# Updated stock assessment for Gummy Shark for 2020 using data to 2019 DRAFT

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*30 November, 2020*

## Contents



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# 1 Executive summary

This report is an update of that prepared for sharkRAG's November meeting, which was in turn an update on the 29-30 September 2020 meeting's report. This version includes:

- an updated base case model that uses age-at-length data for 2016-2019 inclusive (left out of the September base case due to the presence of a space in the supplied CAAB code field for the 2016-2019 dataset),
- RBC calculations, and
- future projections.

During 2020 SharkRAG made the following choices regarding the 2020 base case assessment model:

- The model should use gillnet CPUE series based net length, rather than those based on operation.
- South Australia gillnet CPUE should continue to be cropped at 2010; no new indices of abundance for that region have been proposed.
- The base case model should use separate trawl CPUE series for each stock, in preference to the old series derived from regions combined.
- The Bass Strait trawl CPUE series should be broken into (1996-2005 and 2008-2019) to reflect changes caused by the introduction of new management regulations in 2005, allowing for a three year period before a new pattern was established.
- Newly available age data should be used in the base case model as conditional age-at-length data.
- The 'effort saturation' effect should continue to be used on the base case model.
- State catches for NSW should continue to be excluded from the assessment.
- Recreational catch data should continue to be ignored.
- Density dependence should affect natural mortality of all sharks (i.e. ages 0-30) and should be based on 1+ biomass (i.e. an unchanged assumption).

A number of model improvements were identified as future work, which would ideally be conducted and examined by sharkRAG before the next assessment update is due.

This report presents a bridging analysis which begins with the 2016 base case model and adds new data, one step at a time, to examine the effect of those data. The final step is the 2020 base case model. A set of standard sensitivity tests were conducted to (almost) the base case model) but because missing age-at-length data were discovered after sharkRAG examined sensitivity tests, the base case model on which the projections are based differs slightly from the one to which the sensitivities were conducted. In addition, because of difficulties in estimating variances for all parameters and quantities of interest, resulting from poor estimation of the slope parameters of the selectivity functions for the trawl and line fleets, these parameters were fixed at their estimated values when conducting forward projections.

The updated model provides results that are consistent with those of the 2016 assessment update - pup depletion (the proxy for spawning abundance that is used by sharkRAG) in 1973 ('Pem73'), and productivity (as measured by MSYR) are reasonably similar, in 2020, to those estimated in 2016. 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 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 well above the 48% target reference point in South Australia and Tasmania, according to the base case model (66% and 69% respectively) and all sensitivity tests examined (66% - 107% and 62% - 86% respectively). For Bass Strait, the base case model estimates depletion at the target (48%) but the range across all sensitivity tests is 32% to 53%. The lowest values are 32% (if natural mortality is 0.15), and 35% and 36% if density dependence acts on only younger age classes. Pup depletion is above the 20% limit reference point for all stocks and all sensitivity models.

The estimated long-term RBC is 1757t with RBC catches over the next 5 years equal to 1899, 1727, 1662, 1648, 1668 tonnes respectively. The average RBC over the most recent three years is 1763t, and over five years is 1721t.

# 2 Introduction

Gummy Shark in the Southern and Eastern Scalefish and Shark Fishery was last assessed in 2016 (Punt and Thomson 2016). This report presents initial data compilation and model exploration for an assessment update for 2020 and was originally presented to the Shark Resource Assessment Group (SharkRAG) at their 29-30 September meeting. This report includes additional work conducted since that meeting, and was prepared for an inter-sessional meeting in November 2020. The additional work is listed about under the head 'Version History'. This model update includes data collected up to and including 2019.

The 2016 Gummy assessment used standardized CPUE time series for gillnets operating in South Australia, Bass Strait, and Tasmania (Punt & Thomson, 2016). Those time series were constructed by 'splicing' together an older set of CPUE series for each region, with a newer set. The older set used the method of Punt & Gason (2006) who used a 'standard fleet' to ensure that only dedicated Gummy Shark vessels contribute to the index of abundance, along with data collected by State fisheries authorities, which pre-date the Commonwealth fishing data stored by AFMA. The newer standardized CPUE time series are drawn from the work presented annually to sharkRAG, most recently by Sporcic (2020a) which uses catch and effort data stored in AFMA's logbook database to construct standardised gillnet CPUE time series for Gummy Shark in the three regions. The 2016 Gummy assessment used recent CPUE that used 'fishing operation' as the unit of effort (so that for every gillnet catch event(shot), the effort was taken to be 'one unit'). This shows the use, in the assessment model, of updated operation-based CPUE time series, as well as more recent work by Sporcic (2020b, and with 2019 data added, Miriana Sporcic, CSIRO, pers commn) that uses recorded gillnet net length as the effort unit.

In addition to gillnet CPUE, the 2016 assessment used standardized trawl CPUE, and (shallow, <200m) bottom line CPUE for all regions (stocks) combined. The bottom line CPUE series has been recalculated using more data and the trawl time series has also been re-estimated, separately, for each Gummy region (Miriana Sporcic, CSIRO, pers commn). This report explores the used of the updated trawl CPUE for all regions combined, the three regionally separate trawl CPUE series, as well as splitting the trawl CPUE series for Bass Strait to account for management changes that took effect from 2015. This is described in more detail below.

Length frequency data collected since 2016 have been processed and added to the assessment model. Gummy Shark vertebrae collected in every year between 2010 and 2019 inclusive have been read by Fish Ageing Services (Simon Robertson, FAS, pers commn) and have been included in the 2020 assessment update. Those data have been incorporated in the assessment as conditional age-at-length data rather than as age composition data, for reasons outlined below.

This Gummy assessment update was originally scheduled for 2019 but was delayed because the removal of Observers from the Gillnet, Hook and Trap (GHAT) fishery in mid-2015 meant that insufficient data were available. The Shark Industry Data Collection (SIDaC) program has provided data for assessment since its inception in early 2019.

This report presents a proposed 'base case' assessment model for the three Gummy shark stocks, Bass Strait (BS), South Australia (SA) and Tasmania (TS) that uses:

- The model should use gillnet CPUE series based net length, rather than those based on operation.
- South Australia gillnet CPUE should continue to be cropped at 2010; no new indices of abundance for that region have been proposed.
- The base case model should use separate trawl CPUE series for each stock, in preference to the old series derived from regions combined.
- The Bass Strait trawl CPUE series should be broken into (1996-2005 and 2008-2019) to reflect changes caused by the introduction of new management regulations in 2005, allowing for a three year period before a new pattern was established.
- Newly available age data should be used in the base case model as conditional age-at-length data.
- The 'effort saturation' effect should continue to be used on the base case model.
- State catches for NSW should continue to be excluded from the assessment.
- Recreational catch data should continue to be ignored.

- Density dependence should affect natural mortality of all sharks (i.e. ages 0-30) and should be based on 1+ biomass (i.e. an unchanged assumption).

## 2.1 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.

# 3 Data

## 3.1 Catches

The catch time series used in the 2016 assessment have been examined and re-analysed, and the updated catch time series are shown in Figure 1. The catch data was processed using an Rmarkdown document, which allows explanatory text as well as figures and tables to be interspersed with the computer code; this should reduce the time taken to process the data used for future assessment updates, and reduce the potential for error.

Recreational catches are available, in weight, for South Australia in 2001, 2008, 2013 and 2014; with a range of 16 to 37t p.a. (Althaus 2020). Two other estimates are available (<10t in NSW for 2010, and 3t in WA for 2013) but these are from areas not included in the gummy shark model. Recreational catch estimates were not included in the assessment model, as they are typically known with relatively large errors, are not available for the full time series (which stretches back to 1927) and are relatively small compared with the roughly 1800t p.a. taken by the commercial fishery. If recreational catches were included in the model, they would also have to be deducted from the RBC when deriving the TAC.

### 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 from mid-1985 for the trawl sector and from mid-1997 for the non-trawl sector (Table 1). The Catch Disposal Record (CDR) dataset for Gummy Shark starts in 2001 when the species was first under quota (Table 2). Note that CDR totals are typically slightly higher than logbook totals - landed catches are accurately weighted, 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 under-estimation (Althaus et al, 2020).

### 3.1.2 State catches and discards

Data on the landings of Gummy Shark by State authorities were taken from Althaus *et al* (2020), whose 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 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 that deep line 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 Deng *et al* (2020). For all years prior to 2011 the average discard over the 2011 to 2015 period was used (roughly 4% p.a.). 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)`.

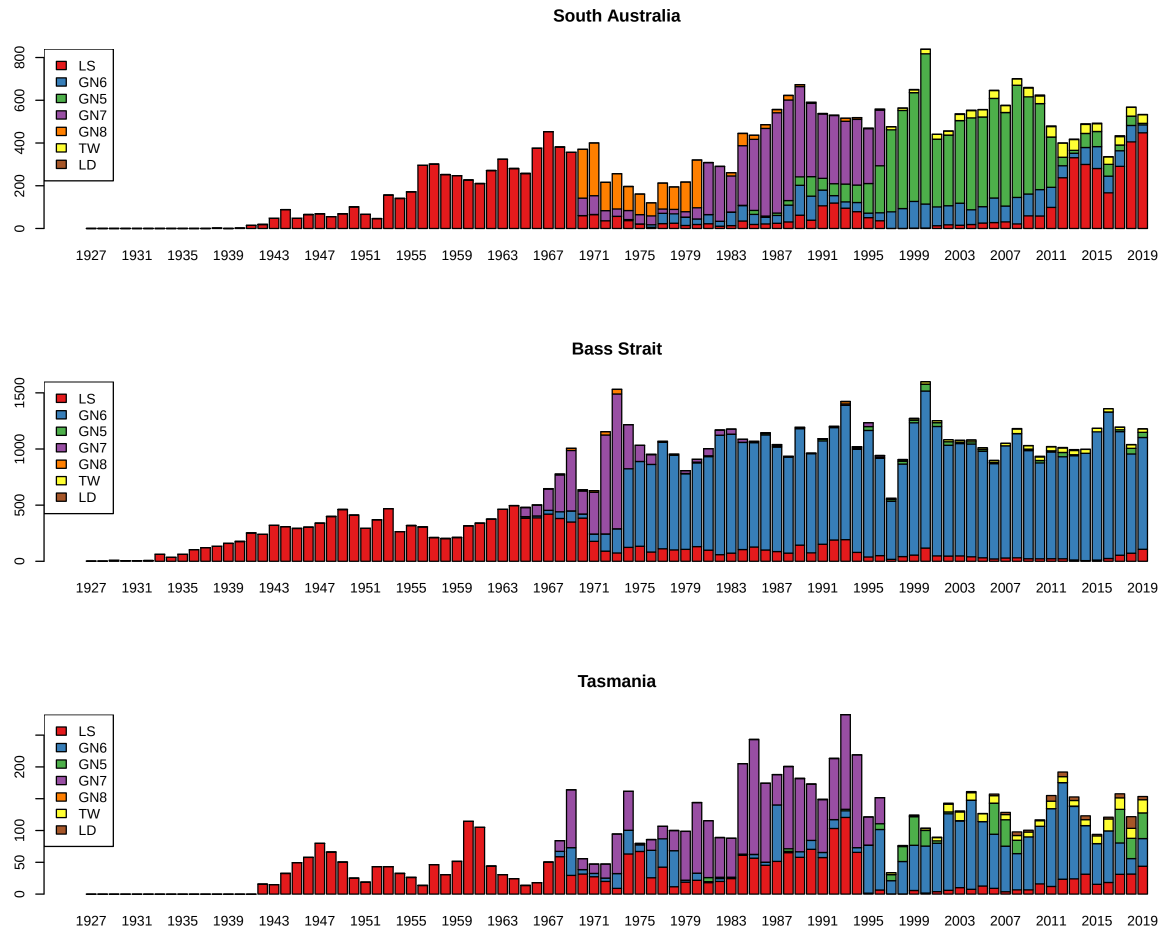



Figure 1: Gummy Shark catches (tonnes) by gear type and stock for fleets: shallow line (LS), 6 inch (GN6), 6.5 inch (GN5), 7 inch (GN7) and 8 inch (GN8) gillnets, trawl (TW) and deep line (LD).

### 3.1.3 Unknowns and historic information

The Gummy Shark assessment uses seven fleets (6, 6.5, 7, 8 inch gillnets, trawl, shallow and deep line) in each of three stocks (Bass Strait, South Australia, Tasmania). Most logbook catch records can be assigned to fleet and stock, but some have missing data such as gear type, or gillnet mesh size, or 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, again, in proportion the catches already allocated across fleets. Finally, records whose location was unknown were allocated to fleet, in proportion to the catch ratios between stocks. Allocation of unknowns was always done in proportion to the known catches, 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 assessment update were used again. In future, it would be informative (if the information is available) to document in the most recent assessment reports, how those catches were derived.

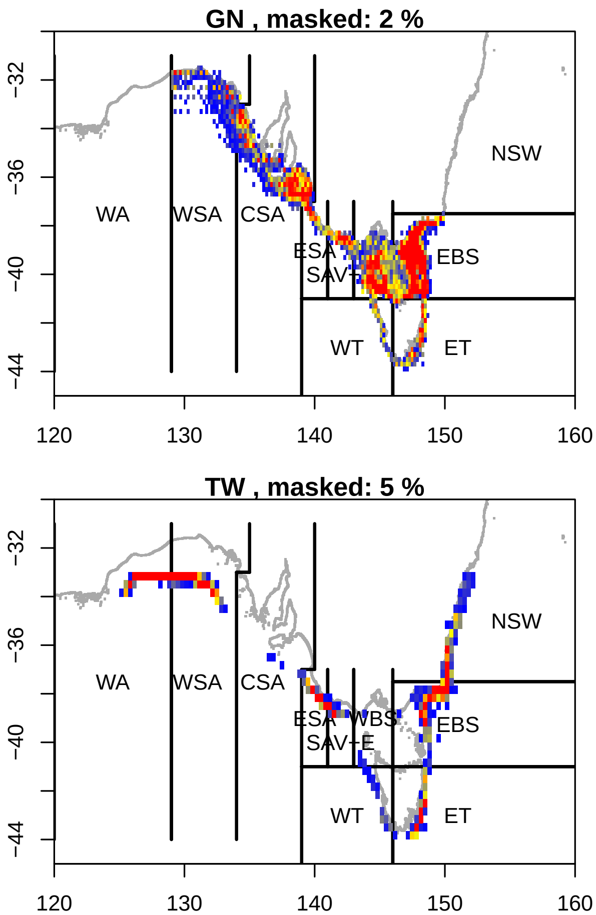



Figure 2: Gummy logbook catches by major gear type for all years combined; red indicates relatively large catches, orange and yellow intermediate, and blue indicates small catches.

Table 3 shows the tonnage, by recorded gear code, of Gummy catches in the logbook dataset. Note the relatively small landings by auto-line vessels.

#### 3.1.4 Spatial distribution of catches

The location of Gummy catches, colour-coded by number of kilograms landed, is shown in Figure 2. The 5 vessel rule has been applied so some cells were removed leading to not showing a percentage of the catch from each gear type (see the plot headings). The percentage excluded from the Danish seine plot is relatively large because a single vessel operates in the GAB.

### 3.2 Standardized CPUE

Standardised catch-per-unit effort (CPUE) was obtained from Sporcic (2020a) and additional series were obtained directly from Miriana Sporcic (CSIRO, pers commn). Sporcic (2020a) provides CPUE time series for gillnet fishing in each of the three Gummy Shark areas, corresponding with the Gummy stocks in South Australia, Bass Strait, and Tasmania. Those analyses assume that every gillnet fishing operation (shot) has equal effort so that the assumed unit of effort for each is one operation (or one shot). The 2010 (Punt and Thomson, 2010) and 2013 (Thomson & Sporcic, 2013) Gummy assessment updates used CPUE series that were standardized in the same way, using operation as the unit of effort.

During 2020, Sporcic (2020b), explored alternative ways of standardizing Gummy Shark CPUE using net length as the unit of effort. At its August 2020 meeting, SESSFRAG (AFMA 2020), requested that those standardizations (which use catch and effort data to the end of 2018) be updated by adding data for 2019 for use in this 2020 Gummy Shark assessment update. The resulting CPUE series were included in the assessment as an alternative to operation-based series (Figure 3).

The CPUE series that use operation are similar to those that use net length (Figure 3). The net length series are a little higher than the operation series in early years, and a little lower in recent years, thus indicating a somewhat greater decline in abundance than is indicated by the operation series.

Sporcic (2020a) also provides CPUE time series for trawl gear, and bottom line gear, for all areas (stocks) combined (Figure 4) and trawl CPUE separately for Bass Strait, South Australia and Tasmania. The bottom line CPUE standardization has been repeated since its presentation to SESSFRAG because some bottom line records (those from ELOGs, which are coded in the database as 'LLD') were accidentally omitted. The newer series is used for the 2020 assessment update presented here. Sporcic's (2020a) CPUE series is restricted to records in the 0-200m range and is therefore used in the Gummy assessment for the 'shallow' line fleet. Relatively little catch of Gummy Shark is landed from deeper than 200m so that it is unlikely there are sufficient data to allow standardization for the 'deep' line fleet (Figure 5).

Autoline vessels land Gummy Shark from both shallower and deeper (than 183m) waters, resulting in a bi-modal distribution that presumably reflects targeting of Gummy Sharks versus targeting of scalefish (Figure 6). SharkRAG have previously noted that vessels operating in shallow water land larger sharks than those operating deeper than 183m (Figure 7). Whether this pattern holds for autoline vessels as well as bottom line vessels, is unknown. It would be advantageous to collect data from autoline vessels in future (these are currently not covered).

A further improvement to the standardised CPUE time series available for this assessment update, has been the production of three standardized trawl CPUE series, one for each Gummy Shark stock (Miriana Sporcic, CSIRO, pers commn, Figure 8). Because of a relatively small number of records available for Tasmania prior to 2002, that series has been provided both with and without the inclusion of pre-2002 records (Figure 8). A distinct change is evident in the trawl CPUE for Bass Strait, after 2005. This is likely to be due to a Ministerial Direction to AFMA and the resultant response from AFMA through its `Securing our Fishing Futures` package which included buyouts of vessel SFRs and quota SFRs for some species (but no shark species) (Natali.e. Couchman, AFMA, pers commn; unpublished document 'Impact of the Securing our Fishing Future Buyout') which took effect in 2005. As a result, sharkRAG recommended splitting the BS trawl CPUE series into one that ends with 2005, and another that begins with 2008 after the 2005 changes had 'settled in'.

Sporcic (2020a) plots fishing depth, showing relatively large Gummy catches from 100m of water after 2016 compared to earlier records. SharkRAG Industry participants at the September 2020 sharkRAG meeting felt that this was credible and resulted from avoidance of dolphins as well as regulations introduced 18 months ago to further protect Australian Sea Lions.

### 3.2.1 Danish seine

A new CPUE time series is available for Danish seine gear (Sporcic 2002a) and Figure 7 shows that that gear catches much smaller Gummy Shark than other gears included in the assessment. The addition of a Danish seine fleet to the assessment would require more work and time than is feasible for 2020, but its addition to future assessment updates could provide useful information on recruitment and on a component of the population 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.

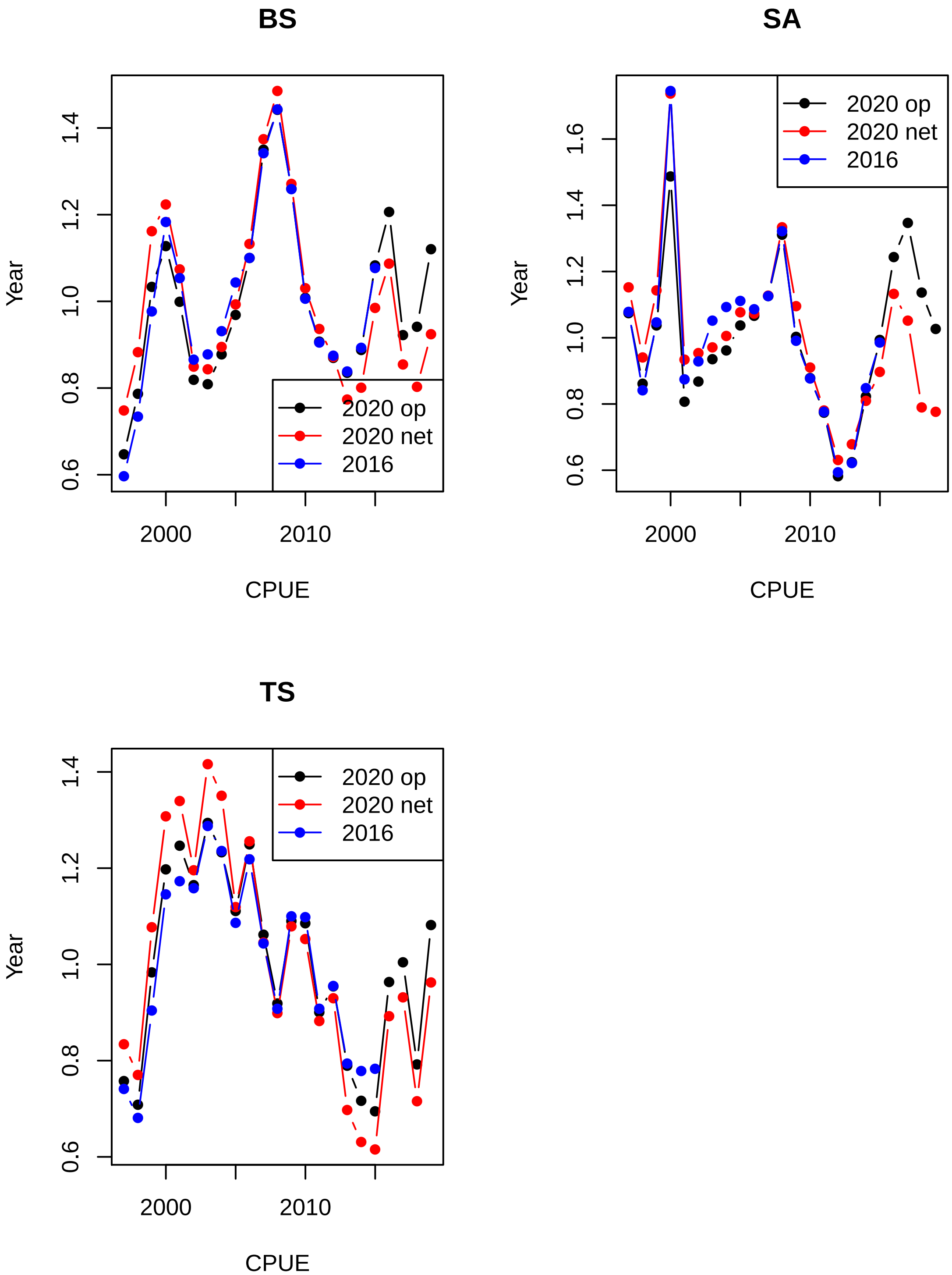



Figure 3: Standardized gillnet CPUE using operation (2020 op), or net length (2020 net), and the older CPUE used on the 2016 Gummy assessment (2016) for the three Gummy stocks.

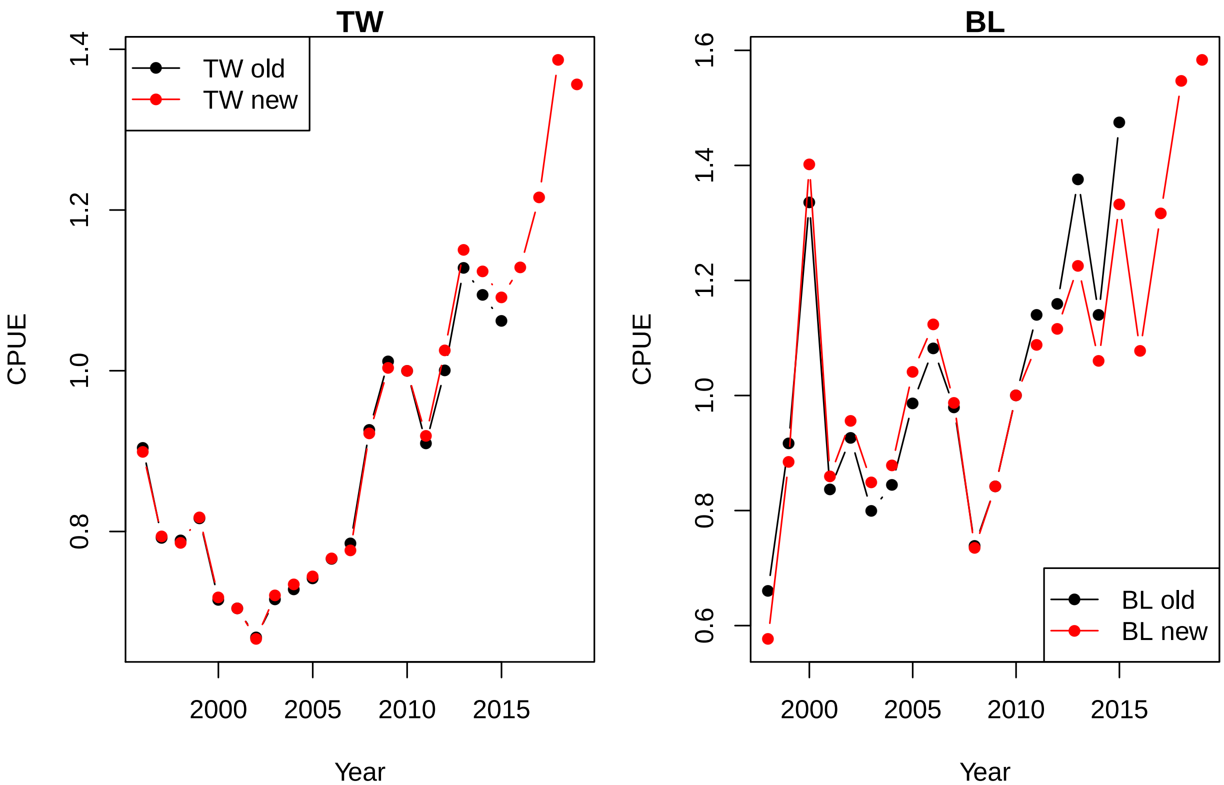



Figure 4: Standardized trawl (TW) and bottom line (BL) CPUE used in the 2016 assessment (old) and the 2020 update (new).

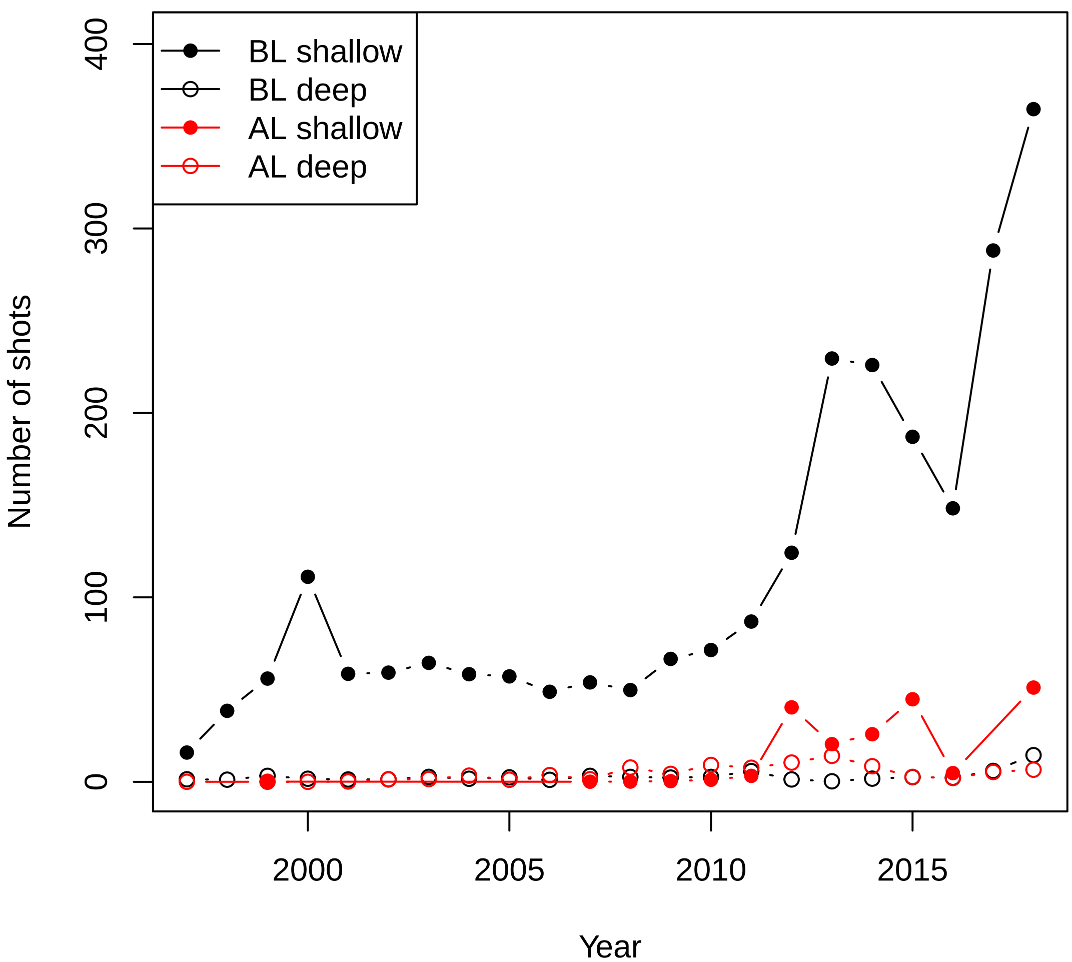



Figure 5: Number of shots containing Gummy Shark, deeper and shallower than 183m, by bottom line (BL) or auto-line (AL).

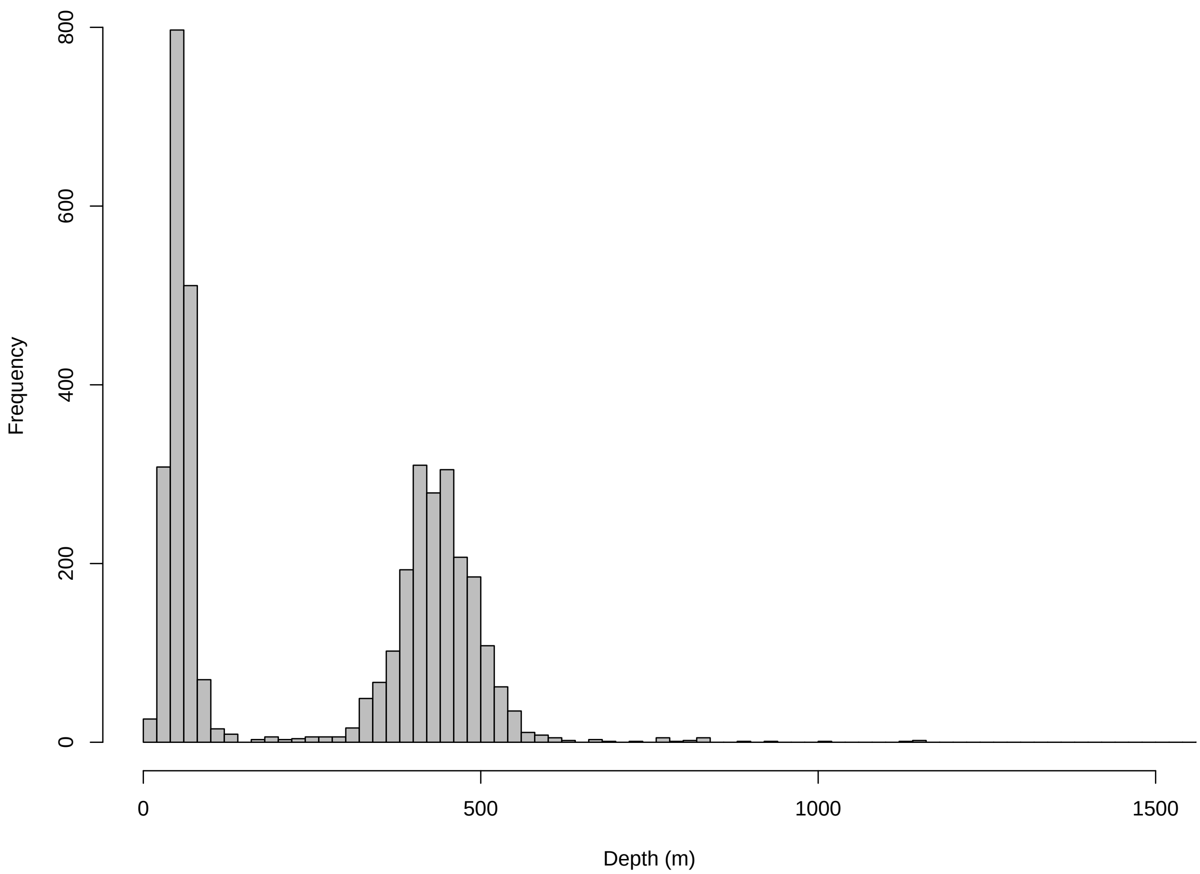



Figure 6: Depth of fishing by autoline vessels

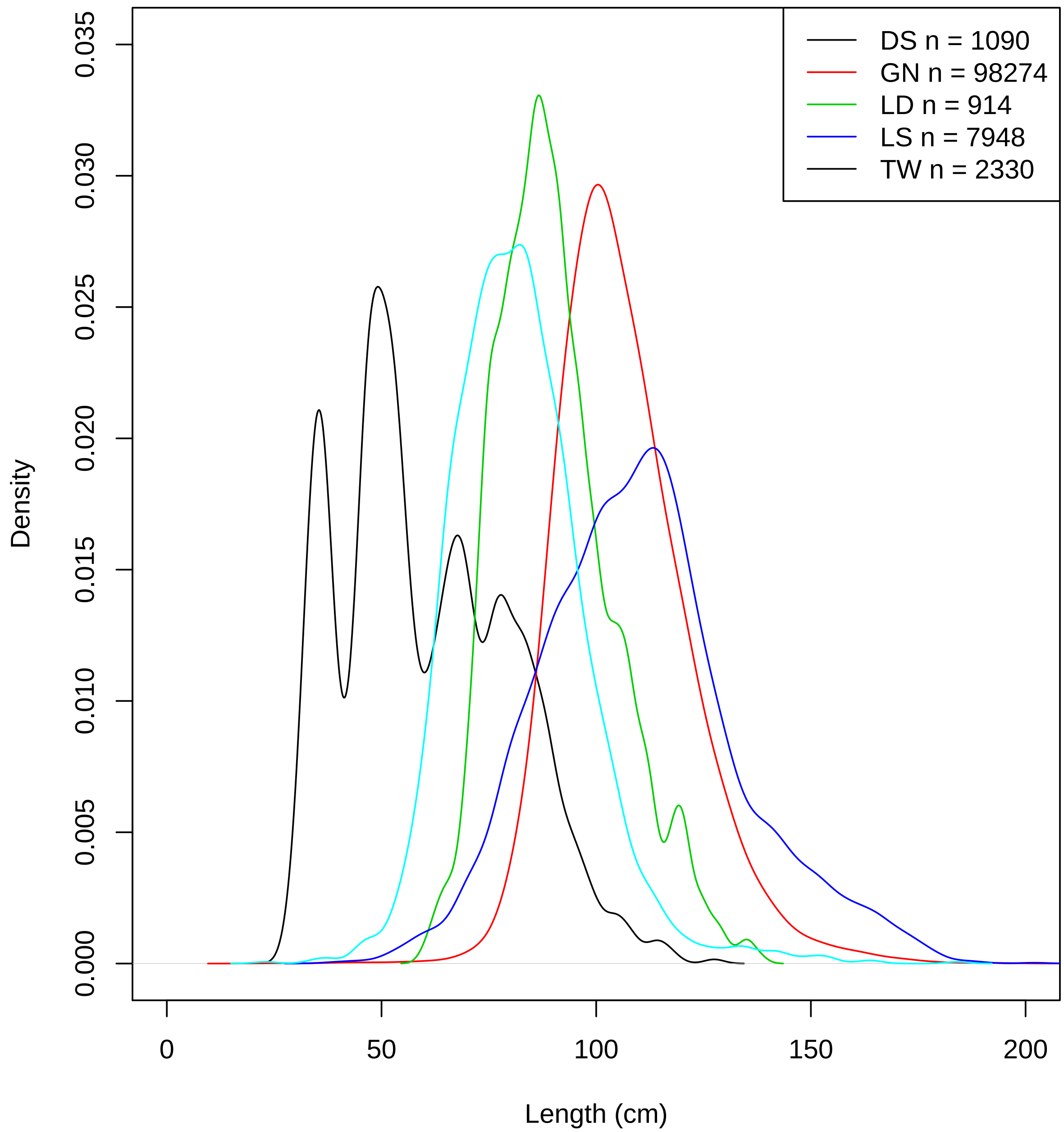



Figure 7: Length frequency generated by kernel density method applied to all length observations made from Danish seine (DS), gillnet (GN), deep line (LD), shallow line (LS) or trawl gears (TW). The number of sharks sampled is also shown (n).

