Fisheries New Zealand

Tini a Tangaroa

The 2021 stock assessment of pāua (*Haliotis iris*) for PAU 2

New Zealand Fisheries Assessment Report 2022/35

P. Neubauer

ISSN 1179-5352 (online)
ISBN 976-1-99-103978-1 (online)

July 2022

Te Kāwanatanga o Aotearoa
New Zealand Government

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Please cite this report as:

Neubauer, P. (2022). The 2021 stock assessment of pāua (*Haliotis iris*) for PAU 2. *New Zealand Fisheries Assessment Report 2022/35*. 108 p.

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EXECUTIVE SUMMARY

Neubauer, P.[1] (2022). The 2021 stock assessment of pāua (*Haliotis iris*) for PAU 2.

***New Zealand Fisheries Assessment Report 2022/35*. 108 p.**

The management of pāua (*Haliotis iris*) fisheries in New Zealand includes regular stock assessments that determine the stock status of a particular quota management area (QMA). These stock assessments are based on statistical models that estimate the current and projected stock status, and the exploitation rate of the portion of the population that is impacted by fishing. This study conducted the first Bayesian length-based stock assessment for pāua in QMA PAU 2 since the initial Total Allowable Commercial Catch was set at 121.19 t in 1989. The assessment model used the same population dynamics model as assessments in other areas, including changes that were first introduced for PAU 5D in 2018: while previous assessment models for other areas fit directly to data, the present model used only model-derived inputs. It, therefore, represents a Bayesian synthesis of available information rather than an integrated model that fits to data directly.

The assessment was initially carried out as a single and a multi-area assessment over small research strata. All multi-area runs for initial models led to near-identical conclusions as the single-area model, so that the latter model was selected to provide a parsimonious base case for the assessment.

The base case suggested stock levels near the target of 40% of unfished biomass, with slow declines over recent decades. All trialled sensitivities showed stock at biomass levels well above Fisheries New Zealand limit reference points, despite diverging trajectories depending on model assumptions. Projections suggested little change from current stock status over the next three years and into the future at current catch levels.

[1] Dragonfly Data Science, New Zealand.

1. INTRODUCTION

The management of New Zealand abalone, pāua (*Haliotis iris*), fisheries in New Zealand includes regular stock assessments that determine the stock status of a particular quota management area (QMA). These stock assessments are based on statistical models that estimate the current and projected stock status, and the exploitation rate of the portion of the population that is impacted by fishing. Of the seven pāua QMAs that are subject to substantial commercial fishing (PAU 2, PAU 3, PAU 4, PAU 5A, PAU 5B, PAU 5D, and PAU 7), only PAU 2 and PAU 4 have not been formally assessed using integrated population models.

This report details the first complete stock assessment of pāua in PAU 2. This QMA is relatively large, from eastern Bay of Plenty around southern North Island to the Waikato west coast (Figure 1). Of this large area, only the Wairarapa coast (pāua statistical areas 01 to 36 in Figure 1) is commercially fished, with most of the catch from the area between Castlepoint and Turakirae Head (i.e., south of pāua statistical area 16 to area 36), with occasional catch from areas north of Castlepoint. No total allowable catch (TAC) is set for this fishery, and the Total Allowable Commercial Catch (TACC) of 121.19 t has been in place since 1989. Catch reporting was initially at a relatively large spatial resolution of General Statistical Areas (014, 015, and 016) and subsequently changed (in 2002) to smaller-scale pāua statistical areas (see Figure 2).

Although the data (especially catch-per-unit-effort, CPUE) from PAU 2 have been previously examined, no formal stock assessment has been attempted, because the CPUE index was considered uninformative by Fisheries New Zealand's Shellfish Working Group (SFWG). Nevertheless, following further review and inclusion of data from the Fisheries Statistical Unit (FSU), CPUE was re-considered by the SFWG, highlighting that the index was similarly variable as CPUE indices from other QMAs, and there was no reason to *a priori* consider the CPUE as uninformative about stock status. This review led to the current full stock assessment for PAU 2, based on methods developed for other QMAs (e.g., Breen et al. 2003, Marsh & Fu 2017, Neubauer & Tremblay-Boyer 2019b). Nevertheless, the Fisheries Assessment Plenary subsequently accepted only PCELR indices as a basis for relative abundance in the PAU 2 stock assessment.

The current report describes the data inputs, methods, and results of the 2021 stock assessment for PAU 2. The fishing year for this fishery is defined as the period from 1 October to 30 September the following year (here, unless the range is explicitly stated, the fishing year is referred to by using the latter year in the corresponding time period).

Although the current stock assessment was based on methods developed for other QMAs, it included several developments and updates to the modelling approach for catch sampling length frequency (CSLF) data. In addition, the current assessment explored the application of a spatial model next to a non-spatial (single-area) model to explore if trends over small spatial scales inferred in the spatial model were consistent with trends over large spatial scales inferred in the single-area model.

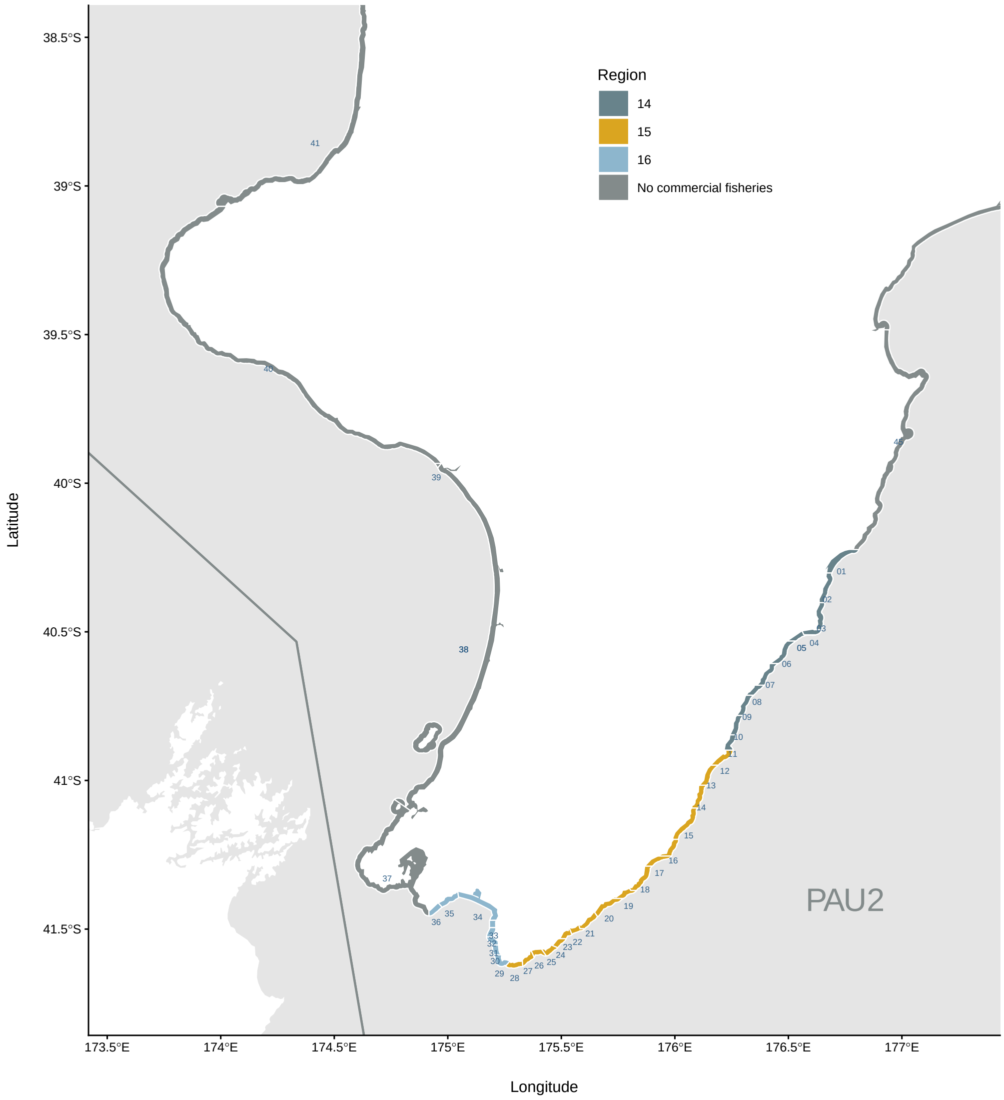

Figure 1: Pāua Quota Management Area (QMA) PAU 2, including key spatial divisions. Catch reporting was initially at a lower spatial resolution of General Statistical Areas (shown as regions 14, 15, and 16), and subsequently changed (in 2002) to finer scale pāua statistical areas (01 to 36).

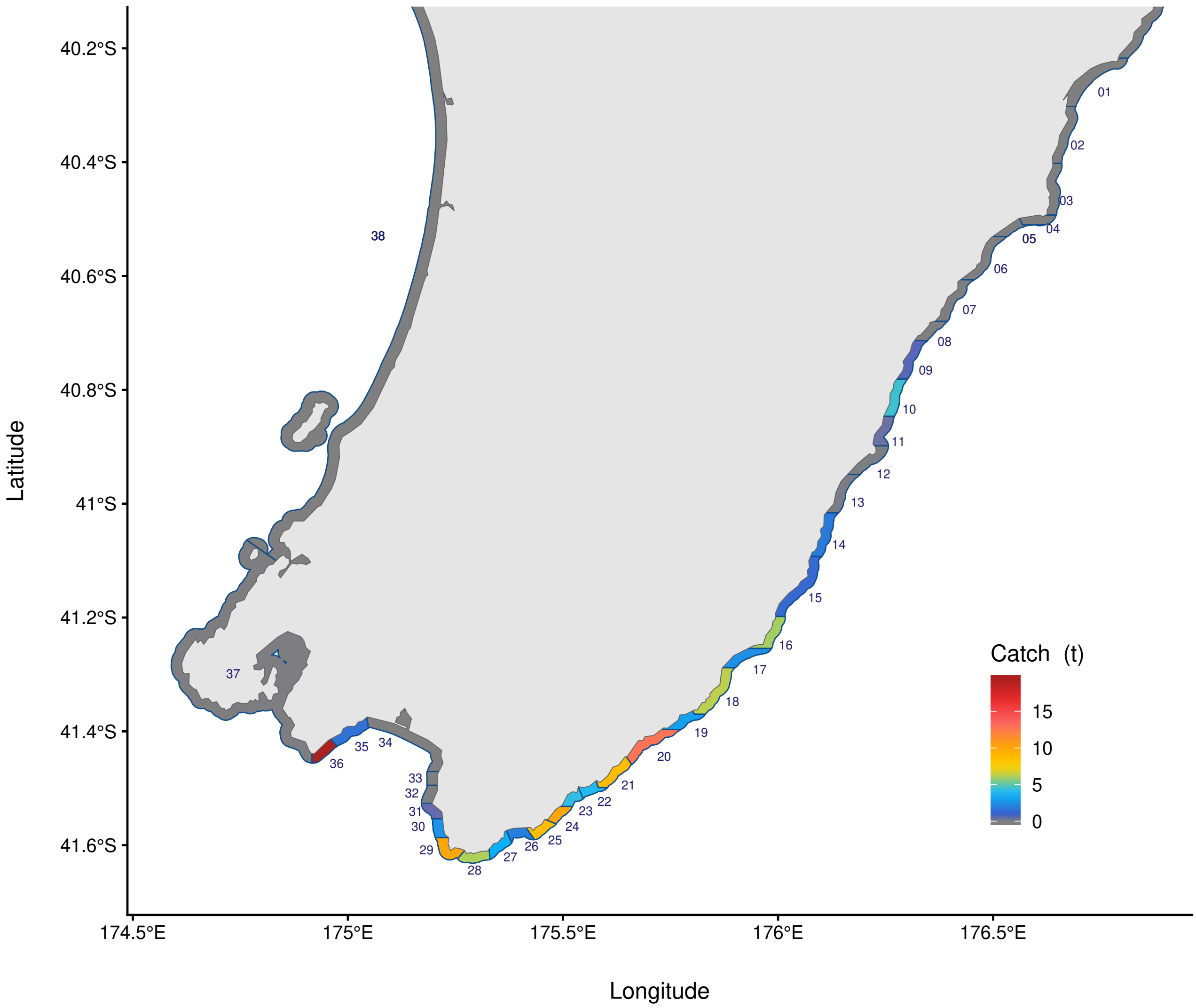

Figure 2: Distribution of commercial catch used in the current stock assessment of pāua in Quota Management Area PAU 2. Colours show the relative proportion of catch from each statistical area (averaged since 2002).

2. METHODS

2.1 Inputs

Inputs to the current stock assessment consisted of data of commercial, recreational, customary, and illegal catch (reconstructed for part of the assessment period), CPUE data from (Paua) Catch Effort Landing Return ((P)CELR) forms, CSLF data from commercial sampling, and maturity and growth measurements from tagging by research divers.

2.1.1 Commercial catch

Commercial catch was reconstructed for the period from 1974 to 2019 from a number of different data sources, including earlier reports (Murray & Akroyd 1984), the FSU database (1983–1989), and catch effort data supplied by Fisheries New Zealand (Figures 3 and 4).

From 1974 to 1995, catch was reported at the unit of research strata (Statistical Areas 014, 015, 016). Although these previous (i.e., pre-1996) statistical areas are generally referred to with a zero preceding the research stratum code, the zeros were subsequently omitted for convenience and refer to these statistical areas as research strata or simply “area 14” compared with the current fine-scale statistical areas.

For the early part of the catch history, the commercial catch reconstruction used data from Murray & Akroyd (1984); however, catches in this area are highly uncertain, and conversations with divers with memories of this period suggest that the true catch was considerably larger than that reported in Murray & Akroyd (1984). Nevertheless, the report by these authors also included a column of export weights per year that were not attributed to any QMA at the time. In view of the relative accessibility and (human) population density in PAU 2, a proportion of these catches was attributed to PAU 2 as part of the current catch reconstruction. For this catch attribution, a smoothing window was applied with fixed weights, using 50% and 25% of the reported values in the following years, and adding them to the reported values in each year. The smoothing window was applied forwards in time, and each year, reported values were successively adjusted for the amounts attributed to the catch in previous years to account for exported catch potentially from fishing that occurred in previous years; one quarter of this backward-smoothed catch was arbitrarily added to PAU 2 to inflate early catches (Figures 3 and 4).

For the 2019 fishing year, the commercial catch was set to the TACC at 121.19 t. Since 2002, catch has been reported at the level of fine-scale pāua statistical areas (on PCELR forms). For the period when the forms were implemented, there was some spatial and temporal variation in commercial catch across the fine-scale statistical areas (Figure 5, and see also Figure 2).

2.1.2 Recreational, customary, and illegal catch

There have been no adjustments of the TACC for PAU 2 after the introduction of the quota management system, so that there is no explicit allowance for recreational and customary take (and no Total Allowable Catch, TAC). The national panel survey consistently estimated near 82 t of annual recreational catch for the entire area of PAU 2; however, it is unclear how much of this catch is from the commercially-fished area along the Wairarapa coast. A previously-used catch weight of 40 t was discussed by the SFWG and was considered too high given population density, accessibility, and weather along the Wairarapa coastline. Considering that the Wellington coast (from Turakarae Head to Mana, statistical area 37) is considerably more accessible and considered high-quality pāua habitat, it is possible that the majority of recreational take occurs along the Wellington coast. Owing to the lack of accurate geographical information, a constant recreational catch of 10 t since 1974 was assumed, which was at the high end of possible values discussed by members of the SFWG. Illegal catch was similarly set at a constant 10 t over the same period.

Figure 3: Commercial catch of pāua reported for each quota management area (QMA) and the New Zealand total between 1974 and 2019. Unknown catch (pink line) could not be attributed to spatial areas and was smoothed backwards in time to account for exported catch potentially derived from fishing that occurred in previous fishing years (dashed black line). Commercial catch for PAU 2 includes a quarter of the backward-smoothed catch, which was arbitrarily added to inflate early catches (PAU 2 adj).

Customary reporting suggested a relatively variable customary catch with mean of 3 t. Because this information was only available for recent years, customary catch was set to a constant 3 t.

Based on the different catch components, the spatial assessment was based on the area-specific catch estimates (Figure 6), whereas the single-area assessment used the sum of individual area catches (Figure 7).

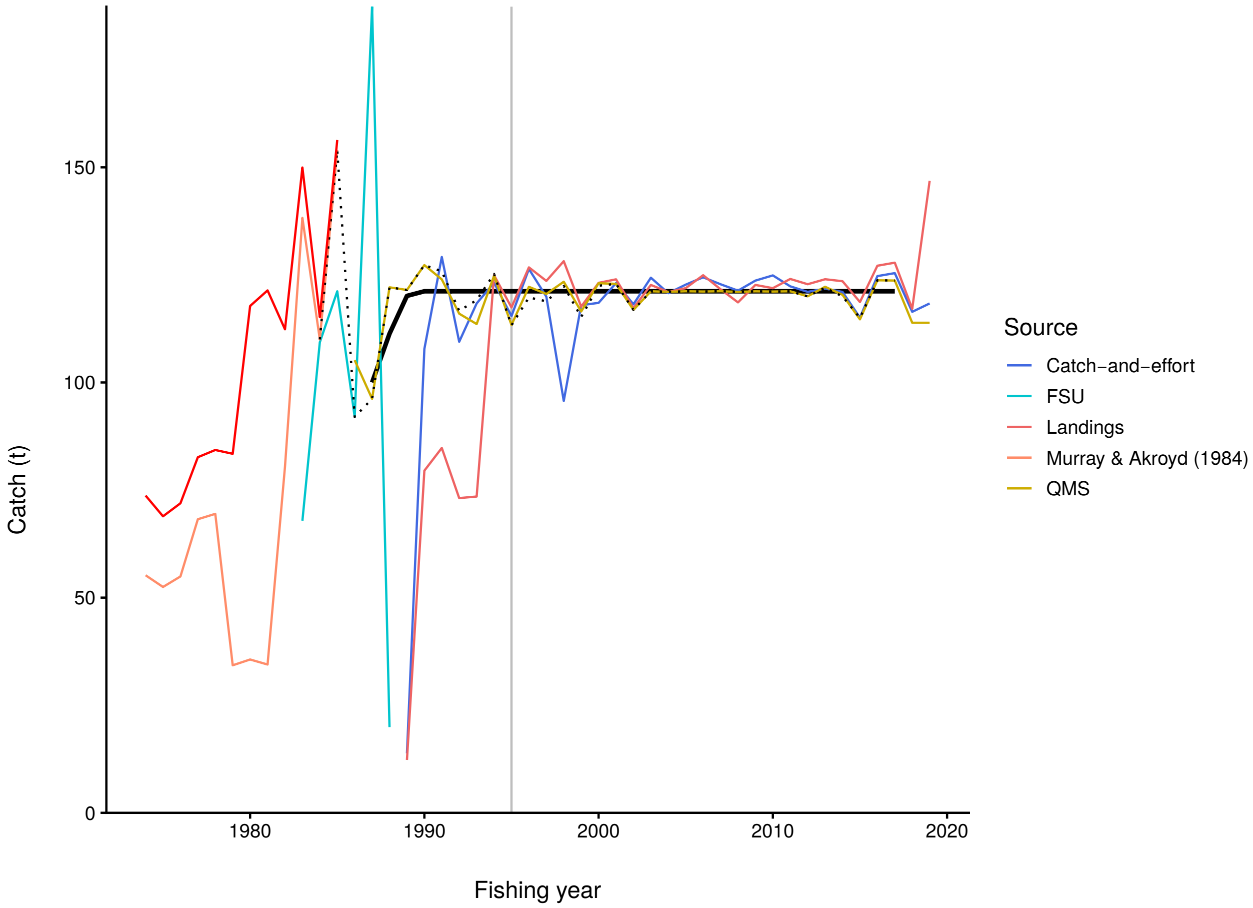

Figure 4: Estimated commercial catch history for pāua Quota Management Area PAU 2 from 1974 to 2019 and Total Allowable Commercial Catch (TACC; black line). Catch to 1983 was reconstructed from data reported by Murray & Akroyd (1984) (orange line). The darker red line for the same period indicates the high catch scenario for the same period. Data 1983–1989 were from the Fisheries Statistical Unit (FSU) database (teal line). Catch-effort data from 1989 supplied by Fisheries New Zealand (catch-and-effort, blue; landings, light red). Reported QMS (Quota Management System) harvest returns in orange, with corresponding estimates reported in the Fisheries Assessment Plenary report (dotted line; see Fisheries New Zealand 2019).

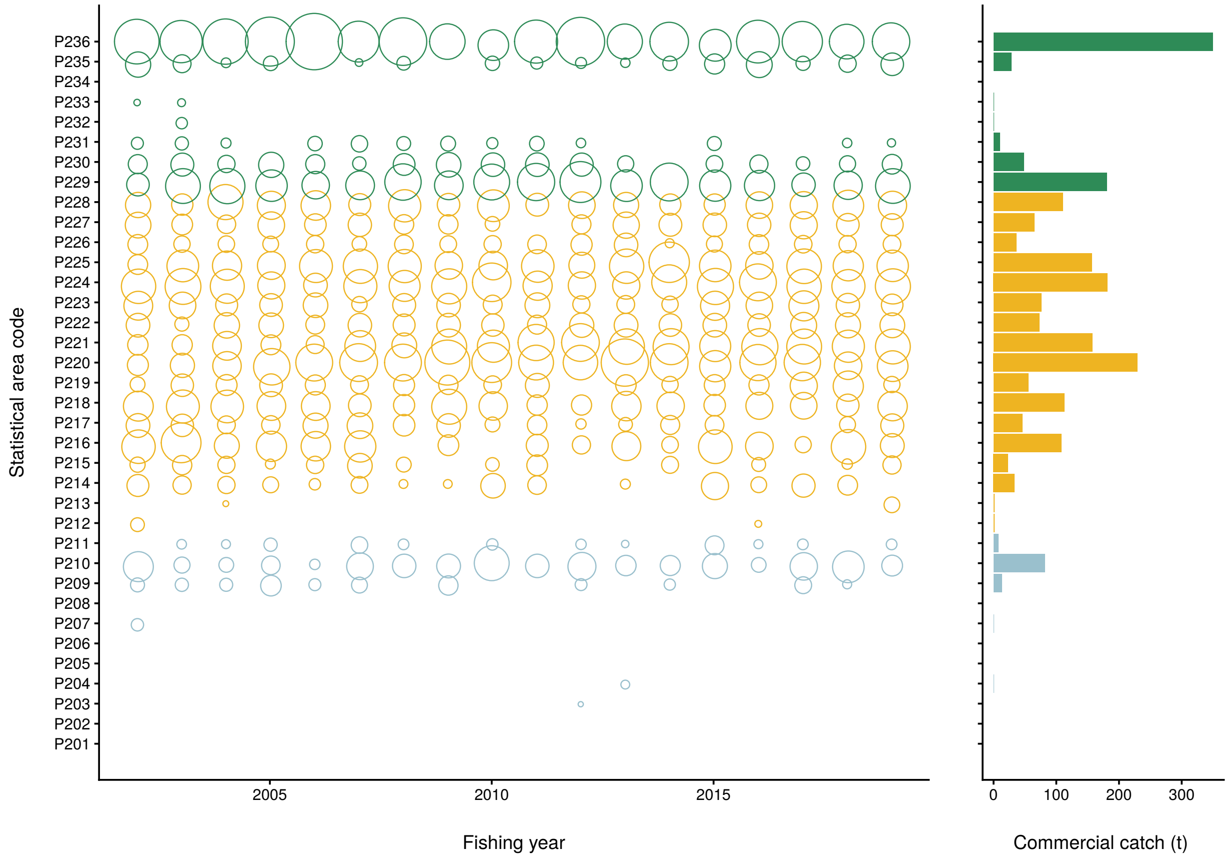

Figure 5: Relative trend in pāua catch (kg) over time by pāua statistical areas in Quota Management Area PAU 2 for the period from 2002 to 2019, with total catch over the same time period (right-hand side). Statistical reporting areas prior to 2002 within PAU 2 are colour coded (green: area 16 (North), orange: area 15 (South Wairarapa), blue: area 14 (Palliser Bay)).

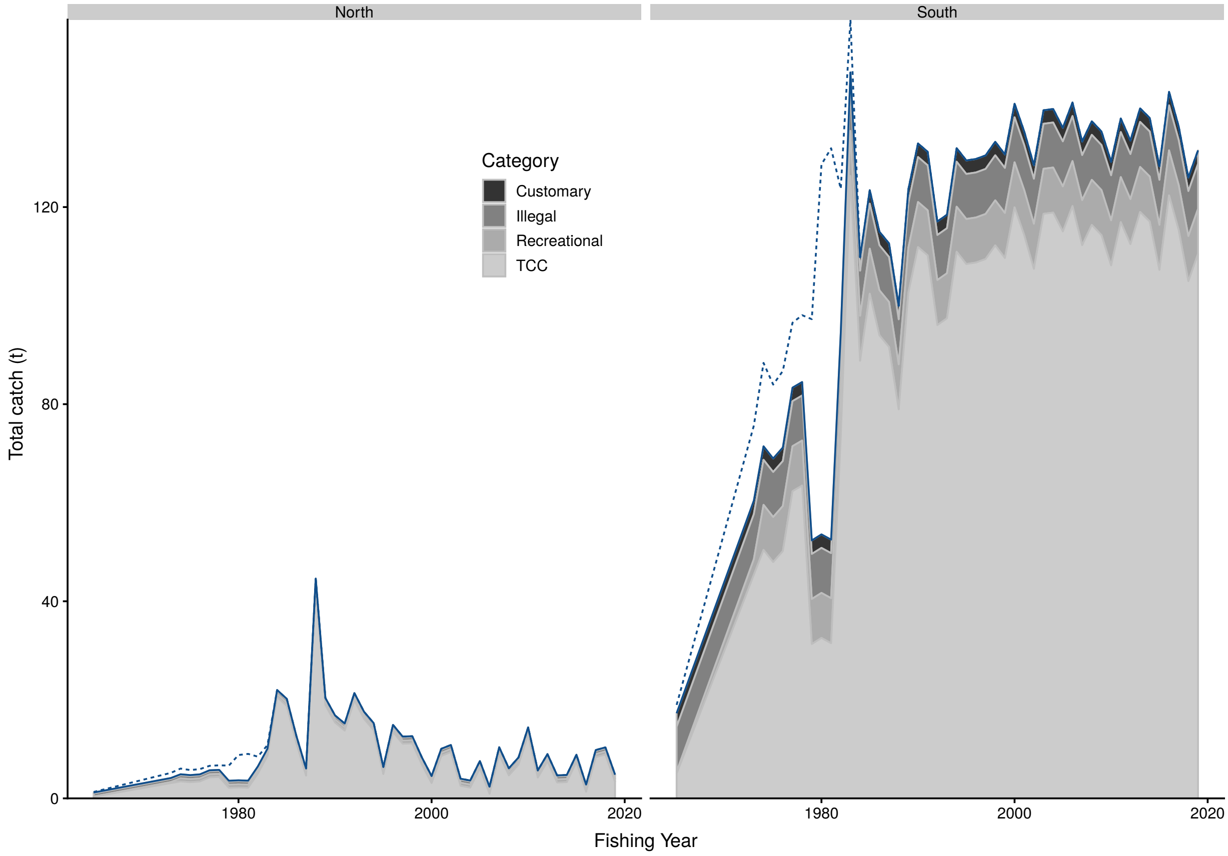

Figure 6: Estimated total catch history for Quota Management Area (QMA) PAU 2 from 1974 to 2019 by fishery component and reporting area. Fishery categories were customary, illegal, recreational and commercial (Total Commercial Catch, TCC) catch. Commercial catch was reconstructed up to 1995 when the QMA was created, and based on landing records thereafter.

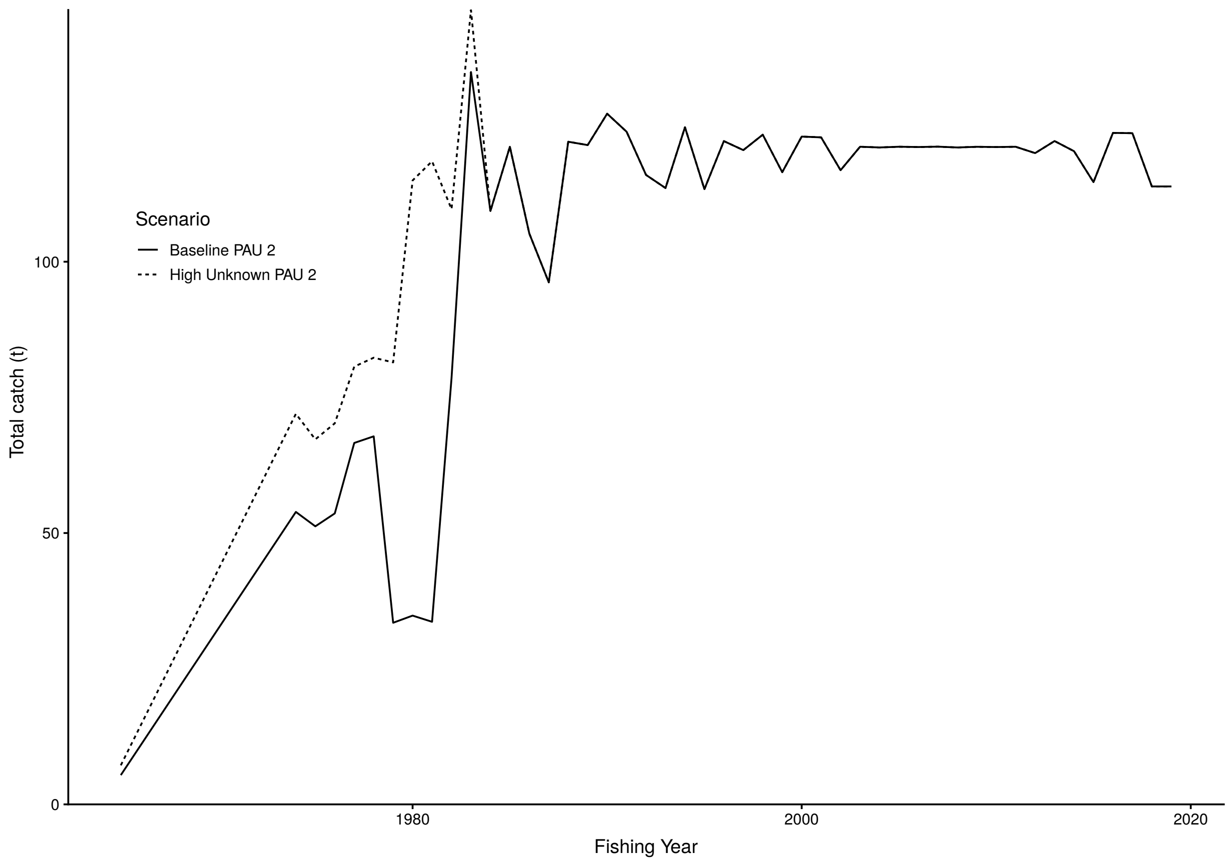

Figure 7: Total pāua catch history used in the single-area stock assessment for PAU 2 from 1974 to 2019 as the sum of all catch components

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2.1.3 Catch-per-unit-effort (CPUE)

In addition to both CELR (1989 to 2001) and PCELR (2002 to 2018) data, the stock assessment used data from the FSU period to construct a single CPUE index for the assessment. Data from the FSU were omitted from all recent assessments as they covered a relatively small proportion of the assumed catch at the time, and had infrequent recording of fisher identification numbers (FINs). This relatively infrequent recording of FINs in FSU data (and inconsistent numbering with subsequent reporting regimes) led to the omission of FINs from FSU data in the model.

The preparation of FSU data led to a 15% reduction in the number of records from a total of 2208 to 1967 FSU records (Table 1). The number of records was low for the last year of the FSU period; however, as the periods before and after this year had higher reporting, the latter was considered to be acceptable, because higher observation error would ensure that the point is less important in fitting CPUE data.

Table 1: Data preparation steps and number of records removed for Fisheries Statistical Unit data by year and in total (DI, diving).

Data preparation	1983	1984	1985	1986	1987	1988	Total
All	523	572	522	287	225	79	2208
Fishing method: DI	382	504	506	248	195	58	1893
Fishing duration: $\leq$10 h	369	443	427	220	189	49	1697

Data preparation procedures for CELR and PCELR data generally followed established protocols detailed by Fu et al. (2017) (see details of the data preparation in Tables 2 and 3). Nevertheless, a vessel correction factor was introduced here to remove records for which the difference between estimated and landed green weight was more than 20%. Discrepancies can result from a number of inconsistencies, such as draining of water from pāua before weighing, misreporting, or data transcription errors. The vessel correction factor is commonly used in stock assessments of New Zealand rock lobster and aims to ensure that these errors will not unduly affect the CPUE. Data preparation steps are summarised as follows:

1. Use only events with "diving" (DI) as method.
2. Remove items with missing fields needed for standardisation.
3. Remove events with a correction factor of $>$0.2.
4. Remove client/Fisher Identification Numbers (FINs), diver, and statistical areas that account for fewer than 20 dive events over all years.
5. Retain only events with eight or less recorded divers, and a recorded fishing duration of $\leq$12 h.

Table 2: Data preparation steps and number of records removed for data from Catch Effort Landing Return (CELR) forms by year and in total (as record numbers retained and percentage retained). DI, diving; VCF, vessel correction factor; FIN, fisher identification number. The number of records with diving method was used as the reference to calculate proportion of records retained.

Data preparation	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total	% retained
All	14	108	129	109	118	123	115	126	120	96	118	118	123	1417	108.67
Fishing method: DI	10	100	91	94	111	115	112	122	114	91	114	113	117	1304	100.00
Missing fields	10	100	89	94	111	115	110	116	113	88	112	111	116	1285	98.54
VCF <0.2	10	96	82	89	106	111	104	111	109	83	109	108	111	1229	94.25
Stat area dives >20	10	96	82	89	106	111	104	111	109	83	109	108	111	1229	94.25
FIN records >20	9	90	78	88	106	107	100	108	101	82	104	108	110	1191	91.33
Diver records >20	9	90	78	88	106	107	100	108	101	82	104	108	110	1191	91.33
No. divers ≤ 8	9	90	78	88	106	107	99	108	101	81	104	108	110	1189	91.18
Fishing duration/diver ≤ 12 h	9	90	78	88	102	107	99	107	100	78	97	101	110	1166	89.42

Table 3: Data preparation steps and number of records removed for data from Paua Catch Effort Landing Return (PCELR) forms by year and in total (as record numbers retained and percentage retained). DI, diving; VCF, vessel correction factor; FIN, fisher identification number.

Data preparation	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total	% retained
All	558	591	548	625	576	589	602	578	624	613	597	554	587	542	669	615	571	604	10643	100.00
Fishing method: DI	558	591	548	625	576	589	602	578	624	613	597	554	587	542	669	615	571	604	10643	100.00
Missing fields	557	591	548	625	576	589	602	578	624	613	597	554	586	539	669	614	570	595	10627	99.85
VCF<0.2	534	546	529	615	556	571	577	555	589	597	582	537	557	524	635	581	536	521	10142	95.29
Stat area dives >20	524	541	527	615	556	571	577	555	589	597	578	536	557	524	634	581	536	513	10111	95.00
FIN records >20	511	534	527	615	556	571	572	543	578	592	575	533	557	522	620	575	534	491	10006	94.01
Diver records >20	403	461	484	574	499	524	505	486	532	551	504	463	484	447	513	467	409	354	8660	81.37
No. of divers ≤ 8	403	461	484	574	499	524	505	486	532	551	504	463	484	447	513	467	409	354	8660	81.37
Fishing duration/diver ≤ 12 h	403	461	484	574	499	524	505	486	532	551	504	463	484	447	513	467	409	354	8660	81.37

For CELR data, records were required to be recorded as combined effort, but were usually recorded as individual effort (i.e., hours per diver instead of hours for all divers). In the data preparation of recent assessments, this aspect was addressed by using a cut-off time for fishing duration. For fishing durations above this threshold time, data were considered to represent combined effort. The threshold value was set by the SFWG upon inspection of fishing duration times recorded for individual divers and comparison with fishing duration records for events with more than one diver (Figure 8).

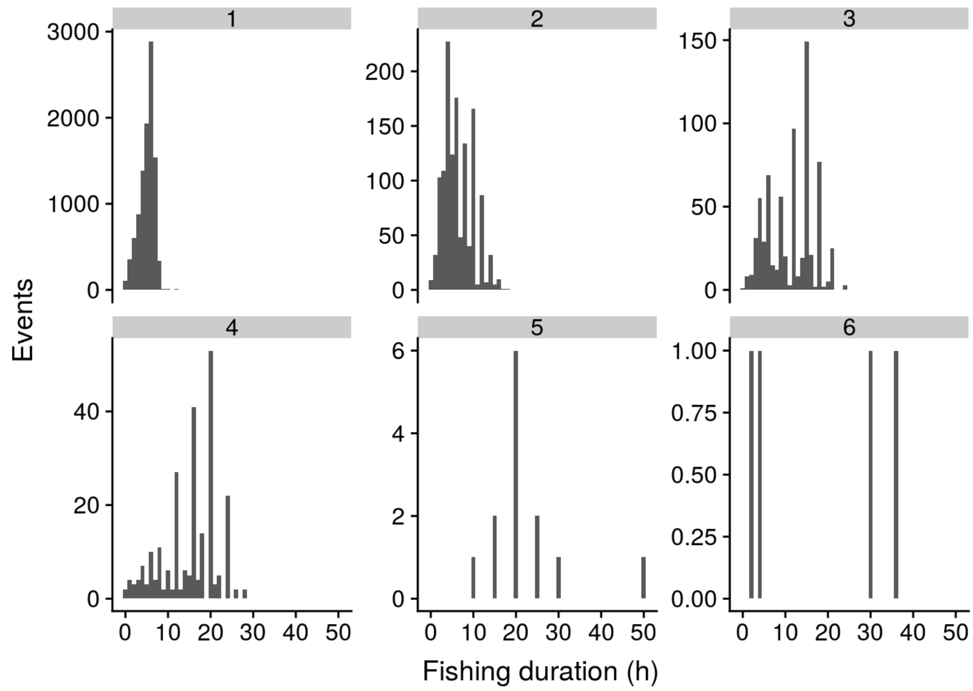

Figure 8: Reported fishing duration for (Pāua) Catch Effort Landing Return records by numbers of divers recorded (panels).

The current 2019 assessment for PAU 2 applied the effort classification model that was first developed for the 2018 stock assessment of PAU 5D. Briefly, the procedure classifies reported effort for each record to one of two reporting types (by diver/by crew) based on reported fishing times for events with single divers for each crew. The model employs year- and crew-specific effects for dive times to capture potential changes in reporting over time (see Neubauer & Tremblay-Boyer (2019a) for more detail on the methods).

In the preparation of CPUE data, one or the other reporting type was applied (i.e., direct use of duration per diver or reported effort divided by the number of divers in a crew), depending on classification outcomes. For any crew/year combinations where $p_{c,y}$ was $p > 0.05$ and $p < 0.95$, data were not used for standardisation because the reporting type was considered too uncertain.

For most crew and year combinations, the estimated reporting regime had high certainty (Figure 9), and the data were, therefore, retained for CPUE analysis (Figure 10). For some crews, the reporting regime changed over time and, for some records, the classification was ambiguous—these records occurred most frequently for crews with few records overall and/or for single years for some crews.

The current assessment of PAU 2 used methods developed previously for the stock assessment of PAU 5D (Neubauer & Tremblay-Boyer 2019a) to partition the observed variance in CPUE across reporting datasets; the residual variance in FSU (CELR) data was estimated due to factors accounted for in CELR (PCELR) data. All PCELR variables commonly used in the standardisation were nested within CELR variables, which were in turn nested in FSU data: divers were nested within Fisher Identification Number, fine-scale statistical areas were nested within larger research strata. The residual variance in FSU (CELR) data was, therefore, due to variance explained by CELR (PCELR) factors plus a common residual (see detailed model configuration by Neubauer & Tremblay-Boyer 2019a). Here, the model was applied both with and without FSU data, and in a spatial (including area-year effects) and non-spatial configuration.

The fit of the log-normal CPUE index model was considered reasonable (Figure 11), with an index that was relatively similar to the raw data, showing a marked increase in reported CPUE in the FSU years, followed by a sharp decline and a second increase during the 1990s (Figure 12). The index declined again over the early 2000s and has been stable since 2005. The FIN, diver identification, and dive conditions had the largest effect in the standardisation model (Figure 13): progressively more professional crews led to an increase in the CPUE index from the mid-1990s to the present year; in contrast, improved dive conditions in recent years led to a slight decrease in the CPUE (Figures 14 to 17). Diver ID and areas had relatively little impact after accounting for crew (FIN) and dive conditions.

The spatial model provided similar results to the non-spatial model in terms of standardisation (see Figure 12, Figure 18), with the more heavily-fished southern area showing a near identical index to the overall area, and the northern area showing an uncertain and highly variable index. The model without FSU data was nearly identical to the full model in all aspects, corresponding with the FSU data having relatively few records and no variables for standardisation.

The CPUE and estimated observation error (σ_{OBS}) were used as direct inputs to the model without further modifications, because process error is estimated within the model, based on relative weights for CPUE and commercial sampling length-frequency (CSLF) data.

2.1.4 Commercial sampling length-frequency (CSLF) data

The present assessment used a standardisation model for composition data (developed by Neubauer 2020) that adjusts the length-frequency samples based on spatial and temporal variability. This adjustment is similar to adjustments in CPUE applied during the standardisation of CPUE. This procedure has the advantage that reasonably smooth length-frequency distributions (i.e., filtering out variance from highly multi-modal length-frequency distributions that result from low sample numbers) for sparsely sampled strata can be extracted, even if individual samples in those strata are unlikely to provide a reliable estimate of the actual length-frequencies. Random effects formulations ensure the sharing of information across strata (see Neubauer 2020).

Composition standardisation was performed for CSLF data 1999–2000 using small-scale statistical areas, research strata (areas 14 to 16), and area-year as standardising variables. Region and year were entered as fixed effects, and area-year and statistical area were entered as random effects.

The standardisation led to small adjustments based on statistical areas for the 2001–02, 2002–03, and 2005–06 fishing years (Figure 19). For these years, a higher number of pāua were from statistical areas that contained individuals at smaller-than-average length. The model downward-adjusted the lower limb of the LF distribution in those years (and, by extension, upward-adjusted the tail of the LF distribution). The error bars for the estimated year and area-year effects from the model were comparatively large when few samples were available for any particular area-year combination, e.g., northern area predictions (Figures 20 and 21). In addition, fishing year 2008–09 was unusual in that large numbers of small pāua determined the length-frequency distributions; however, the corresponding CPUE did not increase, even though the peak was determined by a large recruitment pulse (see Figure 12).

2.1.5 Growth and maturation

In the present assessment, data were not fitted from individual growth tagging sites (i.e., three sites in PAU 2), because the sample size was generally insufficient to adequately estimate mean growth and variability across a fishery with high spatial heterogeneity in growth. Recent developments for pāua growth models suggest that flexible growth models based on energy balance equations (e.g., Ohnishi et al. 2012) can describe observed growth and maturation differences across pāua QMAs (Neubauer & Tremblay-Boyer 2019a). Here, an informed prior was used, derived from a meta analysis of pāua growth, allowing the model to adjust growth in accordance with other sources of information (priors on mortality M, CSLF, and CPUE input)(see priors for mean growth and growth standard deviation in Figure 22). At each length l, a proportion $z(l)$ of the population grows according to a log-normal growth prior, and a proportion $(1 - z(l))$ of pāua is located in areas with no growth at length l (Figure 22). Maturation was estimated simultaneously with growth in the meta-analysis.

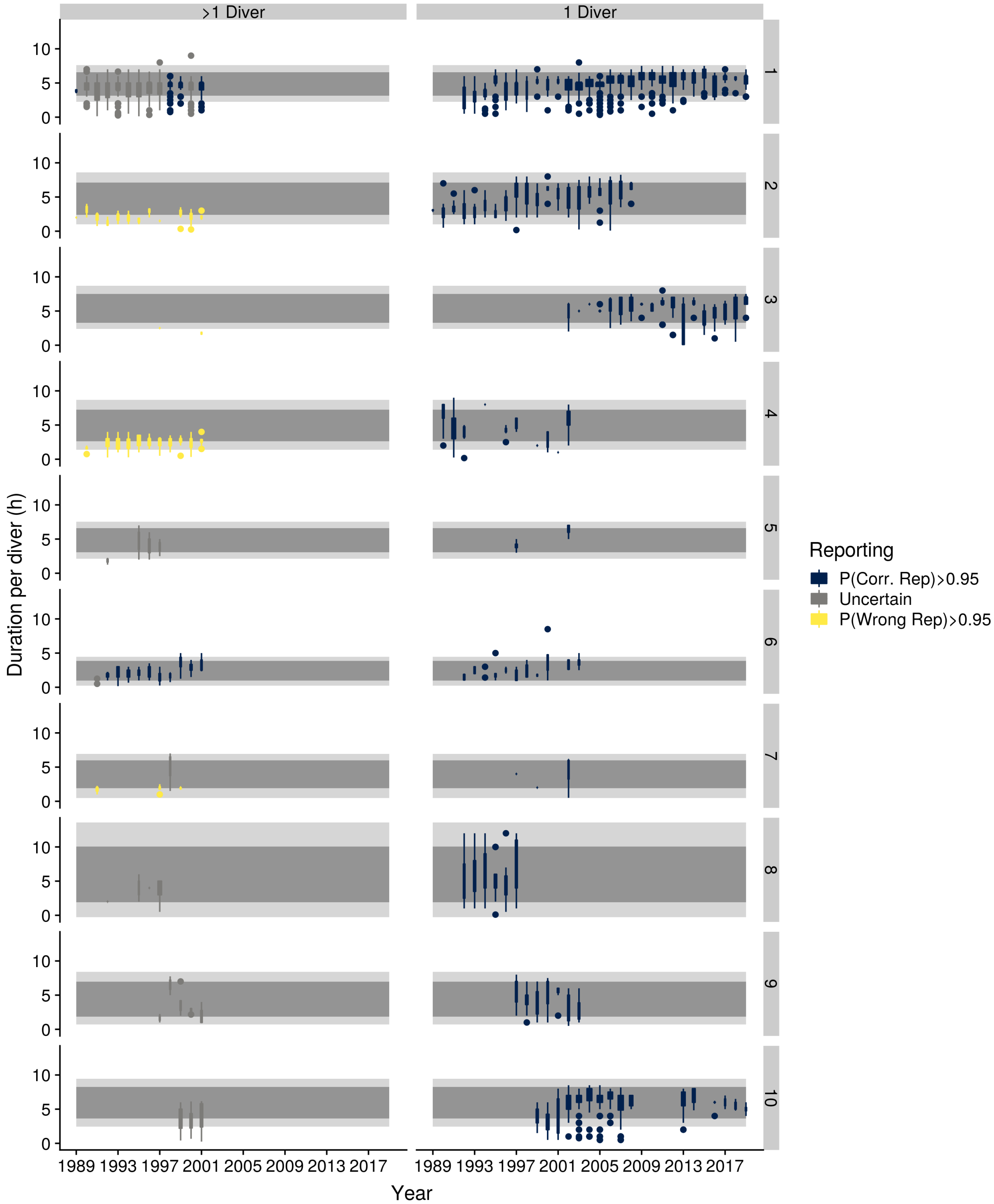

Figure 9: Classification of pāua fishing duration records into reporting by diver ($p \approx 1$; yellow) and by combined time in water ($p \approx 0$; blue) for events with more than one diver (left column). The right column is the "training data" with single diver records. Each line corresponds with one fishing crew (Fisher Identification Number), with the estimated distribution of fishing duration per single diver in grey (dark grey: 80% confidence; light grey: 95% confidence). For events with more than one diver (left column), the reported fishing duration was divided by the number of crew (boxplot), so that for records where reporting was by crew (i.e., correct; blue), the boxplot should be within the distribution indicated by the grey ribbon. Yellow boxplots are outside the grey distribution with >95% certainty and were reported incorrectly by diver rather than a combined total effort.

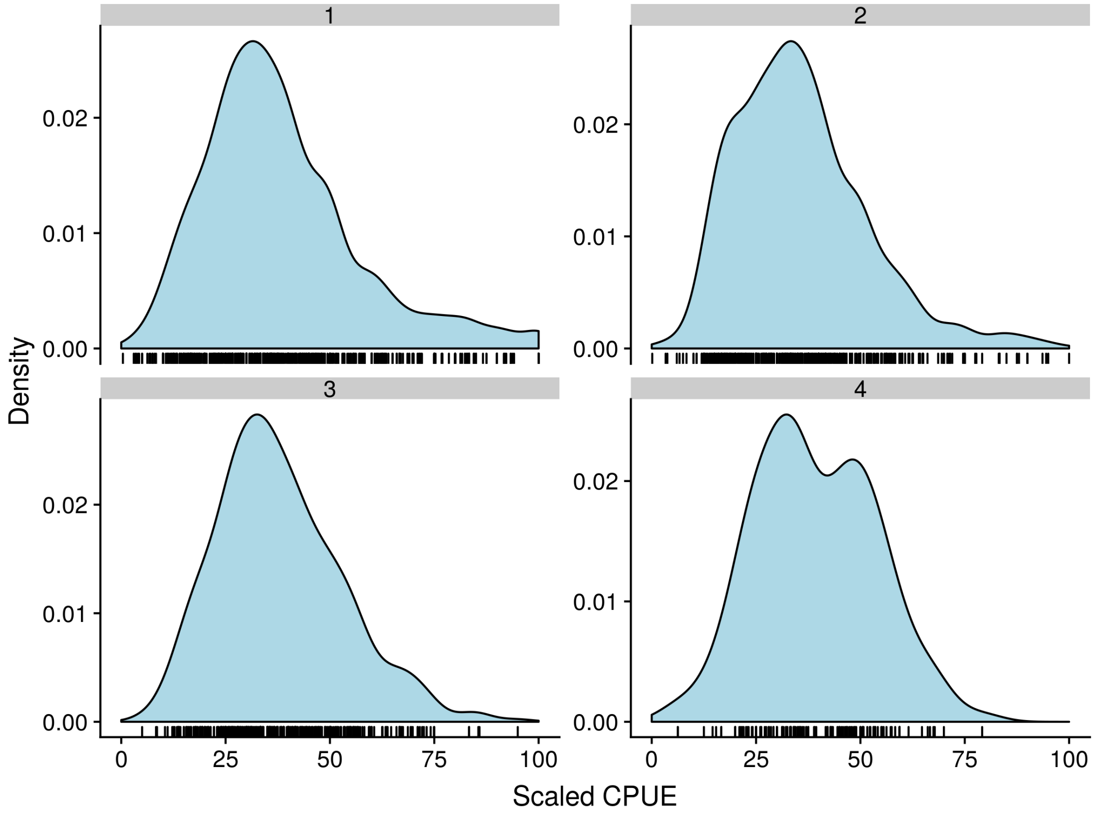

Figure 10: Densities of corrected pāua catch-per-unit-effort (CPUE) in PAU 2 by diver, for records with one to six divers in the crew.

