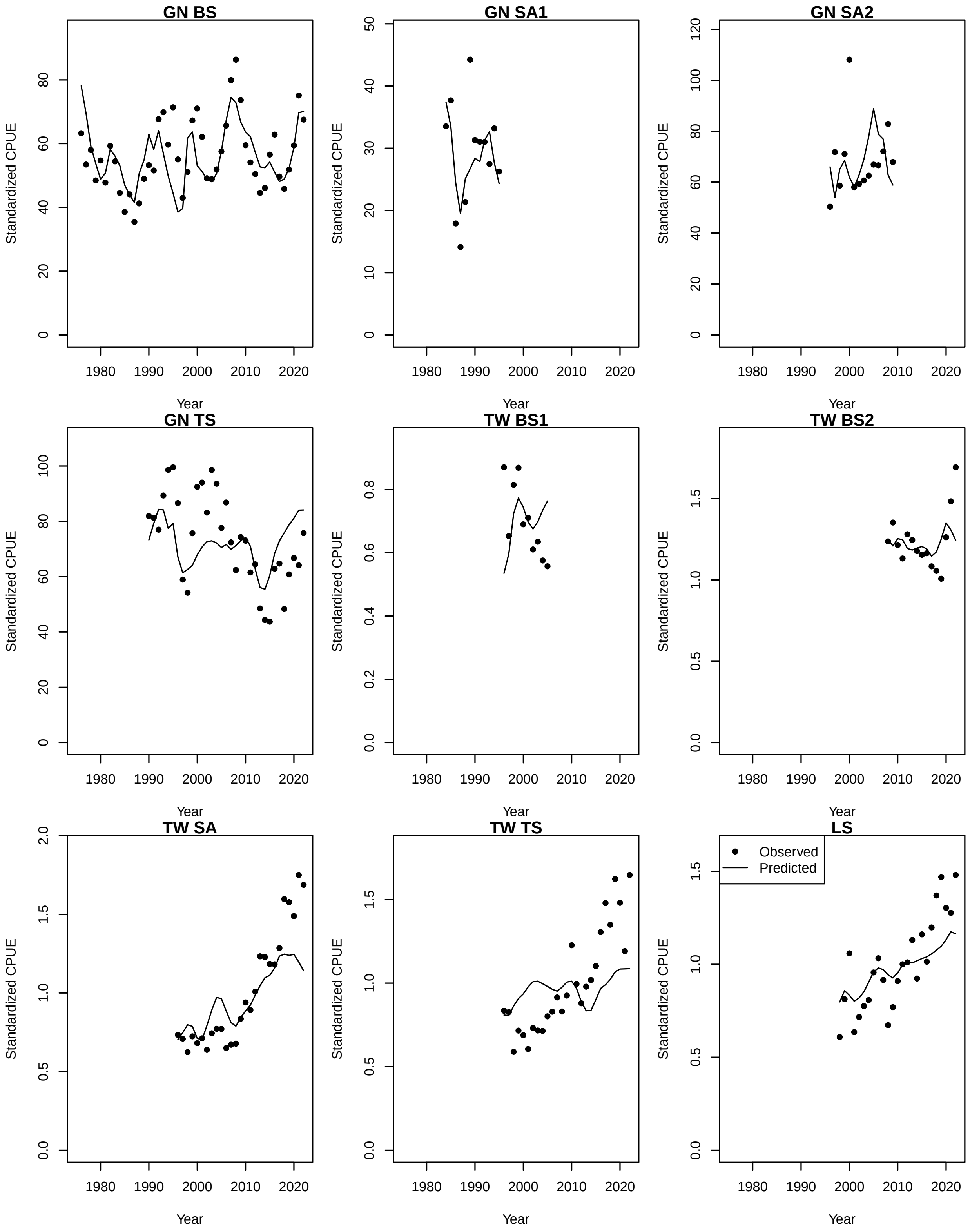

Figure 15: Standardised CPUE time series (Observed) and associated model estimated relative exploitable biomass (Predicted) for Bridge 17 where South Australia gillnet CPUE timeseries is broken into two at 1995.

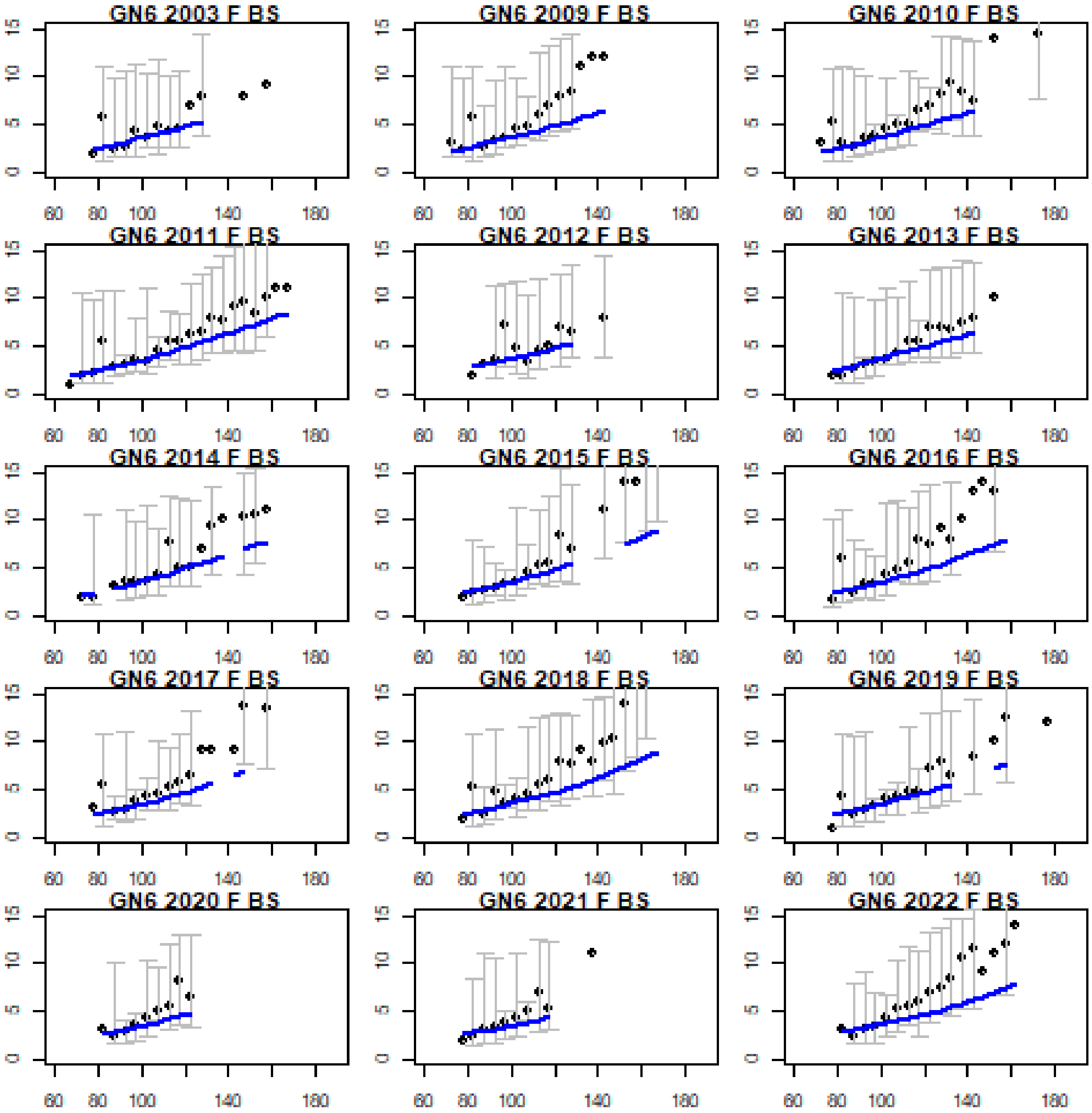

Figure 16: Observed conditional age-at-length (dots and 90% error bars) and expected age-at-length (blue line) for model Bridge 14 where the plus age group is 10.