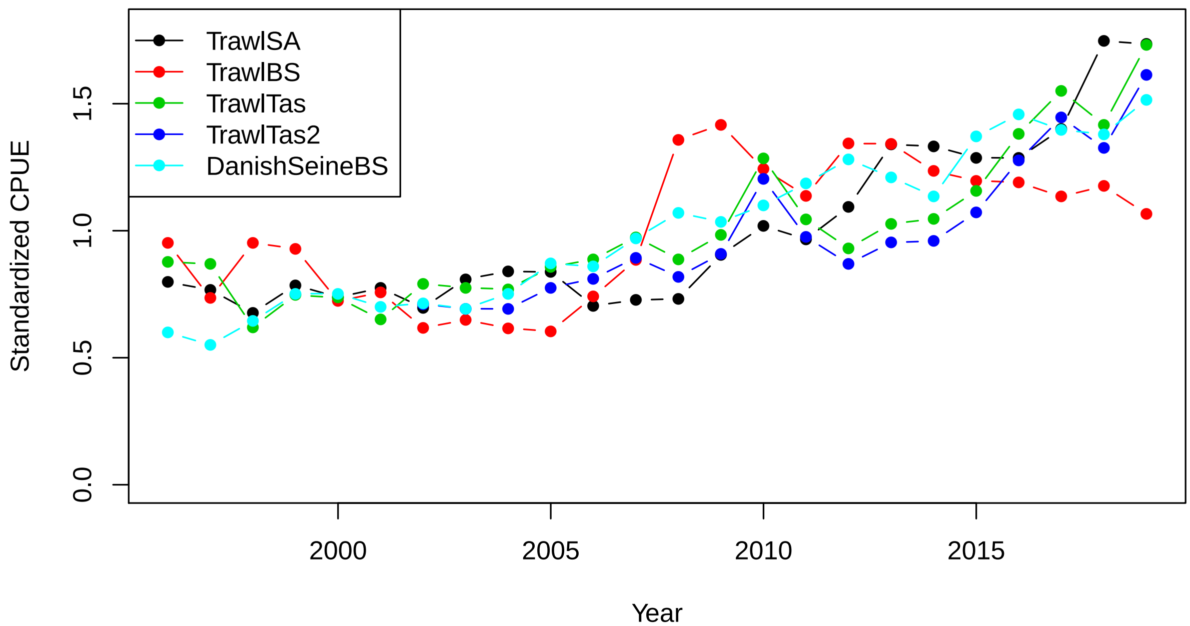



Figure 8: Trawl standardizations for each population (Tas begins with 1996 and Tas2 begins in 2002), and Danish seine.

### 3.2.2 Nominal effort

The effort totals used in the 2016 assessment are somewhat different from those calculated here, which could result from improvements to the database, or 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. 'Nominal effort' is the total effort for each year, by gear type, as reported in the logbooks. For unknown gear types, and for gill nets of unknown mesh size, the effort data is assigned in proportion to known gear totals.

## 3.3 Length frequencies

The 2016 assessment (and earlier versions of the Gummy assessment) used some length frequencies that were 'inherited' from older assessment updates - those were processed (by Terry Walker and Anne Gason, MAFFRI, prior to 2006) from shark length measurements that are not available to the author of the 2020 assessment. Those length frequencies are included in the 2020 assessment. The 2016 assessment also used length frequency data developed from the data held in the AFMA Observer database - those have been reprocessed, along with additional Observer data for 2016 to 2019 inclusive. The 2016 assessment made use of length frequencies based on as few as 7 sharks - the 2020 assessment imposes a threshold of a minimum of 100 measurements for any length frequency used in the assessment. In addition, the 2016 assessment excluded 11 length frequencies: some had small sample sizes but the reason for excluding the others is unknown. These have been restored, and the effect on the model of using them is included in the bridging analysis.

The length frequencies (LFs) used in the 2016 assessment, and the 2020 update, are shown in the Appendix. The LFs have been divided into those collected before 2003, 2003-2007, and after 2007. For years prior to 2007, the 2016 Gummy assessment used LFs that had been compiled for earlier assessments, when data collection and processing was done by in Victoria (MAFFRI); the data from which those LFs were compiled is not available to the author. For the 2003-2007 period 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 in the 2016 assessment is stored in the AFMA Observer database. Most of these more recent LFs, being based on the same length observations, match very closely between the 2016 and 2020 versions, however there are some slight differences. The reasons for these include:

- revision to the shot weight field (LFRET/LFDIS) - see the Data Summary report (Burch *et al* 2020) for more details,
- tidying up of the onboard length dataset by AFMA between the 2015 and 2019 'data dumps' provided to CSIRO,
- the use in 2016 of length frequencies based on fewer than 10 sampled animals.

## 3.4 Age data

The 2016 assessment used age composition data collected between 1986 and 2008 that had been prepared for, and used in, earlier assessment updates, as well as data for 1995, 1997, 2002 and 2003 that were not previously available. More age data (for every year between 2010 and 2019 inclusive) are available for this 2020 assessment update. The vertebrae were collected by AFMA Observers but had not previously been sectioned and read. Age data for future assessments will be provided by vertebrae collected by the new Shark industry Data Collection (SIDaC) program, starting in early 2019.

The 2010-2019 age data, along with that from 1995, 1997 and 2002-3, have been incorporated in the assessment as conditional age-at-length data rather than as age composition data. Because age data are more expensive to collect than length data, fisheries observers (including AFMA observers) are typically instructed to collect age data from all length classes rather than randomly with respect to the catch. This provides representative information on the distribution of ages for each length class, including those that are poorly represented in the catch, without needing to collect and age large numbers of sharks from the more frequently caught length classes. 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 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 individual sharks is not available to the model. The better (more recent) method, termed conditional age-at-length, allows estimation of both growth and selectivity within the model. For the older method, because the model does not 'know' both the age and length of any individual animal, growth estimation must be done separately and then entered into the model as fixed biological parameter values. 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 Gummy Shark model, 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 sharks collected prior to 1995 is not available to the author 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 assumed to be representative of the age distribution of sharks in the catch.

Size at age seems very similar for both sexes, although females attain greater length and age than males (Figure 9). The growth curves used by the model are also shown (the data are shown for each year separately in Appendix B). Note that the curve for males does not appear to fit the data well for older ages. The parameters for the growth curve are those used for the Gummy assessment model for many years (see Table A.1, Pribac & Punt, 2005) and were derived from vertebral readings of Gummy Shark collected in Bass Strait during 1973-76 (Moulton *et al* 1992, Table 4). The poor correlation between the data and the growth curve for male sharks is even clearer when the data are presented in terms of 5cm length class (Figure 10); points that do not have error bars had only a single age observation in the length class). The female curve tends to fall below the median of the data for many length classes (Figure 10). The plus group for age in the model is 10 so that this poor fit is of little consequence, but with greater representation of older sharks in the line catch, future assessment updates ought to consider raising the age of the plus group.

## 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. While that has not yet been implemented, some data exploration has been performed. Catches of Gummy Shark by Danish seine are relatively small (Figure 11, note that this plot does not include catch data from State agencies and therefore begins with 1997 for non-trawl data).

Relatively good (in terms of numbers of samples collected and years covered) length frequency data are available from onboard observers (Figure 12); a smaller collection is available from port sampling (Figure 13). There is clear evidence of size-based discarding with smaller sharks evident in the onboard samples but not in the port samples. The size frequencies of the port samples are quite variable, suggesting either quite variable discarding practices, or possibly variable availability of smaller Gummy Shark to Danish seine gear, possibly by location or time of year (which has not yet been investigated). The onboard dataset appears to be a more consistent source of information than the port dataset. If the variability in the port data is indicative of a variable discarding practice, rather than observation error, then, in principal, it would be necessary to attempt to model that variability accurately. However, given the small landed catches of this fleet, provided the discards are not very large (i.e. not higher than the landings themselves) then it would not be necessary to capture the annual dynamics of the discard practice in the model, provided port collected length data is not used.

Just 26 Danish seine caught Gummy Shark have been aged, all from a single trip in 2003 in the Bass Strait region (Figure 14). Most of those were aged 3-4, ages that have predicted mean lengths of 87cm and almost 100cm respectively. These are relatively large compared with typical onboard-measured Gummy Shark (Figure 12) indicating that the data are not representative of the catch by Danish seiners. A lack of age data

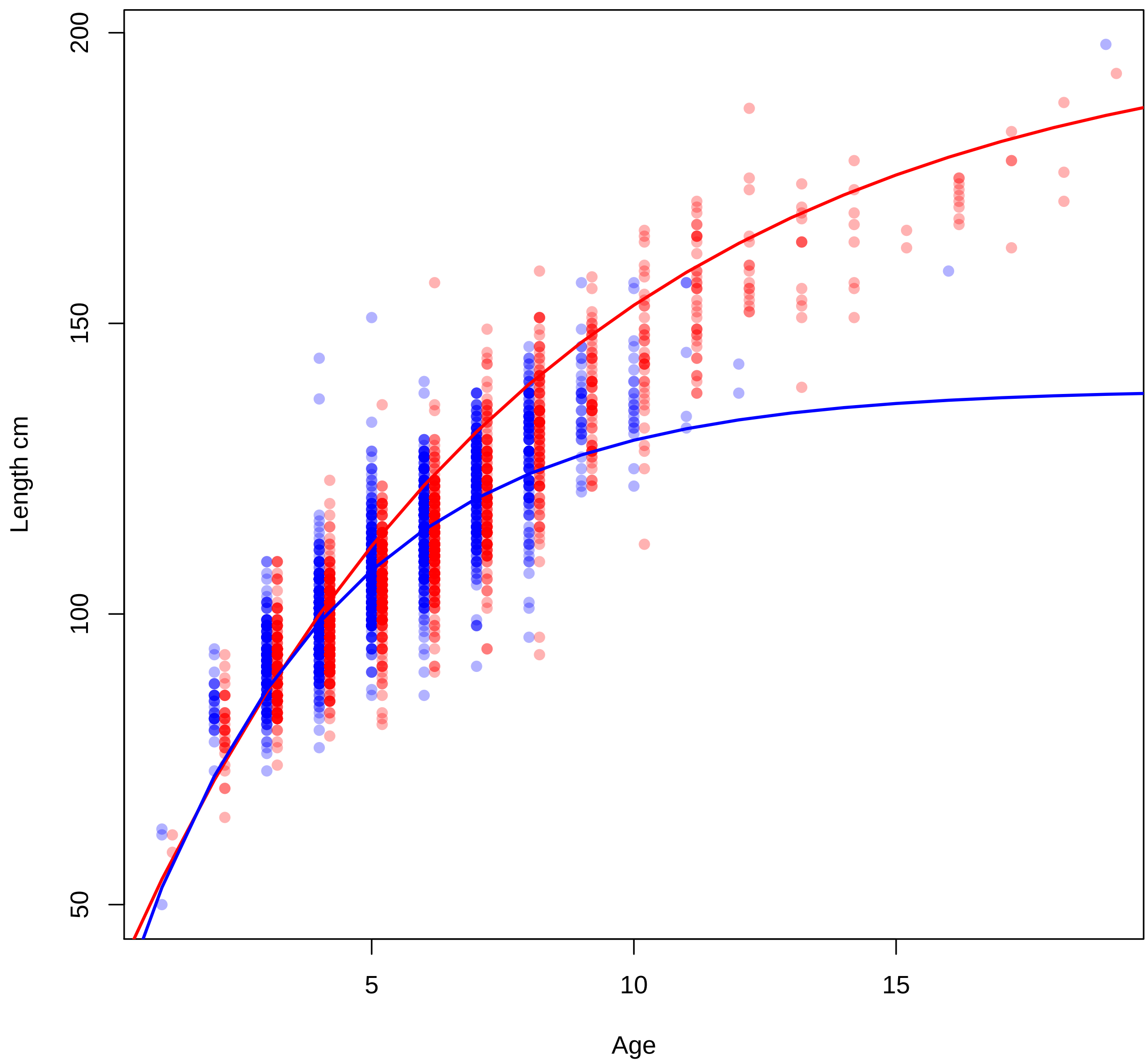



Figure 9: Observed age and length for Gummy Shark collected during 1995, 1997, 2002-2003, 2010-2015. Data from males are shown as blue dots, and females as red dots (which are slightly shifted along the Age axis for clarity of presentation). Theoretical growth curves are shown a red (females) and blue (line).

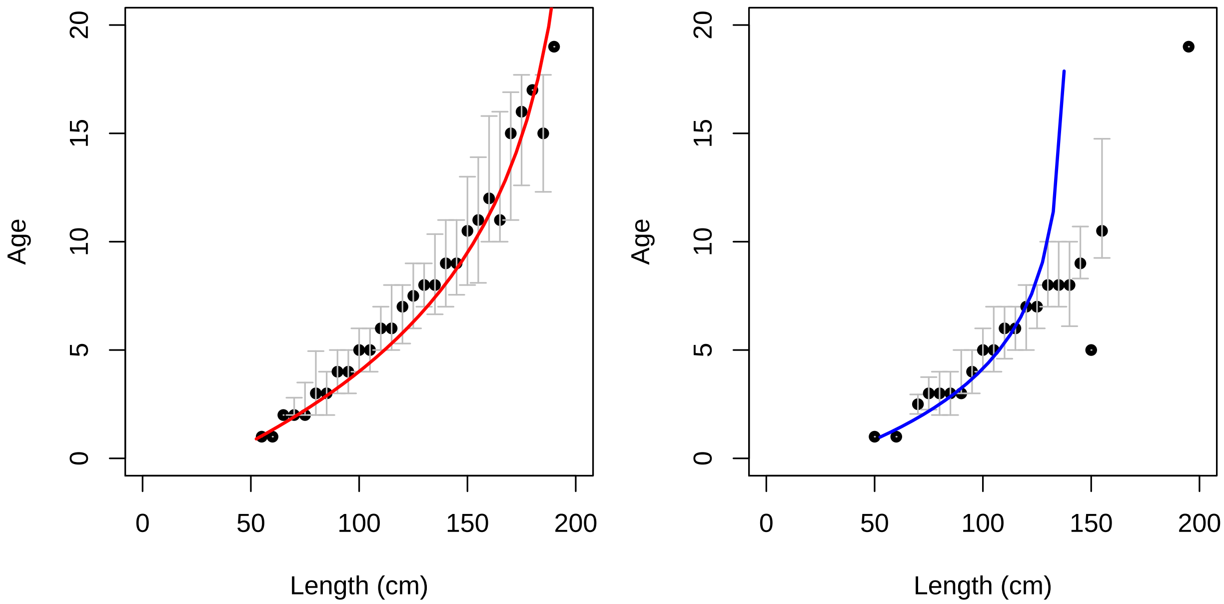



Figure 10: Quantiles (5%, 50%, 95%) for observed age at 5cm length class intervals for Gummy Shark data (1995, 1997, 2002-2003, 2010-2015) for females (left) and males (right).

for this fleet is not greatly detrimental to the model because sufficient length data are available, and the relationship between length and age is dictated by the growth curve.

It is recommended that future Gummy Shark assessment model updates include a Danish seine fleet for Bass Strait, and use the onboard data in preference to port data. Ongoing collection of onboard data for the Danish seine fleet is expected. Provided the total catch (landings plus discards) for the Danish seine fleet continues to be small relative to the total catch by all gear types, and onboard length frequency data continues to be available, it should not be necessary to model length-based discarding practices for the Danish seine fleet. This fleet captures relatively small Gummy Shark so ought to provide a useful index of recruitment, that provides an earlier signal than data from other fleets.

# 4 Assessment Method

The Gummy Shark 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 is 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) model CPUE as a non-linear function of effort (Equation 1). Figure 15 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 is zero, then CPUE is considered to be linearly related to biomass so that CPUE in the scenario depicted in Figure 15, 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.

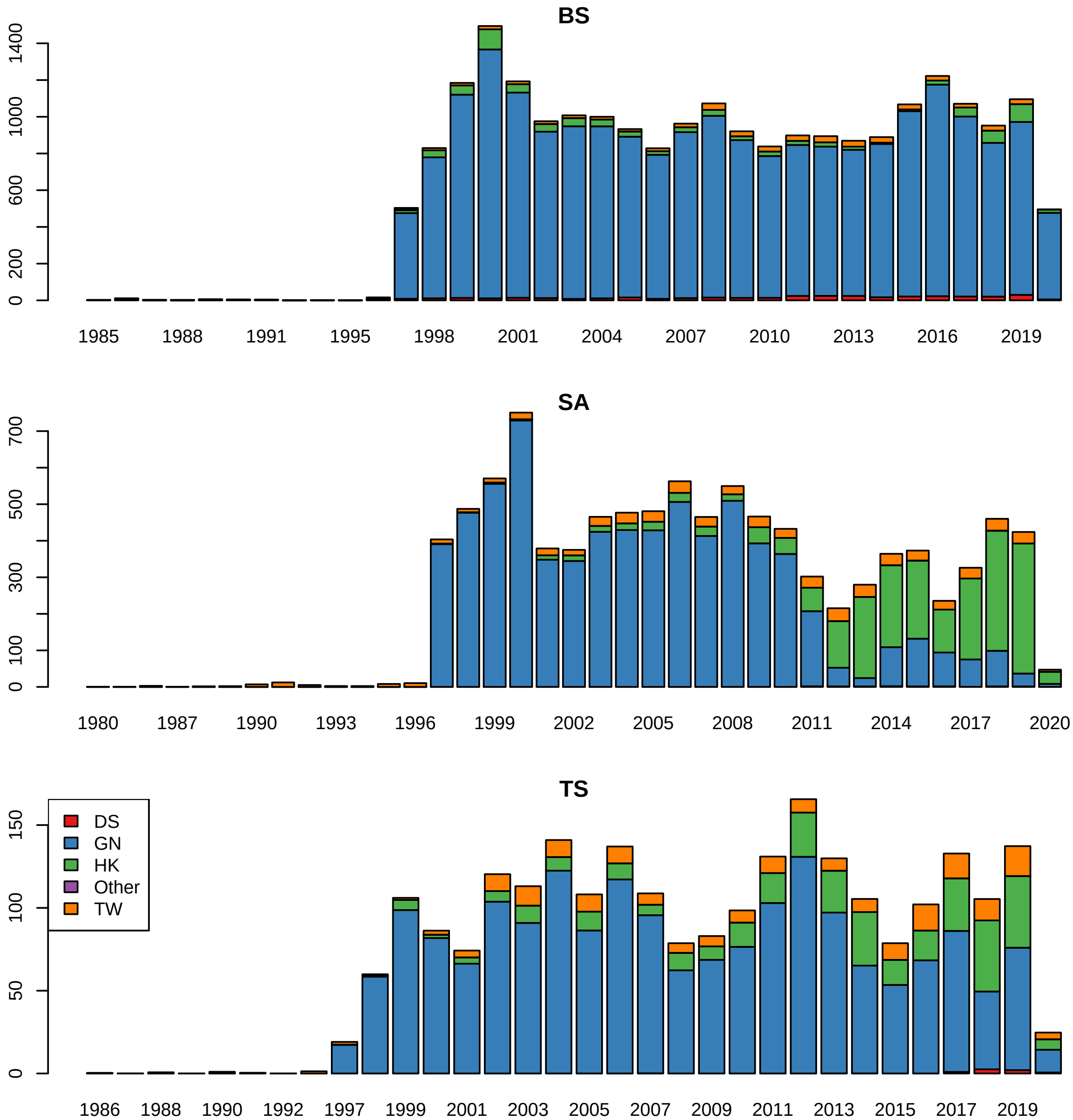



Figure 11: AFMA logbook reported catches of Gummy Shark by Danish seine (DS), gillnet (GN), line (HK), trawl (TW) and other gear types (Other).

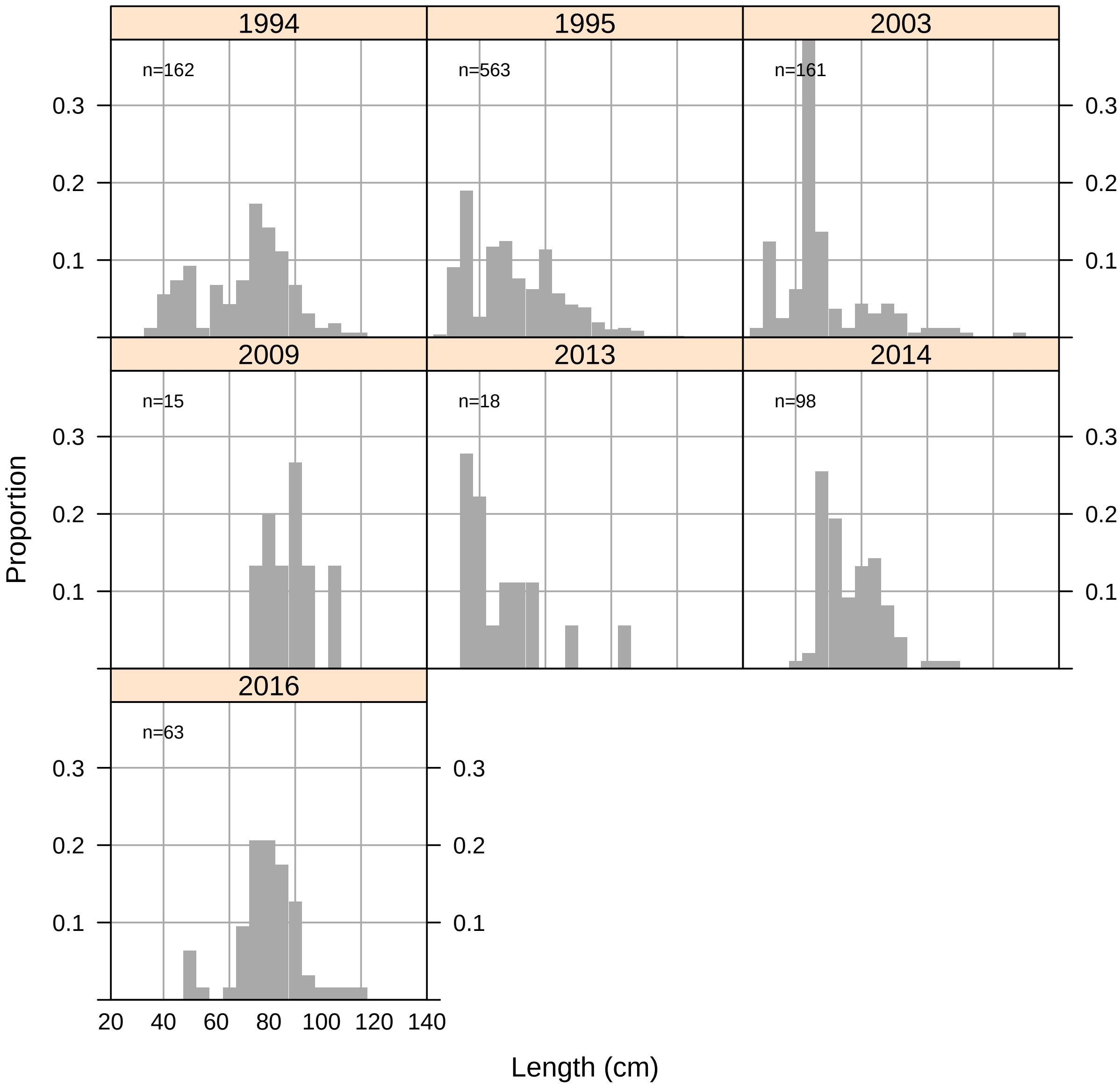



Figure 12: Length frequencies of Danish seine caught Gummy Shark collected by onboard observers.

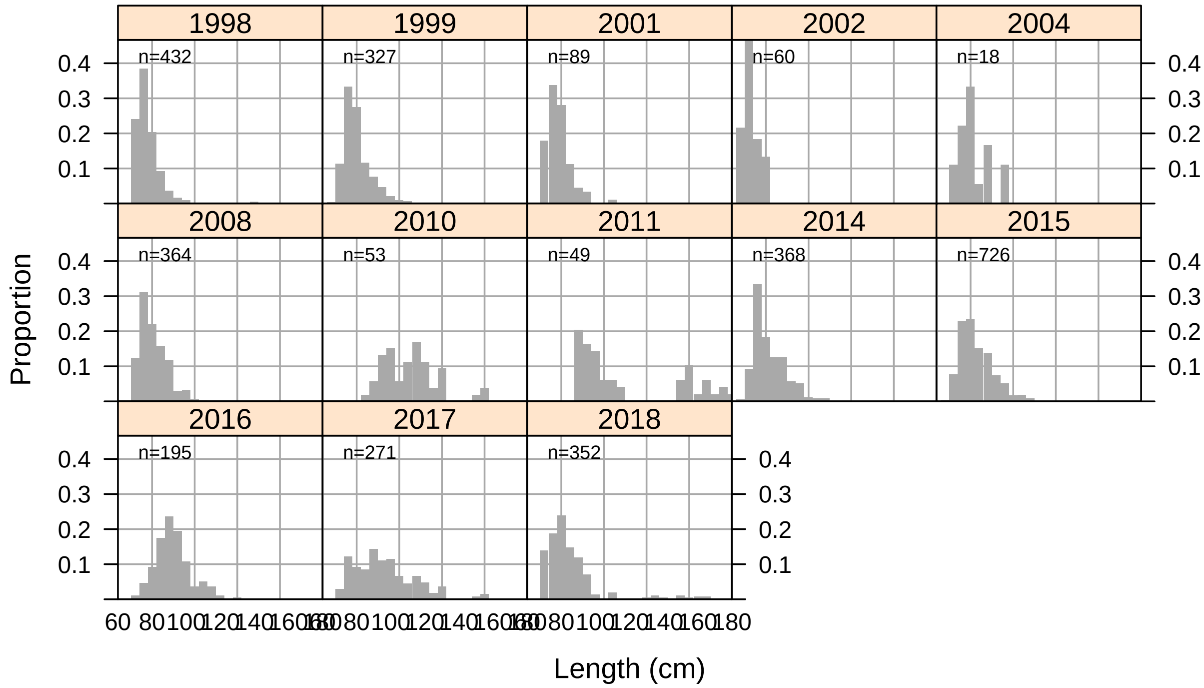



Figure 13: Length frequencies of Danish seine caught Gummy Shark collected by port-based observers.

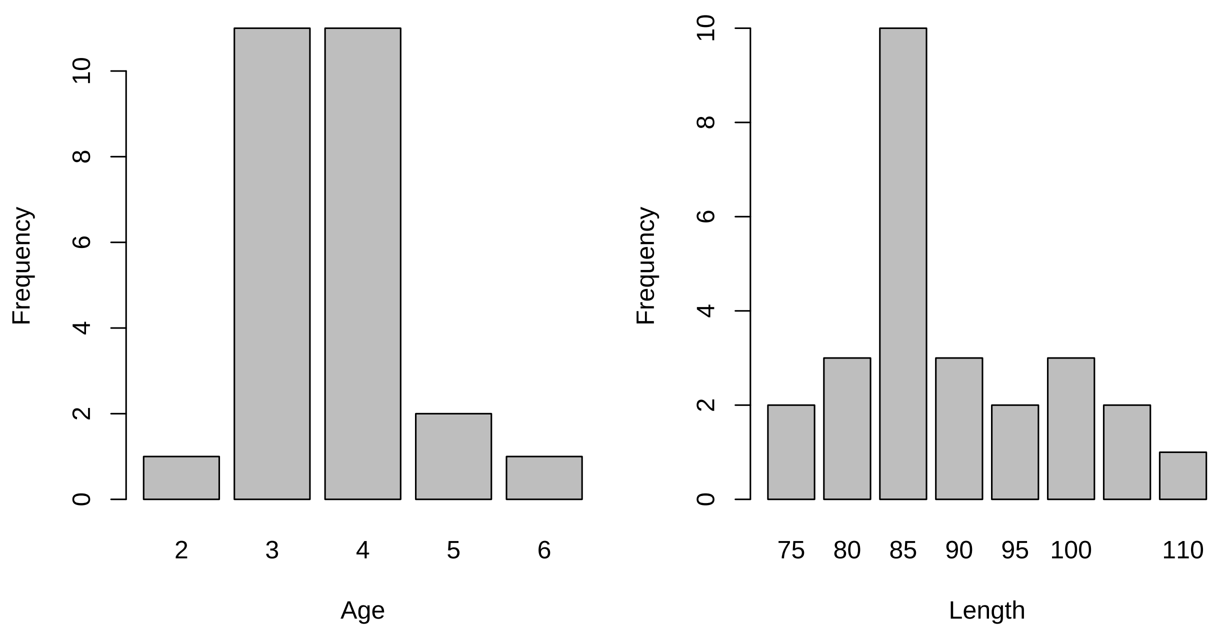



Figure 14: Age (left) and length (right) frequency of 26 Danish seine caught Gummy Shark.

Predicted CPUE is also plotted against effort in Figure 15. Note that in this example true biomass is constant so that the y-axis of the lower plot which is labelled 'Predicted CPUE' could equally accurately have been labelled 'Predicted CPUE  Available Biomass'.

$$CPUE = q \, \frac{B}{1+gE} \qquad (1)$$

The base case gummy shark model estimates an 'availability' function that modifies the fixed gear selectivity for (only) gillnet gears. 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 Punt & Thomson (2016) 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 there no inadvertent changes were made to the results. Those results are not shown here because all were identical to the 2016 base case model, as they should be.

We present a 'bridging analysis' which bridges from the 2016 base case model to a proposed 2020 base case 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 of adding the new data (from 2016 to 2019 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

## 5.1 Bridging

The code that was written this year to process the data is implemented (and documented) within Rmarkdown documents. This new data processing code is intended to be more easily re-usable than the R-scripts used in the past, so that future assessment updates will require less time spent on data processing work and will be less error-prone. These Rmarkdown documents produce the input files used by the model; they were tested by using them to produce the data that was used for the 2016 assessment update, and then ensuring that the model gave the same result as that given in the 2016 report (Punt and Thomson 2016) when applied to those data (results not shown because they are identical to the 2016 base case). The Gummy assessment code itself has been altered to allow easier implementation of the new system, and those changes were also tested to ensure that they did not introduce error (again, results not shown because they are identical to the 2016 base case result).