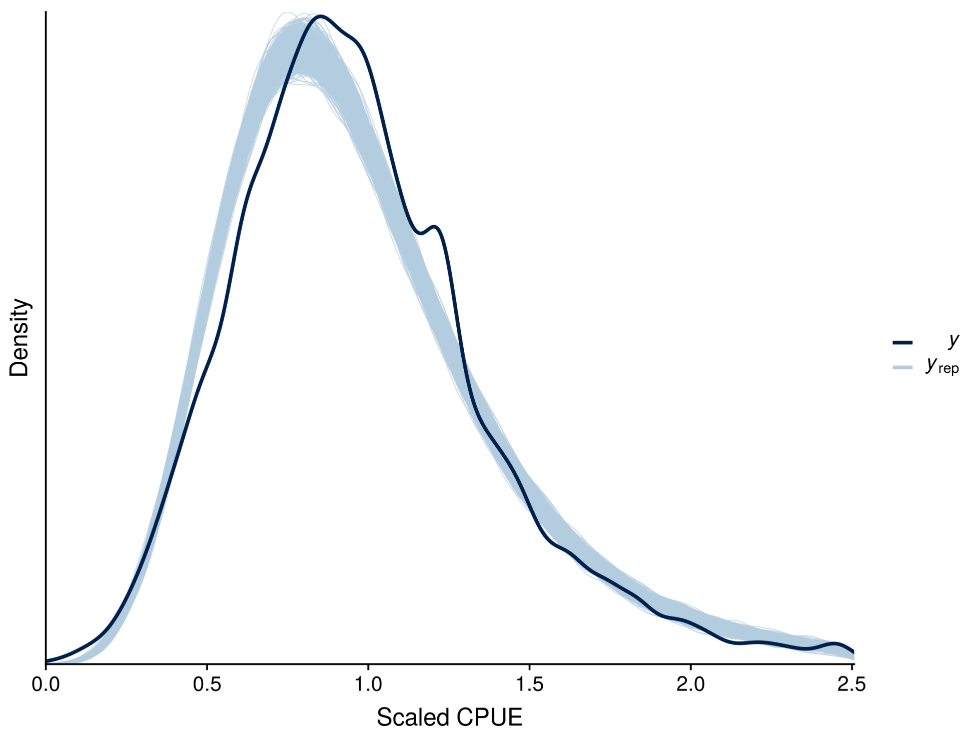

Figure 11: Fit of the log-normal generalised linear mixed model used for catch-per-unit-effort (CPUE) index standardisation. Shown is the cumulative distribution from posterior predictive draws from the model (i.e., predicting each data point; blue) compared with the empirical cumulative distribution (black line).

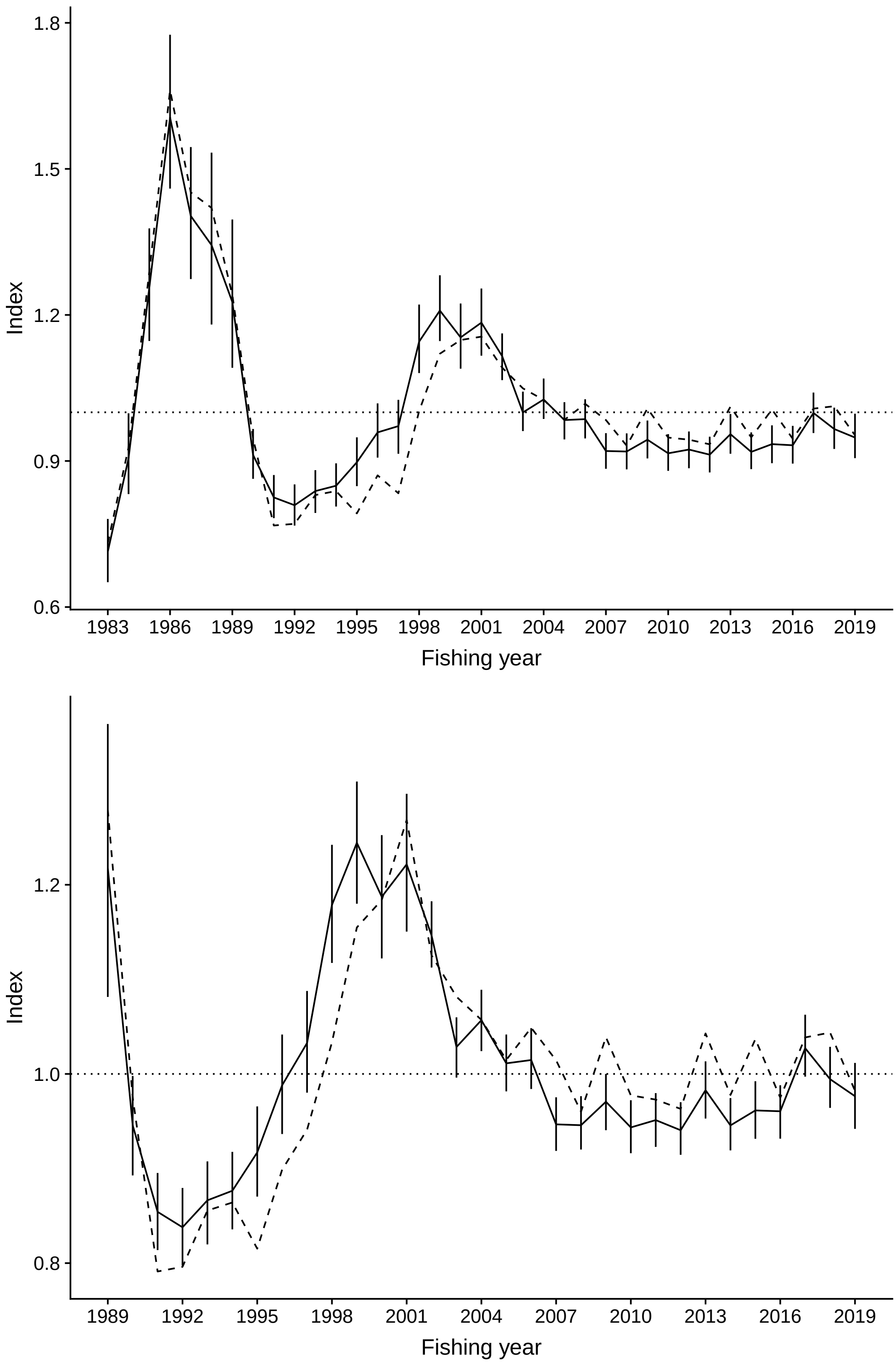

Figure 12: Standardisation of catch-per-unit-effort (CPUE) data using the generalised linear mixed model used for CPUE index standardisation. Shown are: (top) model applied to data including Fisheries Statistical Unit (FSU) data (bottom) above model with FSU data removed. Black lines/points with error bars show estimated CPUE index and 95% posterior quantiles. Un-standardised geometric mean CPUE included for reference (dashed line). All models were applied to data corrected by the classification procedure.

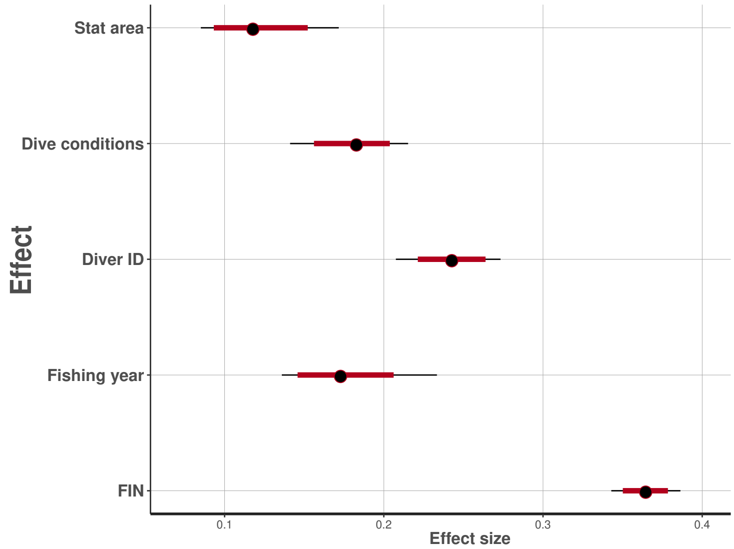

Figure 13: Effect size as variance explained for variables included in the random effects standardisation model.

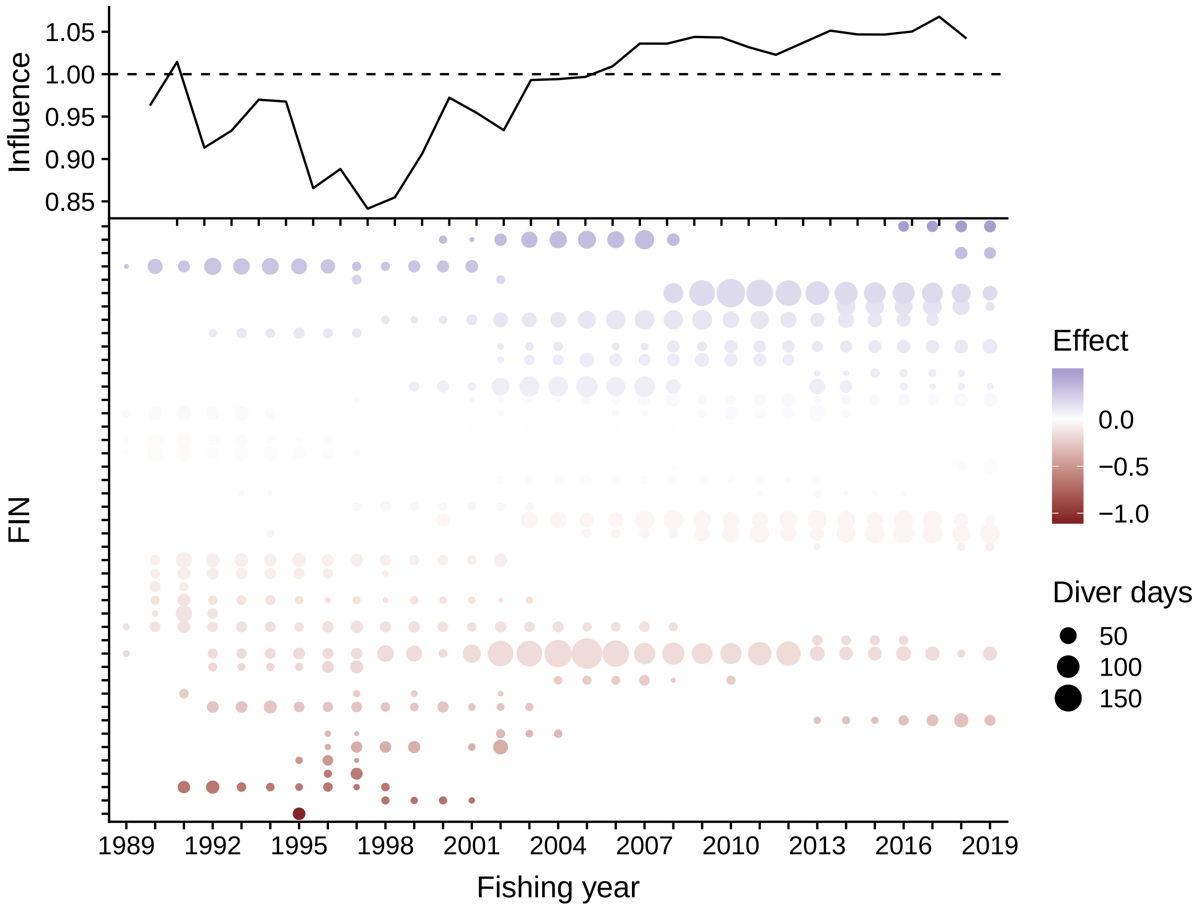

Figure 14: Influence plots for client number (FIN) effect, showing the effect on raw catch-per-unit-effort (CPUE; top graph) of applying estimated effect sizes (bottom graph) from the factor levels encountered each fishing year. (A positive (>1) influence for a given time period means that the unstandardised index was increased due to the relative distribution of the covariate.)

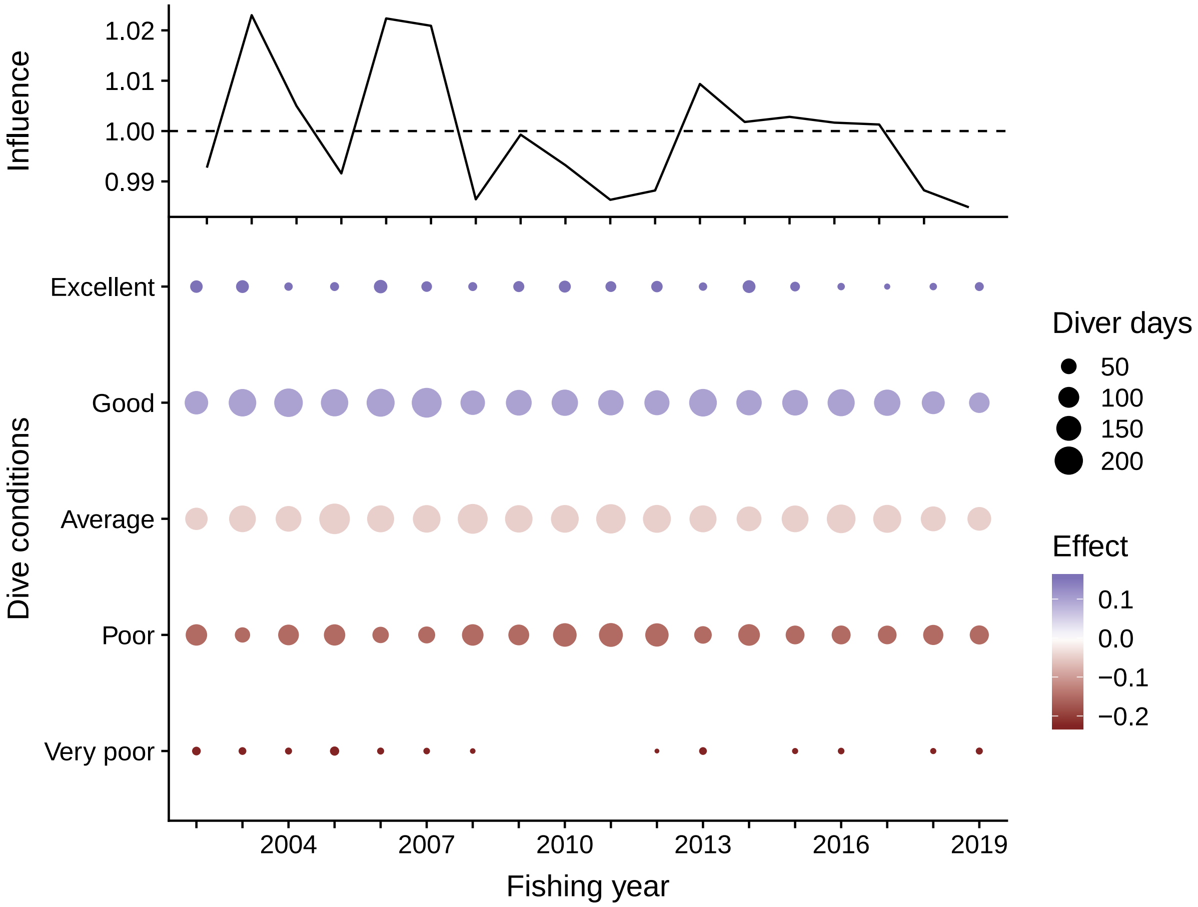

Figure 15: Influence plots for dive condition, showing the effect on raw catch-per-unit-effort (CPUE; top graph) of applying estimated effect sizes (bottom graph) from the factor levels encountered each fishing year. (A positive (>1) influence for a given time period means that the unstandardized index was increased due to the relative distribution of the covariate.)

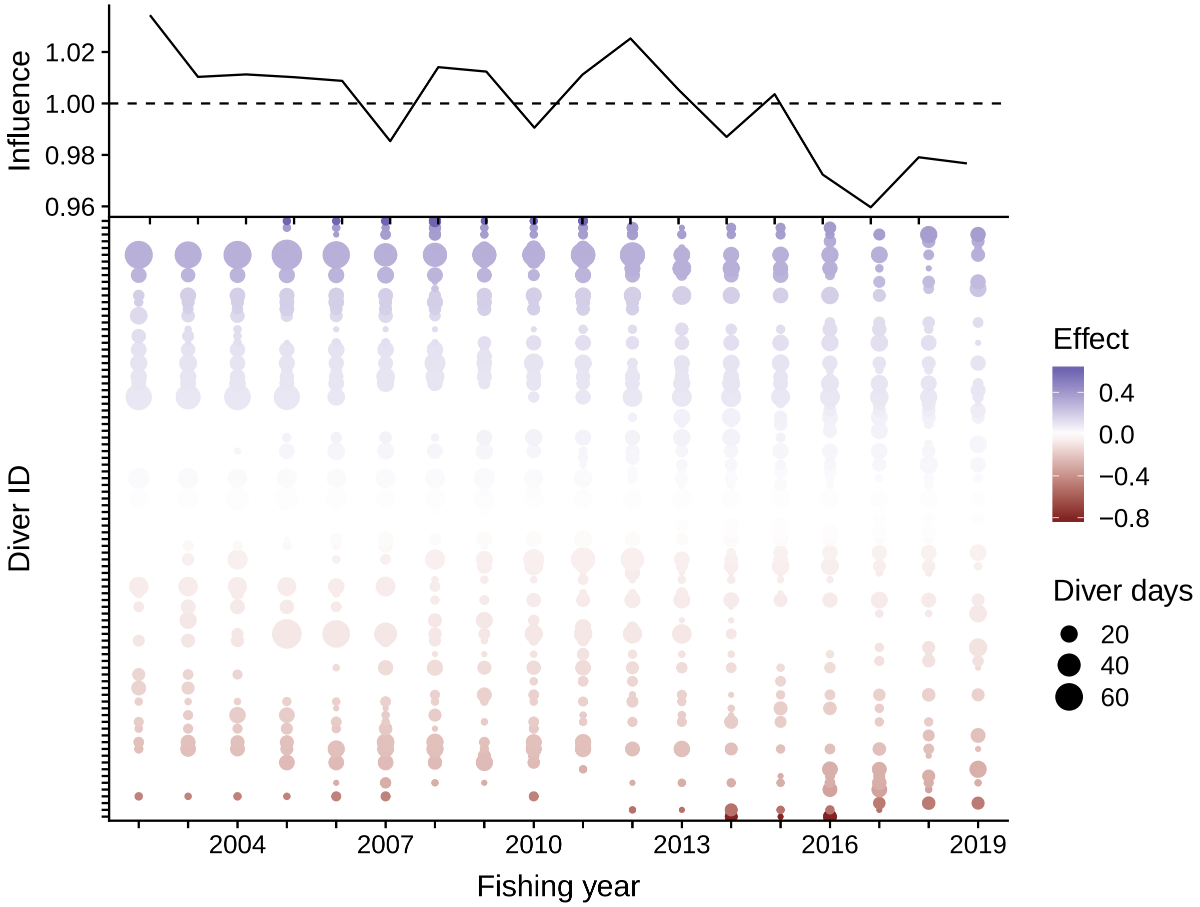

Figure 16: Influence plots for diver random effects, showing the effect on raw catch-per-unit-effort (CPUE; top graph) of applying estimated effect sizes (bottom graph) from the factor levels encountered each fishing year. (A positive (>1) influence for a given time period means that the unstandardised index was increased due to the relative distribution of the covariate.)

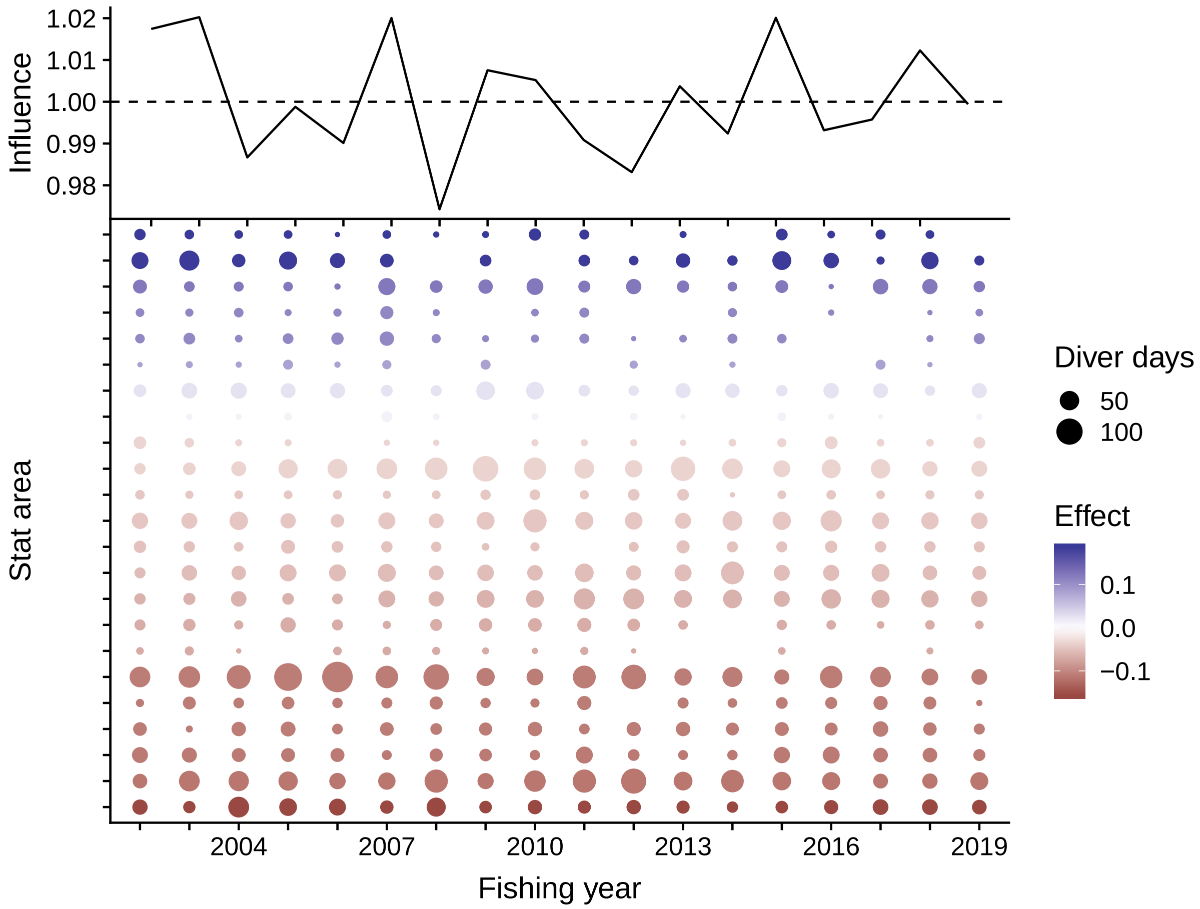

Figure 17: Influence plots for statistical (stat) area effect, showing the effect on raw catch-per-unit-effort (CPUE; top graph) of applying estimated effect sizes (bottom graph) from the factor levels encountered each fishing year. (A positive (>1) influence for a given time period means that the unstandardised index was increased due to the relative distribution of the covariate.)

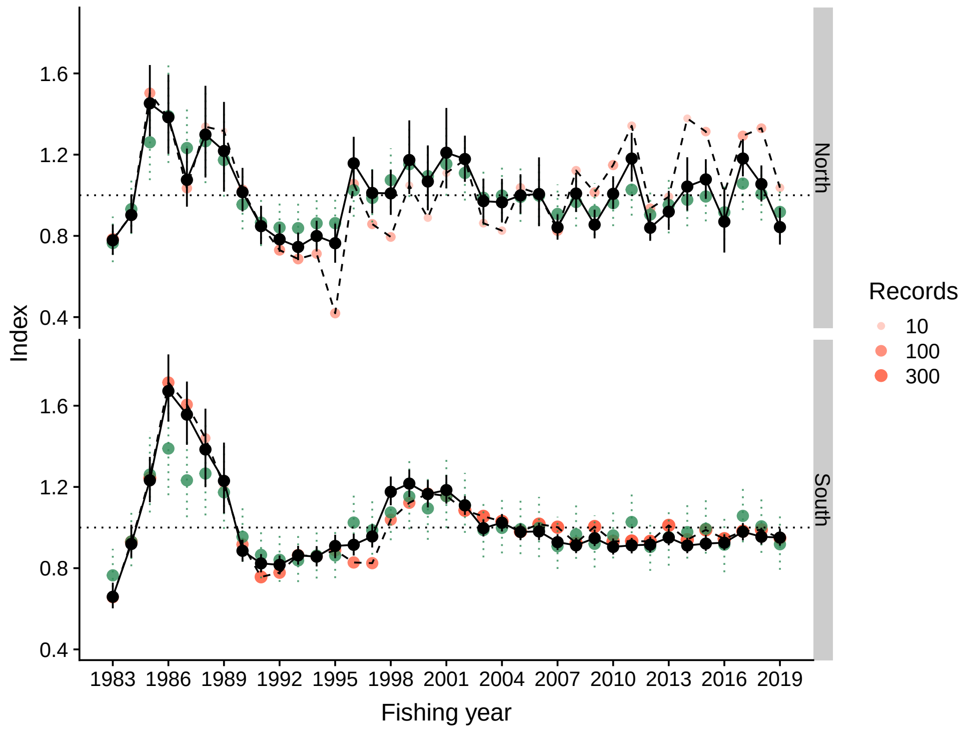

Figure 18: Standardisation of catch-per-unit-effort (CPUE) data using the generalised linear mixed model used for CPUE index standardisation using a model with area-year interaction; showing CPUE by area with FSU data included. Black points with error bars show estimated CPUE index and 95% posterior quantiles. Un-standardised geometric mean CPUE included for reference (dashed line). Red points show raw geometric mean CPUE with size and shading to indicate the number of records per year. Green points and intervals are estimated year effects across all of PAU 2.

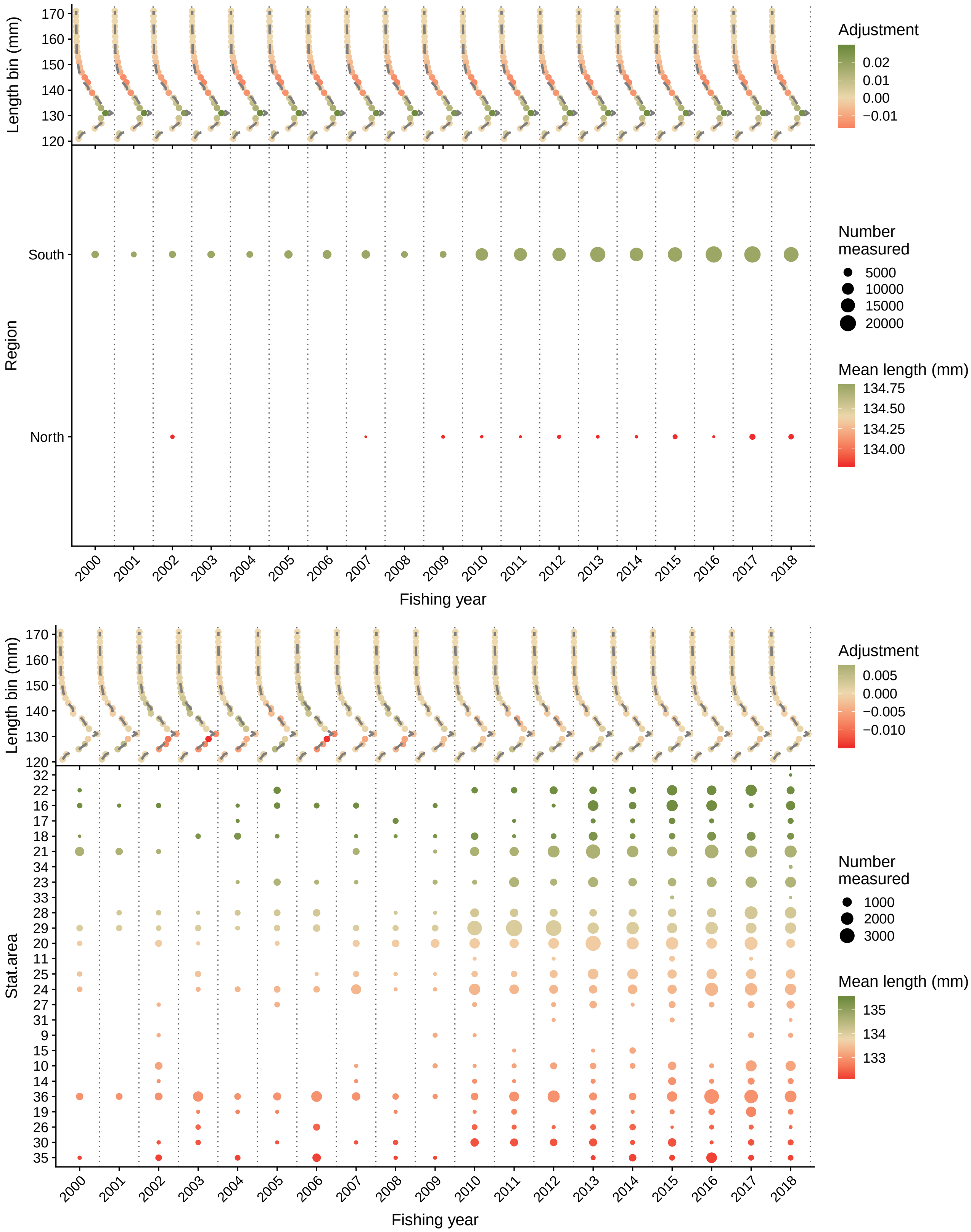

Figure 19: Effects plot for reporting area (top graph) and small-scale statistical area (bottom graph) effects plot for pāua management area PAU 2. For each graph, the top panel displays the direction of the adjustment from the raw catch sampling length frequency (LF; coloured points for LF classes) in each year and length class in relation to the fishing pattern (shown in the lower panel). Strata in the lower panel are sorted by the observed mean length to allow comparisons of their influence on estimated deviations in the upper panel.

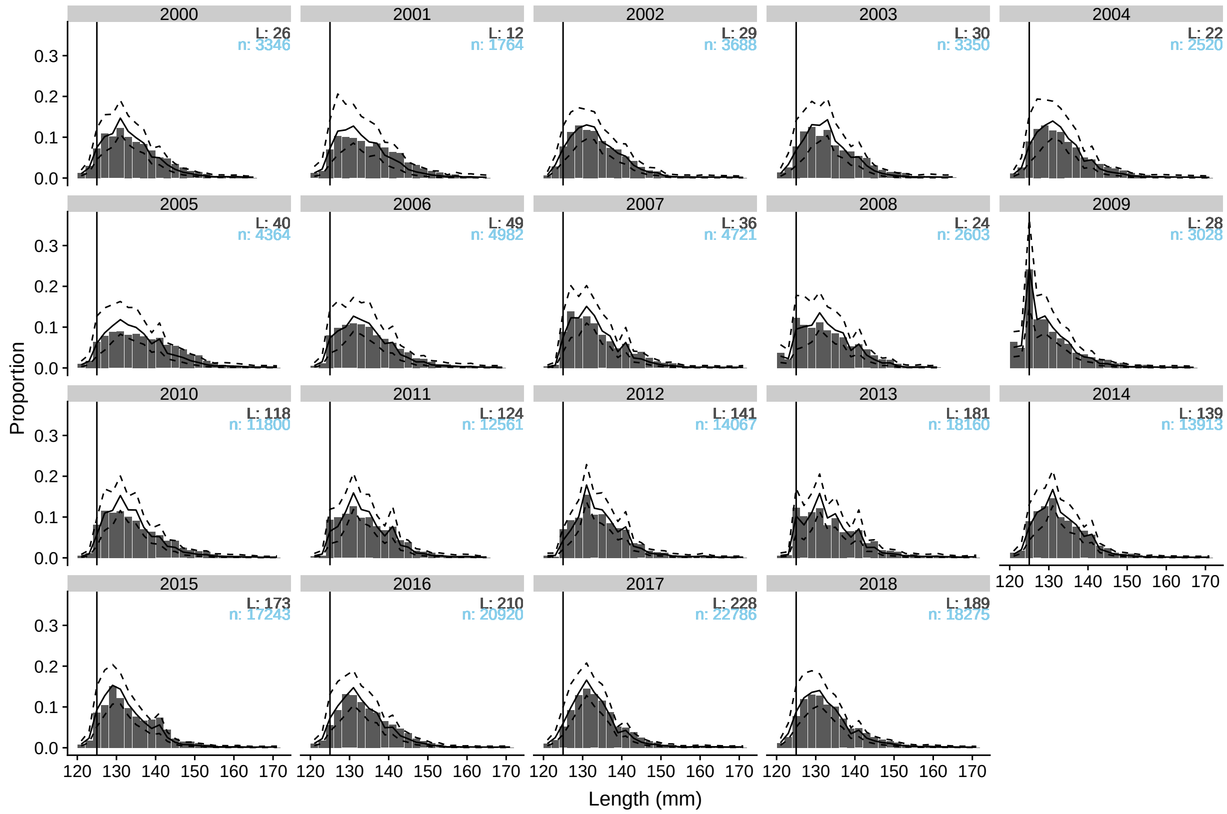

Figure 20: Dirichlet-Multinomial posterior distributions for yearly proportions π_y (black line) in pāua management area PAU 2, with 95% confidence intervals (dashed line). Raw catch sampling length frequency proportions are in grey; number of landings (L) in black; number of measurements (n) in blue.

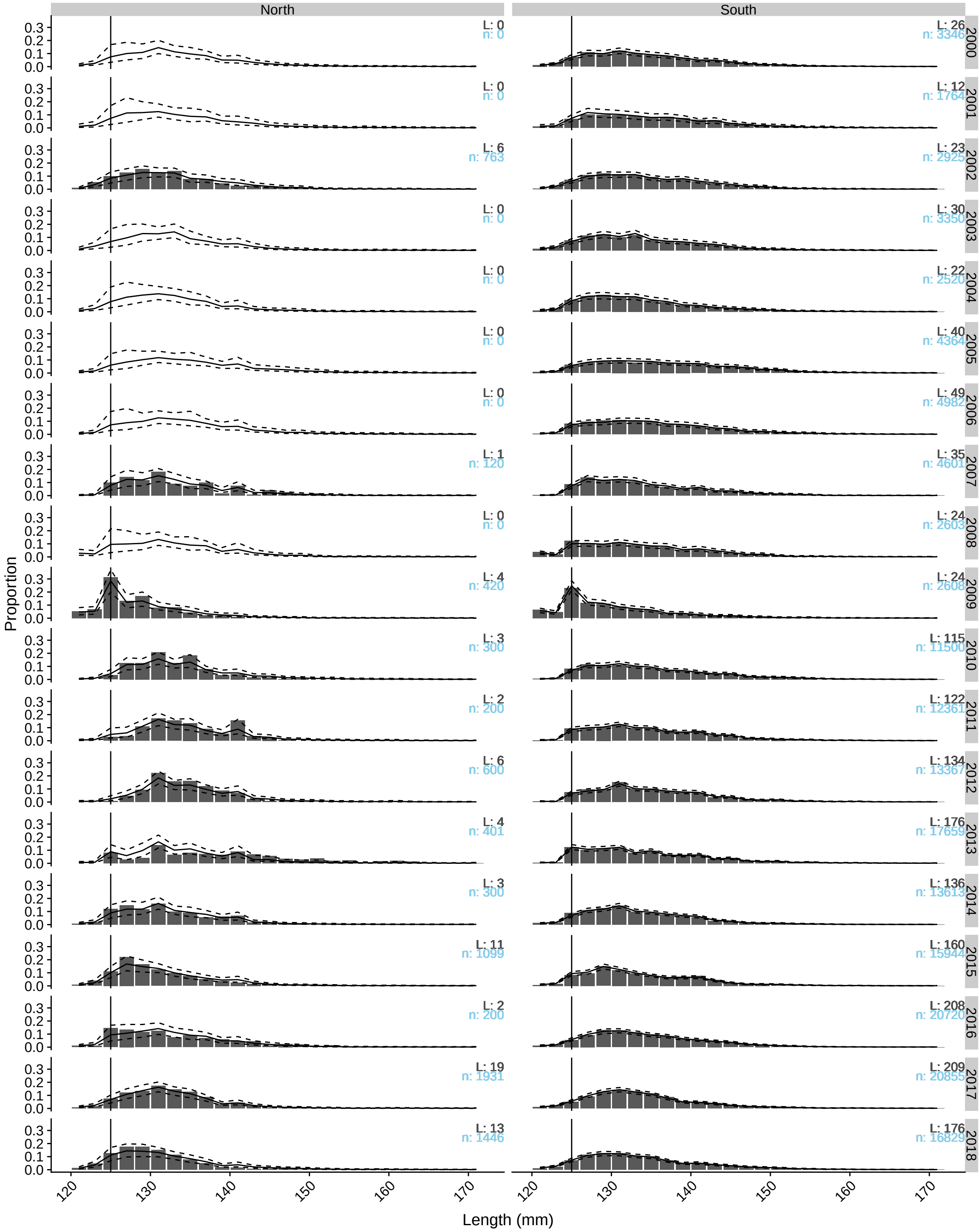

Figure 21: Dirichlet-Multinomial posterior distributions for yearly proportions $\pi_{r,y}$ (black line) in each of two geographical areas in pāua management area PAU 2, with 95% confidence intervals (dashed line). Raw catch sampling length frequency proportions are in grey; number of landings (L) in black; number of measurements (n) in blue.

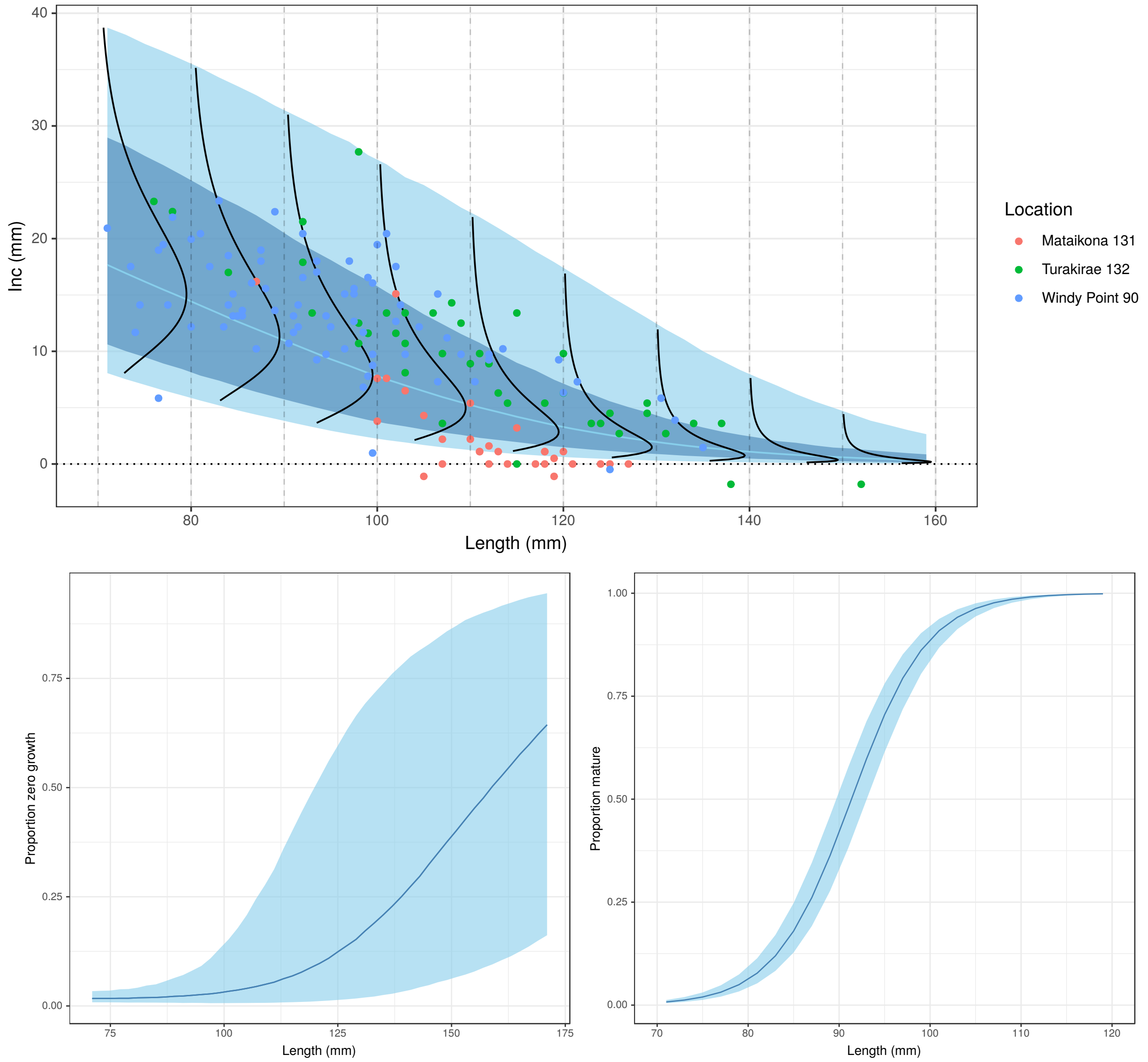

Figure 22: Priors implied from a meta-analysis of growth of pāua, based on model-fitting to all tag-increment data. Shown is the joint prior for positive growth increments and tag-recapture data from three sites in PAU 2 (top graph), proportion of local populations not growing at a particular size l (bottom left graph), and population level maturity (bottom right graph). For positive increments, dark blue shading shows uncertainty about mean growth, light blue line indicates posterior median for mean growth; light blue area shows the posterior median for the population standard deviation applied to mean growth; black line indicates the implied distribution of growth at the median of the prior.

2.2 Assessment model

2.2.1 Summary of changes from recent assessments

The stock assessment model in this assessment used the general length-based population dynamics model that was developed by Breen et al. (2003) and used in subsequent stock assessments (e.g., Marsh & Fu 2017), with changes introduced in the 2018 pāua stock assessment for PAU 5D by Neubauer & Tremblay-Boyer (2019b).

Key developments in the current analysis included:

- Restricting estimation of recruitment deviations to years with CSLF data to avoid over-fitting CPUE in early years and introducing spurious patterns in other parts of the model (e.g., estimated increases in catchability).
- Estimating dome-shaped selectivity: although diver-level selectivity is likely determined by minimum harvest sizes, population-level selectivity likely varies with spatial fishing patterns (Waterhouse et al. 2014). Because the latter patterns are variable, large pāua may be left in the water in some areas and years. For this reason, the present assessment trialled a dome-shaped selectivity and also a time-varying selectivity as a process error term for both logistic (variable size at 50% maturity) and dome-shaped (variable doming) selectivity to explore potential effects.
- Increases in catchability q were estimated either across the entire period for which CPUE data were available, or for CPUE reporting epochs (i.e., fitting separate catchability coefficients [q]).
- A spatial assessment model of the same form as the single-area model, but split by area, was applied alongside the single-area model to ensure that differences in dynamics among areas do not bias the large-scale assessment (Neubauer 2020).

2.2.2 Assessment specification

The main pāua population dynamics are described by Breen et al. (2003), but some changes were recently implemented following recommendations by an international expert review panel for the stock assessment (Butterworth et al. 2015). Detailed equations for the most recent version of the population dynamics mode are provided by Neubauer & Tremblay-Boyer (2019b).

2.2.3 Prior distributions

The CPUE process error was estimated in the model using a half-normal prior distribution (N^0), with prior standard deviation $\tau_{PE_{CPUE}}$:

$$\mathrm{PE}_{\mathrm{CPUE}} \sim \mathrm{N}^0(\tau_{\mathrm{PE}_{\mathrm{CPUE}}}).$$

Similarly, the CSLF process error was estimated in the model using a half-normal prior distribution, with prior standard deviation $\tau_{\mathrm{PE}_{\mathrm{CPUE}}}$.

Recruitment deviations (R_{dev}), equilibrium recruitment (R_0), natural mortality (M), catchability (log(q), length at 50% selectivity (D_{50}), and 95% selectivity offset (D_{95}) were assigned log-normal priors, parameterised in terms of mean and standard deviation (sd; on the log-scale), with the sample mean for R_{dev} forced to one.

Steepness h was estimated in this iteration of the assessment model and was assigned a beta distribution prior with parameters a and b, with $a = 10$ and $b = 4$ the default prior, leading to a wide prior that put most of the weight at $h > 0.5$ (see Table 4 for other default priors).

Table 4: Default priors used in the pāua stock assessment model (LN=Lognormal, N=Normal, N^0=half-normal), with prior mean and standard deviation (SD) shown on the log-scale and on the positive scale (CPUE, catch-per-unit-effort; CSLF, catch sampling length frequency).

Parameter	Symbol	Prior	Mean	SD	Mean (pos)	SD (pos)
Equilibrium recruitment	R_0	LN	13	0.5	5.01×10^5	2.67×10^5
Recruitment deviations	R_{dev}	LN	0	1	1.65	2.16
Natural mortality	M	LN	log(0.1)	0.2	0.1	0.02
Catchability	q	LN	-13	2	1.67×10^{-5}	0
Length at 50% selectivity	D_{50}	LN	log(123)	0.05	123.15	6.16
95% selectivity offset	D_{95}	LN	log(5)	0.5	5.67	3.02
Steepness	h	Beta			0.71	0.12
CPUE process error	PE_{CPUE}	$N^0(0.05)$		0.04	0.03	
CSLF process error	PE_{CSLF}	$N^0(1)$		0.80	0.6	

Prior predictive simulations were used to assess the impact of different formulations of priors for R_0 for final stock status and maximum depletion. The procedure is similar to stochastic stock-reduction analysis (Walters et al. 2006) and can be considered as deriving a joint prior for R_0 and depletion level in the absence of *a priori* information on R_0 (Poole & Raftery 2000). The procedure is as follows:

1. Draw *n* values from prior for all parameters.
2. Simulate trajectories using same length-based dynamics used in the stock assessment, removing observed catches for each area and year.
3. Compare the parameter space where available biomass is greater than zero for all years with the prior, discard any prior values where available biomass is below zero, retain *n* trajectories simulated from the reduced prior.
4. Inspect the distribution of stock status and maximum depletion implied by all *n* retained draws.

An overly vague prior for either R_0 implies a strong prior on current stock status and maximum depletion: at high values for R_0, the resulting scale of the biomass implies that fishing has no impact—the prior markedly favours a stock status that reflects no fishing impact. In contrast, small values for R_0 will lead to the rapid depletion of stocks in prior simulations, and these values are thus discarded. The prior for R_0 is then adjusted to obtain a prior on stock status that is consistent with expectation. For PAU 5A, the prior was set at $R_0 = LN(13.5, 0.5)$, which leads to a near-normally distributed prior over stock status that is centred on 0.5 and allows for some prior weight near the soft- and hard-limit reference points of 0.2 and 0.1 of spawning stock biomass SSB_0 (Figure 23). For additional detail about the procedure see Neubauer (2020).

2.2.4 Data weighting

In this assessment, the Kullback-Leibler divergence (KLD) was used as an alternative method for data weighting through a measure of information loss. The method relies on the premise that there should be no *a priori* weight for any one dataset, and that relative weight should emerge as part of the analysis and model refinement process. In addition, the method makes use of the total distribution for the compositional data instead of only the first moment (e.g., mean length).

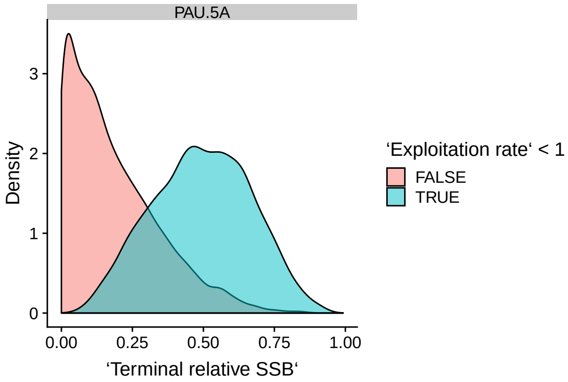

Figure 23: Prior induced on stock status (relative depletion) by the informative prior on equilibrium recruitment R_0 and all other priors in the model. Red shows draws that are discarded *a priori* based on exceeding the exploitation rate limit.

The method used previously (in the 2018 stock assessment for PAU 5D, see Neubauer & Tremblay-Boyer 2019b) was slightly modified to calculate the KLD. The combination of process and observation error (OE) was used previously to calculate the KLD across Y years for the normally-distributed log CPUE index:

$$\mathrm{KLD}_{\mathrm{CPUE}} = 1/Y \sum_y 0.5(\log(\frac{\mathrm{OE}_y^2 + \mathrm{PE}^2}{\mathrm{OE}_y^2}) + \frac{\mathrm{OE}_y^2 + (\mathrm{CPUE}_y - \mathrm{CPUE}_y^M)^2}{\mathrm{OE}_y^2 + \mathrm{PE}^2} - 1), \tag{1}$$

and the multivariate equivalent (scaled to match the univariate KLD) for the CSLF inputs:

$$\begin{aligned}\mathrm{KLD}_{\mathrm{CSLF}} = 1/Y \sum_y 0.5L^{-1}\Big(\log\left(\frac{|\Sigma_y^M|}{|\mathrm{OE}_y|}\right) + \mathrm{tr}((\Sigma_y^M)^{-1}\mathrm{OE}_y) - L + \\ (\mathrm{CSLF}_y - \mathrm{CSLF}_y^M)(\Sigma_y^M)^{-1}(\mathrm{CSLF}_y - \mathrm{CSLF}_y^M)\Big),\end{aligned} \tag{2}$$

with $\Sigma_y^M = \mathrm{OE}_y(1 + \mathrm{PE})$ the covariance matrix including OE and PE. The latter terms refer to observation and process error for each data source, respectively.

This previous formulation limits the divergence from the inputs since the process error will be larger for larger deviations, leading to a smaller KLD. For the present assessment, a parametric (multivariate) normal approximation was assumed instead for the posterior distribution of the log CPUE, and the centred-log-ratio (clr)-transformed CSLF data. This assumption has the advantage that marked deviations from the inputs that are nevertheless certain (i.e., they have low posterior variance, but high process error) lead to larger KLDs. The updated formulation is then:

$$\mathrm{KLD}_{\mathrm{CPUE}} = 1/Y \sum_y 0.5(\log(\frac{\mathrm{var}(\mathrm{CPUE}^M)}{\mathrm{OE}_y^2}) + \frac{\mathrm{OE}_y^2 + (\mathrm{CPUE}_y - \mathrm{CPUE}_y^M)^2}{\mathrm{var}(\mathrm{CPUE}^M)_y} - 1). \tag{3}$$

For the CSLF data, Σ_y^M was re-defined to be the empirical covariance matrix of model-predicted CSLF, $\Sigma_y^M = \mathrm{var}(\mathrm{CSLF}^M)$.