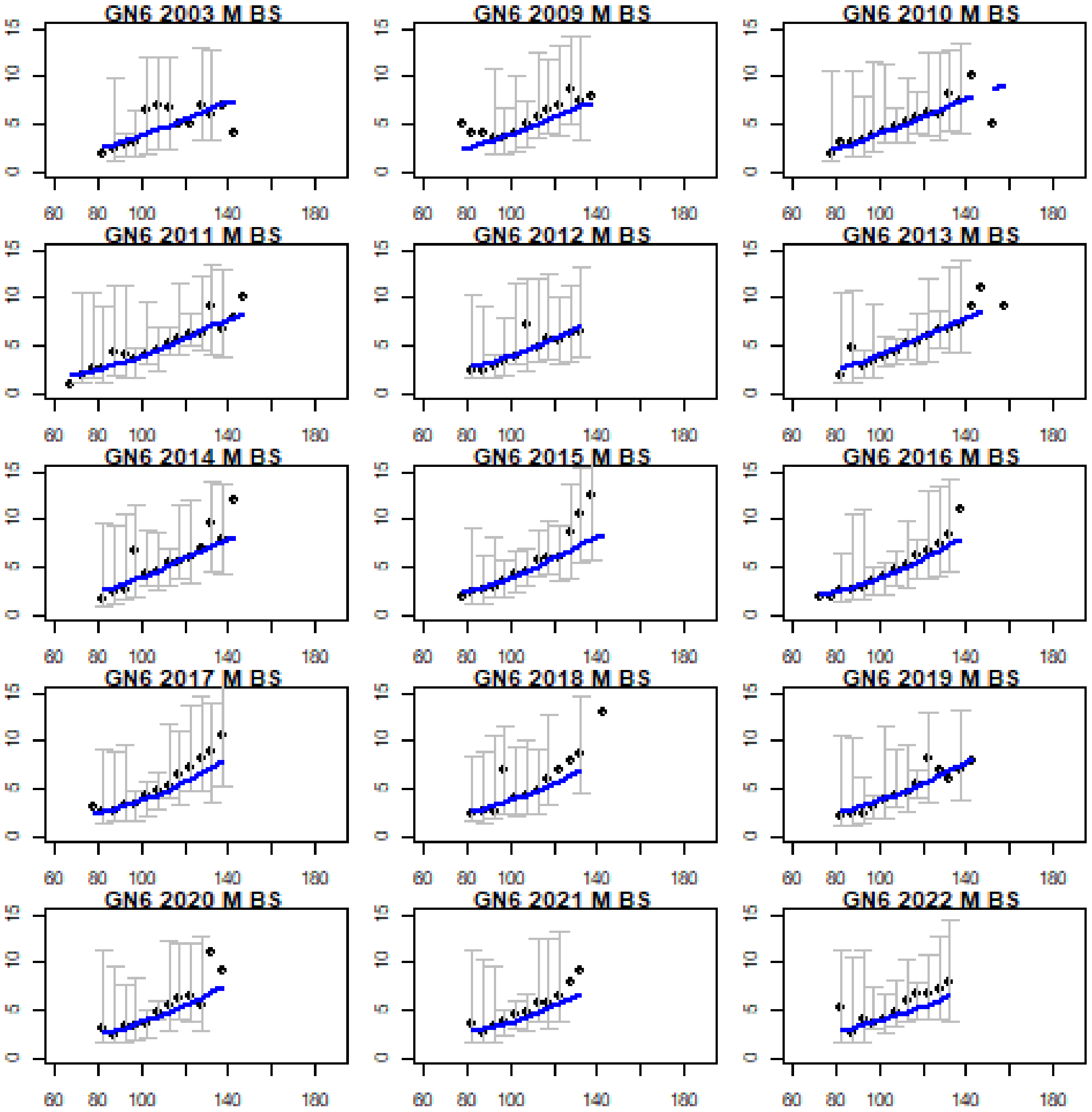

Figure 17: (continued) Observed conditional age-at-length (dots and 90% error bars) and expected age-at-length (blue line) for model Bridge 14 where the plus age group is 10.

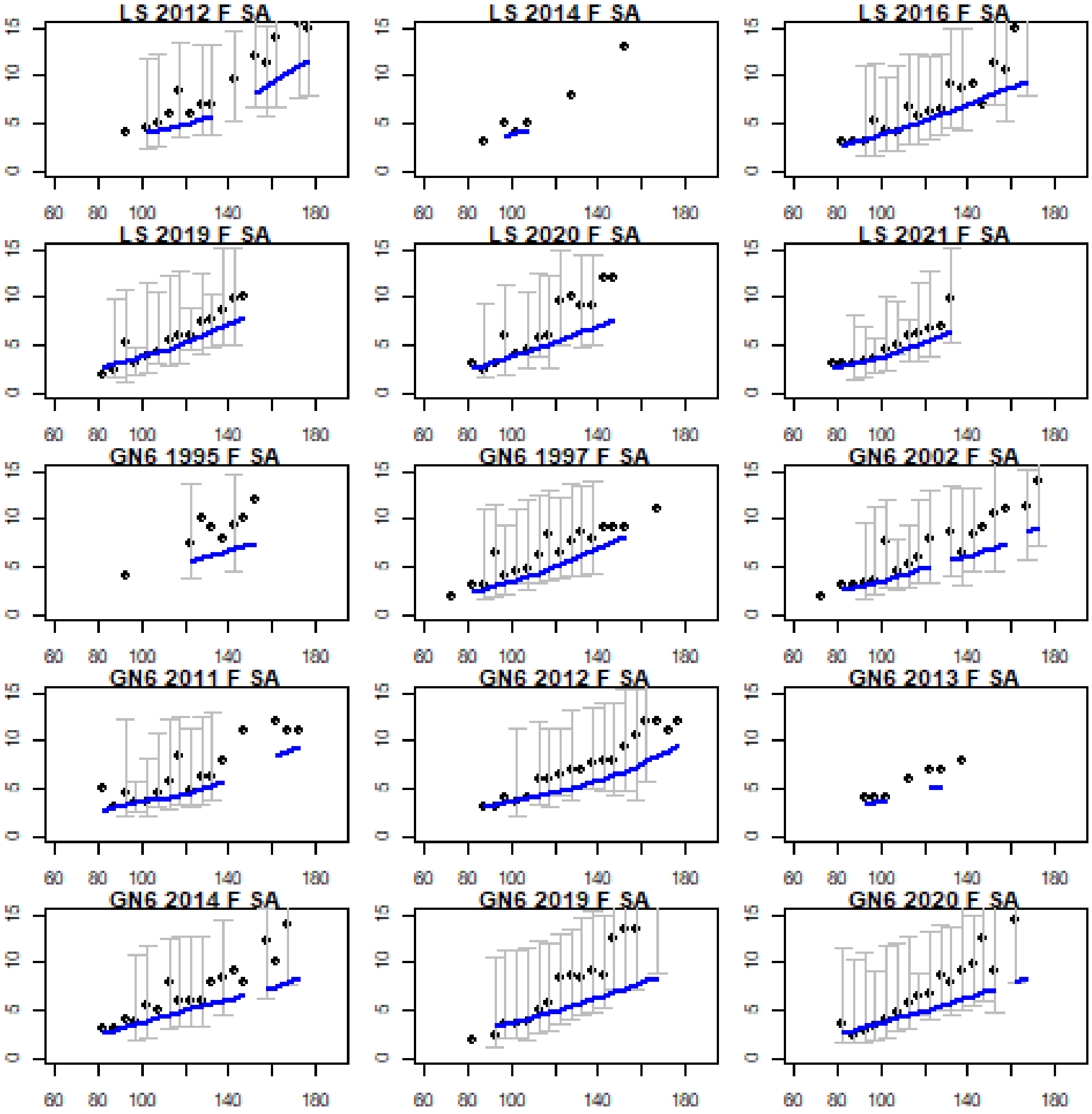
LS 2012 F SA
LS 2014 F SA
LS 2016 F SA
LS 2019 F SA
LS 2020 F SA
LS 2021 F SA
GN6 1995 F SA
GN6 1997 F SA
GN6 2002 F SA
GN6 2011 F SA
GN6 2012 F SA
GN6 2013 F SA
GN6 2014 F SA
GN6 2019 F SA
GN6 2020 F SA

Figure 18: (continued) Observed conditional age-at-length (dots and 90% error bars) and expected age-at-length (blue line) for model Bridge 14 where the plus age group is 10.