When re-processing the data to 2015 (that was used for the 2016 assessment update) changes were made to some of the processed data. These might have resulted from corrections to the database itself (such as tidying up of the length data that was recently undertaken by AFMA), or improvements to the way the data is processed, or differences in data selection rules (such as not using length frequencies based on fewer than 100 animals). These 'corrections' made only relatively small changes to the results of the base case model (Table 6).

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 the model result. This is termed a 'bridging analysis' because it bridges from the old to the new data. Introducing the new catch, CPUE

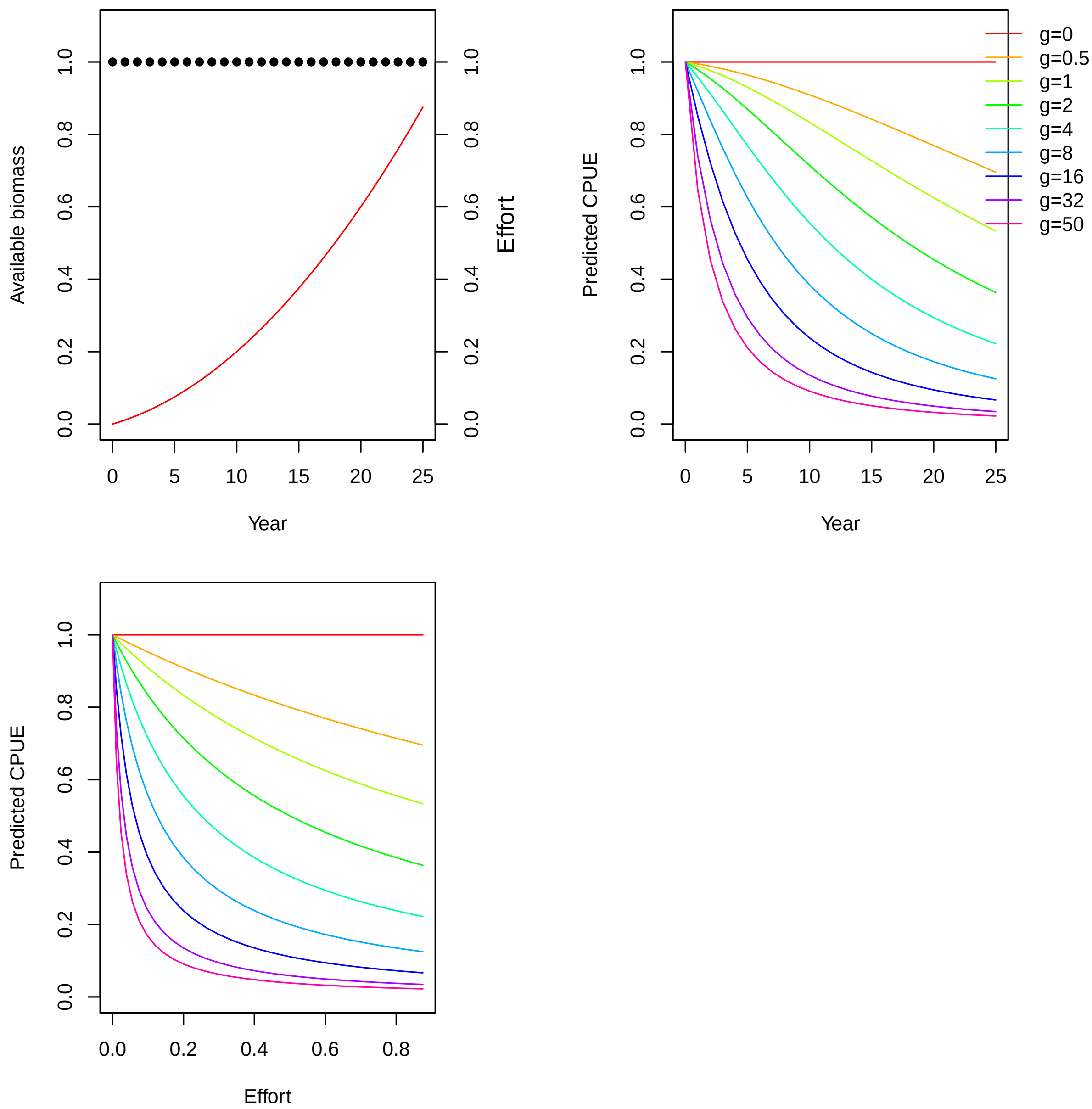



Figure 15: A theoretical scenario in which biomass is steady, but effort is increasing (upper left plot), illustrating the influence of the effort saturation parameter on predicted CPUE (upper right plot). Predicted CPUE against effort is shown (lower plot).

and length frequency data made large changes to the results (Table 7) - the CPUE data was particularly influential especially on the effort saturation parameter.

The abundance (pup production) for each stock, generated from the models that altered some of the pre-2016 data are shown in Figure 16. Those that add data to 2019, and that alter the model assumptions, are shown in Figure 17.

Tables 6 and Table 7 were presented to sharkRAG's September 2020 meeting, culminating with a model that used CPUE using operation as the unit of effort, fitting to separate trawl CPUE time series for each stock, and with no additional age data since the 2016 assessment update ('op3TW'). Additional bridging work is presented in Table 8. Cropping the Bass Strait trawl CPUE time series (i.e. using trawl CPUE in Bass Strait for only 2008 to 2019 inclusive) changes the effort saturation for Bass Strait, slightly, but has little effect on depletion in Bass Strait ('cropTW' in Table 8). Splitting Bass Strait CPUE (fitting separately to CPUE before 2005 and after 2008) similarly has little influence on results ('splitTW' Table 8).

The operation-based CPUE for gillnets are very similar to those based on net length (Figure 3) so it not surprising that these also make minor change to the model results ('nlGNBS', 'nlGNSA' and 'nlGNTS' Table 8).

In bridging from using age composition data for the all years, to using conditional age-at-length where possible, first, the four years of age data (1995, 1997, 2003-2004) that were added to the model in 2016, were removed. This caused an increase in estimated natural mortality (M) of adult sharks from 0.16 to 0.18 and a corresponding drop in unfished biomass in all stocks (higher $M$ means higher productivity, so that lower biomass can sustain the same level of catches). Depletion drops by 3 or 4 percentage points for each stock ('MinusAge' in Table 8). Adding those data back into the model, this time as length and age data in a conditional age-at-length approach, gives similar results to the 'MinusAge' model although with a slight shift back towards higher biomass and depletion ('CAL2016', Table 8).

Adding the new age data (for six years, 2010-2015) as conditional age-at-length returns the estimate of $M$ to 0.16 but with higher biomass and less depletion in all regions than before ('CAL2019', Table 8). Adding the age data for 2016 to 2019 inclusive makes only a slight difference ('CAL2019c', Table 8).

Further bridging is shown in Figure 18.

## 5.2 Sensitivities

Sensitivity tests were conducted to the 'CAL2019' model for the September 2020 sharkRAG meeting. Subsequent to that, the omission of 2016-2019 age-at-length data was discovered so that was the model used for future projections and RBC calculations. Because the result of the two models were very similar, the sensitivity tests were not repeated.

Several standard sensitivity tests that are routinely conducted for the Gummy Shark assessment (e.g. Punt & Thomson 2016) are repeated here (Table 9), however two tests that allow fecundity to be density dependent were dropped. This was done because of work by Walker (2010) who wrote that 'Density-dependent natural mortality is the principal mechanism for population regulation in *M. antarcticus*, evidenced from undetectable decompensation in growth rate and in reproductive rate when measured before and after major changes in population size in response to large changes in fishing mortality'.

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 slight.

Assuming that effort saturation does not occur (i.e. saturation parameter is zero for all stocks) has very little effect ('noSat', Table 9). Assuming that all sharks are equally available to capture by gillnets greatly alters the results, but more importantly, greatly degrades the fit to the data (negLL is 1954 for the 'Avail' model compared with 1894 for the 'CAL2019' model) indicating that non-uniform availability should be estimated. The model that estimates gillnet selectivity ('GNsel', Table 9) has to fit the data at least as well as the 'CAL2019' model because it differs only in that two parameters that are fixed in the 'CAL2019' model are

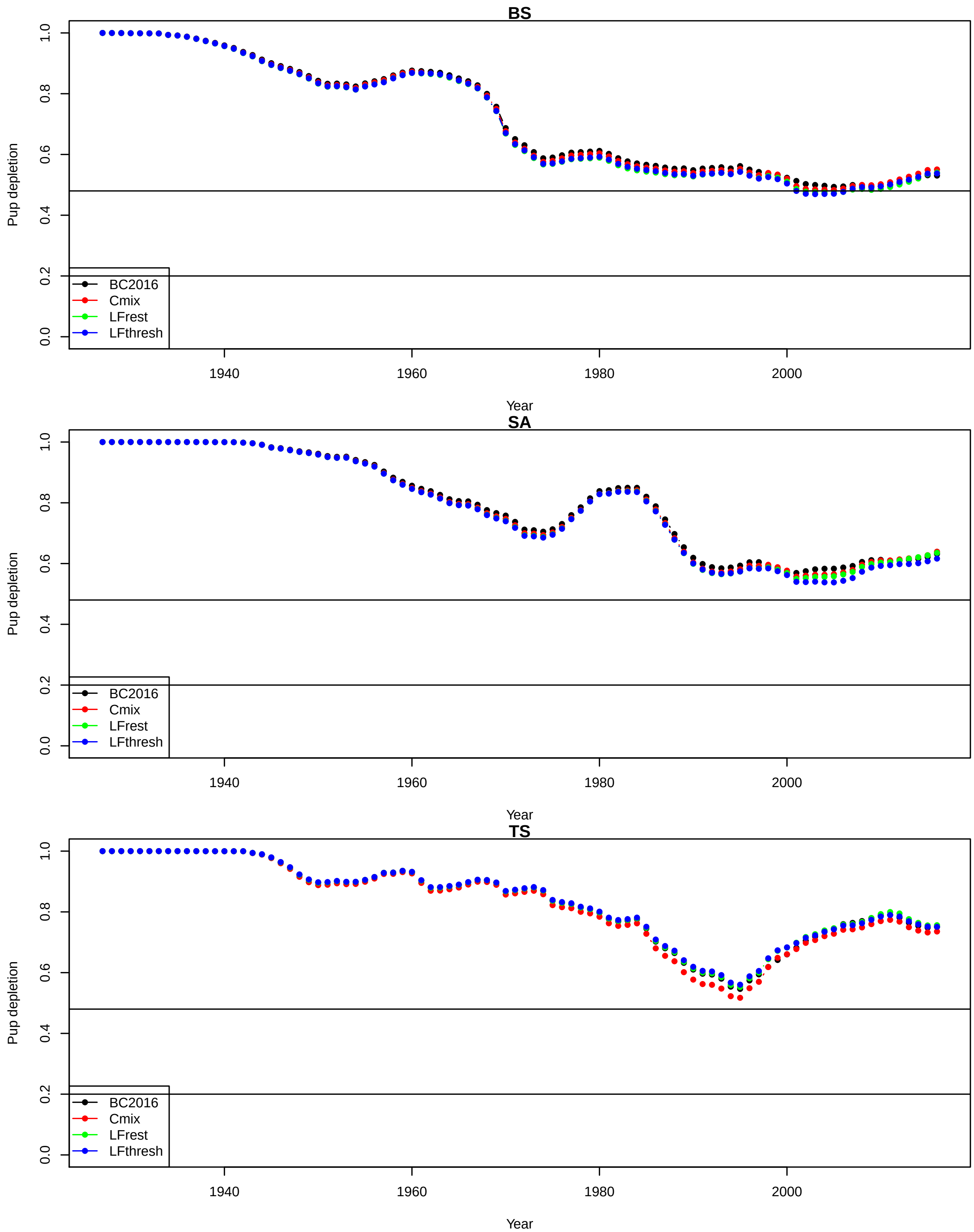



Figure 16: Pup depletion for models that altered some of the pre-2016 data, for each Gummy stock. Limit (20%) and target (48%) reference points are shown as horizontal lines.

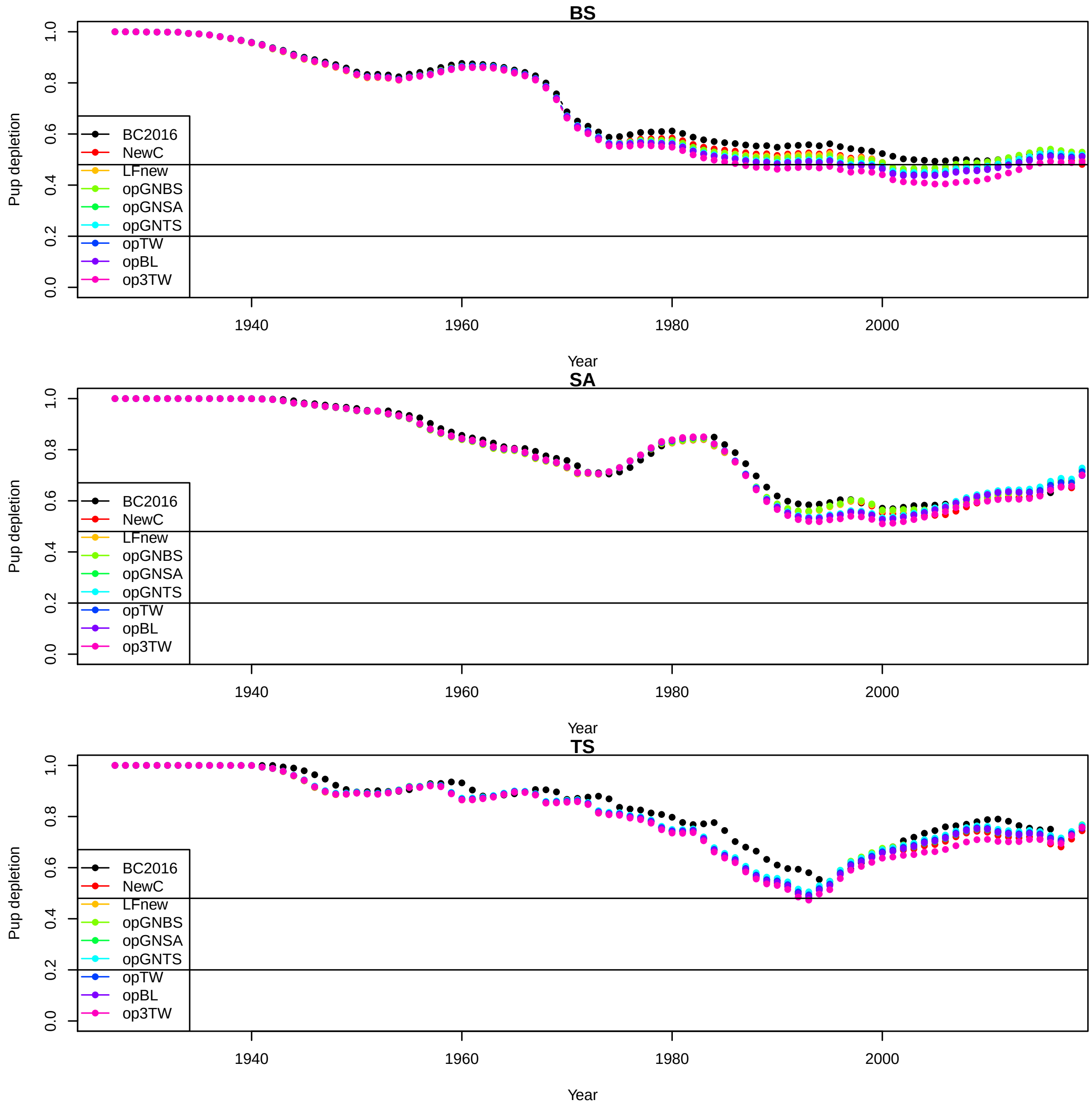



Figure 17: Pup depletion for models that add data to 2019, and that alter the model assumptions, for each Gummy stock.

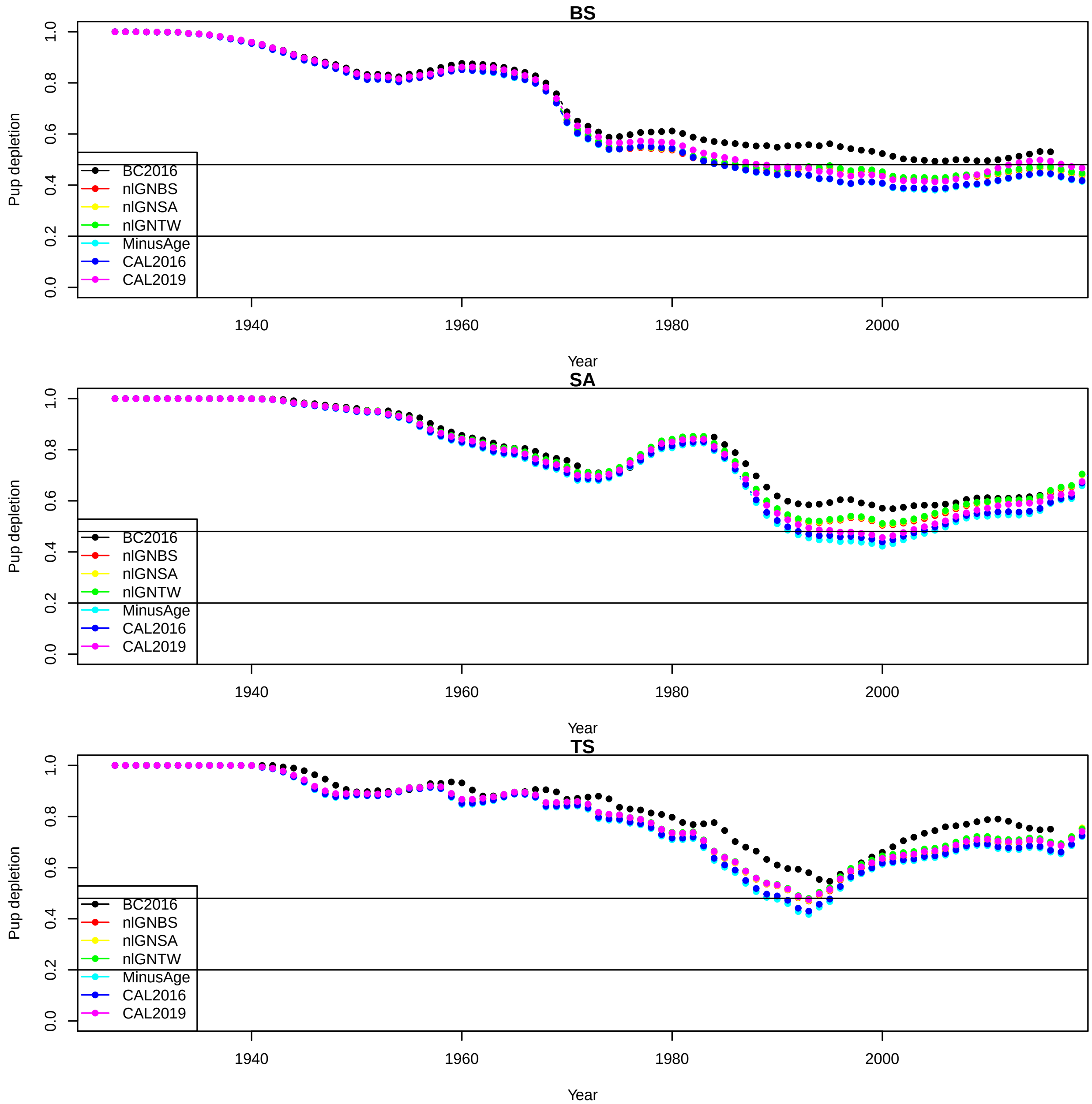



Figure 18: Pup depletion for additional models that alter data and model assumptions, for each Gummy stock, along with the 2016 base case.

estimated in the sensitivity. The model varies those values only slightly, achieving a small improvement to the fit (1894 versus 1892). A likelihood ratio test does not support the estimation of two additional parameters for so small an improvement - a reduction of more than 5.99 in required. Note that the 'GNsel' model fits the trawl length frequency data particularly poorly (Figure 22).

When estimating selectivity, it ought to be unnecessary to estimate availability as well, provided a sufficiently flexible form of model selectivity is used, and indeed, a very similar fit is achieved ('GNselAva', Table 9) albeit with a slightly more productive but smaller population. This model has one parameter less than the 'GNsel' model and one parameter more than the 'CAL2019' model. Despite the additional parameter, it gives a slightly worse fit to the data than the 'CAL2019' model because it does not have the flexibility to achieve exactly the same patterns of exploitation at age. A more flexible form of selectivity function (e.g. double logistic) might achieve the same or slightly better fit. Punt & Thomson (2016) also recommended estimating selectivity separately or each stock.

The small perturbation to natural mortality ($M$) has little effect on the model results ('Mup' and 'Mdown', Table 9), however, a larger perturbation would likely have greater effect as stock assessment models are typically sensitive to $M$.

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 (low negLL values for 'ddM2' and 'ddM2m', Table 9). 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 32 to 53% in Bass Strait, 66 to 107% in South Australia, and 62 to 79% in Tasmania. Similar results were shown by Punt & Thomson (2016). Interestingly, the models that allow density dependence to be a function of mature biomass are more similar to one another, regardless of the ages over which M is affected, than they are to the 1+ biomass sensitivities. This warrants further investigation.

The impact on the of the density dependence assumption on length frequency and age composition results is slight (Figure @ref:allLF2) and @ref:allAGES2)). Further discussion by sharkRAG regarding which density dependence assumption to use in the base case, or whether to return to model averaging, is warranted.

Doubling or halving the weight given to data sources reveals conflicts between data. The estimate of $M$ is clearly strongly influenced by the tagging data, as would be expected. Other than the tagging sensitivity, none of the other weighting changes greatly alters the result, indicating little conflict between data sources (final 6 rows in Table 9).

Table 1: Gummy Shark landed tonnage from AFMA logbook data set for gillnet (GN), hook (HK), trawl (TW), Danish seine (DS) and Other gear types.

| | GN | HK | TW | DS | Other | Total |
|---|---|---|---|---|---|---|
| 1980 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1985 | 0 | 0 | 4 | 1 | 0 | 5 |
| 1986 | 0 | 0 | 23 | 2 | 0 | 25 |
| 1987 | 0 | 0 | 13 | 0 | 0 | 13 |
| 1988 | 0 | 0 | 13 | 0 | 0 | 13 |
| 1989 | 0 | 0 | 16 | 1 | 0 | 17 |
| 1990 | 0 | 0 | 20 | 1 | 0 | 21 |
| 1991 | 0 | 0 | 27 | 2 | 1 | 30 |
| 1992 | 0 | 0 | 8 | 0 | 0 | 8 |
| 1993 | 0 | 0 | 5 | 0 | 0 | 5 |
| 1994 | 0 | 0 | 5 | 0 | 0 | 5 |
| 1995 | 0 | 0 | 15 | 0 | 0 | 15 |
| 1996 | 0 | 0 | 42 | 7 | 0 | 49 |
| 1997 | 878 | 17 | 45 | 9 | 4 | 953 |
| 1998 | 1310 | 40 | 40 | 11 | 0 | 1401 |
| 1999 | 1766 | 61 | 39 | 13 | 0 | 1879 |
| 2000 | 2171 | 115 | 53 | 11 | 0 | 2350 |
| 2001 | 1535 | 62 | 59 | 14 | 0 | 1670 |
| 2002 | 1356 | 64 | 62 | 13 | 0 | 1495 |
| 2003 | 1456 | 71 | 83 | 8 | 0 | 1618 |
| 2004 | 1489 | 65 | 91 | 11 | 0 | 1656 |
| 2005 | 1393 | 63 | 98 | 16 | 0 | 1570 |
| 2006 | 1408 | 56 | 105 | 9 | 0 | 1578 |
| 2007 | 1414 | 59 | 89 | 12 | 0 | 1574 |
| 2008 | 1562 | 60 | 90 | 15 | 0 | 1727 |
| 2009 | 1322 | 74 | 91 | 13 | 0 | 1500 |
| 2010 | 1213 | 85 | 93 | 14 | 0 | 1405 |
| 2011 | 1131 | 105 | 103 | 26 | 0 | 1365 |
| 2012 | 996 | 178 | 104 | 27 | 0 | 1305 |
| 2013 | 917 | 265 | 99 | 26 | 0 | 1307 |
| 2014 | 1011 | 264 | 92 | 20 | 1 | 1388 |
| 2015 | 1197 | 240 | 84 | 24 | 0 | 1545 |
| 2016 | 1314 | 158 | 87 | 27 | 0 | 1586 |
| 2017 | 1142 | 303 | 92 | 25 | 0 | 1562 |
| 2018 | 983 | 440 | 107 | 30 | 0 | 1560 |
| 2019 | 1052 | 498 | 118 | 40 | 0 | 1708 |
| 2020 | 494 | 57 | 13 | 8 | 0 | 572 |

Table 2: Gummy Shark tonnage landed from CDR database, and State catches.

| Year | CDR | WA | SA | VIC | TAS | NSW |
|---|---|---|---|---|---|---|
| 2001 | 1703 | 297 | 54 | 33 | 13 | 77 |
| 2002 | 1605 | 354 | 54 | 33 | 13 | 74 |
| 2003 | 1678 | 413 | 54 | 33 | 13 | 44 |
| 2004 | 1735 | 507 | 54 | 33 | 13 | 56 |
| 2005 | 1645 | 504 | 53 | 33 | 13 | 74 |
| 2006 | 1646 | 552 | 58 | 33 | 13 | 95 |
| 2007 | 1665 | 655 | 84 | 33 | 13 | 70 |
| 2008 | 1866 | 691 | 107 | 23 | 13 | 0 |
| 2009 | 1646 | 545 | 148 | 20 | 9 | 31 |
| 2010 | 1540 | 448 | 150 | 16 | 9 | 60 |
| 2011 | 1517 | 344 | 144 | 23 | 9 | 62 |
| 2012 | 1450 | 391 | 161 | 19 | 8 | 54 |
| 2013 | 1471 | 448 | 104 | 17 | 7 | 47 |
| 2014 | 1527 | 490 | 89 | 17 | 7 | 28 |
| 2015 | 1682 | 407 | 86 | 19 | 8 | 26 |
| 2016 | 1746 | 406 | 77 | 13 | 9 | 22 |
| 2017 | 1720 | 405 | 75 | 16 | 11 | 25 |
| 2018 | 1673 | 381 | 74 | 18 | 8 | 24 |
| 2019 | 1809 | 315 | 84 | 18 | 8 | 26 |

Table 3: Gummy Shark landed tonnage from AFMA logbook data set shown for LINE gear codes used in the assessment: auto-line (ALL and AL), bottom line (BL and LLD).

| | AL | ALL | BL | LLD |
|---|---|---|---|---|
| 1997 | 0 | 0 | 17 | 0 |
| 1998 | 0 | 0 | 40 | 0 |
| 1999 | 0 | 0 | 59 | 0 |
| 2000 | 0 | 0 | 114 | 0 |
| 2001 | 0 | 0 | 60 | 0 |
| 2002 | 1 | 0 | 61 | 0 |
| 2003 | 1 | 0 | 69 | 0 |
| 2004 | 3 | 0 | 61 | 0 |
| 2005 | 1 | 0 | 62 | 0 |
| 2006 | 4 | 0 | 50 | 0 |
| 2007 | 1 | 0 | 57 | 0 |
| 2008 | 8 | 0 | 52 | 0 |
| 2009 | 5 | 0 | 69 | 0 |
| 2010 | 10 | 0 | 74 | 0 |
| 2011 | 11 | 0 | 93 | 0 |
| 2012 | 51 | 0 | 125 | 0 |
| 2013 | 35 | 0 | 230 | 0 |
| 2014 | 34 | 0 | 229 | 0 |
| 2015 | 48 | 0 | 192 | 0 |
| 2016 | 7 | 0 | 151 | 0 |
| 2017 | 5 | 0 | 296 | 0 |
| 2018 | 53 | 6 | 261 | 119 |
| 2019 | 14 | 73 | 201 | 211 |

Table 4: 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 (2015 or 2019) |
| Satn | Effort saturation parameter |
| negLL | Negative log-likelihood |
| Pr | Prior for recruitment residuals |
| BS | Bass Strait |
| SA | South Australia |
| TS | Tasmania |

Table 5: Description of the models presented in this report. 'CAL2019' is the proposed base case, models listed above CAL2019 are bridging steps whose changes are cumulative; those below are sensitivities that differ from the base case by just the described change.

| modname | fulldesc |
|---|---|
| BC2016 | The 2016 base case model |
| Cmix | New processing used to generate catches to 2015 |
| LFrest | New processing and database used to generate LFs to 2015 |
| LFthresh | LFs based on fewer than 100 samples eliminated |
| NewC | New catches for 2016 to 2019 added and model run to 2019 |
| LFnew | New LFs for 2016 to 2019 added |
| opGNBS | New CPUE series for gillnets in BS added |
| opGNSA | New CPUE series for gillnets in SA added |
| opGNTS | New CPUE series for gillnets in TS added |
| opTW | New CPUE series for trawl (all regions combined) added |
| opBL | New CPUE series for line (all regions combined) added |
| op3TW | Separate trawl CPUE time series for each stock |
| cropTW | Bass Strait trawl CPUE before 2008 is deleted |
| splitTW | Bass Strait trawl CPUE split into 1996-2005 and 2008-2019 |
| nlGNBS | Net length-based CPUE gillnets in BS replaces operation-based series |
| nlGNSA | Net length-based CPUE gillnets in SA replaces operation-based series |
| nlGNTS | Net length-based CPUE gillnets in TS replaces operation-based series |
| MinusAge | Age compositions data for 1995, 1997, 2003-4 is removed from the model |
| CAL2016 | Age data (with length) for 1995, 1997, 2003-4 is used as conditional age-at-length |
| CAL2019 | Age data for 2010-2015 is added as conditional age-at-length |
| CAL2019c | Age data for 2016-2019 added to the conditional age-at-length calculation |
| noSat | No effort saturation for gillnet CPUE (i.e. linear relationship with abundance) |
| Avail | All age classes are equally available to gillnet gear |
| GNsel | Selectivity for gillnet fleets is estimated (and so is availability) |
| GNselAva | Selectivity for gillnet fleets is estimated but all age classes are equally available |
| Mdown | M is 0.1 lower than the base case estimate |
| Mup | M is 0.1 greater than the base case estimate |
| ddM15 | density dependence acts on M for ages 0-15, as a function of 1+ biomass |
| ddM4 | density dependence acts on M for ages 0-4, as a function of 1+ biomass |
| ddM2 | density dependence acts on M for ages 0-2, as a function of 1+ biomass |
| ddM30m | density dependence acts on M for ages 0-30, as a function of mature biomass |
| ddM15m | density dependence acts on M for ages 0-15, as a function of mature biomass |
| ddM4m | density dependence acts on M for ages 0-4, as a function of mature biomass |
| ddM2m | density dependence acts on M for ages 0-2, as a function of mature biomass |
| dblCPUE | the weight given to the CPUE data is doubled |
| halfCPUE | the weight given to the CPUE data is halved |
| halfLF | the weight given to the length frequency data is halved |
| halfAGE | the weight given to the age composition data is halved |
| halfCAL | the weight given to the conditional age-at-length data is halved |
| halfTAG | the weight given to the tagging data is halved |

Table 6: Model estimates from the 2016 base case compared with those using updated data to 2016. Abbreviations are described in Tables 4 and 5.

| | | 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 |
| BC2016 | 0.16 | 9406 | 6104 | 1949 | 0.25 | 0.27 | 0.25 | 61 | 71 | 88 | 53 | 63 | 75 | 4.38 | 50 | 0 | 1610 | 129 | 751 | 366 | 0 | 315 | 48 |
| Cmix | 0.17 | 9019 | 5795 | 1801 | 0.25 | 0.28 | 0.25 | 60 | 70 | 87 | 55 | 64 | 74 | 4.17 | 50 | 0 | 1619 | 126 | 751 | 365 | 0 | 326 | 50 |
| LFrest | 0.16 | 9014 | 5818 | 1971 | 0.25 | 0.27 | 0.25 | 59 | 69 | 88 | 54 | 64 | 76 | 6.09 | 50 | 0 | 1578 | 124 | 709 | 363 | 0 | 331 | 51 |
| LFthresh | 0.16 | 9142 | 5842 | 2009 | 0.25 | 0.27 | 0.25 | 59 | 69 | 88 | 54 | 62 | 75 | 2.83 | 50 | 0 | 1413 | 116 | 560 | 356 | 0 | 330 | 51 |

Table 7: Model estimates from the 2016 base case compared with those using updated data to 2019. Abbreviations are described in Tables 4 and 5.