The initial data weighting started with a set of weights that had been found to provide reasonable fits for both CPUE and CSLF data in the spatial stock assessment model for pāua and the stock assessment for PAU 5D (Neubauer 2020, Neubauer & Tremblay-Boyer 2019b). These weights were then varied to assess the effect of weighting of CSLF and CPUE data on model outcomes.

2.2.5 Technical model details

The model was initialised for a period of 60 years with constant recruitment at R_0 and no fishing.

All Markov chain Monte Carlo algorithms (MCMCs) were run using the no-u-turn-sampler (NUTS) implemented in Stan (Stan Development Team 2018). The Stan language is more efficient than conventional Metropolis Hastings or Gibbs sampling for MCMC, and it also provides diagnostics that can signal biased MCMC transitions (divergences) and potential bias in estimated quantities from these transitions. All MCMC chains were, therefore, monitored for divergent transitions to ensure that MCMCs were not biased. Initial models were run with four independent chains for the MCMC, and 500 iterations were kept after discarding the initial 500 iterations. For the final base case and sensitivity, eight independent chains were run over 6000 iterations, with the first 1000 samples discarded for each chain, and a further 5000 samples saved for inference and post-processing.

2.3 Stock assessment

The stock assessment included several sets of model runs, including an initial exploration.

Set 1: CPUE, catch set and structural sensitivities

A first set of model runs explored several aspects:

- Including or excluding the CPUE data from the FSU.
- Estimating a trend in catchability q and forcing hyper-stable CPUE.
- High catch in the 1970s to account for potential mis-reporting of catch during the 1970s and 1980s.
- Low recruitment variability.

The trend in q was implemented as a linear trend, with an intercept of $log(q)$ and slope $\theta_{\log(q)}$. Data weight parameters were set to values that produced fits that were considered in other assessments.

Set 2a: Selectivity, using separate q for epochs, and estimating recruitment for CSLF years only

The outcomes from the first set of models showed that the models were using recruitment to adjust the biomass for increases in CPUE during the period of the FSU data; and also, after an initial decline in the late 1980s and early 1990s (for models without FSU data). Interviews with divers at the time suggested that mis-reporting was prevalent in early years preceding the Quota Management System (QMS; i.e., before 1986), and that a considerable amount of catch was un-reported at the time. In addition, the late 1980s and early 1990s marked a period of change with operators selling quota to new entrants into the fishery, who started fishing with little experience or geographical knowledge of the stocks, leading to a rapid decline in CPUE that was likely largely unrelated to the stock itself. The ensuing period of CPUE increase coincided with a period of rapidly increasing efficiency of these new operators (e.g., improvements in dive gear, operational aspects, weather forecasting) in all pāua fisheries throughout New Zealand. This aspect was evident in some degree of CPUE increases during this period. The SFWG, therefore, decided to use fixed recruitment for all years until CSLF information is available (in 2000–01); in addition, the SFWG decided to use variable catchability by splitting catchability into reporting epochs (FSU, CELR, and PCELR) and estimating the increase in catchability for each epoch.

Owing to uncertainty about the accuracy in early FSU reporting and implausible scenarios resulting from excluding FSU data, the present assessment trialled estimating initial depletion in 1986 (and not considering both catch and CPUE prior to 1986), starting CPUE in 1986 instead of 1983, and only using the catch time series with high unreported catch from 1965.

In addition to fixing early recruitment, it also trialled using variable selectivity to account for spatially-variable fishing patterns that likely determine some of the CPUE variation (instead of variation being determined by recruitment): if fishers only fish a subset of available areas in any given year (due to weather or market constraints), variable (and potentially dome-shaped) selectivity would be expected given small-scale variation in growth and fishing pressure. Both variable logistic selectivity (variable length at 50% selection), and fixed and variable dome-shaped selectivity (with variable right hand limb of the inverted quadratic curve) were trialled. Models with variable dome-shaped selectivity did not converge, and were, therefore, excluded from this assessment.

In summary, the second set of models was set up as follows:

- including the CPUE index from the FSU data, but starting CPUE in 1986, or estimating initial depletion in 1986 (starting catch and CPUE in 1986);
- estimating a trend in catchability by CPUE reporting period (using separate initial q for FSU, CELR, and PCELR);.
- using the high-catch scenario for which a quarter of the un-attributed catch was attributed to PAU 2;
- fixed recruitment prior to CSLF data availability (estimated from three years prior to first year of CSLF data);
- variable logistic selectivity and dome-shaped selectivity (fixed; variable dome-shape did not converge).

Set 2b: Spatial model runs for Set 2a

A variation of the second set of model runs explored the same scenarios as above (Set 2a), using the spatial model described in Neubauer (2020) for each of the two large-scale reporting strata: areas 15 and 16 (South Wairarapa) were grouped into one southern stratum, with the sporadically-fished area 14 included as the northern stratum. Natural mortality and steepness were shared parameters, whereas recruitment was estimated independently for each area; unfished recruitment was partitioned into each of the two areas using a composition vector that is estimated within the model.

Set 3: Data weights, and estimating recruitment for CSLF years only

Subsequent investigation focused on the robustness of models from the first two sets (1 and 2) that were considered plausible (baseline catch with CPUE from the FSU data from 1986, with or without recruitment deviations for pre-CSLF period, with or without variable selectivity) by varying model weights. Three sets of weights were trialled in addition to weights used in sets 1 and 2: all sets down weighed CPUE by a factor of two relative to sets 1 and 2, and either doubled (0.20) or halved (0.05) CSLF weights.

Plenary model runs: base case and sensitivities

Review of the Fisheries Assessment Plenary identified concerns about the reliability of early FSU and CELR data, and about recent CPUE from PCELR and Electronic Reporting System (ERS) data. The latter data were considered to be potentially affected by COVID-19 related changes in markets and fishing behaviour, and by a substantial reduction in ACE-holders in the fishery for 2020 and 2021. As a result, the Fisheries Assessment Plenary requested updates to the models to remove CELR and recent (2019–20 and 2020–21) ERS CPUE from the analysis.

The Fisheries Assessment Plenary also requested a number of minor changes, such as the recruitment lag (moved from 3 to 5 years), and fixing natural mortality in favour of estimating the parameter. This request led to a base case scenario with M=0.11, and sensitivities at M=0.06 and M=0.16 (diagnostics for these three model runs are reported in detail in Appendix B).

3. RESULTS

Set 1: CPUE, catch set and structural sensitivities

The initial set of model runs showed poor MCMC diagnostics, likely due to an inability of the model to reproduce the strongly oscillating CPUE trend in the absence of concomitant changes in catch. Reproducing considerable CPUE oscillations can only be achieved with large recruitment variations and high mortality M that pomptly removes the new recruits from the partition. These models were not developed further, but were used to guide modelling selections for Set 2 (results from the model runs are in Appendix A.1, Figures A-1 to A-9).

Set 2a: Selectivity, using separate q for CPUE epochs, and estimating recruitment for CSLF years only

Models in the second set of model runs produced two sets of outcomes: all models with variable selectivity and/or estimated recruitment prior to CSLF data fit CPUE well in the late 1980s and early 1990s, but these models did not estimate the increase in catchability q that is considered to have occurred during the CELR years (see Appendix A.2, Figures A-10 to A-18). All models that assumed constant recruitment prior to 1999–2000 led to an estimate of considerable (but variable among models) increase in q for the CELR period (1990s; shown as lnqCPUE[4] in Figure A-10). Outcomes from all models were at or near 40% of unfished stock biomass.

Estimating initial depletion in 1986 did not lead to a number of markedly divergent estimates for initial depletion (i.e., the mode of the posterior distribution for initial depletion was highly variable; see examples in Figure A-10). Due to this lack of consistency and challenges in estimating plausible initial depletion states in the stock assessment for PAU 5A (conducted in parallel, see Neubauer 2022), initial depletion state estimates were considered unreliable.

Models with variable estimated selectivity provided both lower and higher stock trajectories and status compared with the model with fixed selectivity (Figures A-18 and A-38). The models with dome-shaped selectivity led to lower stock status than models with logistic selectivity, and models with variable logistic selectivity led to the highest estimated stock status. The (invariable) left-hand limb of the curve was estimated near post-2006 selectivity for models with logistic selectivity (Figure A-14). The model with variable logistic selectivity suggested some limited variability in selectivity (Figure A-14). Nevertheless, models with no time-varying process error (i.e., no yearly variable selectivity or recruitment) prior to the availability of CSLF data provided acceptable fits to CPUE during the CELR years, providing a linear smoother through a period with an initial decline and subsequent improvement in CPUE. The latter corresponded with assertions by divers who were active during the late 1980s and early 1990s that a transition to new operators in the late 1980s and early 1990s caused CPUE to decrease; it subsequently increased again when the new operators steadily increased the efficiency of their operations.

Set 2b: Spatial model for PAU 2

Spatial model runs (see Appendix A.3, Figures A-19 to A-29) suggested that the southern area accounted for about 90% of recruitment (shown as parameter p[2] in Figure A-19). The northern area had a highly variable and uncertain exploitation level, with significantly slower growth than the southern area (Figures A-21 to A-23), whereas patterns for the southern area largely resembled patterns in the single-area model (e.g., Figure 24). For this reason, the more parsimonious single-area model was preferred by the SFWG.

Set 3: Data weights, and estimating recruitment for CSLF years only

Changing the weights for CSLF and CPUE data had a relatively small impact on the stock trajectory (see Appendix A.4, Figures A-30 to A-38): Increasing CSLF weights generally led to a lower stock status, but all estimates remained near or above 40% or B_0. A reduction in CSLF weight also led to greater variation in estimated selectivity for the variable-domed selectivity model (Figure A-34).

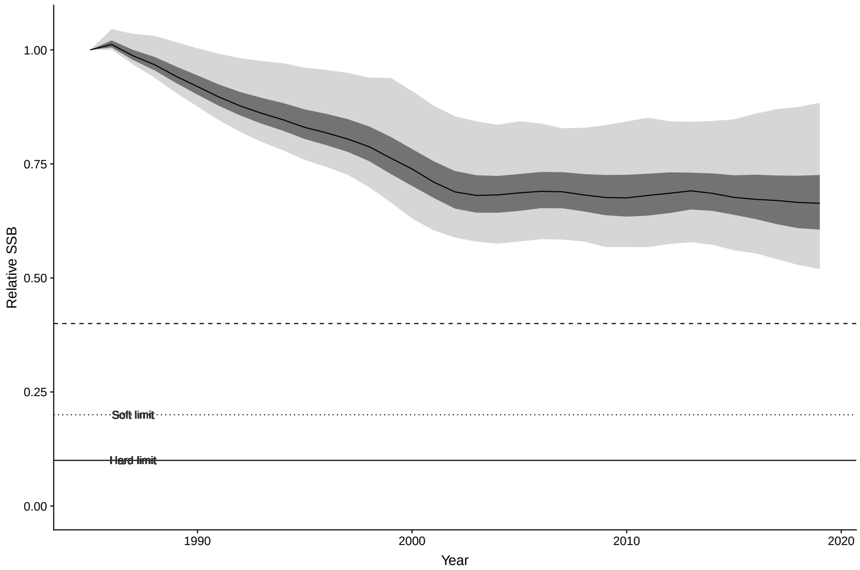

Figure 24: Estimated relative spawning stock biomass trend for pāua for the baseline spatial stock assessment model of pāua in PAU 2 (black line and 95% confidence interval). Comparison with the aggregated model suggest that the spatial model gives near identical results to the aggregated model (c.f., dark blue line in Figure A-18).

3.1 Base case results and agreed sensitivity runs

As a suitable base case, the Fisheries Assessment Plenary selected a model with the following characteristics:

- CPUE starting in 2002 (PCELR), therefore, removing early (FSU and CELR data) and recent (ERS) CPUE,
- estimated recruitment from 1999–2000,
- fixed M at 0.11.

The proposed base case (see Appendix B) suggested a relatively slow but steady downward trend in spawning stock biomass for much of the 1980s and 1990s. There was a more recent downward trend in the last five years of the assessment, which was attributed to estimates of recruitment being forced low to compensate for early estimates of above-average recruitment in the early 2000s (Figure B-9).

Model fits for the base case were reasonable for CSLF data (Figure B-6) except for the 2008–09 fishing year, when a considerable number of small pāua was caught. Nevertheless, given that CPUE did not increase at the same time, the model did not link this catch of small pāua to a prior recruitment event and increasing numbers of pāua entering the fishery. CPUE fits were relatively good for recent (PCELR) CPUE (Figure B-4).

Estimated growth in the base-case model was slower than the nationwide average given as the prior distribution (Figure B-3).

The base case indicated a high probability that the stock is currently near target spawning stock biomass (Figure B-10), with little to no probability that it is below the soft limit of 0.2SSB_0. Projections from the base-case model suggested little movement in spawning stock biomass over the coming years at current catch levels, with a near 50-to-50 chance of being above or below current biomass in the future (i.e., at equilibrium, assumed to occur after 50 years of forward simulation). An increase in catch by 20% was projected to lead to a decline in biomass to near 40% of unfished SSB, but with markedly low relative available biomass (near 22%; Table B-2).

The biological parameters estimated from the base case for the PAU 2 stock assessment were as follows, (means with 0.025, 0.500, and 0.975 posterior quantiles in parentheses for natural mortality M, relative available biomass, stock status (relative spawning stock biomass SSB) and probability of the stock status being below the soft limit of $0.2\mathrm{SSB}_0$; see details in Appendix B):

- stock status: 0.53 (0.39, 0.52, 0.73);
- P(SSB>0.2): 1.00.

4. DISCUSSION

The present assessment represents the first integrated stock assessment for PAU 2. A previous assessment considered the CPUE data for this QMA (McKenzie 2015), and the SFWG concluded that these data were not likely to be informative about stock status. Considering that pāua assessments are largely determined by CPUE trends and productivity assumptions, integrated assessments for this QMA were, therefore, not attempted previously.

Review of the CPUE data for this QMA found that CPUE was similarly variable as in other QMAs for which integrated assessments had been conducted; especially the later FSU data (i.e., post-QMS entry) provided an indicator of a decline in the fishery during those years. In addition, conversations with pāua fishers who were active during the 1980s suggested that CPUE may be a poor indicator of abundance until the mid-1980s and for the 1990s. The views were based on a considerable amount of quota being fished by new operators, following the entry of this fishery into the QMS, and new fishers subsequently steadily improving their performance. These aspects suggested that CPUE by itself does not provide sufficient information about early trends in the fishery. These arguments lead the Fisheries Assessment Plenary to reject early (FSU and CELR) CPUE as indicators of relative abundance in this fishery.

The integrated assessment model provides two ways to account for early fluctuations in CPUE: via large recruitment events, or by blocking CPUE and estimating increases in catchability. Large recruitment events to account for early fluctuations in CPUE have been a common occurrence across pāua assessments up to now (Breen et al. 2003, Neubauer & Tremblay-Boyer 2019b), but there are a number of arguments against this approach. For example, recruitment events tend to be substantial early in the assessment period to explain oscillations in CPUE, but CPUE in pāua fisheries tended to be more stable recently (i.e., few considerable fluctuations in CPUE, even in areas with marked long-term differences in CPUE, specifically PAU 5B, see Neubauer 2020). In addition, estimated recruitment variability tended to be low since the early 2000s across pāua assessments. This period coincided with the advent of more regular CSLF sampling, which provides additional constraints on recruitment. Given the potential lack of reliability of CPUE as an indicator of abundance, it seems appropriate to remove recruitment variation as a possible explanation for variability in early CPUE.

The estimated increases in catchability in early iterations of the stock assessment model for PAU 2 coincide with the highest increase in CPUE in the 1990s, with limited increases in catchability q for both the (short) FSU period and the PCELR period. Although gear innovation over the past decades is considered to have led to an increase in catchability over time, there had previously been little effort to develop a model which reflects these trends with some realism; for instance, previous attempts for PAU 5D using a random walk in q were considered to provide unrealistic results (Neubauer & Tremblay-Boyer 2019b). The present formulation, using separate values for q for each reporting period, with an estimated linear increase, provided results that appear consistent with expectations. Nevertheless, these estimates cannot be verified, and were not accepted by the Fisheries Assessment Plenary as a basis for assessment.

The results for PAU 2 were robust to both the model structure (estimating initial depletion, using recruitment to explain early CPUE fluctuations) and dataset weights once early CPUE points were removed. The results suggested a stable fishery at or above 40% of unfished SSB. This finding is consistent with the relatively unchanged CPUE over the past two decades, suggesting the fishery has been in a relatively stable state for some time. Although projections to equilibrium suggest that present catch levels are sustainable into the future, it should be noted that the fishery is at the northern limit of the commercial pāua fishery, with largely stunted growth in warmer northern statistical areas. Given ongoing and projected warming of these waters, the projected equilibrium may only be a theoretical value with uncertain future relevance.

5. ACKNOWLEDGMENTS

Many thanks to Storm Stanley and Jeremy Cooper for helping to identify fishers who were active during the early years of the fishery, and the members of the Shellfish Working Group for helpful discussion. Stimulating discussion with M. Dunn (NIWA) led to various developments in this assessment.

This research was funded by Fisheries New Zealand project PAU2019-01.

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APPENDIX A: MODEL COMPARISON

A.1 Model runs: Set 1

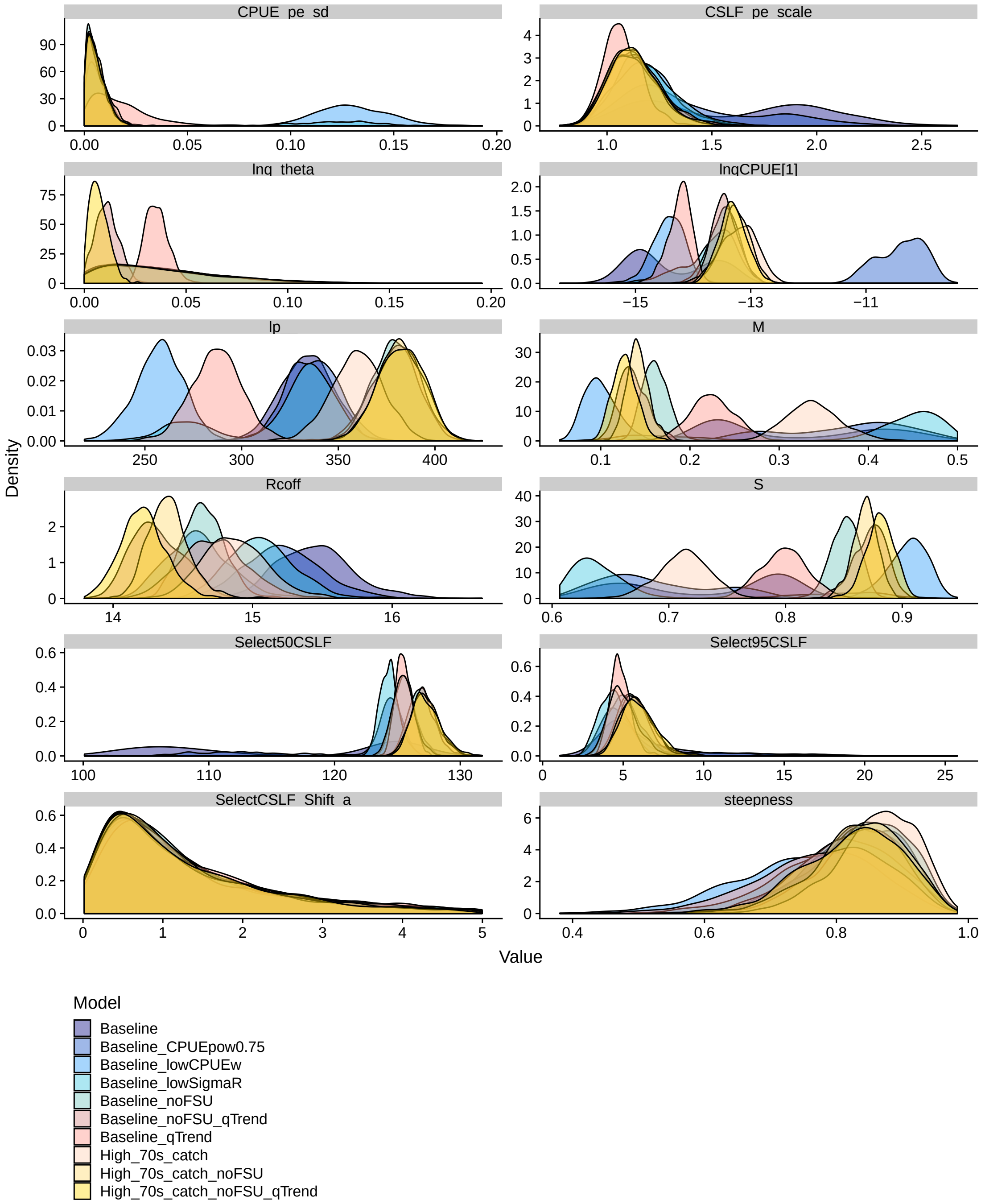

Figure A-1: Comparison of posterior densities for parameters in the stock assessment model using parameters for Set 1. Model scenario names show differences in catch (baseline, high catch in the 1970s). Catch-per-unit-effort (CPUE) with or without Fisheries Statistical Unit (FSU) data (noFSU). CPUE hyperstability (CPUEpow – fixed at 0.75) and trends in catchability (qTrend; estimated linear); low recruitment variation (σ_R = 0.4)(CSLF, catch sampling length frequency).

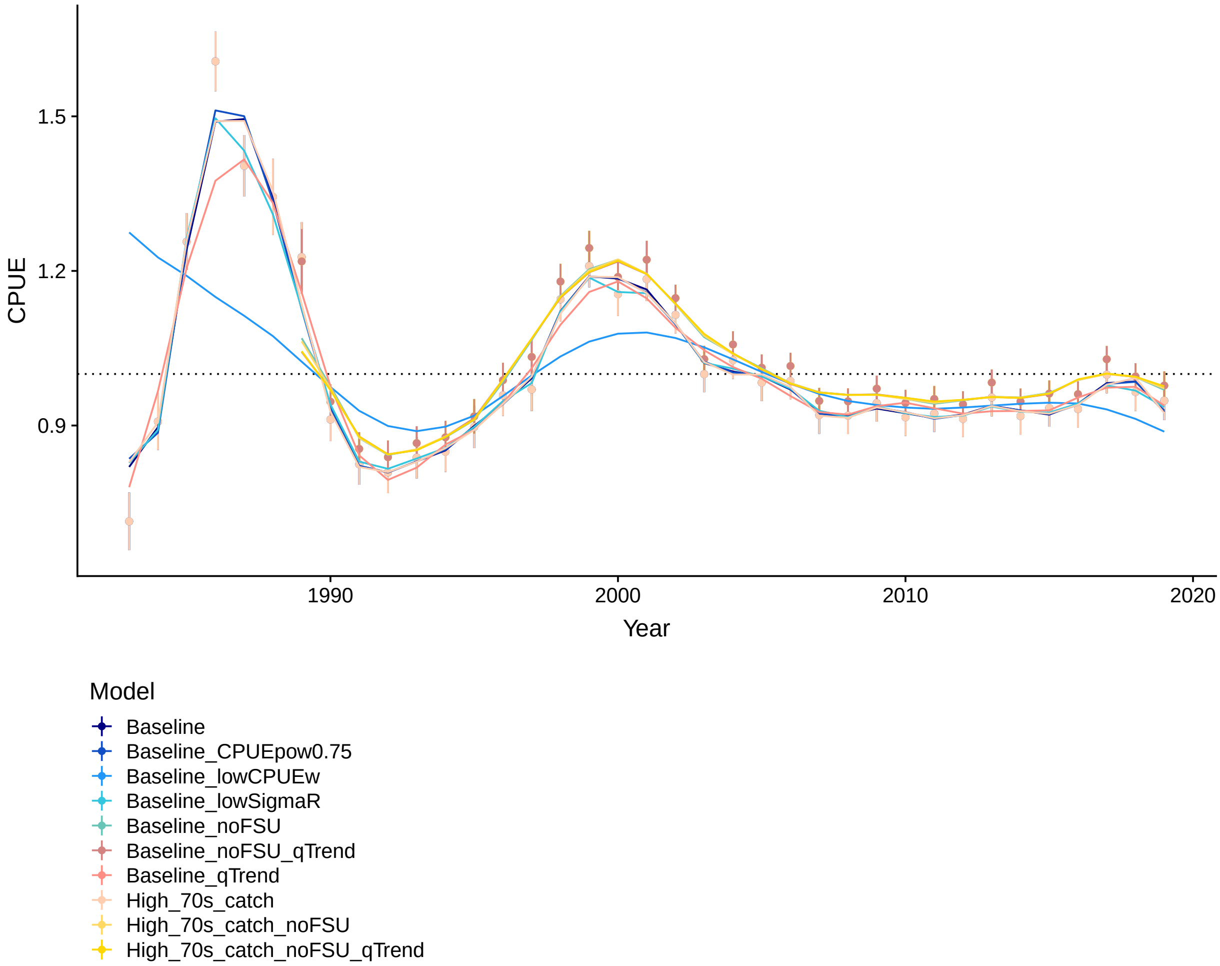

Figure A-2: Comparison of posterior median predicted catch-per-unit-effort (CPUE) in the stock assessment model using parameters for Set 1. Model scenario names show differences in catch (baseline, high catch in the 1970s); CPUE with or without Fisheries Statistical Unit (FSU) data (noFSU). CPUE hyperstability (CPUEpow – fixed at 0.75) and trends in catchability (qTrend; estimated linear); low recruitment variation (σ_R = 0.4).

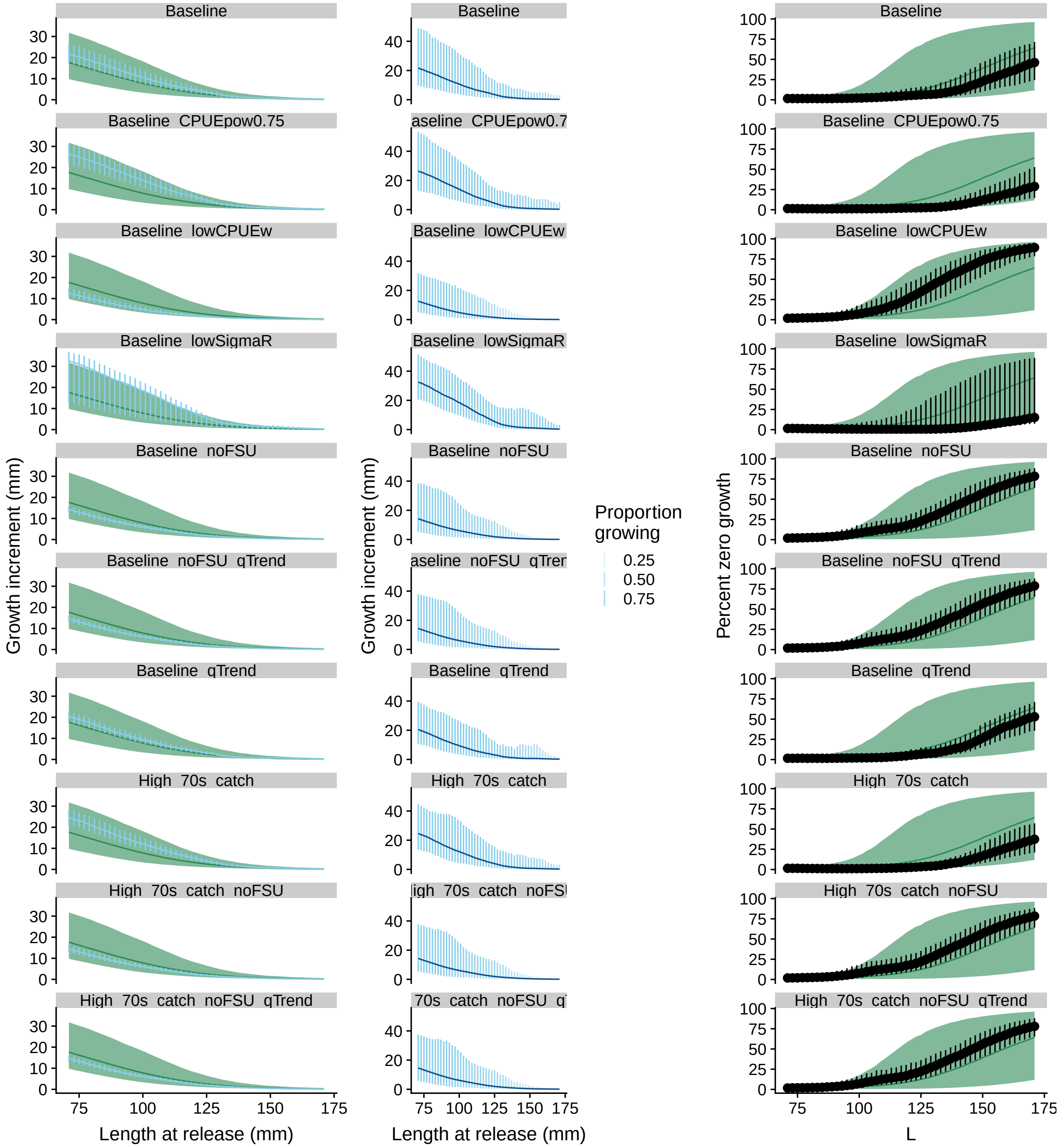

Figure A-3: Comparison of prior and posterior growth in the stock assessment model using parameters for Set 1. Left graphs: prior for population mean growth (prior mean (green line) and 95% prior interval (green shading)), and posterior mean growth (light blue posterior median and 95% posterior interval). Middle graphs: median distribution of population somatic growth by size class with posterior mean (dark blue line) and 95% growth intervals. Right graphs: prior for proportion of pāua not growing at each length class (prior mean (green line) and confidence interval (green shading) and posterior distribution (black dots and 95% posterior confidence). Model scenario names show differences in catch (baseline, high catch in the 1970s); catch-per-unit-effort (CPUE) with or without Fisheries Statistical Unit (FSU) data (noFSU). CPUE hyperstability (CPUEpow – fixed at 0.75) and trends in catchability (qTrend; estimated linear); low recruitment variation (σ_R = 0.4).

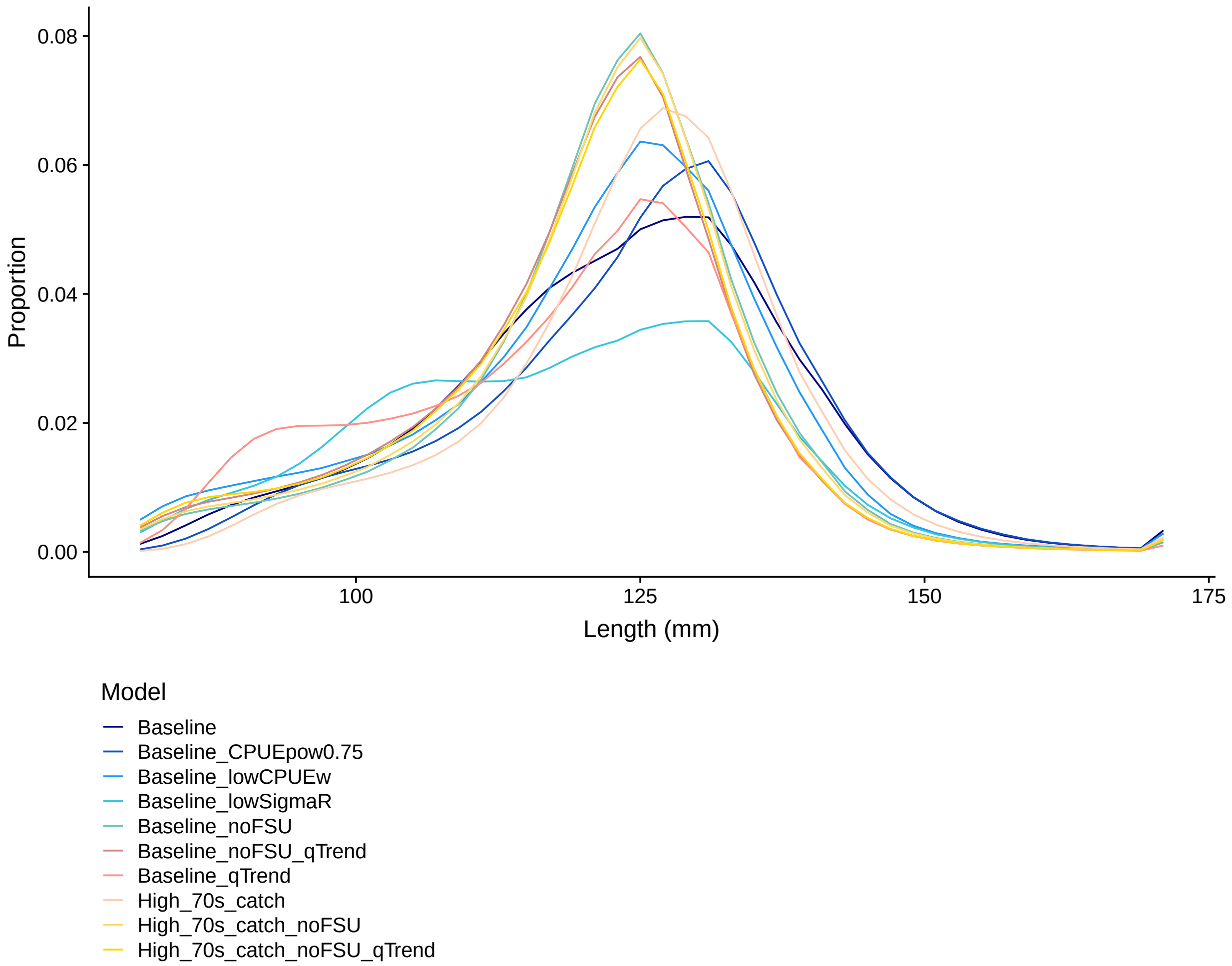

Figure A-4: Comparison of posterior mean proportions-at-length in the stock assessment model using parameters for Set 1. Model scenario names show differences in catch (baseline, high catch in the 1970s); catch-per-unit-effort (CPUE) with or without Fisheries Statistical Unit (FSU) data (noFSU) . CPUE hyperstability (CPUEpow – fixed at 0.75) and trends in catchability (qTrend; estimated linear); low recruitment variation (σ_R = 0.4).

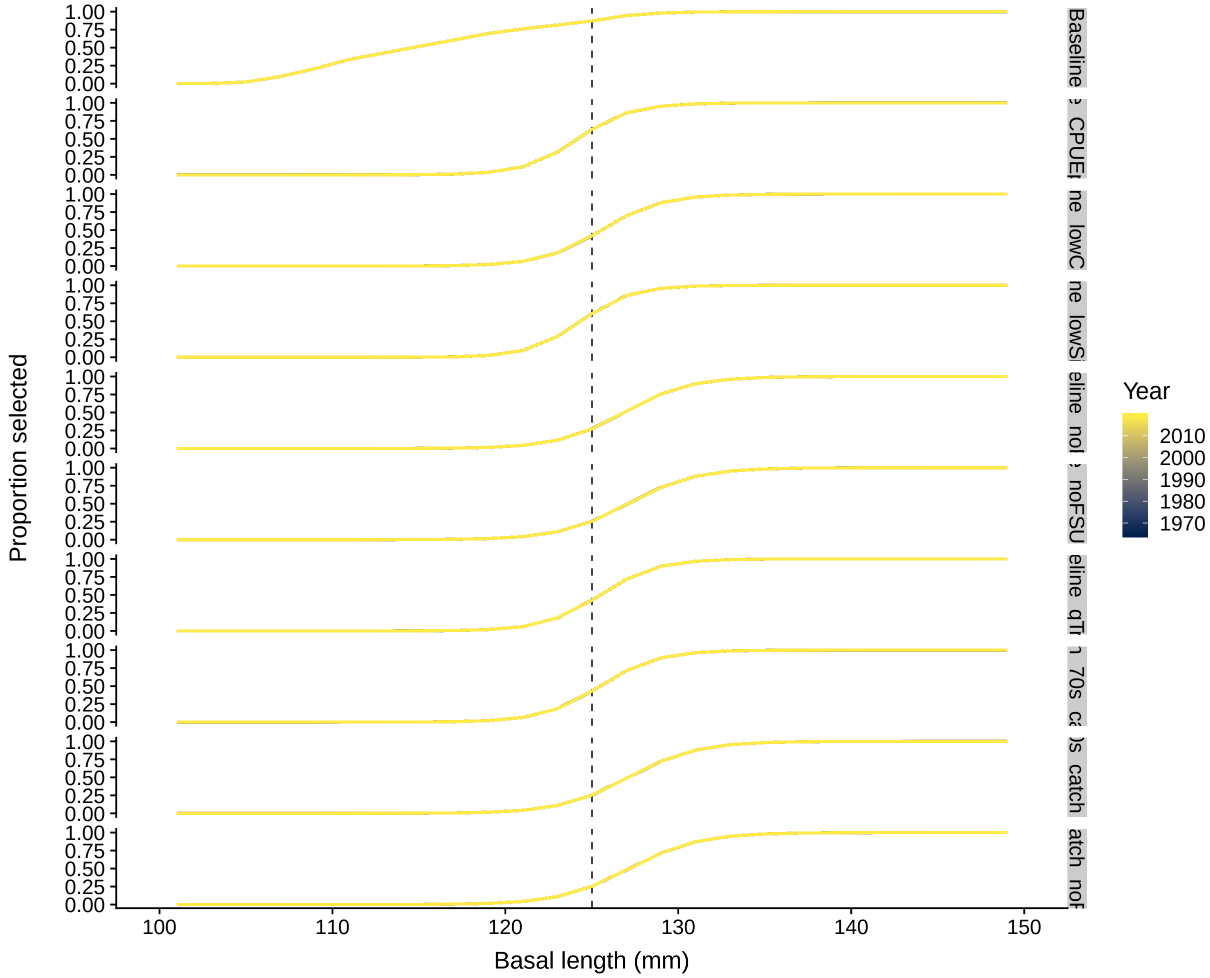

Figure A-5: Comparison of posterior mean selectivity-at-length in the stock assessment model using parameters for Set 1. Model scenario names show differences in catch (baseline, high catch in the 1970s); catch-per-unit-effort (CPUE) with or without Fisheries Statistical Unit (FSU) data (noFSU). CPUE hyperstability (CPUEpow – fixed at 0.75) and trends in catchability (qTrend; estimated linear); low recruitment variation (σ_R = 0.4).

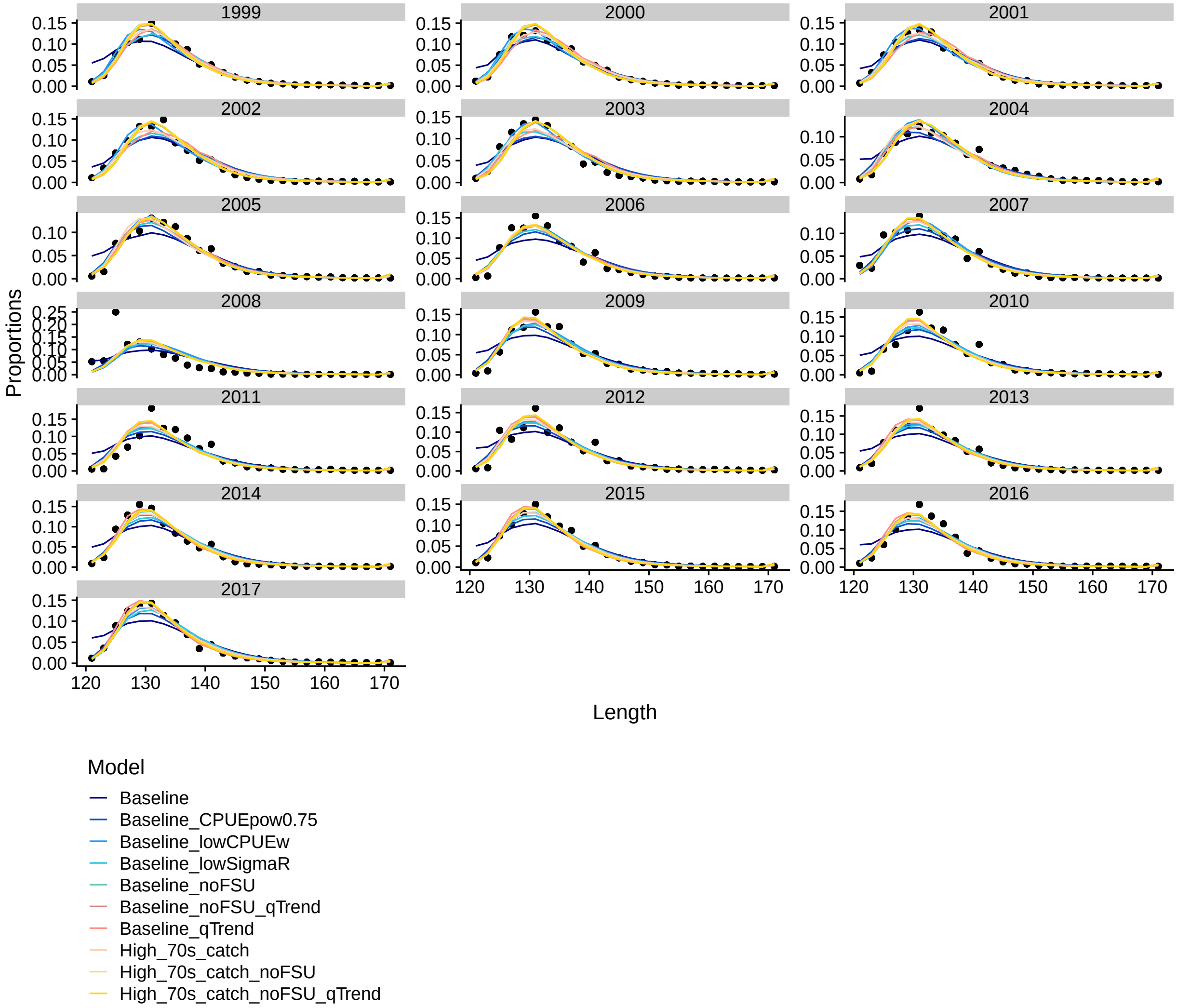

Figure A-6: Comparison of posterior mean predicted catch sampling length frequency (CSLF; length in mm) with estimated CSLF proportions, in the stock assessment model using parameters for Set 1. Model scenario names show differences in catch (baseline, high catch in the 1970s); catch-per-unit-effort (CPUE) with or without Fisheries Statistical Unit (FSU) data (noFSU). CPUE hyperstability (CPUEpow – fixed at 0.75) and trends in catchability (qTrend; estimated linear); low recruitment variation (σ_R = 0.4).

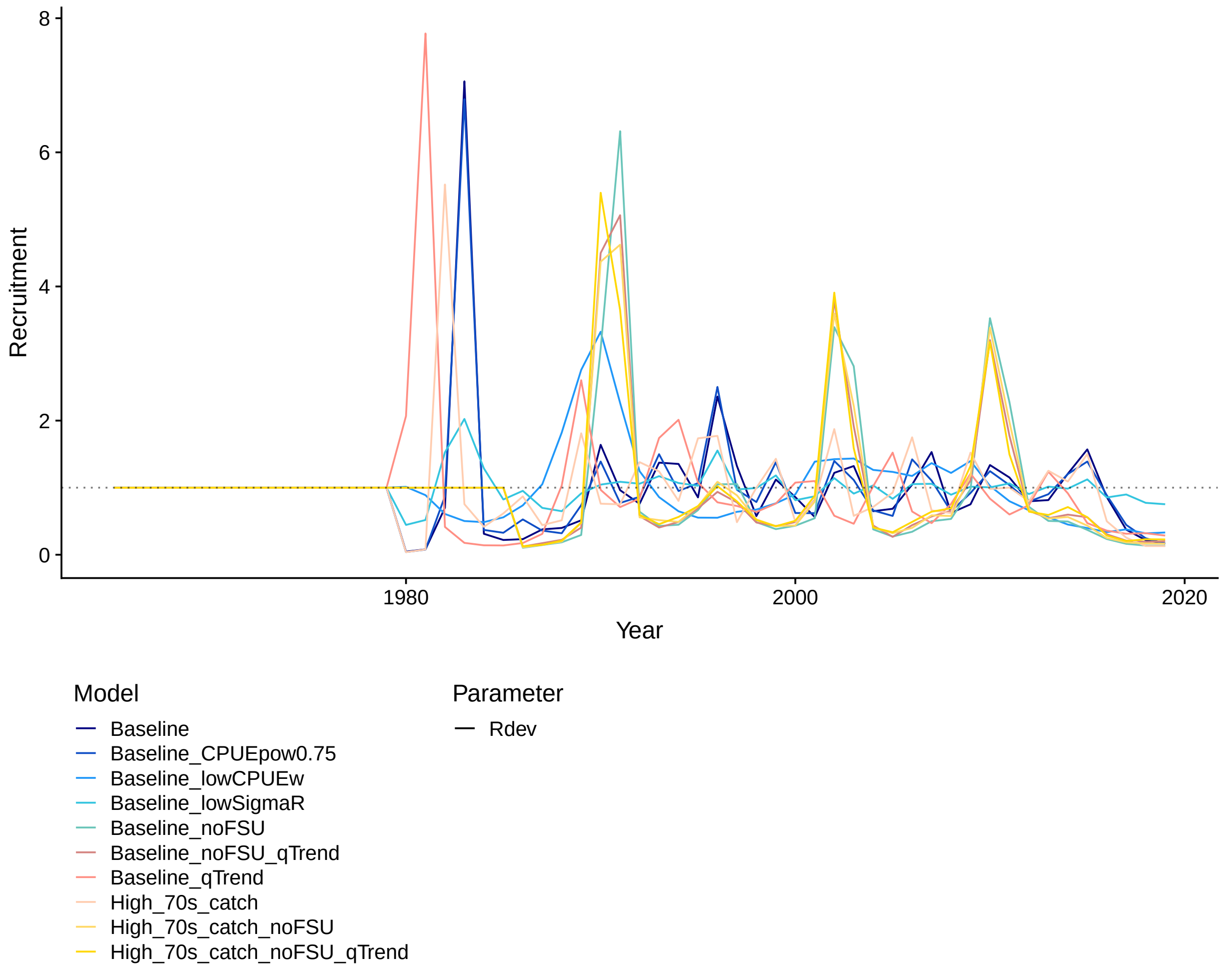

Figure A-7: Comparison of posterior mean recruitment deviations (Rdev) in the stock assessment model using parameters for Set 1. Model scenario names show differences in catch (baseline, high catch in the 1970s); catch-per-unit-effort (CPUE) with or without Fisheries Statistical Unit (FSU) data (noFSU). CPUE hyperstability (CPUEpow – fixed at 0.75) and trends in catchability (qTrend; estimated linear); low recruitment variation (σ_R = 0.4).

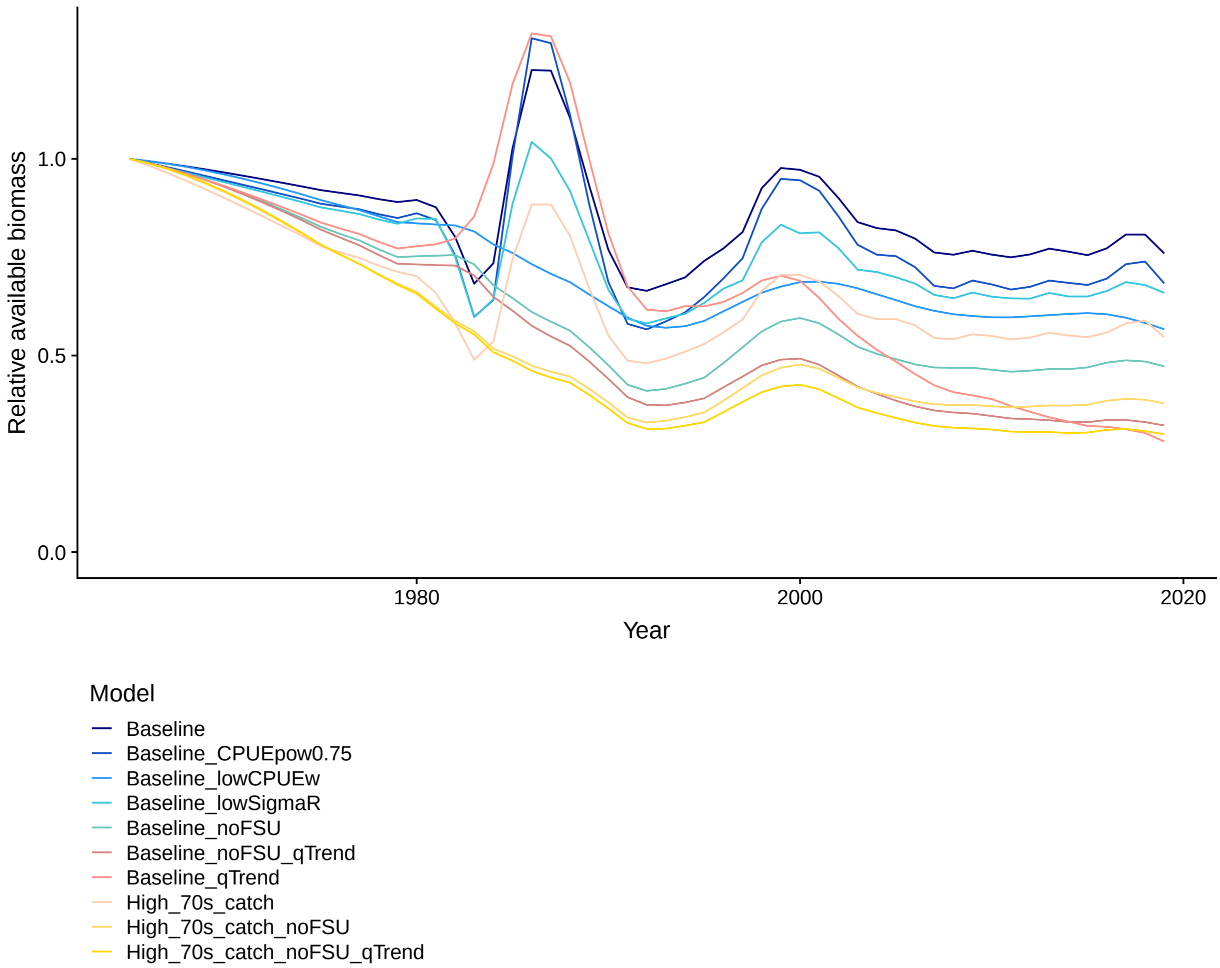

Figure A-8: Comparison of posterior median predicted relative available biomass trend in the stock assessment model using parameters for Set 1. Model scenario names show differences in catch (baseline, high catch in the 1970s); catch-per-unit-effort (CPUE) with or without Fisheries Statistical Unit (FSU) data (noFSU). CPUE hyperstability (CPUEpow – fixed at 0.75) and trends in catchability (qTrend; estimated linear); low recruitment variation (σ_R = 0.4).