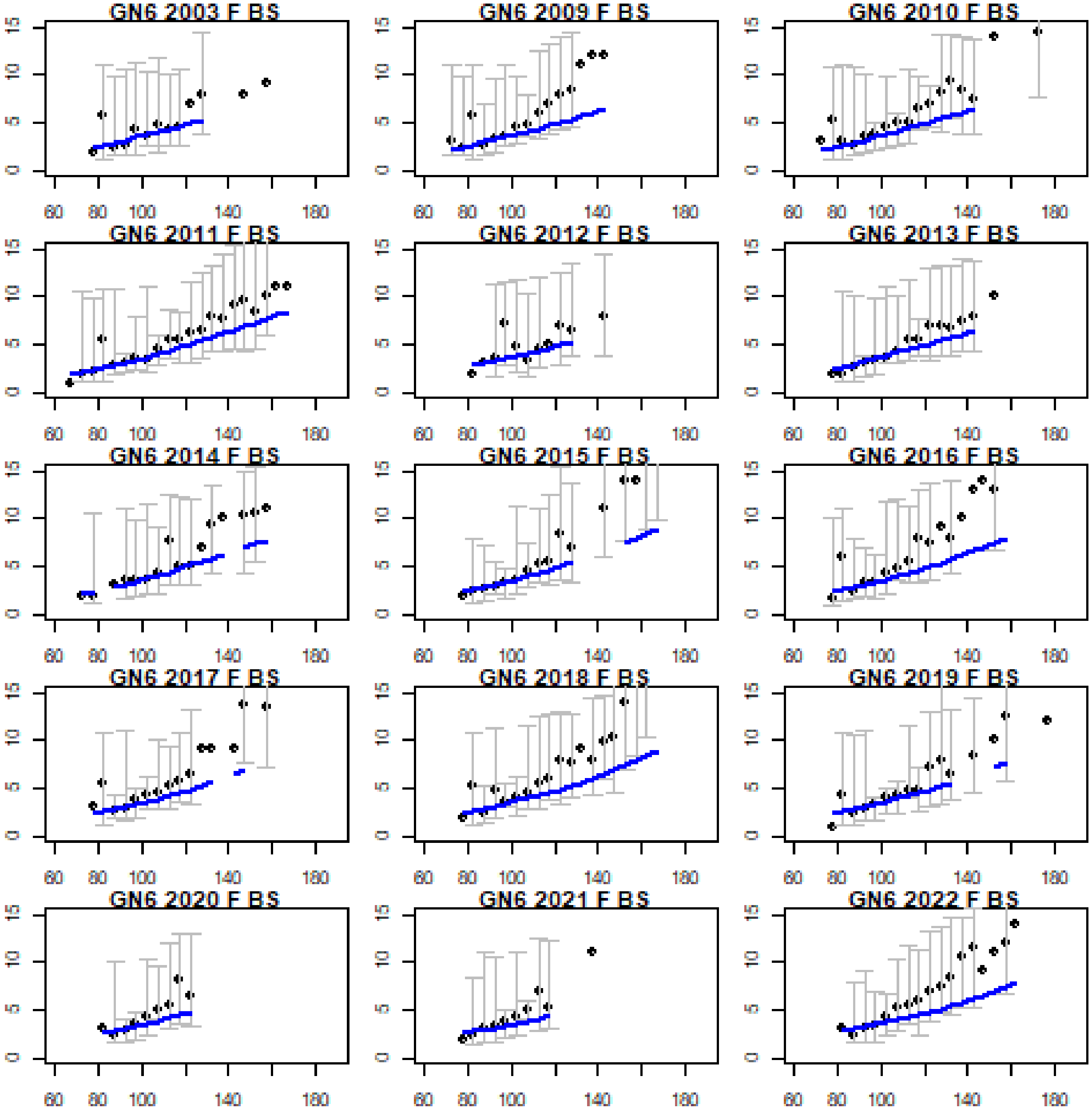

Figure 19: Observed conditional age-at-length (dots and 90% error bars) and expected age-at-length (blue line) for the preliminary 2023 base case model (Bridge 17) where the plus age group is extended to 20.