| | | 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 |
| BC2016 | 0.16 | 9406 | 6104 | 1949 | 0.25 | 0.27 | 0.25 | 61 | 71 | 88 | 53 | 63 | 75 | 4.38 | 50.00 | 0 | 1610 | 129 | 751 | 366 | 0 | 315 | 48 |
| NewC | 0.16 | 9221 | 6142 | 1818 | 0.24 | 0.26 | 0.24 | 59 | 70 | 81 | 51 | 74 | 78 | 2.90 | 50.00 | 0 | 1468 | 122 | 567 | 354 | 0 | 374 | 51 |
| LFnew | 0.16 | 9109 | 6152 | 1838 | 0.24 | 0.26 | 0.24 | 58 | 70 | 82 | 53 | 76 | 80 | 4.81 | 50.00 | 0 | 1536 | 129 | 623 | 356 | 0 | 377 | 52 |
| opGNBS | 0.16 | 9176 | 6149 | 1838 | 0.24 | 0.26 | 0.24 | 59 | 71 | 82 | 57 | 76 | 80 | 3.03 | 50.00 | 0 | 1543 | 132 | 624 | 358 | 0 | 377 | 51 |
| opGNSA | 0.16 | 9613 | 6467 | 1915 | 0.22 | 0.24 | 0.22 | 59 | 71 | 82 | 55 | 77 | 79 | 2.94 | 1.95 | 0 | 1582 | 153 | 627 | 364 | 0 | 378 | 60 |
| opGNTS | 0.15 | 9756 | 6551 | 1968 | 0.22 | 0.24 | 0.22 | 59 | 71 | 82 | 55 | 77 | 79 | 2.96 | 1.94 | 0 | 1587 | 157 | 626 | 363 | 0 | 380 | 61 |
| opTW | 0.15 | 9718 | 6541 | 1934 | 0.22 | 0.24 | 0.22 | 59 | 71 | 82 | 55 | 76 | 79 | 2.82 | 1.94 | 0 | 1598 | 167 | 628 | 363 | 0 | 378 | 61 |
| opBL | 0.16 | 9749 | 6570 | 1924 | 0.22 | 0.24 | 0.22 | 59 | 71 | 82 | 55 | 74 | 78 | 2.71 | 1.92 | 0 | 1602 | 170 | 629 | 363 | 0 | 377 | 63 |
| op3TW | 0.16 | 9842 | 6753 | 1937 | 0.21 | 0.22 | 0.21 | 58 | 71 | 81 | 53 | 75 | 80 | 2.05 | 1.93 | 0 | 1674 | 229 | 629 | 367 | 0 | 379 | 70 |

Table 8: Model estimates from the 2016 base case compared with those using further additional updated data to 2019. Abbreviations are described in Tables 4 and 5.

| | | 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 |
| op3TW | 0.16 | 9842 | 6753 | 1937 | 0.21 | 0.22 | 0.21 | 58 | 71 | 81 | 53 | 75 | 80 | 2.05 | 1.93 | 0 | 1674 | 229 | 629 | 367 | 0 | 379 | 70 |
| cropTW | 0.16 | 9874 | 6795 | 1948 | 0.2 | 0.22 | 0.2 | 58 | 71 | 81 | 52 | 75 | 79 | 2.68 | 1.94 | 0 | 1647 | 205 | 630 | 364 | 0 | 377 | 70 |
| splitTW | 0.16 | 9778 | 6775 | 1949 | 0.21 | 0.22 | 0.21 | 57 | 71 | 81 | 50 | 75 | 80 | 2.72 | 1.93 | 0 | 1659 | 214 | 630 | 365 | 0 | 380 | 69 |
| nlGNBS | 0.16 | 9745 | 6838 | 1956 | 0.2 | 0.22 | 0.2 | 57 | 71 | 81 | 47 | 76 | 79 | 2.84 | 1.89 | 0 | 1660 | 215 | 632 | 365 | 0 | 379 | 69 |
| nlGNSA | 0.16 | 9698 | 6798 | 1944 | 0.2 | 0.22 | 0.2 | 57 | 71 | 81 | 47 | 75 | 79 | 2.69 | 2.01 | 0 | 1661 | 215 | 631 | 366 | 0 | 379 | 69 |
| nlGNTS | 0.16 | 9712 | 6814 | 1961 | 0.21 | 0.23 | 0.21 | 57 | 71 | 82 | 48 | 75 | 79 | 2.69 | 2.02 | 0 | 1674 | 229 | 630 | 366 | 0 | 381 | 69 |
| MinusAge | 0.18 | 9168 | 5977 | 1746 | 0.2 | 0.22 | 0.2 | 56 | 68 | 79 | 45 | 71 | 76 | 1.73 | 2.04 | 0 | 1420 | 204 | 626 | 158 | 0 | 360 | 71 |
| CAL2016 | 0.18 | 9315 | 6172 | 1800 | 0.2 | 0.22 | 0.2 | 56 | 68 | 80 | 45 | 73 | 76 | 1.81 | 2.28 | 0 | 1530 | 207 | 627 | 157 | 108 | 362 | 69 |
| CAL2019 | 0.16 | 10295 | 6680 | 2000 | 0.19 | 0.21 | 0.19 | 59 | 70 | 82 | 50 | 73 | 78 | 0.93 | 2.17 | 0 | 1894 | 204 | 632 | 160 | 462 | 369 | 66 |
| CAL2019c | 0.16 | 10127 | 6254 | 2082 | 0.2 | 0.22 | 0.2 | 59 | 68 | 87 | 48 | 66 | 69 | 1.76 | 2.32 | 0 | 1781 | 195 | 632 | 155 | 402 | 327 | 70 |

Table 9: Model estimates from the 2019 proposed base case compared with sensitivity test results. Abbreviations are described in Tables 4 and 5.

| | | 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 |
| CAL2019 | 0.16 | 10295 | 6680 | 2000 | 0.19 | 0.21 | 0.19 | 59 | 70 | 82 | 50 | 73 | 78 | 0.93 | 2.17 | 0 | 1894 | 204 | 632 | 160 | 462 | 369 | 66 |
| noSat | 0.16 | 10356 | 6779 | 2010 | 0.19 | 0.21 | 0.19 | 59 | 70 | 82 | 49 | 73 | 77 | 0 | 0 | 0 | 1910 | 213 | 634 | 165 | 461 | 368 | 70 |
| Avail | 0.27 | 7022 | 4703 | 1292 | 0.25 | 0.27 | 0.25 | 46 | 66 | 73 | 40 | 68 | 77 | 0.85 | 1.8 | 0 | 1954 | 218 | 679 | 161 | 480 | 338 | 79 |
| GNsel | 0.16 | 10161 | 6521 | 1902 | 0.2 | 0.21 | 0.2 | 58 | 68 | 80 | 49 | 72 | 76 | 0.87 | 2.21 | 0 | 1892 | 204 | 639 | 161 | 462 | 361 | 64 |
| GNselAva | 0.17 | 9654 | 6136 | 1725 | 0.2 | 0.22 | 0.2 | 57 | 67 | 77 | 48 | 70 | 74 | 0.82 | 2.2 | 0 | 1895 | 204 | 651 | 161 | 464 | 351 | 64 |
| Mdown | 0.15 | 10498 | 6801 | 2081 | 0.19 | 0.21 | 0.19 | 59 | 70 | 82 | 50 | 73 | 78 | 0.95 | 2.15 | 0 | 1894 | 203 | 631 | 160 | 461 | 373 | 66 |
| Mup | 0.17 | 9893 | 6440 | 1871 | 0.2 | 0.22 | 0.2 | 58 | 69 | 80 | 49 | 72 | 77 | 0.9 | 2.2 | 0 | 1895 | 206 | 635 | 161 | 464 | 362 | 67 |
| ddM15 | 0.16 | 10128 | 6586 | 1953 | 0.21 | 0.23 | 0.21 | 55 | 66 | 79 | 44 | 70 | 74 | 0.94 | 2.28 | 0 | 1895 | 206 | 637 | 159 | 461 | 365 | 68 |
| ddM4 | 0.17 | 10230 | 6471 | 1815 | 0.22 | 0.24 | 0.22 | 48 | 60 | 72 | 39 | 66 | 62 | 0.54 | 4.36 | 0 | 2059 | 249 | 687 | 160 | 458 | 357 | 148 |
| ddM2 | 0.12 | 10922 | 7083 | 2167 | 0.22 | 0.24 | 0.22 | 46 | 60 | 76 | 32 | 67 | 65 | 1.22 | 3.13 | 0 | 1880 | 203 | 615 | 156 | 462 | 383 | 62 |
| ddM30m | 0.17 | 8838 | 6260 | 1852 | 0.17 | 0.19 | 0.17 | 51 | 91 | 82 | 53 | 104 | 79 | 1.09 | 1.23 | 0 | 1849 | 173 | 621 | 159 | 464 | 378 | 53 |
| ddM15m | 0.17 | 8736 | 6243 | 1806 | 0.17 | 0.18 | 0.17 | 48 | 93 | 80 | 48 | 103 | 76 | 1.14 | 1.22 | 0 | 1847 | 172 | 627 | 159 | 463 | 376 | 52 |
| ddM4m | 0.14 | 9101 | 6012 | 1830 | 0.15 | 0.16 | 0.15 | 39 | 92 | 85 | 36 | 98 | 77 | 1.21 | 1.71 | 0 | 1854 | 165 | 635 | 153 | 463 | 387 | 50 |
| ddM2m | 0.14 | 7877 | 5526 | 1536 | 0.16 | 0.17 | 0.16 | 28 | 93 | 82 | 35 | 107 | 72 | 1.43 | 1.49 | 0 | 1826 | 168 | 602 | 155 | 468 | 381 | 52 |
| dblCPUE | 0.15 | 10900 | 6898 | 1996 | 0.18 | 0.19 | 0.18 | 58 | 68 | 80 | 44 | 73 | 74 | 0.98 | 1.71 | 0 | 2072 | 143 | 669 | 173 | 463 | 392 | 89 |
| halfCPUE | 0.17 | 9513 | 6094 | 1847 | 0.22 | 0.24 | 0.22 | 59 | 70 | 81 | 52 | 71 | 80 | 0.85 | 3.46 | 0 | 1776 | 277 | 629 | 151 | 460 | 349 | 48 |
| halfLF | 0.17 | 11054 | 6371 | 1830 | 0.18 | 0.2 | 0.18 | 62 | 67 | 79 | 49 | 71 | 73 | 0.7 | 2.58 | 0 | 1561 | 189 | 723 | 152 | 455 | 343 | 59 |
| halfAGE | 0.16 | 9978 | 6318 | 1937 | 0.2 | 0.22 | 0.2 | 59 | 69 | 81 | 49 | 71 | 78 | 0.65 | 2.1 | 0 | 1808 | 196 | 629 | 185 | 462 | 364 | 65 |
| halfCAL | 0.17 | 9783 | 6356 | 1880 | 0.2 | 0.22 | 0.2 | 58 | 69 | 81 | 48 | 72 | 77 | 1.18 | 2.12 | 0 | 1660 | 203 | 629 | 159 | 473 | 365 | 67 |
| halfTAG | 0.1 | 10945 | 7516 | 2899 | 0.21 | 0.23 | 0.21 | 59 | 71 | 88 | 48 | 76 | 86 | 1.6 | 1.71 | 0 | 1690 | 191 | 594 | 157 | 458 | 461 | 59 |

## 5.3 Results plots

The standardized CPUE time series used by the proposed base case model, 'CAL2019', which uses separate trawl CPUE for each Gummy stock, are show in Figure 19.

Even though growth is not estimated within the model, the close correspondence between observed and predicted age at size (Figure 20) proves support for the assumed growth rates (recall that the poor correspondence between theoretical male growth rate and the data for older ages is overcome by the use of a plus group at age 10). It is therefore not a priority to estimate growth within the model until the plus group is raised. When growth estimation is added to the model, the possibility of regional growth differences should be explored. Moulton *et al* (1992) found growth difference between Bass Strait and South Australia and it is their Bass Strait curve that is used here. By eye, the model does seem to fit the Bass Strait age-at-length data somewhat better than the South Australian data (Figure 20).

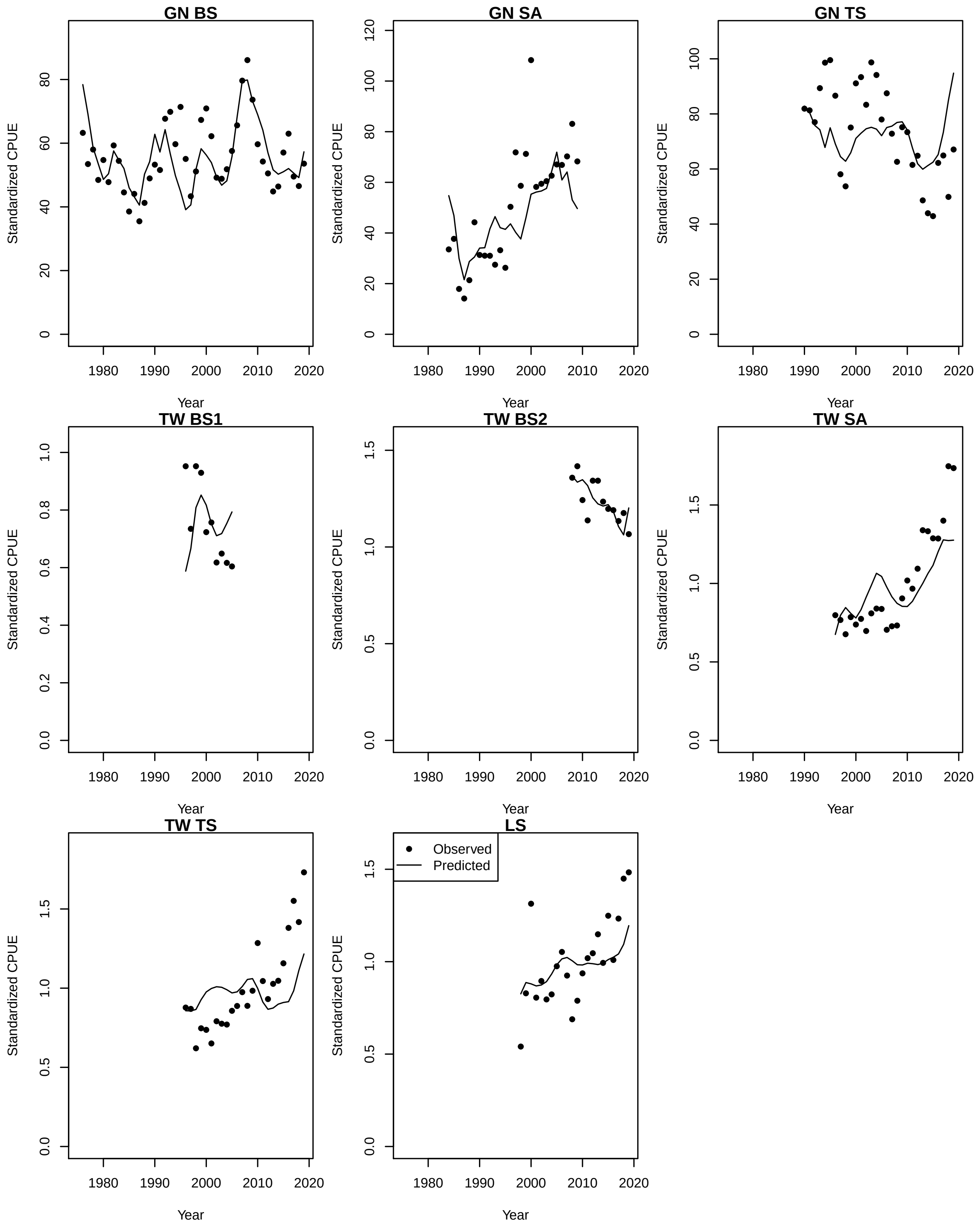
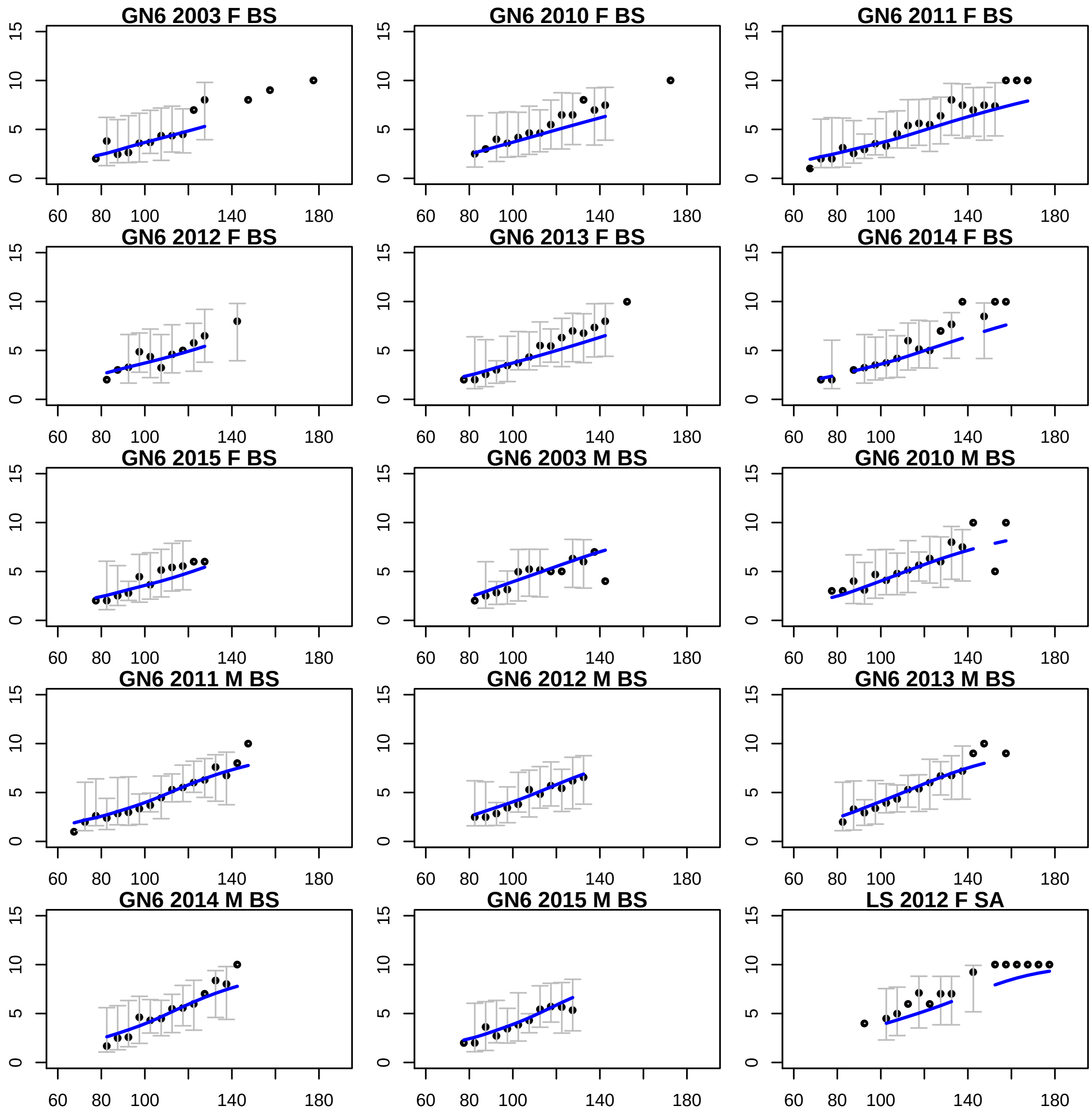
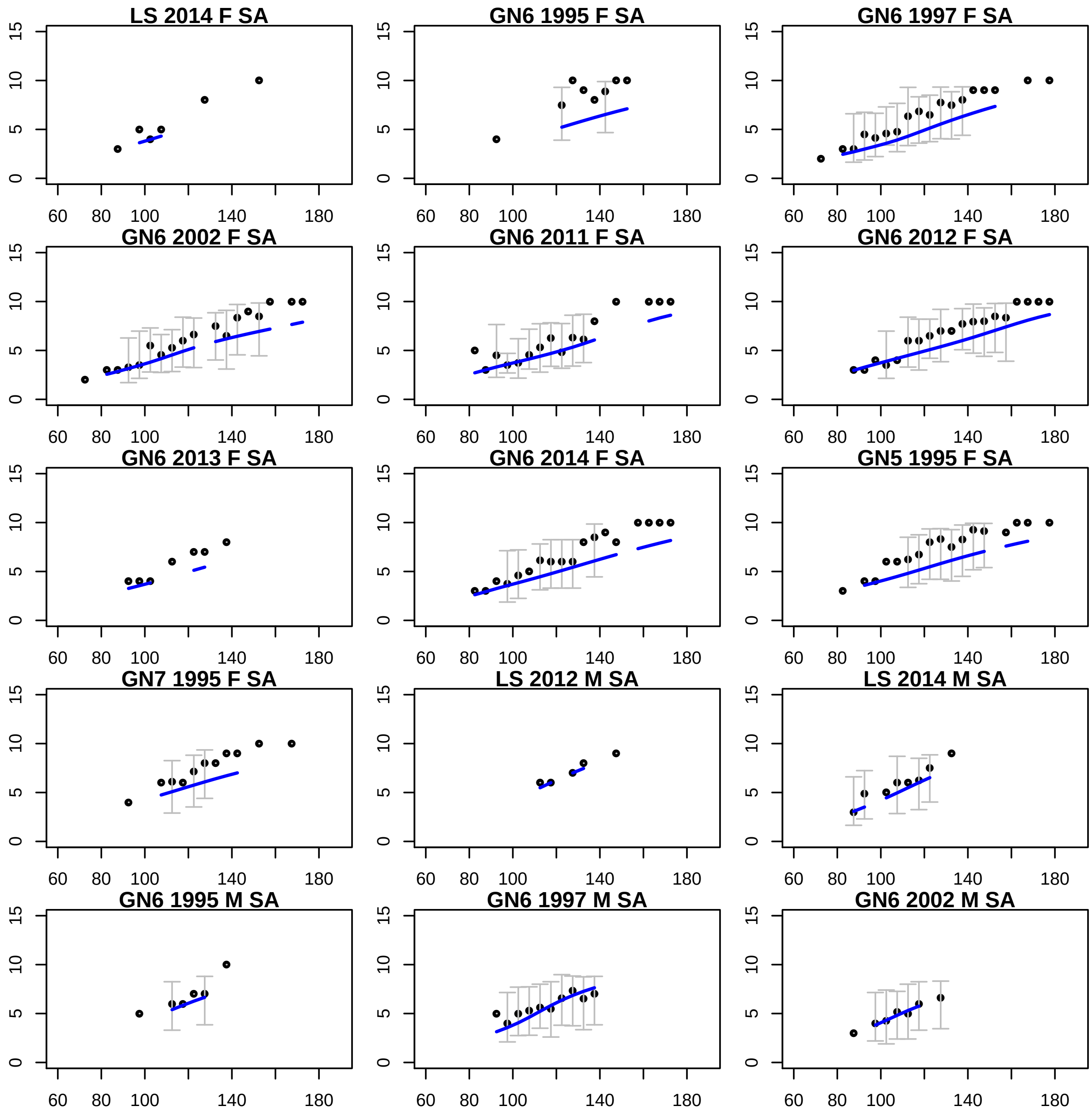



Figure 19: Standardised CPUE time series (Observed) and associated model estimated relative exploitable biomass (Predicted).


GN6 2003 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 2003 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
LS 2012 F SA
0 5 10 15
60 80 100 140 180


LS 2014 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
GN5 1995 F SA
GN7 1995 F SA
LS 2012 M SA
LS 2014 M SA
GN6 1995 M SA
GN6 1997 M SA
GN6 2002 M SA
0 5 10 15
60 80 100 140 180

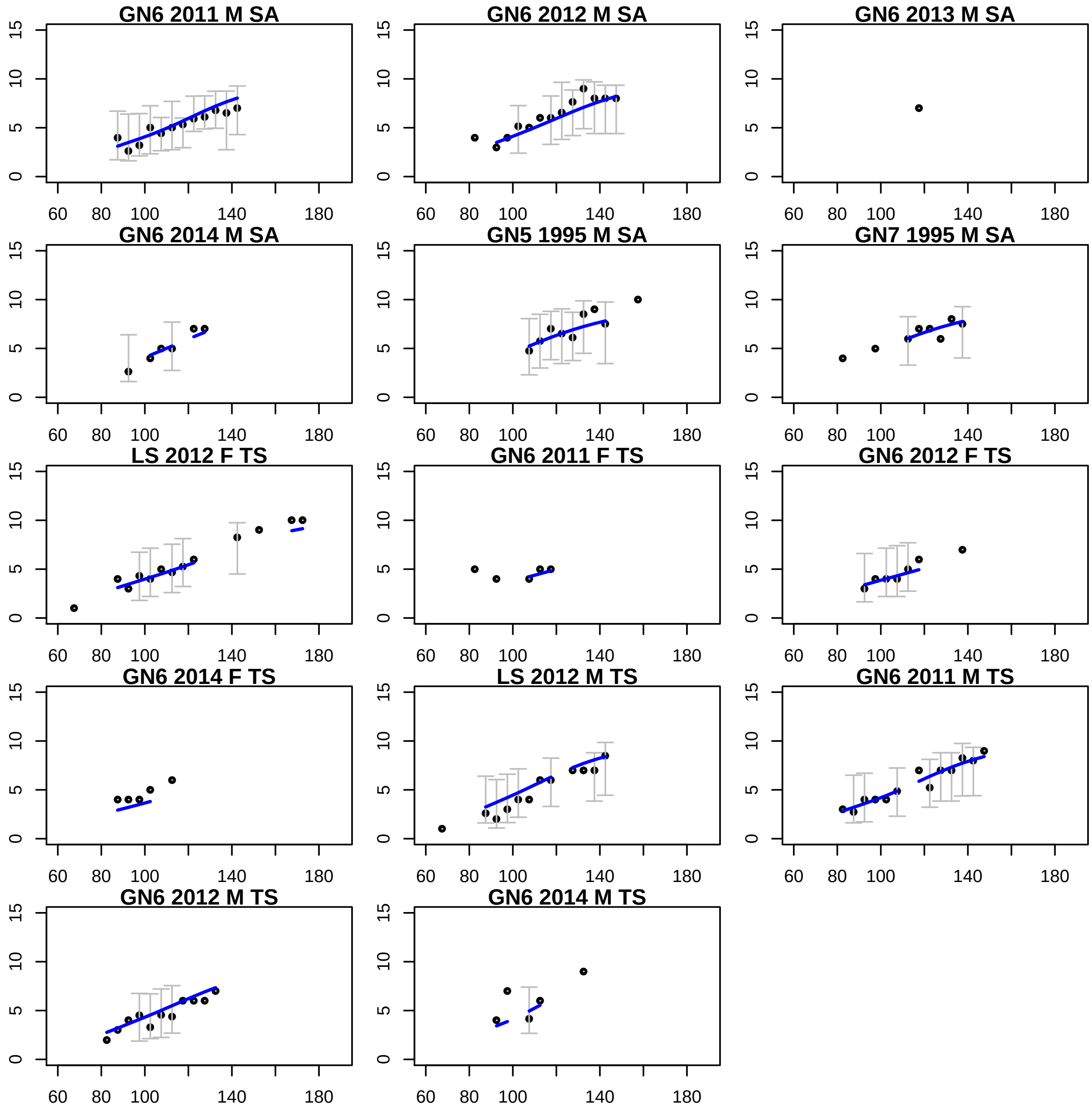



Figure 20: Observed conditional age-at-length (dots and 90% error bars) and expected age-at-length (blue line).

The selectivities for the seven gear types for the ‘CAL2019’ model are shown in Figure 21. 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. Estimated selectivities are also shown for the sensitivity ‘GNsel’ which estimates both gillnet selectivity and availability, as well as for ‘GNselAva’ which estimates selectivity but assumes equal availability for all age classes. The model that estimates selectivity but has constant availability is very similar to the ‘CAL2019’ model.

Summed observed and predicted length frequencies are shown in Figure 22. 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).

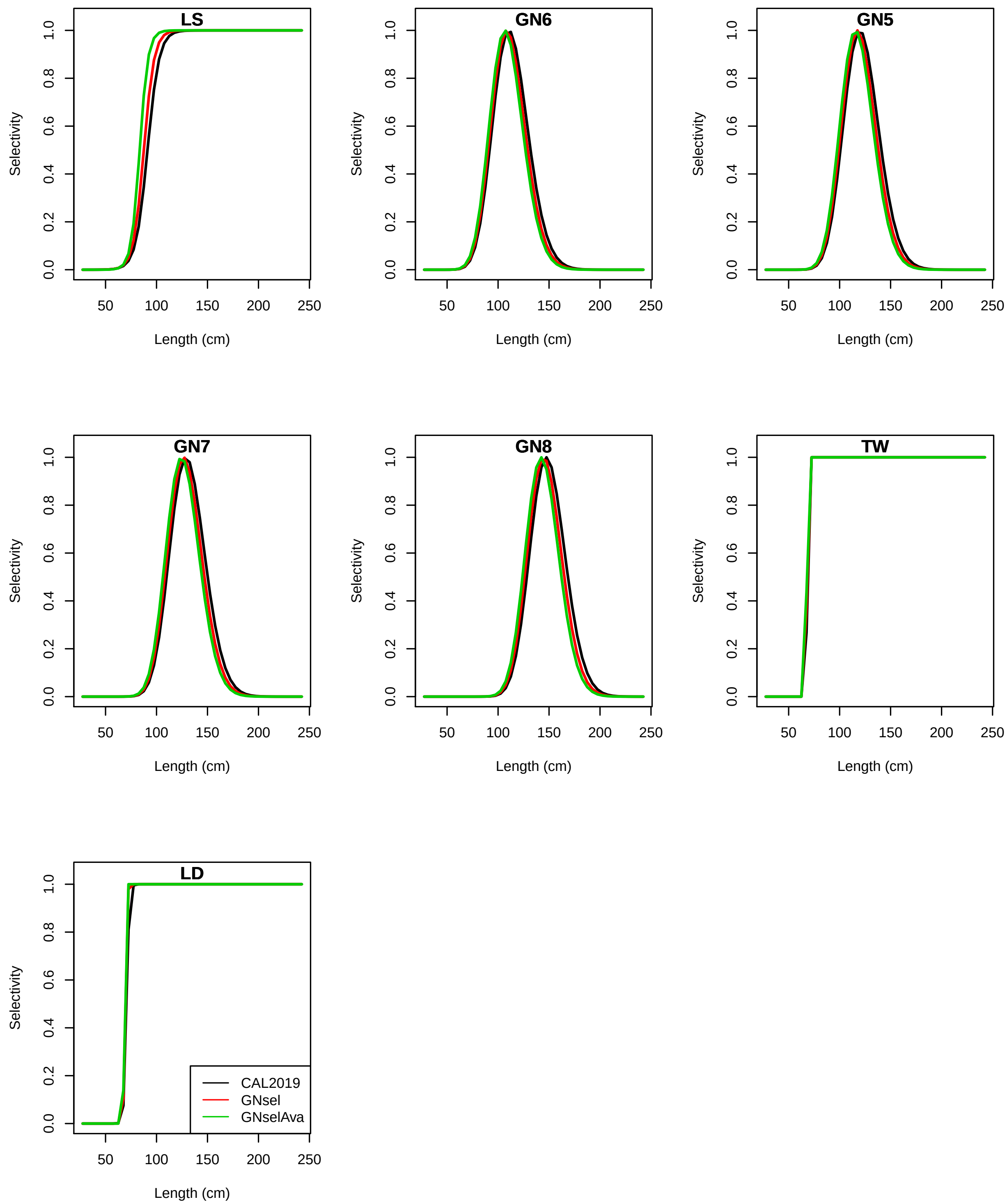
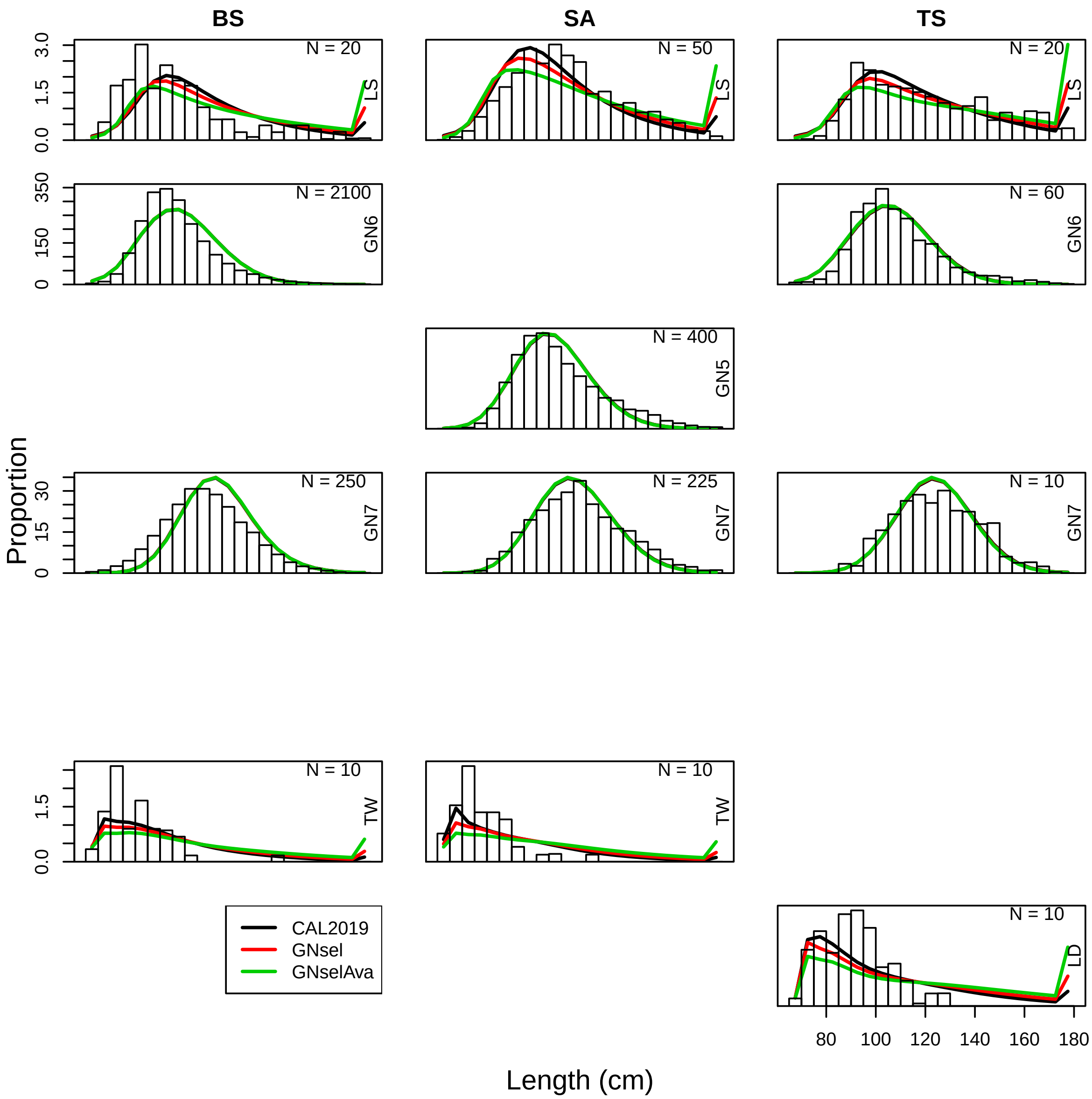
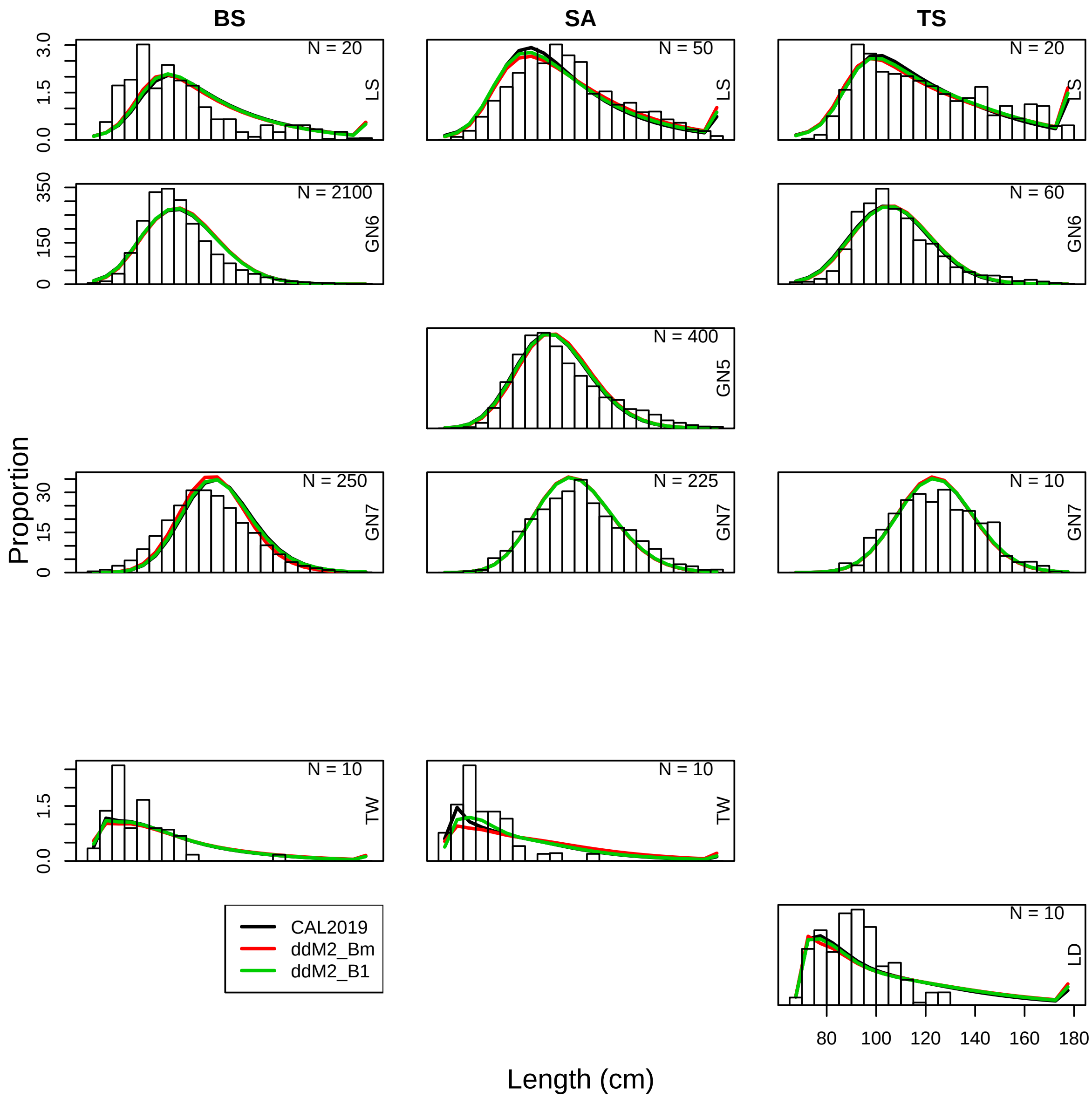



Figure 21: Selectivity functions for the seven gear types for the final model.