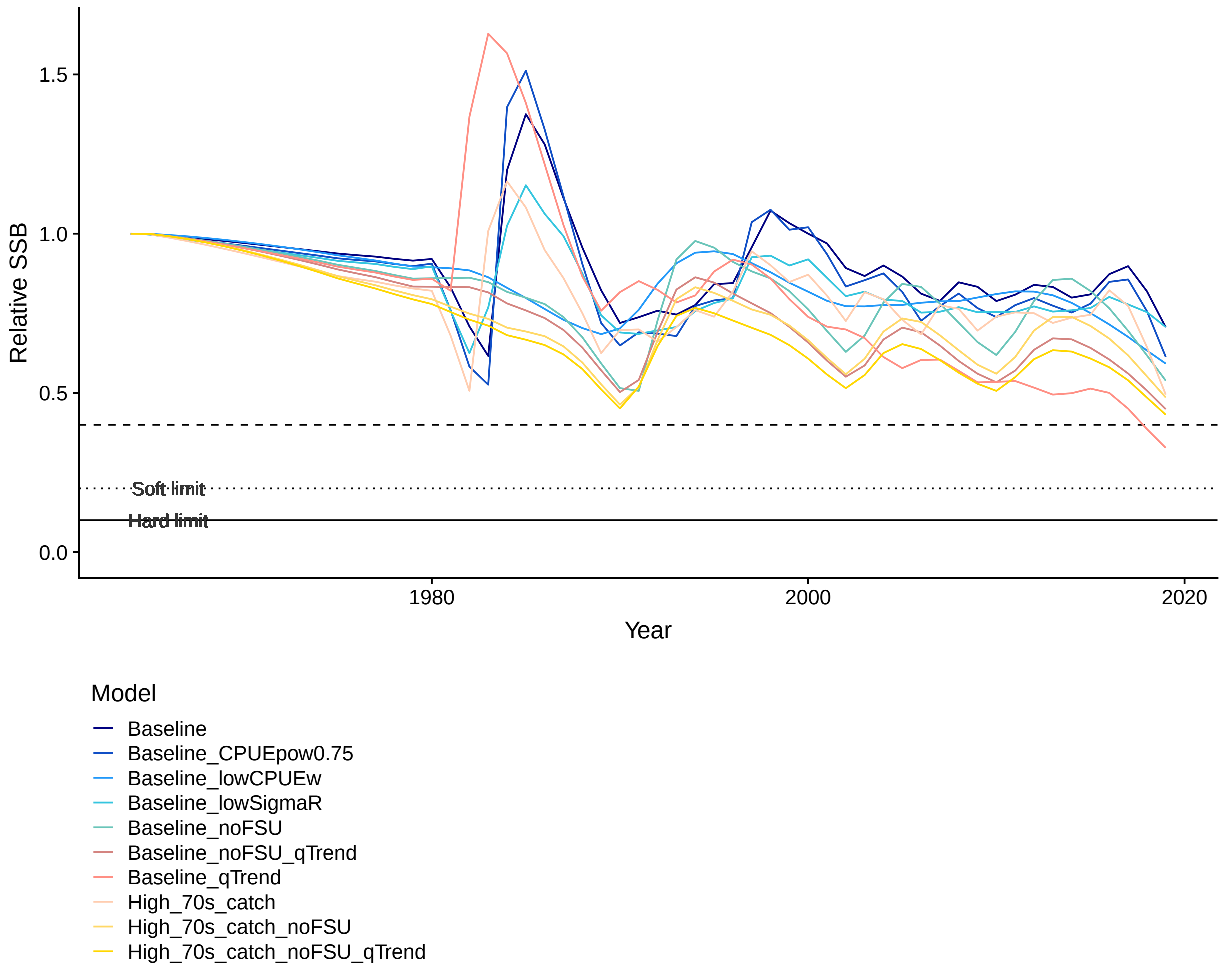

Figure A-9: Comparison of posterior median predicted relative spawning stock biomass (SSB) trend in the stock assessment model using parameters for Set 1. Soft and hard limit refer to Fisheries New Zealand harvest strategy standard limit reference points. Model scenario names show differences in catch (baseline, high catch in the 1970s); catch-per-unit-effort (CPUE) with or without Fisheries Statistical Unit (FSU) data (noFSU). CPUE hyperstability (CPUEpow – fixed at 0.75) and trends in catchability (qTrend; estimated linear); low recruitment variation (σ_R = 0.4).

A.2 Model runs: Set 2

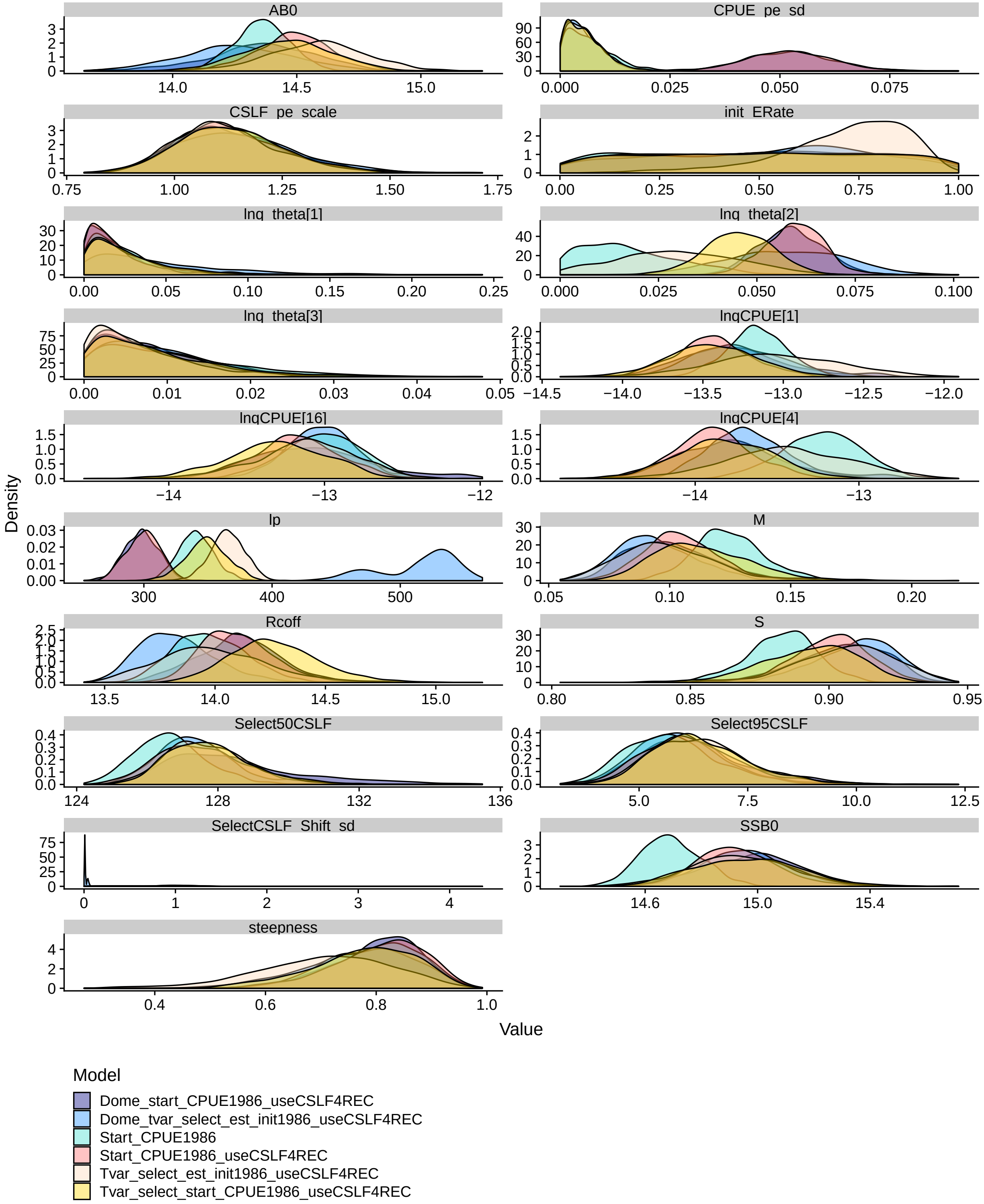

Figure A-10: Comparison of posterior densities for parameters in the stock assessment model using parameters for Set 2. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

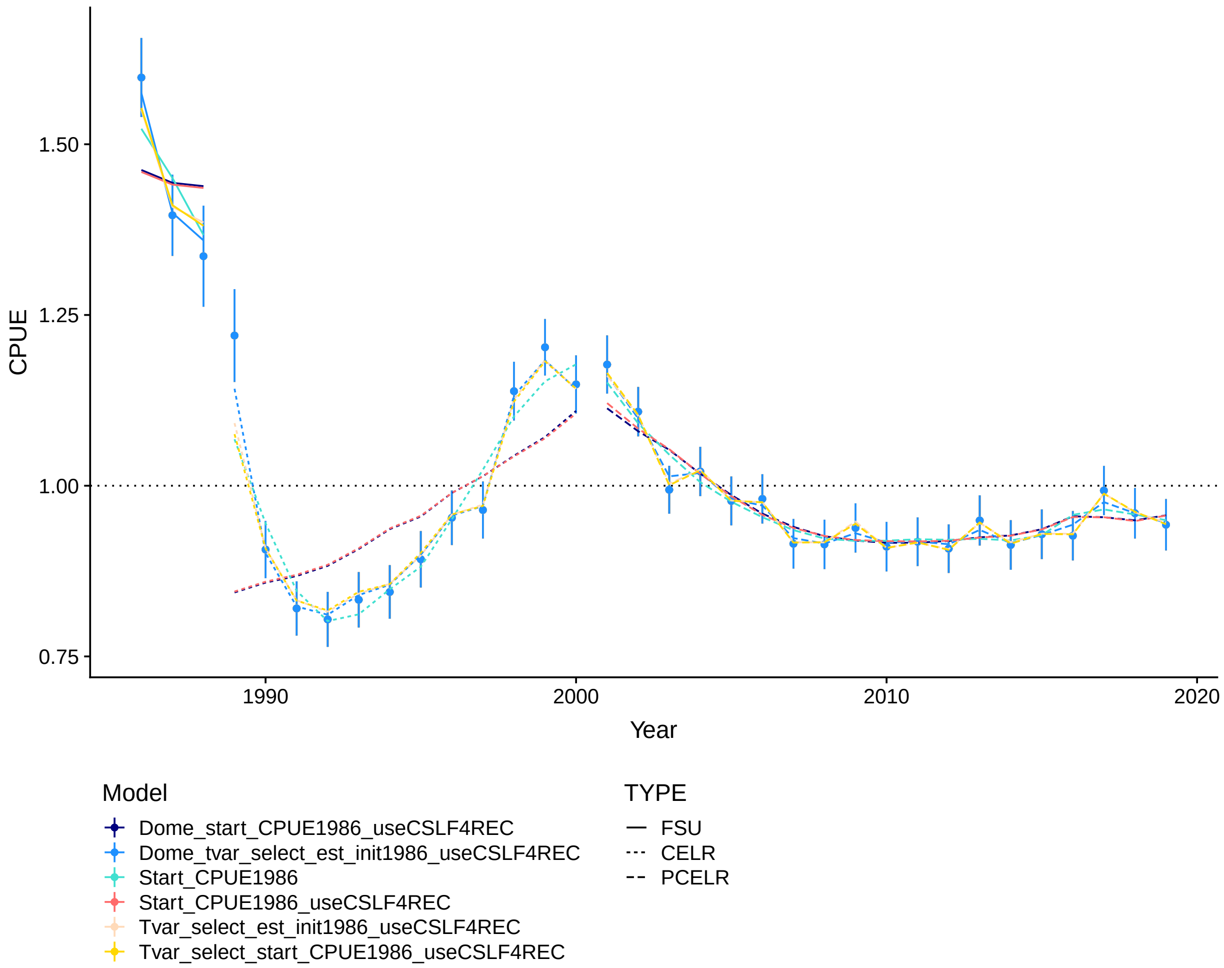

Figure A-11: Comparison of posterior median predicted catch-per-unit-effort (CPUE) in the stock assessment model using parameters for Set 2. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting CPUE in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

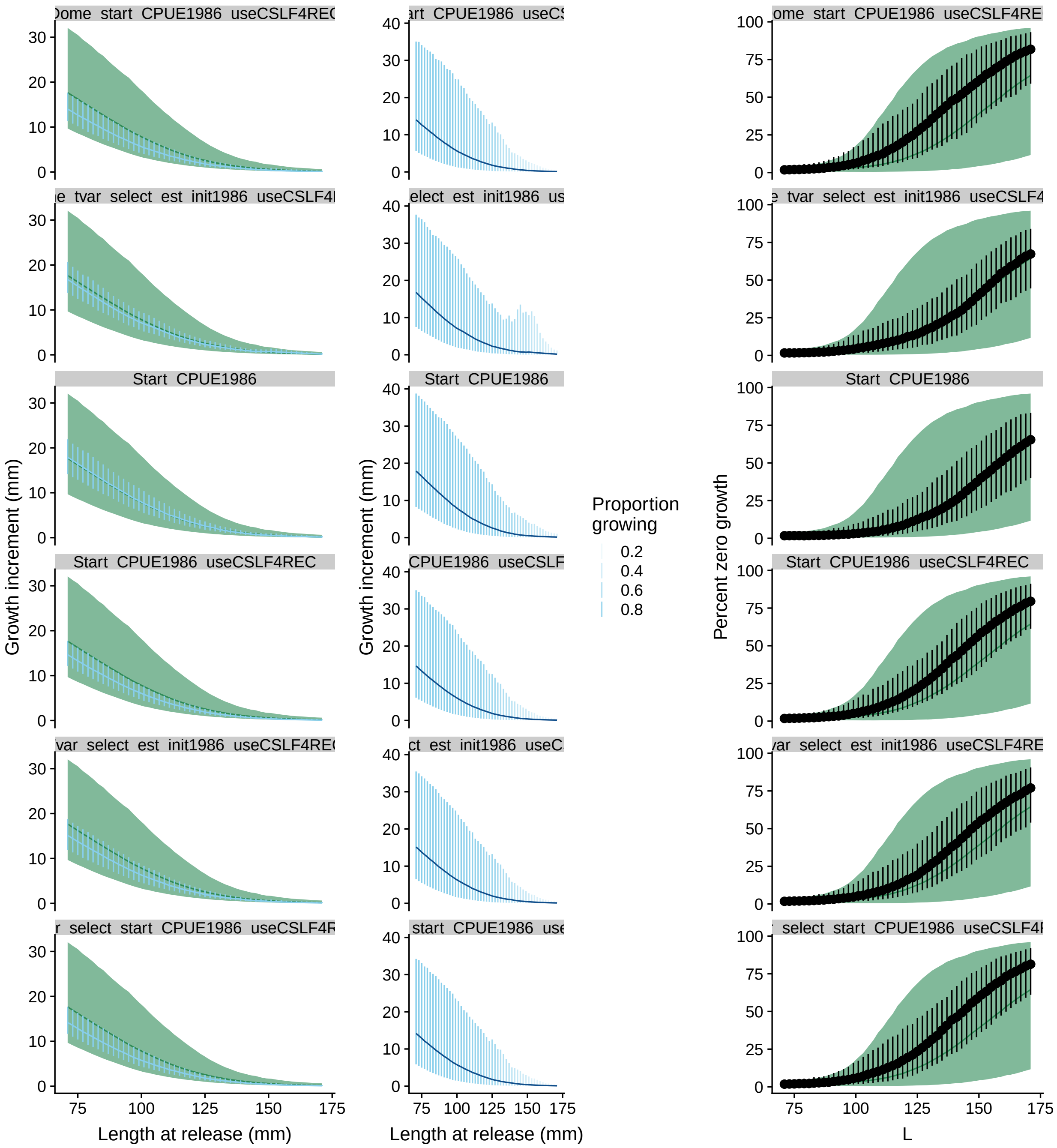

Figure A-12: Comparison of prior and posterior growth in the stock assessment model using parameters for Set 2. Left graphs: prior for population mean growth (prior mean (green line) and 95% prior interval (green shading)), and posterior mean growth (light blue posterior median and 95% posterior interval). Middle graphs: median distribution of population somatic growth by size class with posterior mean (dark blue line) and 95% growth intervals. Right graphs: Prior for proportion of pāua not growing at each length class (prior mean (green line) and confidence interval (green shading) and posterior distribution (black dots and 95% posterior confidence). Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

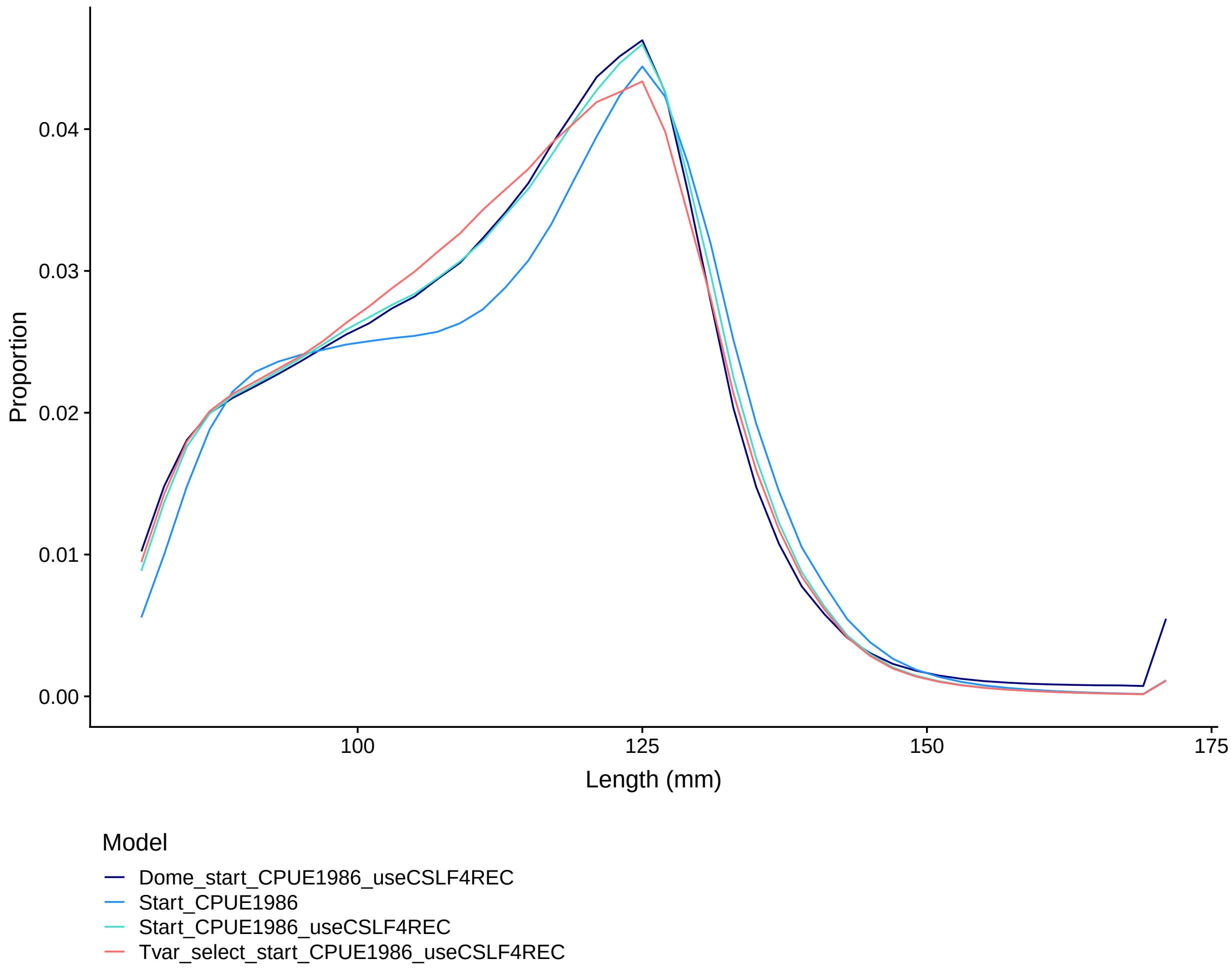

Figure A-13: Comparison of posterior mean proportions-at-length in the stock assessment model using parameters for Set 2. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

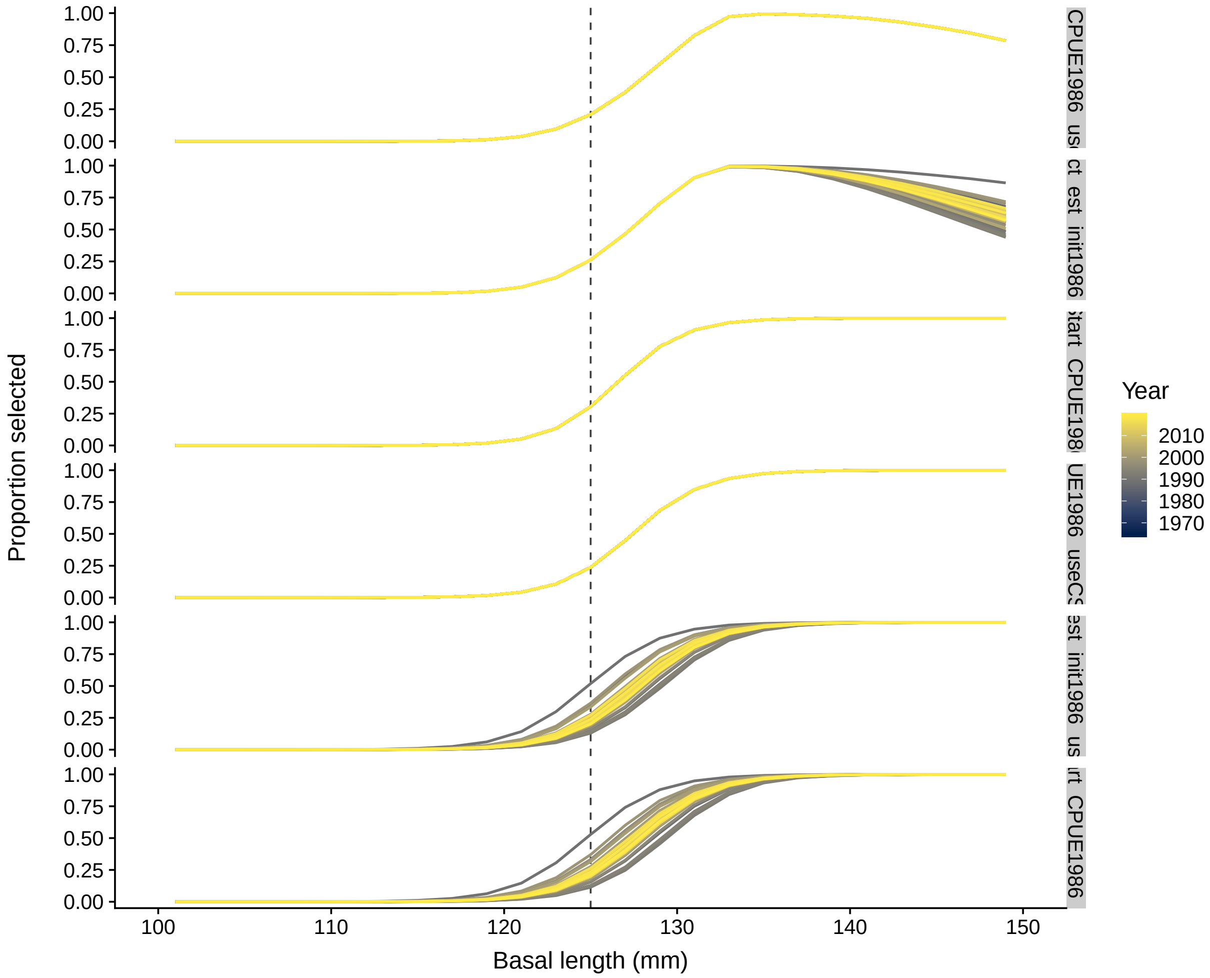

Figure A-14: Comparison of posterior mean selectivity-at-length in the stock assessment model using parameters for Set 2. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

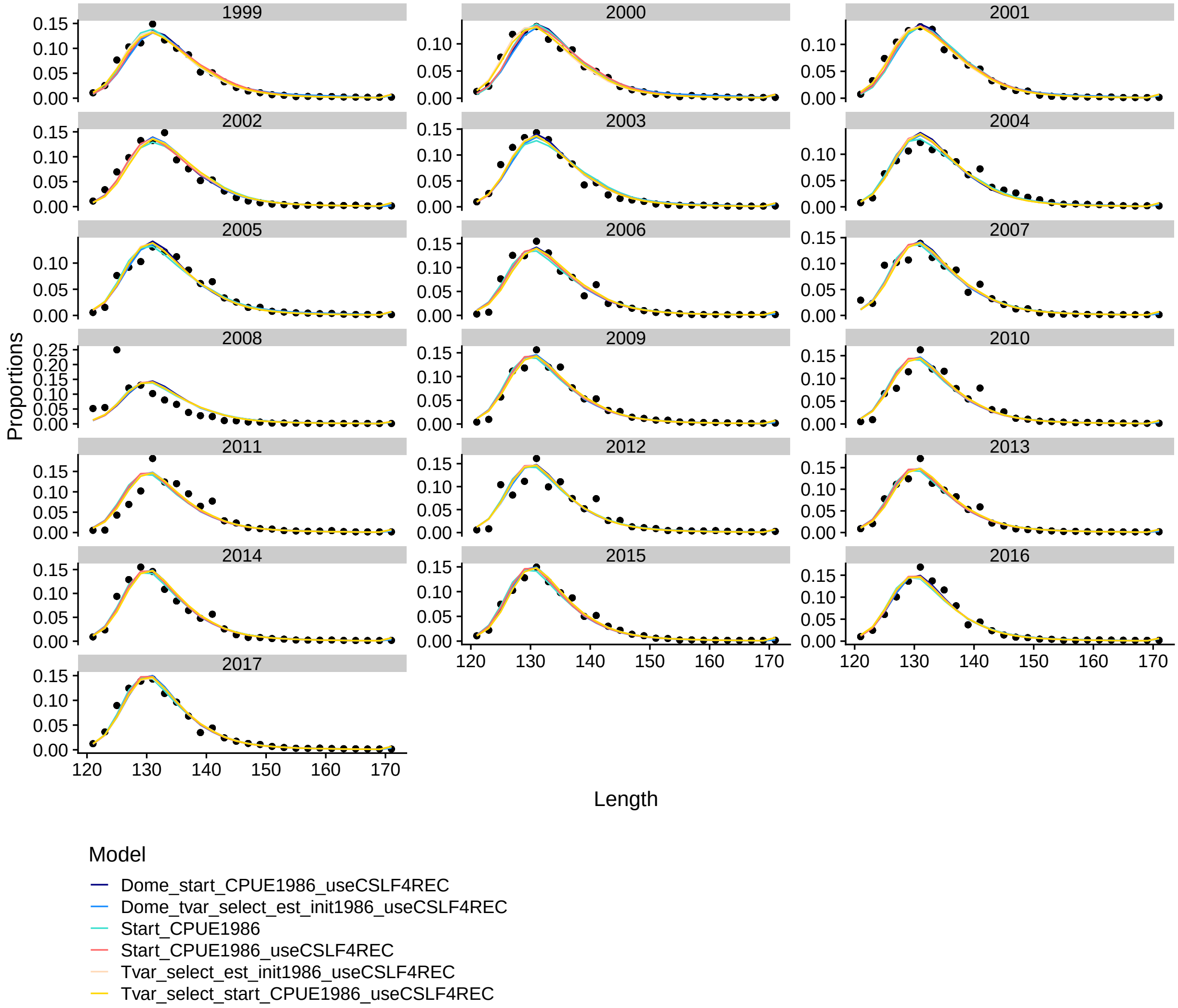

Figure A-15: Comparison of posterior mean predicted catch sampling length frequency (CSLF; length in mm) with estimated CSLF proportions, in the stock assessment model using parameters for Set 2. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency data.

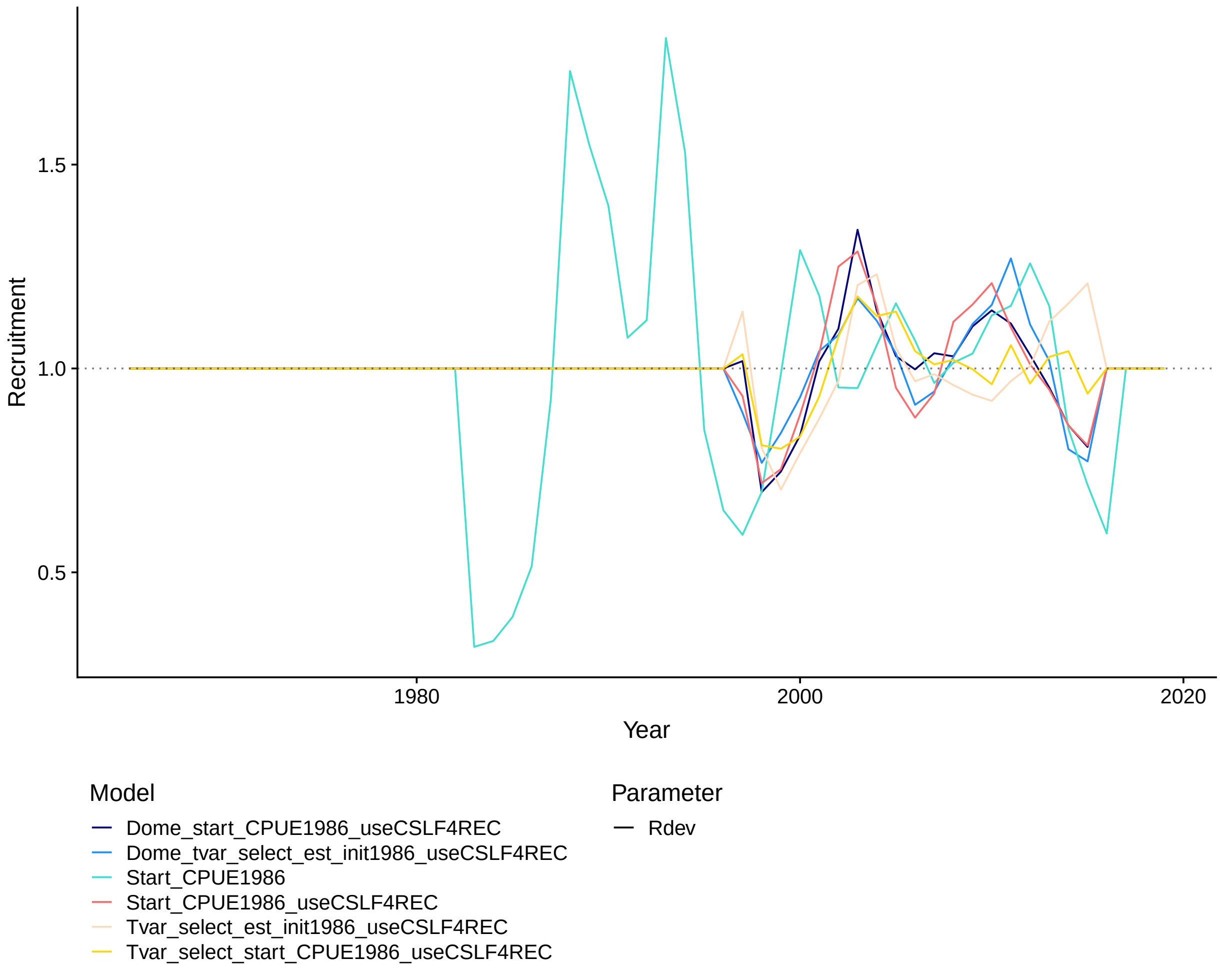

Figure A-16: Comparison of posterior mean recruitment deviations (Rdev) in the stock assessment model using parameters for Set 2. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

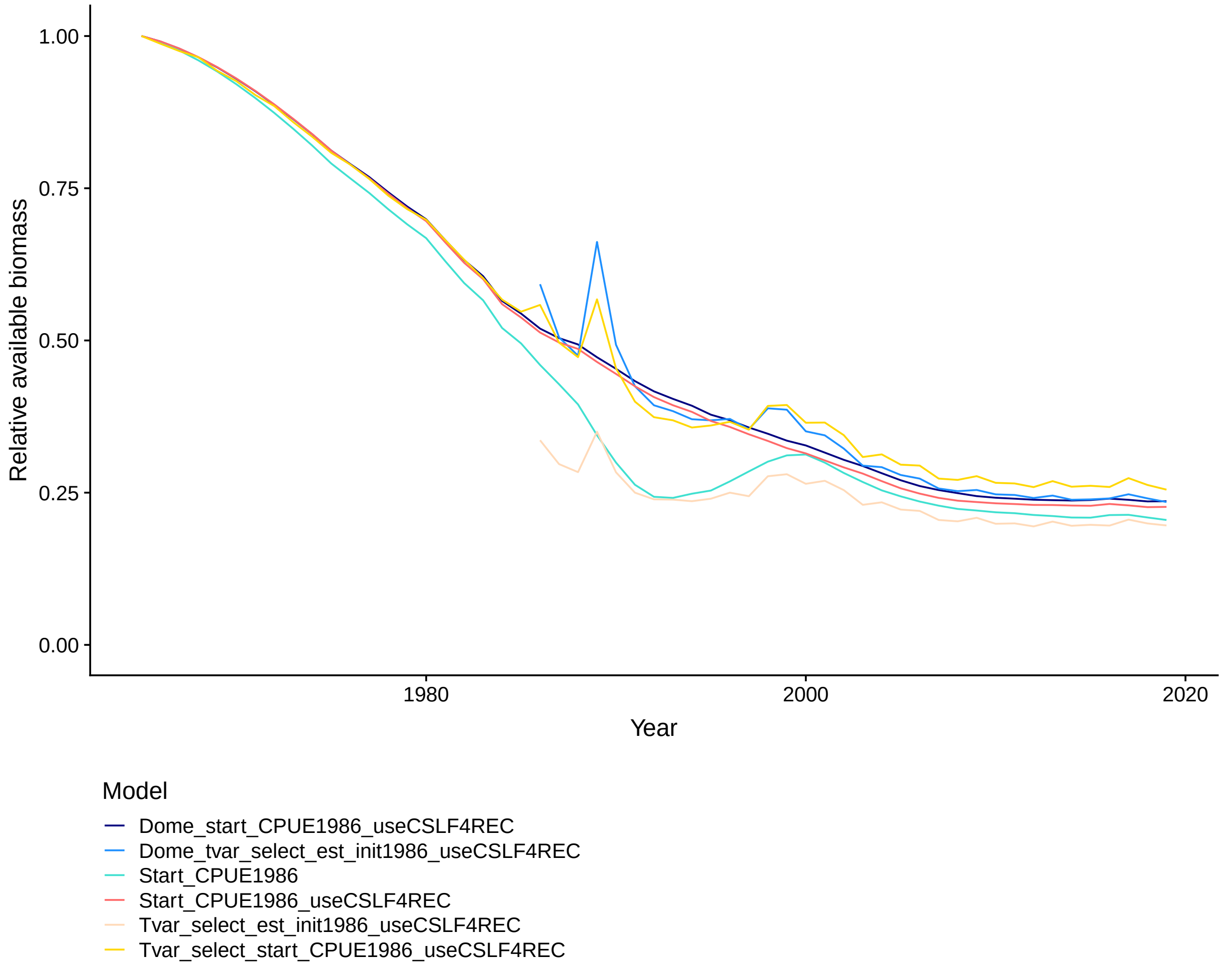

Figure A-17: Comparison of posterior median predicted relative available biomass trend in the stock assessment model using parameters for Set 2. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

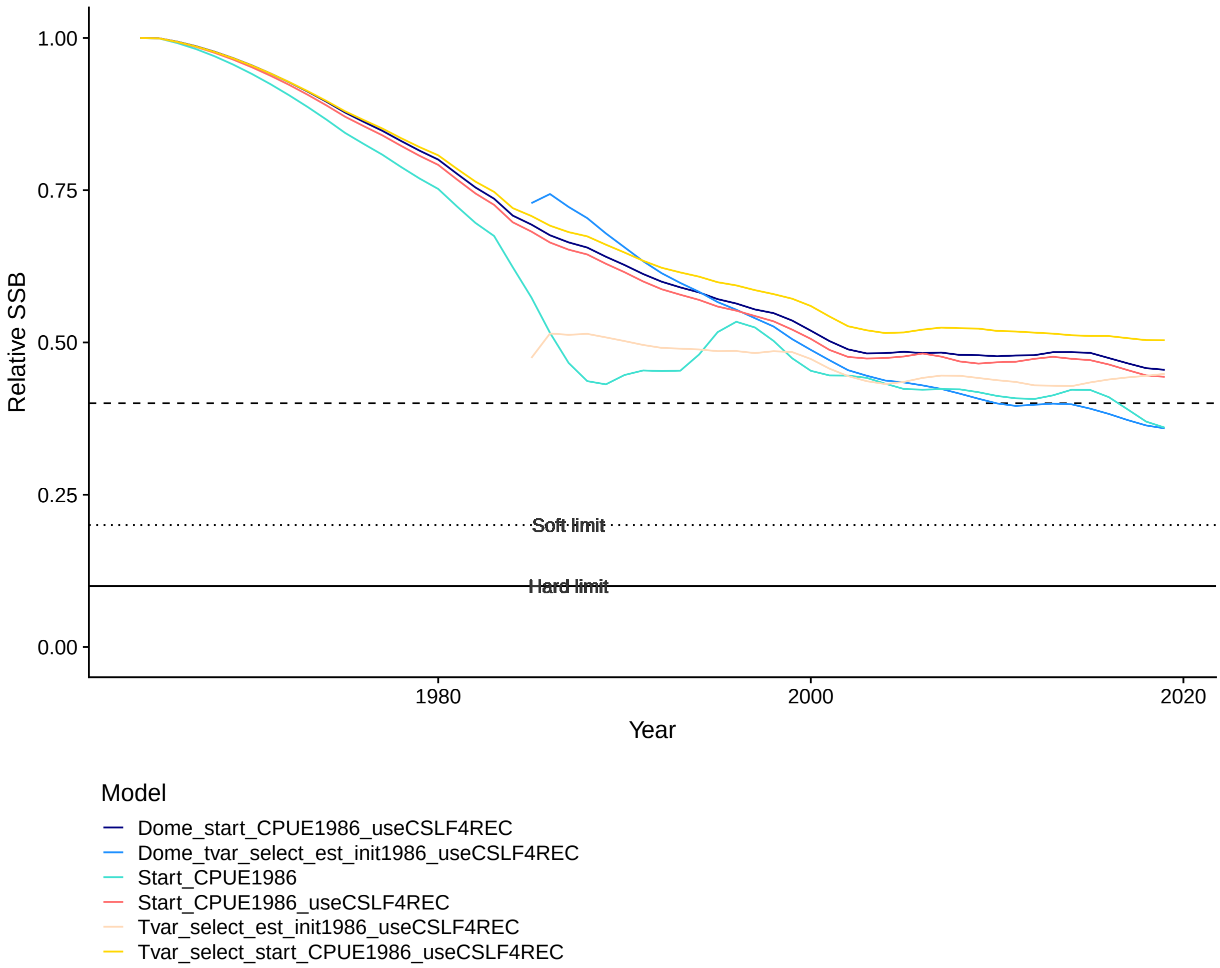

Figure A-18: Comparison of posterior median predicted relative spawning stock biomass trend in the stock assessment model using parameters for Set 2. Soft and hard limit refer to Fisheries New Zealand harvest strategy standard limit reference points. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

A.3 Model runs Set 2b – Spatial models

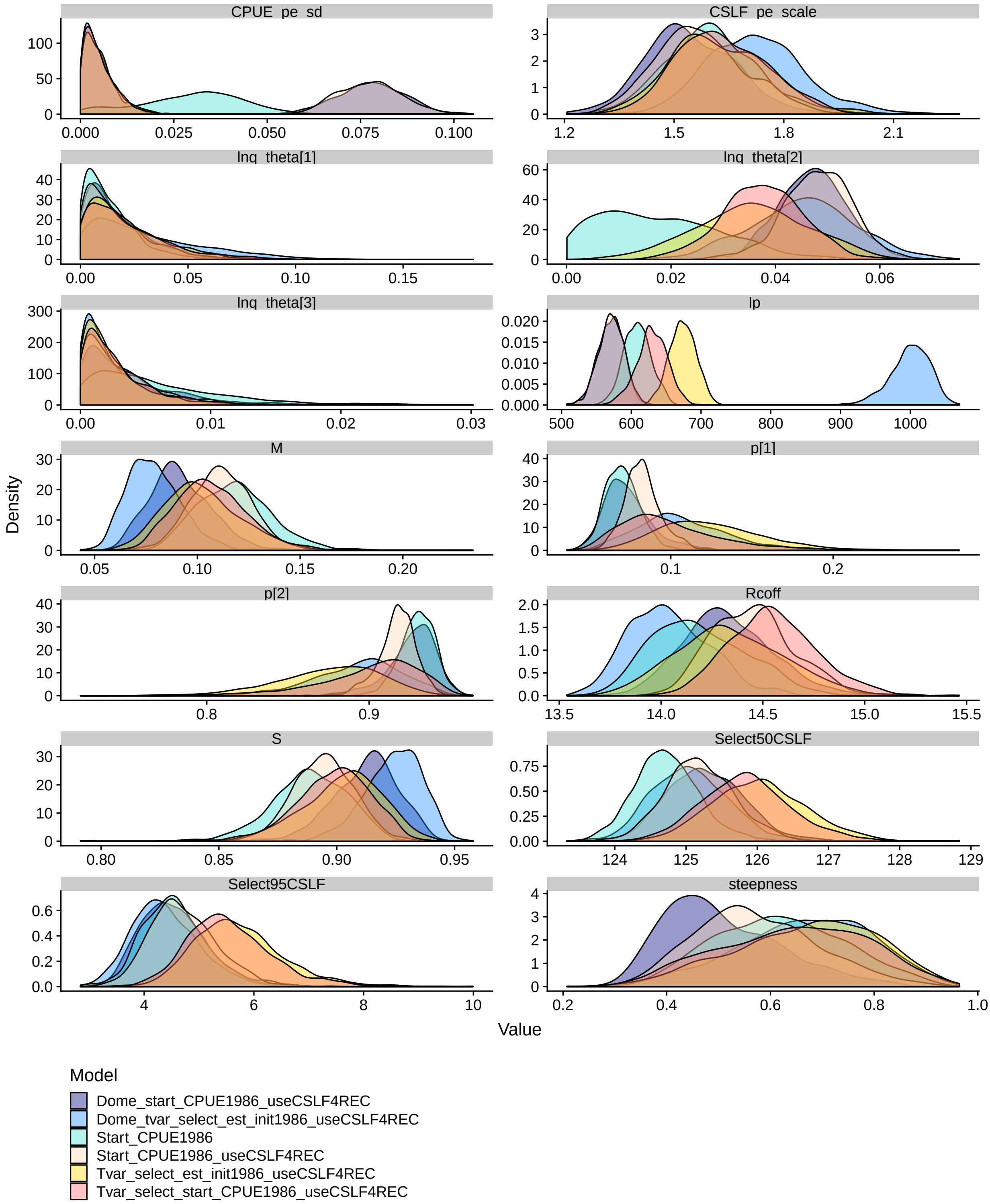

Figure A-19: Comparison of posterior densities for parameters in the stock assessment model using parameters for Set 2b. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

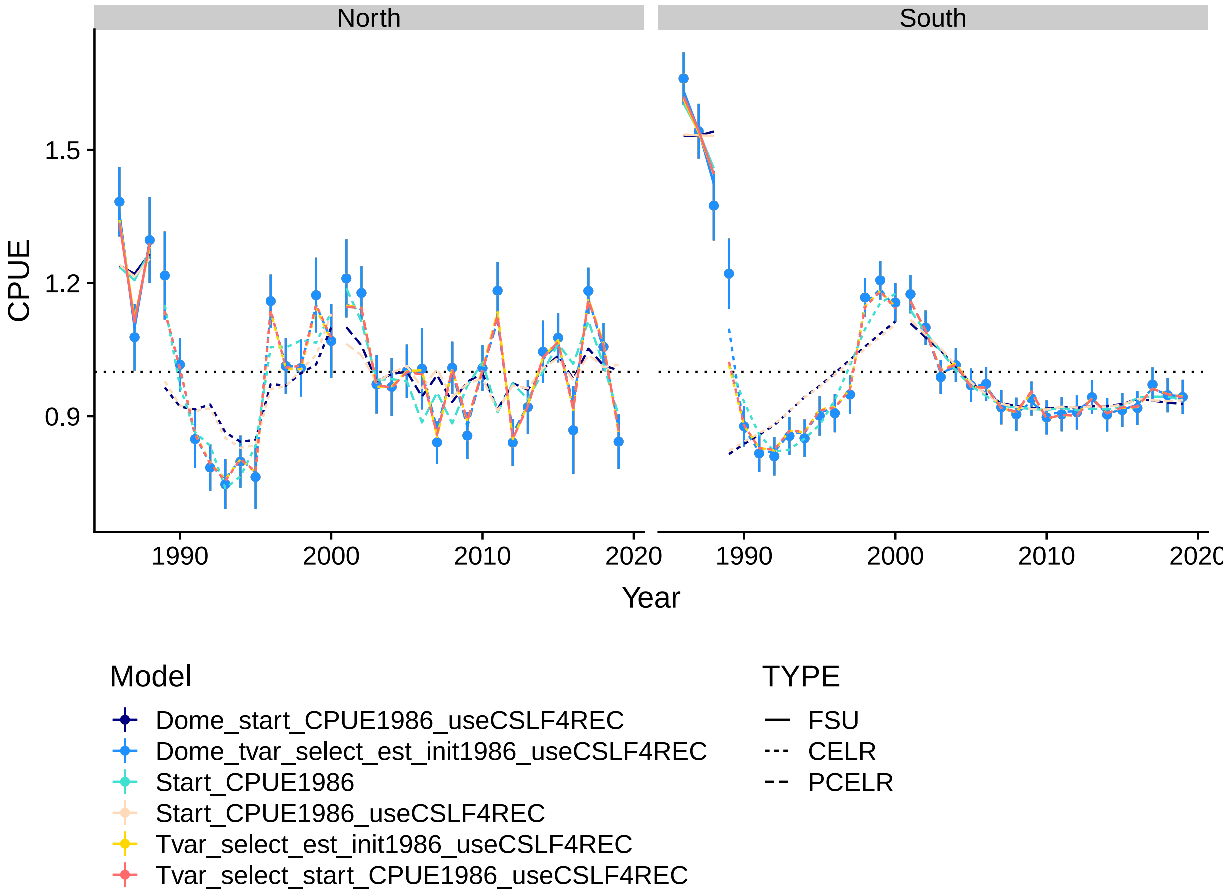

Figure A-20: Comparison of posterior median predicted catch-per-unit-effort (CPUE) in the stock assessment model using parameters for Set 2b. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting CPUE in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

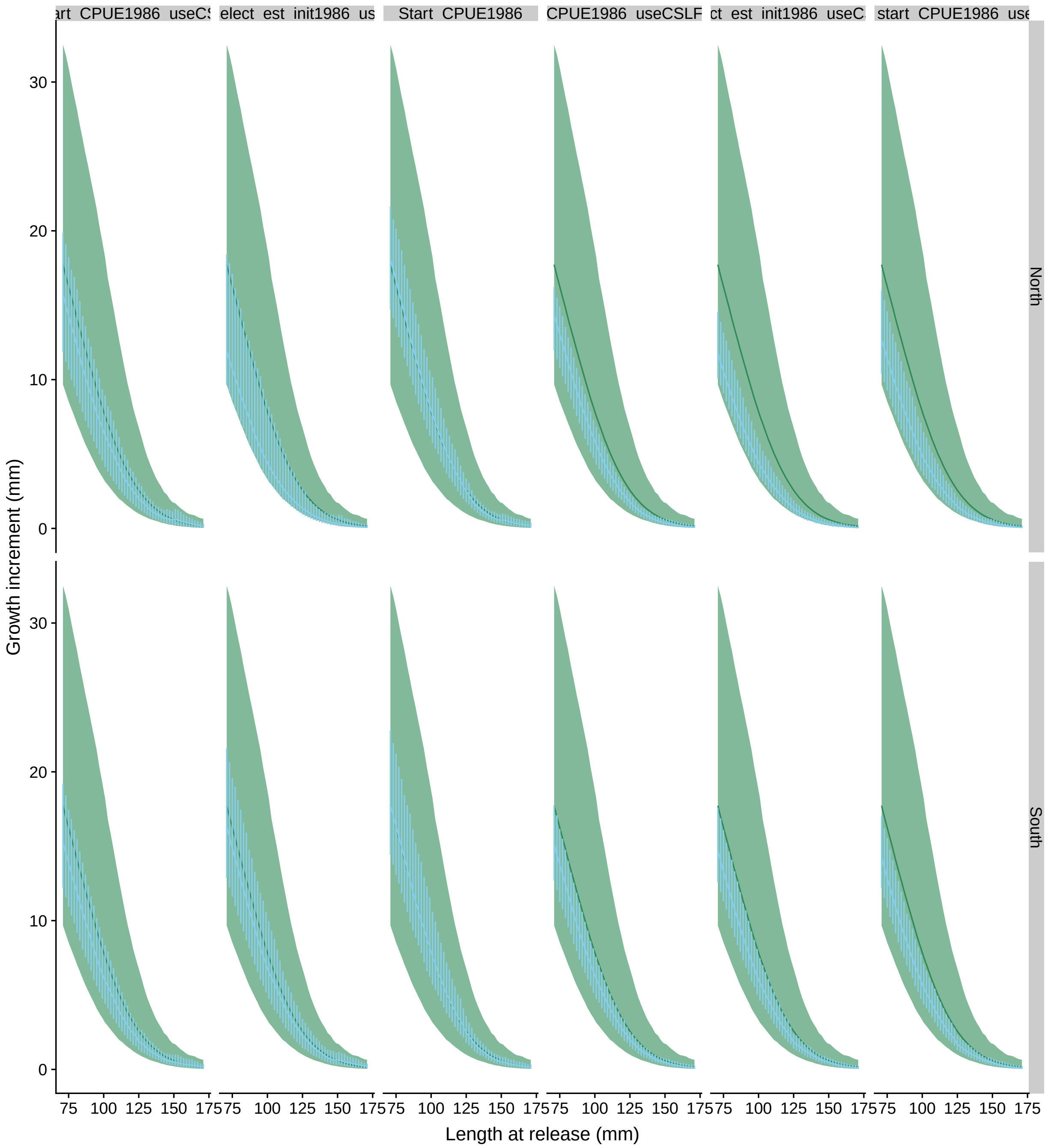

Figure A-21: Comparison of prior and posterior growth in the spatial stock assessment model using parameters for Set 2b. Prior for population mean growth (prior mean (green line) and 95% prior interval (green shading)), and posterior mean growth (light blue posterior median and 95% posterior interval). Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