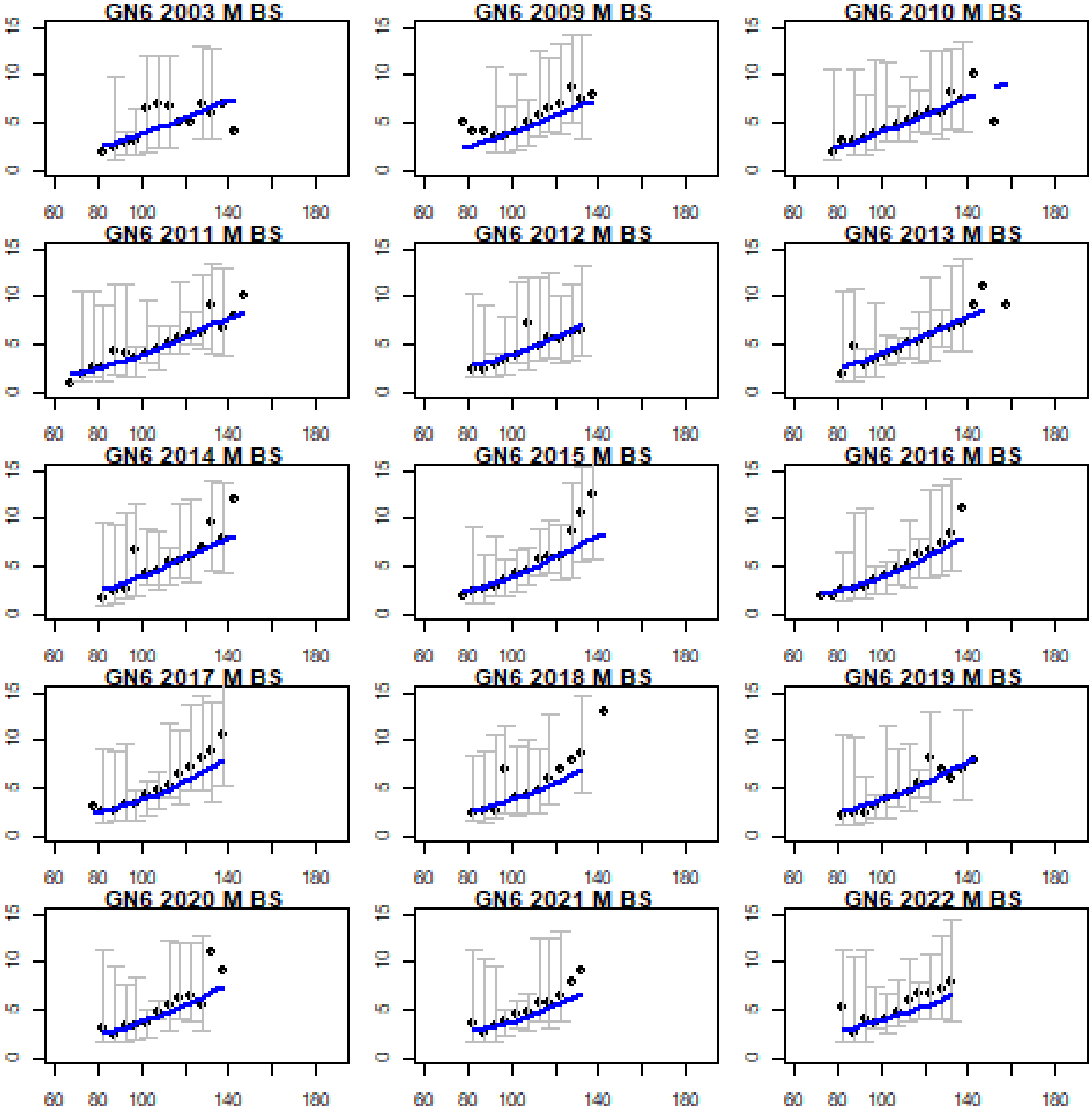

Figure 20: (continued) Observed conditional age-at-length (dots and 90% error bars) and expected age-at-length (blue line) for the preliminary 2023 base case model (Bridge 17) where the plus age group is extended to 20

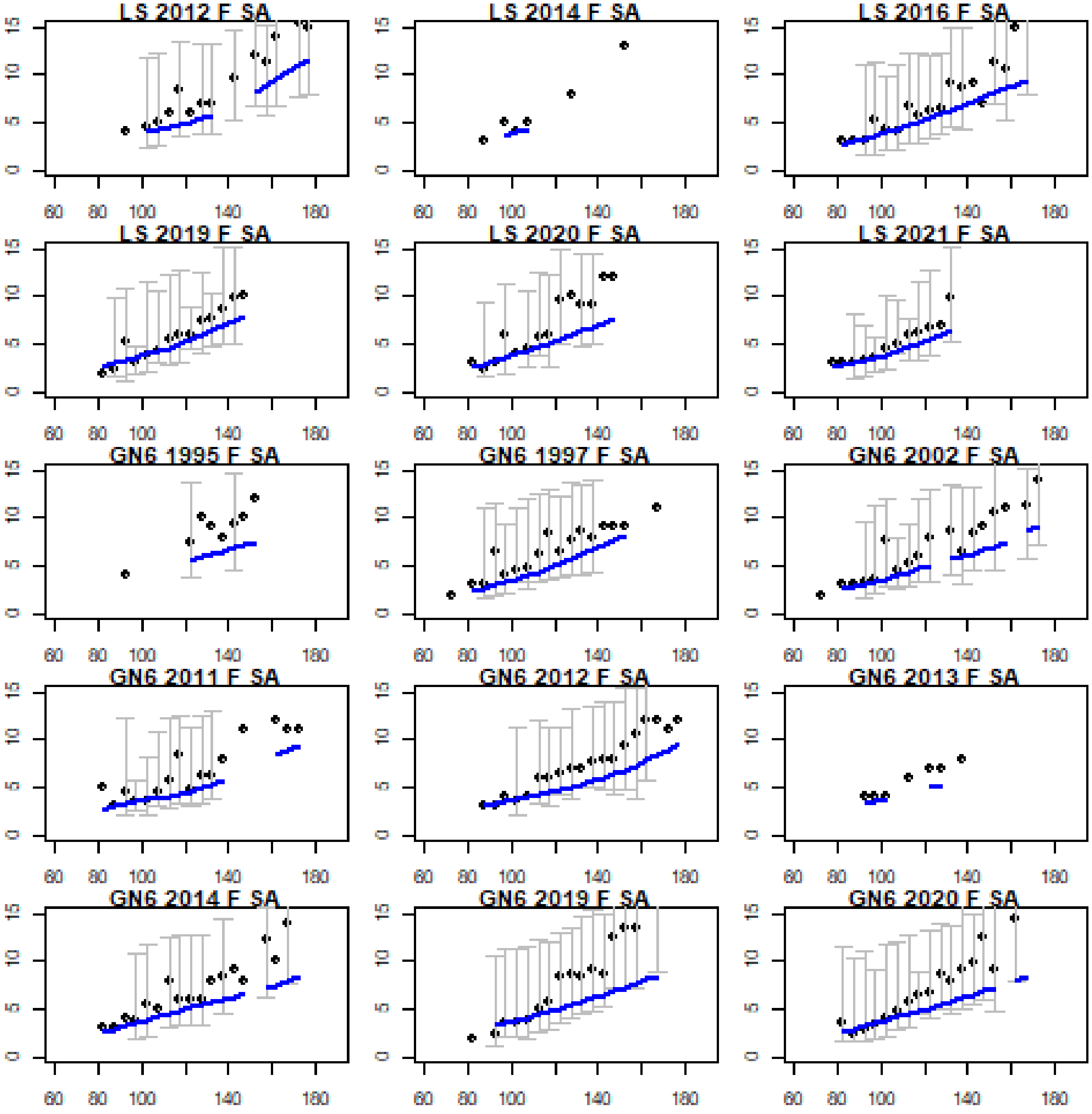

Figure 21: (continued) Observed conditional age-at-length (dots and 90% error bars) and expected age-at-length (blue line) for the preliminary 2023 base case model (Bridge 17) where the plus age group is extended to 20.

5.3.3 Selectivity

The selectivities for the seven gear types are shown in Figure 22 across several models (BC2019, 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.