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
CAL2019
GNsel
GNselAva
Proportion
Length (cm)
0.0
1.5
3.0
0
150
350
15
30
80
100
120
140
160
180


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
CAL2019
ddM2_Bm
ddM2_B1
Proportion
Length (cm)
80
100
120
140
160
180

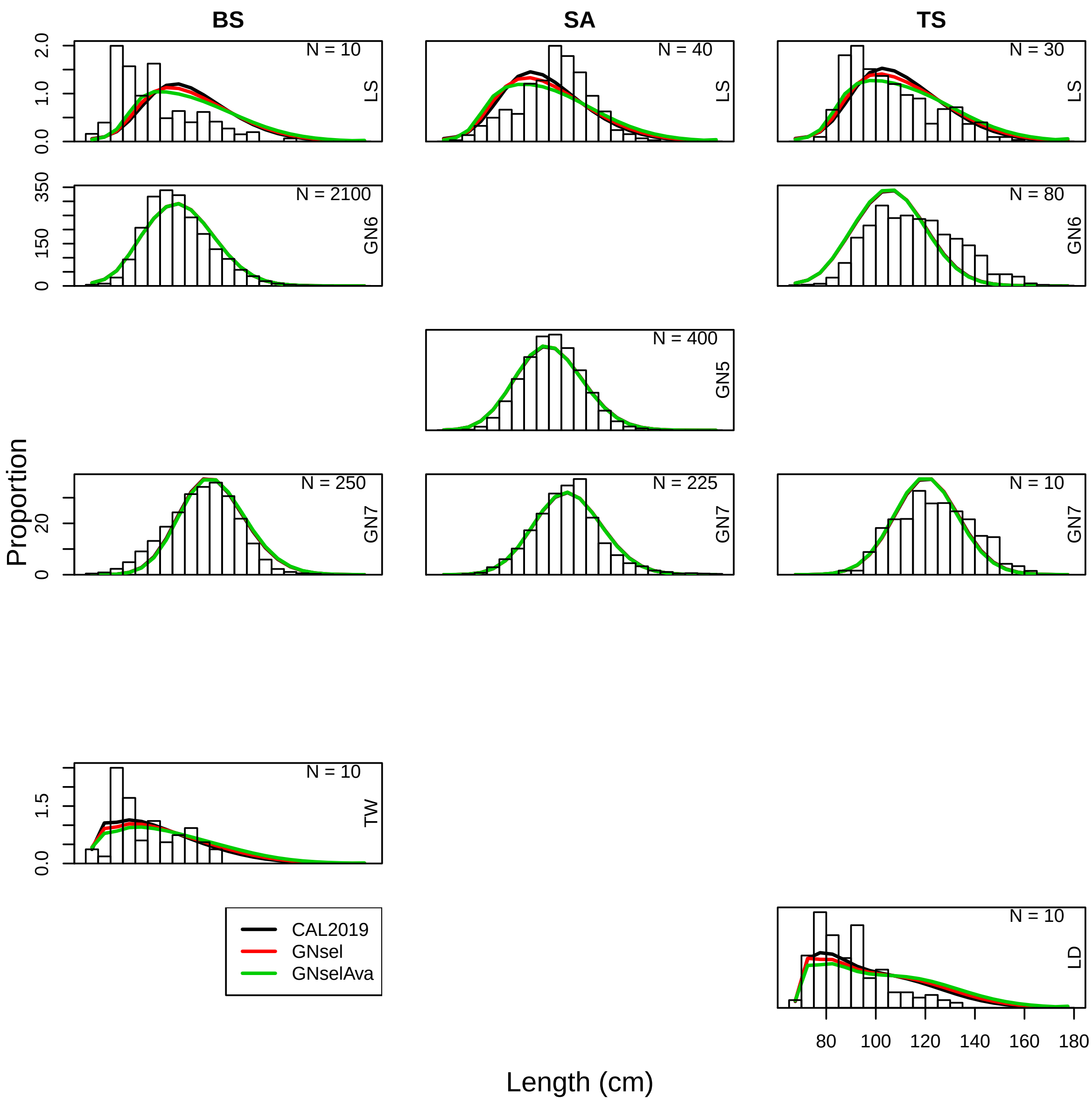



Figure 22: Observed (bars) and predicted (lines) length frequencies for the final model. Observations and predictions have been summed over all years. The number of years for which data is available is shown (N). Results are shown for females and then males.

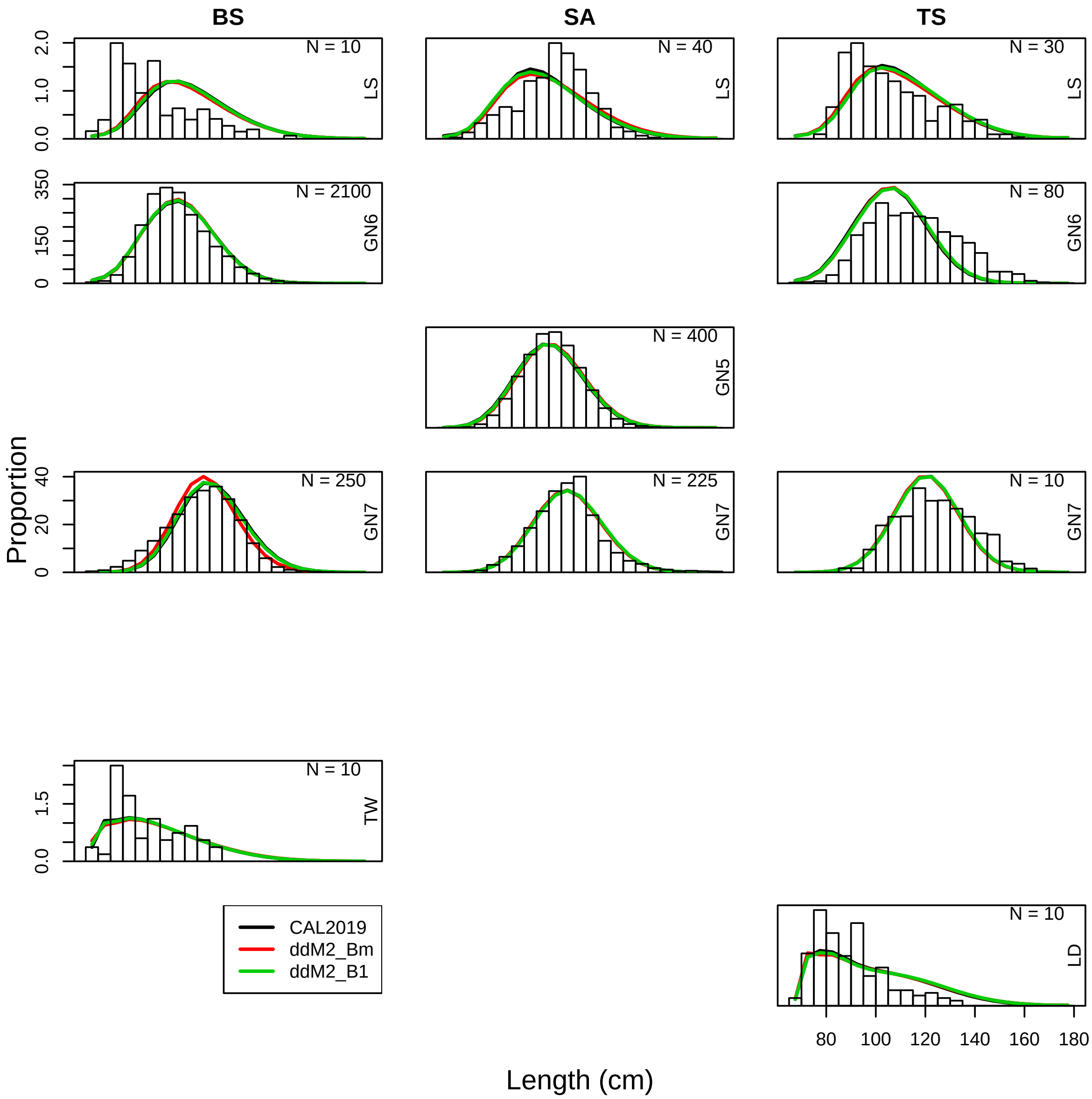
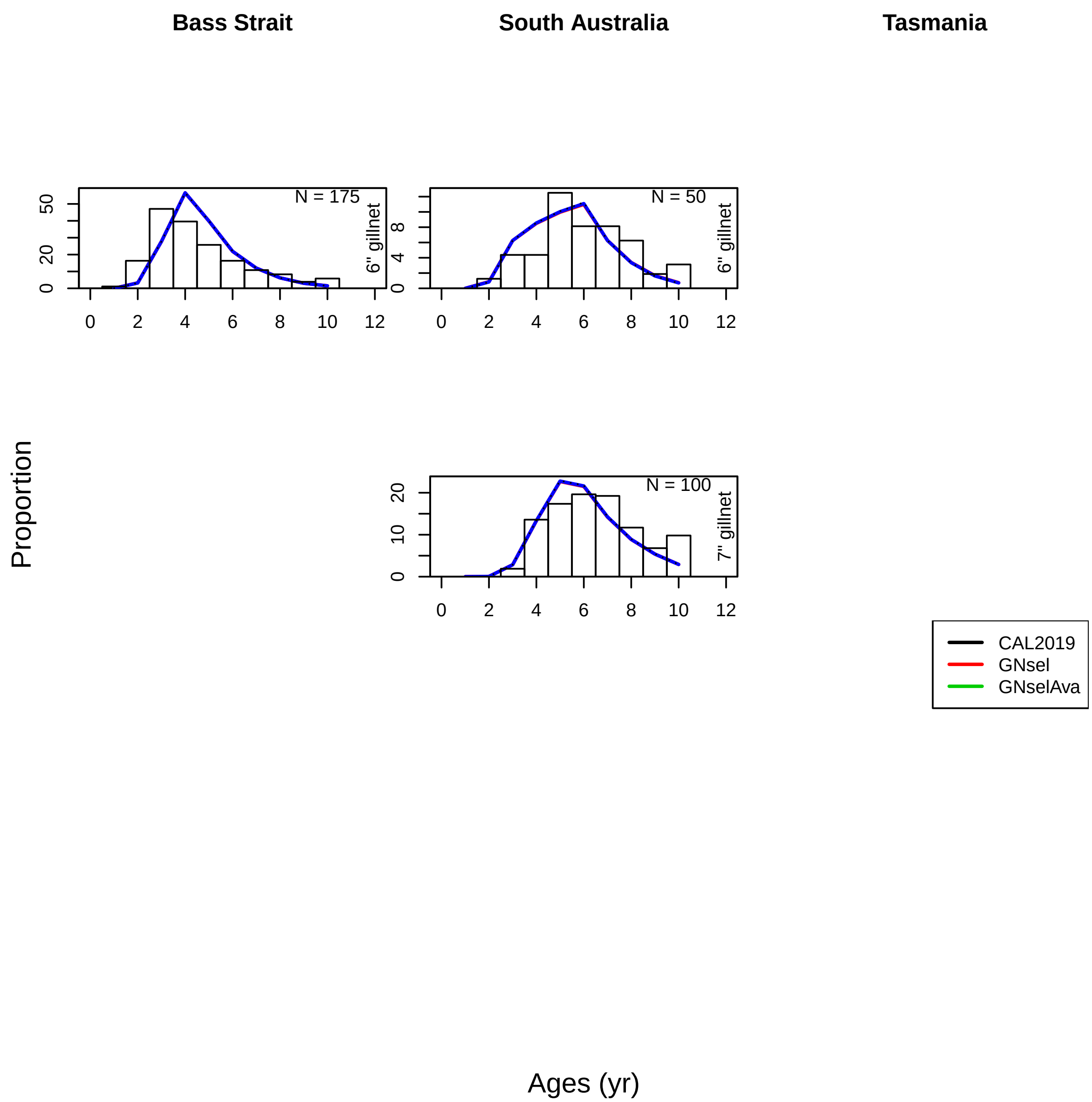



Figure 23: Observed (bars) and predicted (lines) length frequencies for the final model. Observations and predictions have been summed over all years. The number of years for which data is available is shown (N). Results are shown for females and then males.



Bass Strait
South Australia
Tasmania
N = 175
6" gillnet
N = 50
6" gillnet
N = 100
7" gillnet
Proportion
Ages (yr)
CAL2019
GNsel
GNselAva

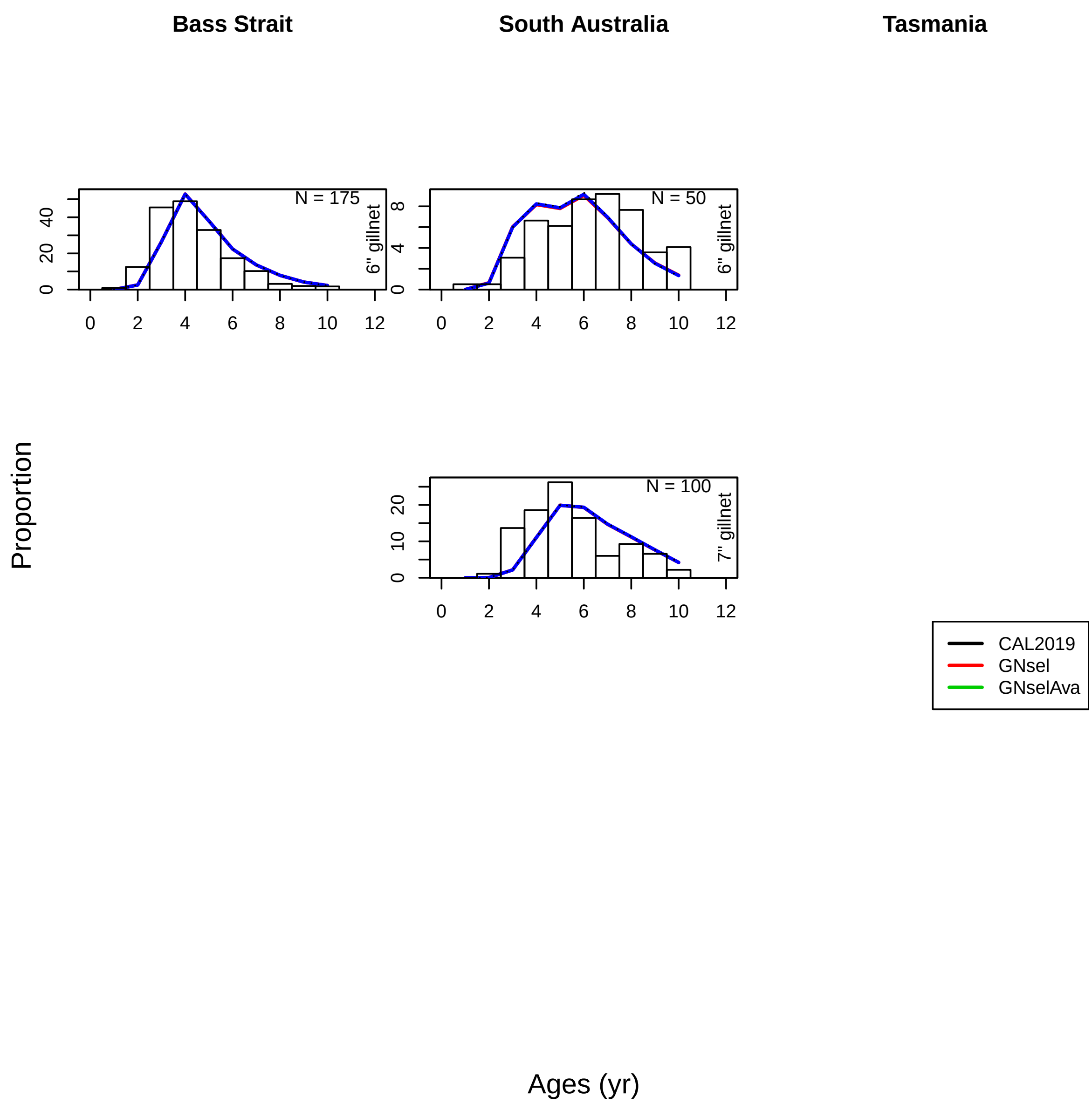
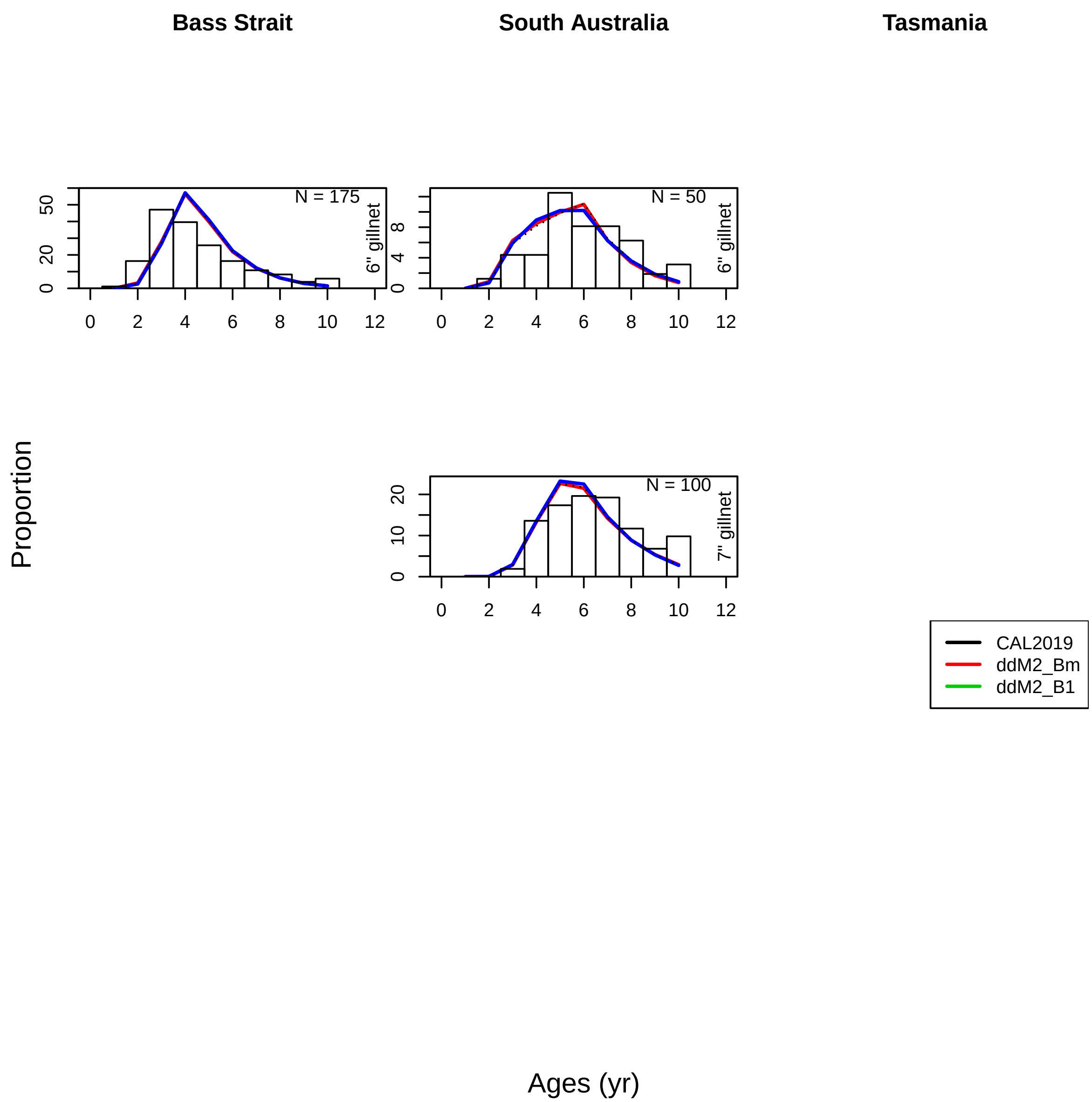



Figure 24: Observed (bars) and predicted (lines) age frequencies for the final model. Observations and predictions have been summed over all years. The number of years for which data is available is shown (N). Results are shown for females and then males.



Bass Strait
South Australia
Tasmania
N = 175
6" gillnet
N = 50
6" gillnet
N = 100
7" gillnet
Proportion
Ages (yr)
CAL2019
ddM2_Bm
ddM2_B1

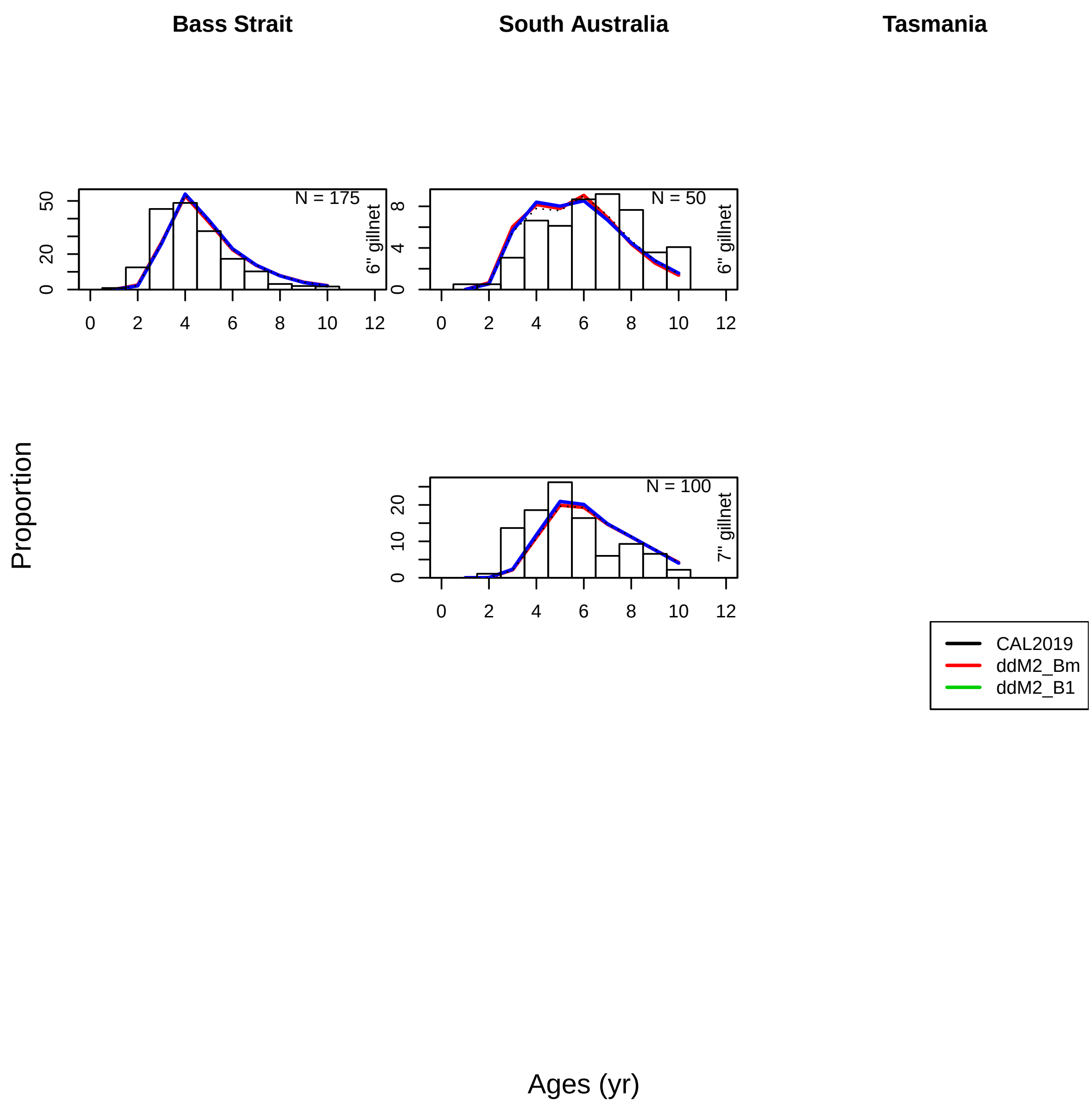



Figure 25: Observed (bars) and predicted (lines) age frequencies for the final model. Observations and predictions have been summed over all years. The number of years for which data is available is shown (N). Results are shown for females and then males.

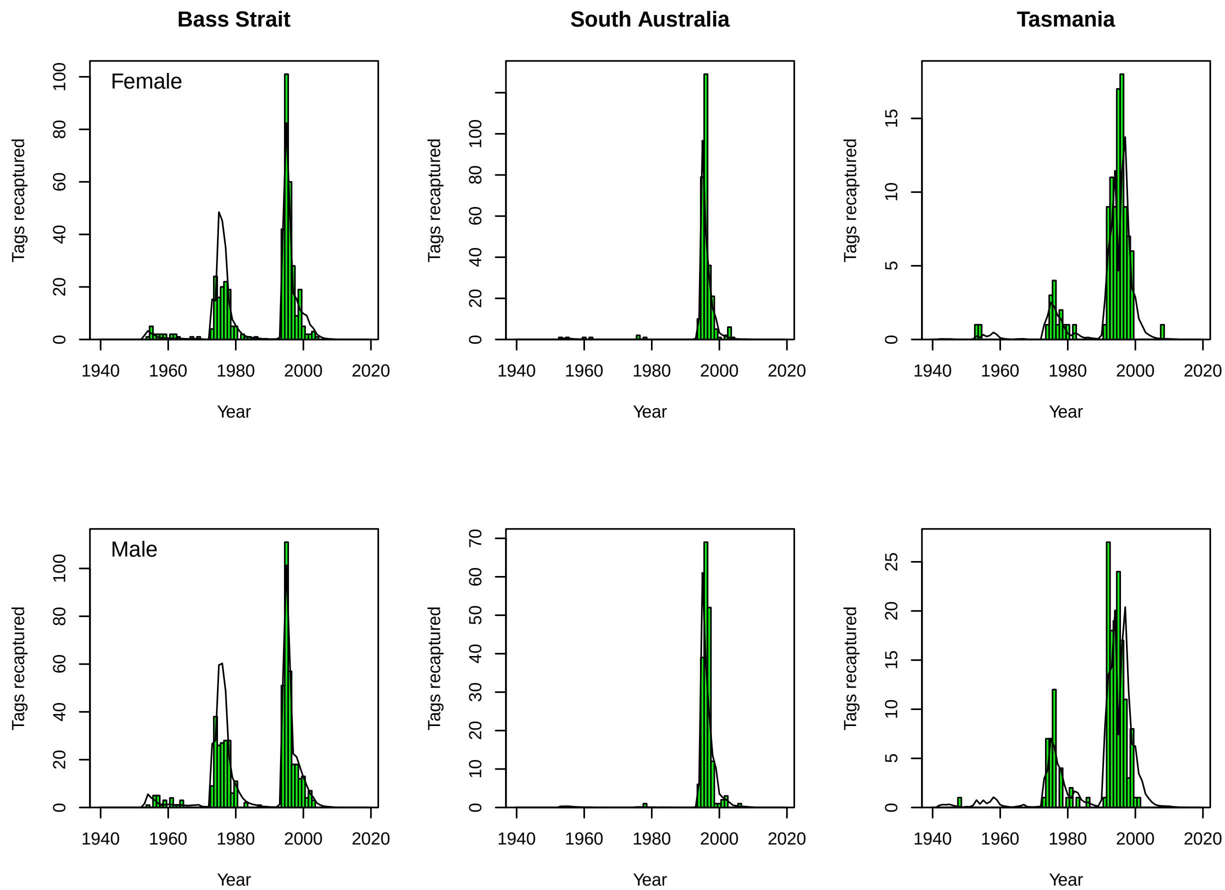



Figure 26: Observed (green bars) and expected (lines) numbers of tags returned by population and year.

Fits (summed over all years for ease of presentation) to the age composition data are shown in Figure 24 for the same models shown for in the length plots.

Fits to the tagging data are quite good (Figure 26) note that it has been assumed that no tag returns are expected after 2005 (i.e. zero tag return rate).

## 5.4 RBCs and future projections

The annual RBCs for each stock, and the total is shown in Table 10. The Bass Strait stock is estimated to be slightly under the 48% target so catches are somewhat lower at first, until the stock rebuilds to the target. Similarly, Tasmania is above the target so catches are high initially and reduce as the target is neared. The pattern for South Australia, which is initially above the target, is somewhat complicated by a period of relatively low recruitment around year 2000 so that catches are high initially, drop in response to lower adult biomass and therefore lower potential pup production, and then increase in response to assumed average recent and future recruitments. The algorithm that calculates annual RBCs is not sophisticated enough to anticipate the drop in pup production when it sets the initial high catch. Nevertheless, all stocks remain well above the 20% limit reference point throughout time series (Table 10).