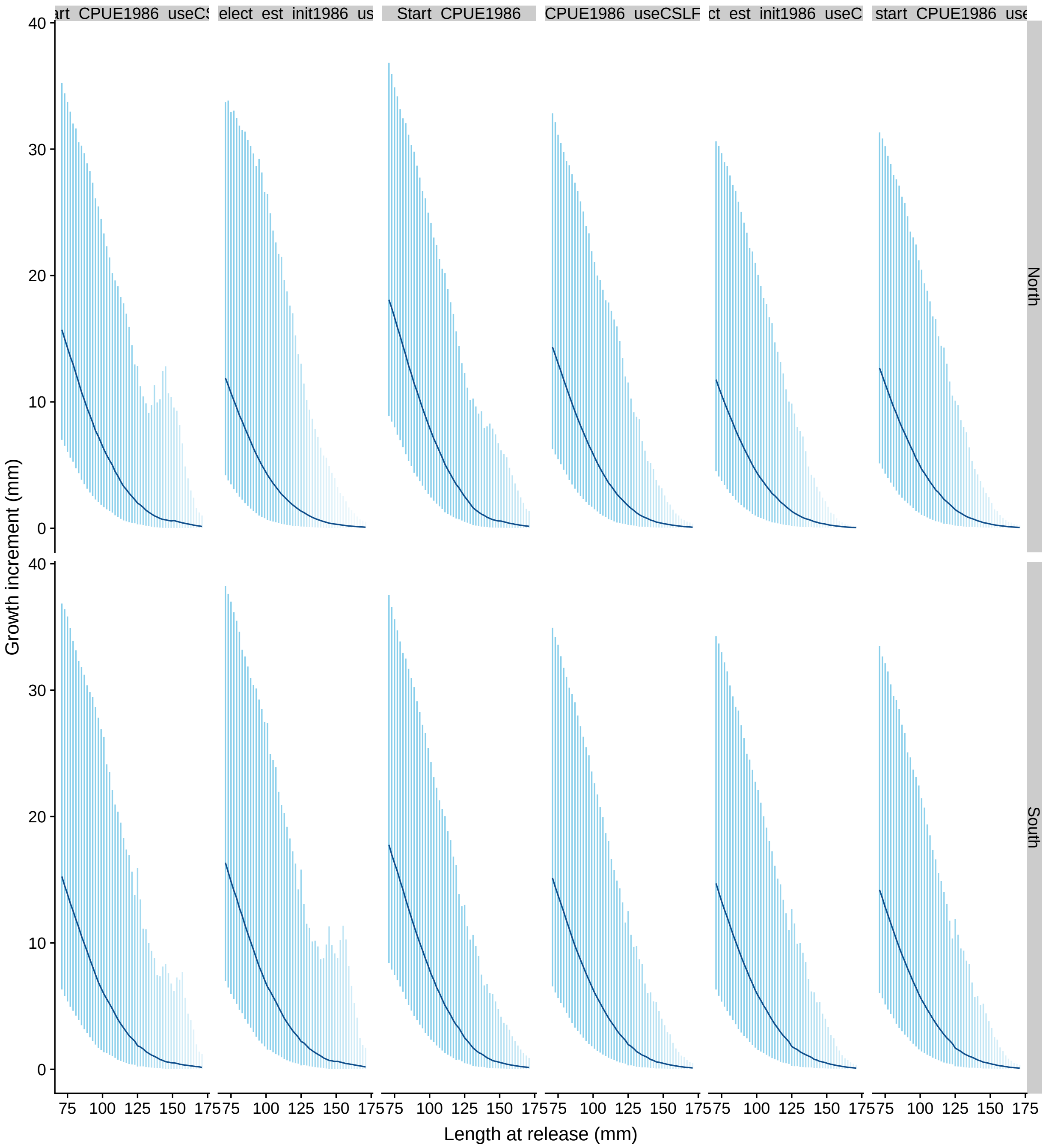

Figure A-22: Comparison of prior and posterior growth in the spatial stock assessment model using parameters for Set 2b. Median distribution of population somatic growth by size bin with posterior mean (dark blue line) and 95% growth intervals. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

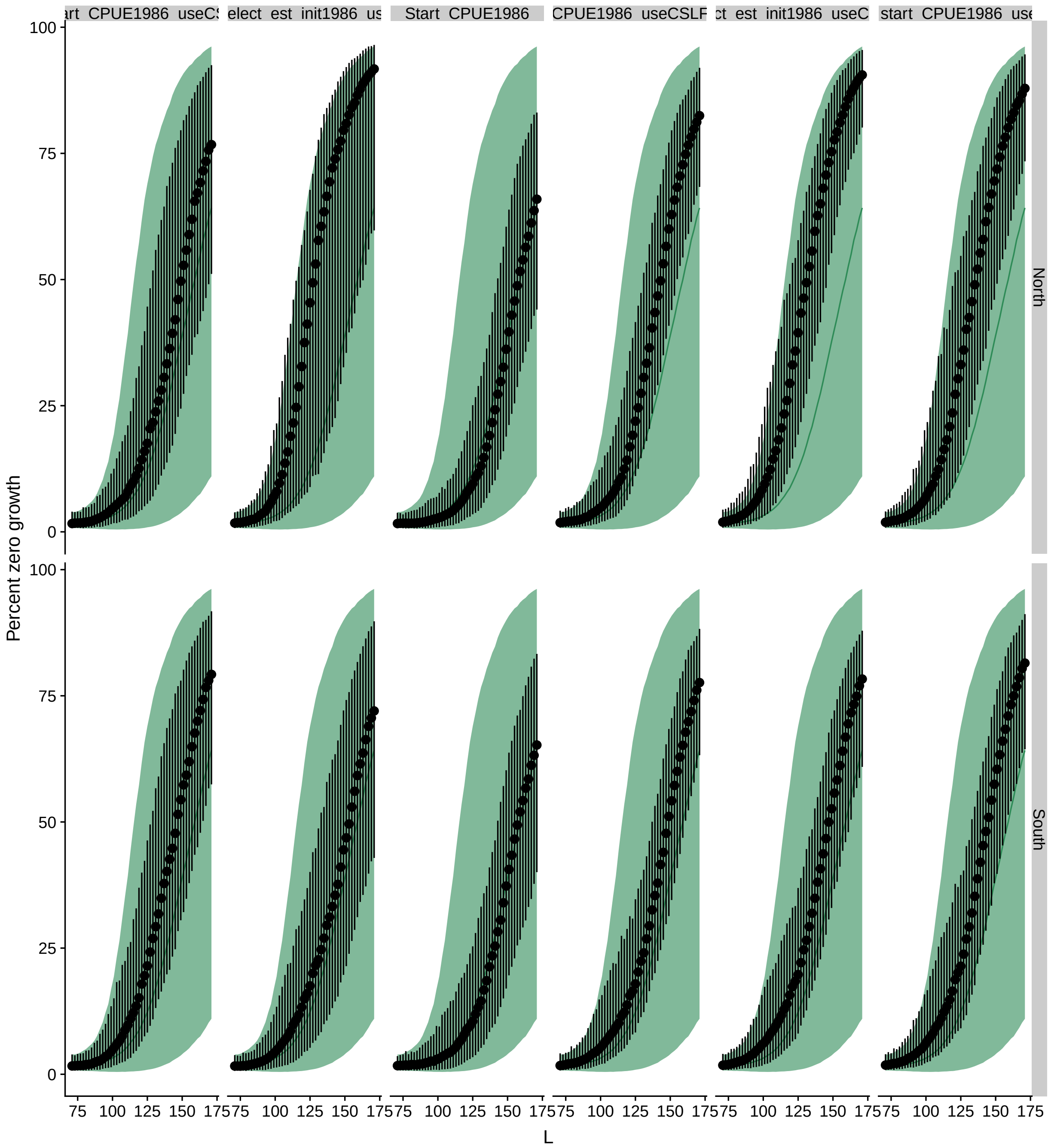

Figure A-23: Comparison of prior and posterior growth (L, mm) in the spatial stock assessment model using parameters for Set 2b. Prior for proportion of pāua not growing at each length class (prior mean (green line) and confidence interval (green shading) and posterior distribution (black dots and 95% posterior confidence). Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

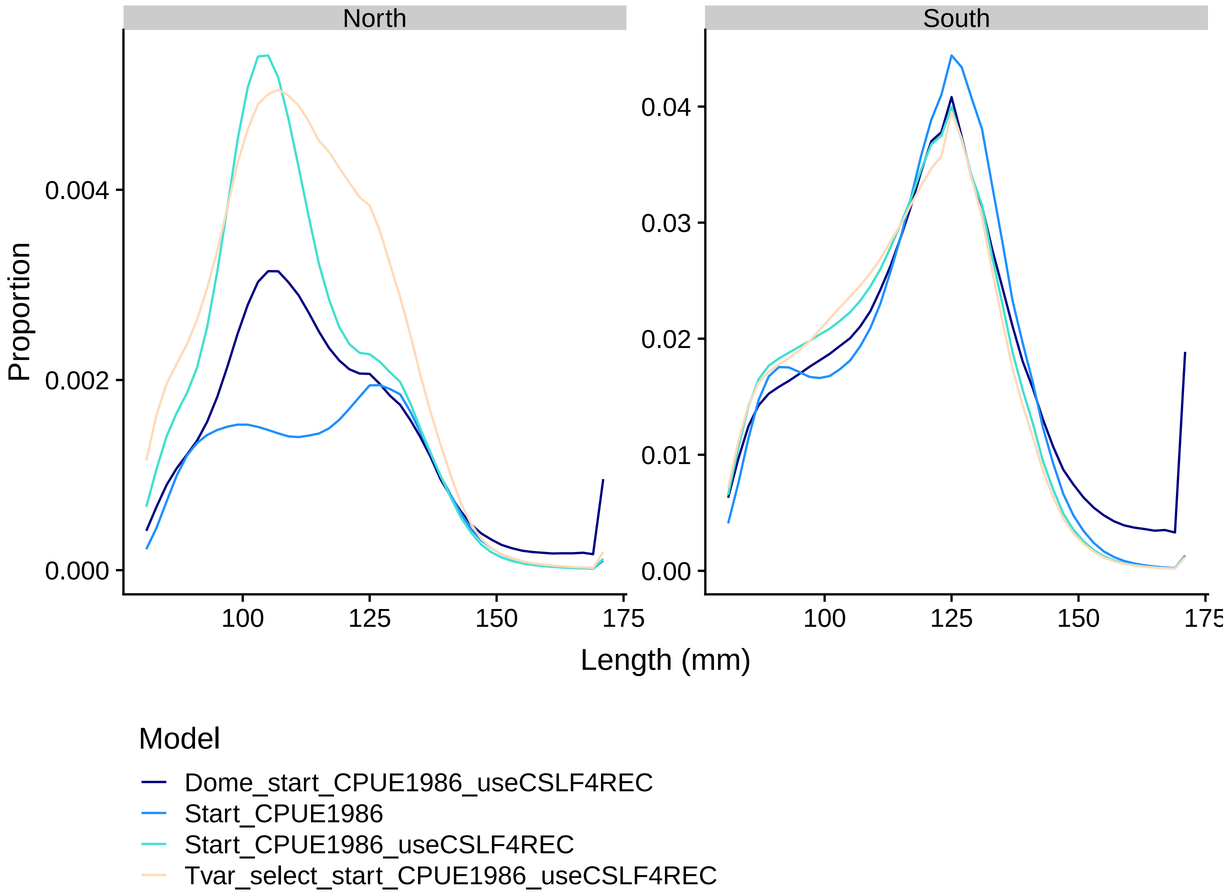

Figure A-24: Comparison of posterior mean proportions-at-length in the stock assessment model using parameters for Set 2b. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

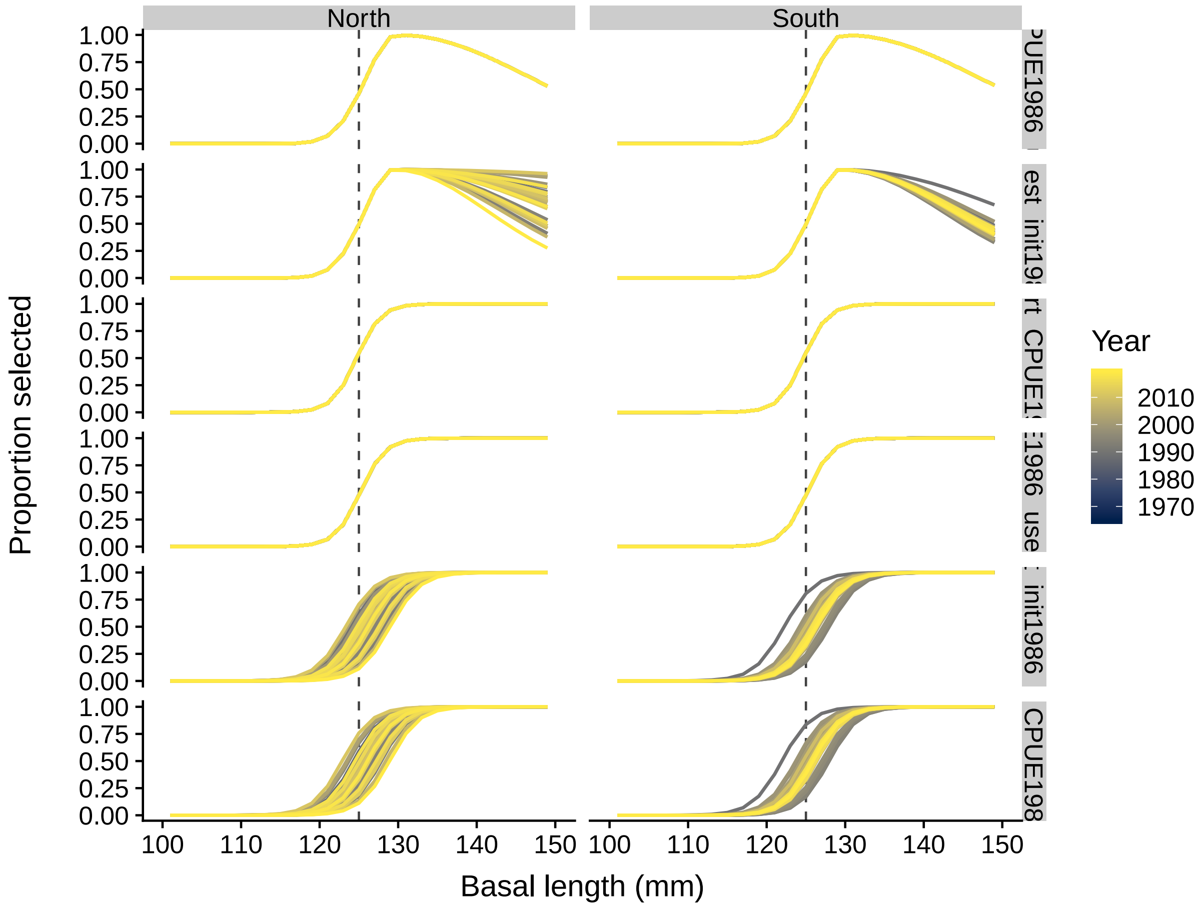

Figure A-25: Comparison of posterior mean selectivity-at-length in the stock assessment model using parameters for Set 2b. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency data.

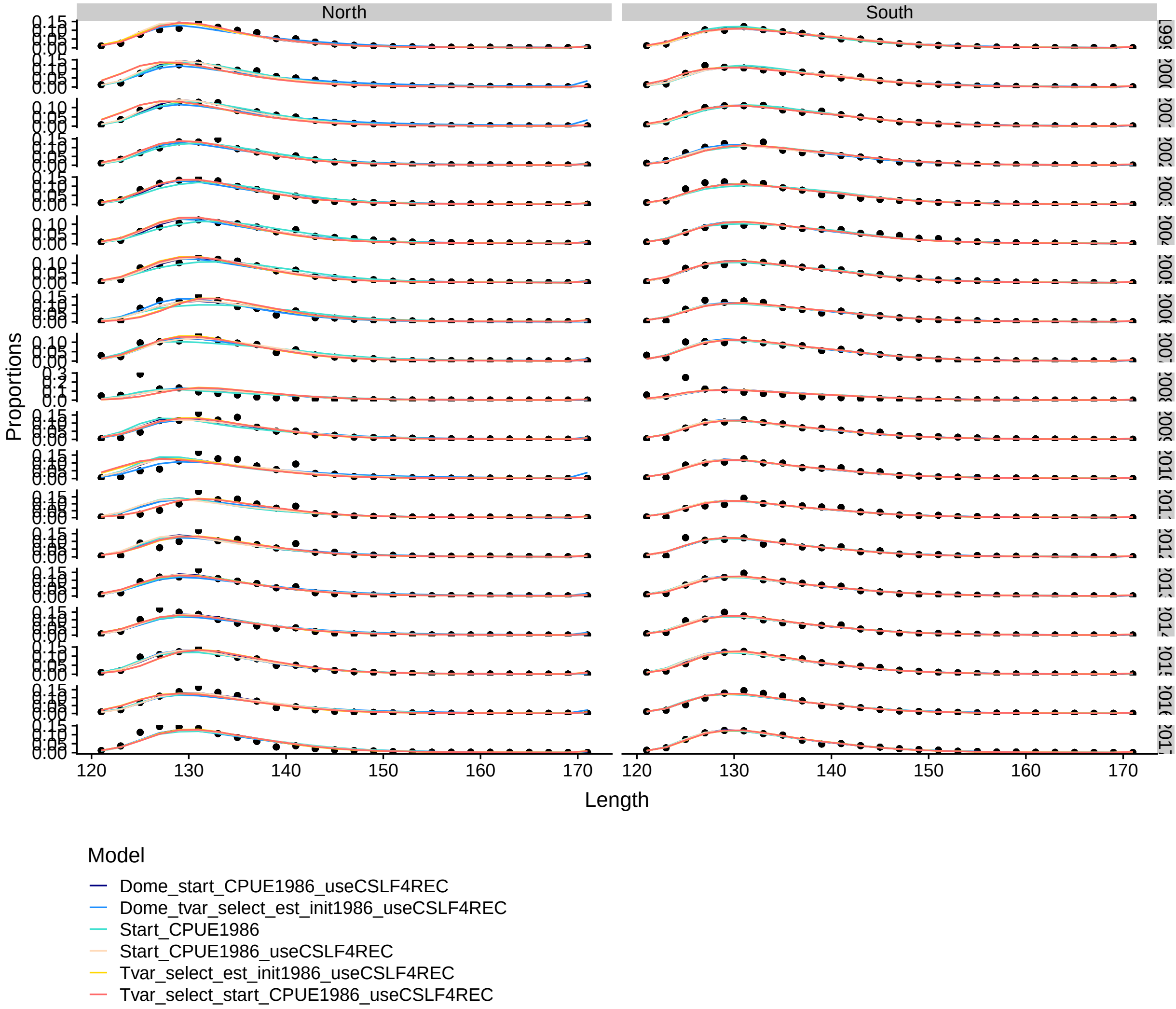

Figure A-26: Comparison of posterior mean predicted catch sampling length frequency (CSLF; length in mm) with estimated CSLF proportions, in the stock assessment model using parameters for Set 2b. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with CSLF data.

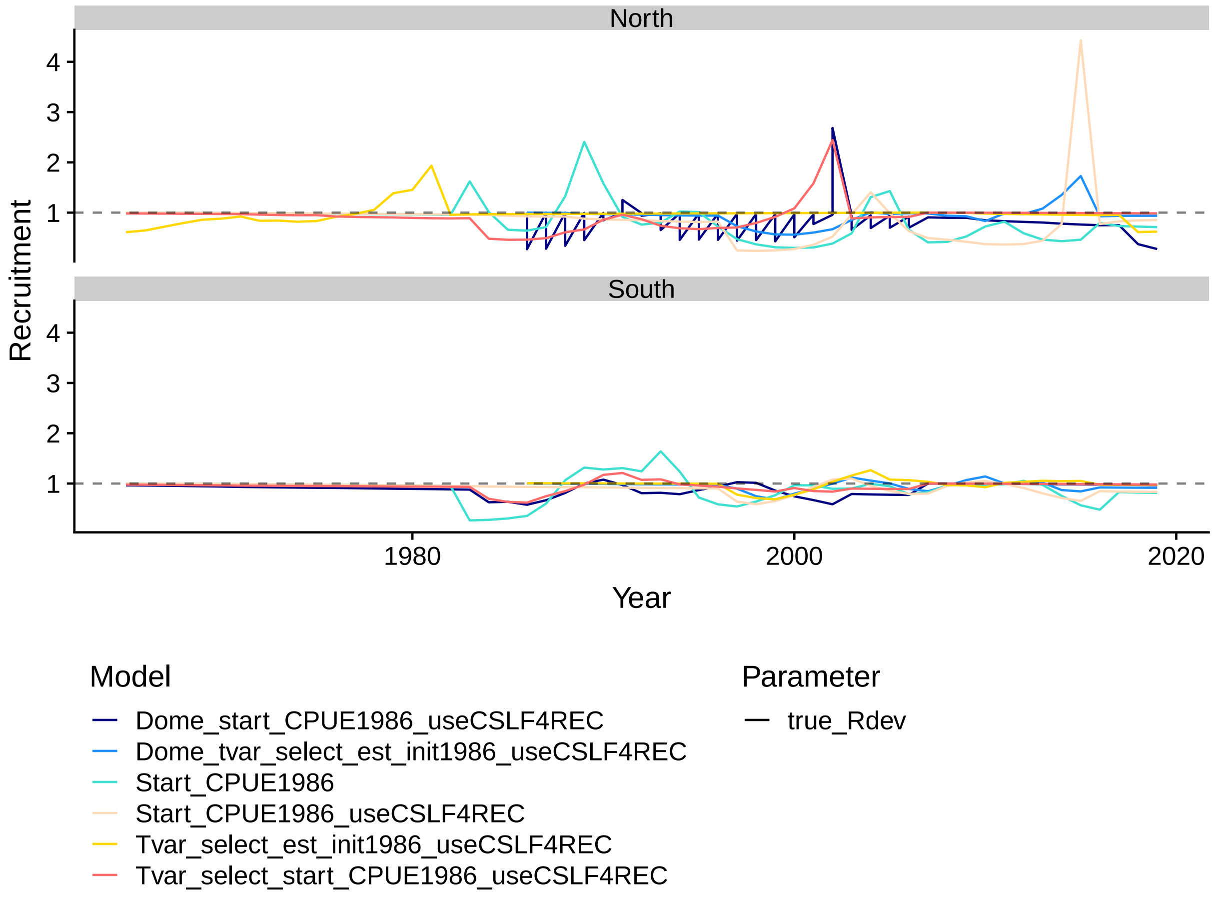

Figure A-27: Comparison of posterior mean recruitment deviations (Rdev) in the stock assessment model using parameters for Set 2b. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

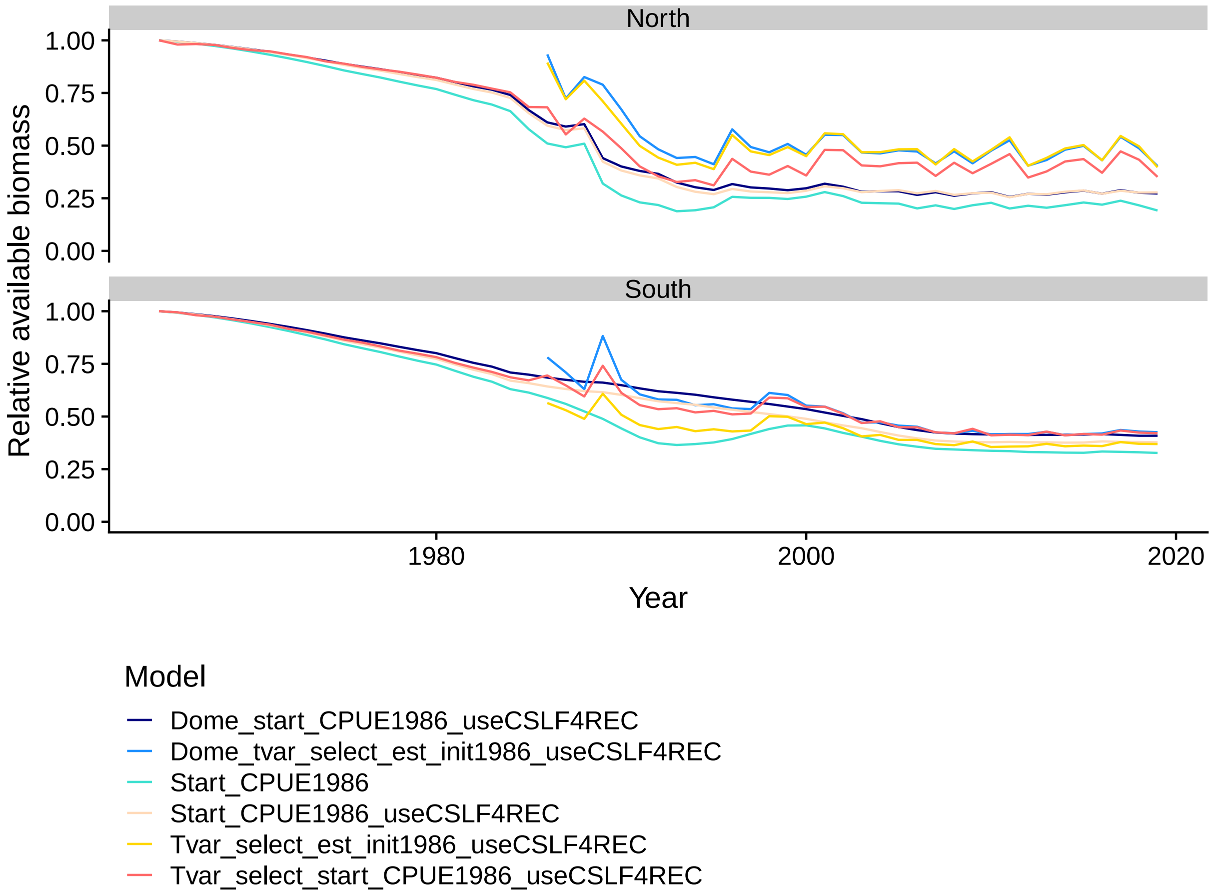

Figure A-28: Comparison of posterior median predicted relative available biomass trend in the stock assessment model using parameters for Set 2b. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

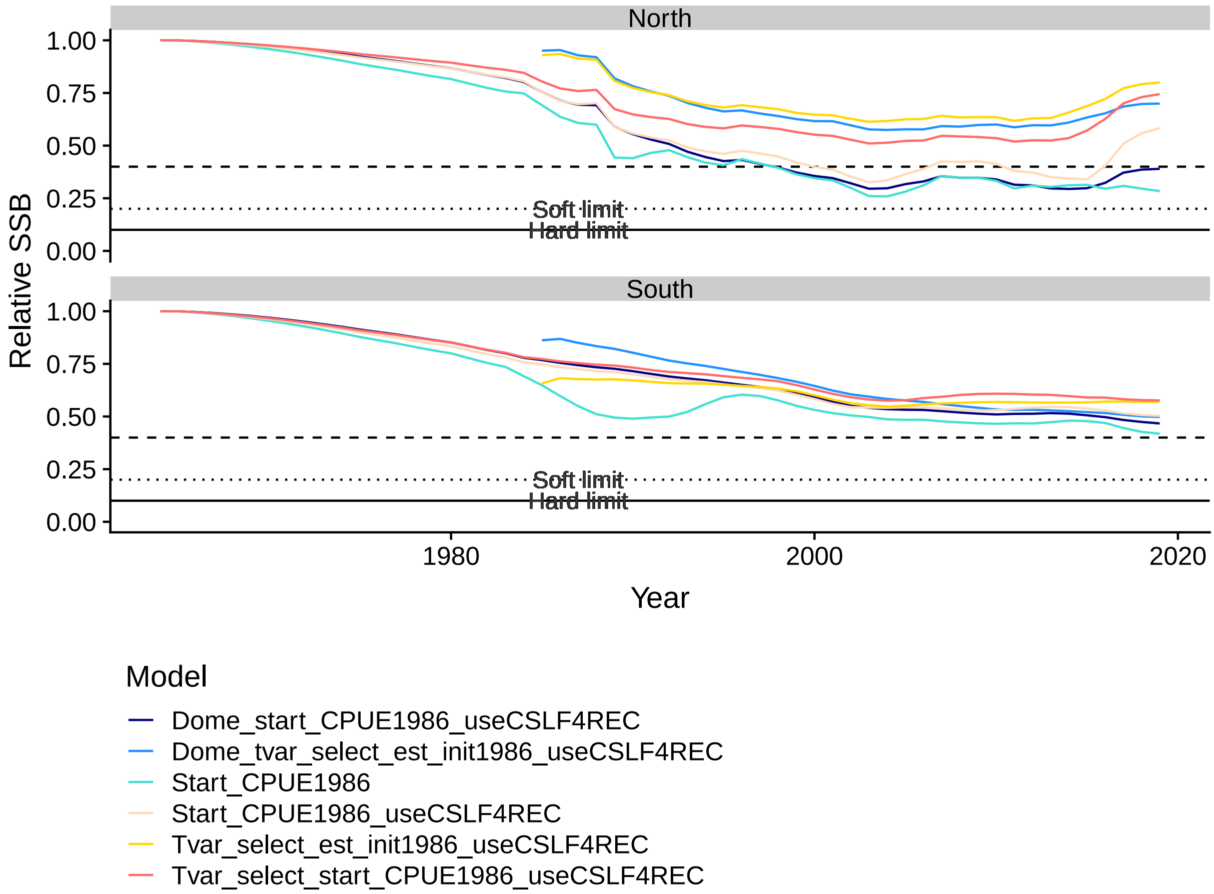

Figure A-29: Comparison of posterior median predicted relative spawning stock biomass trend in the stock assessment model using parameters for Set 2b. Soft and hard limit refer to Fisheries New Zealand harvest strategy standard limit reference points. Model scenario names show differences in initialisation (estimating initial depletion in 1986 (est init1986), or starting catch-per-unit-effort (CPUE) in 1986), selectivity (logistic, dome, or time-varying (tvar select) logistic). All models estimated three separate catchability parameters for reporting epochs, trends in catchability by epoch, and only estimated recruitment for years with catch sampling length frequency (CSLF) data.

A.4 Model runs: Set 3

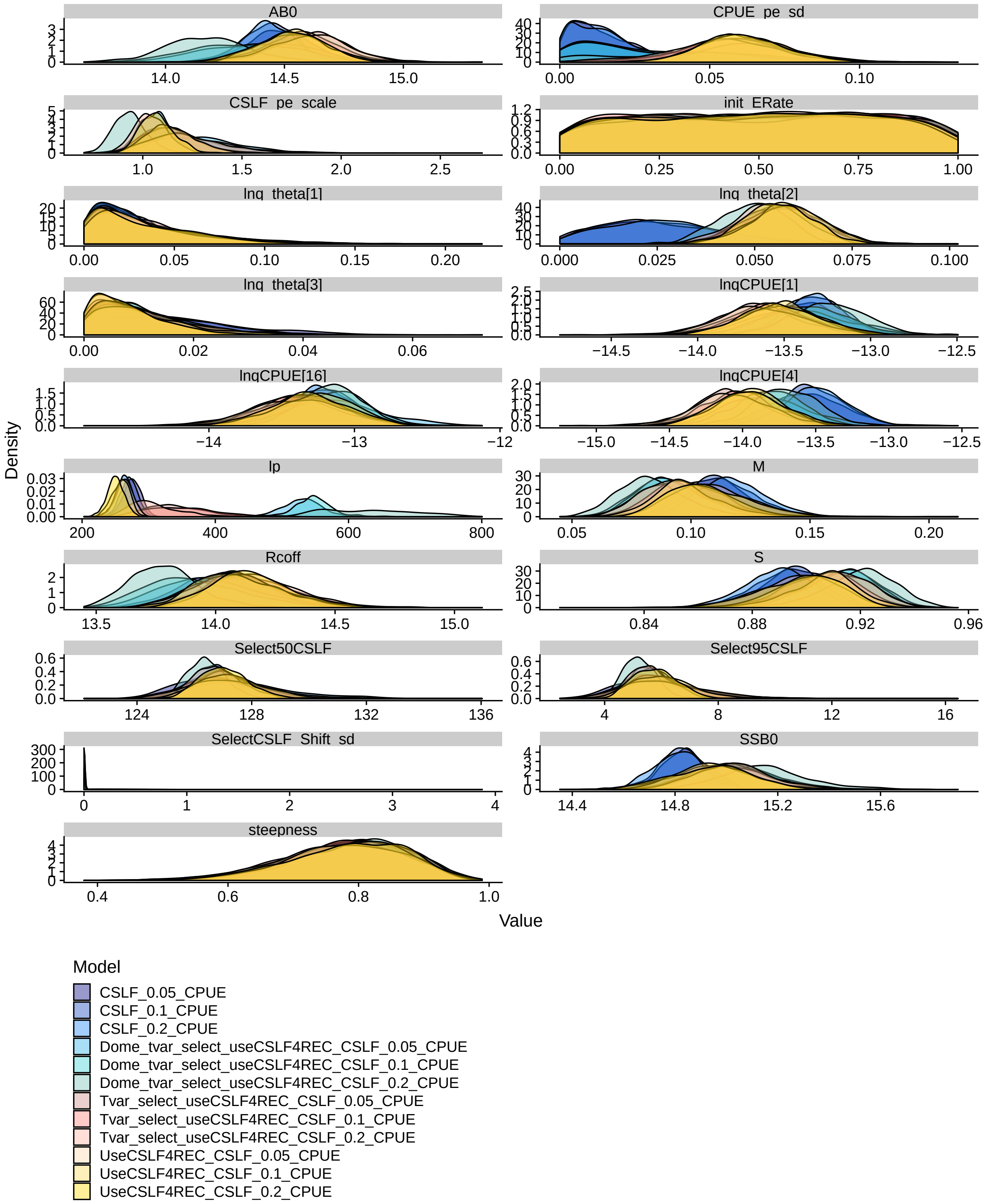

Figure A-30: Comparison of posterior densities for parameters in the stock assessment model using parameters for Set 3. Model scenario names show differences in selectivity (logistic or time-varying logistic (tvar select) and estimation of recruitment (useCSLF4REC – only estimated recruitment for years with catch sampling length frequency (CSLF) data). All models estimated three separate catchability parameters for reporting epochs and trends in catchability by epoch. Values for CSLF indicate likelihood weights, catch-per-unit-effort (CPUE) weights were reduced by 50% relative to earlier runs (Sets 1 and 2).

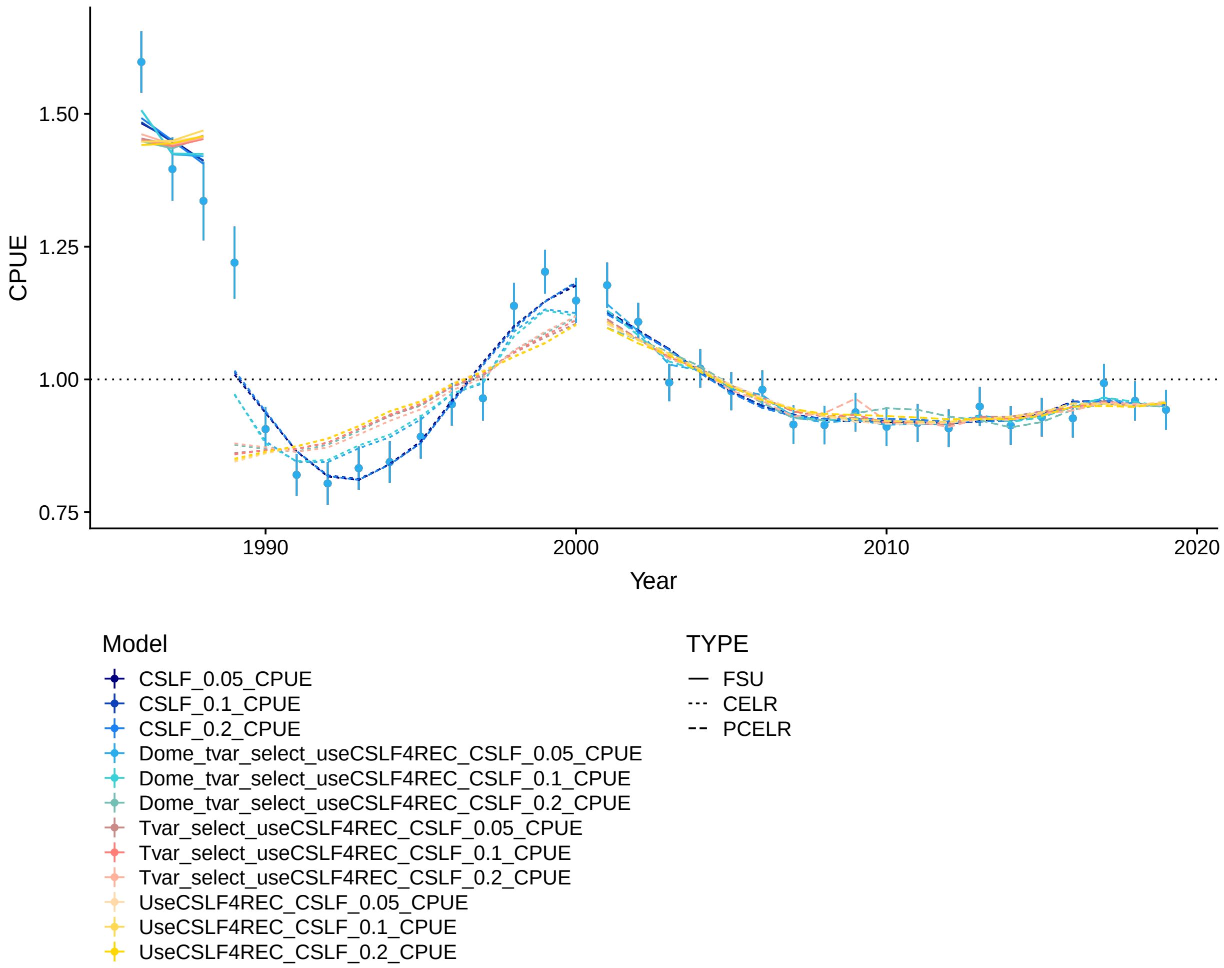

Figure A-31: Comparison of posterior median predicted catch-per-unit-effort (CPUE) in the stock assessment model using parameters for Set 3. Model scenario names show differences in selectivity (logistic or time-varying logistic (tvar select) and estimation of recruitment (useCSLF4REC – only estimated recruitment for years with catch sampling length frequency (CSLF) data). All models estimated three separate catchability parameters for reporting epochs and trends in catchability by epoch. Values for CSLF indicate likelihood weights, catch-per-unit-effort (CPUE) weights were reduced by 50% relative to earlier runs (Sets 1 and 2).

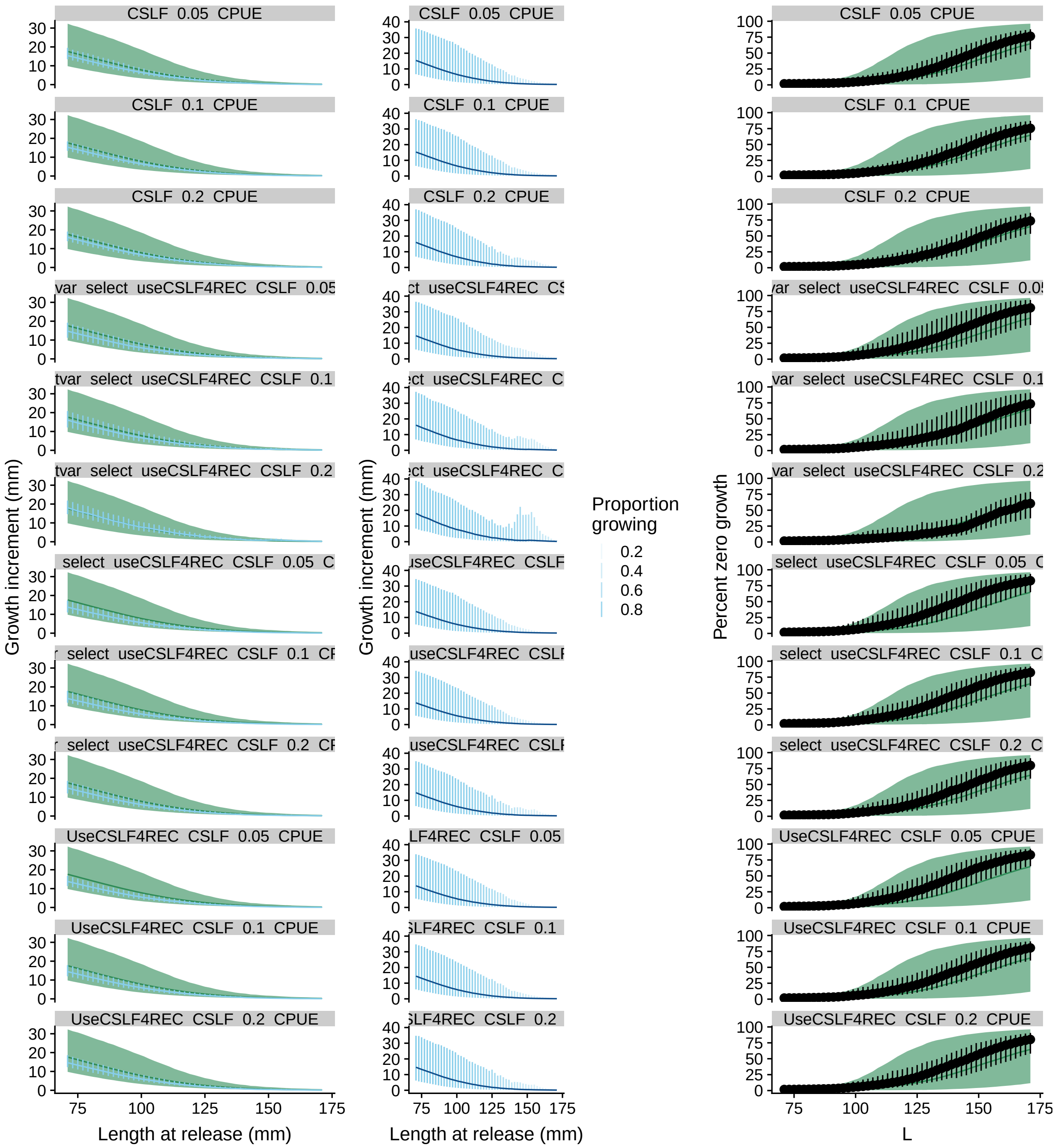

Figure A-32: Comparison of prior and posterior growth in the stock assessment model using parameters for Set 3. Left graphs: prior for population mean growth (prior mean (green line) and 95% prior interval (green shading)), and posterior mean growth (light blue posterior median and 95% posterior interval). Middle graphs: median distribution of population somatic growth by size class with posterior mean (dark blue line) and 95% growth intervals. Right graphs: Prior for proportion of pāua not growing at each length class (prior mean (green line) and confidence interval (green shading) and posterior distribution (black dots and 95% posterior confidence). Model scenario names show differences in selectivity (logistic or time-varying logistic (tvar select) and estimation of recruitment (useCSLF4REC – only estimated recruitment for years with catch sampling length frequency (CSLF) data). All models estimated three separate catchability parameters for reporting epochs and trends in catchability by epoch. Values for CSLF indicate likelihood weights, catch-per-unit-effort (CPUE) weights were reduced by 50% relative to earlier runs (Sets 1 and 2).

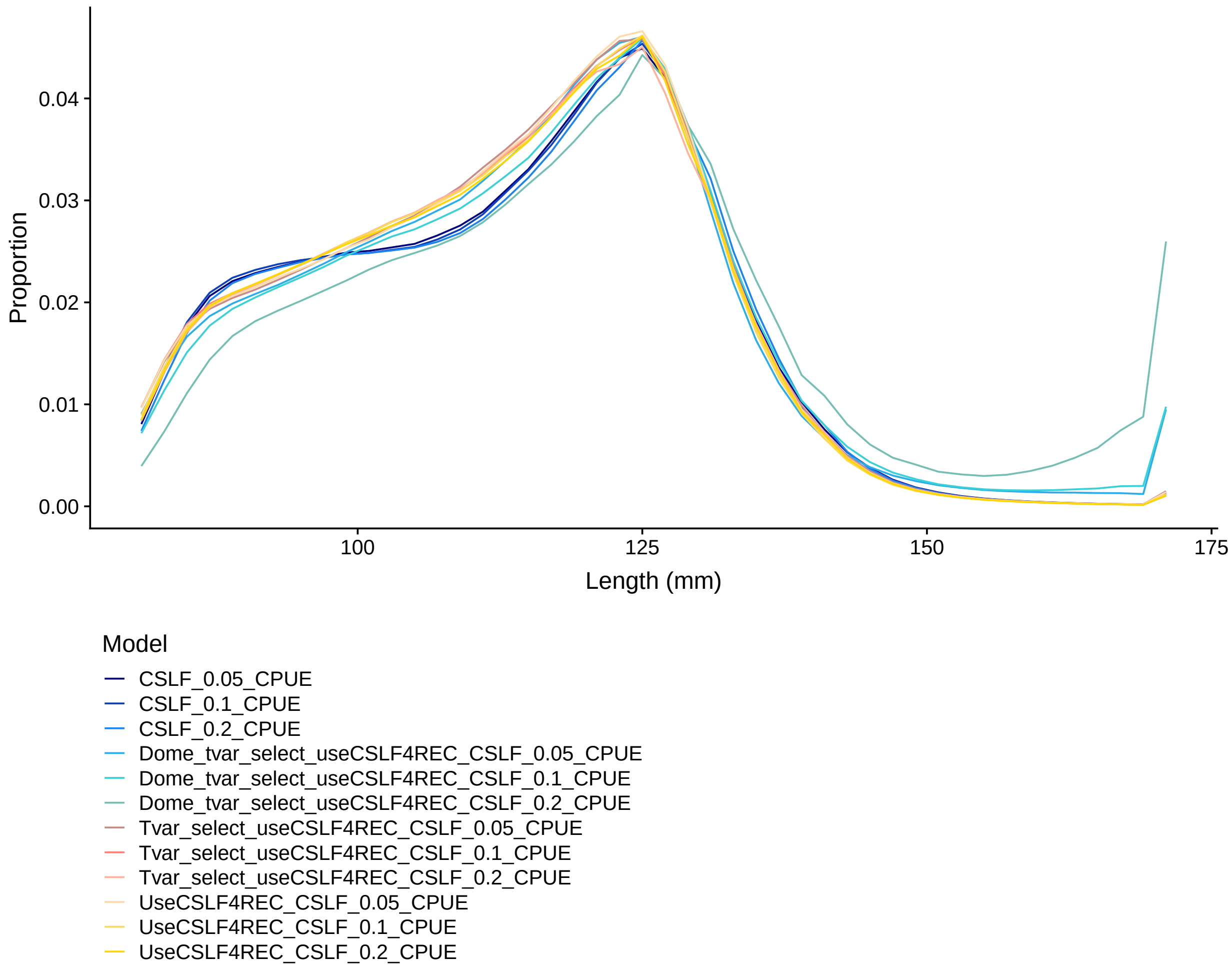

Figure A-33: Comparison of posterior mean proportions-at-length in the stock assessment model using parameters for Set 3. Model scenario names show differences in selectivity (logistic or time-varying logistic (tvar select) and estimation of recruitment (useCSLF4REC – only estimated recruitment for years with catch sampling length frequency (CSLF) data). All models estimated three separate catchability parameters for reporting epochs and trends in catchability by epoch. Values for CSLF indicate likelihood weights, catch-per-unit-effort (CPUE) weights were reduced by 50% relative to earlier runs (Sets 1 and 2).

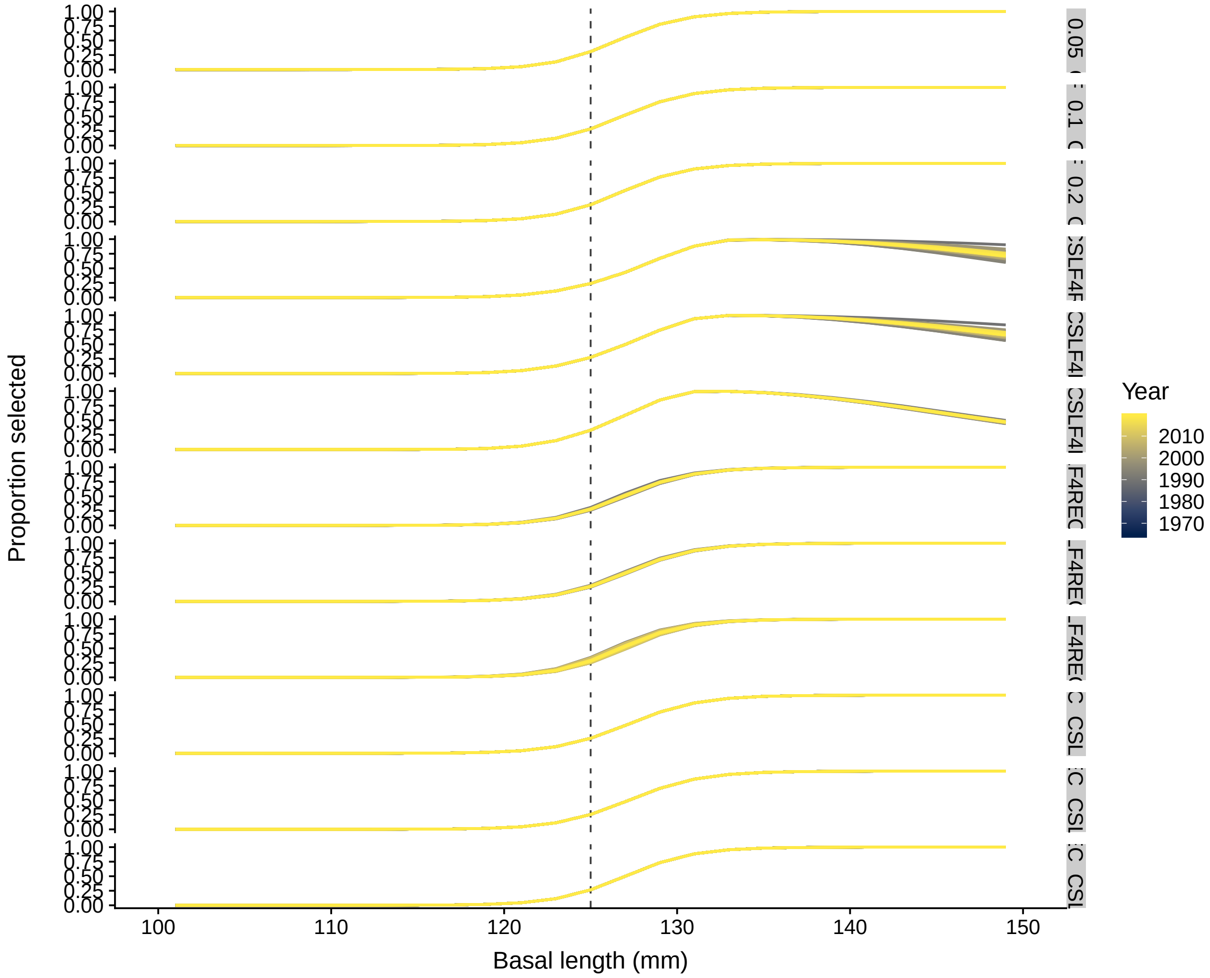

Figure A-34: Comparison of posterior mean selectivity-at-length in the stock assessment model using parameters for Set 3. Model scenario names show differences in selectivity (logistic or time-varying logistic (tvar select) and estimation of recruitment (useCSLF4REC – only estimated recruitment for years with catch sampling length frequency (CSLF) data). All models estimated three separate catchability parameters for reporting epochs and trends in catchability by epoch. Values for CSLF indicate likelihood weights, catch-per-unit-effort (CPUE) weights were reduced by 50% relative to earlier runs (Sets 1 and 2).