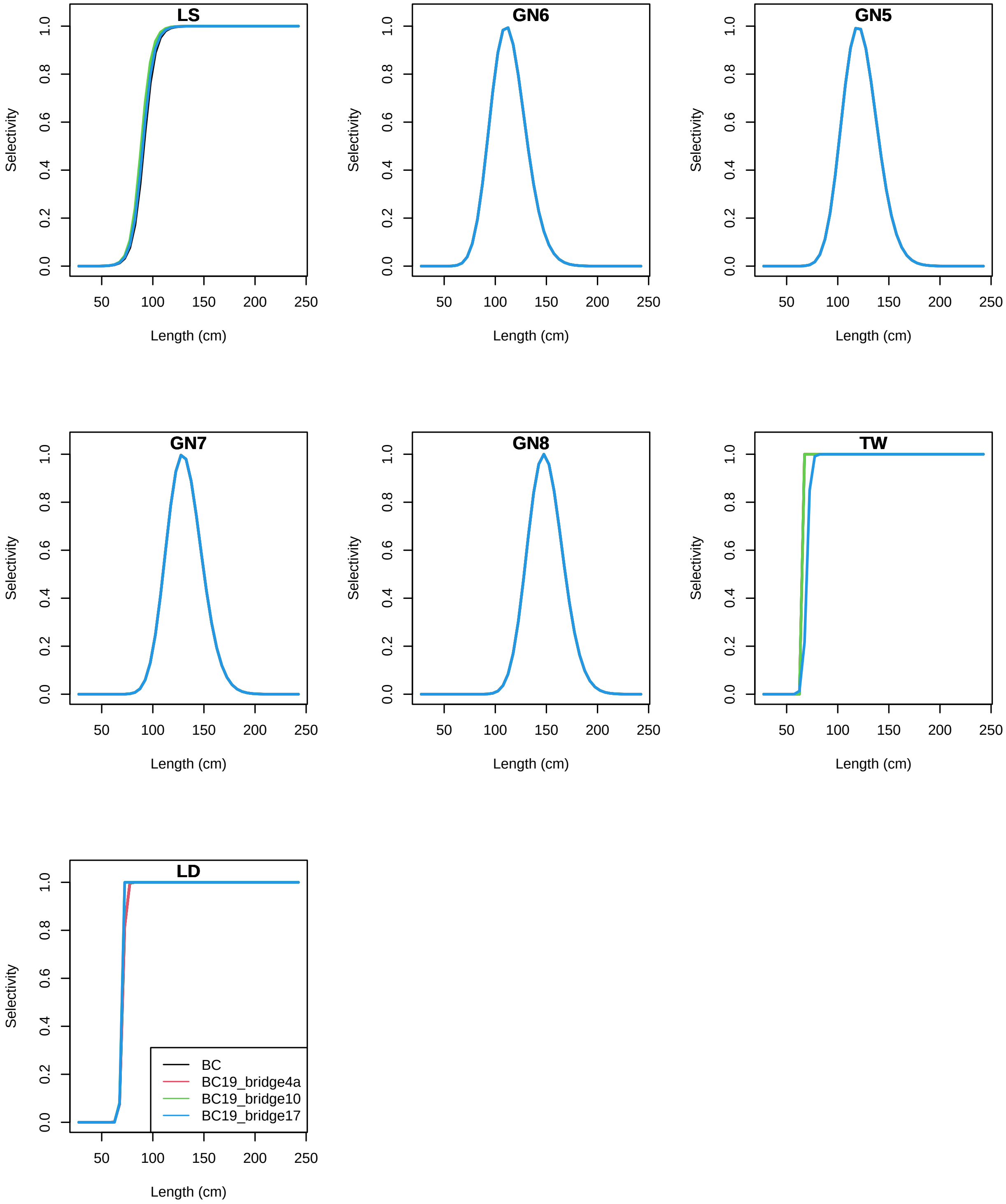

Figure 22: Selectivity functions for the seven gear types for selected model runs. Shallow line (LS), 6in Gillnet (GN6), 6.5in Gillnet (GN5), 7in Gillnet (GN7), 8in Gillnet (GN8), Trawl (TW), Deep line (LD).

5.3.4 Lengths

Summed observed and predicted length frequencies are shown in Figure 23 and 24. 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 doesn't have much data to fit to. This also means that these fits shouldn't be given much weight by the model.

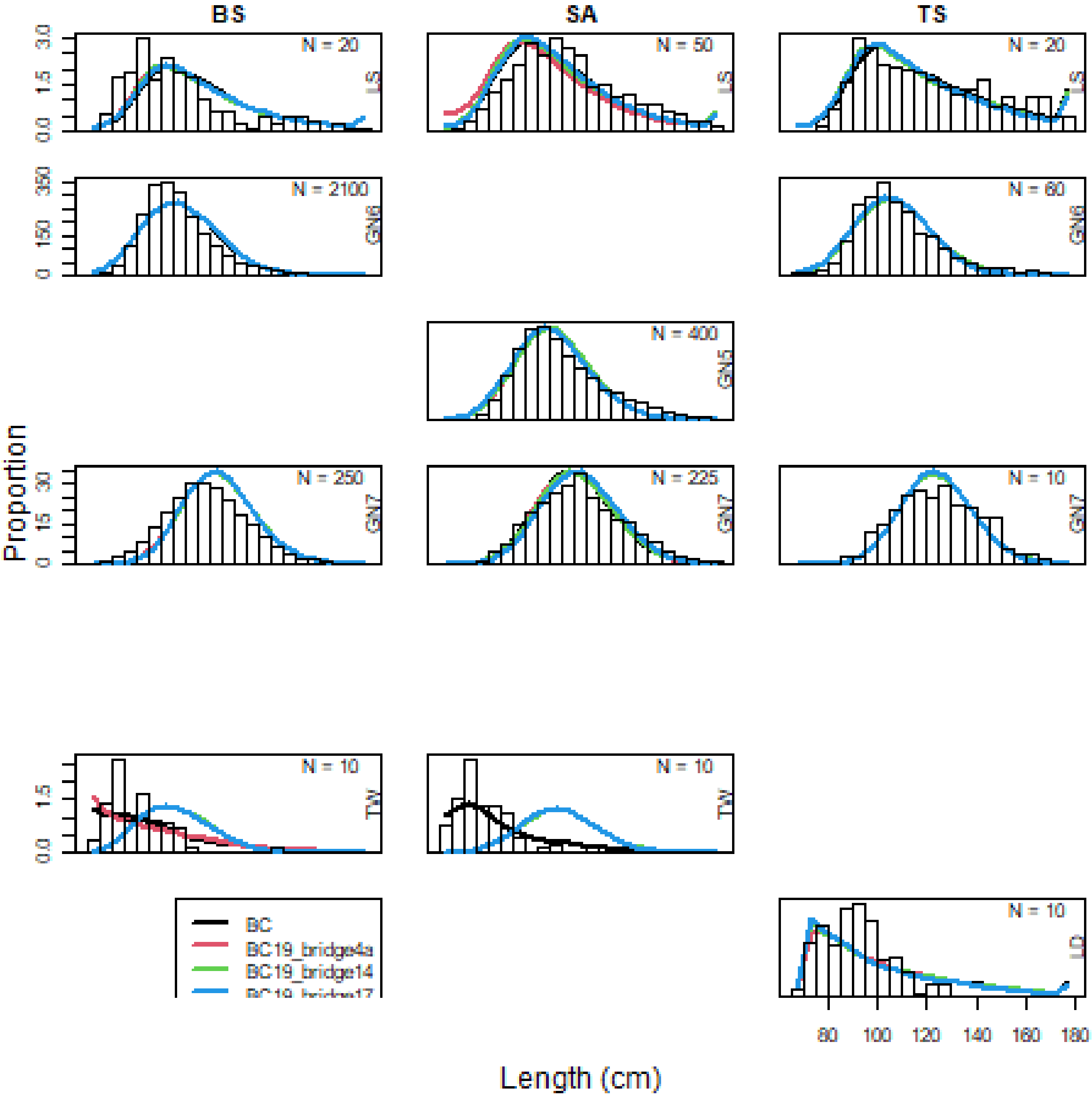

Figure 23: Observed (bars) and predicted (lines) length frequencies for females for selected models during bridging. Observations and predictions have been summed over all years. The number of years for which data is available is shown (N).