Table 10: Annual Recommended Biological Catches and predicted depletions for the three gummy shark stocks and the total across stocks.

| | RBC | | | | Depletion | | |
|---|---|---|---|---|---|---|---|
| Year | BS | SA | TS | Total | BS | SA | TS |
| 2020 | 853 | 802 | 244 | 1899 | 48 | 66 | 70 |
| 2021 | 909 | 606 | 212 | 1727 | 48 | 67 | 68 |
| 2022 | 958 | 510 | 194 | 1662 | 48 | 68 | 66 |
| 2023 | 993 | 471 | 184 | 1648 | 48 | 68 | 64 |
| 2024 | 1006 | 479 | 183 | 1668 | 48 | 67 | 63 |
| 2025 | 1003 | 516 | 187 | 1707 | 48 | 66 | 61 |
| 2026 | 994 | 563 | 193 | 1749 | 48 | 64 | 59 |
| 2027 | 984 | 602 | 197 | 1783 | 48 | 61 | 58 |
| 2028 | 978 | 625 | 200 | 1803 | 48 | 59 | 57 |
| 2029 | 975 | 633 | 201 | 1808 | 48 | 57 | 55 |
| 2030 | 974 | 629 | 200 | 1804 | 48 | 56 | 54 |
| 2031 | 975 | 621 | 199 | 1795 | 48 | 55 | 54 |
| 2032 | 976 | 611 | 198 | 1785 | 48 | 54 | 53 |
| 2033 | 976 | 604 | 197 | 1777 | 48 | 53 | 52 |
| 2034 | 976 | 599 | 196 | 1771 | 48 | 52 | 52 |
| 2035 | 976 | 596 | 196 | 1768 | 48 | 52 | 51 |
| 2036 | 976 | 595 | 195 | 1766 | 48 | 51 | 51 |
| 2037 | 975 | 595 | 195 | 1766 | 48 | 51 | 50 |
| 2038 | 975 | 596 | 195 | 1766 | 48 | 50 | 50 |
| 2039 | 975 | 595 | 194 | 1765 | 48 | 50 | 50 |
| 2040 | 975 | 595 | 194 | 1764 | 48 | 50 | 50 |
| 2041 | 975 | 594 | 194 | 1763 | 48 | 49 | 49 |
| 2042 | 975 | 593 | 194 | 1762 | 48 | 49 | 49 |
| 2043 | 976 | 592 | 193 | 1761 | 48 | 49 | 49 |
| 2044 | 976 | 591 | 193 | 1760 | 48 | 49 | 49 |
| 2045 | 976 | 590 | 193 | 1759 | 48 | 49 | 49 |
| 2046 | 976 | 590 | 193 | 1759 | 48 | 49 | 49 |
| 2047 | 976 | 590 | 193 | 1758 | 48 | 48 | 49 |
| 2048 | 976 | 589 | 193 | 1758 | 48 | 48 | 48 |
| 2049 | 976 | 589 | 193 | 1758 | 48 | 48 | 48 |

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

Table 11: The average RBC over 3 or 5 years and the long term RBC by stock and the total over stocks are shown.

| Case | BS | SA | TS | NA |
|---|---|---|---|---|
| 3y average | 907 | 639 | 217 | 1763 |
| 5y average | 944 | 574 | 203 | 1721 |
| Long term | 976 | 588 | 192 | 1757 |

Future projections were conducted using the annual RBCs, as well as projections that use fixed catches matching the 3 and 5 year averages and long term RBC (from Table 11). Pup depletions from the future projections are shown in Table 12 and Figure 27.

Table 12: Predicted pup depletions for the three gummy shark stocks under a range of future catches, all using the 2019 proportional catch splits between gears.

| Year | BS | SA | TS | BS | SA | TS | BS | SA | TS | BS | SA | TS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 47.9 | 66.0 | 69.5 | 47.9 | 66.0 | 69.5 | 47.9 | 66.0 | 69.5 | 47.9 | 66.0 | 69.5 |
| 2021 | 47.9 | 66.8 | 67.5 | 47.7 | 68.1 | 68.2 | 47.5 | 68.6 | 68.5 | 47.4 | 68.5 | 68.8 |
| 2022 | 47.8 | 67.9 | 65.9 | 47.5 | 69.1 | 66.5 | 47.2 | 70.4 | 67.2 | 46.9 | 70.1 | 67.8 |
| 2023 | 47.6 | 68.3 | 64.3 | 47.5 | 68.2 | 64.4 | 47.0 | 70.3 | 65.5 | 46.5 | 69.8 | 66.5 |
| 2024 | 47.5 | 67.6 | 62.6 | 47.7 | 65.5 | 61.8 | 47.0 | 68.6 | 63.4 | 46.3 | 67.9 | 64.8 |
| 2025 | 47.5 | 66.0 | 61.0 | 48.1 | 62.0 | 59.1 | 47.1 | 66.0 | 61.2 | 46.2 | 65.1 | 62.9 |
| 2026 | 47.5 | 63.9 | 59.4 | 48.7 | 58.4 | 56.5 | 47.4 | 63.0 | 59.0 | 46.3 | 62.0 | 61.1 |
| 2027 | 47.5 | 61.5 | 57.9 | 49.3 | 55.2 | 54.0 | 47.8 | 60.2 | 56.9 | 46.4 | 59.1 | 59.4 |
| 2028 | 47.6 | 59.2 | 56.6 | 50.1 | 52.4 | 51.9 | 48.2 | 57.8 | 55.2 | 46.6 | 56.6 | 57.8 |
| 2029 | 47.6 | 57.2 | 55.5 | 50.7 | 50.2 | 50.2 | 48.7 | 55.9 | 53.7 | 46.9 | 54.6 | 56.6 |
| 2030 | 47.6 | 55.6 | 54.5 | 51.3 | 48.6 | 48.8 | 49.1 | 54.5 | 52.5 | 47.1 | 53.2 | 55.6 |
| 2031 | 47.6 | 54.5 | 53.7 | 51.8 | 47.7 | 47.6 | 49.4 | 53.7 | 51.6 | 47.2 | 52.4 | 54.8 |
| 2032 | 47.7 | 53.6 | 53.0 | 52.2 | 47.3 | 46.7 | 49.6 | 53.4 | 50.8 | 47.4 | 52.1 | 54.3 |
| 2033 | 47.7 | 52.9 | 52.4 | 52.5 | 47.2 | 45.9 | 49.8 | 53.6 | 50.3 | 47.4 | 52.2 | 53.8 |
| 2034 | 47.7 | 52.4 | 51.8 | 52.7 | 47.3 | 45.2 | 49.9 | 53.8 | 49.8 | 47.4 | 52.4 | 53.5 |
| 2035 | 47.7 | 51.8 | 51.3 | 52.9 | 47.3 | 44.5 | 50.0 | 54.1 | 49.3 | 47.4 | 52.6 | 53.1 |
| 2036 | 47.7 | 51.4 | 50.9 | 53.1 | 47.1 | 43.9 | 50.1 | 54.1 | 48.8 | 47.4 | 52.6 | 52.8 |
| 2037 | 47.7 | 50.9 | 50.5 | 53.2 | 46.6 | 43.2 | 50.2 | 54.0 | 48.3 | 47.4 | 52.4 | 52.5 |
| 2038 | 47.7 | 50.5 | 50.2 | 53.4 | 46.0 | 42.5 | 50.3 | 53.7 | 47.9 | 47.4 | 52.1 | 52.1 |
| 2039 | 47.8 | 50.1 | 49.9 | 53.6 | 45.3 | 41.8 | 50.4 | 53.2 | 47.4 | 47.4 | 51.6 | 51.8 |
| 2040 | 47.8 | 49.7 | 49.6 | 53.7 | 44.6 | 41.1 | 50.5 | 52.7 | 46.9 | 47.4 | 51.0 | 51.5 |
| 2041 | 47.8 | 49.4 | 49.4 | 53.9 | 43.9 | 40.4 | 50.6 | 52.2 | 46.5 | 47.4 | 50.5 | 51.2 |
| 2042 | 47.8 | 49.2 | 49.2 | 54.1 | 43.4 | 39.8 | 50.7 | 51.8 | 46.1 | 47.5 | 50.0 | 50.9 |
| 2043 | 47.8 | 48.9 | 49.1 | 54.2 | 42.9 | 39.2 | 50.8 | 51.4 | 45.7 | 47.5 | 49.6 | 50.6 |
| 2044 | 47.8 | 48.8 | 48.9 | 54.4 | 42.5 | 38.6 | 50.9 | 51.2 | 45.4 | 47.6 | 49.4 | 50.4 |
| 2045 | 47.9 | 48.6 | 48.8 | 54.5 | 42.3 | 38.1 | 51.0 | 51.0 | 45.0 | 47.6 | 49.2 | 50.2 |
| 2046 | 47.9 | 48.5 | 48.7 | 54.6 | 42.1 | 37.6 | 51.0 | 50.9 | 44.7 | 47.6 | 49.1 | 50.0 |
| 2047 | 47.9 | 48.4 | 48.6 | 54.7 | 41.9 | 37.1 | 51.1 | 50.9 | 44.5 | 47.7 | 49.0 | 49.8 |
| 2048 | 47.9 | 48.3 | 48.5 | 54.8 | 41.8 | 36.7 | 51.2 | 50.9 | 44.2 | 47.7 | 49.0 | 49.7 |
| 2049 | 47.9 | 48.3 | 48.5 | 54.9 | 41.6 | 36.2 | 51.2 | 50.9 | 44.0 | 47.7 | 49.0 | 49.6 |
| 2050 | 47.9 | 48.2 | 48.4 | 54.9 | 41.5 | 35.8 | 51.3 | 50.9 | 43.8 | 47.7 | 49.0 | 49.5 |
| 2051 | 47.9 | 48.2 | 48.4 | 55.0 | 41.3 | 35.3 | 51.3 | 50.8 | 43.6 | 47.7 | 48.9 | 49.4 |
| 2052 | 47.9 | 48.1 | 48.3 | 55.1 | 41.1 | 34.9 | 51.4 | 50.8 | 43.4 | 47.7 | 48.8 | 49.3 |
| 2053 | 47.9 | 48.1 | 48.3 | 55.1 | 40.9 | 34.5 | 51.4 | 50.7 | 43.2 | 47.7 | 48.7 | 49.2 |
| 2054 | 47.9 | 48.1 | 48.3 | 55.1 | 40.7 | 34.0 | 51.4 | 50.6 | 43.1 | 47.8 | 48.6 | 49.1 |
| 2055 | 47.9 | 48.0 | 48.2 | 55.2 | 40.5 | 33.6 | 51.5 | 50.5 | 42.9 | 47.8 | 48.5 | 49.0 |
| 2056 | 47.9 | 48.0 | 48.2 | 55.2 | 40.3 | 33.2 | 51.5 | 50.4 | 42.7 | 47.8 | 48.4 | 48.9 |
| 2057 | 47.9 | 48.0 | 48.2 | 55.3 | 40.2 | 32.8 | 51.5 | 50.3 | 42.6 | 47.8 | 48.3 | 48.9 |
| 2058 | 47.9 | 48.0 | 48.2 | 55.3 | 40.1 | 32.4 | 51.5 | 50.3 | 42.4 | 47.8 | 48.3 | 48.8 |
| 2059 | 47.9 | 47.9 | 48.1 | 55.3 | 39.9 | 32.0 | 51.6 | 50.3 | 42.3 | 47.8 | 48.2 | 48.7 |
| 2060 | 47.9 | 47.9 | 48.1 | 55.3 | 39.8 | 31.5 | 51.6 | 50.2 | 42.2 | 47.8 | 48.2 | 48.7 |

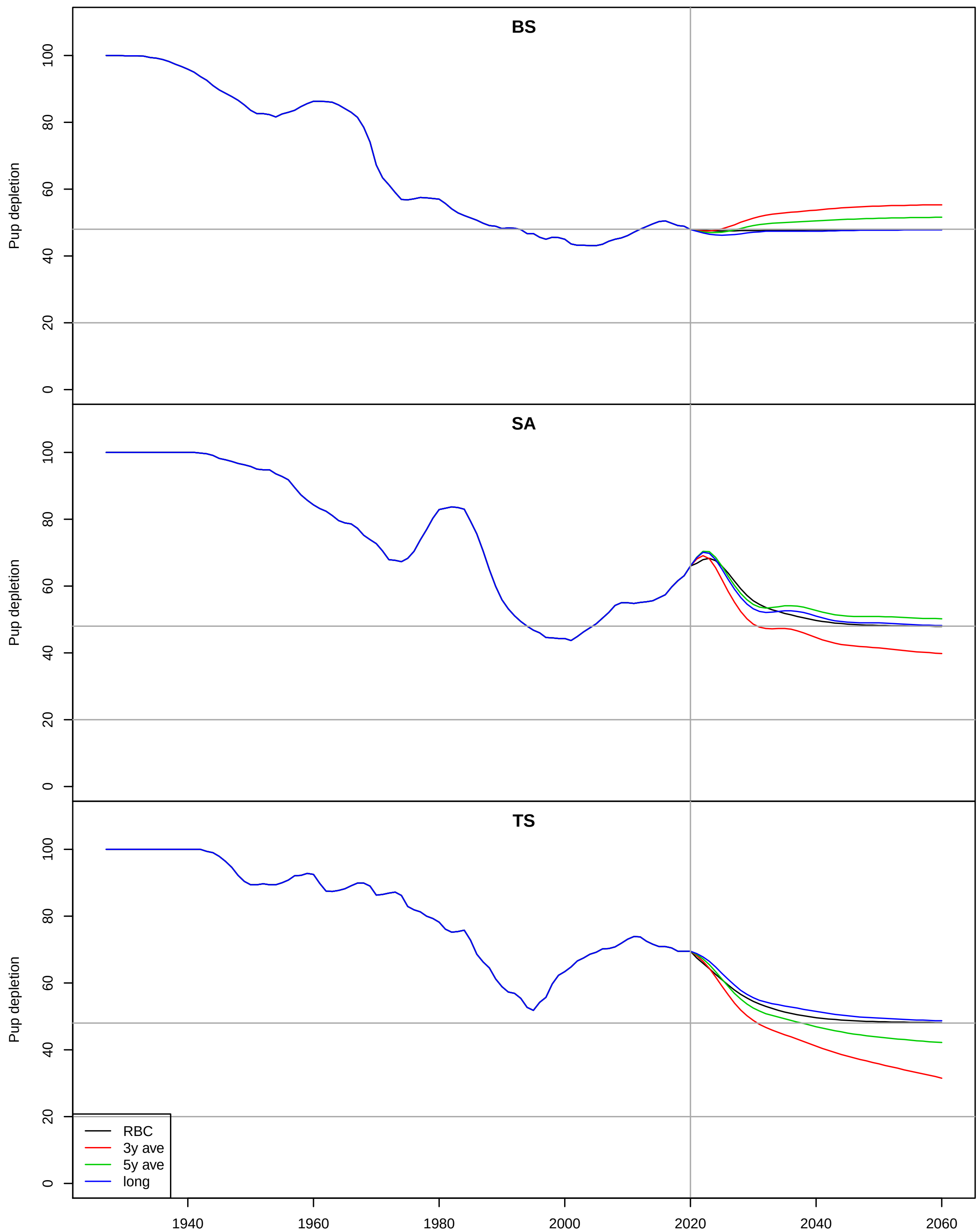



Figure 27: Pup depletion for the three gummy stocks showing future projections using annual RBC (RBC), the average over the most recent three RBCs (3y ave) and the most recent five (5y ave) as well as the long-term RBC (long). A vertical grey line marks the year 2020, and horizontal grey lines mark the 20% and 48% reference points.

# 6 Discussion

Extensive work was done this year to ensure smoother, automated (where possible) operation of data processing for the Gummy Shark assessment. This will vastly reduce the amount of time that will need to be spent working out how data were processed in the past, and guarantee consistency, as well as reduce the potential for error in future assessments. In addition, the running of the model with new data and subsequent plotting of results is part of the same system that processes the data. Again, this introduces automation that reduces repetition of work done previously, thus speeding up the work, and reducing the potential for error. In future, there should be less time spent re-inventing the wheel and more time available for thoughtful data exploration and model investigation. This was achieved by using a set of Rmarkdown documents to implement data processing, model runs, and the plotting and tabulation of results within the report document itself.

The Gummy Shark assessment incorporates an unusual formula which allows the CPUE time series to index abundance non-linearly, and in a way that varies by stock through the estimation of a 'effort saturation' parameter. It is concerning that the 2016 assessment included a 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 2016 to 2019 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 abundance. It is recommended that a linear relationship is assumed for Tasmanian gillnet CPUE so that the effort saturation parameter is no longer estimated. This will not alter model results (because the estimate is always zero anyway) but should improve model stability and therefore estimation performance.

It seems unlikely that Gummy Shark biology and/or fishing operations should differ so greatly between areas as to produce such divergent effort saturation parameter values as those estimated for Tasmania and South Australia in 2016. Although the model is now producing more reasonable estimates for South Australia, it is concerning that the estimate has changed so much after simply adding updated data, and this undesirable result might be seen again in future model updates. The 2016 Gummy assessment (the most recent update, Punt & Thomson 2016) was the first to fit to trawl and line CPUE as well as to gillnet CPUE, and it too showed both Tasmanian and South Australian effort saturation parameters hitting opposite bounds. The assessment update prior to that, in 2013, the effort saturation was zero for Tasmania but within the bounds for the other stocks. This was also true of the 2010 update (Punt & Thomson 2010).

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 abundance 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.

For South Australia, closure of historical fishing grounds to avoid bycatch of Australian Sea Lions, is thought (by SharkRAG) to have altered the ability of the CPUE to consistently index abundance, so the CPUE time series has been truncated at 2010 - this has been effected in the 2013, 2016 and now the 2020 assessment updates. SharkRAG are asked to consider whether it might be useful to standardize CPUE for that area, after 2010 (either from 2010, or from a year or two later, once fishing had settled into a new pattern) to re-establish an index of abundance for that stock. Alternatively, are the trawl or potentially the line catch and effort data likely to provide a reliable index of abundance? Use of the GAB and SET FIS to provide an index were debated at the 2016 sharkRAG meetings but were dismissed, for reasons outlined by Punt & Thomson (2016).

A change in management arrangements in 2005 seems to have influenced the trawl CPUE for that stock, effectively 'breaking' the series at that time. Fitting separately to data before and after that time seems appropriate.

Estimating gillnet gear selectivity, instead of using experimentally derived values, provides insufficient improvement to model fits to support the estimation of additional parameters. Estimation of separate selectivity parameters for each region (stock) has been suggested (Punt & Thomson 2016), however, that would require length frequency data for each fleet in each region, or 'mirroring' of selectivity patterns between some regions when insufficient data is available for separate estimation. Punt & Thomson (2016) also recommend using a double logistic selectivity pattern for gillnet gears, that would require an assumption regarding 8-inch gillnets, for which no length frequency data is available. The selectivity formula currently used provides patterns for all gillnet mesh sizes, using just two parameters and the mesh size itself. A double logistic would involve 2 parameters per fleet, and per region, greatly increasing the number of parameters in the model with subsequent computational cost and perhaps resulting in model instability.

The updated model provides results that are consistent with those of the 2016 assessment update - pup depletion (the proxy for spawning abundance that is used by sharkRAG) in 1973 ('Pem73'), and productivity (as measured by MSYR) are reasonably similar, in 2020, to those estimated in 2016. 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 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 Tasmania and is steady in Bass Strait and South Australia. Pup depletion is well above the target reference point of 48% for all stocks.

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 the most (or almost the most) pessimistic depletion for Bass Strait and Tasmania (32 and 35% for BS, 72 and 65% for TS; Table 9). Depletion for South Australia is 67% or 107% depending on whether density dependence is a function of 1+ biomass or mature biomass, a very variable result that warrants further model exploration.

The estimated long term RBC is 1757t with RBC catches over the next 5 years equal to 1899, 1727, 1662, 1648, 1668 tonnes respectively.

## 6.1 Future work

The 2016 assessment report suggests the following future work:

1. A more flexible for of selectivity such as the double-logistic as well as region specific selectivity curves.
2. The use of conditional length-at-age. (this has now been achieved)
3. Weighting of the data sources using methods such as Francis weighting.
4. Changing the base case model to one of the sensitivities regarding how density dependence is implemented.

The second point above has been implemented in this update, although not for the older age composition data for which the original age data are not available to the author. The first is not considered a high priority, given the relatively good fits to the length frequency data for gillnet gears (see discussion for more details). The lack of conflict between the data (as evidenced by the sensitivity tests that varied the weight on the data sources) suggests that implementing modern data weighting methods (the third point above) will greatly influence the model results. Changing the density dependence assumptions would profoundly alter the results (fourth point above), which leads to the first of several new recommendations for future work:

5. Investigate the reasons for the wide range of results stemming from differing density dependence assumptions and for the greater support for those that operate on younger ages, as well as the clustering of results depending on whether density dependence is a function of mature biomass or 1+ biomass.
6. Consider raising the age of the plus group for fitting to age data from 10 to (perhaps) 15 to account for older sharks caught by line.
7. Estimate growth within the model (especially in conjunction with point 6) including consideration of population-specific growth parameters, also possible change with time.
8. 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.

9. Try to achieve a better fit to the plus group for length for trawl and line gears.
10. Add a Danish seine fleet to the model, using onboard but not port-collected length frequency data.
11. 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).
12. Encourage collection of length data from the line vessels that fish deeper than 183m, and from autoline vessels at any depth.
13. Perform retrospective analysis to examine the effect of new data on the estimate of the effort saturation parameters for each stock.
14. Calculate likelihood profiles to assess the support from each data type for the estimated parameters as well as the precision with which those parameters are estimated.
15. The two logistic selectivity parameters for the trawl and line gears are highly correlated (almost 100% for trawl) suggesting that a knife-edged form would be better (although adding more data by using port data might help support the estimation of two parameters).
16. Age data for 1995/7 and 2002/3 are present in both the age composition and age-at-length datasets. Although the sample sizes and sometimes gillnet mesh sizes associated with these data differ, it seems likely that there is at least some overlap between these data. Further investigation is needed to ensure that samples are not used twice.
17. Launch an investigation (through simulation-estimation as outlined in Appendix E of Punt & Thomson, 2016) into possible future sampling schemes that involve similar or bigger same sizes taken less frequently than annually. (If this is still of interest to sharkRAG.)

# 7 Acknowledgements

Andre Punt is thanked for providing code and data files used in the 2016 Gummy assessment as well as useful discussions about some of the results. Simon Robertson (Fish Ageing Service) is thanked for hard work in providing Gummy Shark ages for four years of collected vertebrae, under trying circumstances including a broken saw. The CSIRO Data Services Team (Paul, Burch, Mike Fuller, Franzis Althaus, and Roy Deng) along with John Garvey (AFMA) and his team are thanked for data provision, data preparation and checking as well as many useful conversations. Paul Burch is 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.

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# 9 Appendix A: Length frequencies available for the assessment

This Appendix displays length frequencies (LFs) that were used in the 2016 Gummy assessment (black lines and filled circles) along with those calculated from AFMA Observer data in 2020. LFs that are based on data collected before 2003, and some from the 2003 to 2006 period, are based on length data collected by Victorian scientists, which is not stored in the AFMA database and therefore not available to the author. For that reason, many of the plots relating to earlier data show a black line only, and no red line. Also, only LFs based on more than 10 samples are shown from the 2020 calculation, so that a small number of the plots relating to the post-2003 period have a (typically 'spikey') black but no red line. In most cases the black and red lines are very similar, because they are calculated from the same underlying AFMA Observer data collection. There are some slight difference however, which relate to 'tidying up' of the database, both by AFMA (in recent years) and by CSIRO in the way that recorded catch and sample weights are used to scale sample numbers up to reflect the weights of the shots from which they were sampled, before they are summed within year by gear by zone strata.

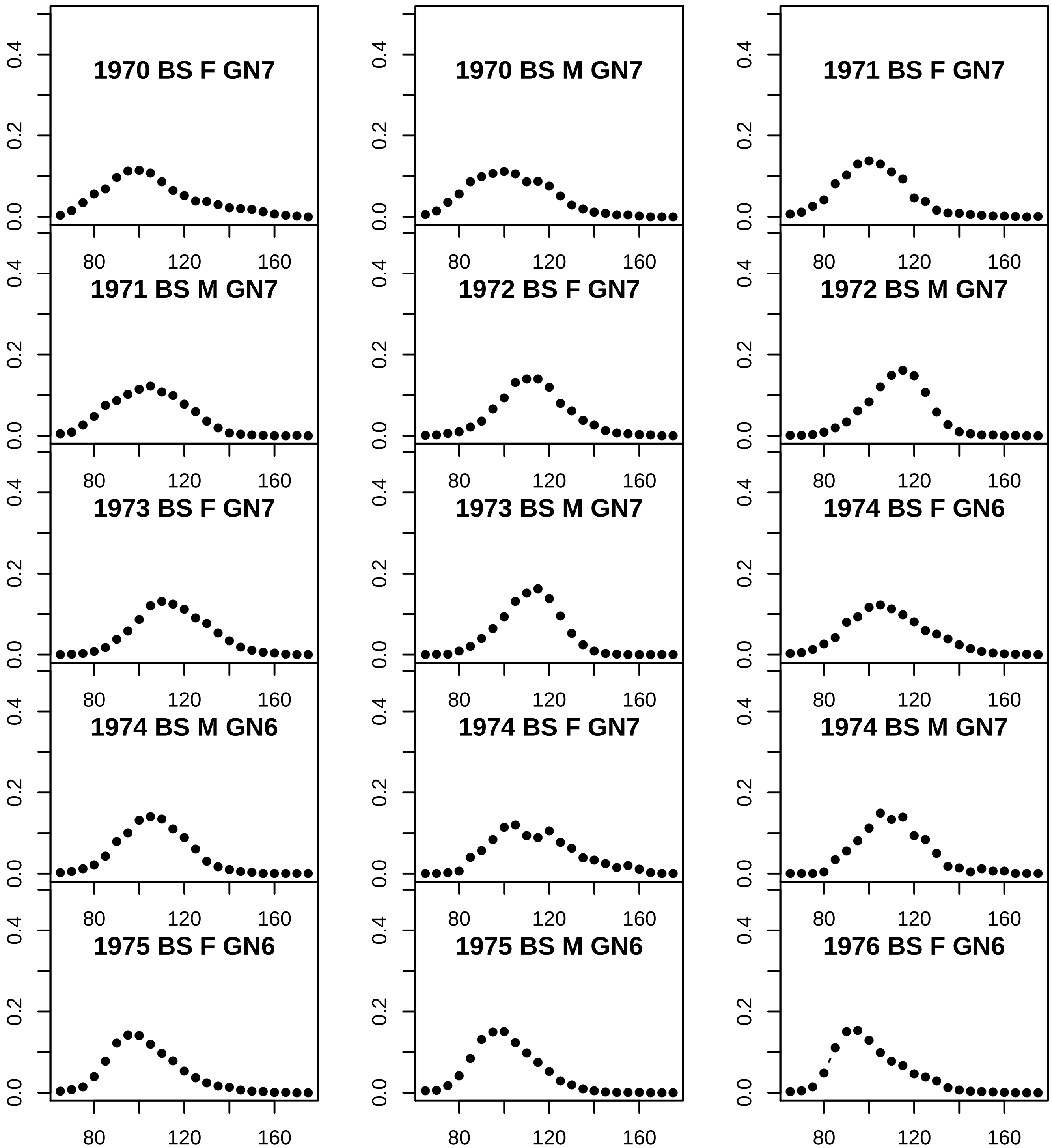
LFs based on as few as 7 samples were used in the 2016 assessment (appropriately down-weighted) but only those based on more than 100 samples were used on most of the assessment model scenarios shown here.

A *black heading*, in the plots below, indicates data prior to 2003; these length frequencies were provided to Andre Punt by Terry Walker and Anne Gason (MAFFRI) for earlier Gummy Shark assessments, in processed form. The data from which they were constructed is not available to the author.

*Orange headings* are used for 2003 to 2006 when some (but not all) data from which these LFs were constructed is available from the AFMA database.

*Green headings* are used for 2007 onwards, for LFs that were processed from Observer data stored in the AFMA database, both for the 2016 assessment, and reprocessed in 2020.

Figure A.1: Length frequencies used on the 2016 Gummy assessment (black) and those re-processed for the 2020 assessment (red). Headings are black for years prior to 2003, orange for 2003-2006, and green thereafter.



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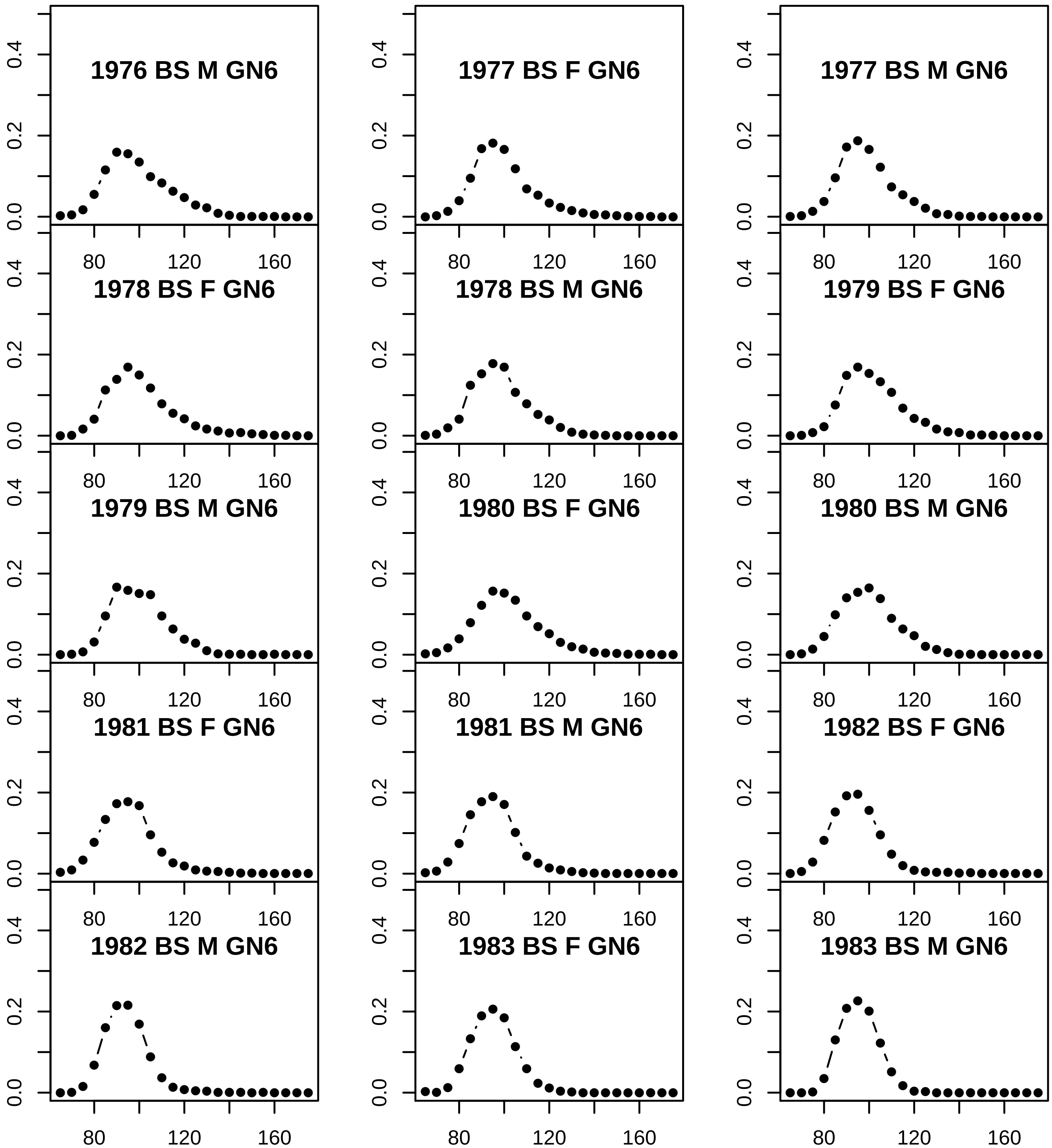
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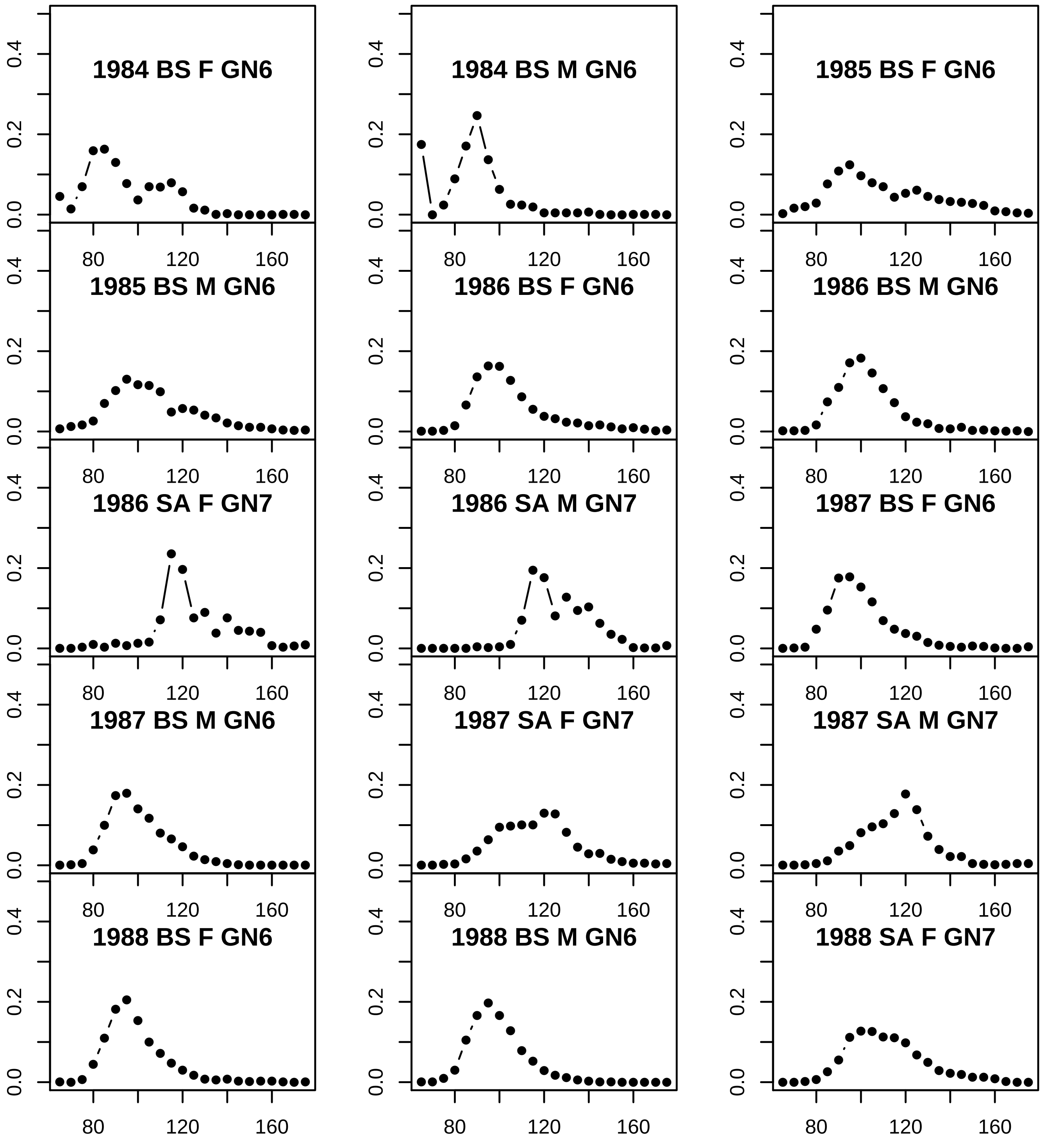