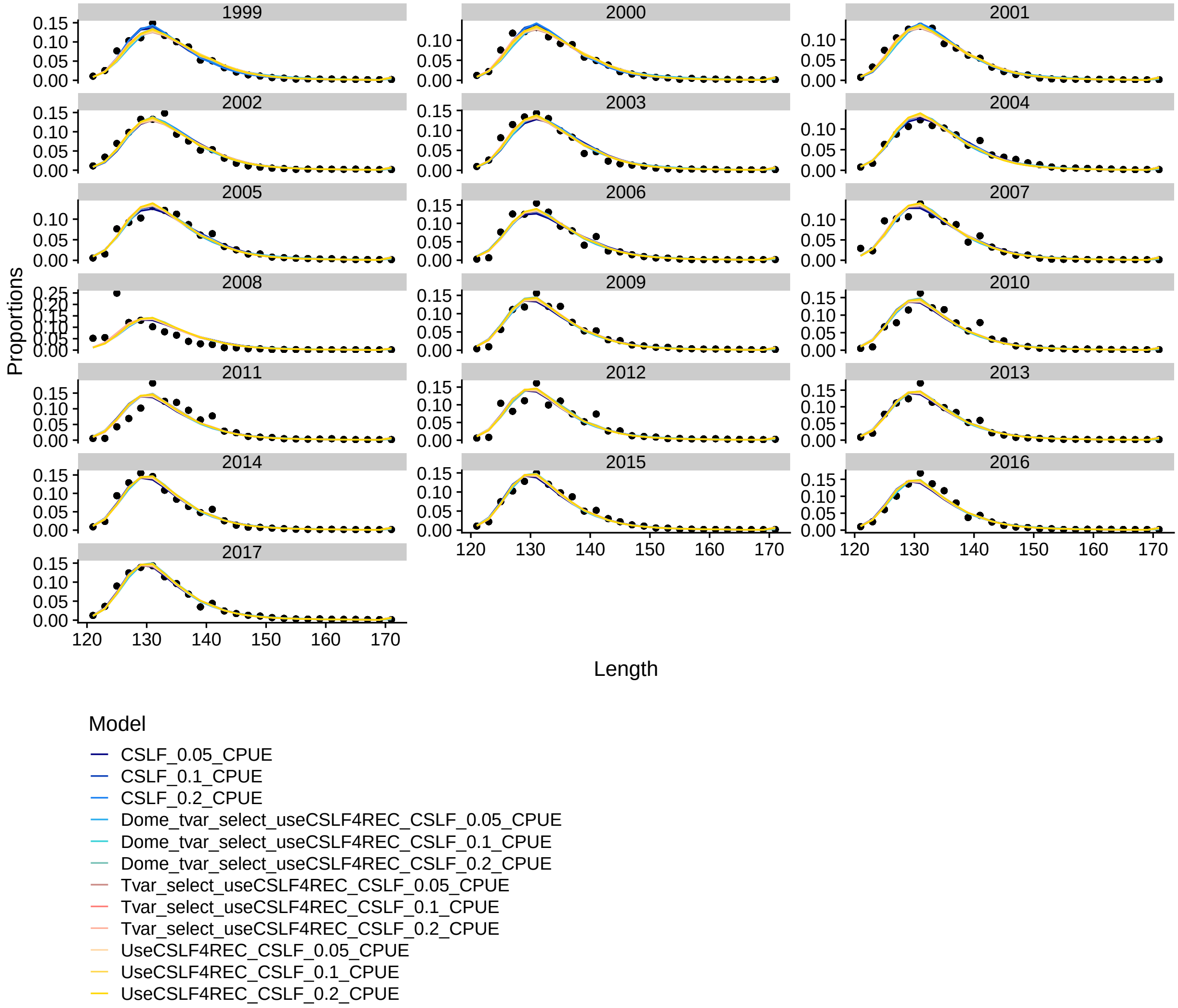

Figure A-35: Comparison of posterior mean predicted catch sampling length frequency (CSLF) with estimated CSLF proportions, in the stock assessment model using parameters for Set 3. Model scenario names show differences in selectivity (logistic or time-varying logistic (tvar select) and estimation of recruitment (useCSLF4REC – only estimated recruitment for years with catch sampling length frequency (CSLF) data). All models estimated three separate catchability parameters for reporting epochs and trends in catchability by epoch. Values for CSLF indicate likelihood weights, catch-per-unit-effort (CPUE) weights were reduced by 50% relative to earlier runs (Sets 1 and 2).

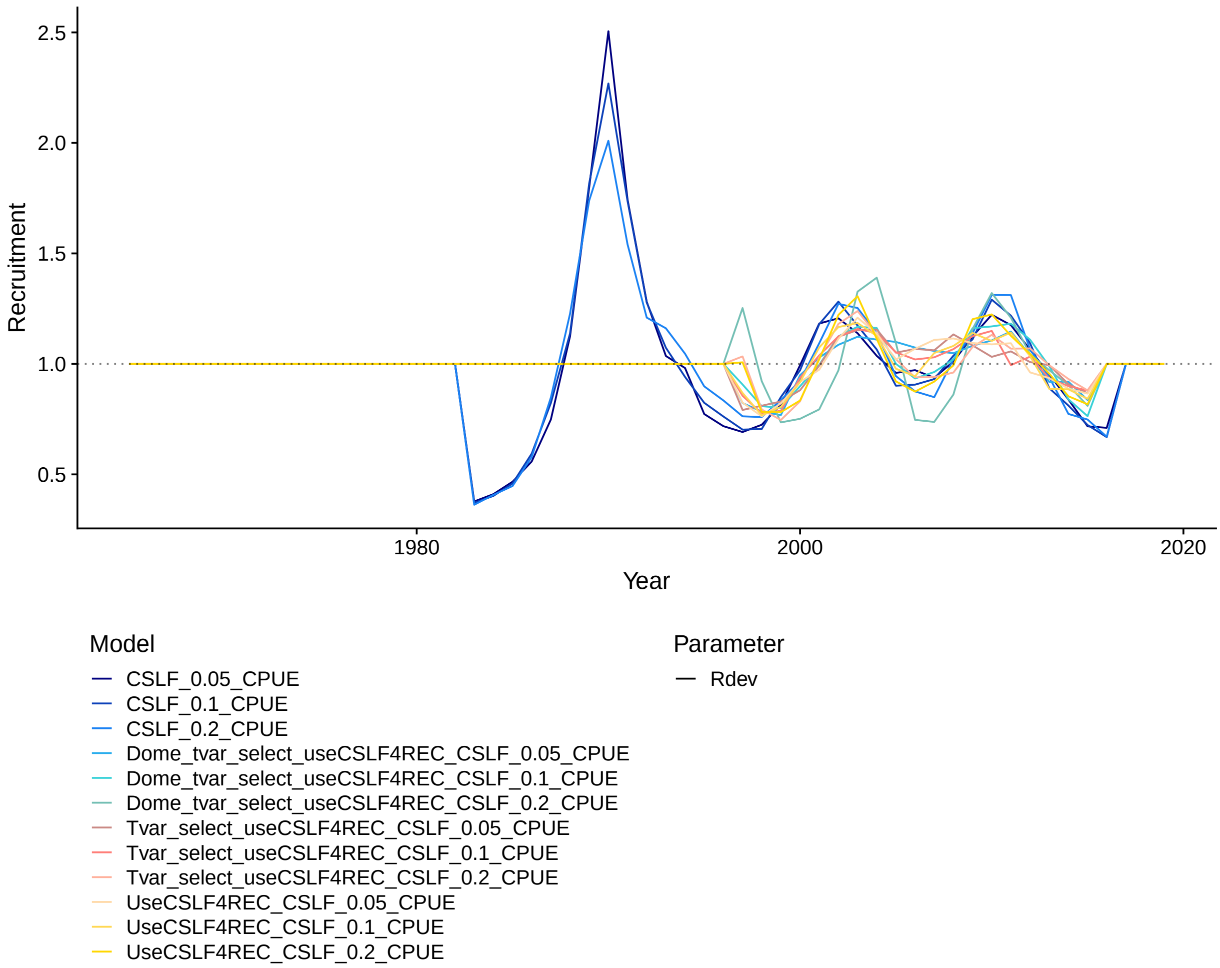

Figure A-36: Comparison of posterior mean recruitment deviations (Rdev) in the stock assessment model using parameters for Set 3. Model scenario names show differences in selectivity (logistic or time-varying logistic (tvar select) and estimation of recruitment (useCSLF4REC – only estimated recruitment for years with catch sampling length frequency (CSLF) data). All models estimated three separate catchability parameters for reporting epochs and trends in catchability by epoch. Values for CSLF indicate likelihood weights, catch-per-unit-effort (CPUE) weights were reduced by 50% relative to earlier runs (Sets 1 and 2).

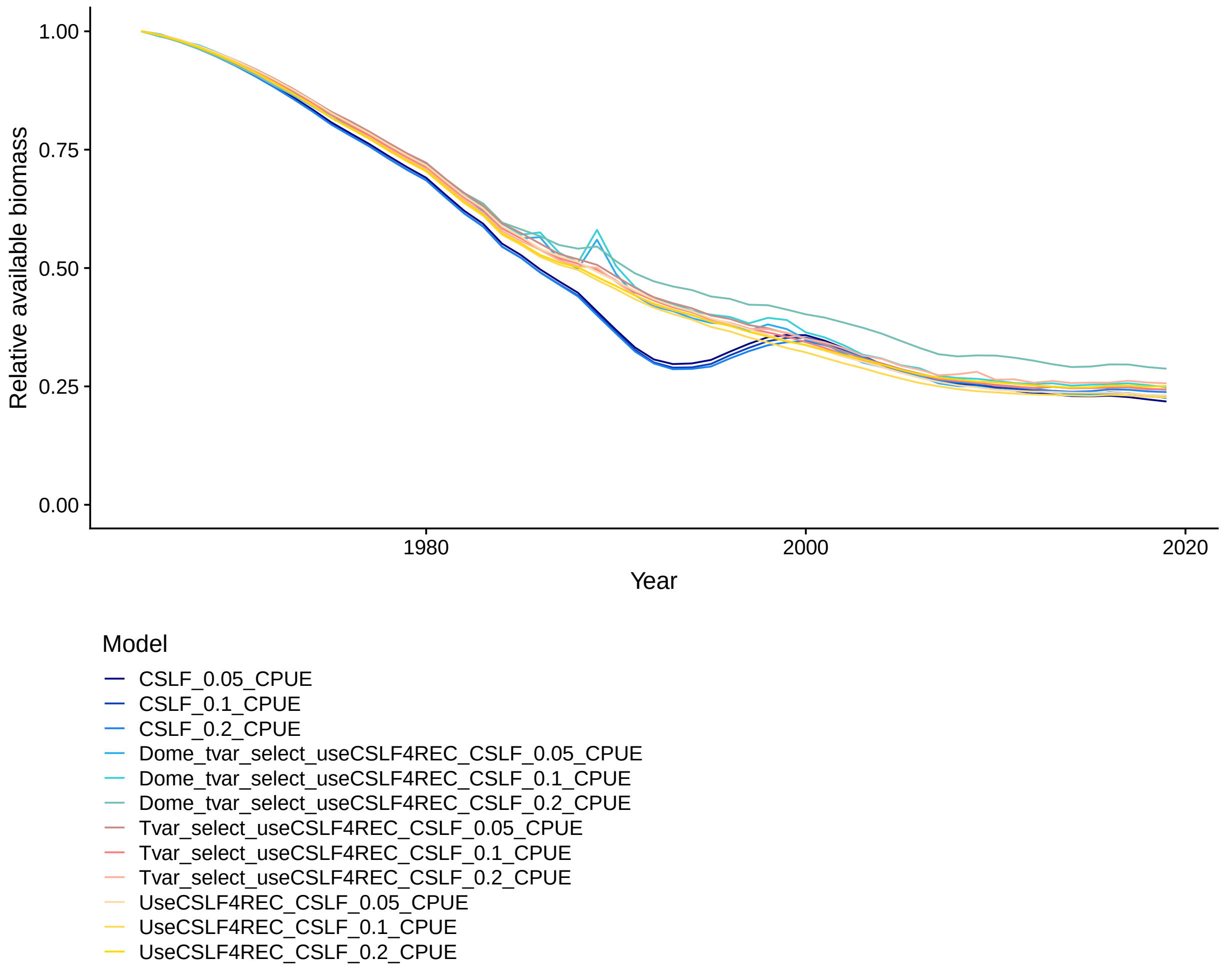

Figure A-37: Comparison of posterior median predicted relative available biomass trend in the stock assessment model using parameters for Set 3. Model scenario names show differences in selectivity (logistic or time-varying logistic (tvar select) and estimation of recruitment (useCSLF4REC – only estimated recruitment for years with catch sampling length frequency (CSLF) data). All models estimated three separate catchability parameters for reporting epochs and trends in catchability by epoch. Values for CSLF indicate likelihood weights, catch-per-unit-effort (CPUE) weights were reduced by 50% relative to earlier runs (Sets 1 and 2).

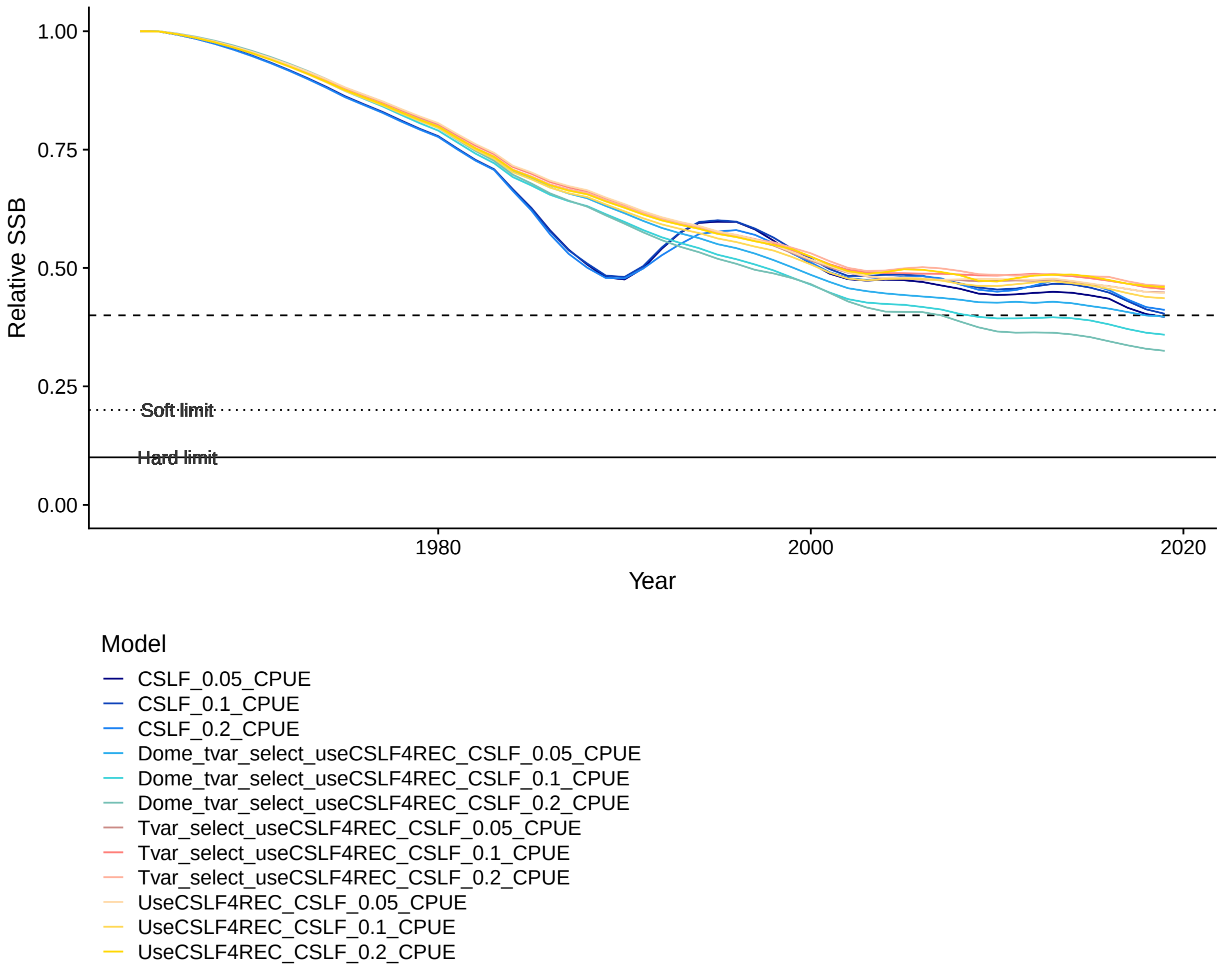

Figure A-38: Comparison of posterior median predicted relative spawning stock biomass trend in the stock assessment model using parameters for Set 3. Soft and hard limit refer to Fisheries New Zealand harvest strategy standard limit reference points. Model scenario names show differences in selectivity (logistic or time-varying logistic (tvar select) and estimation of recruitment (useCSLF4REC – only estimated recruitment for years with catch sampling length frequency (CSLF) data). All models estimated three separate catchability parameters for reporting epochs and trends in catchability by epoch. Values for CSLF indicate likelihood weights, catch-per-unit-effort (CPUE) weights were reduced by 50% relative to earlier runs (Sets 1 and 2).

APPENDIX B: INDIVIDUAL MODEL RUNS

B.1 Base case: M0.11

B.1.1 Markov chain Monte Carlo and posteriors

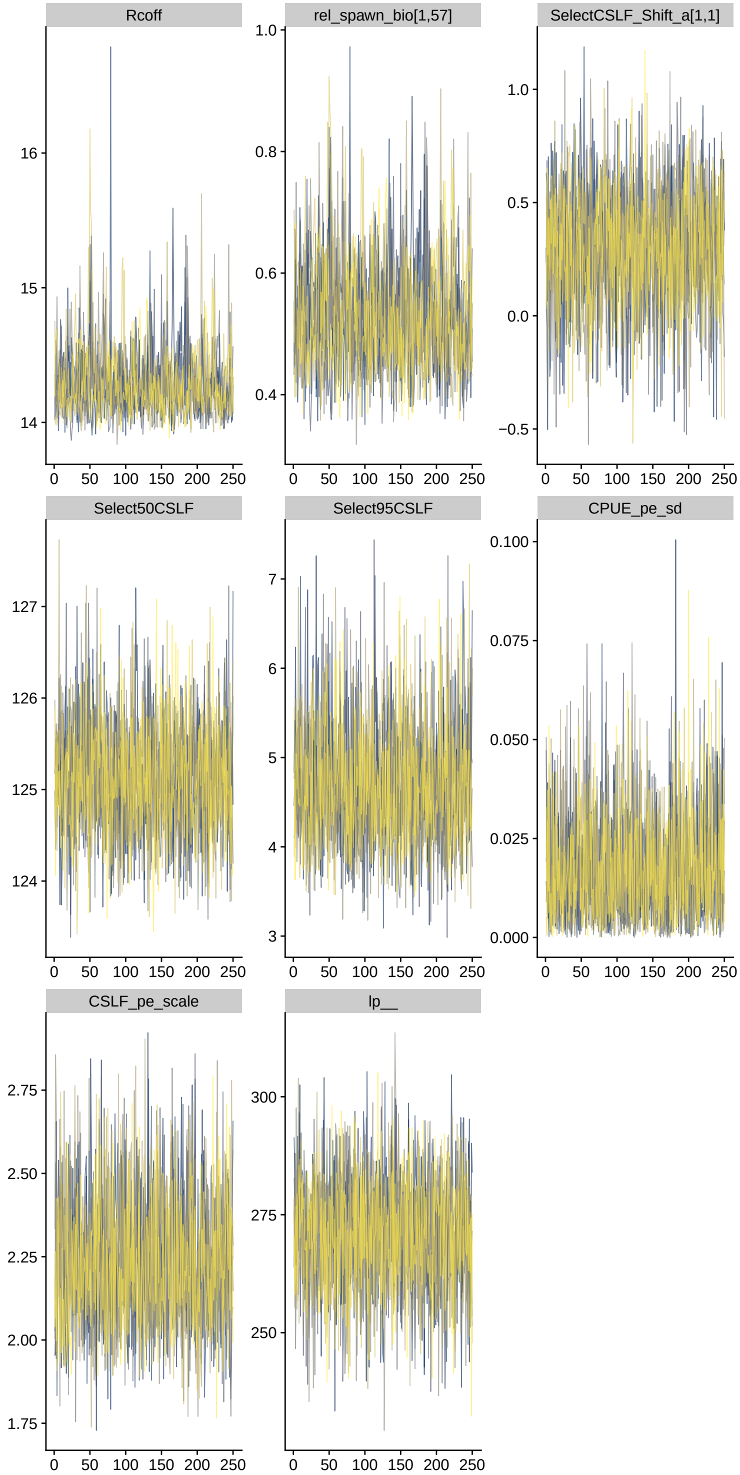

Figure B-1: Traces of Markov chain Monte Carlo estimation for the marginal posterior distribution of key model parameters for the base case stock assessment model of pāua in Quota Management Area PAU 2.

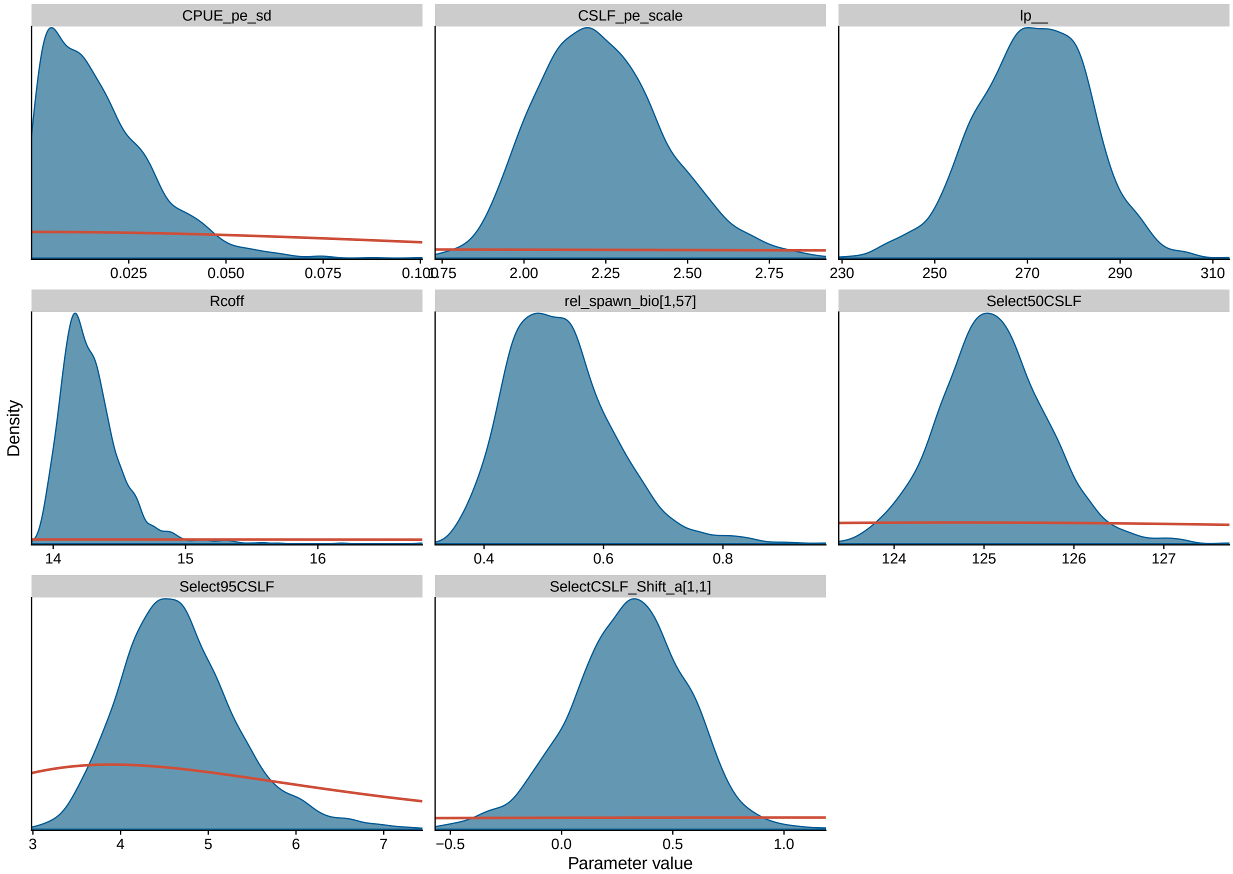

Figure B-2: Marginal posterior densities of key model parameters for the base case stock assessment model of pāua for Quota Management Area PAU 2, with prior densities indicated in red.

Table B-1: Posterior quantities for key parameters in the base case pāua stock assessment model for quota management area PAU 2. Equilibrium recruitment, R_0; size at which 50% of individuals are selected, D_{50}; size at which 95% of individuals are selected, D_{95}; shift in selectivity curve between periods, D_a; exploitation rate (U) leading to 40% spawning stock biomass (SSB); Bayes log posterior; process error, PE (CPUE, catch-per-unit-effort; CSLF, catch sampling length frequency); relative SSB.

Parameter	Posterior percentile				
	2.5%	25%	50%	75%	97.5%
$\log(R_0)$	13.97	14.13	14.25	14.39	14.88
D_{50}	123.96	124.72	125.09	125.48	126.35
D_{95}	3.56	4.21	4.62	5.05	6.19
D_a	-0.25	0.13	0.31	0.48	0.77
$U_{40\%\mathrm{SSB}_0}$	0.13	0.22	0.28	0.36	0.69
log posterior	245.94	263.01	271.58	279.80	293.81
$\mathrm{PE}_{\mathrm{CPUE}}$	0.00	0.01	0.01	0.03	0.05
$\mathrm{PE}_{\mathrm{CSLF}}$	1.91	2.09	2.22	2.36	2.67
relative SSB_{2021}	0.39	0.46	0.52	0.58	0.73

B.1.2 Growth

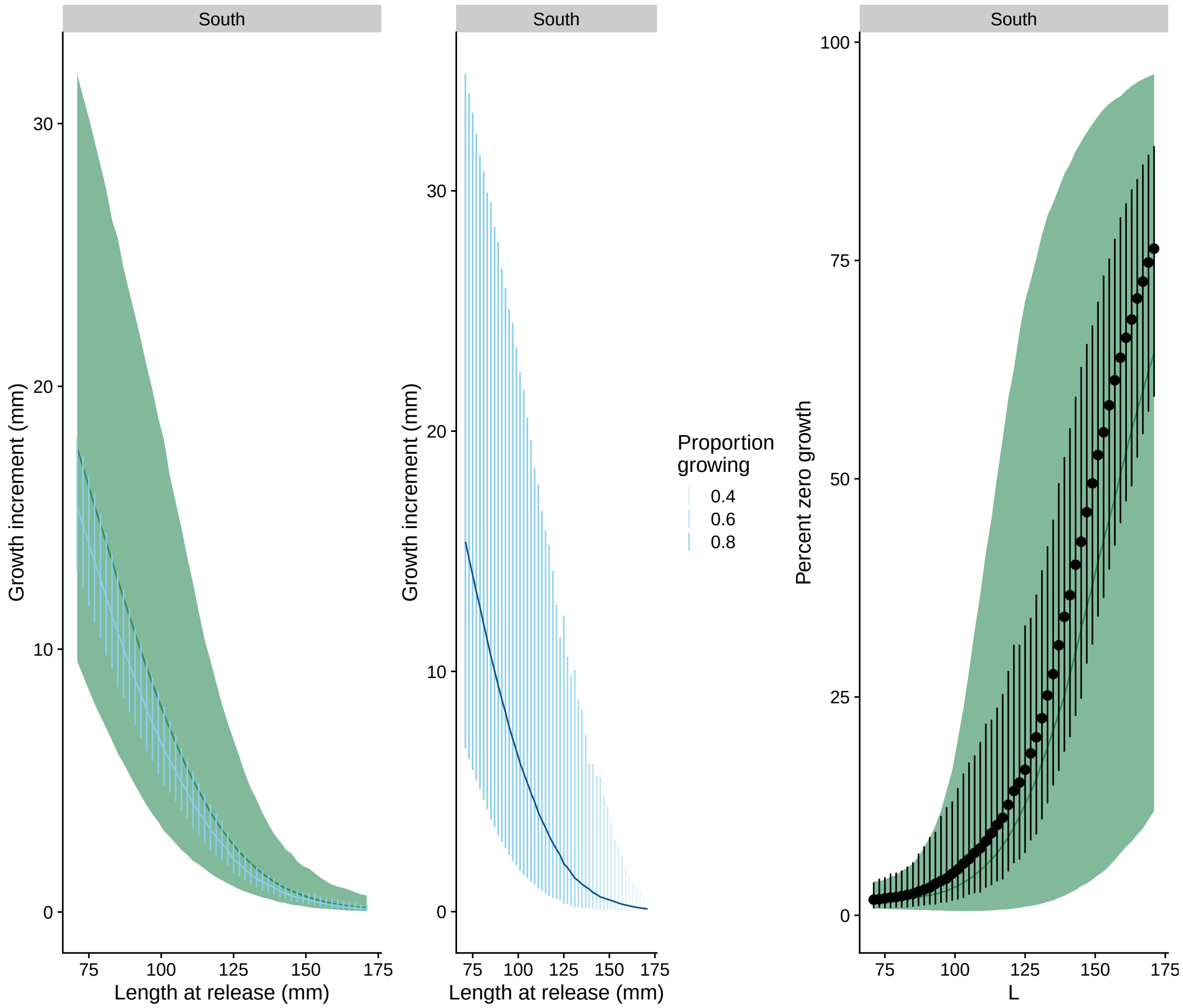

Figure B-3: Top: Posterior mean growth (population mean (dark blue line) and standard deviation of the estimate (light blue ribbon)), relative to the prior (dark green), middle: estimated population standard deviation (posterior median; light blue) relative to estimated population mean (blue line), bottom panel: estimated proportion of pāua stock not growing at each length relative to the prior (green) for the base case stock assessment model of pāua for Quota Management Area PAU 2.

B.1.3 Catch-per-unit-effort fits

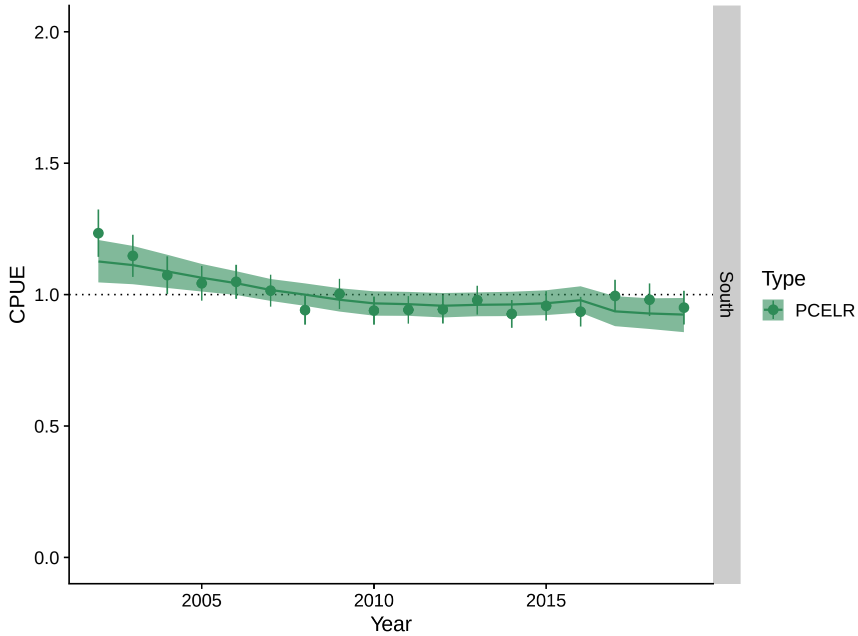

Figure B-4: Comparison of posterior median predicted catch-per-unit-effort (CPUE) with estimated CPUE index and observation error for the base case stock assessment model of pāua for Quota Management Area PAU 2 (black points and error bars; PCELR, data from (Paua) Catch Effort Landing Return forms.

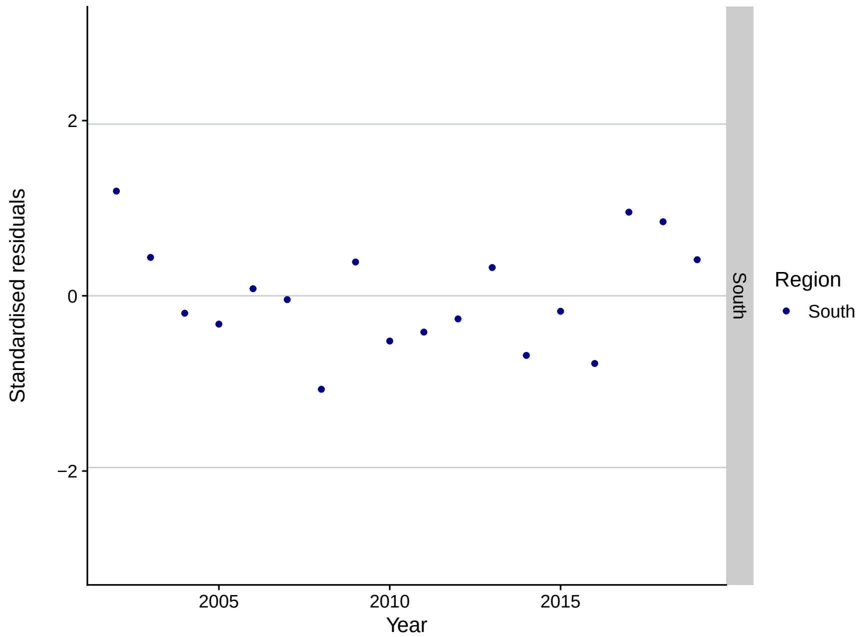

Figure B-5: Standardised residuals at the posterior median of predicted catch-per-unit-effort for the base case stock assessment model of pāua for Quota Management Area PAU 2.

B.1.4 Catch sampling length frequency fits

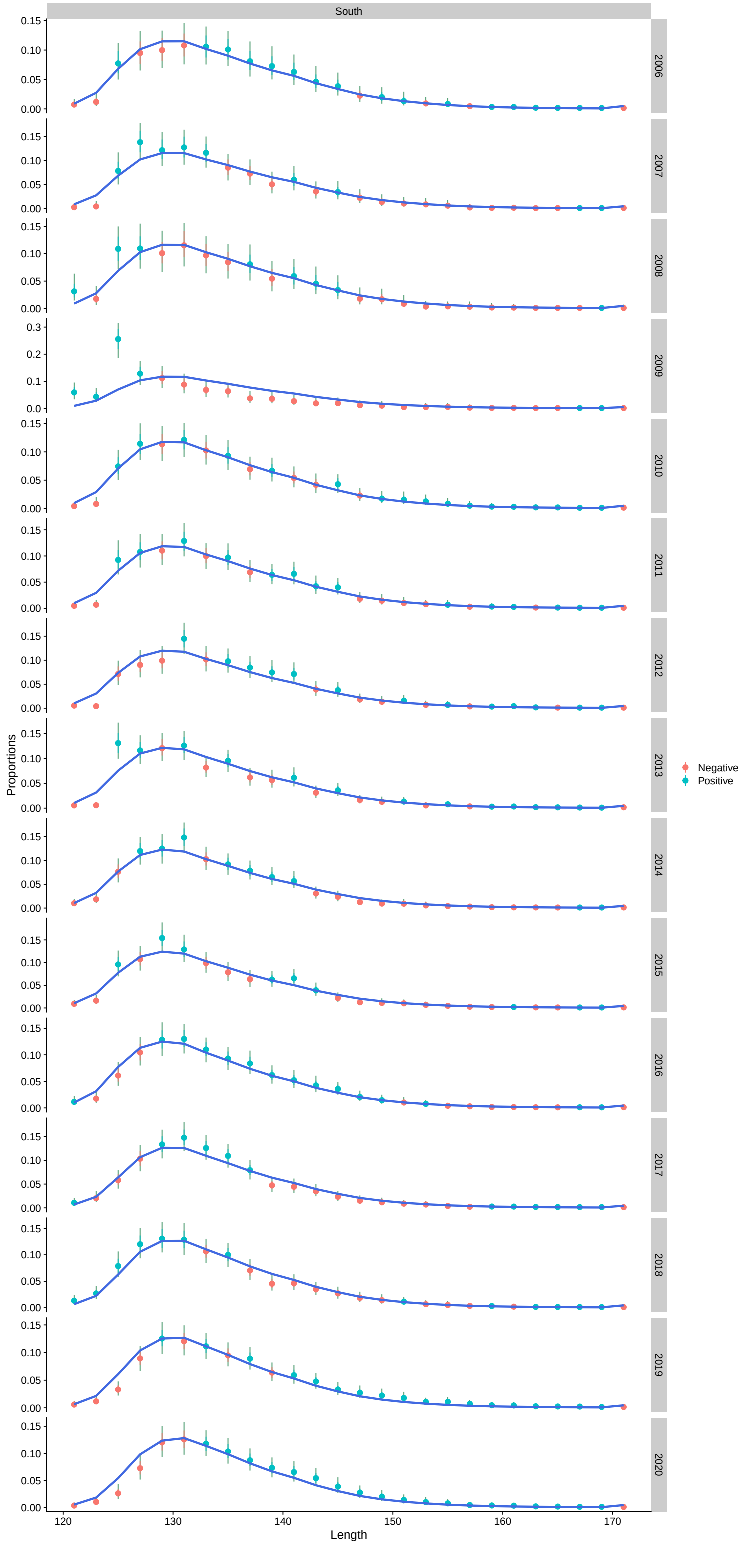

Figure B-6: Comparison of posterior mean predicted catch sampling length frequency (CSLF; length in mm) with estimated CSLF proportions and observation error for the base case stock assessment model of pāua for Quota Management Area PAU 2. Length classes with positive residuals in blue, with negative residuals in red.

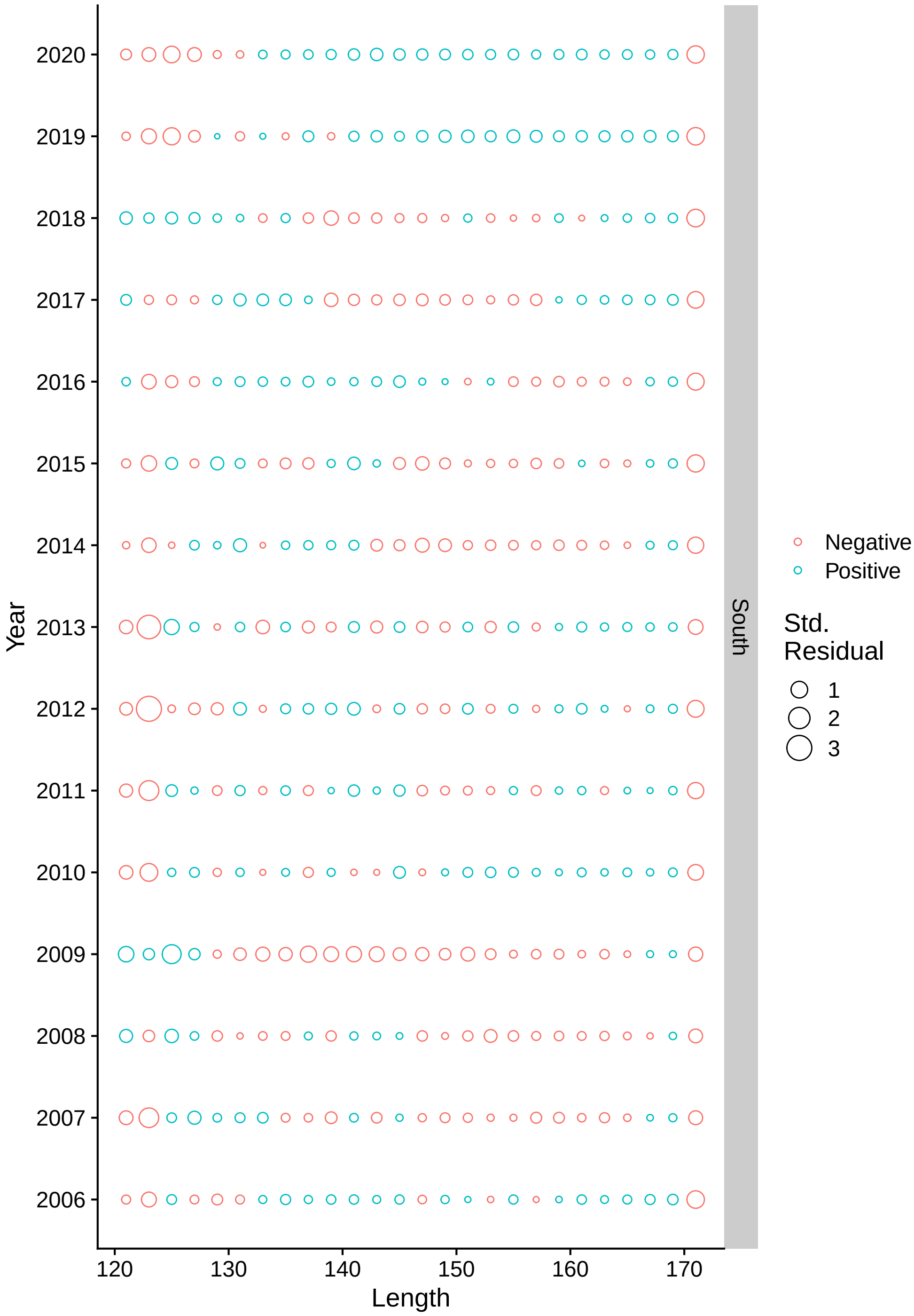

Figure B-7: Catch sampling length frequency model residuals for the base case stock assessment model of pāua for quota management area PAU 2. Length classes with positive residuals in blue, with negative residuals in red.

B.1.5 Selectivity

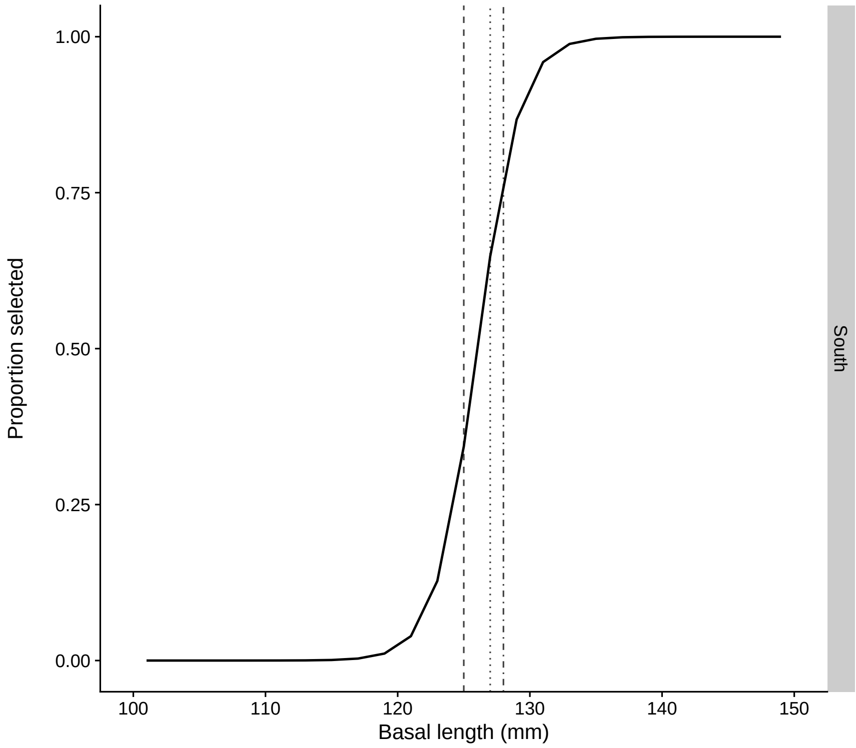

Figure B-8: Estimated selectivity (posterior mean) for the base case stock assessment model for quota management area PAU 2.

B.1.6 Recruitment and biomass trends

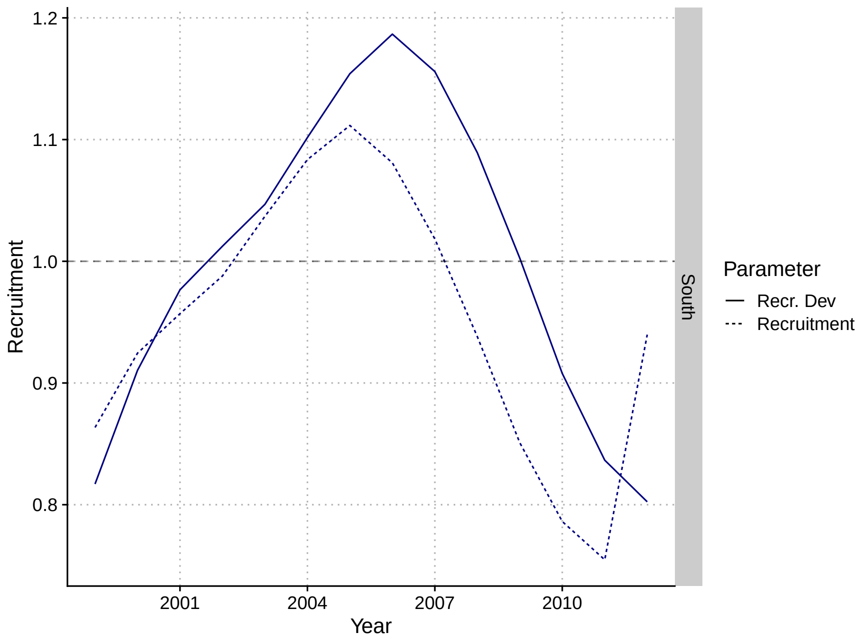

Figure B-9: Posterior mean recruitment for the base case stock assessment model of pāua for Quota Management Area PAU 2 (R_{dev}, recruitment deviation).

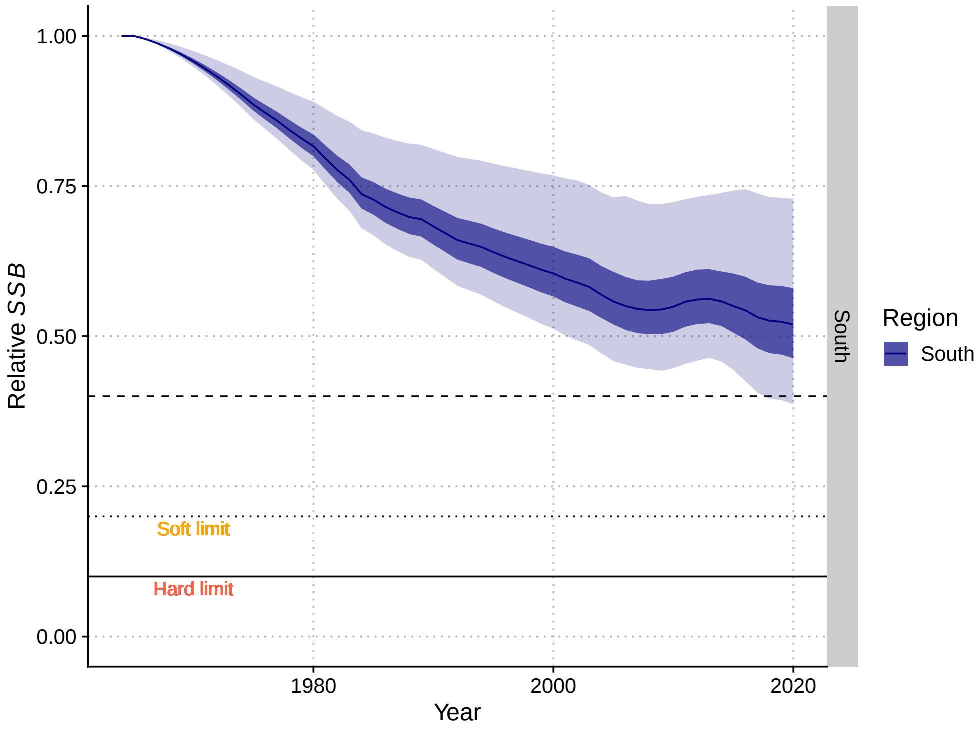

Figure B-10: Estimated relative spawning stock biomass (SSB) trend for pāua for the base case stock assessment model for Quota Management Area PAU 2 (black line and 95% confidence interval).