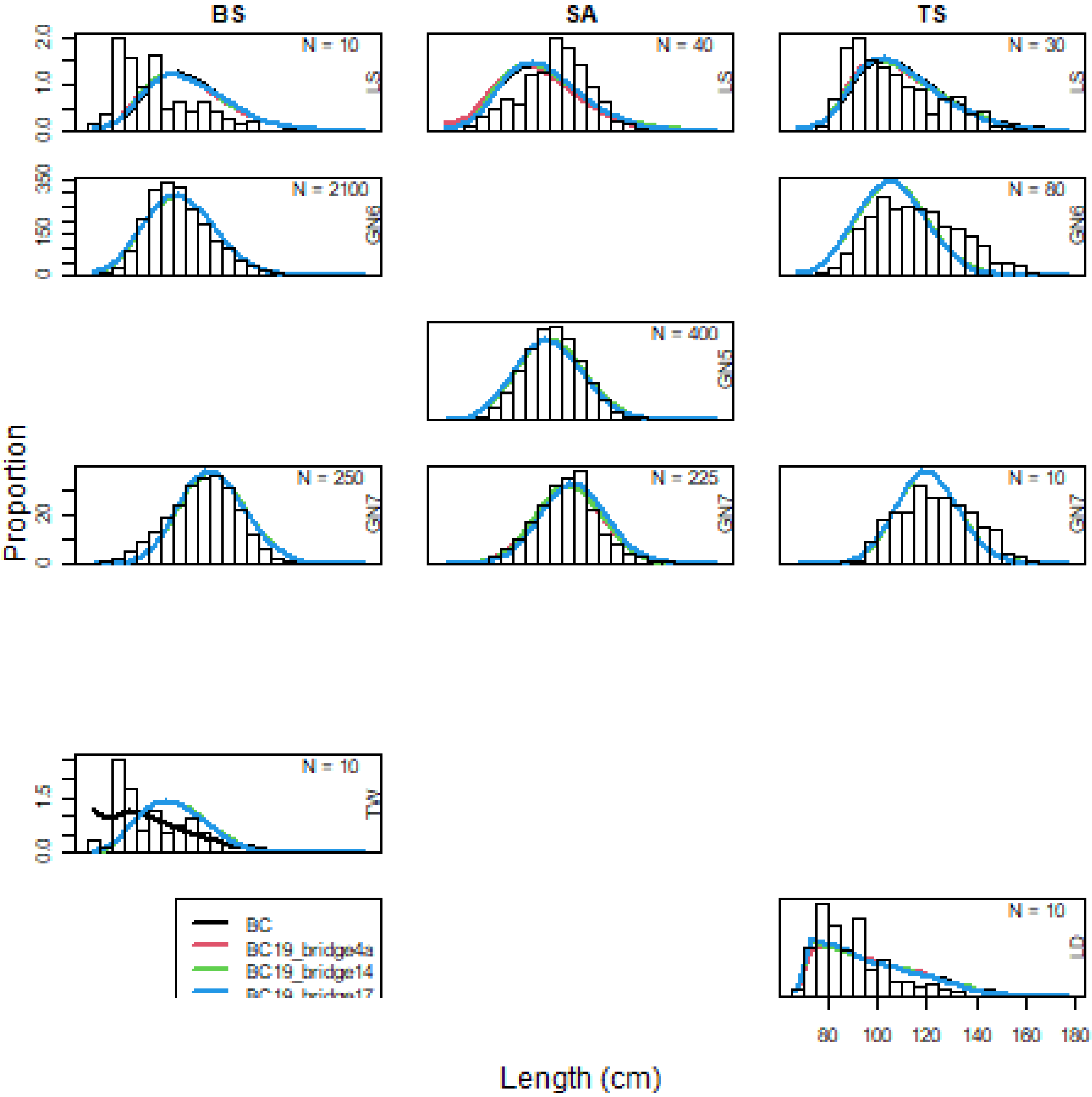

Figure 24: Observed (bars) and predicted (lines) length frequencies for males for selected models during bridging. Observations and predictions have been summed over all years. The number of years for which data is available is shown (N).

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 was updated from 2020–2022 across all data inputs and in particular for conditional age-at-length data which was only available until 2015 for the 2020 stock assessment. Several model upgrades were also explored including the extension of the plus age group from 10 to 20, and the exploration of different South Australia gillnet CPUE timeseries. These updates constitute several improvements to the model, however the results have remained largely stable and consistent with the previous 2020 base case stock assessment (Thomson 2020). The addition of the Danish seine fleet, and port length data is ongoing. Retrospectives and likelihood profiles will be presented once a base case model has been chosen.

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 South Australia. 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 preliminary 2023 base case model (Bridge 17). A base case model is yet to be formally proposed to SharkRAG, with remaining sensitivities and additions to the model yet to be completed.

The preliminary 2023 Gummy Shark stock assessment model (Bridge 17) has several changes to it relative to the 2020 base case stock assessment model. This includes updating data inputs from 2020–2022 inclusive, extending the plus age group from 10 to 20 for the underlying model, and splitting the South Australia gillnet CPUE timeseries into two at 1995 (1984–1995; 1996–2009). These changes allow the model to better fit to the conditional age-at-length data for larger, older Gummy Sharks. The break in the SA gillnet CPUE timeseries also allows the 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 which allows CPUE timeseries 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 age group from 10 to 20 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 fixes growth based on vertebral ageing of Gummy Sharks in the 1970s and 1980s (Moulton *et al.* 1992). It may be that these growth parameters were not well estimatesd, 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.

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 6). 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. Estimation of growth rates within the model should explore the inclusion estimation of sex-specific natural mortality rates.

6.1 Future work

In 2020, a number of suggestions for future work were made. In this 2023 stock assessment update a number of these have been addressed and the following remain:

1. Estimate growth and sex specific natural mortality within the model.
2. Investigate the use of port-collected length data for the trawl fleet; it might also be possible to use port data for gillnets and line vessels if the assumption is made that collections are in proportion to catches of gillnet fleets and line fleets – Underway.
3. Add a Danish seine fleet to the model, using onboard but not port collected length frequency data – Underway.
4. Recalculate the ageing error matrix using the new age data and attempt to calculate age error by age class (which was not previously possible, due to lack of data).

The following RBC calculations and forward projections are proposed for presentation at SharkRAG2 once a base case model is chosen:

1. Annual RBCs, by stock over a 5 year period (2024 to 2028);
2. Long term average RBC;
3. 5 year forward projection using the annual RBCs;
4. 5 year forward projection using the average of the 2024 to 2026 RBCs (3y average);
5. 5 year forward projection using the average of the 2024 to 2028 RBCs (5y average);
6. 5 year forward projection using the long term average RBC;
7. Projection of the 3 year average RBC but assuming a shift towards greater line fishing in BS, and less in SA, assuming that line selectivity in BS is; (a) The same as in SA, or; (b) Matches 5-inch GN selectivity on the LHS but is logistic.

Regarding point 7 above, SharkRAG advice is sought regarding the degree of shift in effort from SA into BS.

7 Acknowledgements

Simon Robertson (Fish Ageing Service) is thanked for hard work in providing Gummy Shark ages ahead of time for the assessment. The CSIRO Data Services Team (Paul, Burch, Pia Bessell-Browne, Mike Fuller, Franzis Althaus, and Roy Deng) along with the AFMA team are thanked for data provision, data preparation and checking as well as many useful conversations. Paul Burch and Pia Bessell-Browne are thanked for helpful comments on an earlier version of this report. Shark Resource Assessment Group members and other participants are thanked for useful conversations and suggestions regarding this work. Ross Bromley and the SIDaC team are thanked for collecting length data and vertebrae for ageing.

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9 Appendix

9.1 Appendix A: Catches as input into the 2023 stock assessment.

Table 7: 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
1	1927	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1928	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1929	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1930	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1931	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	1932	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1933	63.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	1934	35.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	1935	63.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	1936	101.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	1937	120.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	1938	134.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	1939	159.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	1940	176.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1941	252.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1942	240.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	1943	320.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1944	306.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	1945	293.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	1946	304.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	1947	340.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1948	399.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1949	461.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	1950	411.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	1951	294.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	1952	368.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	1953	467.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	1954	263.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1955	318.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	1956	305.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	1957	211.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	1958	202.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	1959	212.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	1960	315.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	1961	340.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1962	376.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	1963	463.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	1964	495.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	1965	383.4	14.2	0.1	80.3	1.9	0.0	0.0	0.0
40	1966	386.5	17.1	0.2	95.9	2.4	0.0	0.0	0.0