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1987 BS M GN6
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80
120
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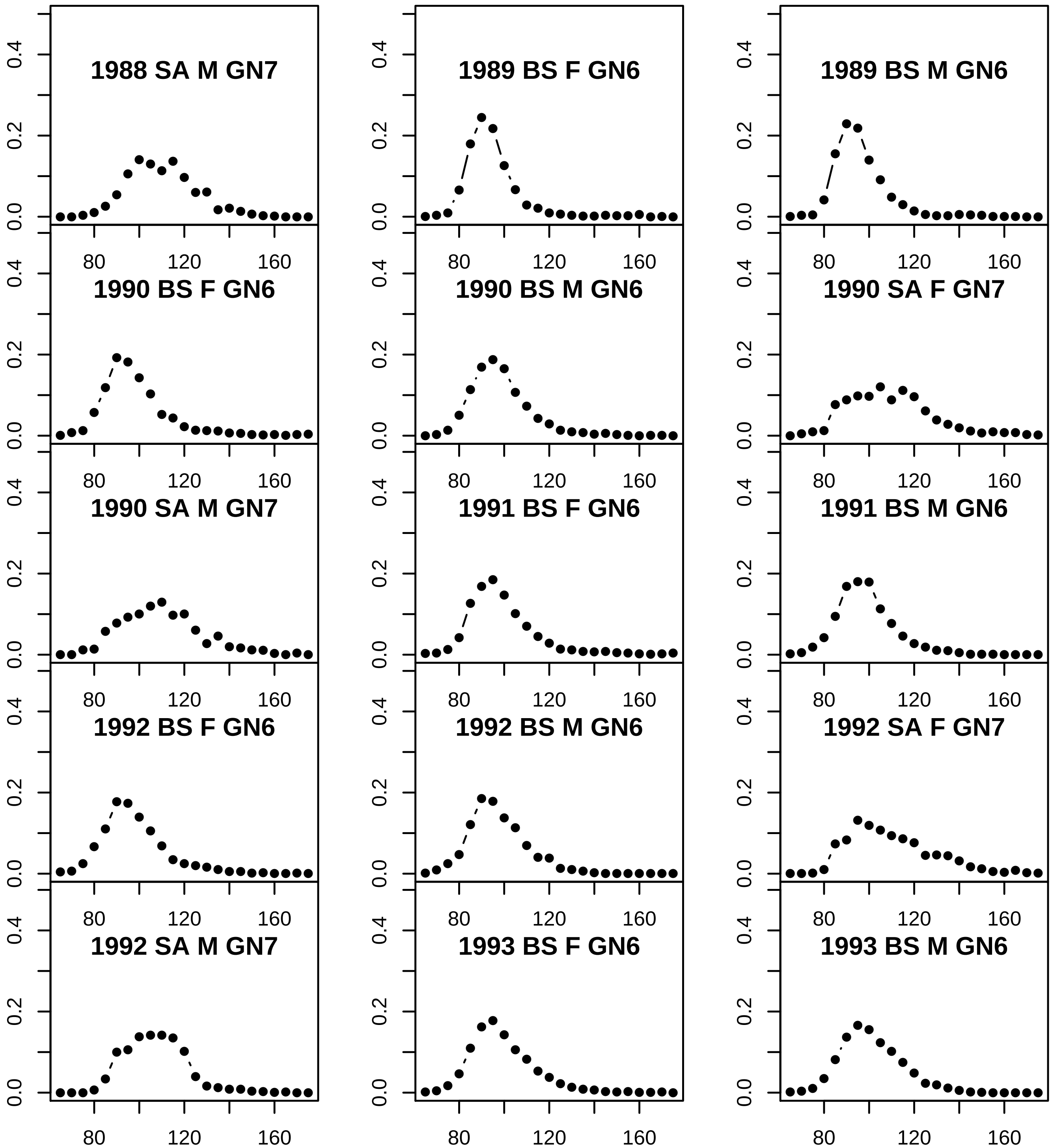
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1992 BS F GN6
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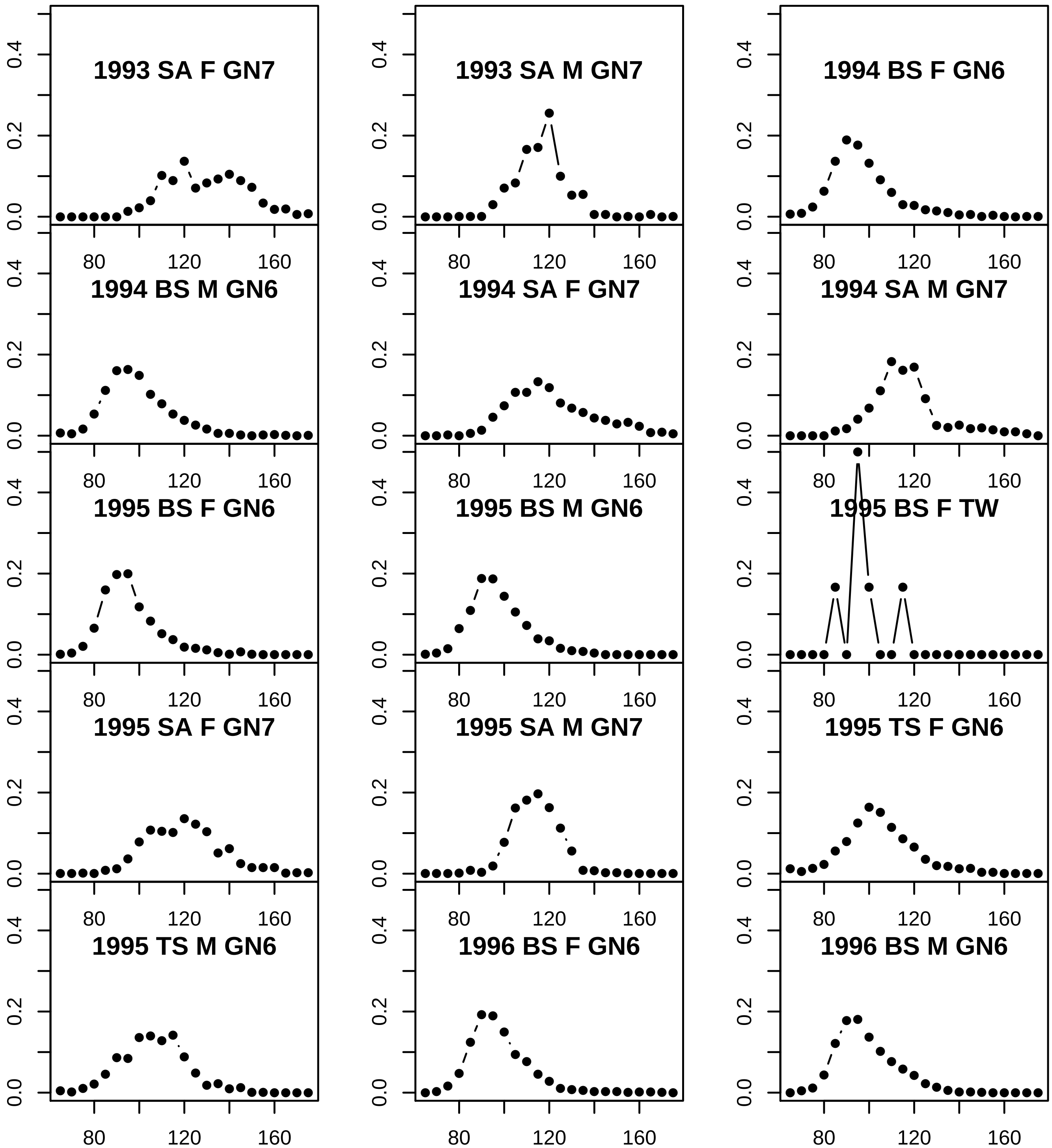

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1994 BS M GN6
1994 SA F GN7
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1995 SA F GN7
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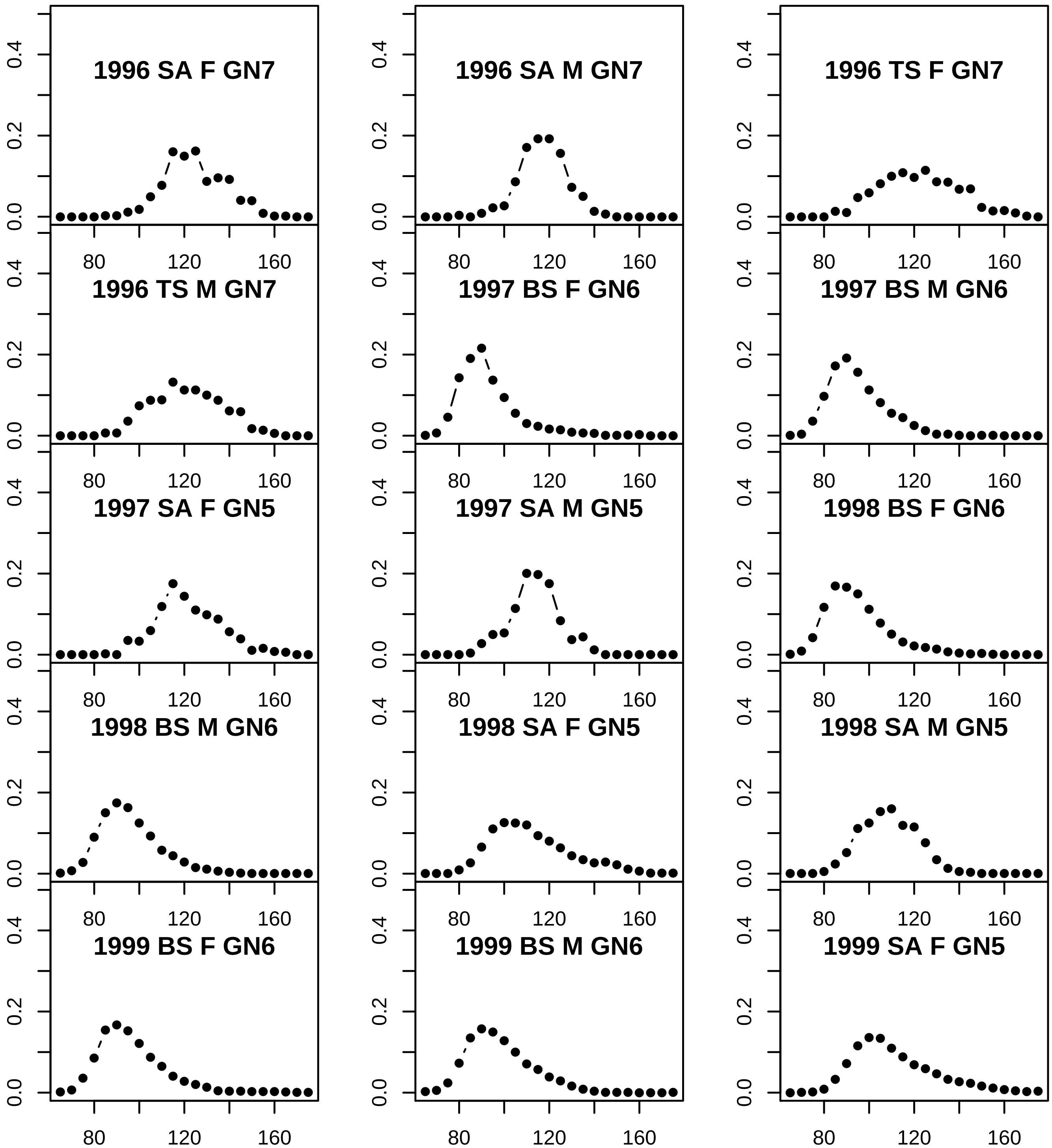
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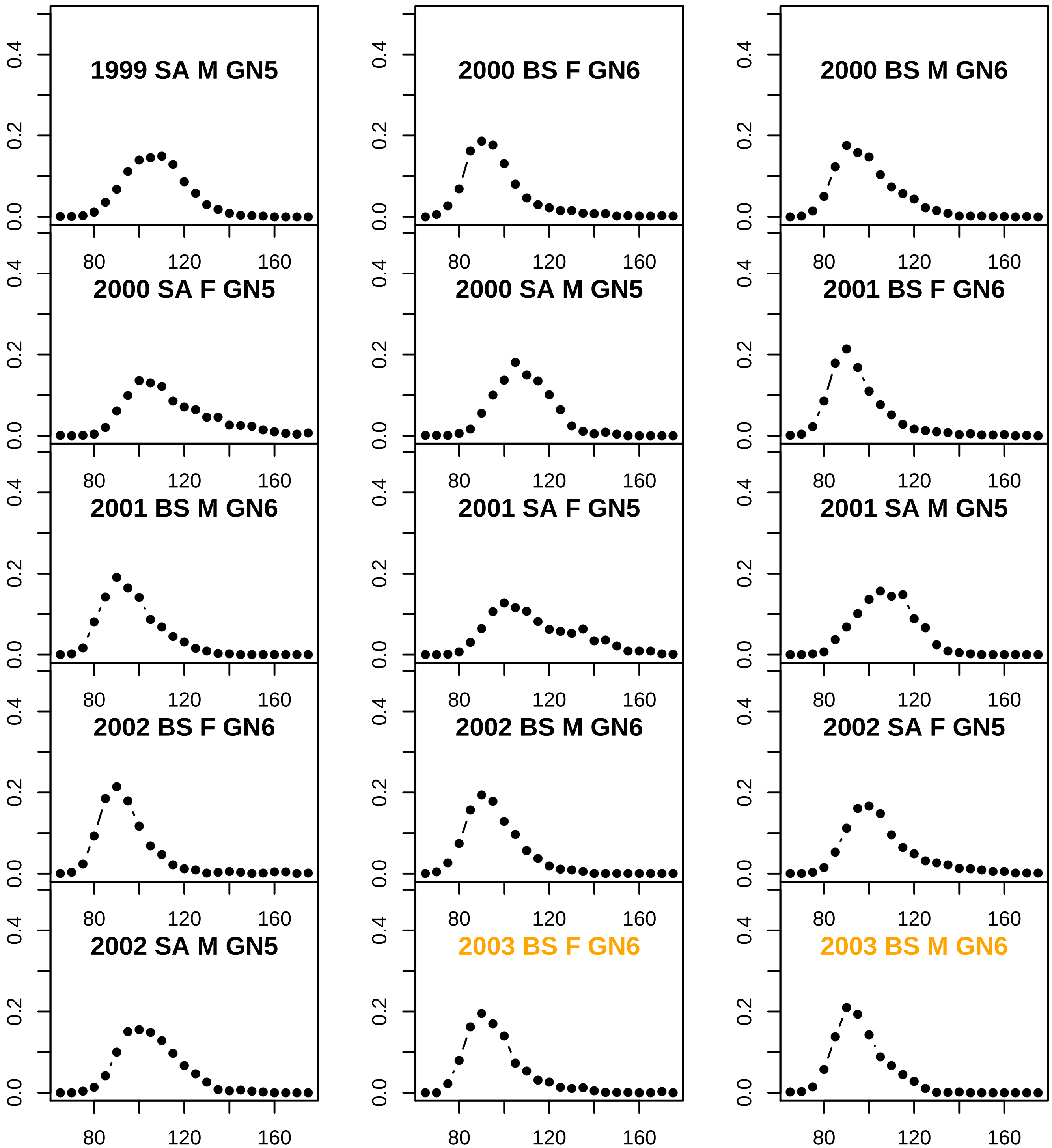
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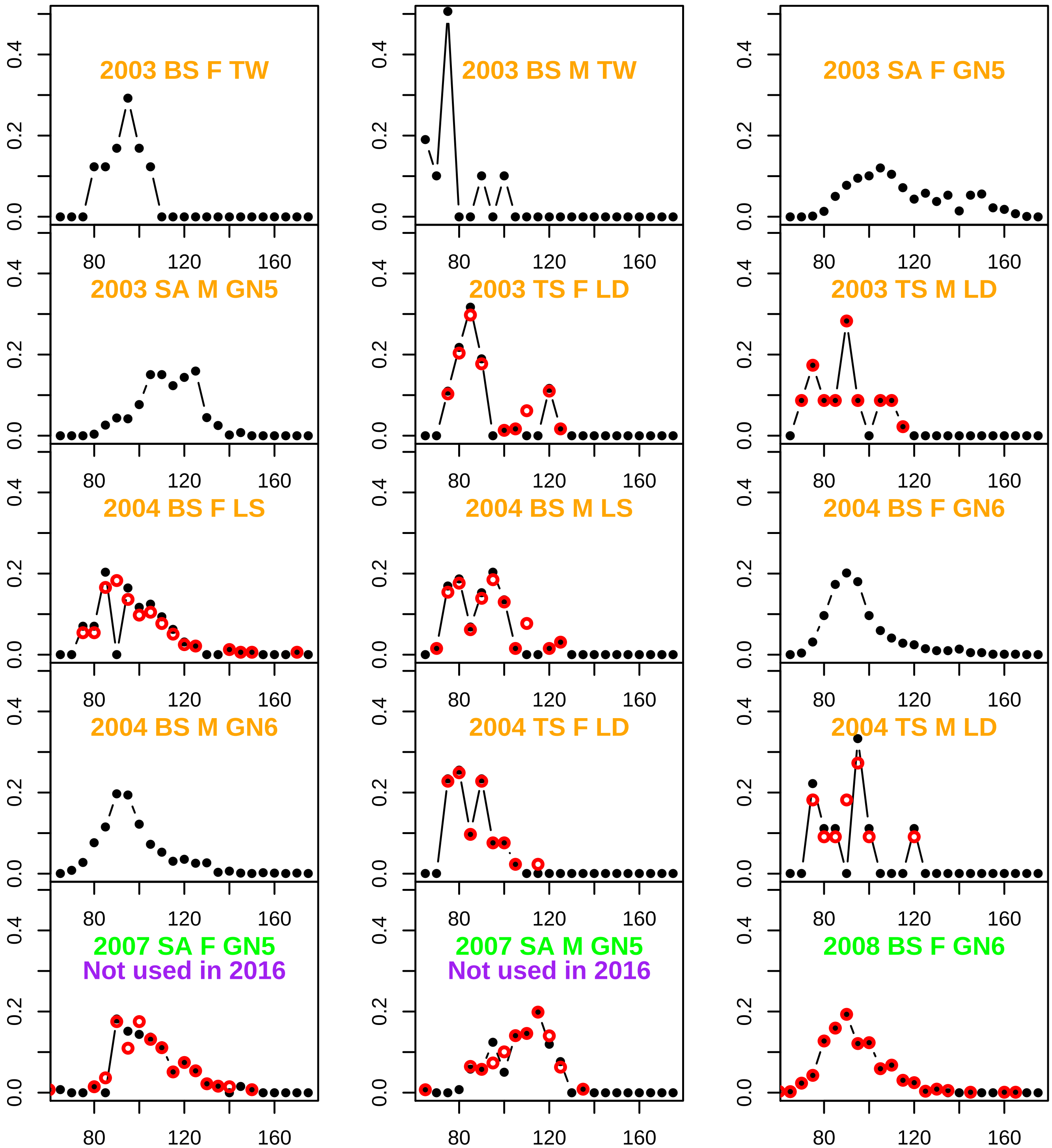
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2004 BS M LS
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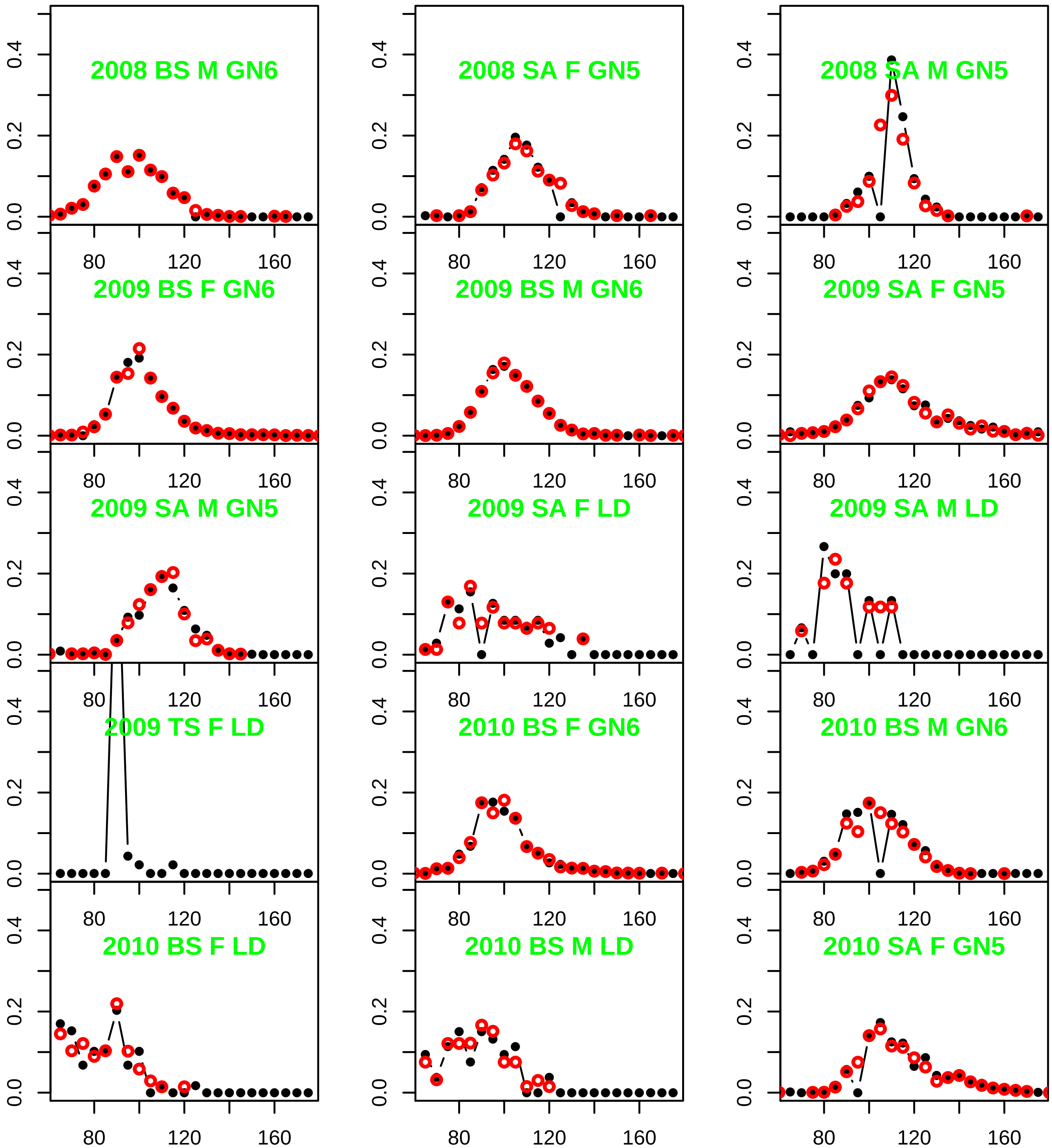
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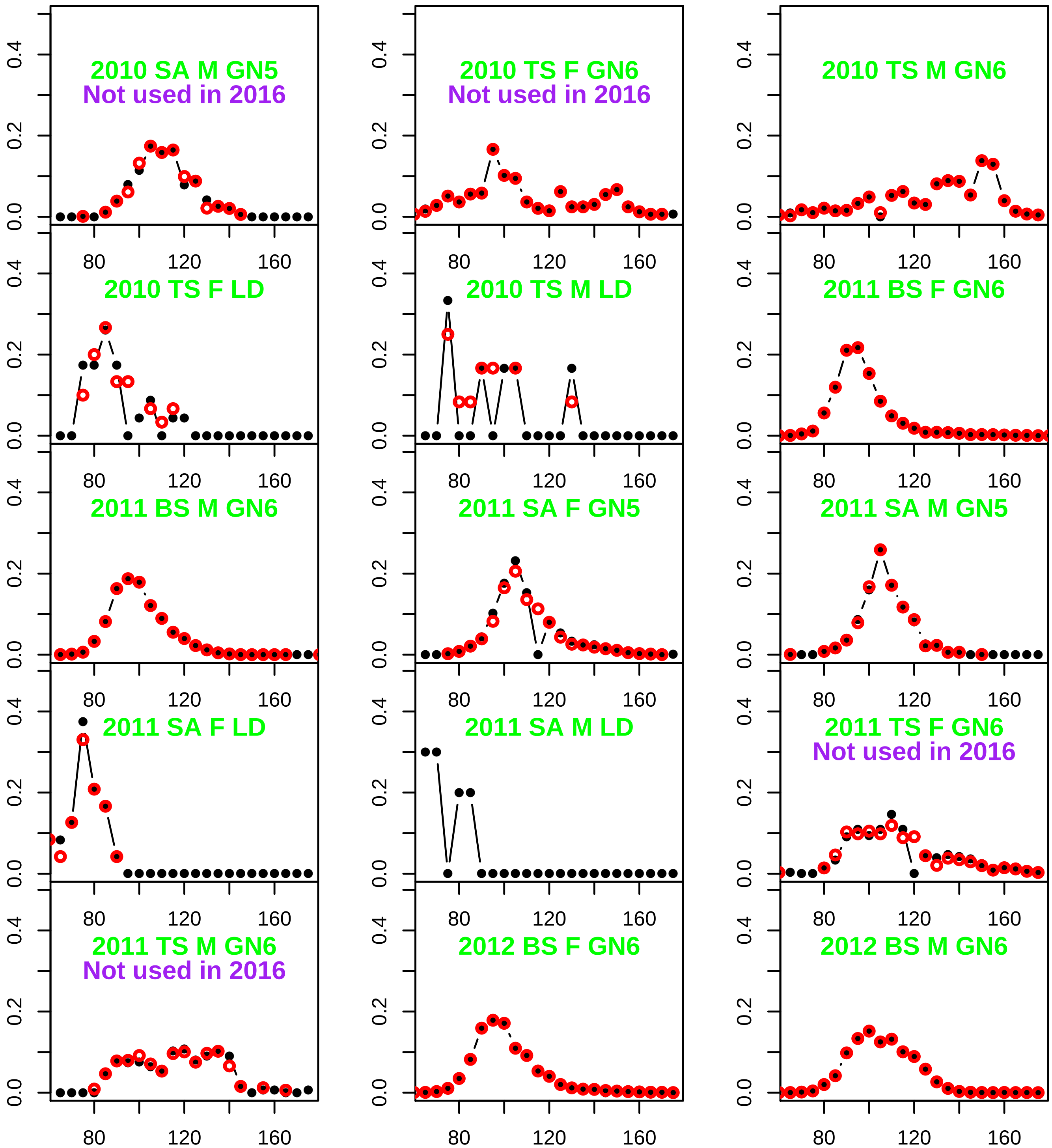

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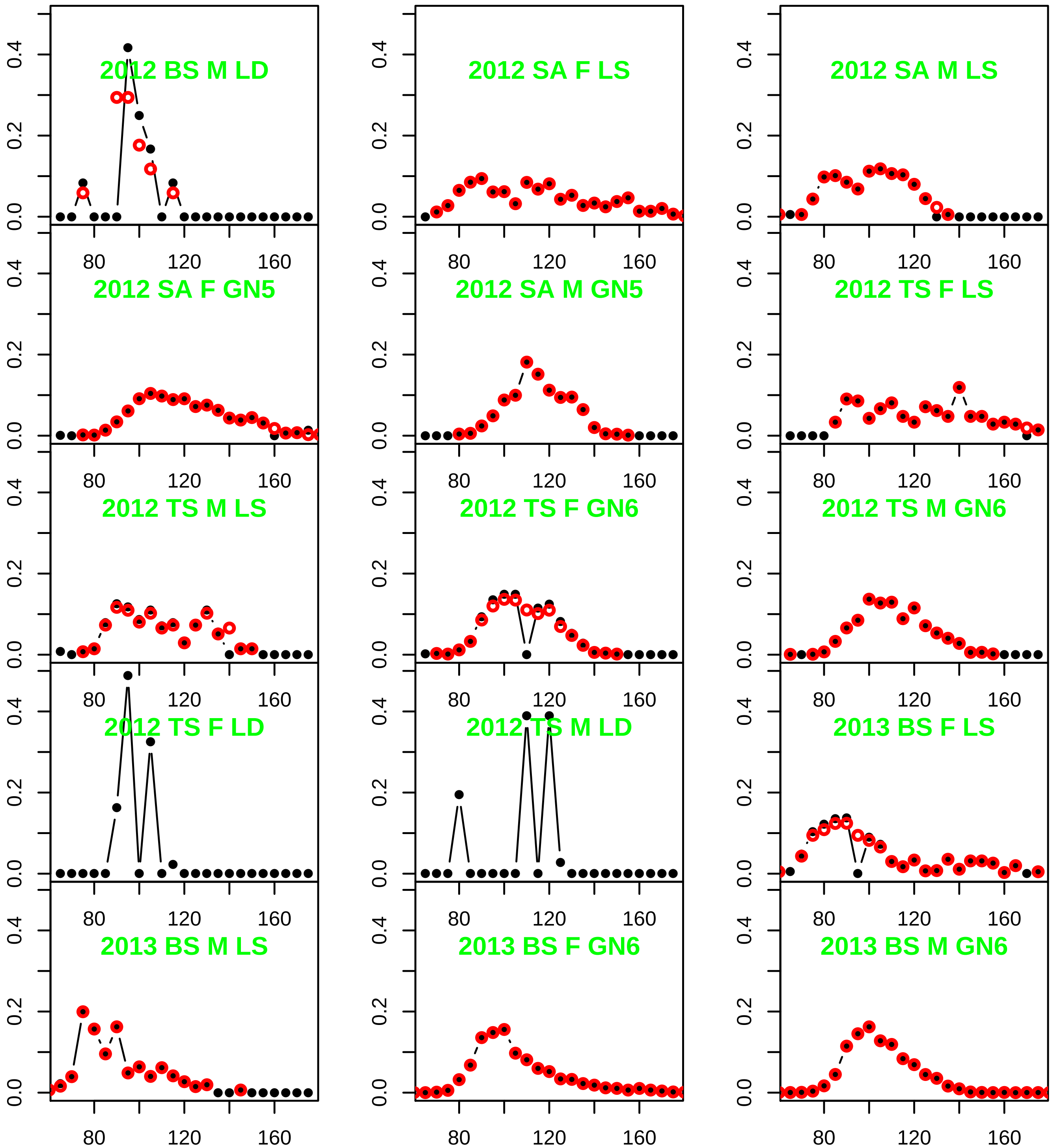
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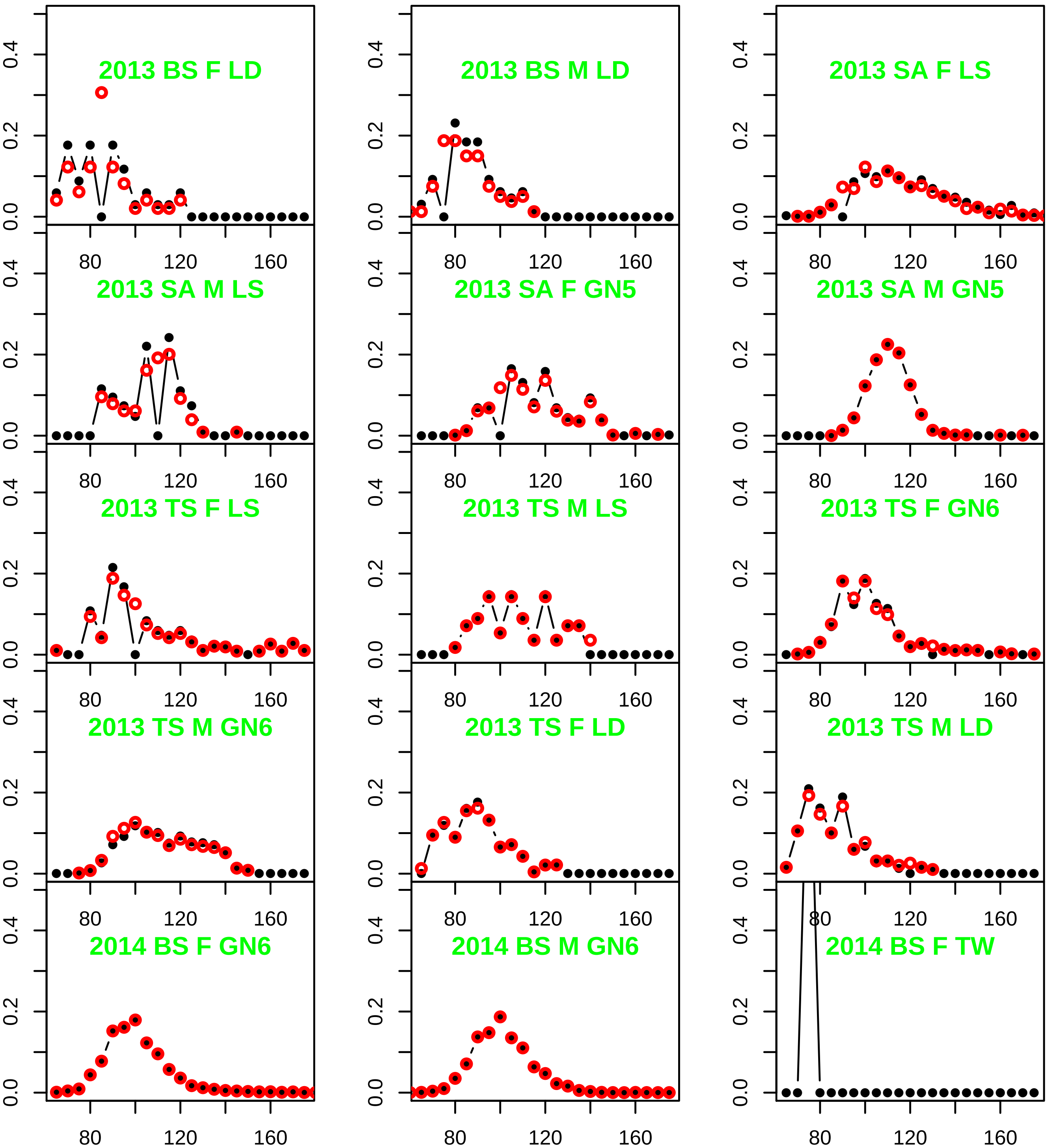