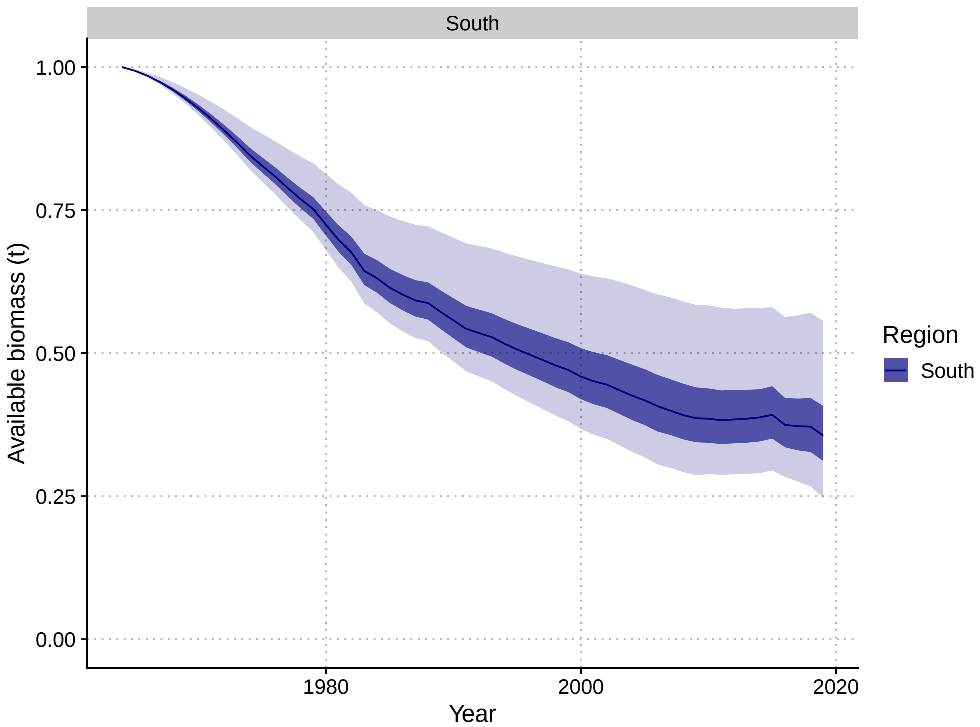

Figure B-11: Estimated relative available biomass trend for pāua for the base case stock assessment model for Quota Management Area PAU 2 (black line and 95% confidence interval).

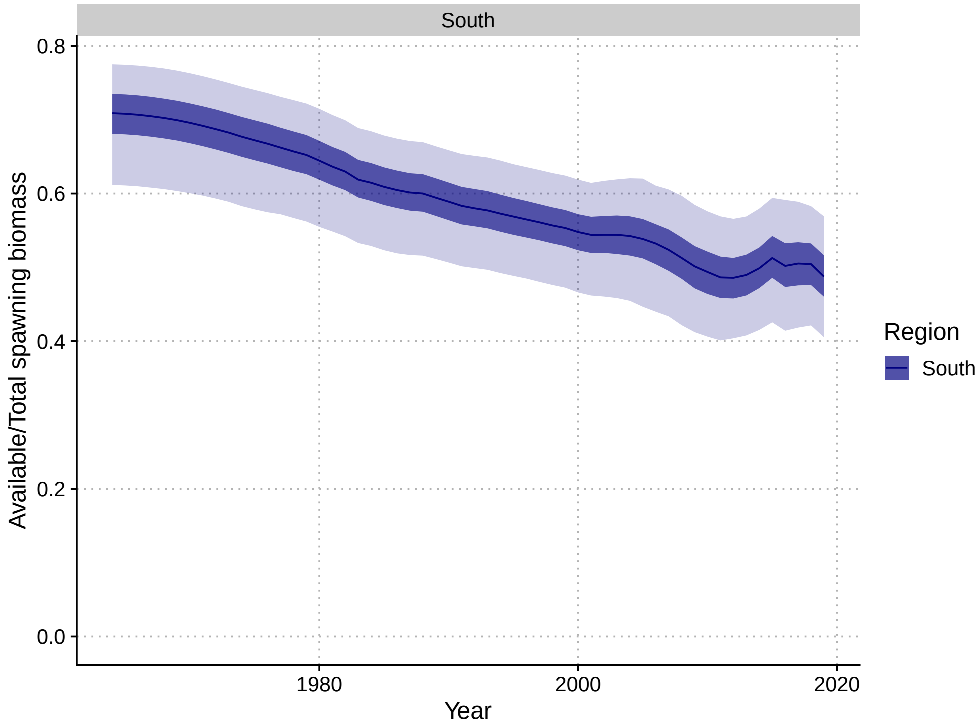

Figure B-12: Estimated relative available pāua biomass (relative to spawning stock) for the base case stock assessment model for Quota Management Area PAU 2 (black line and 95% confidence interval).

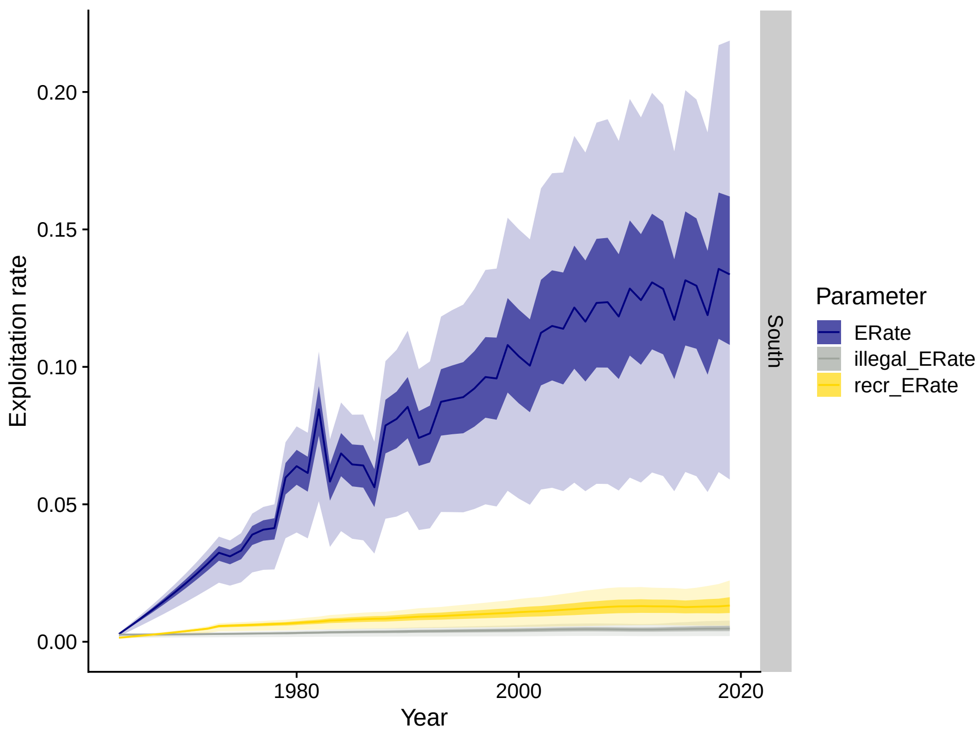

Figure B-13: Estimated exploitation rate (black line and 95% confidence interval) for the base case relative to the posterior median estimate of the explotiation rate (U) leading to 40% SSB $U_{40\%\mathrm{SSB}_0}$ (red line) of pāua for Quota Management Area PAU 2.

B.1.7 Status and projections

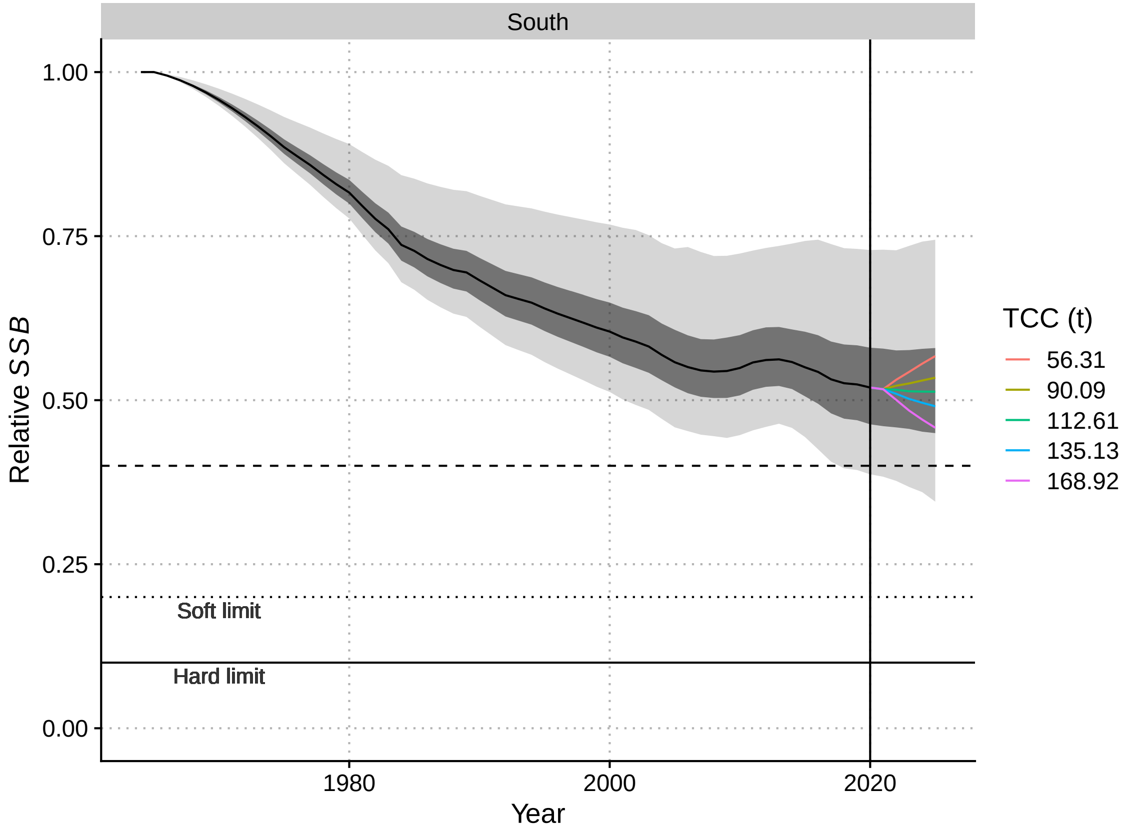

Figure B-14: Estimated (left of solid vertical line) and projected (right of solid vertical line) relative spawning stock biomass (SSB) trend for pāua for the base case stock assessment model for Quota Management Area PAU 2 (black line (current/observed catch) and 95% confidence interval). Projections are for current catch (green line) and 20% reduction(olive)/increase(blue) and 50% reduction(red)/increase(pink) from current catch. Confidence interval corresponds to current catch (blue) projections only.

Table B-2: Stock status and fishery indicators for the last fishing year considered in this assessment and projections for key fishery indicators from the base case stock assessment model of pāua for quota management area PAU 2 for three years, for current catch (indicated by the asterisk), and 20% and 50% increases and reductions from current catch. Results at equilibrium (Eq.) are also included (assumed to be reached after 50 years). Columns are: probabilities of being above 40% (P(SSB>0.4SSB$_0$)) and 20% (P(SSB>0.2SSB$_0$)) of unfished spawning stock biomass (SSB), the probability that SSB in the projection year is above current SSB, the posterior median relative SSB, the posterior median relative available biomass (B^{avail}), the posterior median relative available spawning biomass (SSB$^{\text{avail}}$), the probability that B^{avail} in the projection year is above current B^{avail}, and the probability that the exploitation rate (U) is greater than the exploitation rate leading to 40% SSB (TACC, total allowable commercial catch).

TACC (t)	Year	Fishery indicator							
		P(SSB>0.4SSB$_0$)	P(SSB>0.2SSB$_0$)	P(SSB>SSB$_{\text{current}}$)	Mean rel. SSB	Mean rel. B^{avail}	Mean rel. SSB$^{\text{avail}}$	P($B^{\text{avail}} > B^{\text{avail}}_{\text{current}}$)	P($U > U_{40\%\text{SSB}_0}$)
56.31	2020	0.97	1.00	1.00	0.54	0.37	0.49	0.09	0.07
	2021	0.97	1.00	0.02	0.53	0.37	0.48	0.09	0.00
	2022	0.98	1.00	0.98	0.55	0.38	0.49	0.12	0.00
	2023	0.98	1.00	0.95	0.56	0.40	0.50	0.14	0.00
	2024	0.99	1.00	0.93	0.57	0.41	0.50	0.18	0.00
	2025	0.99	1.00	0.93	0.58	0.42	0.51	0.21	0.00
	Eq.	0.99	1.00	0.98	0.75	0.63	0.59	0.88	0.00
90.09	2020	0.97	1.00	1.00	0.54	0.37	0.49	0.09	0.07
	2021	0.97	1.00	0.02	0.53	0.37	0.48	0.09	0.04
	2022	0.97	1.00	0.56	0.54	0.37	0.48	0.10	0.04
	2023	0.97	1.00	0.60	0.54	0.37	0.48	0.11	0.03
	2024	0.96	1.00	0.63	0.55	0.38	0.48	0.12	0.03
	2025	0.96	1.00	0.65	0.55	0.38	0.48	0.13	0.03
	Eq.	0.93	0.99	0.77	0.61	0.45	0.51	0.42	0.06
112.61*	2020	0.97	1.00	1.00	0.54	0.37	0.49	0.09	0.07
	2021	0.97	1.00	0.02	0.53	0.37	0.48	0.09	0.09
	2022	0.96	1.00	0.26	0.53	0.36	0.47	0.09	0.10
	2023	0.95	1.00	0.34	0.53	0.36	0.47	0.09	0.11
	2024	0.94	1.00	0.38	0.53	0.36	0.47	0.09	0.11
	2025	0.93	1.00	0.40	0.53	0.35	0.46	0.09	0.12
	Eq.	0.77	0.94	0.45	0.51	0.33	0.43	0.16	0.22
135.13	2020	0.97	1.00	1.00	0.54	0.37	0.49	0.09	0.07
	2021	0.97	1.00	0.02	0.53	0.37	0.48	0.09	0.16
	2022	0.95	1.00	0.12	0.53	0.36	0.47	0.08	0.18
	2023	0.93	1.00	0.17	0.52	0.34	0.46	0.07	0.21
	2024	0.90	1.00	0.18	0.51	0.33	0.45	0.06	0.23
	2025	0.87	1.00	0.21	0.51	0.32	0.44	0.06	0.25
	Eq.	0.53	0.88	0.17	-2.61	-3.95	0.34	0.06	0.48
168.92	2020	0.97	1.00	1.00	0.54	0.37	0.49	0.09	0.07
	2021	0.97	1.00	0.02	0.53	0.37	0.48	0.09	0.28
	2022	0.92	1.00	0.03	0.52	0.34	0.46	0.07	0.33
	2023	0.87	1.00	0.05	0.50	0.32	0.44	0.05	0.39
	2024	0.81	1.00	0.05	0.49	0.30	0.42	0.04	0.43
	2025	0.75	1.00	0.06	0.48	0.28	0.41	0.04	0.47
	Eq.	0.25	0.84	0.03	0.32	0.12	0.23	0.02	0.79

B.2 Sensitivity 1: M0.16

B.2.1 Markov chain Monte Carlo and posteriors

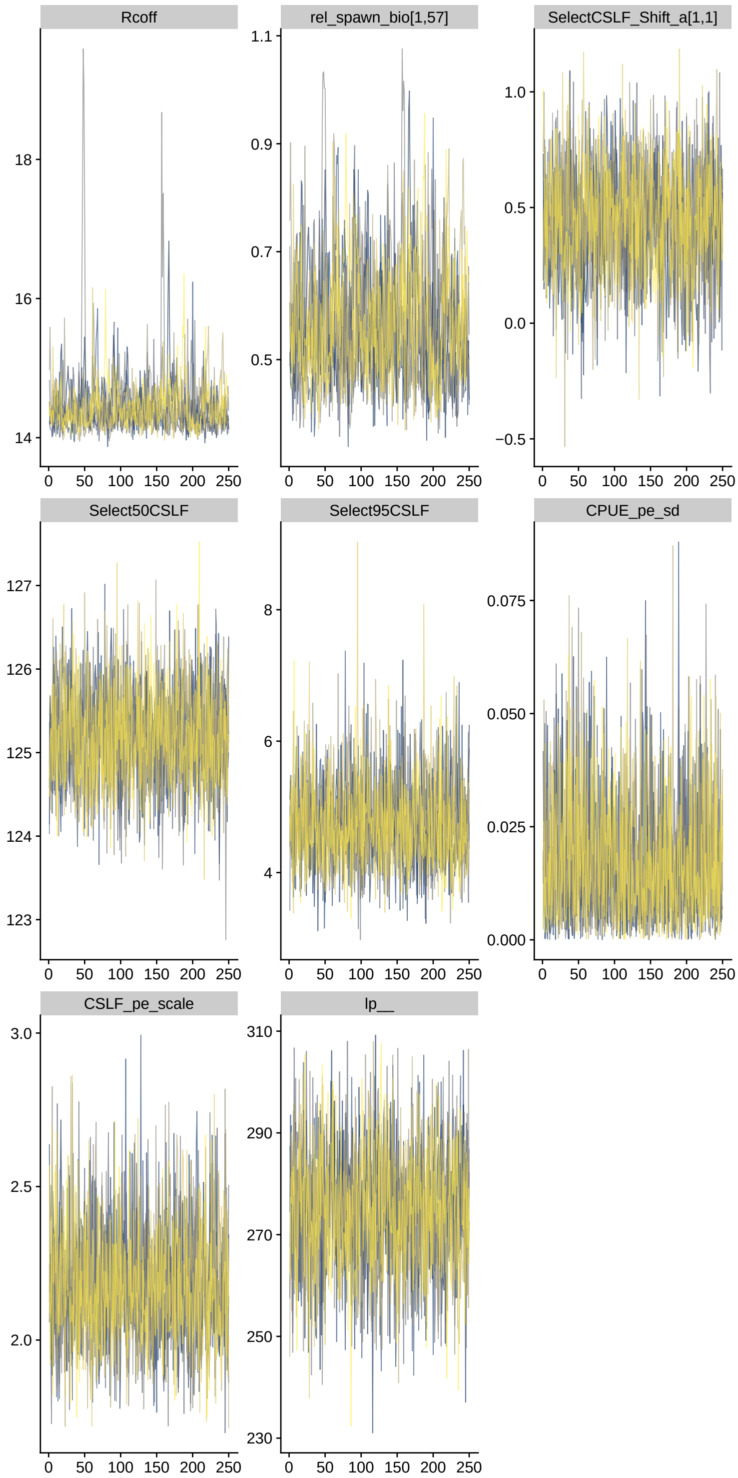

Figure B-15: Traces of Markov chain Monte Carlo estimation for the marginal posterior distribution of key model parameters for the main sensitivity run 2 of the stock assessment model of pāua in Quota Management Area PAU 2.

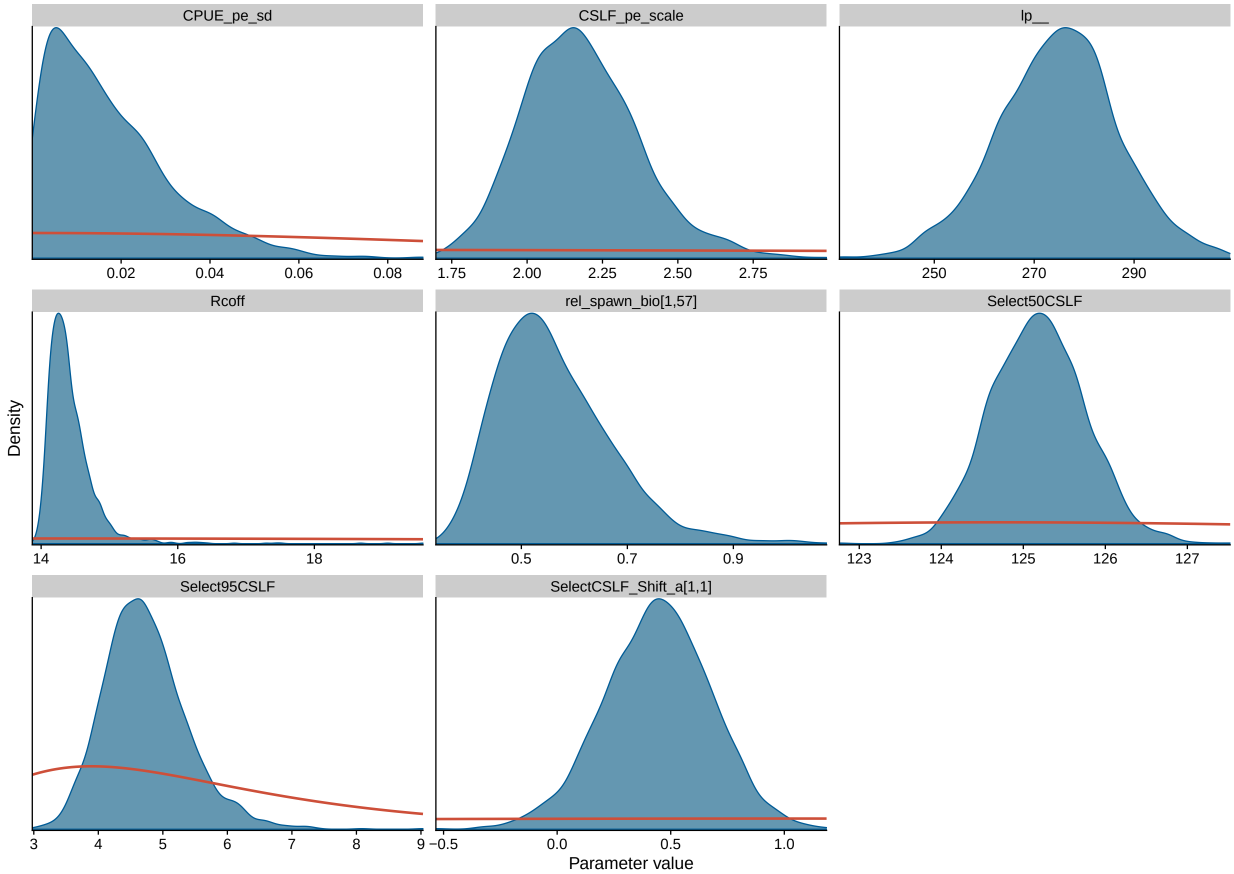

Figure B-16: Marginal posterior densities of key model parameters for the main sensitivity run 2 of the stock assessment model of pāua for Quota Management Area PAU 2, with prior densities indicated in red.

Table B-3: Posterior quantities for key parameters in the main sensitivity run 2 of the pāua stock assessment model for quota management area PAU 2. Equilibrium recruitment, R_0; size at which 50% of individuals are selected, D_{50}; size at which 95% of individuals are selected, D_{95}; shift in selectivity curve between periods, D_a; exploitation rate (U) leading to 40% spawning stock biomass (SSB); Bayes log posterior; process error, PE (CPUE, catch-per-unit-effort; CSLF, catch sampling length frequency); relative SSB.

Parameter	Posterior percentile				
	2.5%	25%	50%	75%	97.5%
$\log(R_0)$	14.04	14.21	14.35	14.55	15.24
D_{50}	124.09	124.79	125.18	125.57	126.31
D_{95}	3.65	4.29	4.67	5.10	6.18
D_a	-0.04	0.28	0.45	0.60	0.89
$U_{40\%\mathrm{SSB}_0}$	0.19	0.35	0.46	0.62	0.94
log posterior	250.23	267.05	275.18	282.57	298.44
$\mathrm{PE}_{\mathrm{CPUE}}$	0.00	0.01	0.01	0.02	0.05
$\mathrm{PE}_{\mathrm{CSLF}}$	1.84	2.04	2.16	2.30	2.61
relative SSB_{2021}	0.40	0.48	0.55	0.62	0.82

B.2.2 Growth

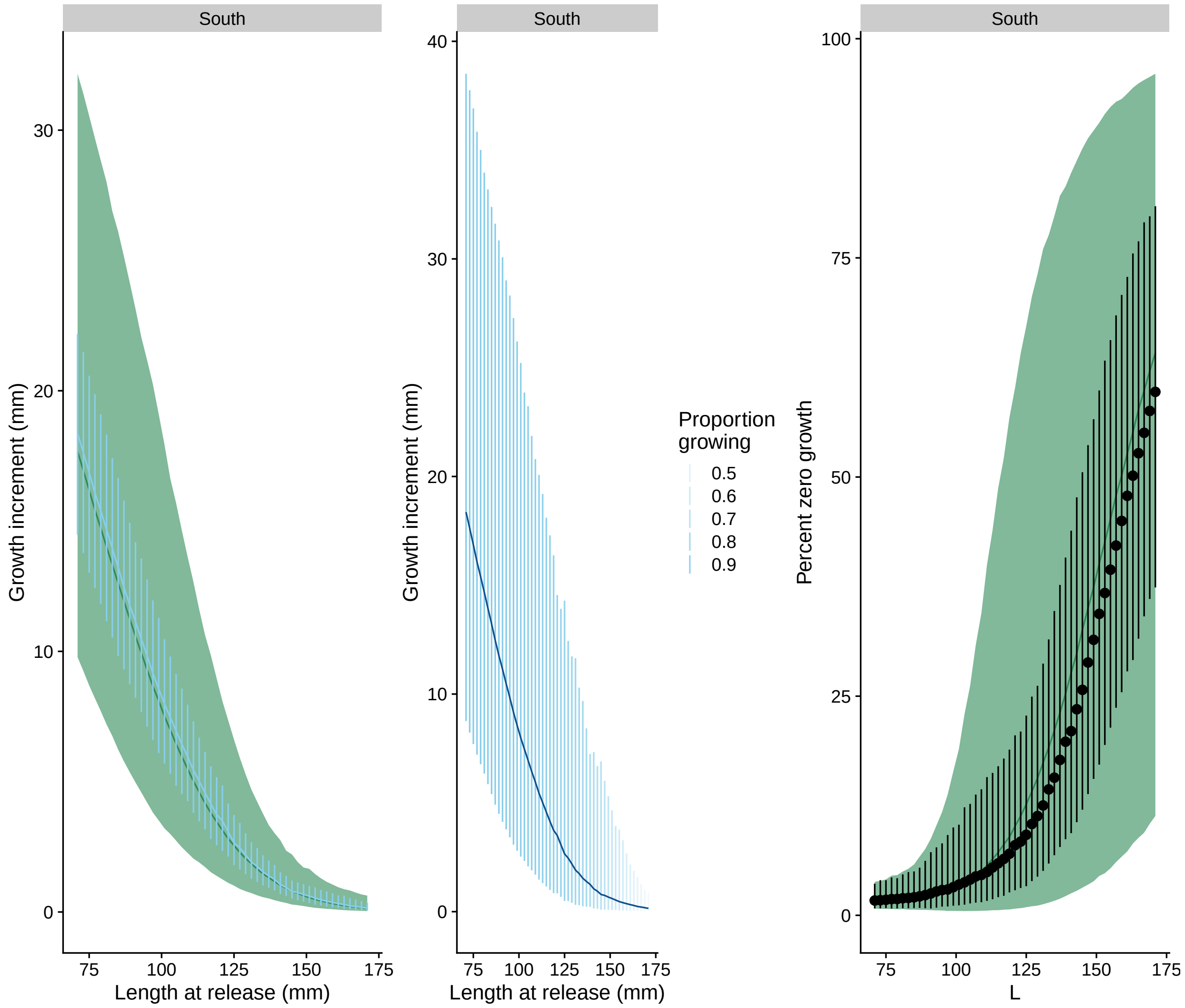

Figure B-17: Top: Posterior mean growth (population mean (dark blue line) and standard deviation of the estimate (light blue ribbon)), relative to the prior (dark green), middle: estimated population standard deviation (posterior median; light blue) relative to estimated population mean (blue line), bottom panel: estimated proportion of pāua stock not growing at each length relative to the prior (green) for the main sensitivity run 2 of the stock assessment model of pāua for Quota Management Area PAU 2.

B.2.3 Catch-per-unit-effort fits

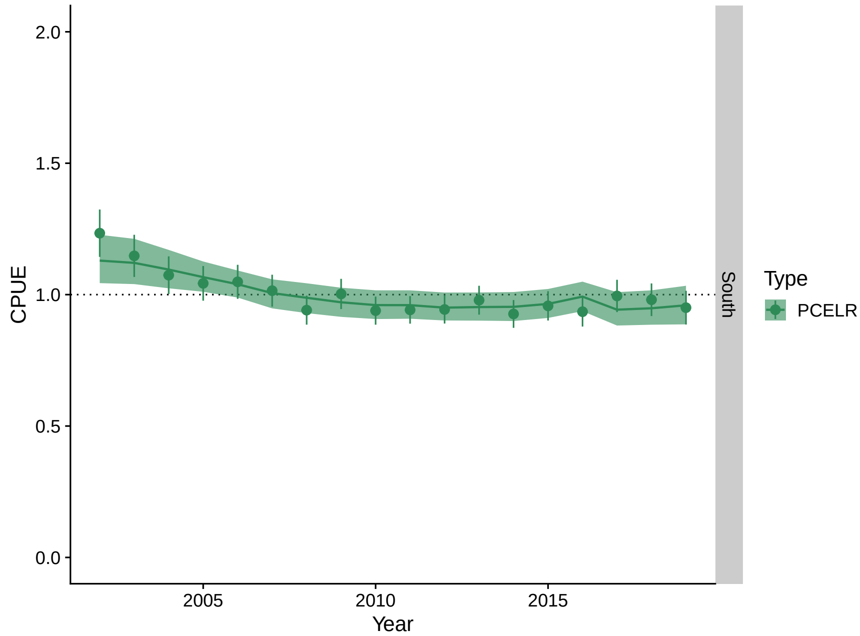

Figure B-18: Comparison of posterior median predicted catch-per-unit-effort (CPUE) with estimated CPUE index and observation error for the main sensitivity run 2 of the stock assessment model of pāua for Quota Management Area PAU 2 (black points and error bars; PCELR, data from (Paua) Catch Effort Landing Return forms.

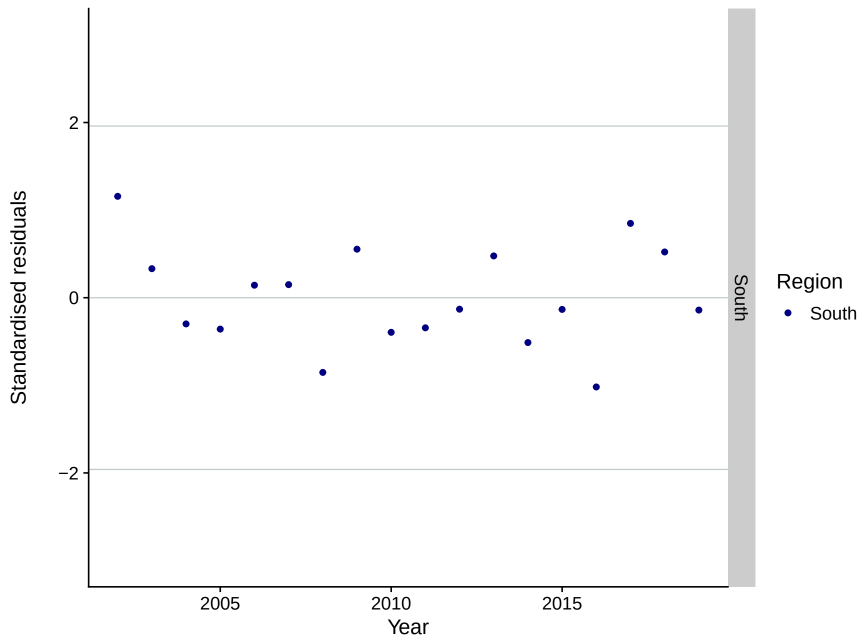

Figure B-19: Standardised residuals at the posterior median of predicted catch-per-unit-effort for the main sensitivity run 2 of the stock assessment model of pāua for Quota Management Area PAU 2.

B.2.4 Catch sampling length frequency fits

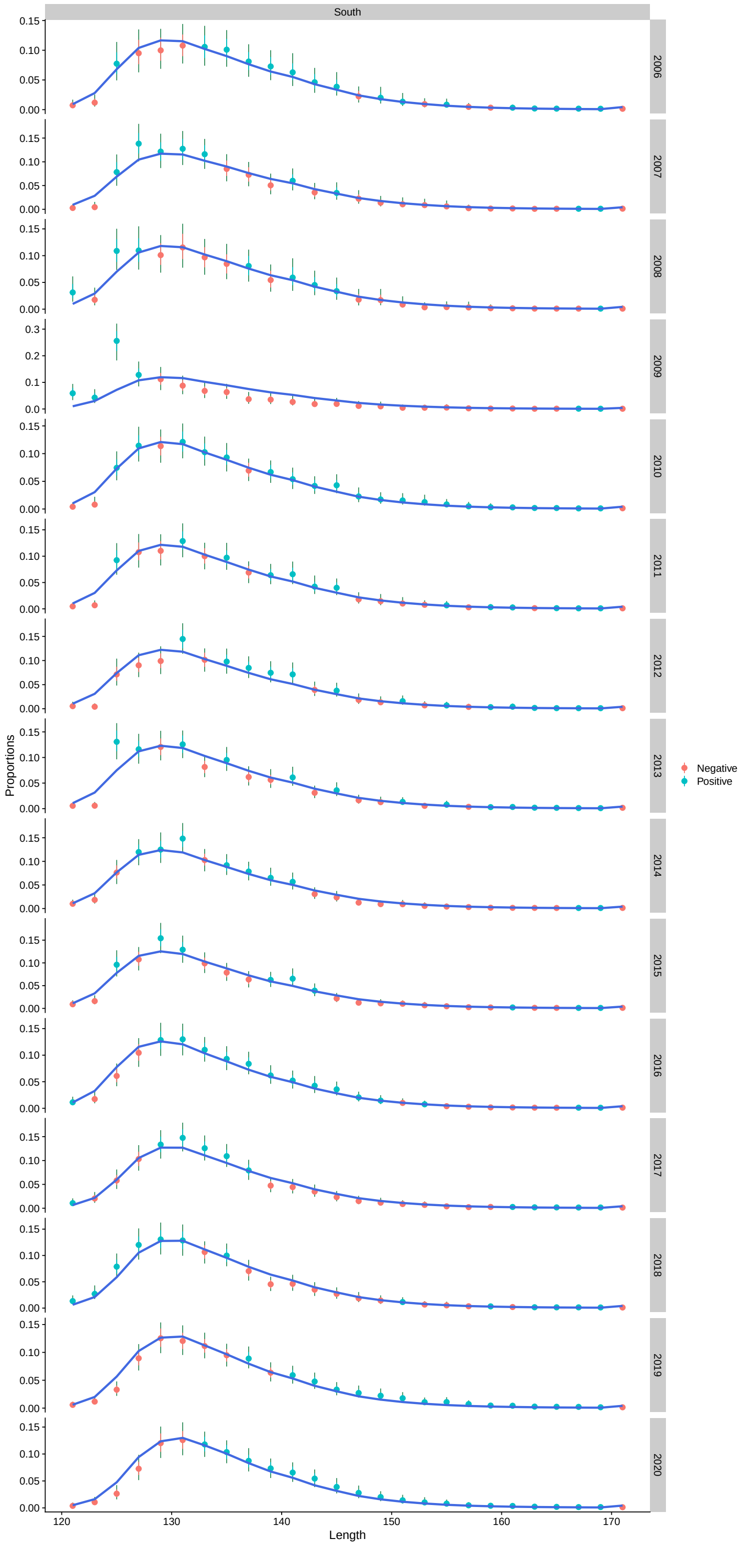

Figure B-20: Comparison of posterior mean predicted catch sampling length frequency (CSLF; length in mm) with estimated CSLF proportions and observation error for the main sensitivity run 2 of the stock assessment model of pāua for Quota Management Area PAU 2. Length classes with positive residuals in blue, with negative residuals in red.

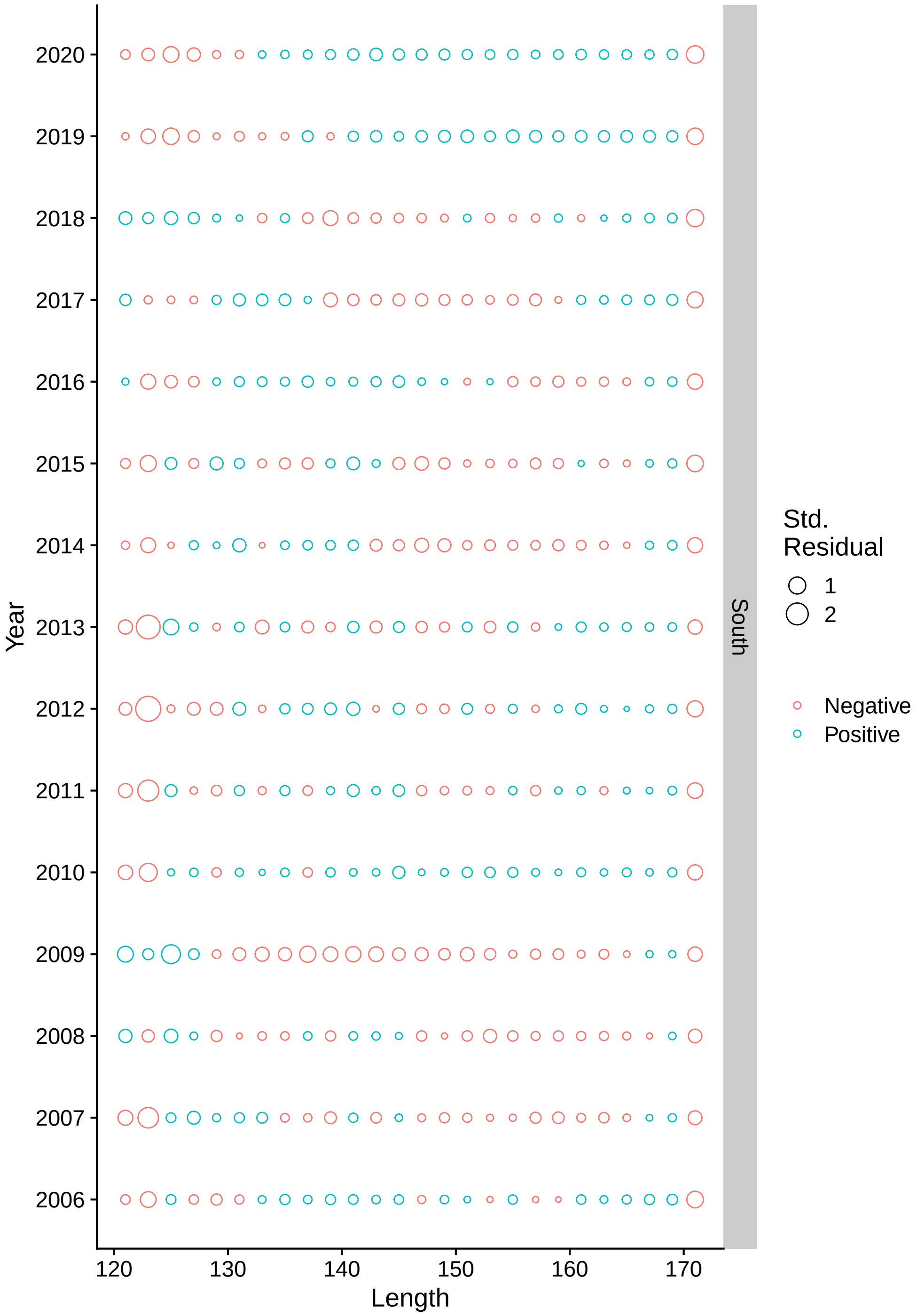

Figure B-21: Catch sampling length frequency model residuals for the main sensitivity run 2 of the stock assessment model of pāua for quota management area PAU 2. Length classes with positive residuals in blue, with negative residuals in red.

B.2.5 Selectivity

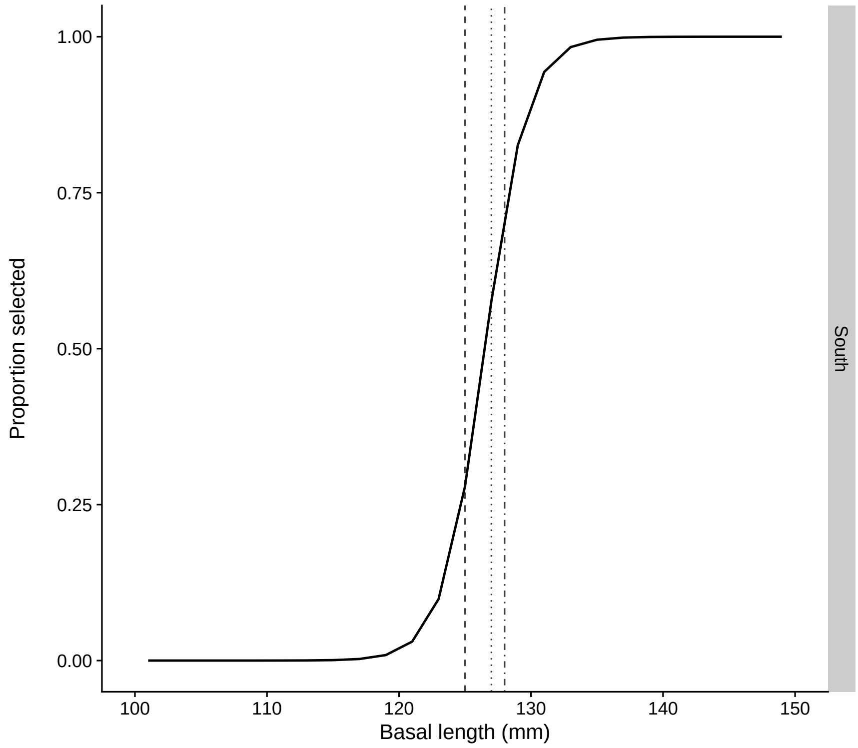

Figure B-22: Estimated selectivity (posterior mean) for the main sensitivity run 2 of the stock assessment model for quota management area PAU 2.

B.2.6 Recruitment and biomass trends

Figure B-23: Posterior mean recruitment for the main sensitivity run 2 of the stock assessment model of pāua for Quota Management Area PAU 2 (R_{dev}, recruitment deviation).

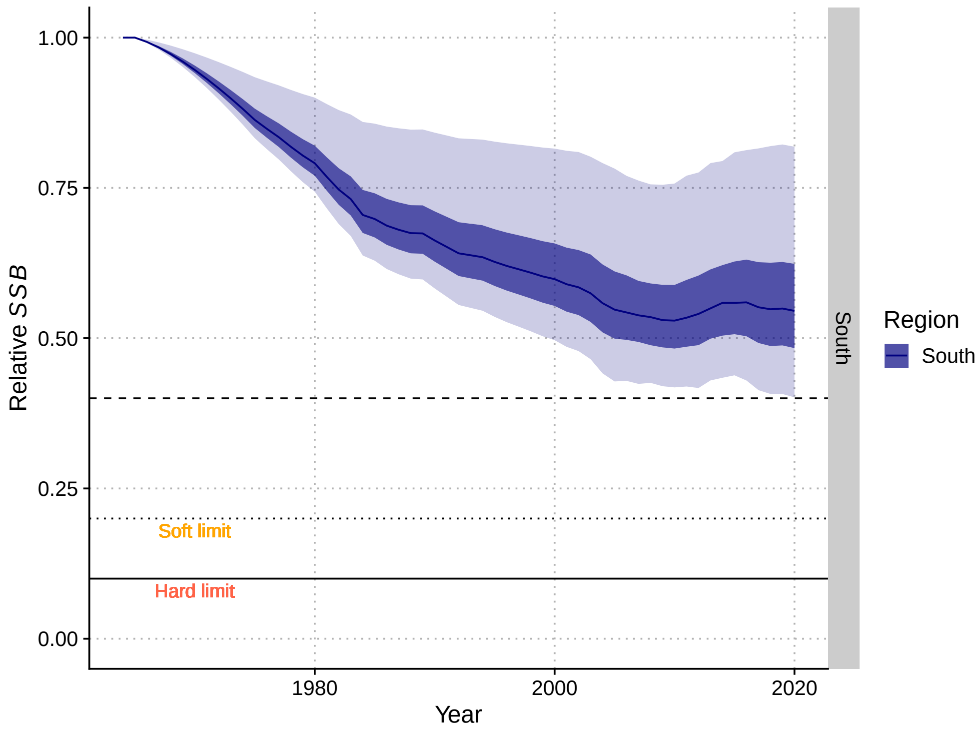

Figure B-24: Estimated relative spawning stock biomass (SSB) trend for pāua for the main sensitivity run 2 of the stock assessment model for Quota Management Area PAU 2 (black line and 95% confidence interval).

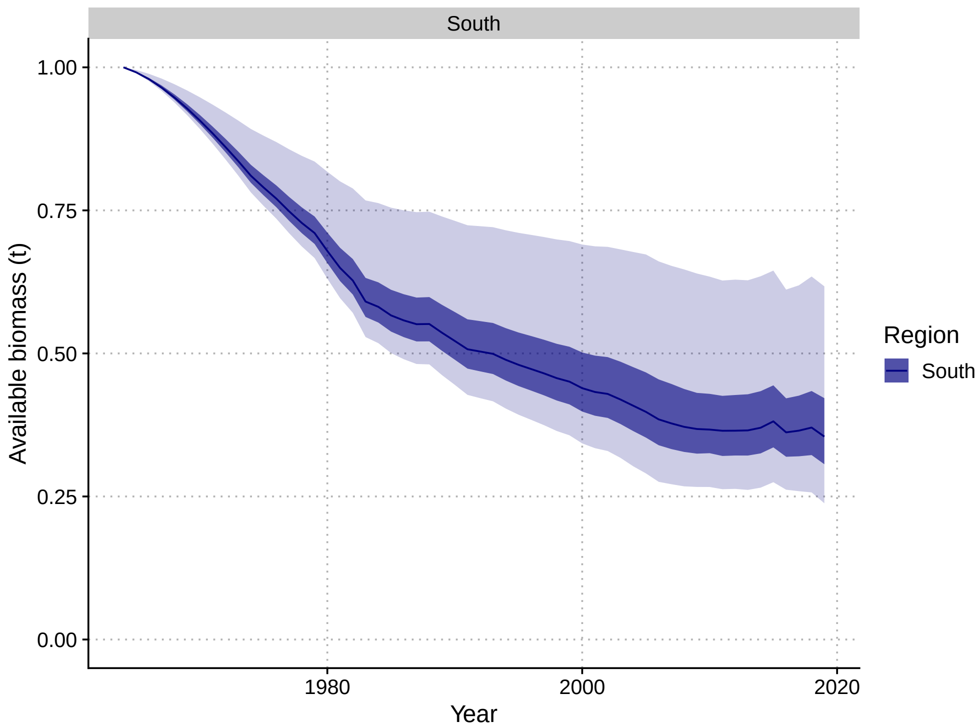

Figure B-25: Estimated relative available biomass trend for pāua for the main sensitivity run 2 of the stock assessment model for Quota Management Area PAU 2 (black line and 95% confidence interval).

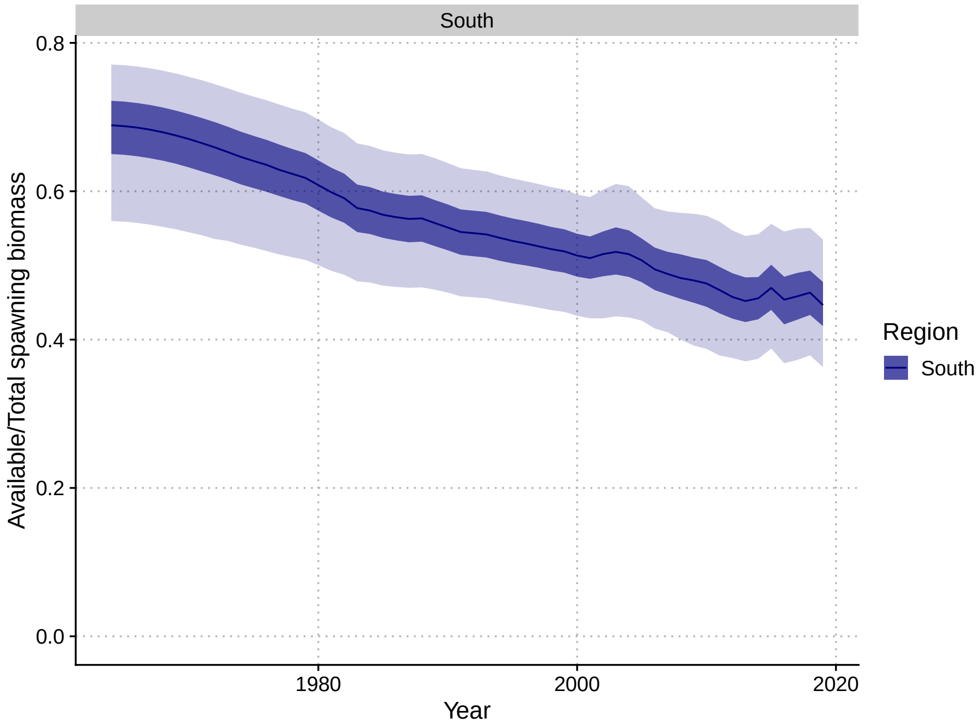

Figure B-26: Estimated relative available pāua biomass (relative to spawning stock) for the main sensitivity run 2 of the stock assessment model for Quota Management Area PAU 2 (black line and 95% confidence interval).

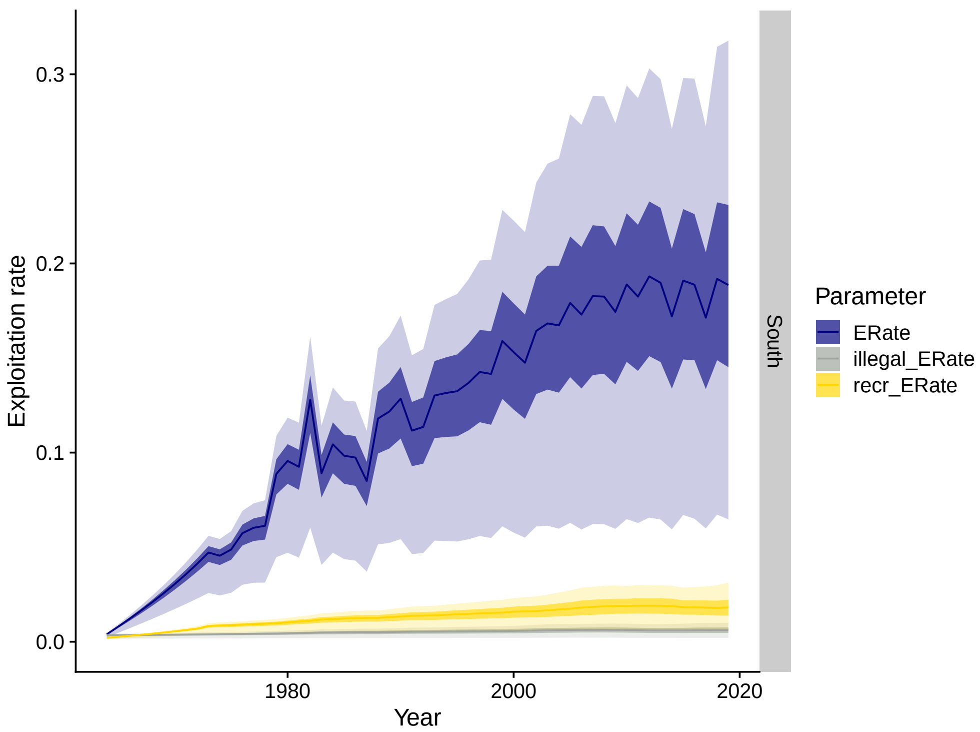

Figure B-27: Estimated exploitation rate (black line and 95% confidence interval) for the main sensitivity run 2 of the relative to the posterior median estimate of the explotiation rate (U) leading to 40% SSB $U_{40\%\mathrm{SSB}_0}$ (red line) of pāua for Quota Management Area PAU 2.