41	1967	420.1	33.4	0.3	188.7	4.4	0.0	0.0	0.0
42	1968	381.3	58.9	0.6	327.5	9.0	0.0	0.0	0.0
43	1969	349.8	97.8	1.1	538.2	20.4	0.0	0.0	0.0
44	1970	384.4	36.5	0.3	204.1	11.2	0.0	0.0	0.0
45	1971	177.5	64.9	0.5	371.1	15.2	0.0	0.0	0.0
46	1972	90.3	152.3	1.1	880.7	28.9	0.0	0.0	0.0
47	1973	74.0	213.5	2.0	1200.3	41.3	0.0	0.0	0.0
48	1974	123.9	700.1	0.0	391.3	1.5	0.0	0.0	0.0
49	1975	133.9	755.1	0.0	144.1	0.3	0.0	0.0	0.0
50	1976	82.4	780.4	0.0	85.4	5.0	0.0	0.0	0.0
51	1977	111.4	948.1	0.0	8.6	0.7	0.0	0.0	0.0
52	1978	101.2	843.6	2.5	7.2	0.2	0.0	0.0	0.0
53	1979	106.2	671.8	4.1	25.0	0.2	0.0	0.0	0.0
54	1980	130.7	744.9	7.6	25.9	0.0	0.0	0.0	0.0
55	1981	98.9	833.0	7.6	63.2	0.0	0.0	0.0	0.0
56	1982	59.0	1063.8	0.1	46.1	0.2	0.0	0.0	0.0
57	1983	72.7	1058.5	1.2	45.4	0.0	0.0	0.0	0.0
58	1984	104.5	954.0	1.1	28.2	0.0	0.0	0.0	0.0
59	1985	127.0	929.1	6.1	7.3	0.0	0.0	0.0	0.0
60	1986	100.4	1024.6	13.1	6.1	0.0	0.0	0.0	0.0
61	1987	86.8	930.0	5.7	11.7	5.1	0.0	0.0	0.0
62	1988	72.7	854.6	4.8	3.0	0.3	0.0	0.0	0.0
63	1989	143.9	1036.2	5.5	6.9	0.9	0.0	0.0	0.0
64	1990	75.1	882.5	0.0	6.2	0.0	0.0	0.0	0.0
65	1991	151.8	920.0	14.7	5.5	0.1	0.0	0.0	0.0
66	1992	189.4	1001.0	2.6	8.4	0.0	0.0	0.0	0.0
67	1993	192.8	1196.0	0.4	12.5	21.4	0.0	0.0	0.0
68	1994	79.2	917.8	1.9	12.2	8.8	0.0	0.0	0.0
69	1995	38.4	1126.9	34.2	33.6	0.0	0.0	0.0	0.0
70	1996	50.5	866.7	9.1	15.3	0.0	0.0	0.0	0.0
181	1997	17.2	503.6	20.6	0.0	0.0	20.4	0.4	9.7
191	1998	41.3	806.0	32.9	0.0	0.0	23.4	0.4	12.2
201	1999	54.7	1157.6	33.8	0.0	0.0	21.3	0.4	14.2
211	2000	116.8	1377.3	73.3	0.0	0.0	26.0	0.3	11.5
221	2001	47.5	1136.1	36.5	0.0	0.0	25.1	0.4	14.7
231	2002	45.8	972.9	32.0	0.0	0.0	25.8	0.3	13.9
241	2003	47.4	992.3	13.1	0.0	0.0	25.6	0.5	8.6
251	2004	39.6	992.9	19.5	0.0	0.0	26.5	1.1	12.0
261	2005	30.6	932.9	16.7	0.0	0.0	25.7	0.5	17.1
271	2006	20.6	839.2	10.1	0.0	0.0	31.3	1.1	9.3
281	2007	28.9	985.4	1.0	0.0	0.0	36.1	0.6	13.4
291	2008	30.6	1088.8	1.9	0.0	0.0	54.9	4.6	16.7
301	2009	22.3	948.8	13.1	0.0	0.0	44.0	1.5	14.9
311	2010	21.6	840.3	21.5	0.0	0.0	48.0	6.5	15.3
321	2011	22.2	924.6	10.7	0.0	0.0	49.4	3.4	27.3
331	2012	21.7	884.1	37.6	0.0	0.0	51.6	4.7	28.9
341	2013	11.3	903.0	9.8	0.0	0.0	49.9	8.3	28.4
351	2014	6.0	940.1	0.0	0.0	0.0	45.6	1.9	20.4
361	2015	10.6	1122.3	0.0	0.0	0.0	39.6	0.4	25.1
371	2016	24.4	1281.3	0.4	0.0	0.0	37.5	0.1	28.2
381	2017	53.1	1079.5	16.2	0.0	0.0	32.4	1.6	26.5

391	2018	70.6	865.5	49.1	0.0	0.0	44.2	2.7	27.0
401	2019	104.3	966.6	45.3	0.0	0.0	44.3	0.7	38.9
411	2020	89.6	1080.6	31.0	0.0	0.0	57.0	0.7	36.3
421	2021	62.6	1093.5	4.1	0.0	0.0	40.1	2.2	25.5
431	2022	76.6	897.9	0.0	0.0	0.0	38.2	0.9	34.0

Table 8: 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
1	1927	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1928	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1929	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1933	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	1934	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	1935	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	1936	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	1937	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	1938	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	1939	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	1940	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1941	14.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1942	18.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	1943	48.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1944	88.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	1945	48.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	1946	65.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	1947	68.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1948	54.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1949	68.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	1950	100.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	1951	66.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	1952	46.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	1953	156.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	1954	140.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1955	171.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	1956	296.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	1957	301.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	1958	252.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	1959	246.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	1960	226.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	1961	210.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1962	271.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	1963	324.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	1964	280.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	1965	257.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	1966	376.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1967	452.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	1968	381.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	1969	357.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	1970	59.9	0.4	0.0	81.8	228.8	0.0	0.0	0.0
45	1971	65.1	0.4	0.0	87.9	246.8	0.0	0.0	0.0

46	1972	35.7	0.2	0.0	47.5	132.9	0.0	0.0	0.0
47	1973	56.6	0.3	0.0	34.4	164.5	0.0	0.0	0.0
48	1974	36.9	4.8	0.0	42.3	112.5	0.0	0.0	0.0
49	1975	21.1	0.1	0.0	43.5	96.5	0.0	0.0	0.0
50	1976	5.5	11.8	0.0	41.6	60.8	0.0	0.0	0.0
51	1977	22.8	48.1	0.0	20.2	121.6	0.0	0.0	0.0
52	1978	24.6	43.9	0.0	20.9	105.0	0.0	0.0	0.0
53	1979	14.1	39.0	0.1	25.3	138.9	0.0	0.0	0.0
54	1980	18.8	25.7	0.0	52.5	223.5	0.0	0.0	0.0
55	1981	22.1	42.9	0.0	243.4	0.0	0.0	0.0	0.0
56	1982	10.7	23.1	0.0	256.8	0.0	0.0	0.0	0.0
57	1983	13.4	63.2	0.3	168.8	14.8	0.0	0.0	0.0
58	1984	35.0	72.0	1.5	279.0	57.4	0.0	0.0	0.0
59	1985	19.0	47.0	18.7	332.5	19.8	0.0	0.0	0.0
60	1986	21.2	31.0	5.9	410.1	17.3	0.0	0.0	0.0
61	1987	24.3	36.9	11.0	469.2	15.3	0.0	0.0	0.0
62	1988	30.6	78.7	21.4	470.5	21.5	0.0	0.0	0.0
63	1989	62.2	139.9	39.5	422.4	9.1	0.0	0.0	0.0
64	1990	38.8	112.6	91.2	342.9	5.5	0.0	0.0	0.0
65	1991	106.0	73.5	55.1	300.8	2.4	0.0	0.0	0.0
66	1992	119.1	34.7	55.7	319.1	2.0	0.0	0.0	0.0
67	1993	95.0	29.4	83.3	293.9	14.8	0.0	0.0	0.0
68	1994	78.7	42.8	81.6	307.4	8.2	0.0	0.0	0.0
69	1995	50.7	21.1	138.5	256.5	2.8	0.0	0.0	0.0
70	1996	36.1	37.2	220.2	260.3	4.9	0.0	0.0	0.0
181	1997	0.4	42.9	416.8	0.0	0.0	27.1	1.1	0.0
191	1998	0.3	51.5	499.7	0.0	0.0	18.7	1.0	0.0
201	1999	1.6	68.7	564.7	0.0	0.0	19.3	2.1	0.0
211	2000	2.1	63.2	751.7	0.0	0.0	27.8	1.2	0.0
221	2001	12.9	71.5	332.5	0.0	0.0	33.4	1.0	0.0
231	2002	17.1	69.4	349.7	0.0	0.0	28.2	1.6	0.0
241	2003	15.2	83.1	405.8	0.0	0.0	45.8	3.1	0.0
251	2004	18.5	66.4	430.6	0.0	0.0	57.2	2.6	0.0
261	2005	25.3	75.3	418.7	0.0	0.0	63.2	1.5	0.0
271	2006	27.6	114.4	464.7	0.0	0.0	65.5	1.0	0.1
281	2007	30.7	73.6	437.0	0.0	0.0	54.4	1.0	0.0
291	2008	21.4	123.7	523.6	0.0	0.0	40.5	1.1	0.0
301	2009	58.7	101.4	452.3	0.0	0.0	60.0	2.9	0.0
311	2010	58.0	122.5	399.4	0.0	0.0	55.7	4.5	0.0
321	2011	96.7	92.2	230.7	0.0	0.0	70.6	3.0	2.7
331	2012	230.6	54.4	38.7	0.0	0.0	86.8	1.1	2.7
341	2013	326.5	20.4	13.5	0.0	0.0	68.0	2.1	2.1
351	2014	297.2	78.5	65.3	0.0	0.0	56.3	3.1	2.9
361	2015	279.2	101.8	70.5	0.0	0.0	46.1	2.9	2.0
371	2016	164.5	76.9	54.5	0.0	0.0	45.9	1.7	2.4
381	2017	288.7	72.4	26.8	0.0	0.0	55.0	4.2	0.5
391	2018	402.9	76.5	43.4	0.0	0.0	58.9	1.6	2.2
401	2019	444.7	37.2	7.4	0.0	0.0	61.5	1.6	2.0
411	2020	457.3	37.9	7.0	0.0	0.0	50.2	1.3	2.4
421	2021	279.2	10.1	23.1	0.0	0.0	62.7	0.5	3.4
431	2022	284.1	3.5	44.2	0.0	0.0	78.7	1.0	1.0