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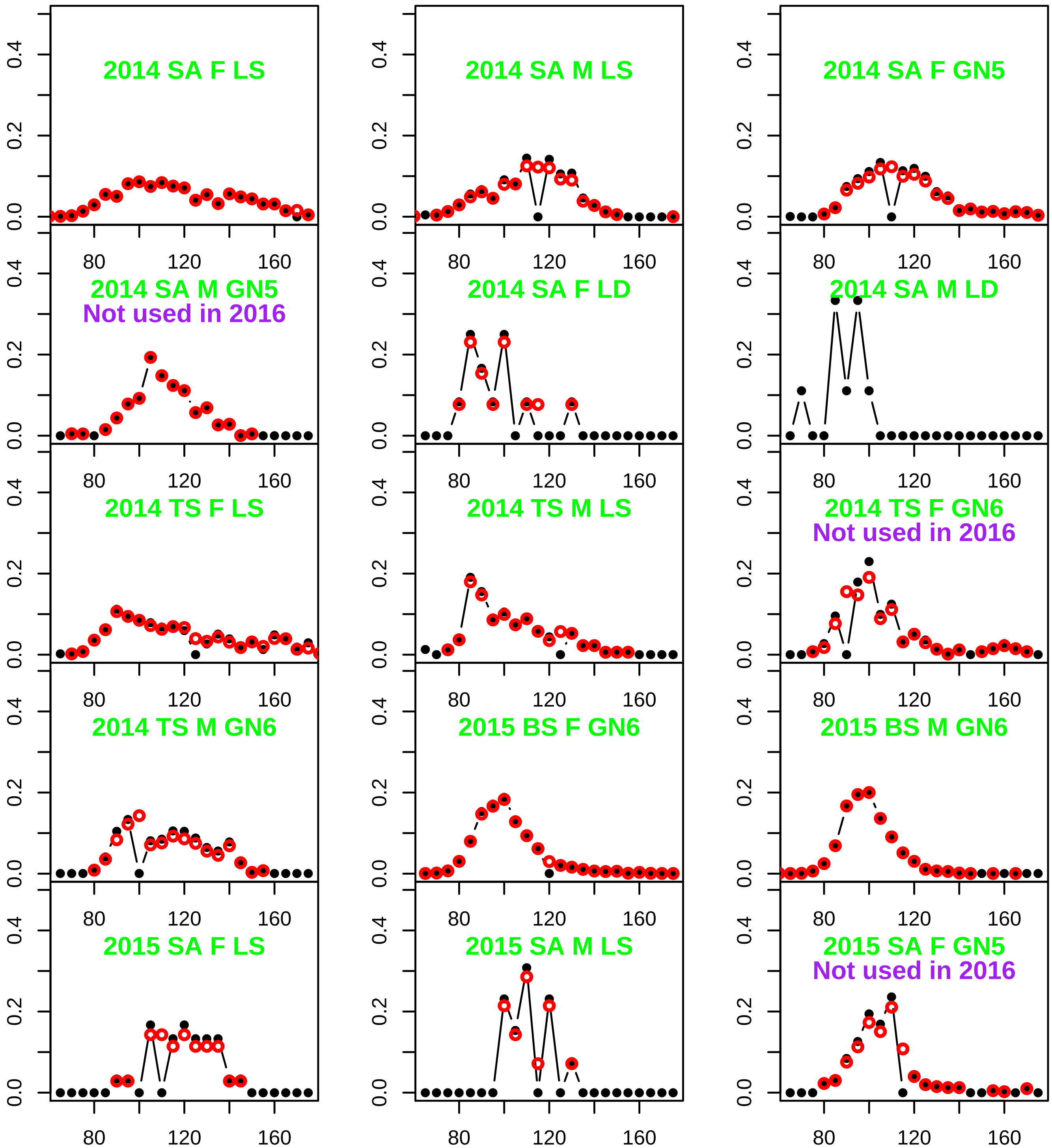

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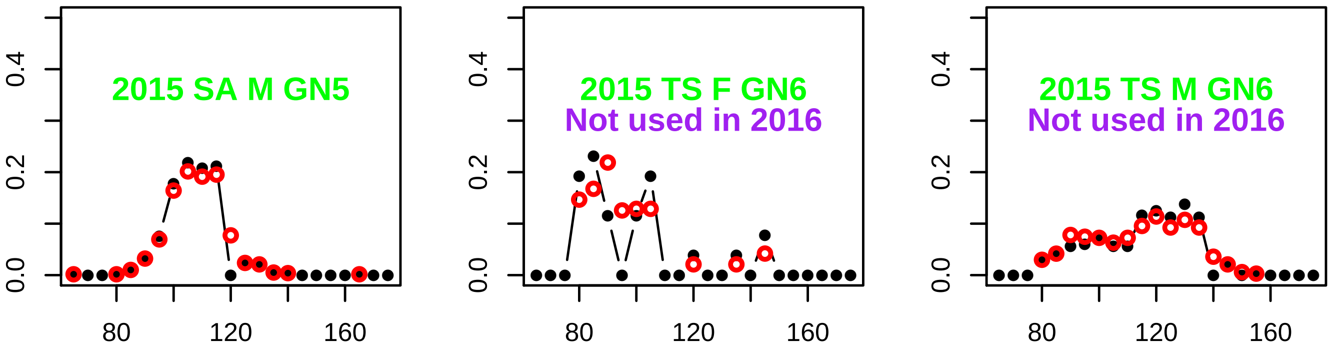

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Not used in 2016
2015 TS M GN6
Not used in 2016
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# 10 Appendix B: Age-Length data by year

Age-length data are available for several years, but not for years for which age composition (without length) data are included in the assessment. Figure 28 shows the age-length data for males and females, plotted separately for each year for which these data are available.

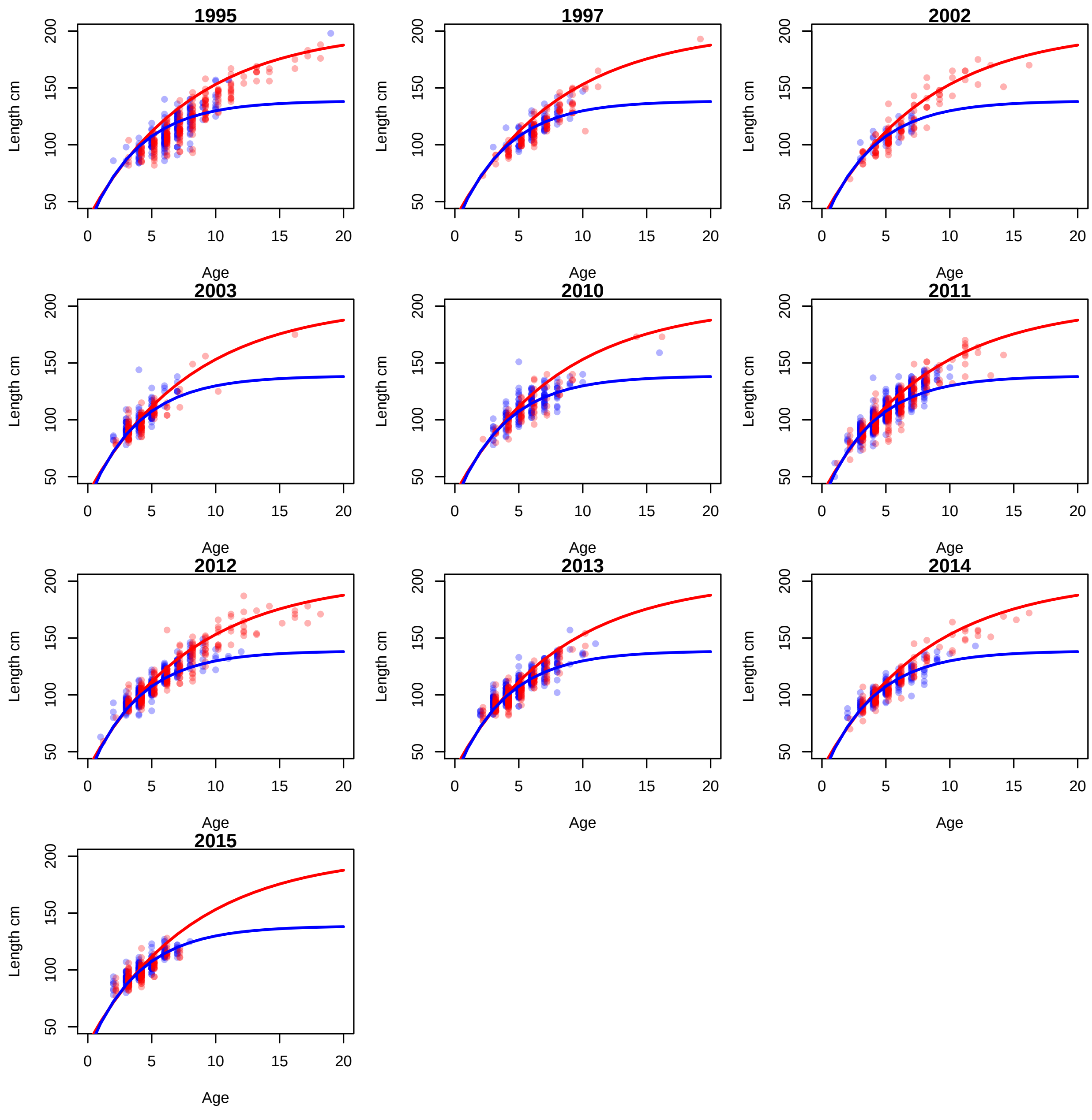


Figure 28: Observed age and length for Gummy Shark collected during 1995, 1997, 2002-2003, 2010-2015. Data from males are shown as blue dots, and females as red dots (which are slightly shifted along the Age axis for clarity of presentation). Theoretical growth curves are shown a red (females) and blue (line).

# 11 Appendix C: Length frequencies and Age compositions by year

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 expected (lines) length frequencies by year, gear, population and sex.


Figure 30: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex.


Figure 31: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex.

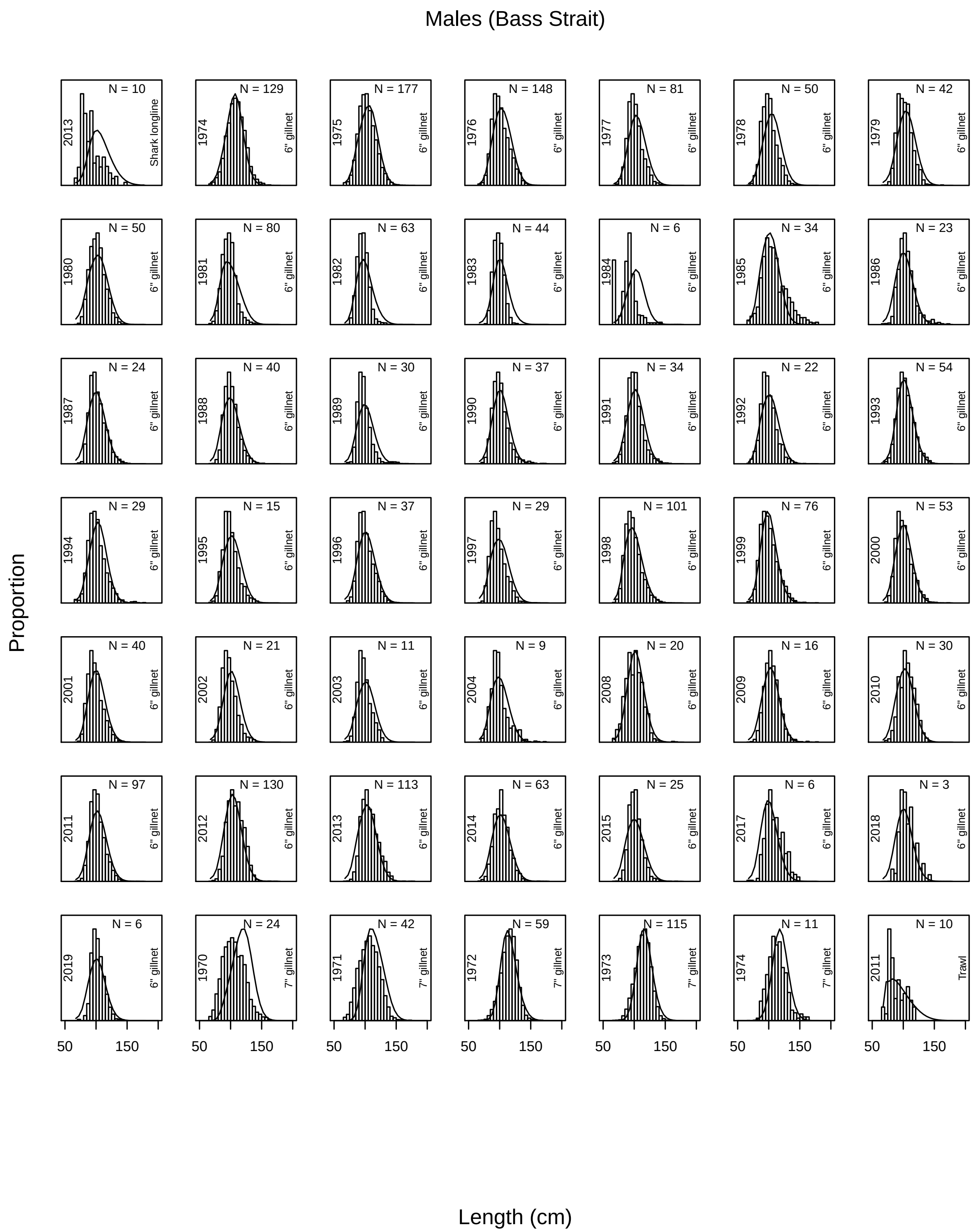


Figure 32: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex.

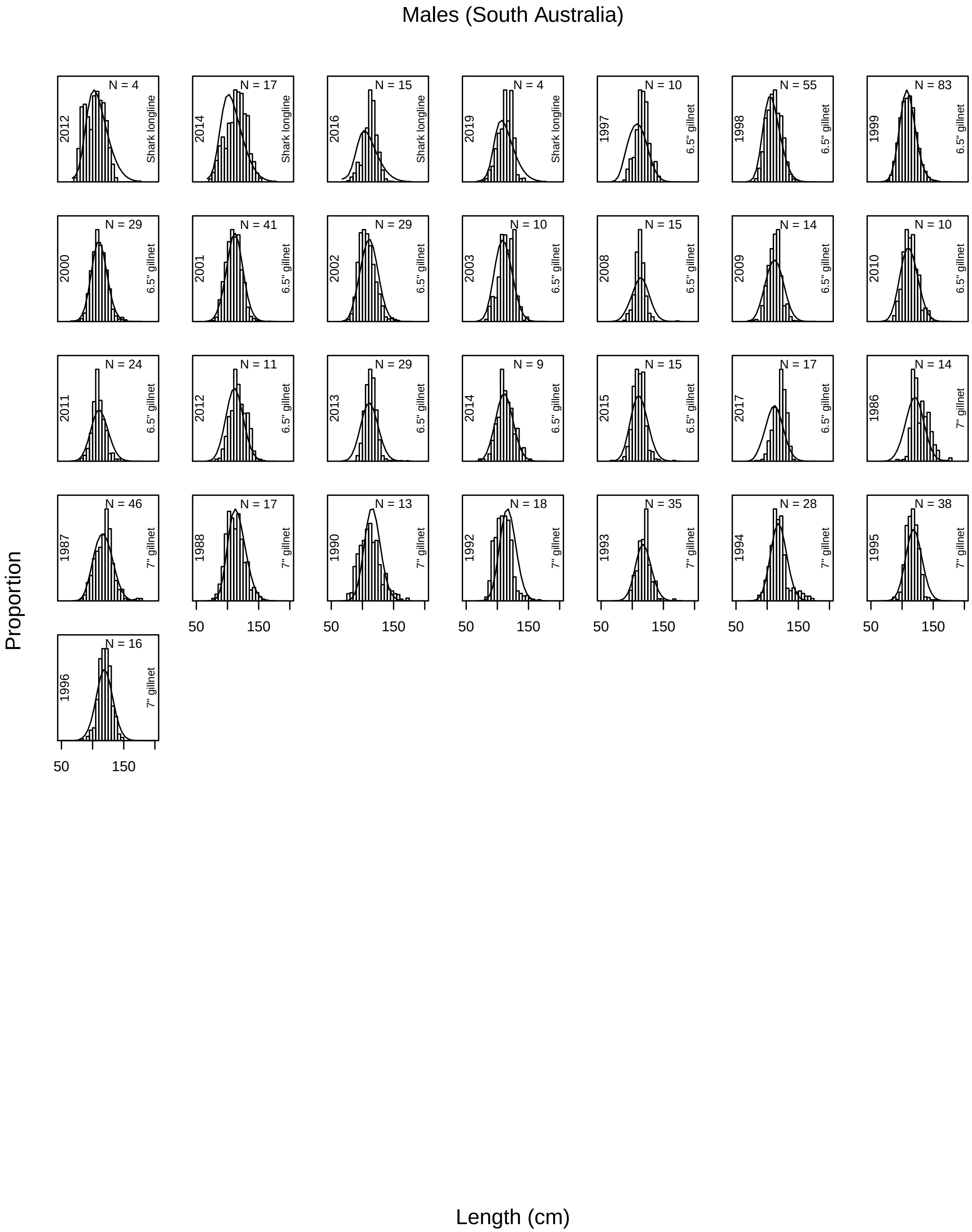


Figure 33: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex.


Figure 34: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex.

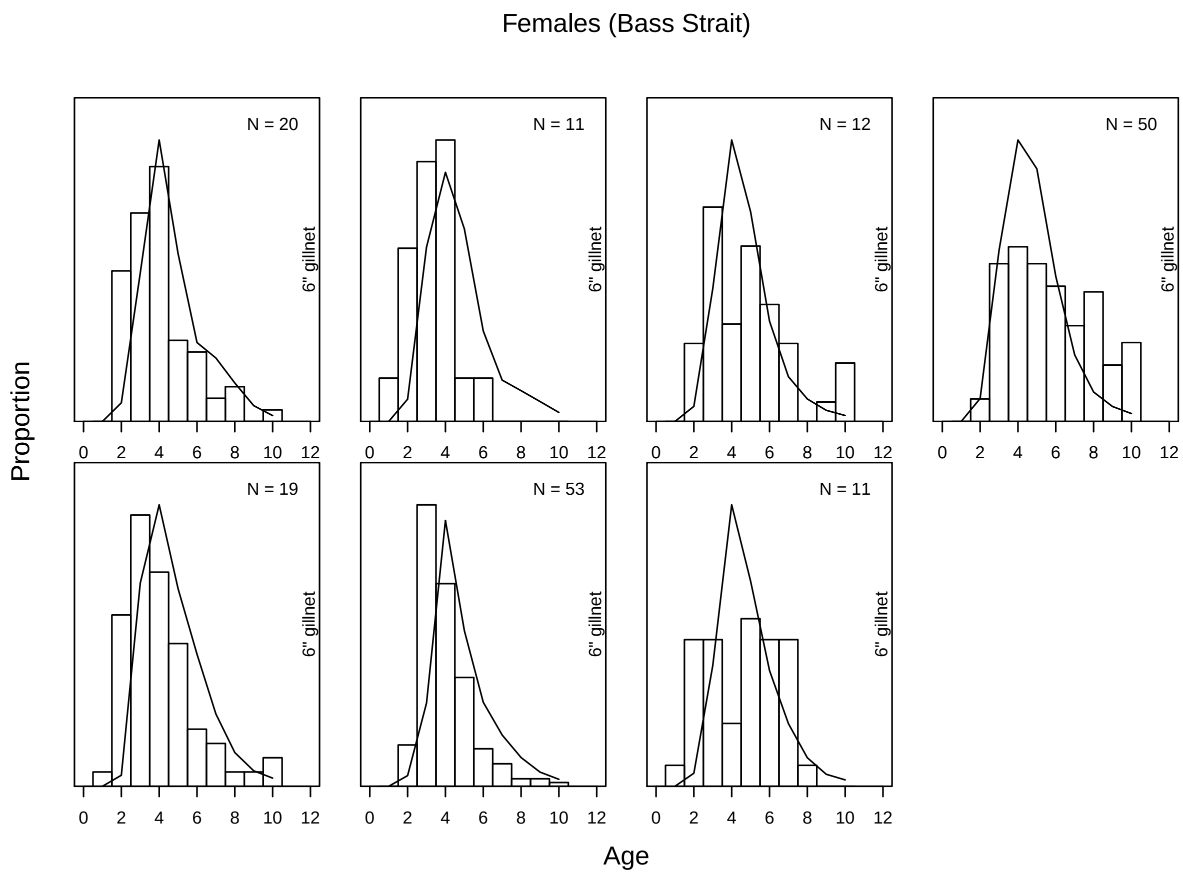


Figure 35: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex.

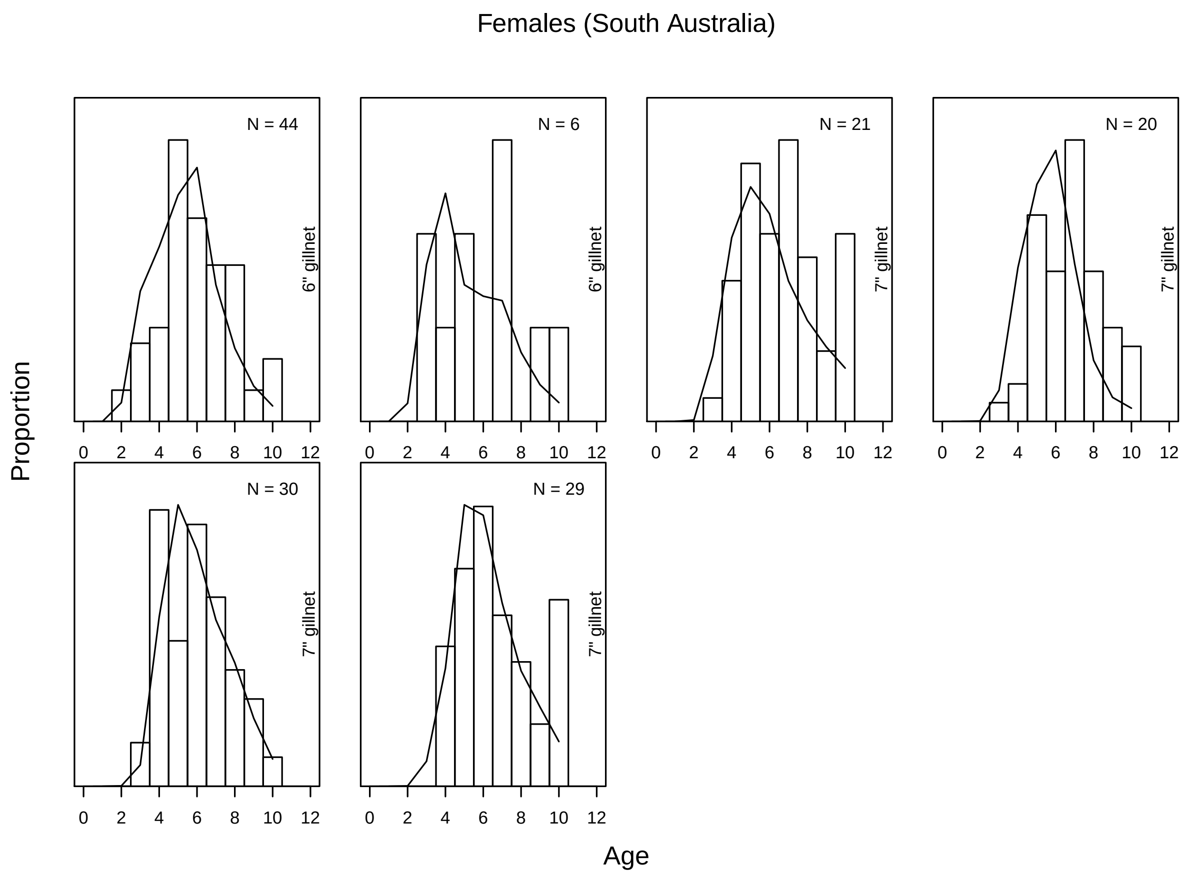


Figure 36: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex.

Males (Bass Strait)

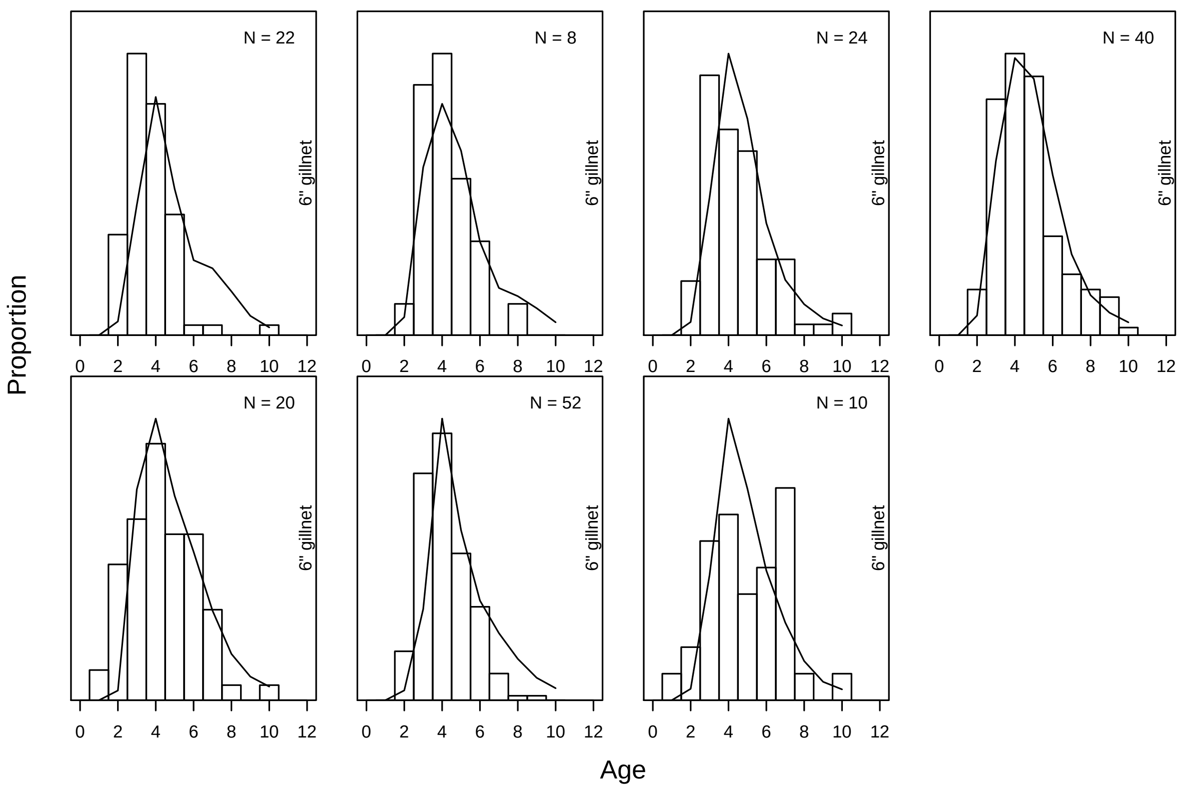


Figure 37: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex.

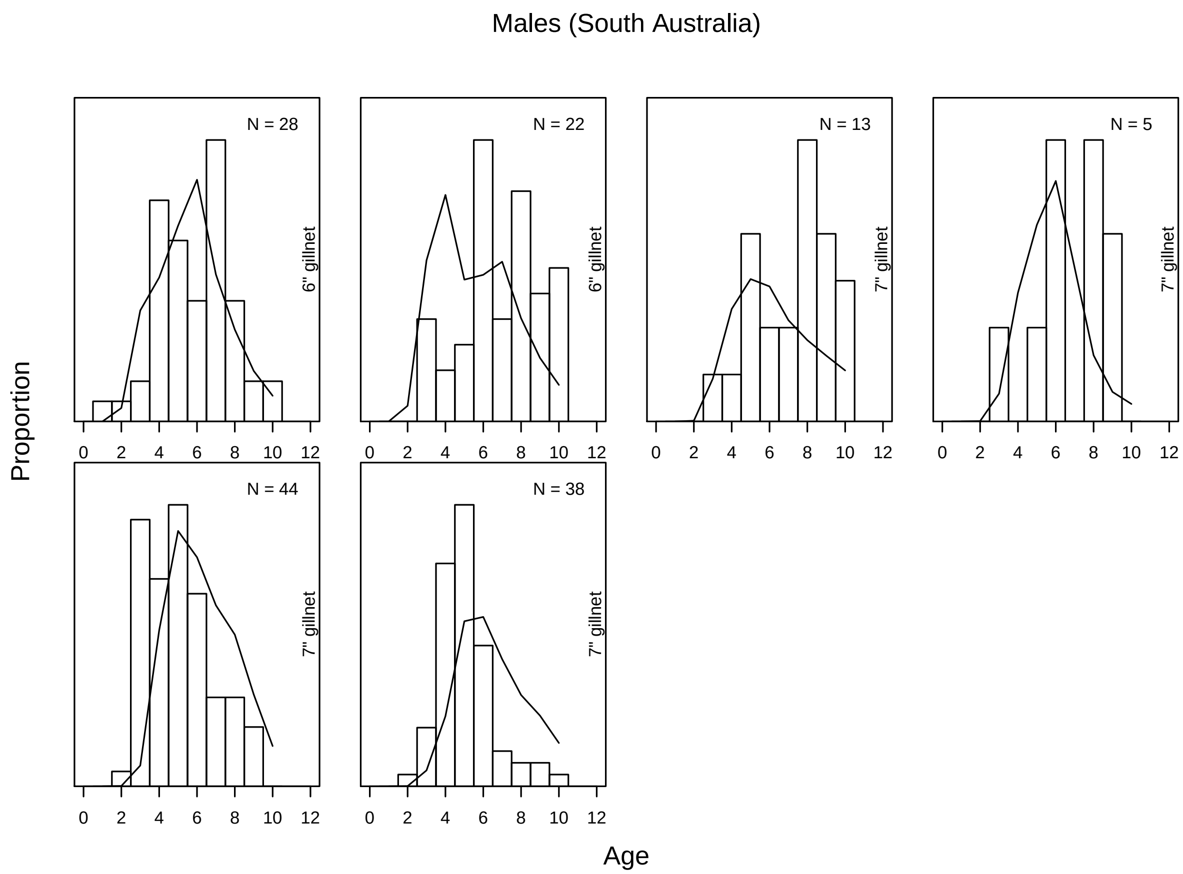


Figure 38: Observed (bars) and expected (lines) length frequencies by year, gear, population and sex.