B.2.7 Status and projections

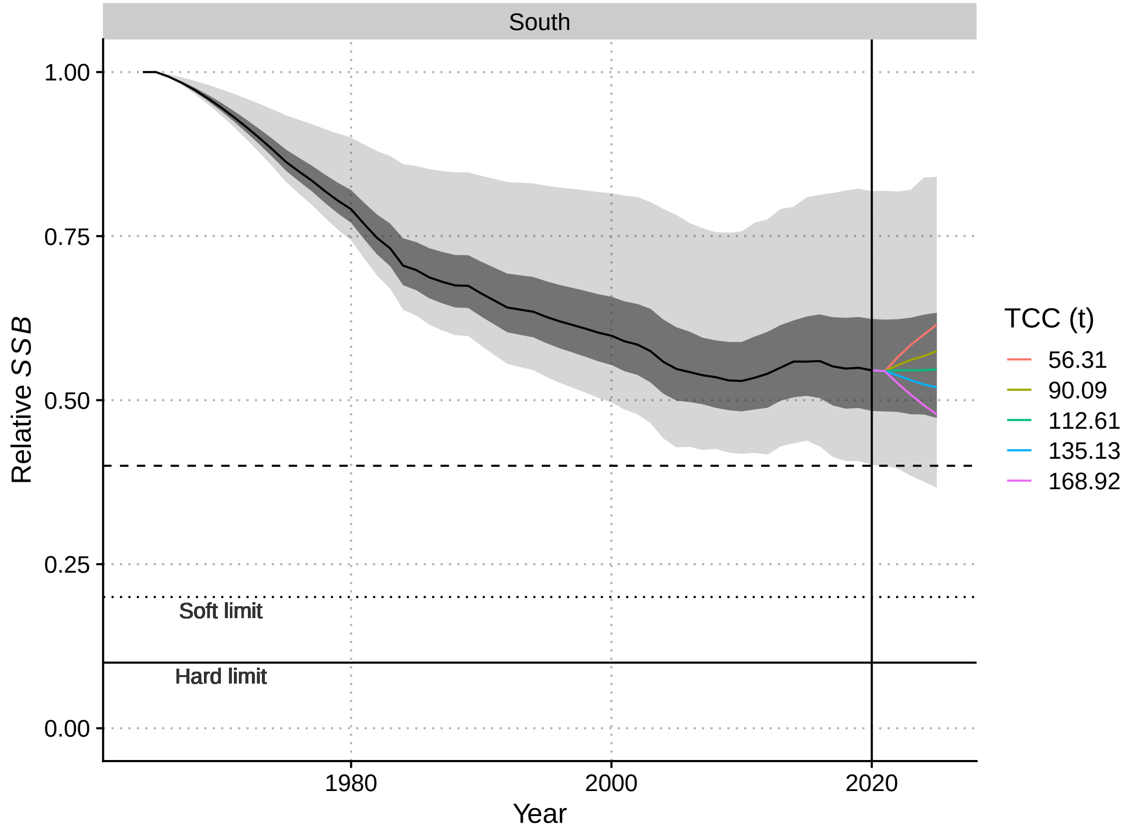

Figure B-28: Estimated (left of solid vertical line) and projected (right of solid vertical line) relative spawning stock biomass (SSB) trend for pāua for the main sensitivity run 2 of the stock assessment model for Quota Management Area PAU 2 (black line (current/observed catch) and 95% confidence interval). Projections are for current catch (green line) and 20% reduction(olive)/increase(blue) and 50% reduction(red)/increase(pink) from current catch. Confidence interval corresponds to current catch (blue) projections only.

Table B-4: Stock status and fishery indicators for the last fishing year considered in this assessment and projections for key fishery indicators from the main sensitivity run 2 of the stock assessment model of pāua for quota management area PAU 2 for three years, for current catch (indicated by the asterisk), and 20% and 50% increases and reductions from current catch. Results at equilibrium (Eq.) are also included (assumed to be reached after 50 years). Columns are: probabilities of being above 40% (P(SSB>0.4SSB$_0$)) and 20% (P(SSB>0.2SSB$_0$)) of unfished spawning stock biomass (SSB), the probability that SSB in the projection year is above current SSB, the posterior median relative SSB, the posterior median relative available biomass (B^{avail}), the posterior median relative available spawning biomass (SSB$^{\text{avail}}$), the probability that B^{avail} in the projection year is above current B^{avail}, and the probability that the exploitation rate (U) is greater than the exploitation rate leading to 40% SSB (TACC, total allowable commercial catch).

TACC (t)	Year								Fishery indicator
		P(SSB>0.4SSB$_0$)	P(SSB>0.2SSB$_0$)	P(SSB>SSB$_{\text{current}}$)	Mean rel. SSB	Mean rel. B^{avail}	Mean rel. SSB$^{\text{avail}}$	P($B^{\text{avail}} > B^{\text{avail}}_{\text{current}}$)	P($U > U_{40\%\text{SSB}_0}$)
56.31	2020	0.98	1.00	1.00	0.55	0.36	0.45	0.14	0.06
	2021	0.98	1.00	0.03	0.55	0.36	0.45	0.15	0.00
	2022	0.99	1.00	0.96	0.57	0.39	0.47	0.21	0.00
	2023	1.00	1.00	0.93	0.59	0.41	0.48	0.29	0.00
	2024	1.00	1.00	0.93	0.60	0.43	0.49	0.39	0.00
	2025	1.00	1.00	0.94	0.62	0.45	0.50	0.48	0.00
	Eq.	0.99	1.00	0.98	0.77	0.64	0.58	0.95	0.00
90.09	2020	0.98	1.00	1.00	0.55	0.36	0.45	0.14	0.06
	2021	0.98	1.00	0.03	0.55	0.36	0.45	0.15	0.03
	2022	0.98	1.00	0.67	0.56	0.37	0.45	0.17	0.03
	2023	0.98	1.00	0.70	0.57	0.38	0.46	0.19	0.02
	2024	0.98	1.00	0.70	0.57	0.39	0.46	0.21	0.02
	2025	0.98	1.00	0.70	0.58	0.40	0.47	0.23	0.02
	Eq.	0.95	0.99	0.79	0.64	0.47	0.50	0.58	0.04
112.61*	2020	0.98	1.00	1.00	0.55	0.36	0.45	0.14	0.06
	2021	0.98	1.00	0.03	0.55	0.36	0.45	0.15	0.06
	2022	0.97	1.00	0.40	0.55	0.36	0.45	0.15	0.06
	2023	0.97	1.00	0.44	0.55	0.36	0.45	0.14	0.06
	2024	0.95	1.00	0.47	0.55	0.36	0.44	0.14	0.06
	2025	0.94	1.00	0.47	0.55	0.36	0.44	0.14	0.07
	Eq.	0.82	0.96	0.52	0.54	0.35	0.43	0.26	0.16
135.13	2020	0.98	1.00	1.00	0.55	0.36	0.45	0.14	0.06
	2021	0.98	1.00	0.03	0.55	0.36	0.45	0.15	0.11
	2022	0.97	1.00	0.20	0.54	0.35	0.44	0.13	0.14
	2023	0.94	1.00	0.24	0.54	0.34	0.43	0.11	0.15
	2024	0.92	1.00	0.26	0.53	0.33	0.42	0.09	0.17
	2025	0.89	1.00	0.27	0.52	0.32	0.42	0.08	0.19
	Eq.	0.60	0.95	0.21	0.51	0.35	0.34	0.08	0.40
168.92	2020	0.98	1.00	1.00	0.55	0.36	0.45	0.14	0.06
	2021	0.98	1.00	0.03	0.55	0.36	0.45	0.15	0.21
	2022	0.94	1.00	0.07	0.53	0.33	0.43	0.10	0.28
	2023	0.88	1.00	0.08	0.51	0.31	0.41	0.07	0.33
	2024	0.83	1.00	0.08	0.50	0.28	0.39	0.05	0.39
	2025	0.77	1.00	0.09	0.48	0.27	0.37	0.04	0.42
	Eq.	0.33	0.93	0.03	0.36	0.14	0.25	0.01	0.72

B.3 Sensitivity 2: M0.06

B.3.1 Markov chain Monte Carlo and posteriors

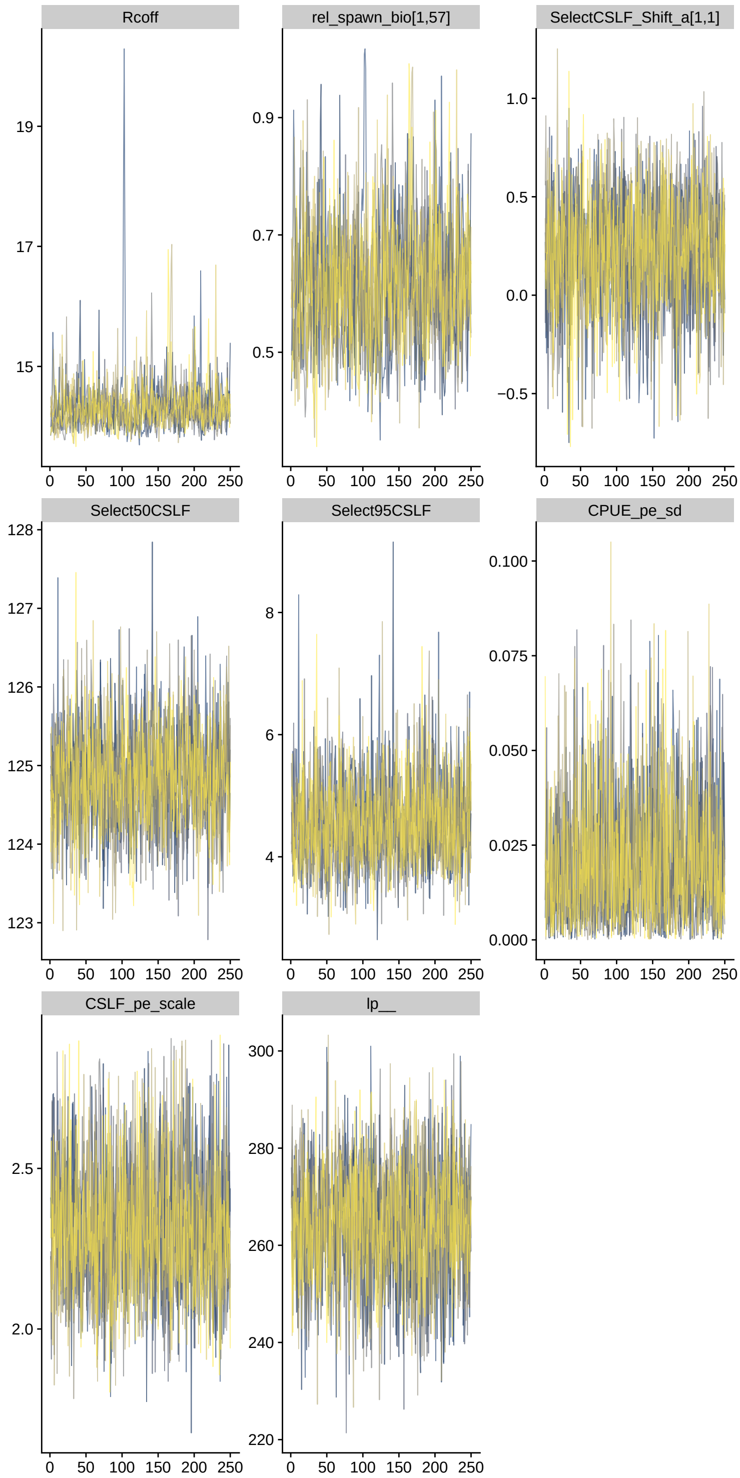

Figure B-29: Traces of Markov chain Monte Carlo estimation for the marginal posterior distribution of key model parameters for the main sensitivity run 1 of the stock assessment model of pāua in Quota Management Area PAU 2.

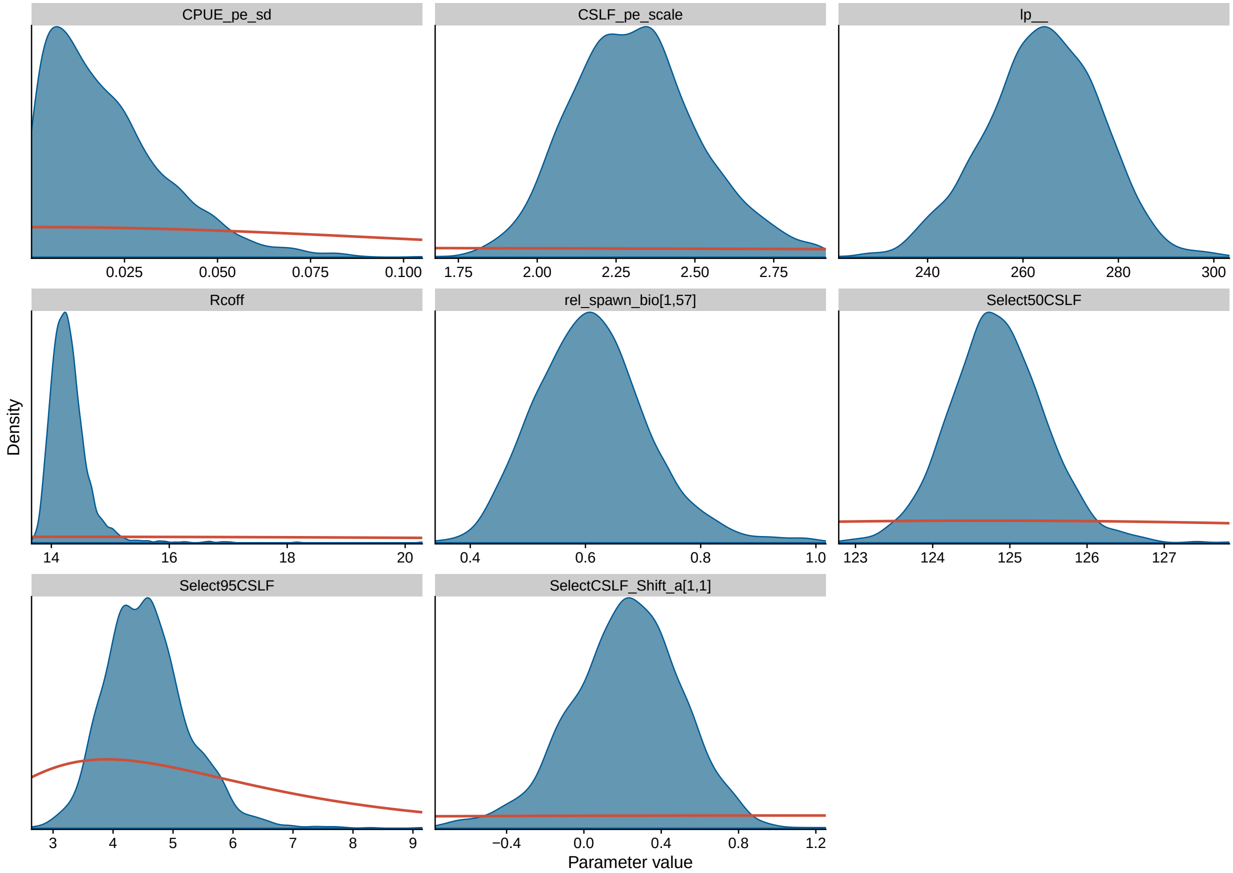

Figure B-30: Marginal posterior densities of key model parameters for the main sensitivity run 1 of the stock assessment model of pāua for Quota Management Area PAU 2, with prior densities indicated in red.

Table B-5: Posterior quantities for key parameters in the main sensitivity run 1 of the pāua stock assessment model for quota management area PAU 2. Equilibrium recruitment, R_0; size at which 50% of individuals are selected, D_{50}; size at which 95% of individuals are selected, D_{95}; shift in selectivity curve between periods, D_a; exploitation rate (U) leading to 40% spawning stock biomass (SSB); Bayes log posterior; process error, PE (CPUE, catch-per-unit-effort; CSLF, catch sampling length frequency); relative SSB.

Parameter	Posterior percentile				
	2.5%	25%	50%	75%	97.5%
$\log(R_0)$	13.86	14.09	14.25	14.43	15.05
D_{50}	123.65	124.43	124.82	125.24	126.08
D_{95}	3.41	4.09	4.52	4.95	6.06
D_a	-0.40	0.04	0.23	0.41	0.75
$U_{40\%\mathrm{SSB}_0}$	0.08	0.12	0.15	0.21	0.38
log posterior	239.69	256.60	264.43	272.51	286.16
$\mathrm{PE}_{\mathrm{CPUE}}$	0.00	0.01	0.02	0.03	0.06
$\mathrm{PE}_{\mathrm{CSLF}}$	1.94	2.17	2.30	2.44	2.75
relative SSB_{2021}	0.44	0.54	0.61	0.67	0.82

B.3.2 Growth

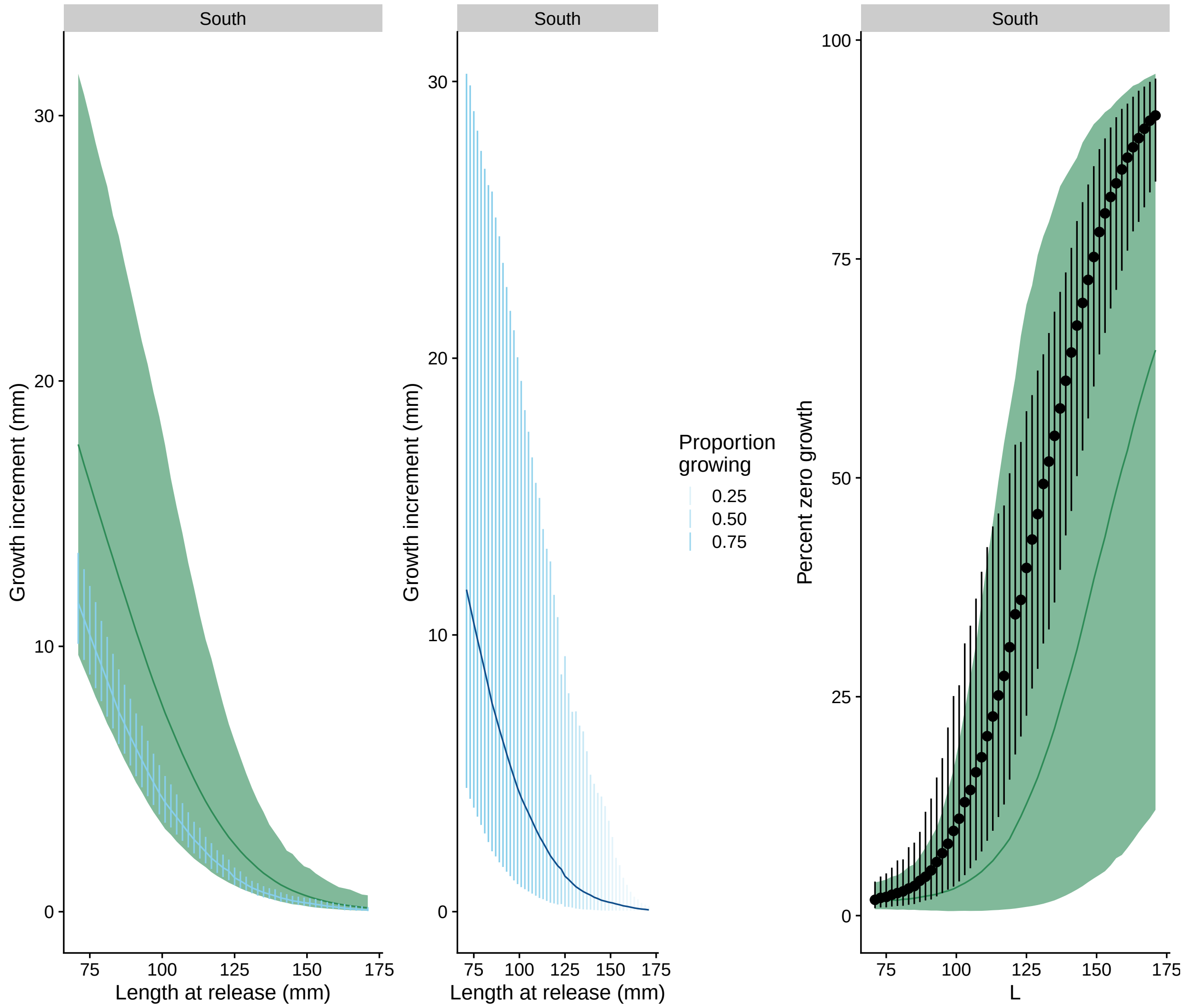

Figure B-31: Top: Posterior mean growth (population mean (dark blue line) and standard deviation of the estimate (light blue ribbon)), relative to the prior (dark green), middle: estimated population standard deviation (posterior median; light blue) relative to estimated population mean (blue line), bottom panel: estimated proportion of pāua stock not growing at each length relative to the prior (green) for the main sensitivity run 1 of the stock assessment model of pāua for Quota Management Area PAU 2.

B.3.3 Catch-per-unit-effort fits

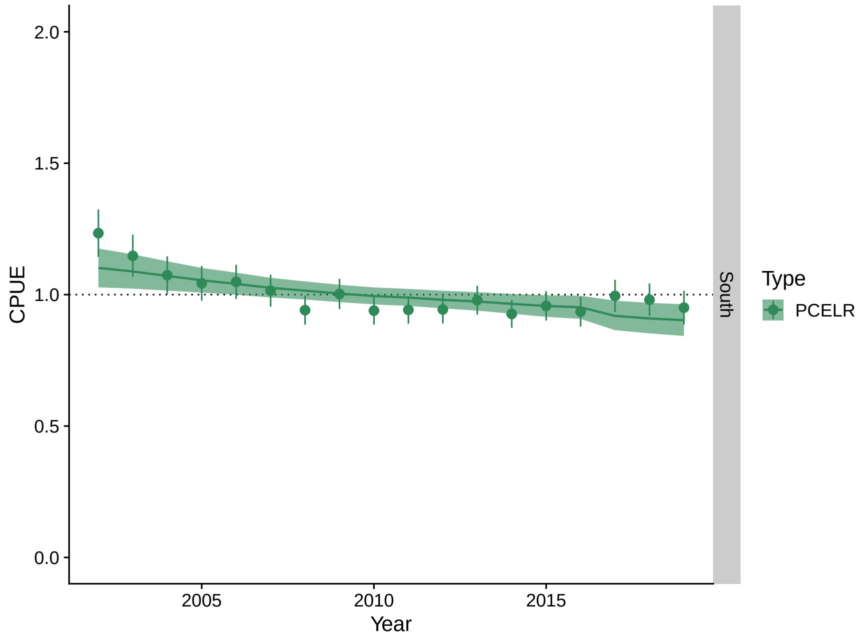

Figure B-32: Comparison of posterior median predicted catch-per-unit-effort (CPUE) with estimated CPUE index and observation error for the main sensitivity run 1 of the stock assessment model of pāua for Quota Management Area PAU 2 (black points and error bars; PCELR, data from (Paua) Catch Effort Landing Return forms.

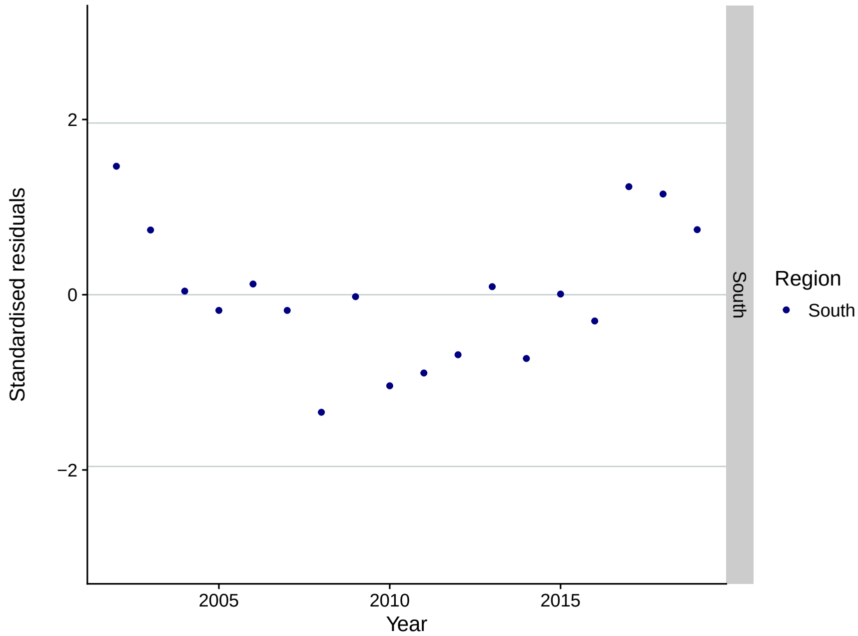

Figure B-33: Standardised residuals at the posterior median of predicted catch-per-unit-effort for the main sensitivity run 1 of the stock assessment model of pāua for Quota Management Area PAU 2.

B.3.4 Catch sampling length frequency fits

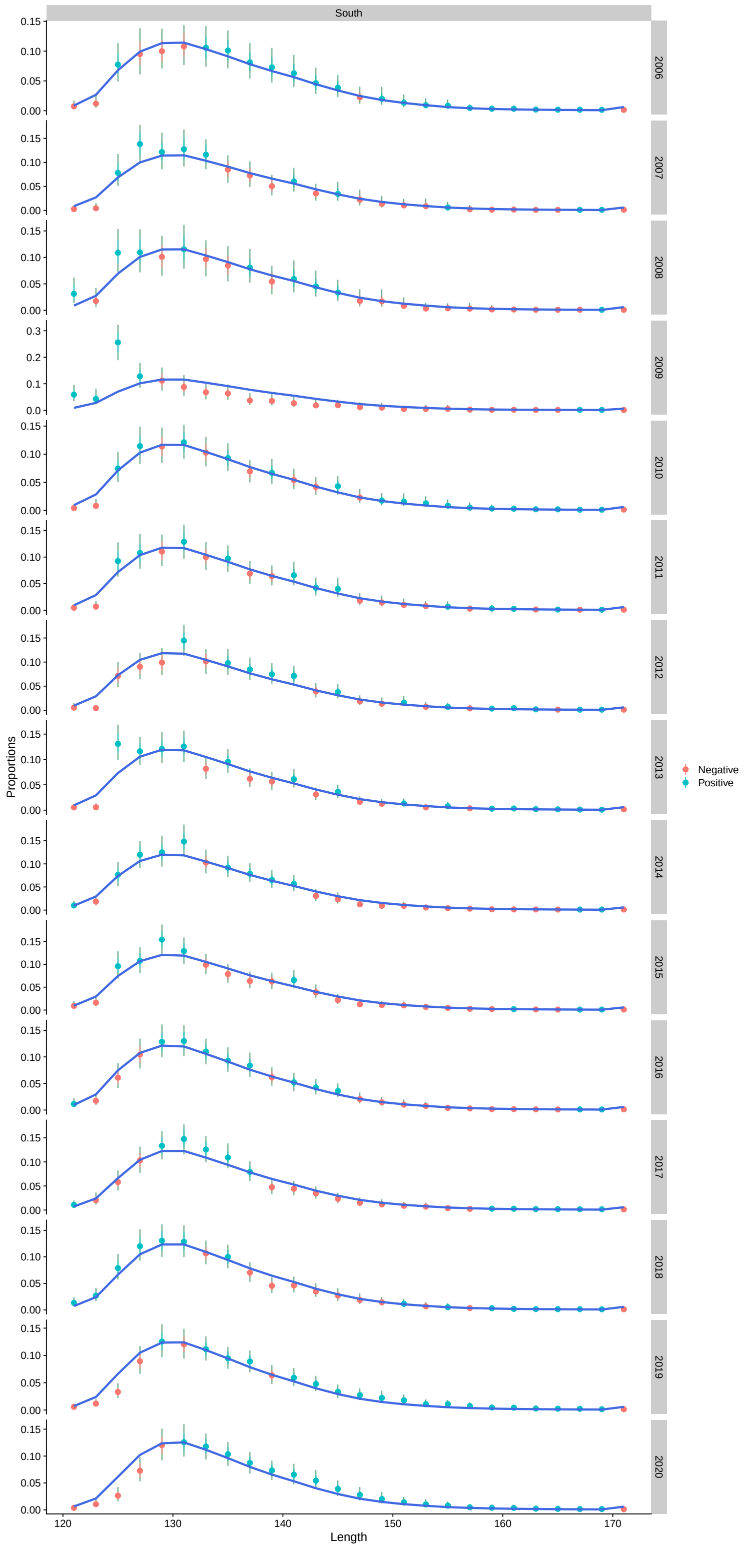

Figure B-34: Comparison of posterior mean predicted catch sampling length frequency (CSLF; length in mm) with estimated CSLF proportions and observation error for the main sensitivity run 1 of the stock assessment model of pāua for Quota Management Area PAU 2. Length classes with positive residuals in blue, with negative residuals in red.

Figure B-35: Catch sampling length frequency model residuals for the main sensitivity run 1 of the stock assessment model of pāua for quota management area PAU 2. Length classes with positive residuals in blue, with negative residuals in red.

B.3.5 Selectivity

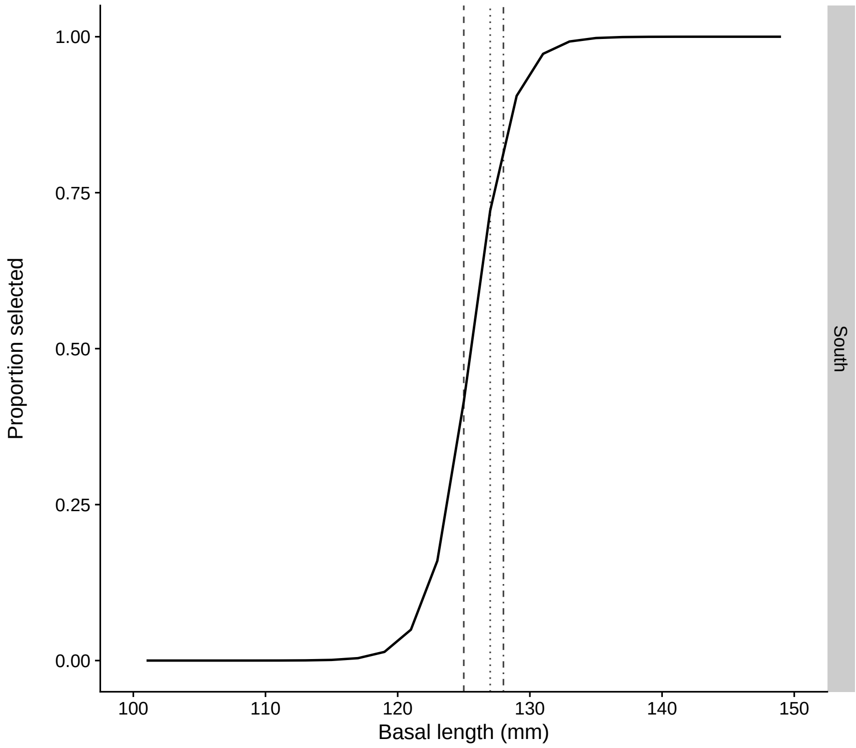

Figure B-36: Estimated selectivity (posterior mean) for the main sensitivity run 1 of the stock assessment model for quota management area PAU 2.

B.3.6 Recruitment and biomass trends

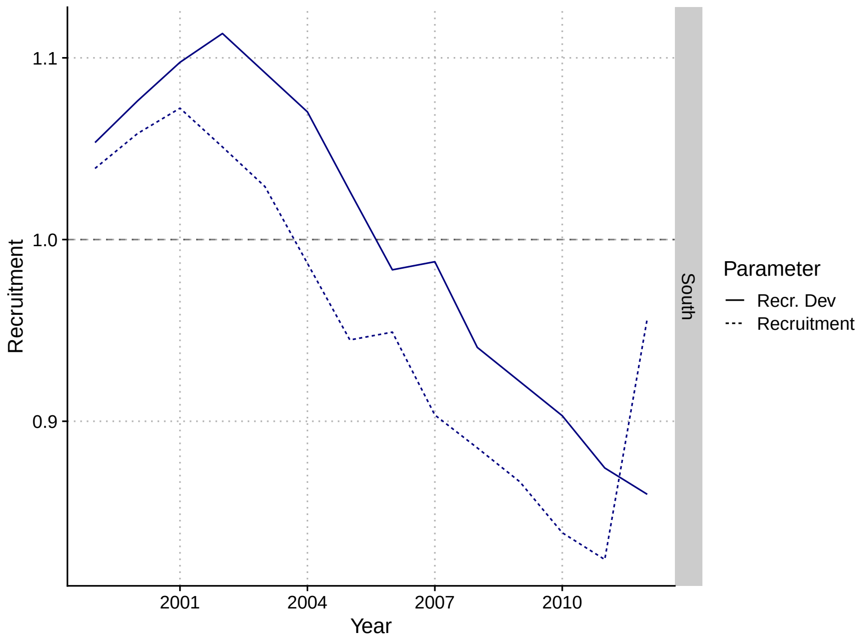

Figure B-37: Posterior mean recruitment for the main sensitivity run 1 of the stock assessment model of pāua for Quota Management Area PAU 2 (R_{dev}, recruitment deviation).

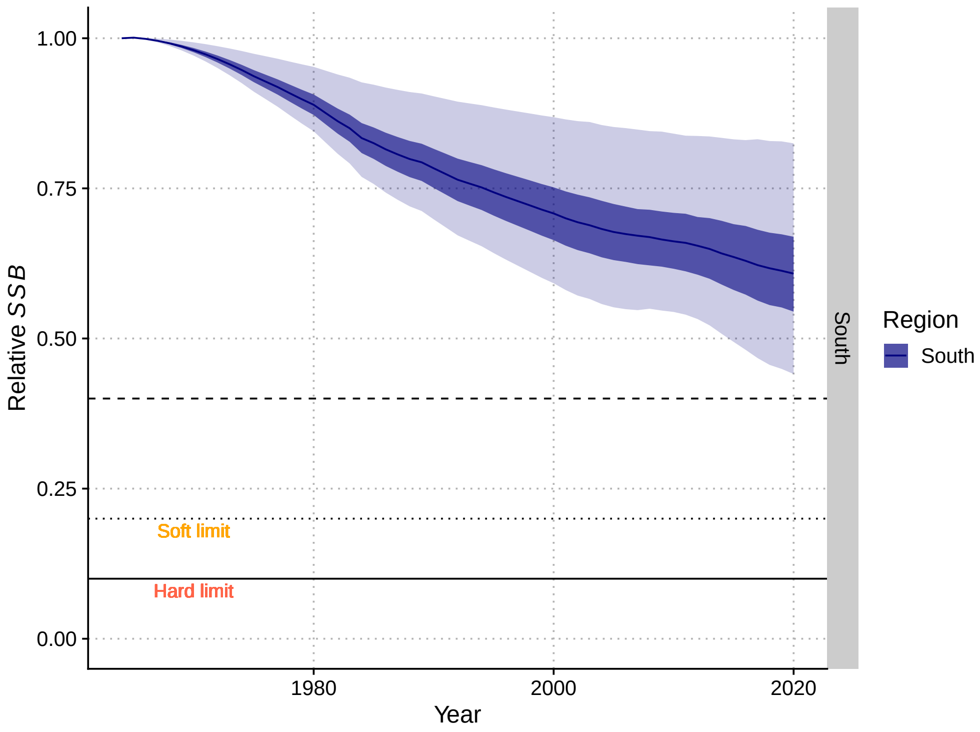

Figure B-38: Estimated relative spawning stock biomass (SSB) trend for pāua for the main sensitivity run 1 of the stock assessment model for Quota Management Area PAU 2 (black line and 95% confidence interval).

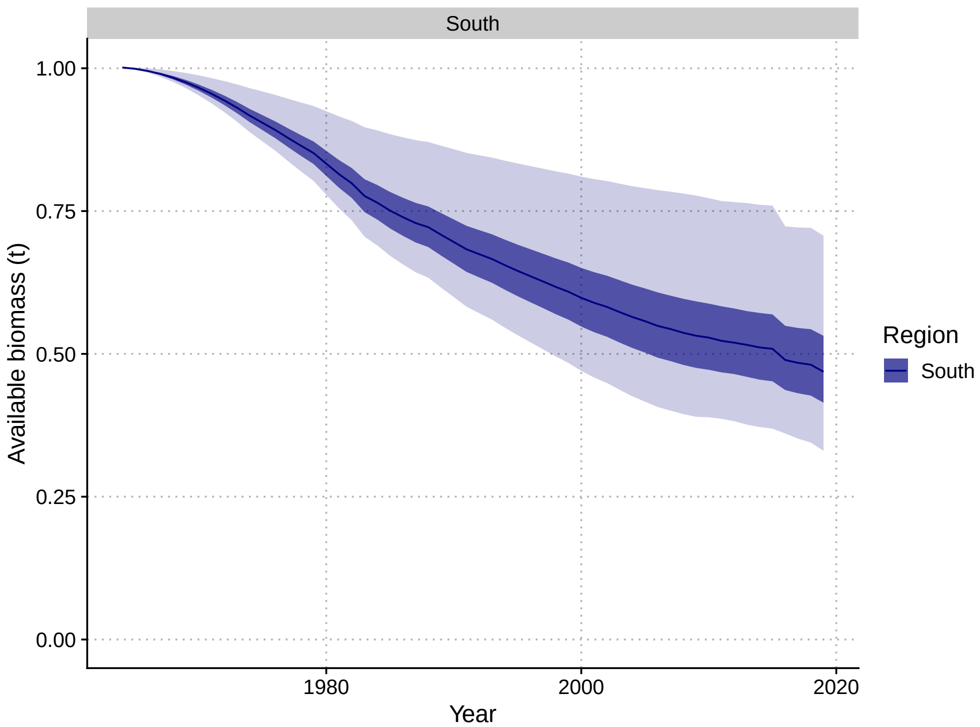

Figure B-39: Estimated relative available biomass trend for pāua for the main sensitivity run 1 of the stock assessment model for Quota Management Area PAU 2 (black line and 95% confidence interval).

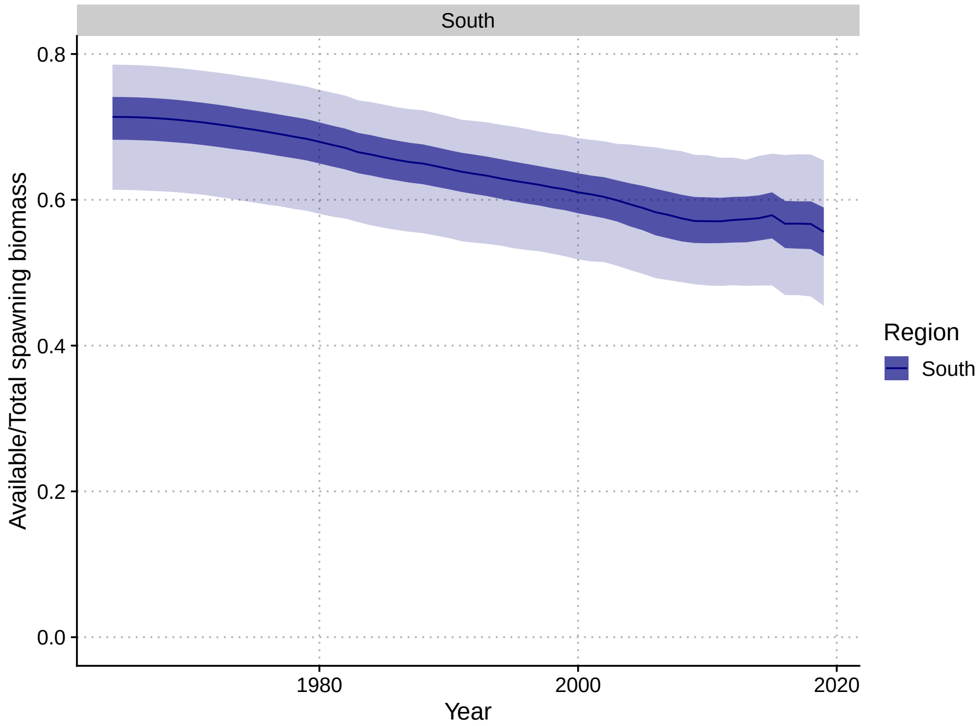

Figure B-40: Estimated relative available pāua biomass (relative to spawning stock) for the main sensitivity run 1 of the stock assessment model for Quota Management Area PAU 2 (black line and 95% confidence interval).

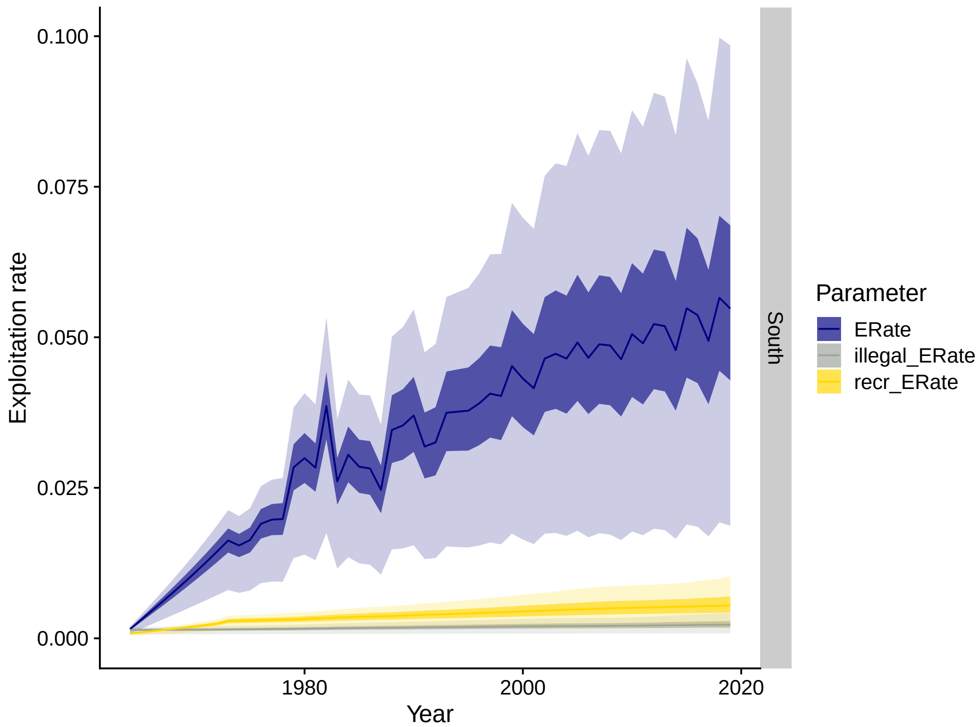

Figure B-41: Estimated exploitation rate (black line and 95% confidence interval) for the main sensitivity run 1 of the relative to the posterior median estimate of the explotiation rate (U) leading to 40% SSB $U_{40\%\mathrm{SSB}_0}$ (red line) of pāua for Quota Management Area PAU 2.

B.3.7 Status and projections

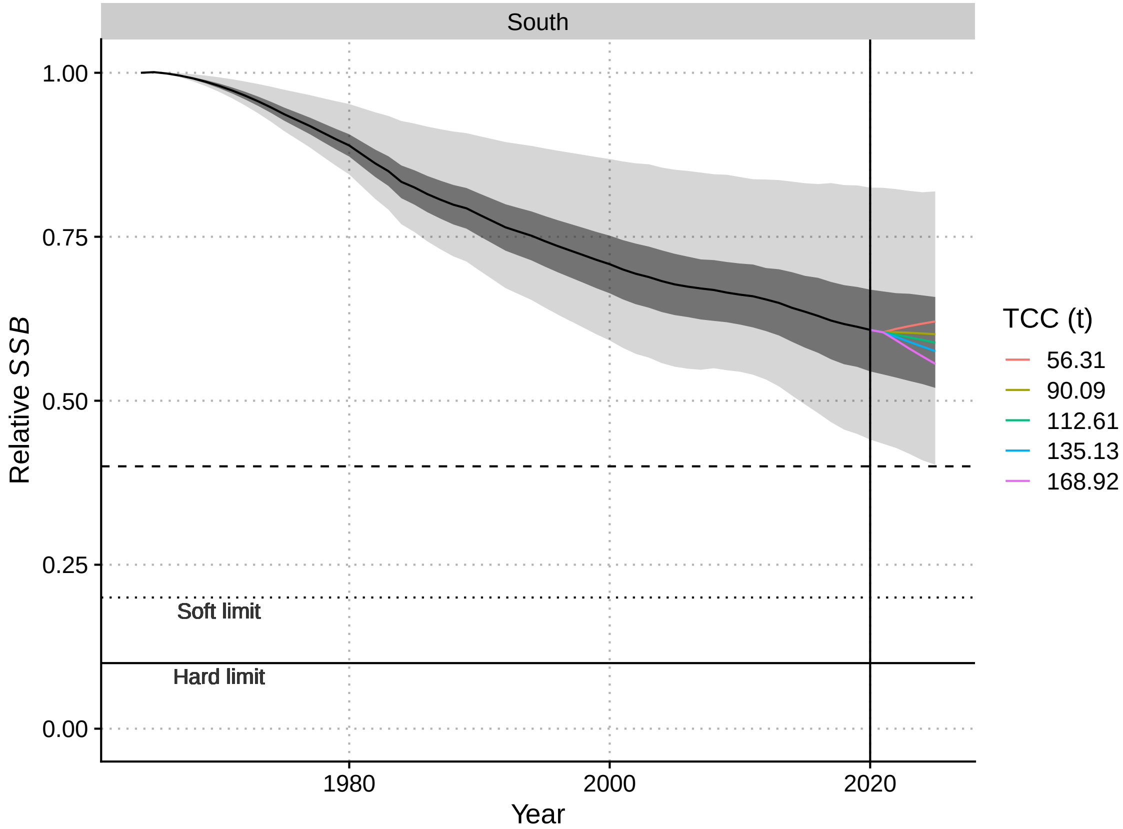

Figure B-42: Estimated (left of solid vertical line) and projected (right of solid vertical line) relative spawning stock biomass (SSB) trend for pāua for the main sensitivity run 1 of the stock assessment model for Quota Management Area PAU 2 (black line (current/observed catch) and 95% confidence interval). Projections are for current catch (green line) and 20% reduction(olive)/increase(blue) and 50% reduction(red)/increase(pink) from current catch. Confidence interval corresponds to current catch (blue) projections only.

Table B-6: Stock status and fishery indicators for the last fishing year considered in this assessment and projections for key fishery indicators from the main sensitivity run 1 of the stock assessment model of pāua for quota management area PAU 2 for three years, for current catch (indicated by the asterisk), and 20% and 50% increases and reductions from current catch. Results at equilibrium (Eq.) are also included (assumed to be reached after 50 years). Columns are: probabilities of being above 40% (P(SSB>0.4SSB$_0$)) and 20% (P(SSB>0.2SSB$_0$)) of unfished spawning stock biomass (SSB), the probability that SSB in the projection year is above current SSB, the posterior median relative SSB, the posterior median relative available biomass (B^{avail}), the posterior median relative available spawning biomass (SSB$^{\text{avail}}$), the probability that B^{avail} in the projection year is above current B^{avail}, and the probability that the exploitation rate (U) is greater than the exploitation rate leading to 40% SSB (TACC, total allowable commercial catch).

TACC (t)	Year	Fishery indicator							
		P(SSB>0.4SSB$_0$)	P(SSB>0.2SSB$_0$)	P(SSB>SSB$_{\text{current}}$)	Mean rel. SSB	Mean rel. B^{avail}	Mean rel. SSB$^{\text{avail}}$	P($B^{\text{avail}} > B^{\text{avail}}_{\text{current}}$)	P($U > U_{40\%\text{SSB}_0}$)
56.31	2020	1.00	1.00	1.00	0.61	0.48	0.55	0.21	0.04
	2021	1.00	1.00	0.02	0.61	0.47	0.55	0.21	0.00
	2022	1.00	1.00	0.64	0.61	0.48	0.55	0.22	0.00
	2023	1.00	1.00	0.79	0.62	0.49	0.56	0.24	0.00
	2024	1.00	1.00	0.79	0.62	0.49	0.56	0.27	0.00
	2025	1.00	1.00	0.79	0.63	0.50	0.56	0.28	0.00
	Eq.	0.97	1.00	0.79	0.68	0.58	0.60	0.57	0.00
90.09	2020	1.00	1.00	1.00	0.61	0.48	0.55	0.21	0.04
	2021	1.00	1.00	0.02	0.61	0.47	0.55	0.21	0.01
	2022	0.99	1.00	0.14	0.61	0.47	0.55	0.21	0.01
	2023	0.99	1.00	0.25	0.61	0.47	0.55	0.21	0.01
	2024	0.99	1.00	0.30	0.61	0.47	0.55	0.21	0.02
	2025	0.99	1.00	0.32	0.61	0.47	0.55	0.21	0.02
	Eq.	0.85	0.98	0.35	0.55	0.41	0.52	0.24	0.09
112.61*	2020	1.00	1.00	1.00	0.61	0.48	0.55	0.21	0.04
	2021	1.00	1.00	0.02	0.61	0.47	0.55	0.21	0.04
	2022	0.99	1.00	0.05	0.61	0.47	0.55	0.20	0.05
	2023	0.99	1.00	0.09	0.60	0.46	0.54	0.19	0.05
	2024	0.99	1.00	0.12	0.60	0.46	0.54	0.18	0.05
	2025	0.98	1.00	0.14	0.59	0.45	0.54	0.18	0.06
	Eq.	0.68	0.91	0.14	0.48	0.33	0.45	0.12	0.26
135.13	2020	1.00	1.00	1.00	0.61	0.48	0.55	0.21	0.04
	2021	1.00	1.00	0.02	0.61	0.47	0.55	0.21	0.08
	2022	0.99	1.00	0.02	0.60	0.46	0.55	0.19	0.09
	2023	0.98	1.00	0.04	0.59	0.45	0.54	0.17	0.10
	2024	0.98	1.00	0.05	0.59	0.45	0.54	0.16	0.11
	2025	0.97	1.00	0.06	0.58	0.44	0.53	0.15	0.12
	Eq.	0.51	0.82	0.06	0.40	0.24	0.36	0.06	0.45
168.92	2020	1.00	1.00	1.00	0.61	0.48	0.55	0.21	0.04
	2021	1.00	1.00	0.02	0.61	0.47	0.55	0.21	0.14
	2022	0.99	1.00	0.00	0.60	0.46	0.54	0.17	0.16
	2023	0.98	1.00	0.01	0.58	0.44	0.53	0.15	0.18
	2024	0.96	1.00	0.01	0.57	0.43	0.52	0.12	0.20
	2025	0.94	1.00	0.02	0.56	0.41	0.52	0.11	0.22
	Eq.	0.30	0.65	0.01	0.31	0.14	0.26	0.02	0.69