Table 9: 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
1	1927	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1928	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	1929	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1930	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	1931	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	1932	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1933	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	1934	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	1935	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	1936	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	1937	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	1938	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	1939	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	1940	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1941	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1942	15.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	1943	14.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	1944	32.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	1945	49.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	1946	57.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	1947	79.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	1948	66.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1949	50.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	1950	25.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	1951	18.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	1952	43.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	1953	43.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	1954	32.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1955	26.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	1956	13.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	1957	46.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	1958	30.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	1959	51.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	1960	114.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	1961	105.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	1962	44.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	1963	30.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	1964	24.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	1965	13.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	1966	17.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	1967	50.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	1968	58.8	8.4	0.0	16.8	0.0	0.0	0.0	0.0
43	1969	29.4	43.6	0.0	90.8	0.0	0.0	0.0	0.0
44	1970	31.5	7.0	0.0	17.2	0.0	0.0	0.0	0.0
45	1971	27.3	5.2	0.0	14.7	0.0	0.0	0.0	0.0

46	1972	20.0	5.2	0.0	22.1	0.0	0.0	0.0	0.0
47	1973	9.0	23.3	0.0	62.2	0.0	0.0	0.0	0.0
48	1974	63.1	37.3	0.0	61.5	0.0	0.0	0.0	0.0
49	1975	67.0	10.3	0.0	2.3	0.0	0.0	0.0	0.0
50	1976	25.7	43.2	0.0	16.9	0.0	0.0	0.0	0.0
51	1977	42.4	44.5	0.0	19.9	0.0	0.0	0.0	0.0
52	1978	11.6	56.7	0.0	31.8	0.0	0.0	0.0	0.0
53	1979	18.8	3.1	0.0	76.8	0.0	0.0	0.0	0.0
54	1980	21.7	11.2	0.0	111.0	0.0	0.0	0.0	0.0
55	1981	18.0	1.5	6.4	89.2	0.0	0.0	0.0	0.0
56	1982	19.9	4.5	2.0	62.4	0.0	0.0	0.0	0.0
57	1983	24.4	2.2	0.0	61.5	0.0	0.0	0.0	0.0
58	1984	60.9	1.9	0.0	142.0	0.0	0.0	0.0	0.0
59	1985	56.5	5.8	0.1	180.7	0.0	0.0	0.0	0.0
60	1986	45.4	4.7	0.1	124.3	0.0	0.0	0.0	0.0
61	1987	51.4	88.7	0.0	47.7	0.0	0.0	0.0	0.0
62	1988	65.1	2.0	4.1	129.3	0.0	0.0	0.0	0.0
63	1989	57.8	8.7	0.0	115.1	0.4	0.0	0.0	0.0
64	1990	70.4	14.0	0.0	88.6	0.0	0.0	0.0	0.0
65	1991	57.5	8.0	0.0	83.0	0.6	0.0	0.0	0.0
66	1992	103.2	13.9	0.0	96.1	0.2	0.0	0.0	0.0
67	1993	120.6	10.3	2.5	148.8	0.0	0.0	0.0	0.0
68	1994	65.6	7.4	0.0	145.8	0.0	0.0	0.0	0.0
69	1995	1.5	75.5	0.1	44.2	0.0	0.0	0.0	0.0
70	1996	6.4	95.2	9.1	40.9	0.0	0.0	0.0	0.0
181	1997	0.3	18.7	10.8	0.0	0.0	5.4	0.0	0.0
191	1998	0.2	47.3	27.2	0.0	0.0	2.1	0.3	0.0
201	1999	5.7	63.7	52.2	0.0	0.0	2.2	1.4	0.0
211	2000	1.6	70.7	27.8	0.0	0.0	3.9	0.7	0.0
221	2001	3.9	74.2	5.3	0.0	0.0	7.6	0.6	0.0
231	2002	5.9	119.8	3.0	0.0	0.0	18.8	1.6	0.0
241	2003	10.1	104.0	0.6	0.0	0.0	21.7	1.7	0.0
251	2004	7.5	139.5	0.1	0.0	0.0	19.8	2.1	0.0
261	2005	12.6	100.6	0.0	0.0	0.0	23.0	0.6	0.0
271	2006	9.0	84.7	48.7	0.0	0.0	20.9	2.6	0.0
281	2007	3.7	71.2	41.5	0.0	0.0	13.7	3.4	0.1
291	2008	6.6	56.8	21.0	0.0	0.0	10.3	5.7	0.0
301	2009	6.6	83.1	0.0	0.0	0.0	11.0	3.0	0.0
311	2010	16.0	90.4	0.0	0.0	0.0	13.6	1.4	0.0
321	2011	12.0	122.0	0.0	0.0	0.0	17.4	8.9	0.0
331	2012	23.4	151.8	0.0	0.0	0.0	12.7	7.3	0.0
341	2013	24.0	113.9	0.5	0.0	0.0	12.0	5.8	0.1
351	2014	31.4	76.3	0.1	0.0	0.0	12.4	6.3	0.1
361	2015	15.4	64.0	0.0	0.0	0.0	15.5	2.6	0.0
371	2016	18.2	80.8	0.0	0.0	0.0	25.2	2.9	0.0
381	2017	30.8	48.8	52.3	0.0	0.0	25.1	6.6	1.3
391	2018	30.6	23.2	31.0	0.0	0.0	22.1	18.2	3.6
401	2019	43.1	43.1	39.9	0.0	0.0	31.1	5.0	2.7
411	2020	32.6	29.7	66.9	0.0	0.0	21.3	7.6	3.5
421	2021	27.3	23.2	39.6	0.0	0.0	14.3	4.1	3.9
431	2022	20.7	15.3	54.7	0.0	0.0	17.4	6.2	2.0